Appendix H

Kanavy (2018): Mineralogy and porosity report, #1 Harry Hatfield and #3299 Hamilton wells, Linden Field, Washington County, PA

Mineralogy and Porosity Report
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Linden Field
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Prepared for: Midwest Regional Carbon Sequestration Partnership (MRCSP) Phase III

November 2018

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Lauren Kanavy
Pennsylvania Geological Survey November 2018

ABSTRACT

This case study examines the mineralogy and porosity of the Gantz and Gordon sandstones in Linden Field, Washington, County, Pennsylvania. Cuttings from the #1 Harry Hatfield well (API 3712590083) as well as geophysical log data from the #3299 Hamilton well (API 3712520703) were collected and used for this work. Three types of analyses were performed on the #1 Hatfield well cuttings: scanning electron microscope (SEM), sieve, and X-ray diffraction (XRD). This study determines an average of 75% quartz minerals and 25% clay minerals for the Gantz and 72% quartz minerals, 23% clay minerals, and 5% carbonates for the Gordon. A majority of 47% medium-fine grained sand comprises the sandstones, and some porosity is observed in the Gordon under the SEM. Using the #3299 Hamilton geophysical log data, both average bulk densities and porosities were calculated for the Gantz and Gordon sandstones. The average bulk densities of the Gantz and Gordon are 2.48 g/cm^3 and 2.51 g/cm^3, respectively. The average percent porosity of the Gantz in this well is 8.25%, while that of the Gordon is 7%.

1.0 INTRODUCTION

This case study was prepared as a companion to Abigail Remis' senior comprehensive project entitled "Reservoir Characteristics of the Gantz and Gordon Sandstones, Linden Field, North Strabane Township, Washington County, Pennsylvania." The project mapped location, depth and gross thickness of the Gantz and Gordon sandstones, as well as computed pore space volumes associated with these units. The case study focuses on rock cuttings from the #1 Harry Hatfield well to understand the mineralogy and pore space characteristics of the Venango Group in Linden Field, which may be a candidate for enhanced oil recovery (EOR). Geophysical log data from the #3299 Hamilton well provides more data on the bulk density and porosity of the Gordon and Gantz sandstones, as well as a gamma ray (GR) log curve. This report is provided to the Midwest Regional Carbon Sequestration Partnership (MRCSP), a public and private consortium assessing the technical potential, economic viability and public acceptability of carbon sequestration within ten contiguous states: Indiana, Kentucky, Maryland, Michigan, Ohio, Pennsylvania, West Virginia, Delaware, New Jersey and New York, as part of its Phase III reporting deliverables.

2.0 METHODS

2.1 Sample Preparation

Dry well cuttings samples from the #1 Harry Hatfield well were collected from the Pennsylvania Geologic Survey (PAGS) core and cuttings repository. In total, thirty samples were collected from fifteen intervals for X-ray diffraction (XRD) and scanning electron microscope (SEM) analyses. The five to ten-foot sample intervals were collected from the depth range of 2420 to 2808 feet (ft), starting with the Gantz sand at the shallowest depth through the Fifth sand at the greatest depth. Approximately 3 grams (g) were measured from each interval. For a total list of sampled intervals and depths from the #1 Hatfield well, refer to Table 1 in Appendix 1.

2.2 Mineralogical Analysis

Fifteen XRD mineralogy samples were ground with a mortar and pestle until powered and transported to the Middletown office of the PAGS. The mineral composition of the samples was determined using X-ray powder diffraction. The analyses were run using a PANalytical Empyrean X-ray diffractometer. The samples were loaded in 16-millimeter (mm)-diameter back-packed sample holders that were mounted in a sample spinner. The results were interpreted using PANalytical HighScore Plus software and the ICDD PDF-4 database.

Replicate analyses of five samples were run as a test of precision. The repeated intervals consisted of the 2480-2485 ft Fifty-Foot sand, the 2680-2690 ft Gordon and all intervals sampled from the Fifth sand. The samples from the Fifth Sand were also ground an additional five minutes

each. Standard procedure when running an XRD scan calls for a certain number of replicate analyses. The first of each replicated scans was used for the results of this study.

2.3 Sieve Analysis

Seven samples were used in the sieve analysis: the 2434-2444 ft and 2444-2454 ft Gantz samples, the 2480-2485 ft and 2500-2510 ft Fifty-Foot samples and the three Gordon samples. Standard U.S. sieves sizes #18, #35, #60, #80, #120, #170, #230 were used. Each sample was weighed and separated using a #18 sieve into chips and loose silt and sand. The silt and sand passed through the #35, #60, #80, #120, #170 and #230 sieves and was weighed. The measured amount of sieved sand was subtracted from the initial weight of loose sand to calculate the grams of sample lost.

2.4 SEM Analysis

For SEM analysis, four intervals were studied, the 2420-2424 ft Gantz and all three Gordon intervals. Larger fragments were chosen, and, from these pieces, approximately four per interval were studied under the SEM. The samples were uncoated before placing into the machine. The SEM machine used was a JEOL JSM-6010LV. Two settings were primarily used, backscattered electron composition imaging (BEC) and secondary electron imaging (SEI).

Figure 1: The SEM machine alongside the monitor used to view the images.

2.5 Geophysical Log Interpretation

For the #3299 Hamilton well, the GR log, geological sample (GEO) log, log analysis form and sample study were collected from PA DCNR's Exploration and Development Well Information

Network (EDWIN). The GR log curve was digitized in PETRA® software. Refer to Appendix 6 for all #3299 Hamilton well documents.

2.6 Possible Errors

2.6.1 XRD Analysis

Two factors that may have affected the results of the XRD analysis are the grinding and loading of the sample. The sample must be ground thoroughly to optimum particle size and homogeneity, and the sample must be loaded into the sample holder in a free-falling manner to reduce preferred orientation and packing (Chung, 1974).

2.6.2 SEM Analysis

A few factors could have affected the results of the SEM analysis: sample choice, preparation methods and the settings used in the SEM machine. The samples chosen for this study were relatively large and intact chips from archived rock cuttings samples. As a result of sample age and/or the air drilling method involved, no pieces of intact sandstone were available to study. The porous, quartz-based sandstone, the primary component of the Gantz and Gordon intervals, could have crumbled into sand particles by the time this case study was performed. The chips that have stayed intact consist of rocks with clay matrices; this may explain the lack of porosity found in the Gantz and majority of Gordon samples studied under SEM.

Sample preparation and the SEM settings could also have contributed to errors in the results. The samples were not coated nor cleaned before insertion into the SEM. Dust from the sample bag may have interfered with what was seen on the surface of the chips. The voltage that was used in the SEM may have been too high and contributed to washout in pictures of the samples.

3.0 RESULTS AND INTERPRETATION

3.1 Sieve Analysis Results

The sieve analysis results show that an average 47.1% of loose grains in the Gantz and Gordon intervals is comprised of fine sand 0.25 mm in size. Medium-coarse sand grains 0.5 mm or more in diameter make up the next largest percentage, averaging 25.1% of the total. Fine to medium fine sand grains 0.177 mm in diameter and very fine sand grains 0.115 mm in diameter account for an average of 11.0% and 12.2% total, respectively. Coarse silt grains 0.088 mm and 0.063 mm in diameter make up an average of 2.7% and 1.4% total, respectively. Fine silt grains less than 0.063 mm in diameter account for an average of 0.5% of the total. Refer to Table 2 in Appendix 1 for a listing of these results.

3.2 XRD Results

The XRD results show that most of the intervals sampled from the #1 Hatfield well are composed of quartz minerals. Clay makes up the next highest percentage, then carbonates and trace minerals. On average, the Gantz consists of 75% quartz minerals, 25% clay minerals and less than 1% magnetite. The Gordon consists of an average 72% quartz minerals, 23% clay minerals and 7% carbonate minerals. Refer to Table 3 for the list of XRD results and to Table 4 for the XRD results including replicates, both in Appendix 1.

3.3 SEM Results

Under the SEM, the Gantz samples look to be primarily comprised of platy clay minerals, and porosity was not visible in any of them. The Gordon samples exhibited some porosity, along with many clay minerals. Backscatter and secondary electron imaging were used to show more detail in selected SEM samples. Refer to Appendix 2 for all images taken of the Gantz sand, and Appendices 3-5 for all images taken of the Gordon sand.

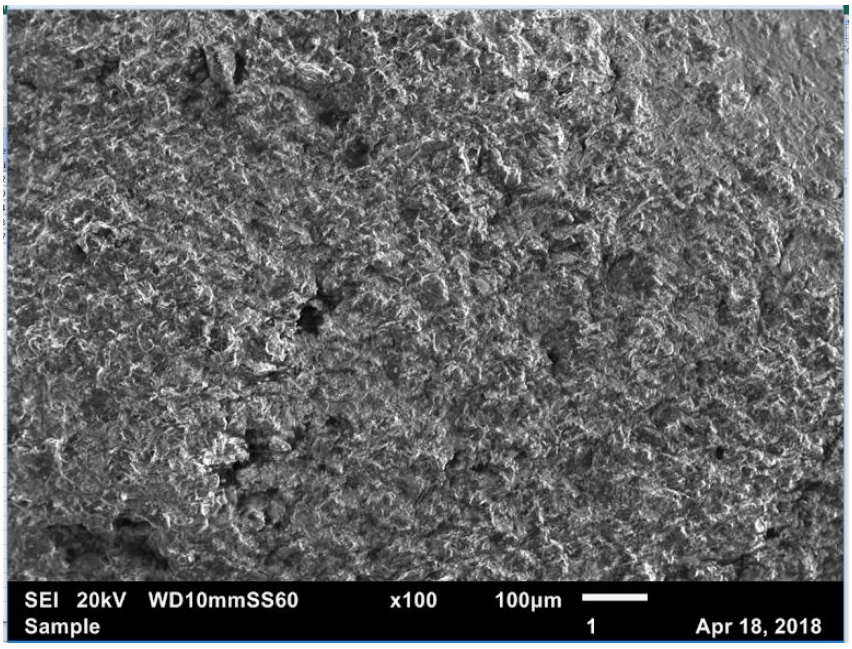


Figure 2: Platy clay minerals in the 2420-2424 ft Gantz sand.

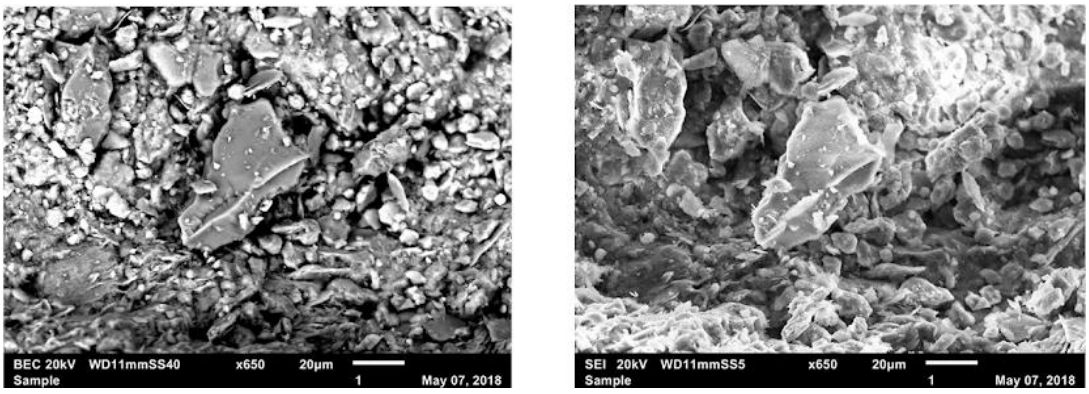


Figure 3: BEC and SEI pictures of the 2690-2700 ft interval of the Gordon sand. The contrasting images give insight into the chemical makeup of this sample, which appears to be mostly clay.

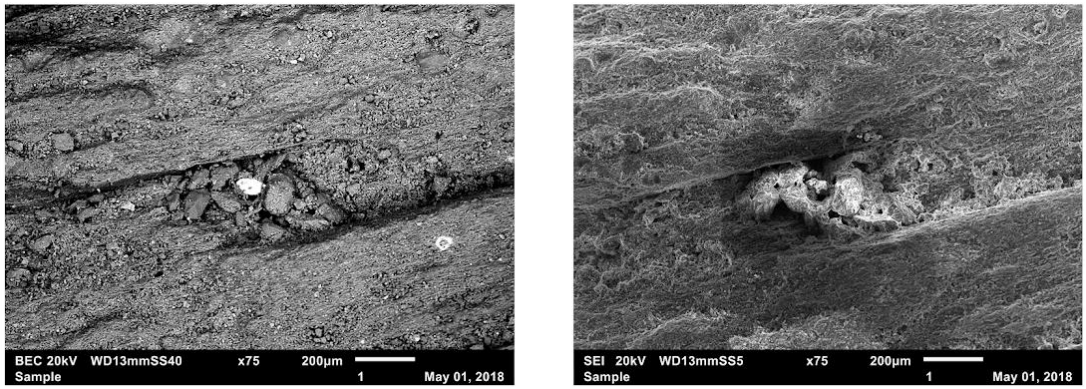


Figure 4: BEC and SEI pictures of the 2672-2680 ft interval of the Gordon sand. The white mineral in the BEC image may be an oxide or sulfide such as pyrite or magnesite.

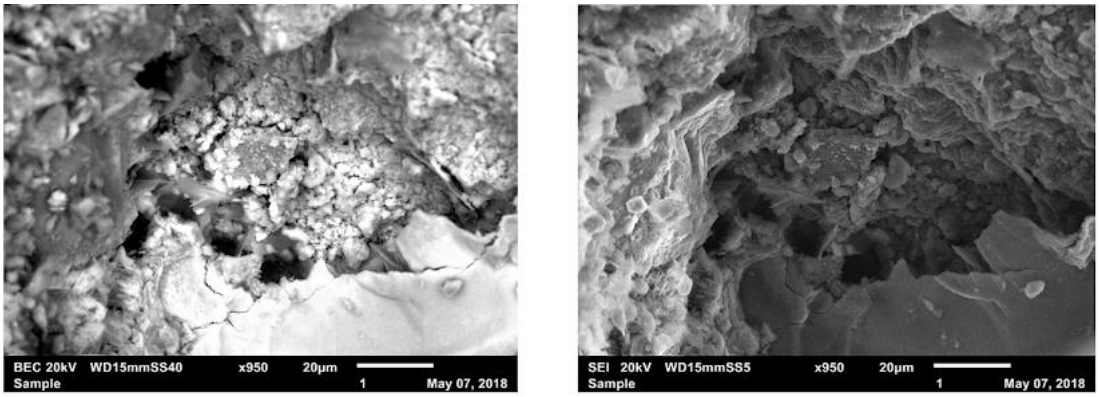


Figure 5: Observable porosity in the 2690-2700 ft interval of the Gordon sand. The darker the void space, the deeper the pore.

3.4 Geophysical Log Interpretation

According to the log analysis report for the #3299 Hamilton well, the average bulk densities of the Gantz and Gordon are 2.48 grams per cubic centimeter (g/cm^3) and 2.51 g/cm^3, respectively.

The porosity of the Gantz averaged 8.25% while the Gordon averaged 7%. Refer to Figure 6 for a section of the GR curve and GEO log where the Gantz and Gordon sandstones were encountered. Refer to Appendix 6 for all #3299 Hamilton well documents.

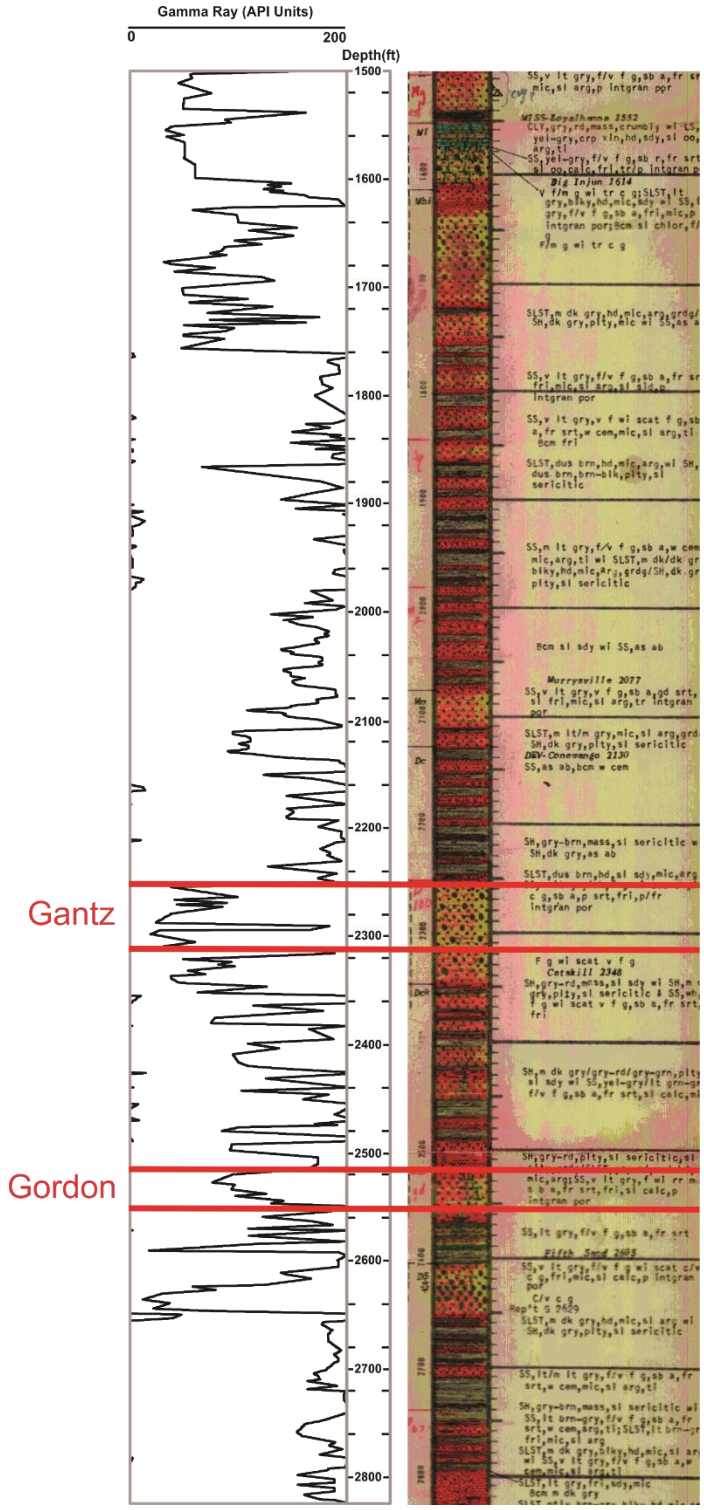


Figure 6: Geophysical logs of the #3299 Hamilton well. The GR curve is on the left and the GEO log is on the right. The Gantz and Gordon sandstone intervals are marked.

4.0 CONCLUSIONS

This case study determined an average of 75% quartz minerals and 25% clay minerals for the Gantz sandstone and 72% quartz minerals, 23% clay minerals and 5% carbonates for the Gordon sandstone, based on rock cuttings samples obtained from an old well completed in the Venango Group in Linden Field, Washington County, Pennsylvania. Based on sieve analysis, these sandstones are comprised mostly of fine grained sand, with lesser amounts of medium-coarse sand, fine to medium sand and silt-size particles. Under the SEM, no porosity was noted for the Gantz, but some was observed in the Gordon. The average bulk densities of the Gantz and Gordon were determined to be 2.48 g/cm^3 and 2.51 g/cm^3, respectively, based on geophysical log data. The average log-derived porosity of the Gantz and Gordon are 8.25% and 7%, respectively.

References Cited

Chung, F.H., 1974, Quantitative interpretation of X-ray diffraction patterns, I. Matrix-flushing method of quantitative multicomponent analysis: Journal of Applied Crystallography, vol. 7, p. 519-525.

Compton, Robert R., 1985, Geology in the Field: New York, John Wiley & Sons, Inc., p. 49.

Appendix 1: Tables

#1 Harry Hatfield Well, Linden Field, Washington County, PA

Tables for Drillers' Sand Names and XRD Analytical Results for the #1 Harry Hatfield Well, depth 2420' to 2808'

Table for Sieve Analysis Results for the Gantz and Gordon sandstones, depths 2434' to 2454' and 2672' and 2700', respectively

Described by Lauren Kanavy, Pennsylvania Geological Survey, November 2018

Drillers' Sand Name	Depth at top (ft)	Depth at bottom (ft)	Weight (g)
Gantz Sand	2420	2424	3.1
Gantz Sand	2434	2444	3
Gantz Sand	2444	2454	3
Fifty-foot Sand	2460	2465	3
Fifty-foot Sand	2480	2485	2.8
Fifty-foot Sand	2500	2510	3
Upper Nineveh	2580	2590	3
Lower Nineveh	2590	2600	3.2
Gordon Sand	2672	2680	3
Gordon Sand	2680	2690	3
Gordon Sand	2690	2700	3
Fourth Sand	2740	2746	3
Fifth Sand	2790	2795	3.1
Fifth Sand	2795	2800	3.2
Fifth Sand	2800	2808	3.5

Table 1: Drillers' Sand Names

Driller's Sand Name	Sampled Interval (ft below the surface)	Starting Sample Weight in g	Loose Sand Weight (g)	Fragment Weight (g)	Sum of Measured Loose Sand	g lost	% Grain Size of Sand							Total %
							500 µm ≤	250 µm ≤	177 µm ≤	115 µm ≤	88 µm ≤	63 µm ≤	63 µm ≥	
Gantz	2434-2444	2.889	0.507	2.382	0.495	0.012	28.7	47.9	8.5	9.1	2.8	2	1	**100**
Gantz	2444-2454	2.943	1.124	1.819	1.078	0.04	30.1	44.8	10.4	11.2	1.2	1.4	0.9	**100**
Gordon	2672-2680	9.908	3.803	6.104	3.796	0.008	29.3	47.4	10.2	10	2.3	0.6	0.1	**99.9**
Gordon	2680-2690	9.918	5.848	4.063	5.826	0.029	20.5	46.9	12.4	14.9	3.3	1.8	0.2	**100**
Gordon	2690-2700	9.92	5.754	4.157	5.725	0.038	16.7	48.6	13.7	15.7	3.7	1.2	0.3	**99.9**

Table 2: Sieve Analysis Results

Sampled Interval (ft below surface)	Driller's Sand Name	XRD scan	PERCENT MINERALOGY								PERCENT OF TOTAL MINERALOGY				TOTAL PERCENTAGE
			QUARTZ+			CLAY		CARBONATE+		OTHER					
			Quartz	Plagioclase	K feldspar	Mica Group	Chlorite Gp.	Calcite	Dolomite	Magnetite?	Total Quartz+	Total Clay	Total Carbonate	Total Other	
2420–2424	Gantz	D18–100	79	<1	N.D.	13	8	N.D.	N.D.	N.D.	79	21	0	0	100
2434–2444	Gantz	D18–101	64	<1	N.D.	22	14	N.D.	N.D.	<1	64	36	0	<1	100
2444–2454	Gantz	D18–102	82	<1	N.D.	12	6	N.D.	N.D.	N.D.	82	18	0	0	100
2460–2465	Fifty-foot	D18–103	77	<1	N.D.	6	17	N.D.	N.D.	N.D.	77	23	0	0	100
2480–2485	Fifty-foot	D18–104	88	1	N.D.	9	1	N.D.	N.D.	N.D.	89	10	0	0	99
2500–2510	Fifty-foot	D18–106	89	4	N.D.	6	1	N.D.	N.D.	N.D.	93	7	0	0	100
2580–2590	Upper Nineveh	D18–107	57	12	N.D.	26	5	N.D.	N.D.	N.D.	69	31	0	0	100
2590–2600	Lower Nineveh	D18–108	74	10	N.D.	14	2	N.D.	N.D.	N.D.	84	16	0	0	100
2672–2680	Gordon	D18–109	74	<1	N.D.	18	2	N.D.	6	N.D.	74	20	6	0	100
2680–2690	Gordon	D18–110	74	<1	N.D.	17	3	N.D.	6	N.D.	74	20	6	0	100
2690–2700	Gordon	D18–112	69	<1	N.D.	20	8	N.D.	2	N.D.	69	28	2	0	99
2740–2746	Fourth Sand	D18–113	77	<1	N.D.	18	3	N.D.	2	N.D.	77	21	2	0	100
2790–2795	Fifth Sand	D18–114	87	N.D.	N.D.	10	2	N.D.	N.D.	N.D.	87	12	0	0	99
2795–2800	Fifth Sand	D18–115	86	N.D.	N.D.	13	1	N.D.	N.D.	N.D.	86	14	0	0	100
2800–2808	Fifth Sand	D18–116	84	N.D.	N.D.	14	2	N.D.	N.D.	N.D.	84	16	0	0	100

N.D. – Not detected

Table 3: XRD Analytical Results

Depth	Formation Name	Replicate	XRD scan	Quartz	Mica Group	Chlorite Gp.	Plagioclase	K feldspar	Calcite	Dolomite	Magnetite?	TOTAL	Comments
2420–2424	Gantz		D18–100	79	13	8	<1					100	
2434–2444	Gantz		D18–101	64	22	14	<1				<1	100	
2444–2454	Gantz		D18–102	82	12	6	<1					100	
2460–2465	50'		D18–103	77	6	17	<1					100	
2480–2485	50'	1	D18–104	88	9	1	1					99	
2480–2485	50'	2	D18–105	90	8	1	2					101	
2500–2510	50'		D18–106	89	6	1	4					100	
2580–2590	Upper Nineveh		D18–107	57	26	5	12					100	
2590–2600	Lower Nineveh		D18–108	74	14	2	10					100	
2672–2680	Gordon		D18–109	74	18	2	<1			6		100	
2680–2690	Gordon	1	D18–110	74	17	3	<1			6		100	
2680–2690	Gordon	2	D18–111	71	17	2	1			9		100	
2680–2690	Gordon	3	D18–117	73	18	3	<1			6		100	
2690–2700	Gordon		D18–112	69	20	8	<1			2		99	
2740–2746	Fourth Sand		D18–113	77	18	3	<1			2		100	
2790–2795	Fifth Sand	1	D18–114	87	10	2						99	
2790–2795	Fifth Sand	2	D18–118	85	12	2	<1					99	Ground 5 additional minutes
2795–2800	Fifth Sand	1	D18–115	86	13	1						100	
2795–2800	Fifth Sand	2	D18–119	92	6	2						100	Ground 5 additional minutes
2800–2808	Fifth Sand	1	D18–116	84	14	2						100	
2800–2808	Fifth Sand	2	D18–120	78	18	2	2					100	Ground 5 additional minutes
2800–2808	Fifth Sand	3	D18–121	81	17	2	<1					100	Same grinding as D18–120

Table 4: Full XRD Analytical Results

Appendix 2: SEM Photomicrographs

#1 Harry Hatfield Well, Linden Field, Washington County, PA

SEM photomicrographs of the Gantz sandstone, depth 2420’ to 2424’

Described by Lauren Kanavy, Pennsylvania Geological Survey, November 2018

Figures 1-4: Surfaces of chip samples taken at x100 magnification.

These samples are most likely mudstone. The majority of grains are silt to clay in size, with some fine sand grains infrequently present.

No porosity observed in the samples.

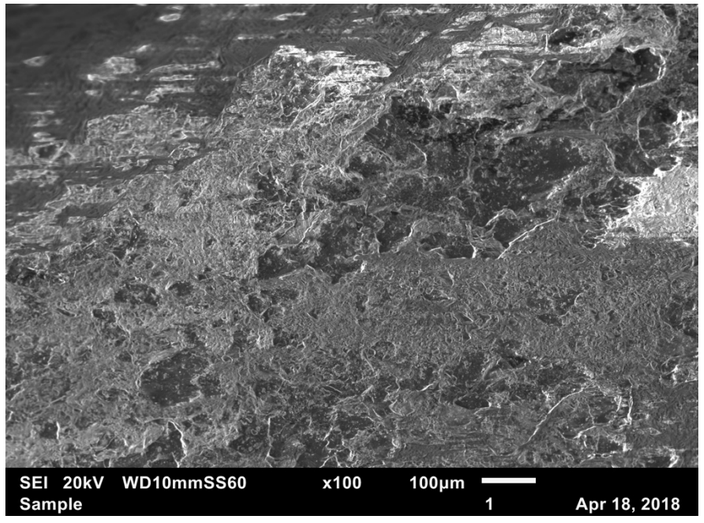


Figure 1: SEI 20kV x100.

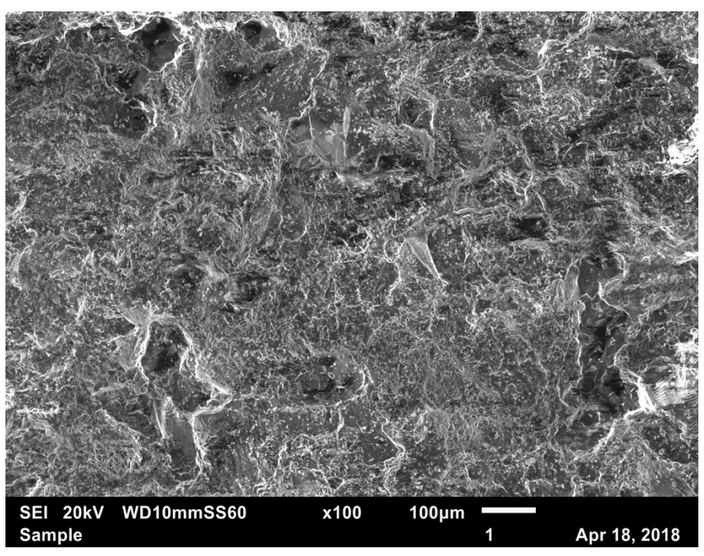


Figure 2: SEI 20kV x100.

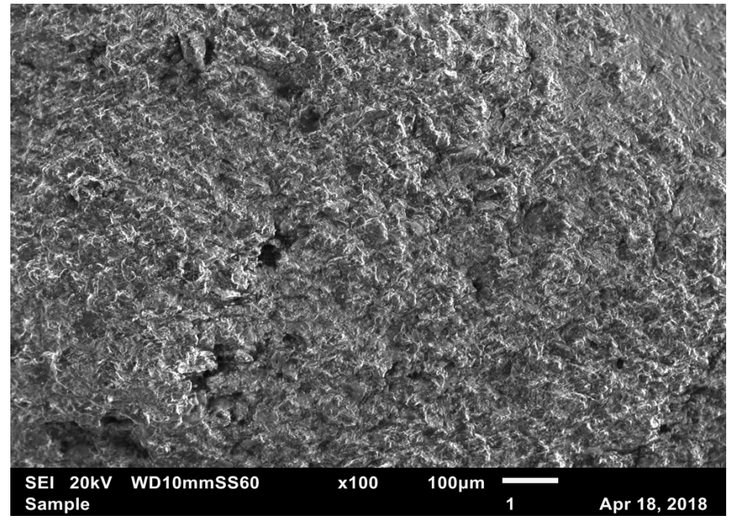


Figure 3: SEI 20kV x100.

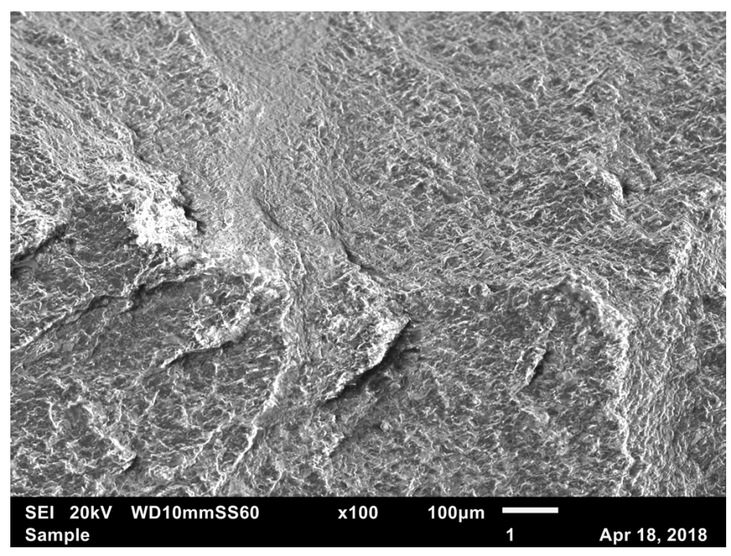


Figure 4: SEI 20kV x1

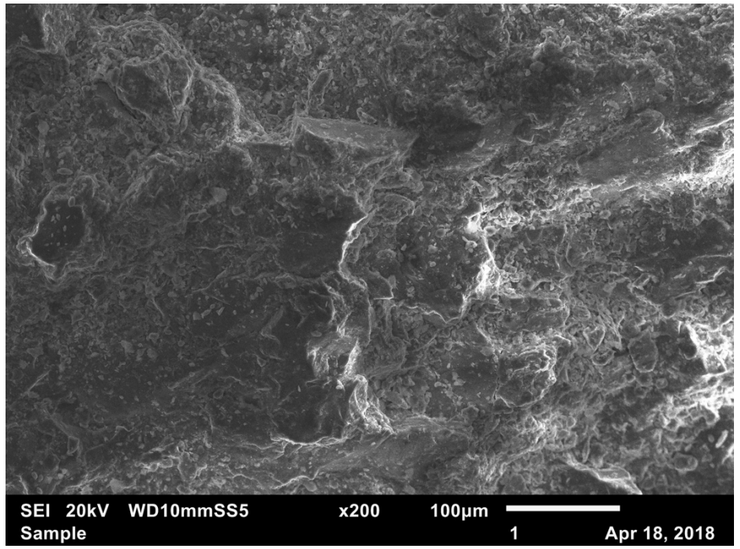


Figure 5: SEI 20kV x200. Platy clay minerals on the surface of the sample.

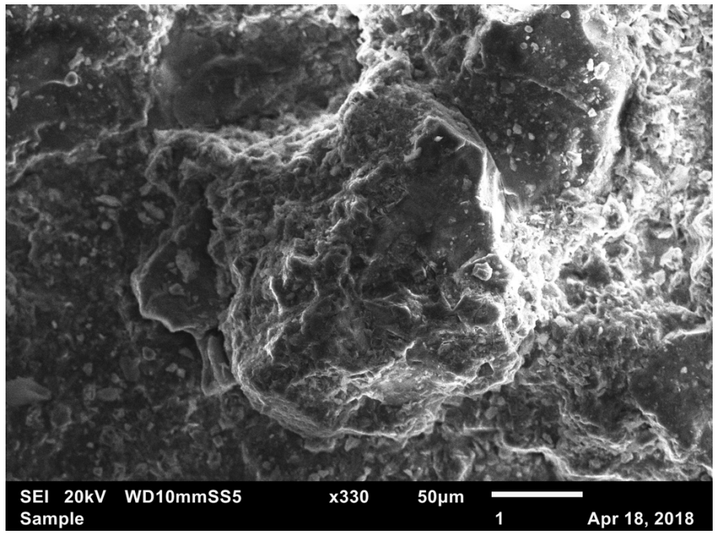


Figure 6: SEI 20kV x330. Platy clay particles surrounding larger fine sand or coarse silt grains.

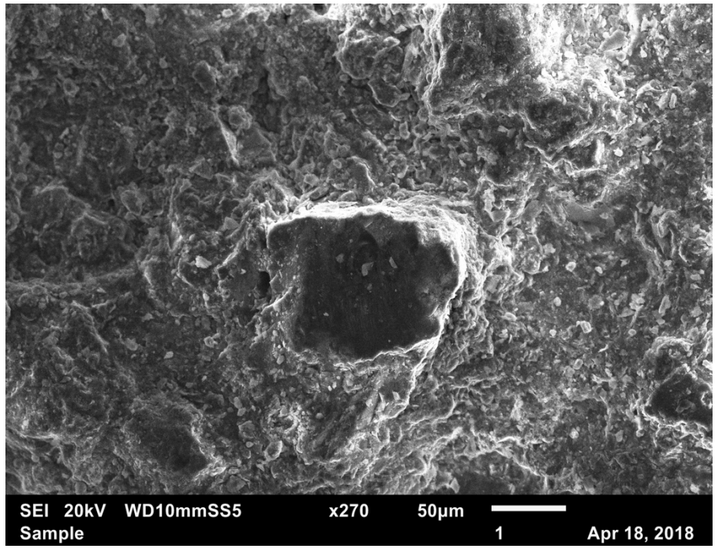


Figure 7: SEI 20kV x270. A larger particle surrounded by clay minerals.

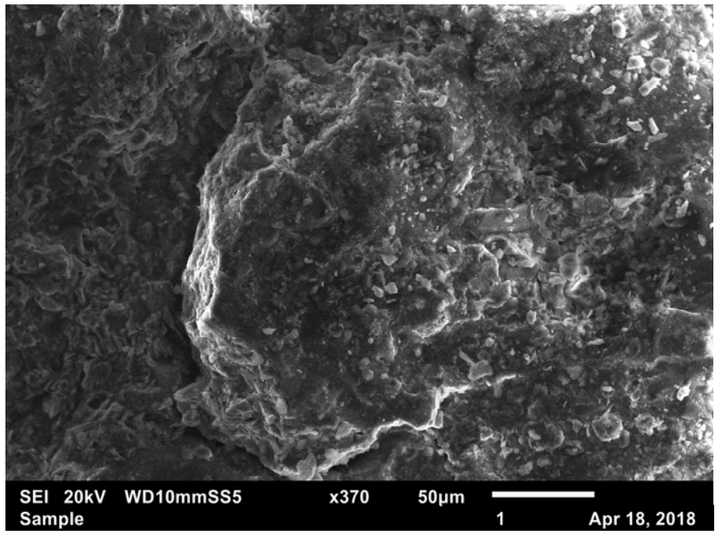


Figure 8: SEI 20kV x370. A larger grain surrounded by clay minerals.

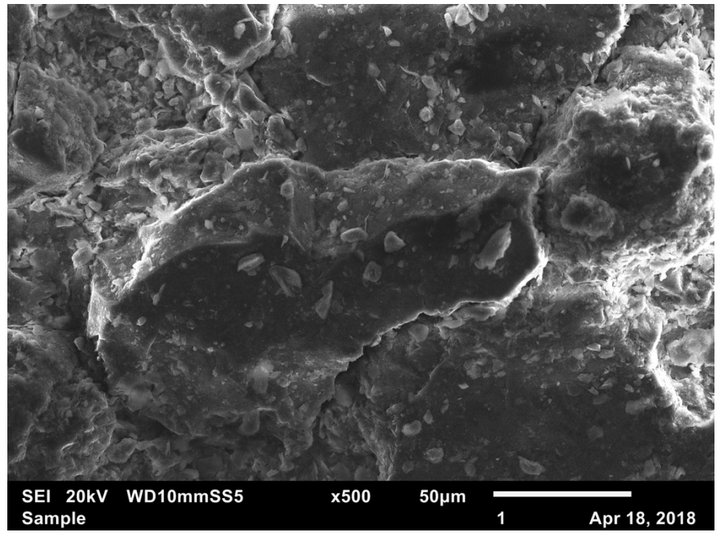


Figure 9: SEI 20kV x500. Varying particle sizes make up the sample.

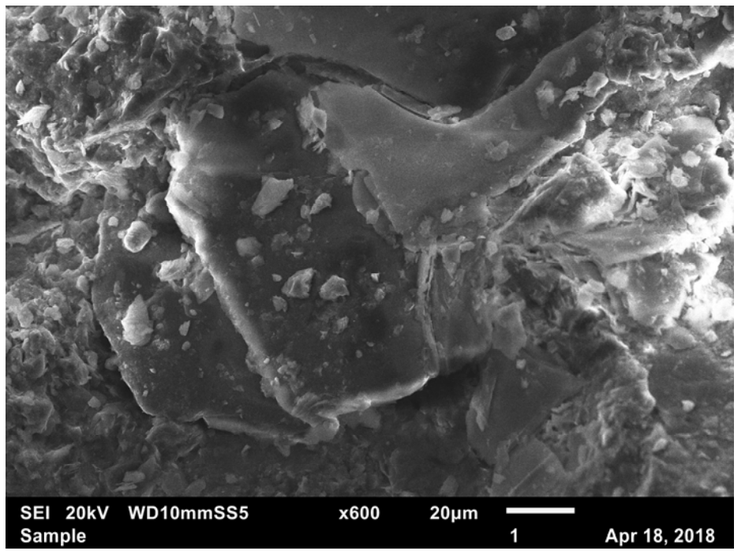


Figure 10: SEI 20kV x600. Particle size ranges from micrometers to 100 micrometers.

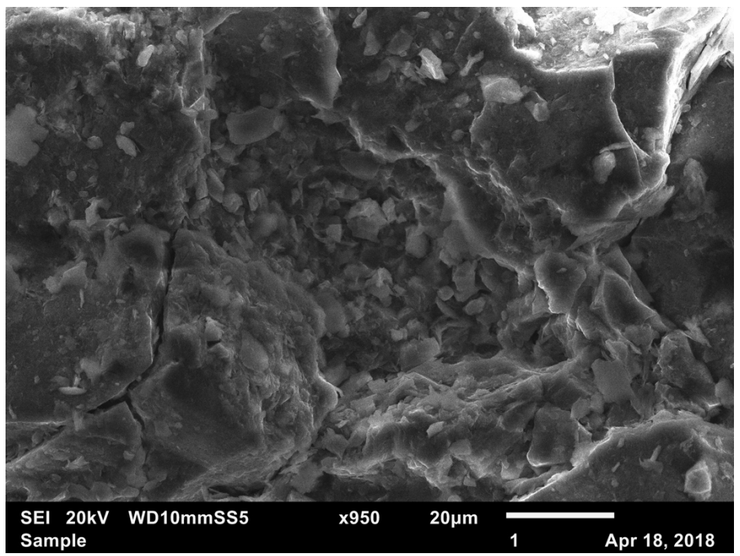


Figure 11: SEI 20kV x950. Most of the particles are flat, platy, and flaky. A crack in one of the grains is present in the bottom of this photomicrograph.

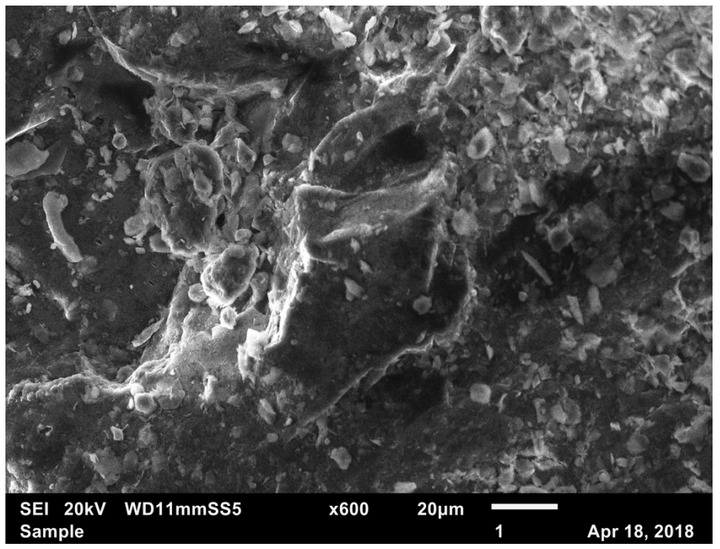


Figure 12: SEI 20kV x600. Smaller silt to clay-sized particles coat the surface of the sample.

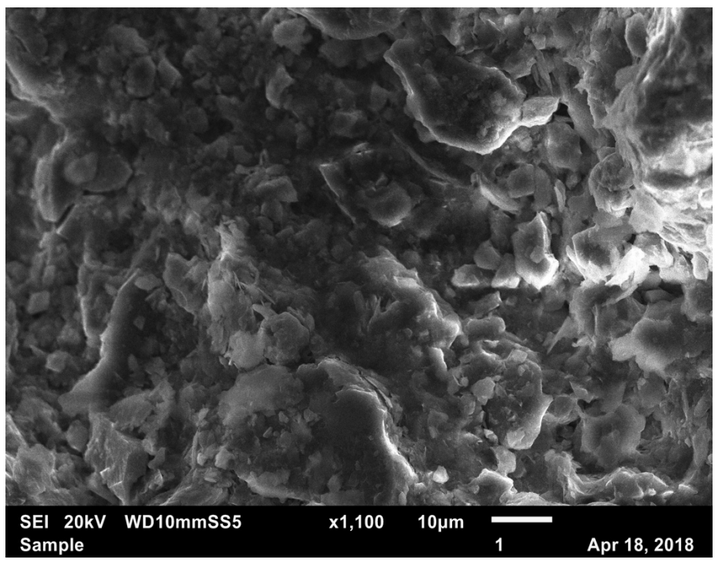


Figure 13: SEI 20kV x1,100. The particles are rounded to sub-rounded.

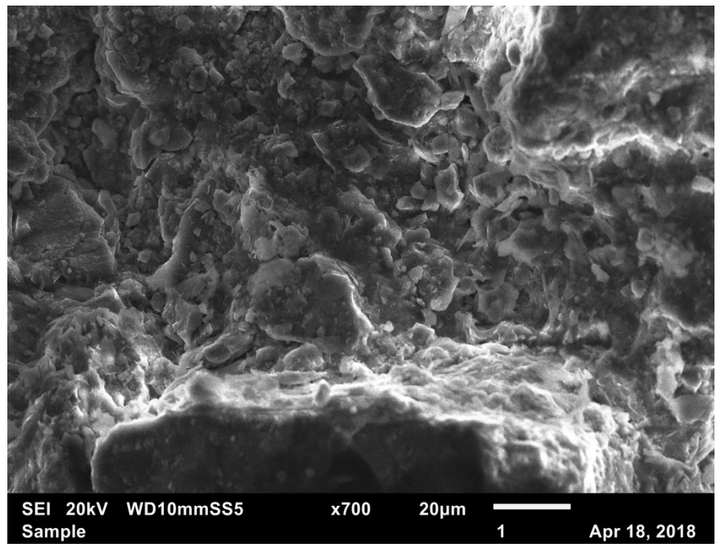


Figure 14: SEI 20kV x700. Very fine silt and clay particles lie on top of and between larger coarse silt particles, serving as the cement of the rock.

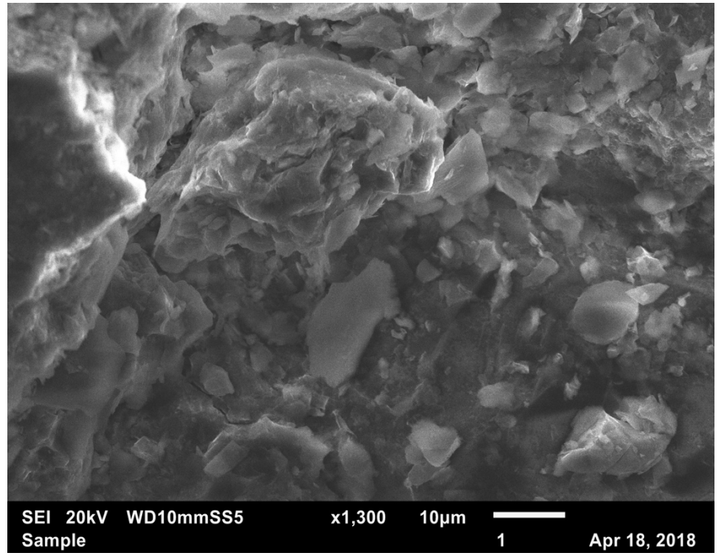


Figure 15: SEI 20kV x1,300. Clay-size particles 1 micrometer in diameter are present.

Appendix 3: SEM Photomicrographs

#1 Harry Hatfield Well, Linden Field, Washington County, PA

SEM photomicrographs for the Gordon sandstone, depth 2672’ to 2680’

Described by Lauren Kanavy, Pennsylvania Geological Survey, November 2018

Figures 1-7: Photomicrographs of a section of one of the samples studied at different magnifications and SEM settings. Backscattered electron composition imaging (BEC) was used alongside secondary electron images (SEI). The SEI and BEC photomicrographs in the same column correspond to each other.

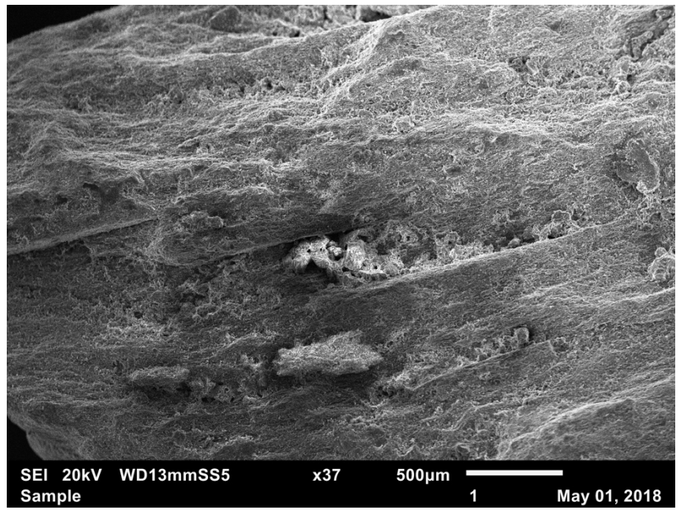


Figure 1: SEI 20kV x37. A section of interest in this sample.

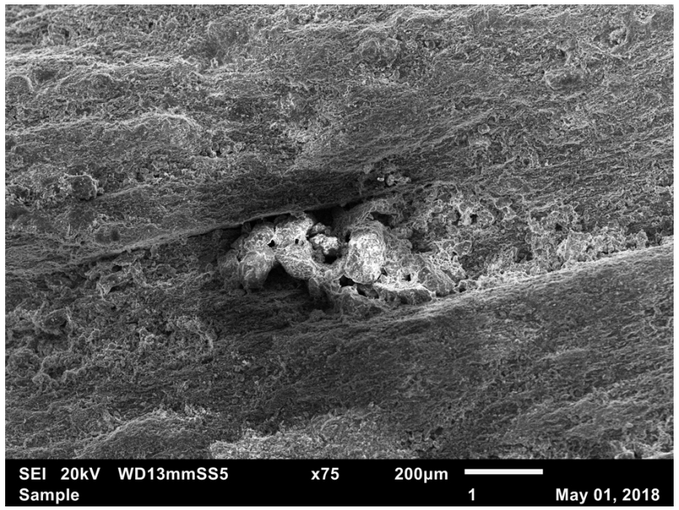


Figure 2: SEI 20kV x75. The SEI and BEC images showcase different qualities of this section of the sample. The SEI image displays more of the shape and geometry of the grains.

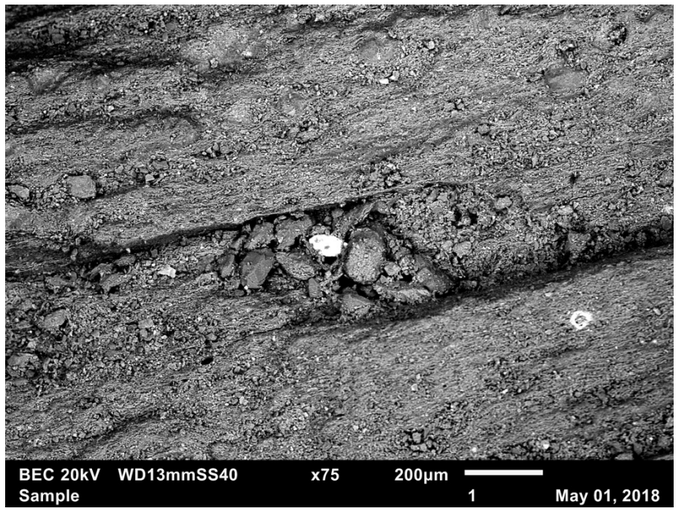


Figure 3: BEC 20 kV x75. The BEC image displays the differing composition of the grains.

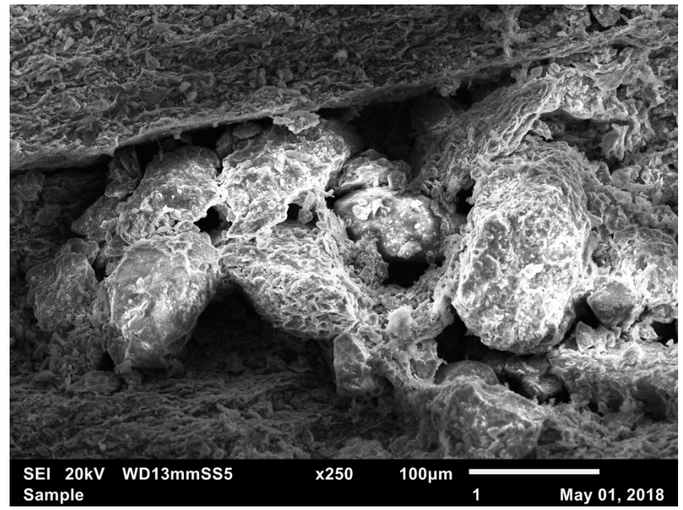


Figure 4: SEI 2kV x250. Large pores are visible between these grains. Large particles over 100 micrometers in diameter and smaller particles less than 10 micrometers are present.

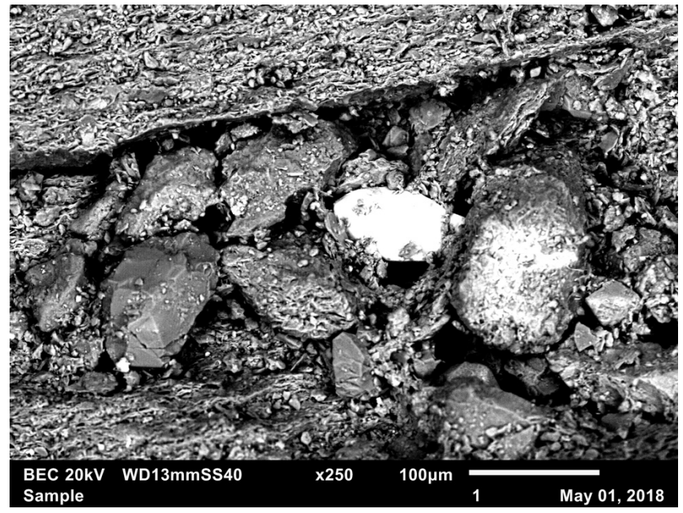


Figure 5: BEC, 20kV x250. Observable porosity in the sample. The white-appearing grain is most likely an oxide or sulfide.

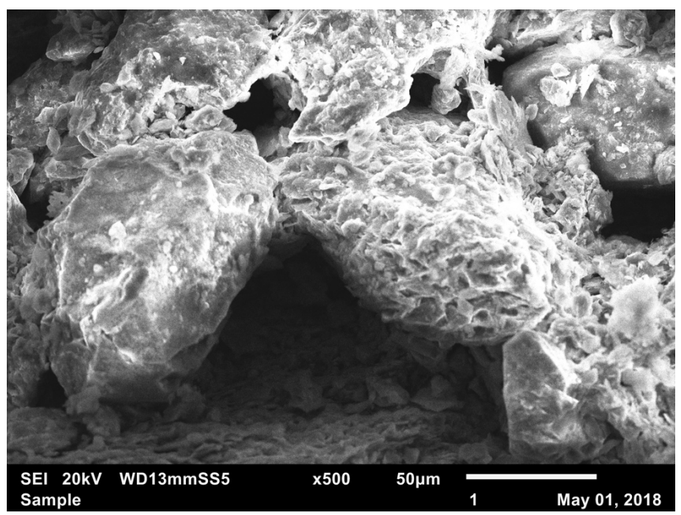
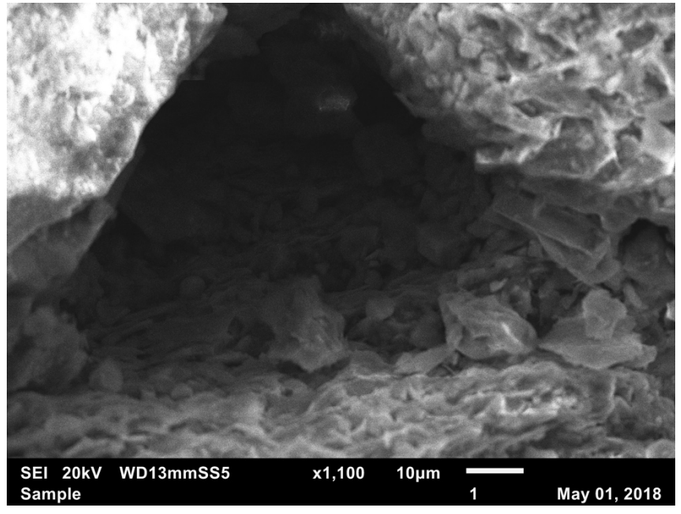


Figure 6: SEI 20kV x500. A closer look at the pore in the bottom left corner of Figure 4.



Figures 7: SEI 20kV x1,100. An even closer look at the same pore from Figure 4. Platy particles 10 micrometers or less can be seen coating the larger grains.

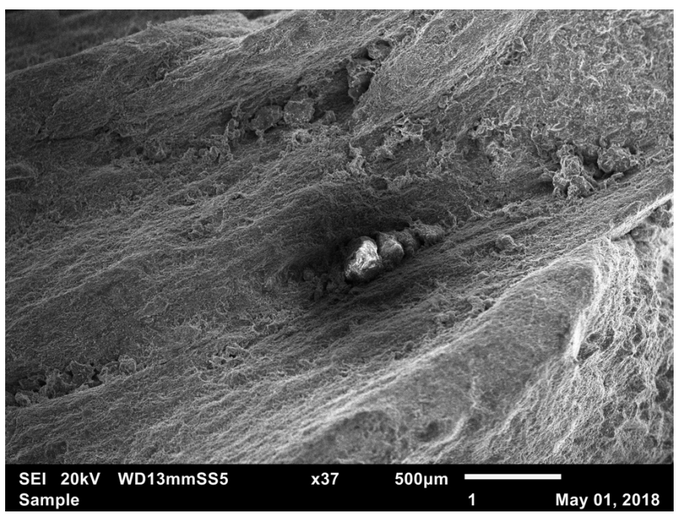


Figure 8: SEI 20kV x37.

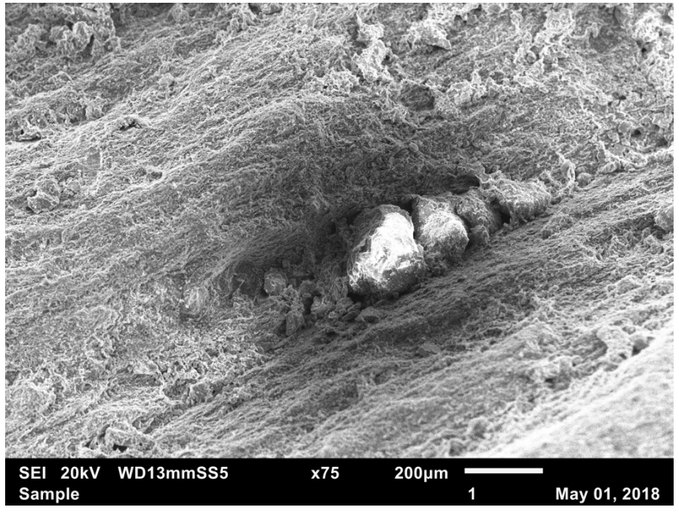


Figure 9: SEI 20kV x75. A closer look at the grains in Figure 8. A 200-micrometer grain is present in the center of the photomicrograph. No observable porosity.

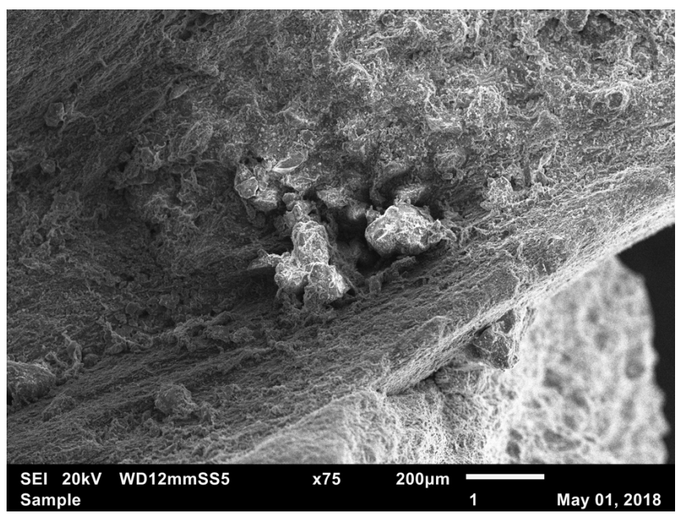


Figure 10: SEI 20kV x75.

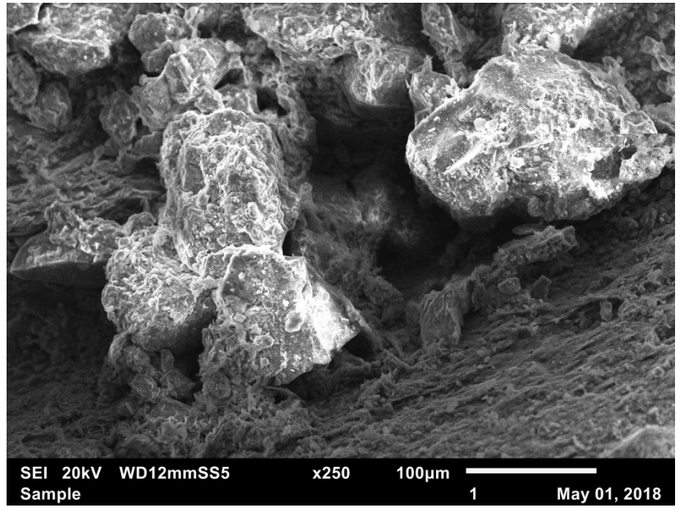


Figure 11: SEI 20kV x250. A closer look at Figure 10. Possible porosity between the larger grains.

Figures 12-15: Another section of interest in a sample from this interval. The photomicrographs show the section at different magnifications.

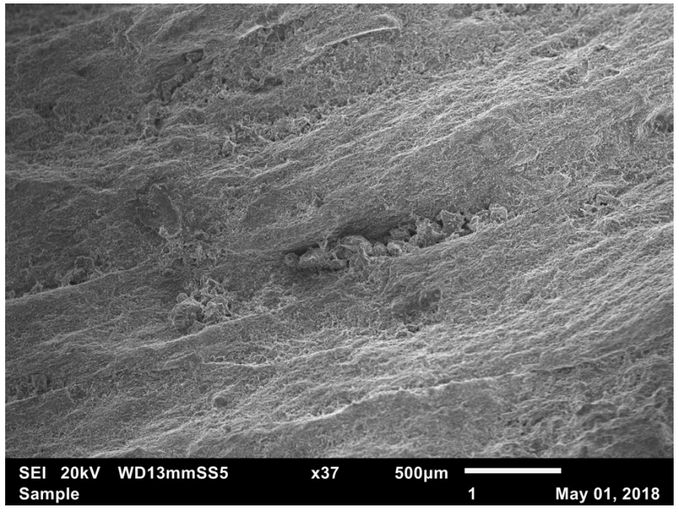


Figure 12: SEI 20kV x37.

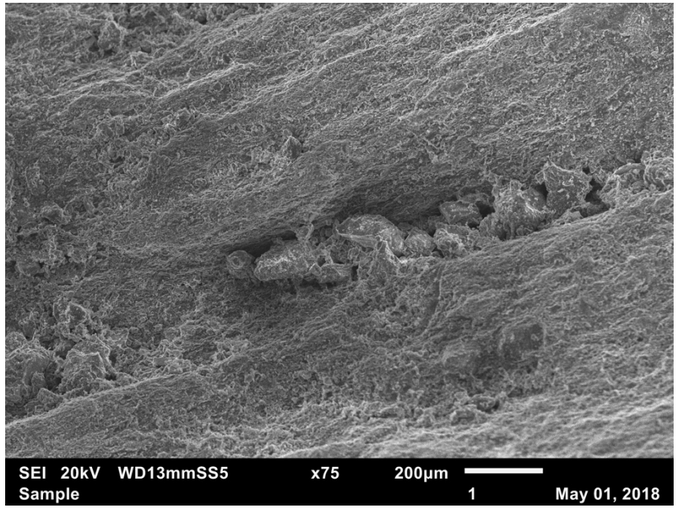


Figure 13: SEI 20kV x75. Grains around 100 micrometers in width are present.

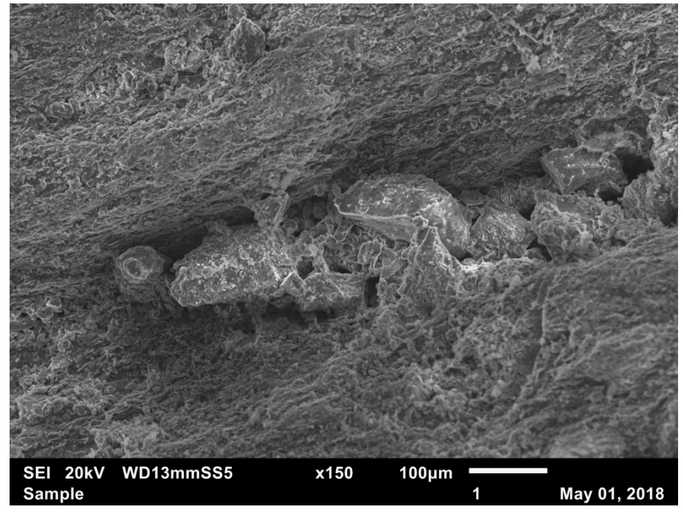


Figure 14: SEI 20kV x150.

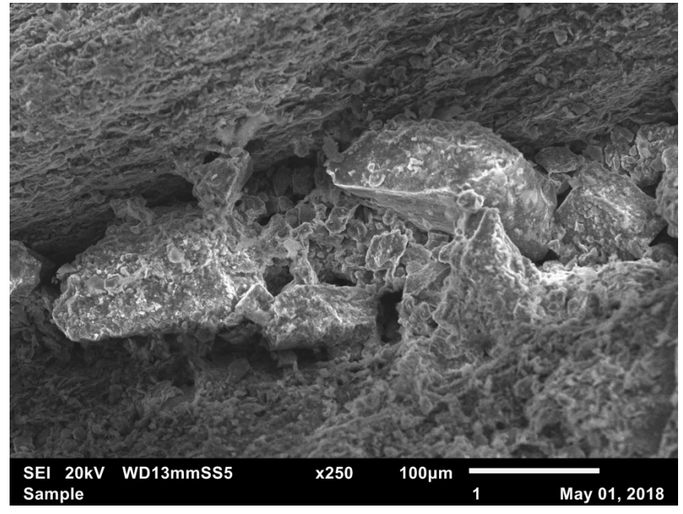


Figure 15: SEI 20kV x250. Some porosity present between the largest grains.

Figures 16-19: SEI images taken to display the surface texture of one section of a sample. These Figures show no observable porosity.

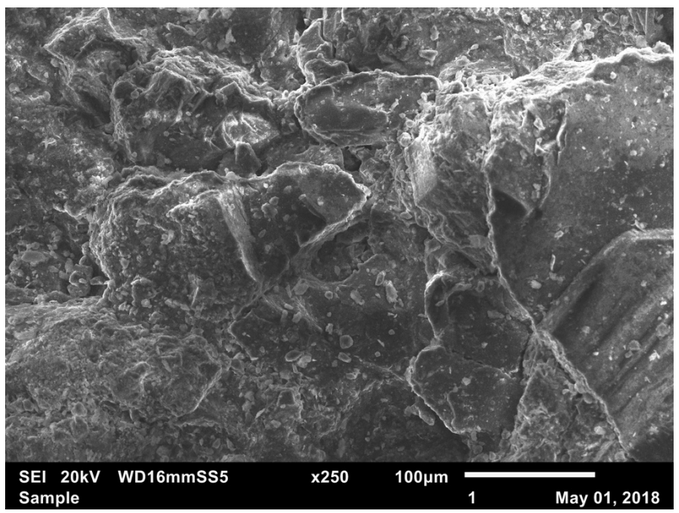


Figure 16: SEI 20kV x250.

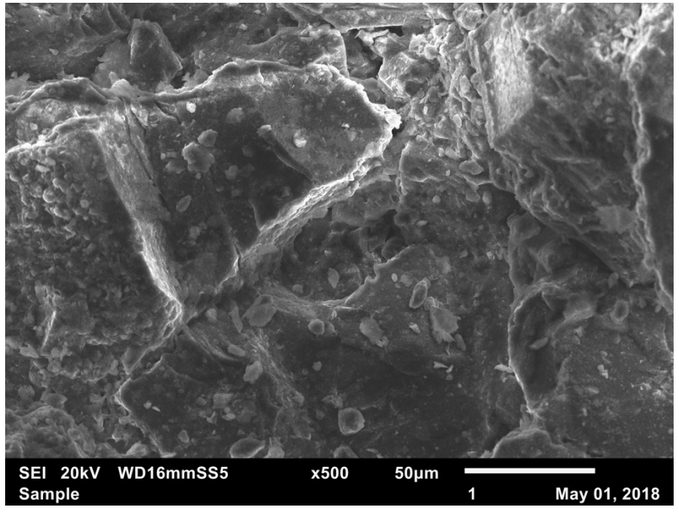


Figure 17: SEI 20kV x500.

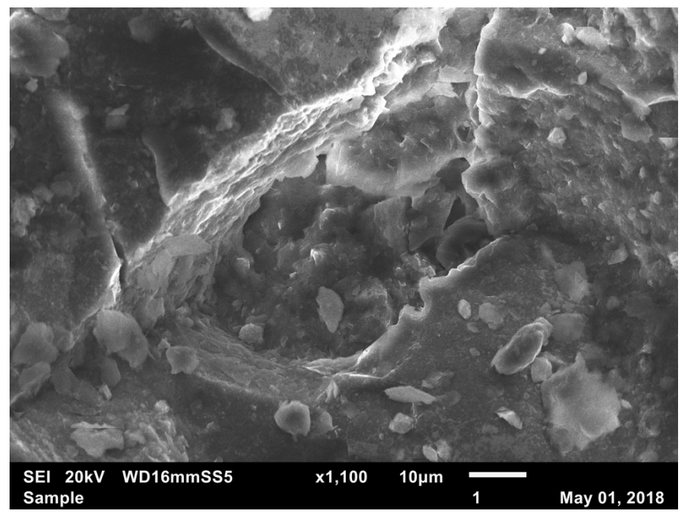


Figure 18: 20kV x1,100.

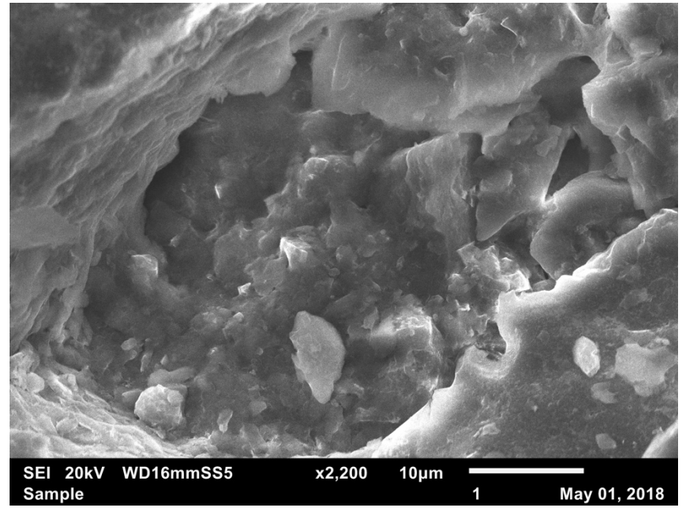


Figure 19: 20kV x2,200. Particles 1-10 micrometers in size are present.

Figures 20-23: These photos focus on one pore of a section within a sample from this interval. This sample is made up of primarily of platy particles ranging from 5 to 15 micrometers in diameter. Some larger grains over 100 micrometers in diameter are also present.

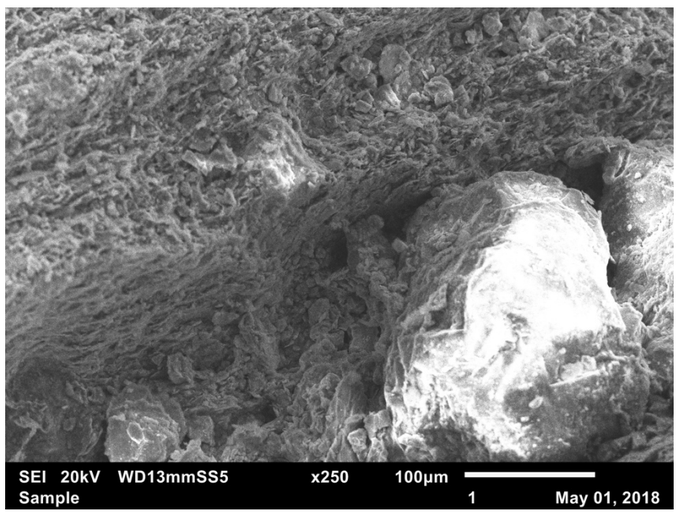


Figure 20: SEI 20kV x250.

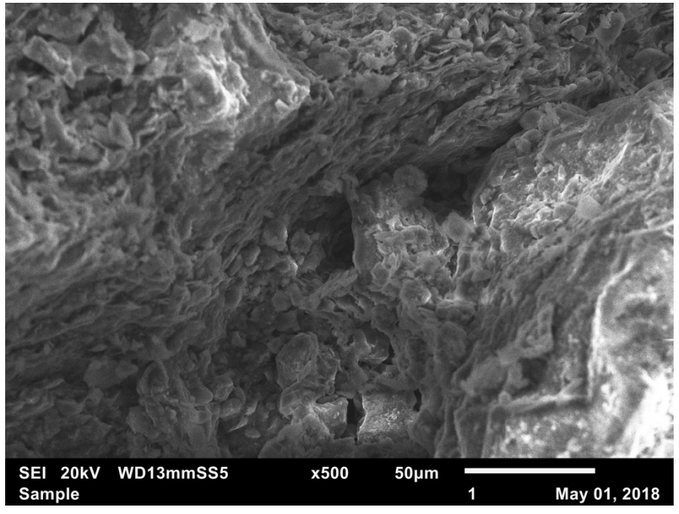


Figure 21: SEI 20kV x500.

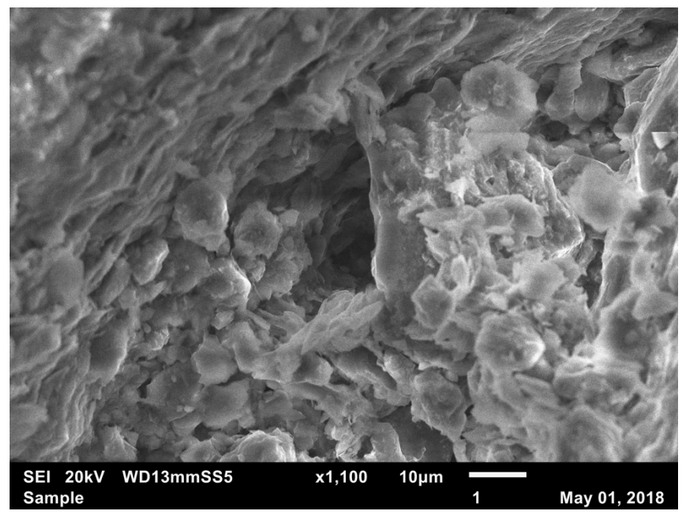


Figure 22: SEI 20kV x1,100. The platy particles are visible in here.

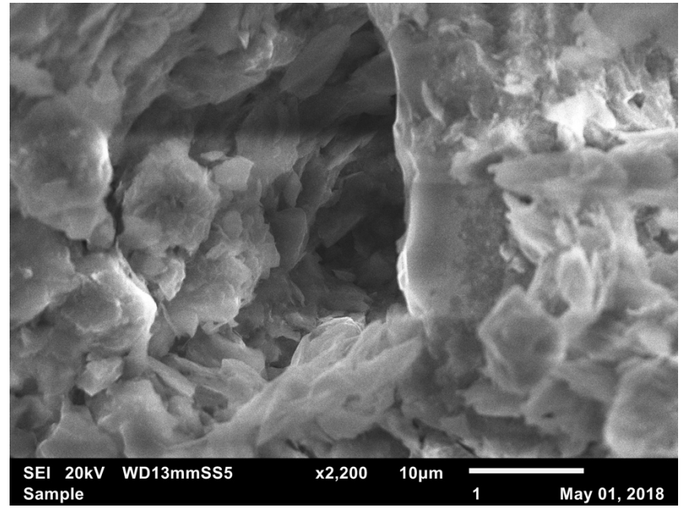


Figure 23: SEI 20kV x2,200. A closer look into the pore. The flat, platy minerals extend into the space.

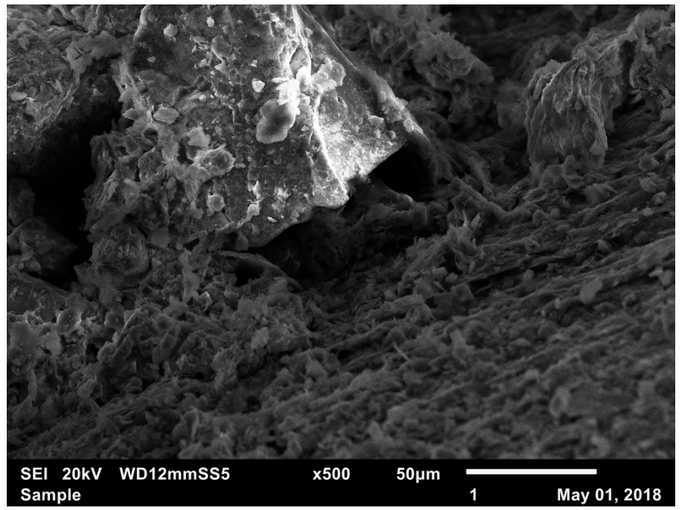


Figure 24: SEI 20kV x500. Three gaps appear to be in the center of this sample.

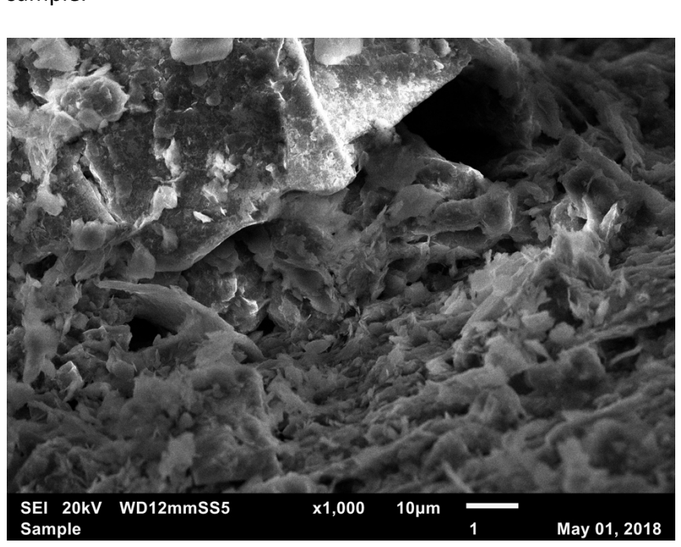


Figure 25: SEI 20kV x1,000. Corresponds to Figure 24—a closer look at the "gaps". What appeared to be a possible pore in Figure 24 was just a dark spot in the photomicrograph. Platy minerals can be seen in a higher magnification.

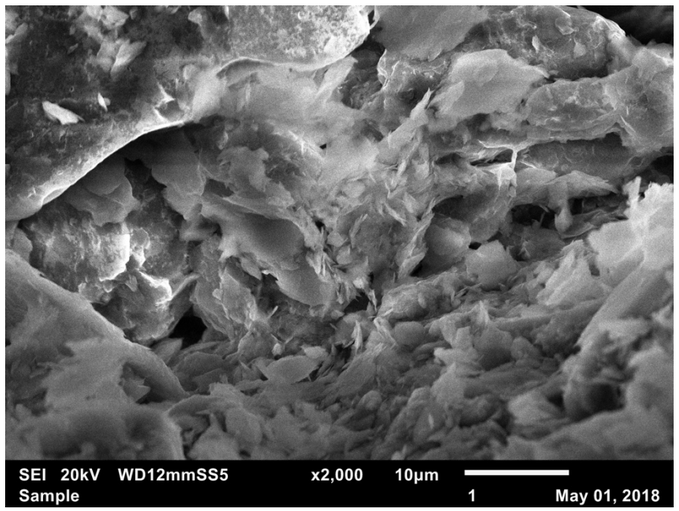


Figure 26: SEI 20kV x2,000. A closer look at the minerals in Figures 24 and 25. Some porosity may be present—a few gaps around 2-3 micrometers in diameter can be seen in the center of the photomicrograph.

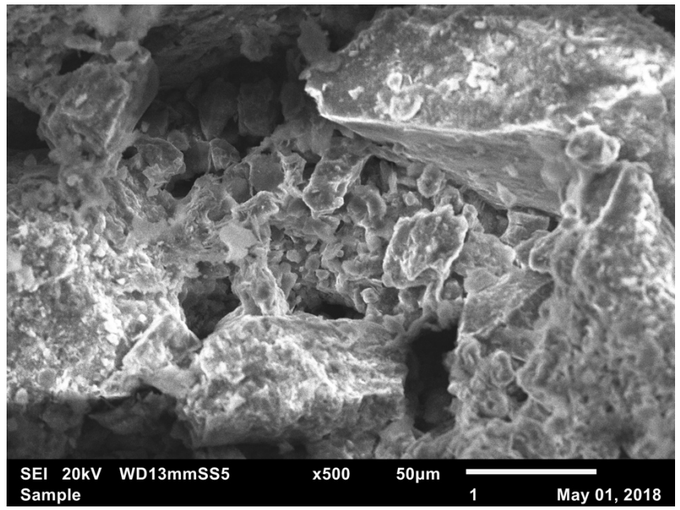


Figure 27: SEI 20kV x500. The gaps present may be instances of porosity.

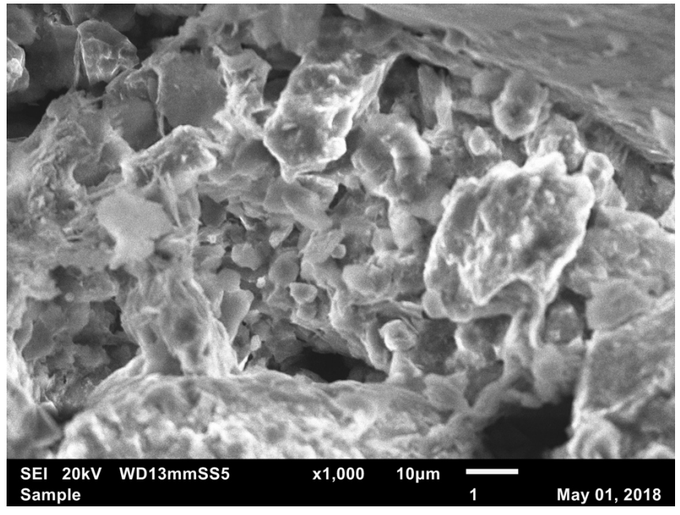


Figure 28: SEI 20kV x1000. Corresponds to Figure 27. A closer look at the gaps of this section as well as the flat, platy minerals composing the sample

Appendix 4: SEM Photomicrographs

#1 Harry Hatfield Well, Linden Field, Washington County, PA

SEM photomicrographs for the Gordon sandstone, depth 2680’ to 2690’

Described by Lauren Kanavy, Pennsylvania Geological Survey, November 2018

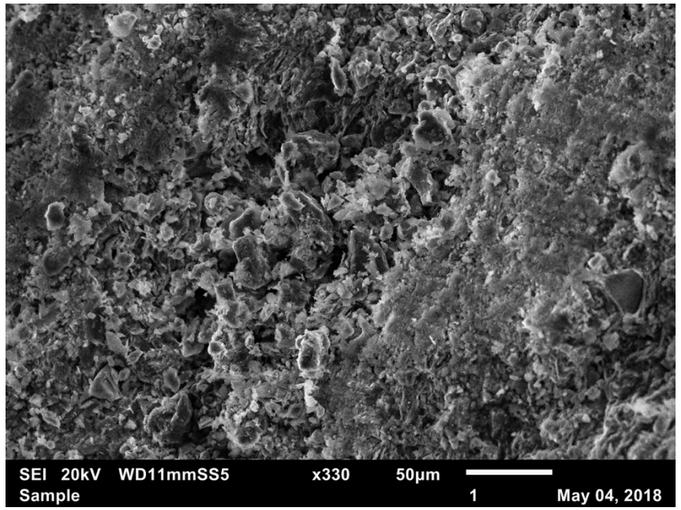


Figure 1: SEI 20kV x330. Flat, platy particles ranging 10-50 micrometers in diameter make up the surface of this sample.

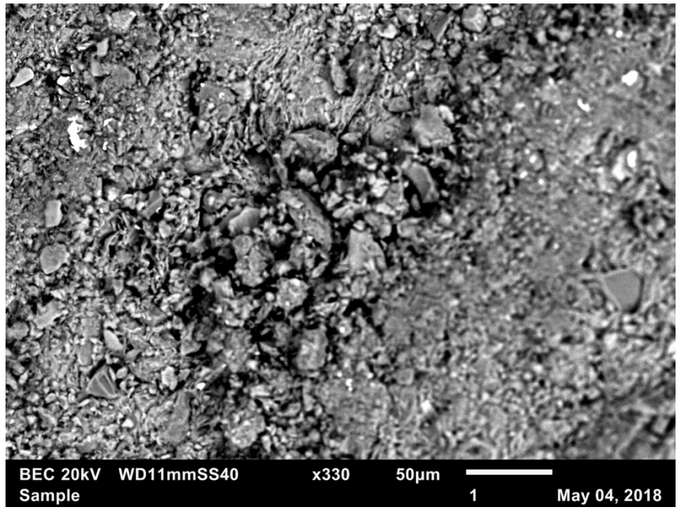


Figure 2: BEC 20kV x330. Corresponds to Figure 1. There could be some pore space between the grains larger than 25 micrometers in the center of the sample.

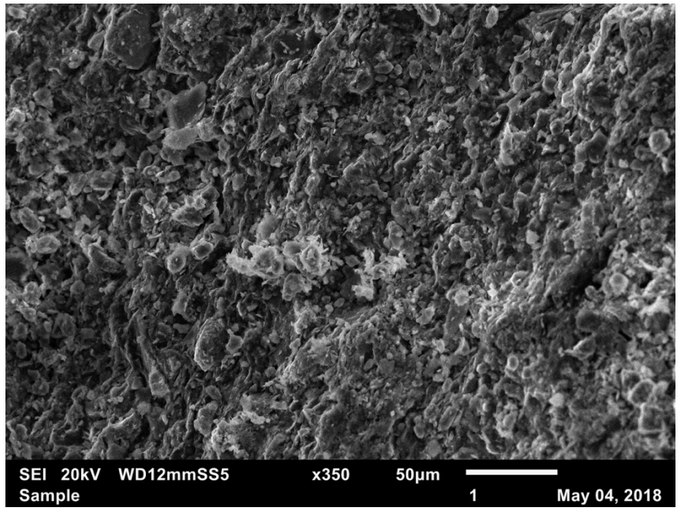


Figure 3: SEI 20kV x350. Another look at the type of minerals composing this sample.

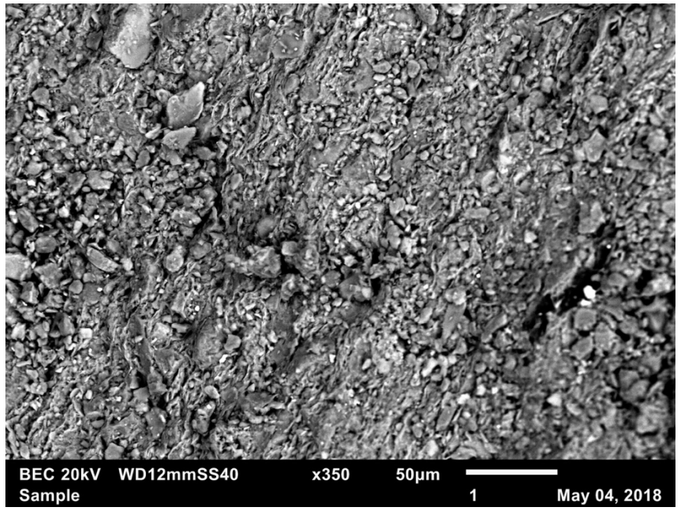


Figure 4: BEC 20kV x350. Corresponds to Figure 3.

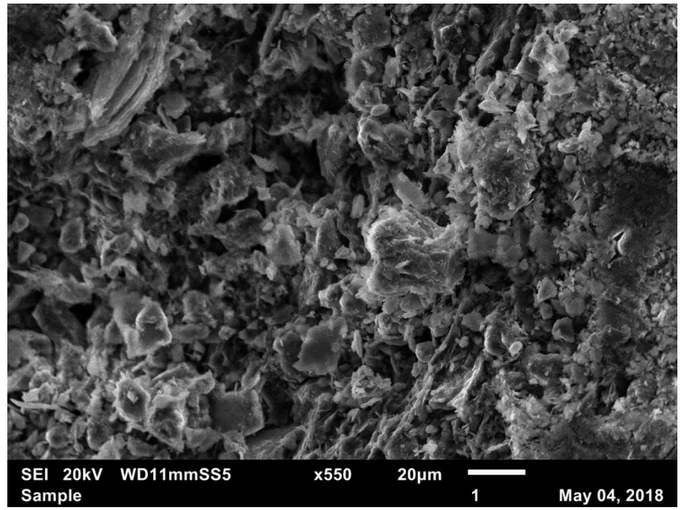


Figure 5: SEI 20kV x550. More platy particles observed.

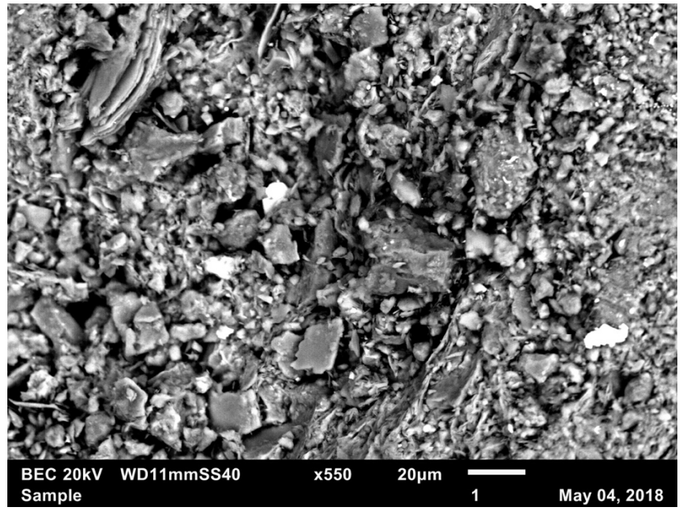


Figure 6: BEC 20kV x550. Corresponds to Figure 5. The gaps between some of the larger grains could be possible pore spaces.

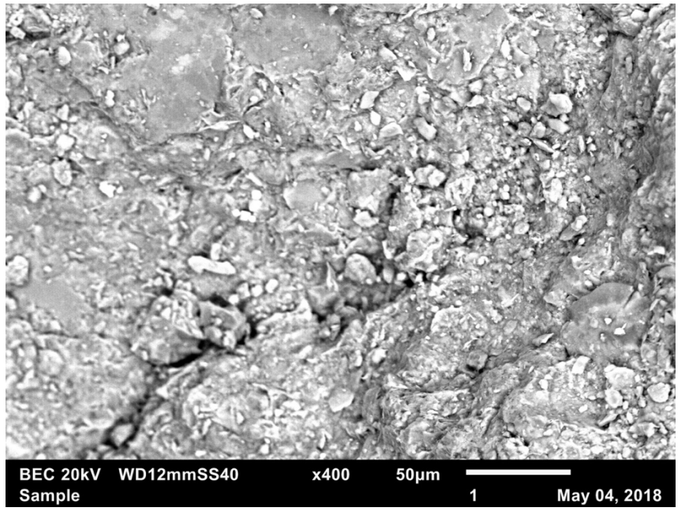


Figure 7: BEC 20kV x400. A variety of different sized particles make up the sample.

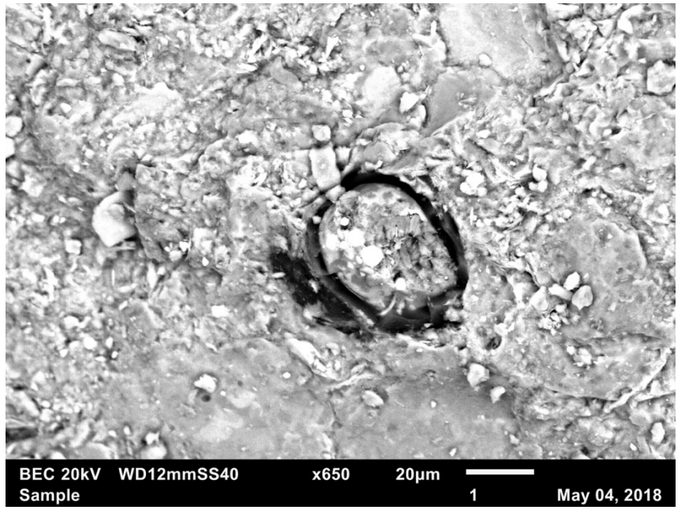


Figure 8: BEC 20kV x650. A grain around 40 micrometers across is surrounded by a gap.

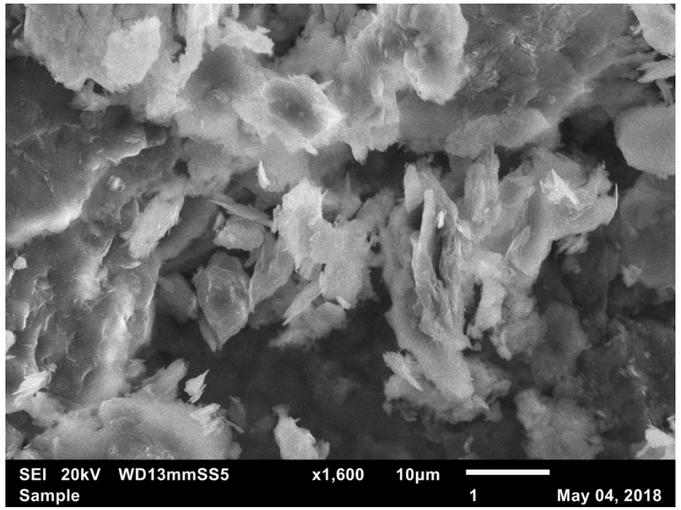


Figure 9: SEI 20kV x1,600. Angular, flat, and platy minerals.

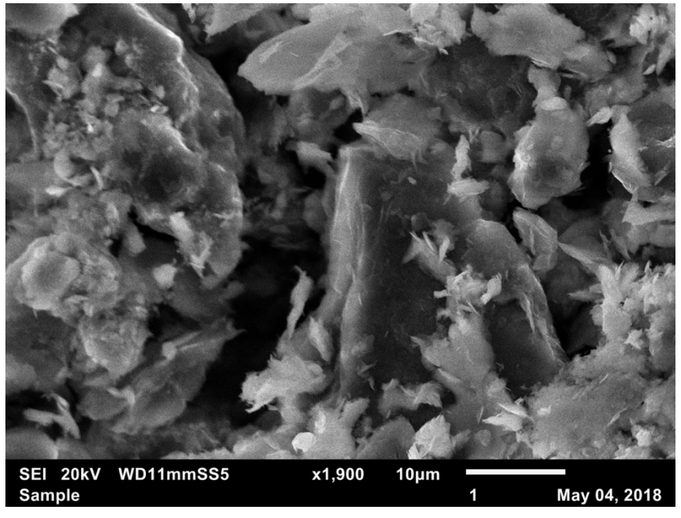


Figure 10: SEI 20kV x1,900. More platy minerals.

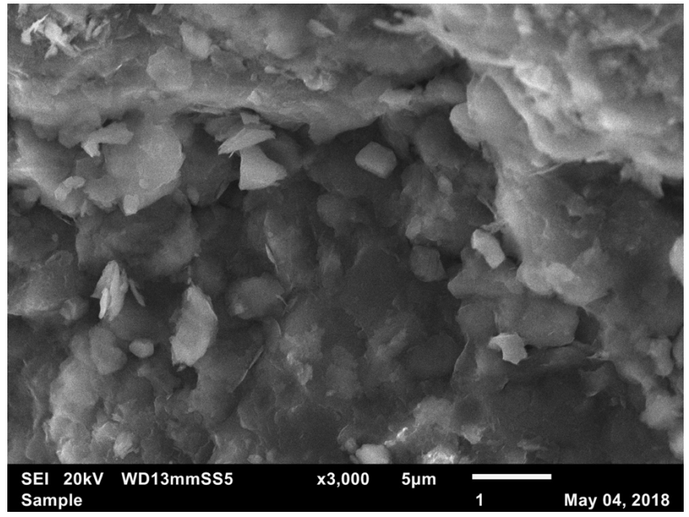


Figure 11: SEI 20kV x3,000.

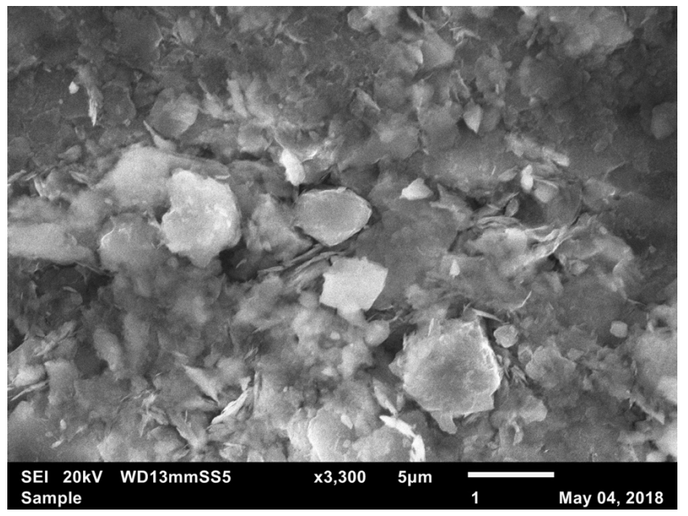


Figure 12: SEI 20kV x3,300.

Appendix 5: SEM Photomicrographs

#1 Harry Hatfield Well, Linden Field, Washington County, PA

SEM photomicrographs for the Gordon sandstone, depth 2690’ to 2700’

Described by Lauren Kanavy, Pennsylvania Geological Survey, November 2018

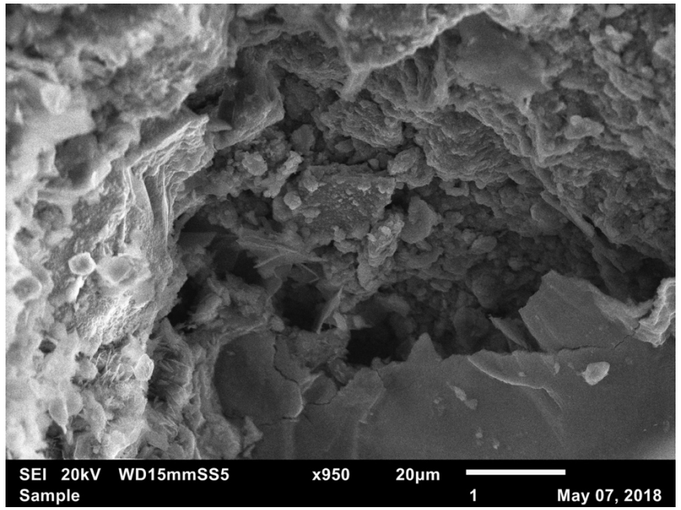


Figure 1: SEI 20kV x950. Pore space is present in the center of the image.

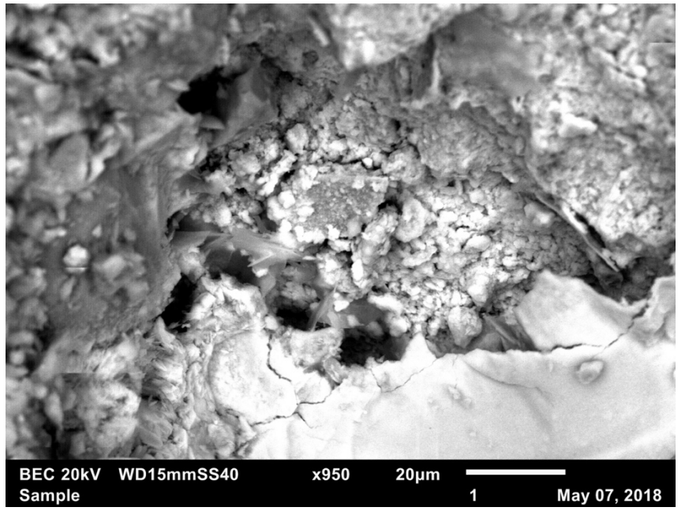


Figure 2: BEC 20kV x950. Corresponds to Figure 1.

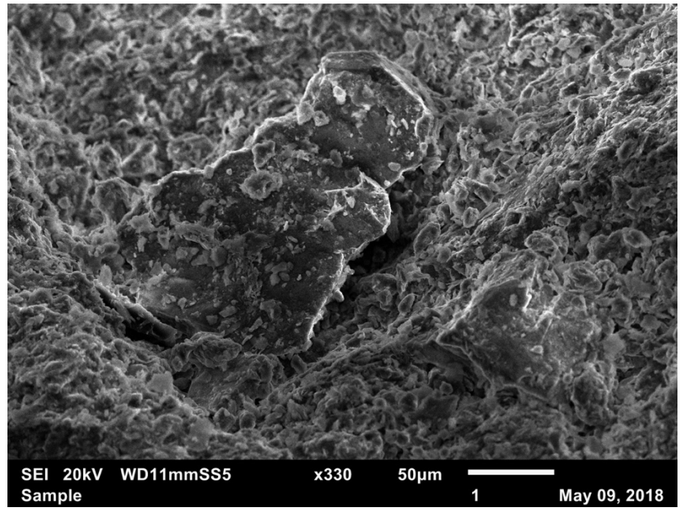


Figure 3: SEI 20kV x330. A large grain around 200 micrometers across is surrounded by particles 10 micrometers in diameter.

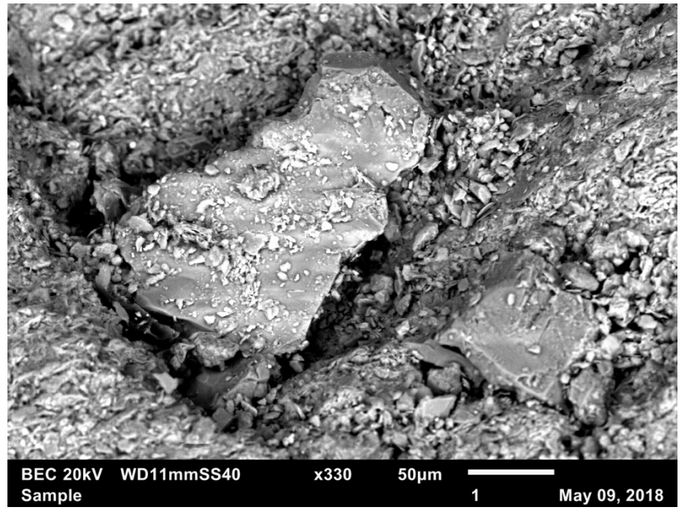


Figure 4: BEC 20kV x330. Corresponds to Figure 3.

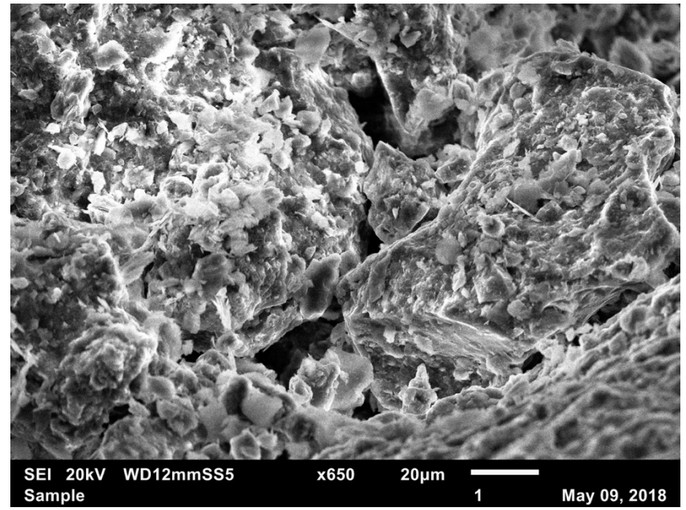


Figure 5: SEI 20kV x650. Pore space is observed around the 100-micrometer grain.

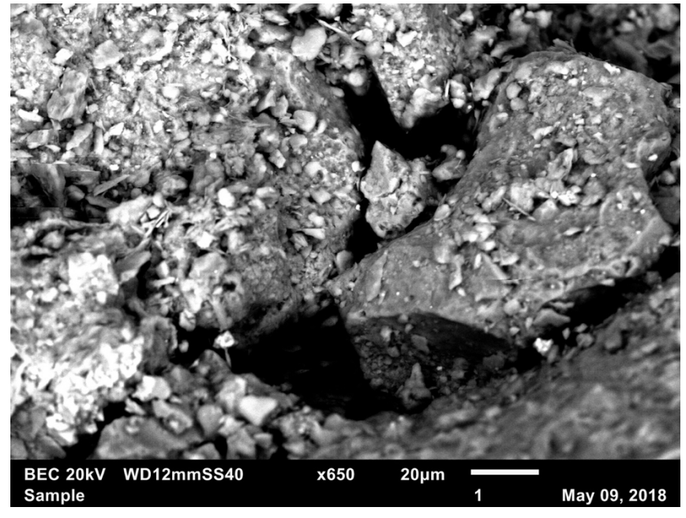


Figure 6: BEC 20kV x650. Corresponds to Figure 5.

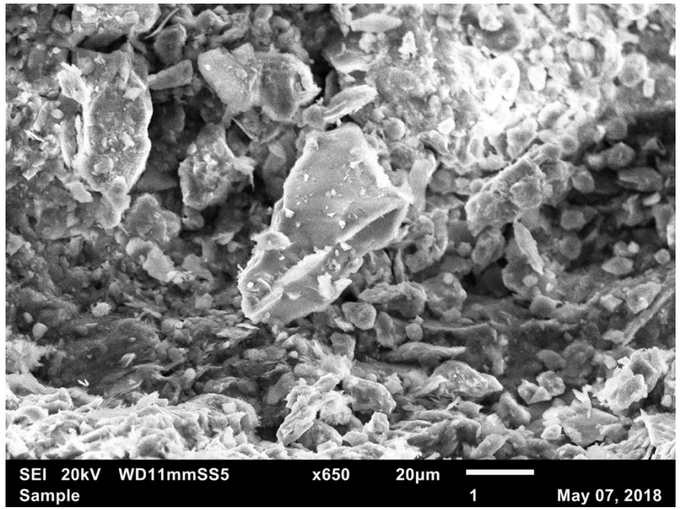


Figure 7: SEI 20kV x650. Particles of varying sizes ranging from 50 to 5 micrometers across make up the sample.

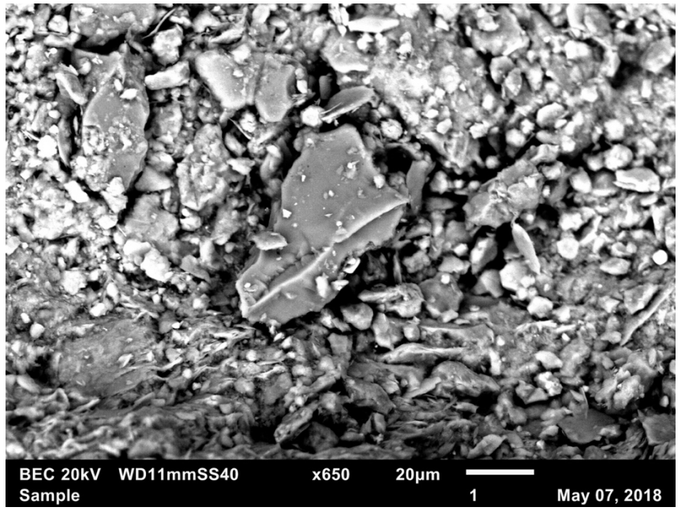


Figure 8: BEC 20kV x650. Corresponds to Figure 7.

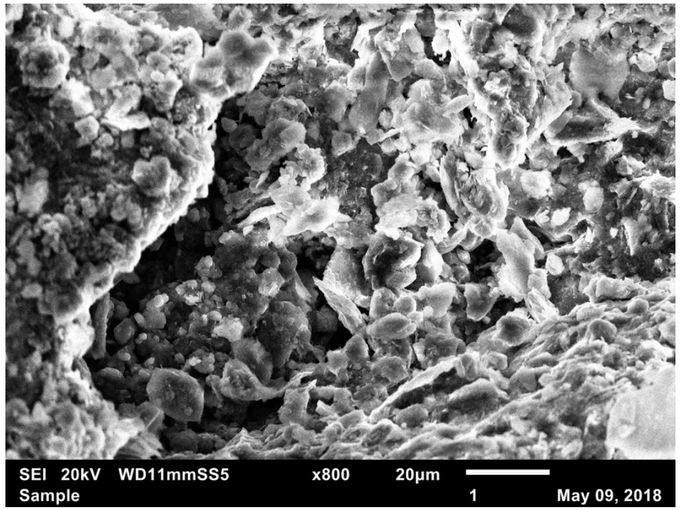


Figure 9: SEI 20kV x800. Pore space seems to be present towards the left of the sample are.

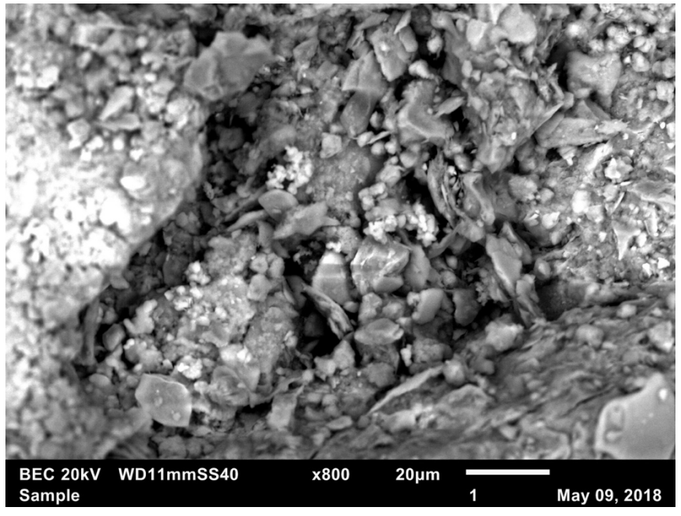


Figure 10: BEC 20kV x800. Corresponds to Figure 9. The BEC photomicrograph of this section shows that what looked like possible pore space in the sample was just a dark spot in the picture.

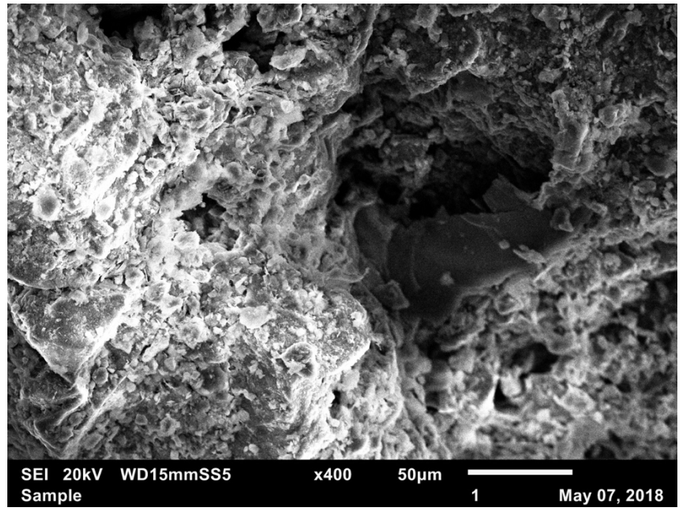


Figure 11: SEM 20kV x400. There is a larger mineral around 60 micrometers of which to take note.

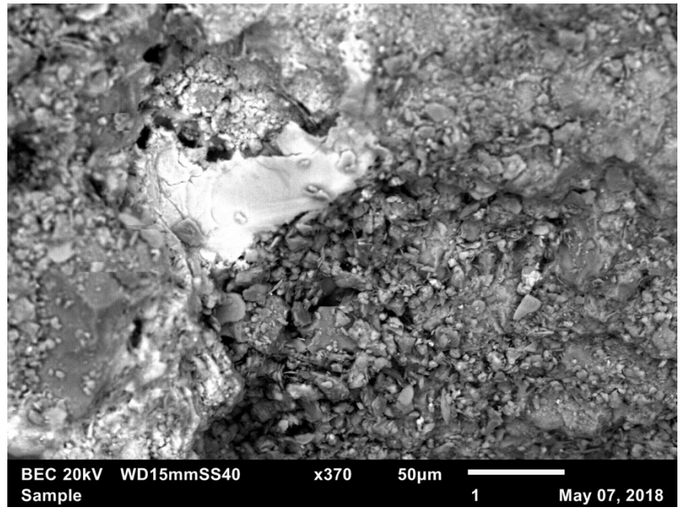


Figure 12: BEC 20kV x370. Corresponds to Figure 11. The larger mineral in Figure 11 is white in this photomicrograph. This indicates that the grain is of a different composition than its surrounding minerals.

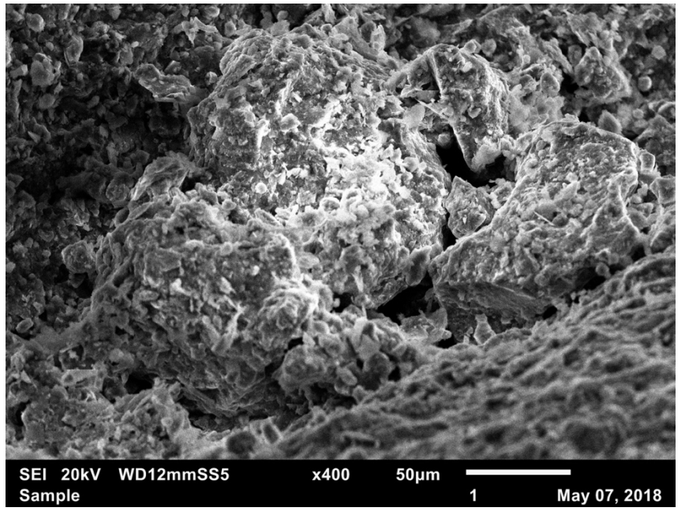


Figure 13: SEI 20kV x400. Larger grains around 100 micrometers in diameter are center in this section. Possible pore space lies in between the large grains.

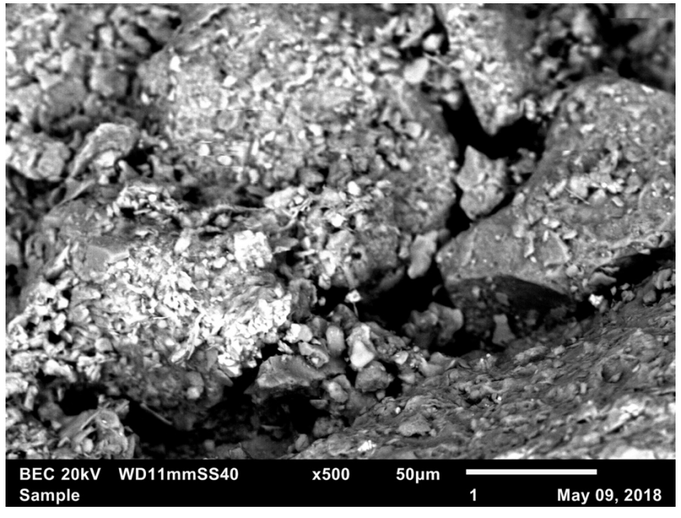


Figure 14: BEC 20kV x500. Corresponds to Figure 13. Pore space is observed between the larger grains.

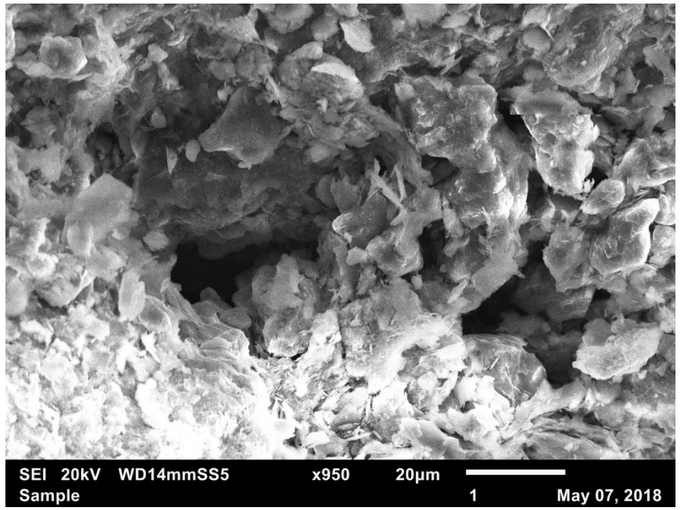


Figure 15: SEI 20kV x950. Porosity as well as flaky minerals are present in this sample.

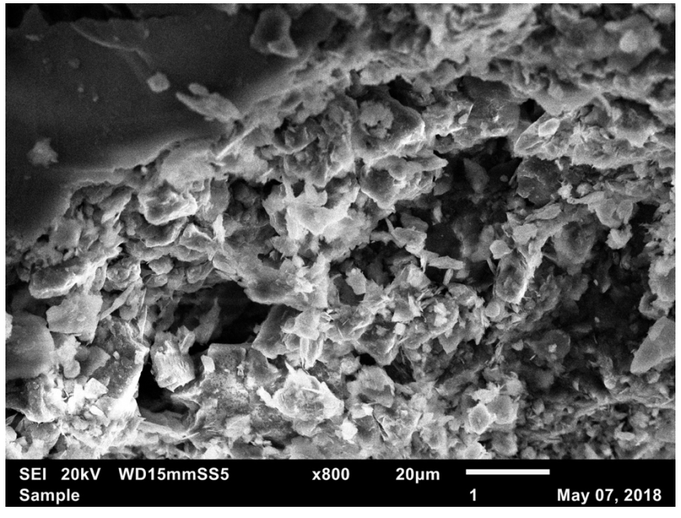


Figure 16: SEI 20kV x800. Platy clay minerals and possible porosity are shown.

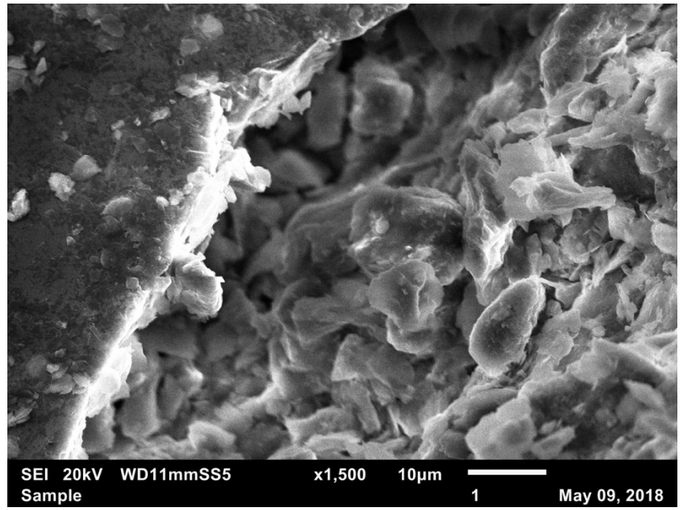


Figure 17: SEI 20kV x1,500. Details of the smaller particles of the sample. The platy and flaky minerals range from 1 to 10 micrometers in diameter.

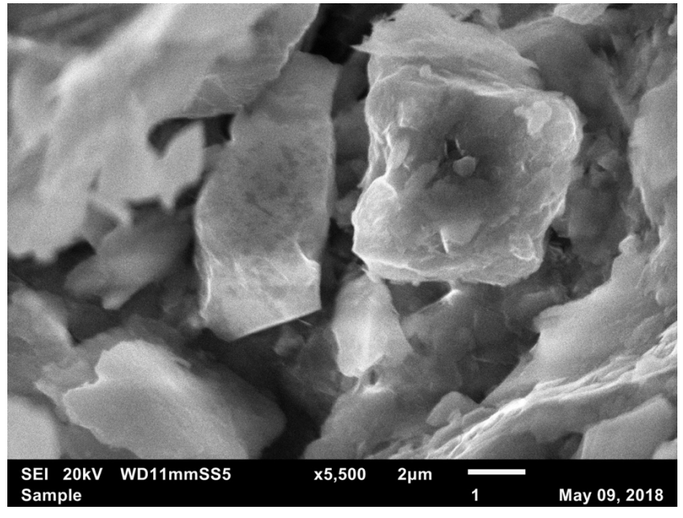


Figure 18: SEI 20kV x5,500. Corresponds to the upper center portion of Figure 17. The mineral pictured is cubic in shape, and the texture appears to be flaky and platy.

Appendix 6: #3299 Hamilton Well Documents

#3299 Hamilton Well, Linden Field, Washington County, PA

Well documents including the geophysical log, GR curve, Log Analysis, and Sample Study Log

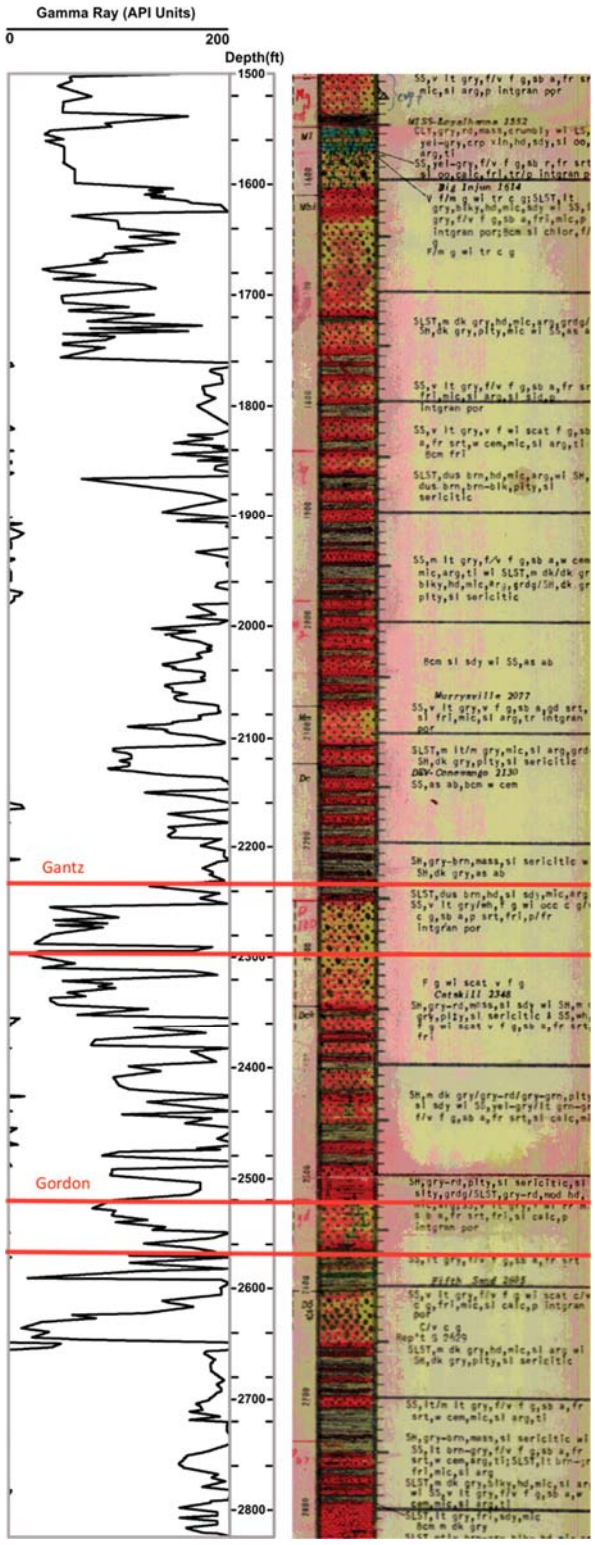


Figure 1: Geophysical logs. GR curve and GEO log. The Gantz and Gordon sandstone intervals are marked on the logs.

3712520703

Log Analysis

SCHLUMBERGER

COMPANY: THE PEOPLES NATURAL GAS CO. | WELL: HAMILTON #3299

FIELD: SOUTHERN | COUNTY: WASHINGTON | STATE: PENNA

DEPTH	% POROSITY	% OIL	% GAS	% WATER	R_t/R_w	R_t	Δ_t	ρ_B	H Ind	N cps	Vm or ρ_g	R_w	REMARKS
1526-32	9½							2.46			2.68		
1532-39	6½							2.52					SHALY
1560-70	7½							2.50					SHY
1570-90	9½							2.46					
1700-04	7½							2.50					SHY
1704-10	8½							2.50					
1714-18	11							2.42					
1720-24	9½							2.46					
1744-58	7½							2.50					
1772-74	6½							2.52					
1780-84	6							2.54					
1864-72	6							2.54					
2109-11	6							2.54					
2120-24	6							2.54					
2126-31	7							2.51					
2255-60	7½							2.50					
2260-64	11							2.42					
2264-70	7							2.51					
2274-78	7½							2.50					
2278-84	8½							2.48					
2294-2300	8							2.44					
2328-38	7	ALL POROSITIES GAS CORRECTED						2.51					
2536-46	7							2.51					SHALY

"This interpretation represents our best judgment. Nevertheless, since all interpretations are opinions based solely on inferences from electrical or other measurements, we cannot and do not guarantee the accuracy or correctness of any interpretations and shall not, except in the case of willful negligence on our part, be liable or responsible for any loss, damages, or expenses that may be incurred or sustained resulting from this or any other interpretations."

DATE: 9-30-65 | LOCATION: INDIANA | ENGINEER: MANGOLD

SWSC-1325

Figure 2: The Peoples Natural Gas Co. Log Analysis containing the corrected porosity and bulk density of selected intervals 1526’ to 2546’ in depth.

Figure 3: The Peoples Natural Gas Co. Sample Study Log. The Gantz is characterized as a medium-grained sandstone with grey shale (p.4). The Gordon is characterized as a sandstone with red and grey shale (p.4-5).

37125207O3

NG-8
EE-1

SAMPLE STUDY LOG

OPERATOR	The Peoples Natural Gas Co.	LOCATION MADE	6-23-41
WELL NO.	3299	DRILLING COMMENCED	7-17-41
FARM NAME	Walla ce Hamilton et ux #1	DRILLING COMPLETED	9-12-41
TOWNSHIP	North Strabane	TOTAL DEPTH	2951
COUNTY	Washington	GAS AT	400-1538-2297-2629-
STATE	Pennsylvania		
DISTRICT	Washington	PRODUCING SANDS	Pittsburgh Coal, Maxton, 50',5th Sand, Bayard Stra
MAP	406 N36-E23		
ELEVATION	1172.3 (Ground)		
QUADRANGLE	Amity	OPEN FLOW - Casing	8¼"-58,000
	Approx. 1.47 mi. W. of Long. 80°-05'	" " - Tubing	3"-67,000
	" 1.59 mi. S. of Lat. 40°-15'	ROCK PRESSURE - Casing	228¼ 11 Day
		" " - Tubing	109½ 11 Day

CASING RECORD

10"	8¼"	8¼" Perf.	3"	3" Perf.
447&7"	1524' 0"	43' 6"	2900' 3"	69' 3"

1 - 10 x 8½" Anchor Set at 1514'
1 - 6⅝ x 3" " " " 2616'

P.N.G. CORRELATION	TOP	BOTTOM	THICKNESS	QUALITY OF SAND	DESCRIPTION
	17	19			Grey Sh.
	19	26			Grey Sh, fossiliferous Ls., yellow calc. clay & white med. gr. Ss.
	26	29			Grey siltstone & Ls.
	29	47			Grey, fine-med. gr., micaceous Ss. Some Ls.
Waynesburg "A"	47	50	3'		
TOP OF MONONGAHELA SERIES					
	47	50			Mostly coal.
	50	54			Lt. grey clay. Some calcareous clay & dk. grey Ls. (20%).
	54	64			Lt. grey, med. gr. cl. Ss. 20%. Buff Ls.
	64	68			Lt. grey siltstone.
	68	98			Grey sandy Sh. Some clay & Ls. Clay increases toward base.
	98	103			Grey Sh, clay, Ls. Coal common.
	103	112			Fine, grey, micaceous Ss.
	112	118			Above Ss. Some black Sh. Coal common.
Waynesburg	117	120	3'		
	118	124			As above - Coal abundant. Coal probably 117-120.
	124	130			Grey clay & brown Ls.
	130	135			Buff pure Ls. Some looks like chert-transl cent.
	135	145			Cream calcareous clay & Ls.
	145	154			Brown Ls. Some green Sh.
Uniontown	157	160	3'		
	154	159			Mostly black Sh. & coal.
	159	164			Cream calc. clay & buff Ls.
	164	171			Mostly buff Ls.
	171	175			Greenish clay-Sh. Some above Ls.
	175	178			Brown Ls. Some green Sh.
	178	183			White clay & lt. grey Ls.
	183	190			Buff Ls. Some clay.
	190	195			Green Sh. & clay-Sh.
	195	205			Brown clayey Ls.
	205	217			Cream calcareous clay.
	217	222			Green Sh. Some brown Ls.
	222	229			Black, limey Sh. Some green Sh.
	229	252			Buff, argillaceous Ls. Some dk. grey & sh. in top.
	252	257			Cream dolomite (?) Looks like Ls. but does not react to HCl. as Ls.
	257	263			Green clay -Sh. & above dolomite (?)
	263	281			Cream argillaceous Ls.-Becomes more pure & darker toward base.
	281	293			Grey fine shaly Ss.
	293	304			Grey Sh. Some above Ss. Sh. is calcareous
	304	309			Buff Ls. Some black Sh. - may be coal.
	309	313			Grey Sh, green Sh, buff Ls. & brown Ls. in equal amounts. Pyrite abundant.
	313	327			As above: - No grey Sh.
	327	333			Red & grey clay. Some above Ls. & Lt. green clay - Sh.

P.N.G. CORRELATION	TOP	BOTTOM	THICK-NESS	QUALITY OF SAND	DESCRIPTION
	333	345			Grey, fine gr. micaceous Ss. 75%. Remainder as above.
	345	353			Dk. grey Sh.Some above Ss. & grey Sh.
Redstone	355	358	3'		
	353	358			As Above: Coal common.
	358	376			Dk. grey, micaceous@ sandy Sh.
	376	382			Above Sh. has graded into a fine gr. carbonaceous Ss. Coal common.
	382	393			Dk. grey sandy Sh.
	393	398			As above: 25% coal.
Pgh.Coal	396	404	8'		
	398	404			Mostly coal:-Top at 396'.
TOP OF CONEMAUGH SERIES					
	404	410			Grey, fine, micaceous cl. Ss. Some fine clay
	410	415			Brown Ls. Some dk. grey Sh.
	415	423			Varigated greenish clay - Sh. Some Ls.
	423	434			Brown Ls.
	434	444			Above Ls. & lt. green Sh.
	444	451			Green, med. gr., cl, micaceous Ss. 50%.
	451	457			Ss. more coarse. 75% - Brown Ls.
	457	463			Above Ss. & grey Sh.
	463	475			Above Ss.-free & cl. - 75%.
	475	482			Grey & green Sh.
	482	507			Dk. grey sandy Sh. Some shaly Ss.
	507	513			As above:-25% brown clay. Pyrite.
	513	518			Sh. & clay equal. Some red clay.
	518	540			Red, yellow & lt. greey clay.(518-35 10% Ls Clay is calcareous.)
	540	551			Green, sandy Sh. & red clay.
	551	563			Green & red Sh.
	563	570			Green sandy Sh. Some red and green Sh.
	570	577			Above sandy Sh. grey sh. & dk.grey Sh.
	577	591			Green, Red & grey clay. Some above Sh. Cla y is calcareous.
	591	630			Greenish grey Sh. Some above clays & some red Sh.
	630	635			Green, red & grey clay. Coal common. Top at 634.
Elk Lick	634	636	2'		
	635	640			Green Sh. & shaly Ss. Some above clays & coal.
	640	649			Red & grey clay. 25% above Ss. Some Ls.
	649	667			Red & green Sh. Some clay. 5% Buff Ls.
	667	673			Buff, fos, Ls. 30%.
	673	680			Olive green & red clay. Some Ls. & grey Sh.
	680	685			" " clay-Sh. Calcareous
	685	704			Red & green clay. Calcareous.
	704	726			Greenish grey Sh. - Some clay in top.
	726	736			Green & red Sh. Some clay.
	736	746			Dk. grey & grey Sh. Some green & red Sh.
	746	751			As above: 20%. lt. green & red clay. Occasional Ls. frag.
	751	757			Above clay. Some grey Sh. & Ls.
	757	769			Lt. grey Sh. & fine gr. cl. Ss.
	769	775			Green Sh. 25% above Ss. Some red clay.
	775	803			Green Sh. Some red clay.
	803	811			Red clay 50%. Some Ls.
	811	817			Green Sh. Some red clay & Ls.
	817	835			Greenish grey Sh.
	835	851			Grey micaceous sandy Sh.
	851	888			Sh. is a little darker
	888	899			Above Sh:-15% red & grey clay. 10% buff shaly Ls. Grey clay is calc.
	899	911			Grey & red clay. Some green Sh. & AboveLs.
	911	922			40% green Sh.-remainder as above: No appreciable Ls.
	922	928			Green Sh.-50%.
	928	945			Green sandy Sh.-75%.
	945	950			Green Sh, green "garnet" Sh, green brecciated Sh. Lt. green Sh. & red clay.
	950	980			Lt. green Sh. 35%. Above green Sh's. with red, grey & purple clay. Some Ls.

P.N.G. CORRELATION	TOP	BOTTOM	THICK-NESS	QUALITY OF SAND	DESCRIPTION
Big Dunkard	980	1023	43'		
	980	987			Grey, fine & med. gr. cl. Ss. Some above Sh. & clay.
	987	1003		Good	Ss. lighter in color and med. gr.
	1003	1007		V. "	Ss. white & med.-coarse gr. Free & cl.
	1007	1016			Above Ss.:-20% grey Sh. Ss. cong.
	1016	1023			Above Ss.:-20% red & brown clay, some grey & green Sh.
TOP OF ALLEGHENY SERIES					
Upper Freeport	1023				
	1023	1030			As above: - Some coal.
	1030	1036			As above: - No coal. Grey clay 40%.
	1036	1048			Grey Sh. Some clay & above Ss.
	1048	1053			Grey Sh.:-Some coal (may be caving)
	1053	1067			Grey Sh. Some sandy Sh. & fine cl. Ss.
Lower Freeport	1067				
	1067	1100			Grey Sh. & sandy Sh. Some coal.
	1100	1112			Dk. grey sandy Sh.
Upper 1st Gas	1112	1145	33'		
	1112	1117			Above Sh:-30% lt. grey, fine-med. gr. cl. Ss.
	1117	1140			Ss. & Sh. 50-50. Ss. in part carbonaceous.
M. Kittanning	1145	1148	3'		
	1140	1147			Ss. 75%. Coal. Top at 1145'.
	1147	1157			Black Sh. & lt. grey "garnet" Sh. Some Ss. & coal.
	1157	1182			Grey Sh. & sandy Sh. Some above black Sh.
	1182	1187			Grey, med. gr. cl. Ss. & grey sandy Sh.
	1187	1198			Ss. 75%.
	1198	1203			Mostly grey Sh. Some above Ss.
L. Kittanning	1209	1213	4'		
	1203	1212			Above Sh:-25% white, fine cl. Ss, Lt. grey clay. Coal common. Top at 1209.
	1212	1222			Grey Sh. & Lt. grey "garnet" clay Sh. Some coal & Ss. in top.
	1222	1228			Above Sh. & grey, fine, shaly, micaceous Ss.
Vanport	1228	1242	14'		
	1228	1242			Grey Sh. & sandy Sh. Occasional Ls. frag.
Clarion	1242	1243	1'		
	1242	1247			As above:-Some med.gr. Ss. & coal. No Ls.
1st Gas	1243	1252	9'		
	1247	1252			Grey Sh. & sandy Sh. 30% med.gr. cl.Ss.
	1252	1287			Grey Sh. Some brown Sh.
	1287	1289			Grey Sh. & lt. grey sandy Sh.
TOP OF POTTSVILLE SERIES					
1st Salt	1290	1384	94'		
	1289	1300		Good	Grey, med. gr., micaceous, cl. Ss.
	1300	1330			Ss. med.-coarse gr, free & cl.
	1330	1383		V. "	Ss. white, cong.
	1383	1390			Dk. grey sandy Sh. & coal. Some above Ss.
	1390	1421			Grey Sh.
	1421	1427			Grey sandy Sh.
	1427	1434			Grey fine shaly Ss. 50%.
2nd Salt	1434	1462	28'		
	1434	1462		Good	Lt. grey, med. gr, cl, micaceous Ss. Lower 10' calcareous.
	1462	1467			Grey sandy Sh. & dk. grey Sh.
	1467	1473			As above:-Coal common.
	1473	1502			Grey Sh.
3rd Salt	1502	1535	33'		
	1502	1510		Good	White, med, gr, cl, Ss.-50%.
	1510	1515			Ss. - 75%. Some red Sh.
	1515	1521			Above Ss.
	1521	1532			Above Ss.-Plant fossils. Some red Sh.
	1532	1538			Above Ss. & 50%. black sandy Sh. Ss. free & cl.
	*1538	1543			Dk. grey sandy Sh.
BIG INJUN SAND	1543	1798	255'		
Loyalhanna Ls.	1543	1610	67'		
	1543	1548			Above Sh:-25% lt. grey, med. gr. cl. Ss. Ss. very calcareous.
	1548	1553			Above Ss.-50%. Lt. greenish-white in color.
	1553	1606			Above Ss.-Rounded & frosted pebbles. Looks like Loyalhanna.
	1606	1611			Above Ss.-10% lt.greenish sandy Sh.(Bot. Clh. at 1610).

P.N.G. CORRELATION	TOP	BOTTOM	THICK-NESS	QUALITY OF SAND	DESCRIPTION
Burgoon Ss.	1610	1798	188'		
	1611	1618			Lt. grey, med, gr. cl. Ss. Rounded & frosted pebbles but not calcareous. 25% sandy Sh.
	1618	1626			Above Ss.-dense & cl. Dk. grey Sh.-30%. No pebbles.
	1626	1636		Good	Lt. grey, med. gr. dense cl. Ss.
	1636	1668			Ss. free & cl.
	1668	1754		V. "	Ss. cong. Some white coarse frag.
	1754	1768			Mostly grey sandy Sh. Some Ss.
	1768	1778			As above:-10% white, med. gr. cl. Ss.
	1778	1790			Ss. - 50%. Cong.
	1790	1798			Ss. - 35%.
	1798	1810			Mostly grey Sh.
	1810	1833			Grey Sh. & sandy Sh.
	1833	1859			Sandy Sh. grades into fine dense cl. Ss.
	1859	1875			Grey Sh.-85%.
Squaw Sand	1875	1905	30'		
	1875	1905			White, med.gr. cl, cong. Ss. 50%.
	1905	1914			Grey Sh. & fine shaly Ss.
	1914	1965			Grey Sh.
	1965	2010			" " - Some brown Sh.
2nd Gas	2010	2053	43'		
	2010	2027		Poor	Grey, fine, dense cl. Ss. 50%.
	2027	2035			Grey Sh. & sandy Sh. Some brown Sh.
	2035	2053			Grey, fine, dense, shaly cl. Ss. 50%.
	2053	2075			Grey Sh. & sandy Sh.
	2075	2084			As above:-occasional fragment of pebble.
Murrysville	2083	2156	73'		
	2084	2095			Pebbles more common - Some fine shaly Ss.
	2095	2097			Ss. - 50%. No pebbles.
	2097	2116			Grey sandy Sh.
	2116	2121		Poor	Lt. grey, fine dense cl. Ss. 50%. No pebbles.
	2121	2134			Ss. 75% plus.
	2134	2149			Grey Sh. Some Ss.
	2149	2156			Grey, fine, dense cl. Ss. 25%.
	2156	2250			Grey Sh. & sandy Sh.
Gantz	2254	2288	34'		
	2250	2261		V.Good	Above Sh.-50%, med. gr. free & cl. very cong. Ss. Top at 2252'.
	2261	2284			Ss. 90%.
	2284	2288			Above Ss.
	2288	2297			Grey Sh. 25% Ss.
50' Sand	2297	2389	92'		
	2297	2305		V.Good	White, very cong. coarse free & cl. Ss.
	2305	2309			Ss. not so cong. 25% grey Sh.
	2309	2314			Ss. 75%. Very cong.
	2314	2330		Good	Grey Sh. & above Ss. Ss. not so cong. & finer gr.
	2330	2345			Ss. 80%.
	2345	2350			Red sandy Sh. 50%. Above Ss.-35%. Grey Sh.
	2350	2359			Mostly grey Sh. Some Red Sh. & above Ss.
	2359	2364		Good	Ss.-15%. No red Sh. Ss. White, med. gr. & Cl.
	2364	2370			Ss. 25% Cong.
	2370	2381			Ss. 50%.
	2381	2389			Ss. 25%.
	2389	2396			Mostly grey Sh.
30' Sand	2400	2430	30'		
	2396	2430			Grey, med. gr. free & cl, cong. Ss. 50%.
	2430	2439			25% Ss. 25% red Sh. 50% grey Sh.
	2439	2441			Ss. 50%. Red Sh. 25%.
Snee Sand	2440	2455	15'		
	2441	2449			Ss. 50%. Grey Sh. 50%.
	2449	2458			Ss. 25%.
	2458	2473			Mostly grey Sh.
Gantz Sand	2475	2504	29'		
	2473	2487			Mostly grey Sh.-Ss. 15%. Cong.
	2487	2504			Ss. 25%.
	2504	2515			Grey & purple Sh. Some white, med. gr. Ss.
	2515	2522			Ss. 25%. Cong.
Gordon Sand	2522	2566	44'		
	2522	2556		V.Good	Ss. 75%. Free & cl.

P.N.G. CORRELATION	TOP	BOTTOM	THICK-NESS	QUALITY OF SAND	DESCRIPTION
	2556	2562			Ss. 25%.
	2562	2566			Ss. very cong. 50%. Some red Sh.
	2566	2573			Grey Sh. & red sandy Sh.-10% Cong.
4th Sand	2573	2591	18'		
	2573	2576			Grey Sh.-50%. Grey, med. gr., cong. cl. Ss. 35%. 15% red Sh.
	2576	2591			Ss. & Sh. equal
	2591	2605			Mostly grey Sh. Some Ss.
5th Sand	2611	2645	34'		
	2605	2617		Good	Ss.-similar to above & very cong.-50%.
	2617	2622		V. "	Ss. 75%.
	2622	2643			Above Ss:-Best sand in holt to depth.
	2643	2648			Ss. & grey Sh.
	2648	2742			Mostly grey Sh.
Bayard Sand	2745	2767	22'		
	2742	2752			Mostly grey Sh. - Some choc. fine shaly Ss.
	2752	2760			25% choc. Ss.
	2760	2767			50% Ss.
	2767	2782			Grey sandy Sh.
	2782	2787			Grey Sh.
	2787	2795			Lt. grey, fine shaly cl. Ss. 25% plus.
Bayard Stray	2795	2863	68'		
	2795	2803		Fair	Ss. 50%.
	2803	2828			Ss. 75%. - Lower part has slight choc. tinge.
	2828	2850			Ss. 50%. more shaly.
	2850	2863			Ss. 90%.
	2863	2872			Mostly grey Sh.
	2872	2880			Mostly grey Sh.-Some lt. grey, fine, fos, shaly, Ss.
	2880	2900			Grey Sh. & grey sandy, fos. Sh.
	2900	2907			Lt. grey, fine shaly, fos. Ss. 75%.
	2907	2944			Grey Sh. - Some above Ss.
	2944				Grey fine shaly Ss. 50%.
		2951			Total Depth