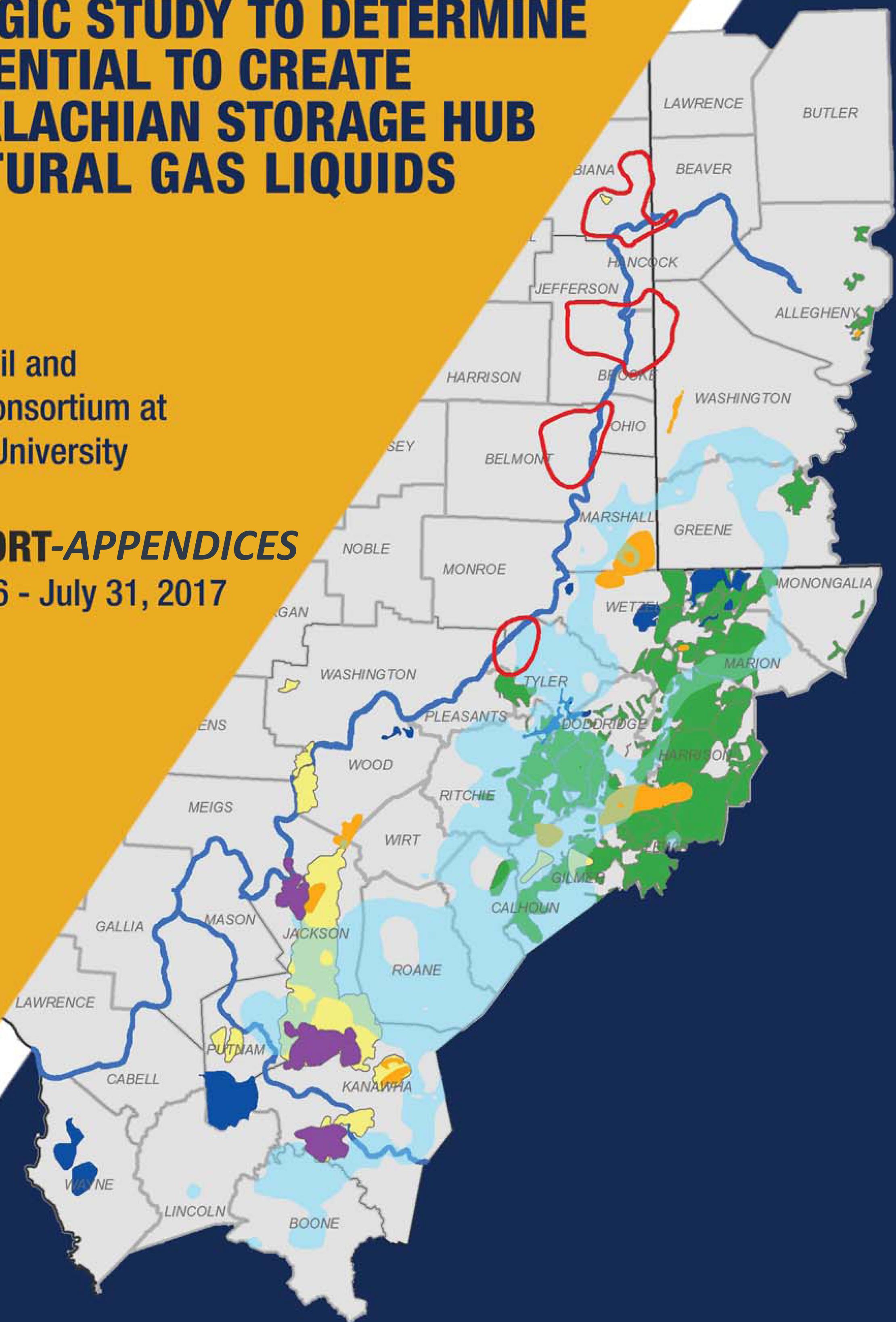
A GEOLOGIC STUDY TO DETERMINE THE POTENTIAL TO CREATE AN APPALACHIAN STORAGE HUB FOR NATURAL GAS LIQUIDS

Coordinated by:

Appalachian Oil and Natural Gas Consortium at West Virginia University

FINAL REPORT-*APPENDICES*

August 1, 2016 - July 31, 2017



West Virginia University

APPENDIX A – ANNOTATED BIBLIOGRAPHY

ANNOTATED BIBLIOGRAPHY

Matchen, David L., and Kammer, Thomas W., 1994, Sequence Stratigraphy of the Lower Mississippian Price and Borden Formations in Southern West Virginia and Eastern Kentucky: Southeastern Geology, V. 34 No. 1, pp. 25-41.

[Document Link: http://pages.geo.wvu.edu/~kammer/reprints/Matchen&Kammer1994.pdf (PDF, 1.28 MB)]

Keywords: *sequence stratigraphy, West Virginia, Kentucky, Mississippian, outcrops, gamma-ray, logs, allo-units*

This sequence stratigraphic study details the progradational wedge formed by the Lower Mississippian in the Appalachian basin. The Lower Mississippian rocks, which can be divided into four separate units, are units of major consideration in other manuscripts detailing prospects for geological sequestration. The researchers used three sets of outcrops and subsurface data, including 340 gamma-ray well logs, to correlate the units within the Lower Mississippian. The evidence presented in this manuscript can be used to further evaluate porosity and permeability of each of the four allo-units, further provided more detailed insight into which of the specific allo-units could be used as prospects for sequestration in West Virginia and Kentucky.

Martens, James H.C., 1943, Rock Salt Deposits of West Virginia: West Virginia Geological Survey, Bulletin No. 7, 67p.

[Document Information Link: http://www.wvgs.wvnet.edu/wvges2/publications/PubCat_Details.aspx?PubCatID=B-7]

Keywords: *West Virginia, Salina, Salt, Cross-sections*

In 1943, the West Virginia Geological Survey authored a Bulletin on the Rock Salt Deposits of West Virginia. Even at that time, the implications of these salt deposits were being explored. This publication illustrated that through the use of "deep" well cuttings, the Salina Rock Salt beds were present in West Virginia, covering almost the entirety of the state. At the time of publication, interest in the salt were high as it represented a commercial economic resource. Today, these same salt beds present the opportunity for carbon capture utilization and storage. The 1943 Bulletin described the stratigraphy of Post-Silurian rocks above the salt and produced a detailed geologic column of the Northwestern Panhandle of West Virginia from the Dunkard Group through the Albion Sandstone for the Gribble well in Harrison County. Two simplified cross sections of the salt position were created: the first, between four wells spanning Washington County, Ohio, and the Gribble Well in Harrison County, West Virginia; and the second, spanning five wells between Wayne County, Ohio, and Harrison County, West Virginia. While these cross sections lack much detail, the show approximate positions and variations of thickness. Table 1 of the Bulletin provides a handy visual showing the maximum and minimum thicknesses between the top of the Onondaga Limestone and top of salt, as well as the number of wells (at the time) penetrating the formation in Ohio, West Virginia, Pennsylvania and New York. Formations associated with the salt were correlated between West Virginia, Maryland and western New York. Individual condensed well records were included in the Bulletin to further identify the position and thickness of the salt at specific localities.

Fergusson, William B. and Prather, Bruce A., 1968, Salt Deposits in the Salina Group in Pennsylvania: Pennsylvania Geological Survey Bulletin, M 58, 37p.

[Document Link: http://dcnr.state.pa.us/cs/groups/public/documents/document/dcnr_016635.zip]

Key Words: *salt, Salina Group, basins, Silurian, reefs, Lockport Dolomite, Bloomsburg Formation, Michigan, West Virginia, New York, Pennsylvania*

In 1968, the Pennsylvania Geological Survey produced a Bulletin describing the thickness and geography of the Salina in formation across Pennsylvania. While at the time, the formation was studied for its economically viable deposits of salt, it was the drilling of oil and gas wells that provided the information about the rock layers. The division of the salt was based on correlations developed by Michigan and Ohio to draw a regional picture of the deposit. In Pennsylvania, the Salina Group units were named Unit A through Unit G. The manuscript details the depositional environment of Upper Silurian evaporates across Michigan, Ohio, West Virginia, New York and Pennsylvania. An extensive description of each of the Salina Group units are described throughout the manuscript including the thickness, pseudonyms and correlation to neighboring states, and isopach and the lithofacies of each.

Sminchak, Joel R. and Gupta, Dr. Neeraj, eds., 2015, Development of Subsurface Brine Disposal Framework in the Northern Appalachian Basin: Research Partnership to Secure Energy for America (RPSEA), 411 p.

[Project Link: http://www.rpsea.org/projects/11122-73/]

[Document Link: http://www.rpsea.org/media/files/project/185d70b8/11122-73-FR-Development_Subsurface_Brine_Disposal_Framework_Northern_Appalachian_Basin-10-06-15_P.pdf (PDF, 18.7 MB]

Key Words: *brine, disposal, subsurface, injection, Battelle, pore*

In 2015, Battelle Memorial Institute sponsored the Development of Subsurface Brine Disposal Framework in the Northern Appalachian Basin. The purpose of the two-and-a-half-year consortium was to develop a geologic framework for disposal of the produced fluids from onshore drilling. While the purpose of this study is different from that of the Appalachian Storage Hub project, the brine disposal study investigates many of the same formations and their characteristics of interest in great detail. Geophysical well logs (690 in all) were utilized to analyze the formations. The injection rates derived from the study provide a clue into the porosity, permeability, and storage capacities of the formations. The most prolific formations used for brine disposal included Cambrian basal sandstone, the Cambrian Copper Ridge Dolomite and Rose Run Sandstone, the Silurian Medina Group/'Clinton" Sandstone, the Silurian Lockport-"Newburg" dolomite, the Devonian Oriskany Sandstone and Mississippian sandstone units. Based on historical gas production in Kentucky, Ohio, West Virginia and Pennsylvania it's estimated that 47 billion barrels of brine void pore space exist in these depleted reservoirs.

Nelson, Paul E., Mathews, Noah H., Flores, Cecilia P., Patel, Pradeep K., Roth, Thomas P., Farnsworth, Lori K., Reichwein, M.C. (Tim)., 2001, Geological Prefeasibility Study of Ethane Storage Opportunities within Salt, Hard Rock, and Oil and Gas Reservoirs in West Virginia: PB Energy Storage Services, Inc., Topical Report PB-0326, 92 p.

[Company Link: https://www.pbenergy.com/]

Key Words: *ethane, storage, feasibility, salt, volume, Marcellus, caverns, oil and gas, infrastructure, logistics, Greenbrier Limestone*

In 2011, West Virginia explored subsurface ethane storage opportunities across the state from the logistics of moving ethane from sources to storage facilities to the screening criteria to be used for geologic prospects for ethane storage. The studied formations included salt caverns, mined-rock caverns and oil and gas reservoirs. The manuscript describes, by county, which formations are present and hold the most potential for ethane storage capacity. The prospects are ranked in order by geological characteristics, geological uncertainty, logistics, environmental impacts, parametric capital costs and estimated development schedules. To summarize the extensive study, a table listing each storage option and the advantages and disadvantages of each is provided at the end of the manuscript discussion. During the study, the total required storage volume was estimated between 2 and 10 million barrels with maximum withdrawal and injections for each facility type at 80,000 barrels per day. The study found that salt caverns are desirable for ethane storage at depth ranges from 1,500-3,000 feet, which is generally shallower than cavern depths in West Virginia. In mined-rock, the Greenbrier Limestone, in intervals at least 40 feet thick and at depths 1,800 feet or greater, presents the most suitable option for storage in the state due to its high strength, stability and low porosity. The study found that due to the prolific oil and gas production in the state, oil and gas reservoirs provide the greatest potential for ethane storage opportunities in terms of existing infrastructure. While the volume is great enough for storage, more wells would need to be drilled to cycle viable amounts of ethane through the reservoir. Each type of storage option provides certain advantages in different situations. The desired location of a storage facility may determine which kind of formation is best utilized for the operation.

Greb, Stephen F., and Chestnut, Donald R. Jr., 2009, Carboniferous Geology and Biostratigraphy of the Appalachian Basin, Special Publication 10: Lexington, Kentucky, Kentucky Geological Survey.

[Document Link: http://www.uky.edu/OtherOrgs/KPS/books/grebchesnut2009/grebchesnut2009.pdf (PDF, 8.0 MB)]

Key Words: *Carboniferous, biostratigraphy, Appalachian, Black Warrior basins*

This work, put together by the Kentucky Geological Survey, is segregated into 12 smaller, specialized manuscripts highlighting various areas of expertise. The introduction, written by editors Donald R. Chestnut Jr. and Stephen F. Greb, provides a brief description of the Mississippian and Pennsylvanian systems including regional correlations and general geology. Other chapters detailing specific fossil types found in the Carboniferous provide detailed insight into the deposition and environmental conditions associated with each formation.

Patchen, Douglas G., and others, 2006, A Geologic Playbook for Trenton-Black River Appalachian Basin Exploration: United States Department of Energy, 582 p.

[Project Link: http://www.wvgs.wvnet.edu/www/tbr/]

[Document Link: http://www.wvgs.wvnet.edu/www/tbr/docs/41856R06.pdf]

[Document Link: https://www.netl.doe.gov/research/oil-and-gas/project-summaries/completed-ep-tech/de-fc26-03nt41856- (PDF, 113 MB)]

Key Words: *Ordovician, Appalachian, gas, oil, exploration, Trenton, Black River, reserves, dolomite, hydrothermal, geothermal, porosity, pores, geochemistry, petrology*

In the early 2000s, interest in the oil and natural gas potential of Ordovician-age formations skyrocketed. Northwestern Ohio oil and gas production on the edge of the Ordovician-age margin warranted further exploration into the interbedded limestone, calcareous shale and black shale of the Trenton-Black River sequence. The manuscript is highlighted by detailed petrographic data, used to determine types and locations of seals, extent of hydrothermal fluid influence and pore shapes and sizes that contribute to viable reservoir space. Geochemical and fluid inclusion analyses on limestones and dolomites as well as natural gas geochemical analyses add to the plethora of technical data used to identify key fields, estimate resources and reserves and point to future trends in production and development.

Roen, John B. and Walker, Brian J., eds., 1996, The Atlas of Major Appalachian Gas Plays: West Virginia Geological and Economic Survey, V. 25, 201 p.

[Document Information Link:
http://www.wvgs.wvnet.edu/wvges2/publications/PubCat_Details.aspx?PubCatID=V-25]

Key Words: *gas, shale, Appalachian, structure, stratigraphy, trends, wells,*

This major volume provides a detailed overview of Appalachian basin structure, stratigraphy and background of major oil and gas development in the region. Each section of the Atlas details individual formations from the Middle Pennsylvanian to Cambrian Pre-Knox Group. Within each formation section of the playbook can be found detailed structural, stratigraphic descriptions as well as reservoir characteristics, future trends in oil and gas development and a map of production wells in the play. The Atlas acts as a compact, yet detailed and informative "one-stop-shop" for any and all information related to oil and gas development in the Appalachian basin through the late 1990s.

Seni, S. J., Mullican, W.F. III, and Hamlin, H. S., 1984, Texas Salt Domes – Aspects Affecting Disposal of Toxic-Chemical Waste in Solution-Mined Caverns: Austin, Texas, Bureau of Economic Geology, the University of Texas at Austin, 34 p.

[Document: Out-of-Print, Limited availability]

Key Words: *salt, disposal, waste, caverns, Texas, salt domes, salt caverns*

The study investigates the mechanical properties of salt caverns used in the disposal of chemical waste. Heavily focused on creep behavior and deformation mechanics of salts, the study reveal how site specific the behavior of salt can be. Even when using empirical models, there is no consensus on how various factors can affect salt creep. The study stresses the need to further refine salt models and identify factors affecting injection into salt storage prospects.

Wickstrom, Lawrence H. and others, 2005, Characterization of Geologic Sequestration Opportunities in the MRCSP Region: Columbus, Ohio, Battelle Memorial Institute, 152 p.

[Document Link: https://geosurvey.ohiodnr.gov/portals/geosurvey/PDFs/OpenFileReports/OFR_2005-1.pdf (PDF, 21.96MB)]

Key Words: *carbon sequestration, oil and gas, subsurface, regional geology, stratigraphy, MRCSP, Battelle, reservoir, seal, porosity, permeability, Appalachian basin, Michigan basin, Arches province, Atlantic Coastal Plain*

The Phase I report of the Midwest Regional Carbon Sequestration Partnership (MRCSP) outlines a preliminary assessment of carbon dioxide (CO_2) sequestration opportunities across New York, Pennsylvania, Ohio, Michigan, Maryland, West Virginia and Kentucky in the Appalachian and Michigan basins, Arches province and Atlantic Coastal Plain. The study identifies nine potential reservoirs and five caprocks within the Middle Devonian-Middle Silurian (MDMS) interval using geological and logistical characteristics. The study identified numerous formation types as potential reservoirs and seals, all with varying characteristics and storage capabilities. The study includes detailed descriptions and evaluations of these numerous siliciclastic and carbonate units present throughout the region. In the Appalachian basin, it was concluded that the Oriskany Sandstone presents the most promising target for sequestration, while in the Michigan basin, the Bass Islands Dolomite and the Dundee Formation present the most promising targets. The study utilized a vast amount of geological information including oil and gas production, drilling records, geophysical logs, laboratory-derived evaluations of core, rock cuttings and outcrop samples. A smaller part of the larger MRCSP report to the U.S. Department of Energy, this Phase I evaluation includes some of the most detailed research on individual sequestration prospects ever compiled.

Patchen, D.G. and Carter, K.M., eds., 2015, A geologic play book for Utica Shale Appalachian basin exploration, Final report of the Utica Shale Appalachian basin exploration consortium, 187 p.

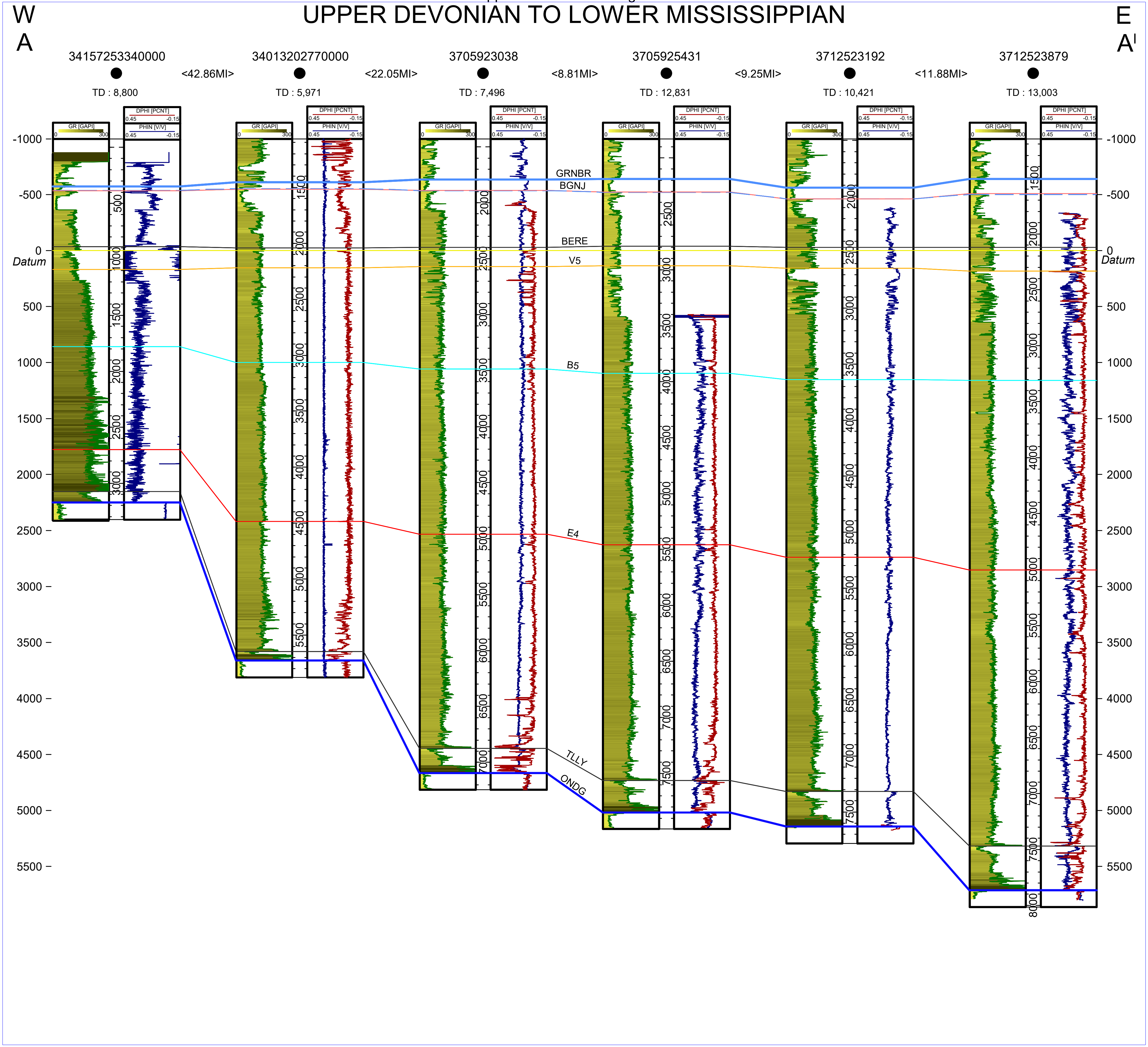
Available from: http://www.wvgs.wvnet.edu/utica.

Key Words: *Utica, Marcellus, shale, natural gas, porosity, permeability, thermal maturity, subsurface, regional geology, stratigraphy, porosity, permeability, Appalachian basin*

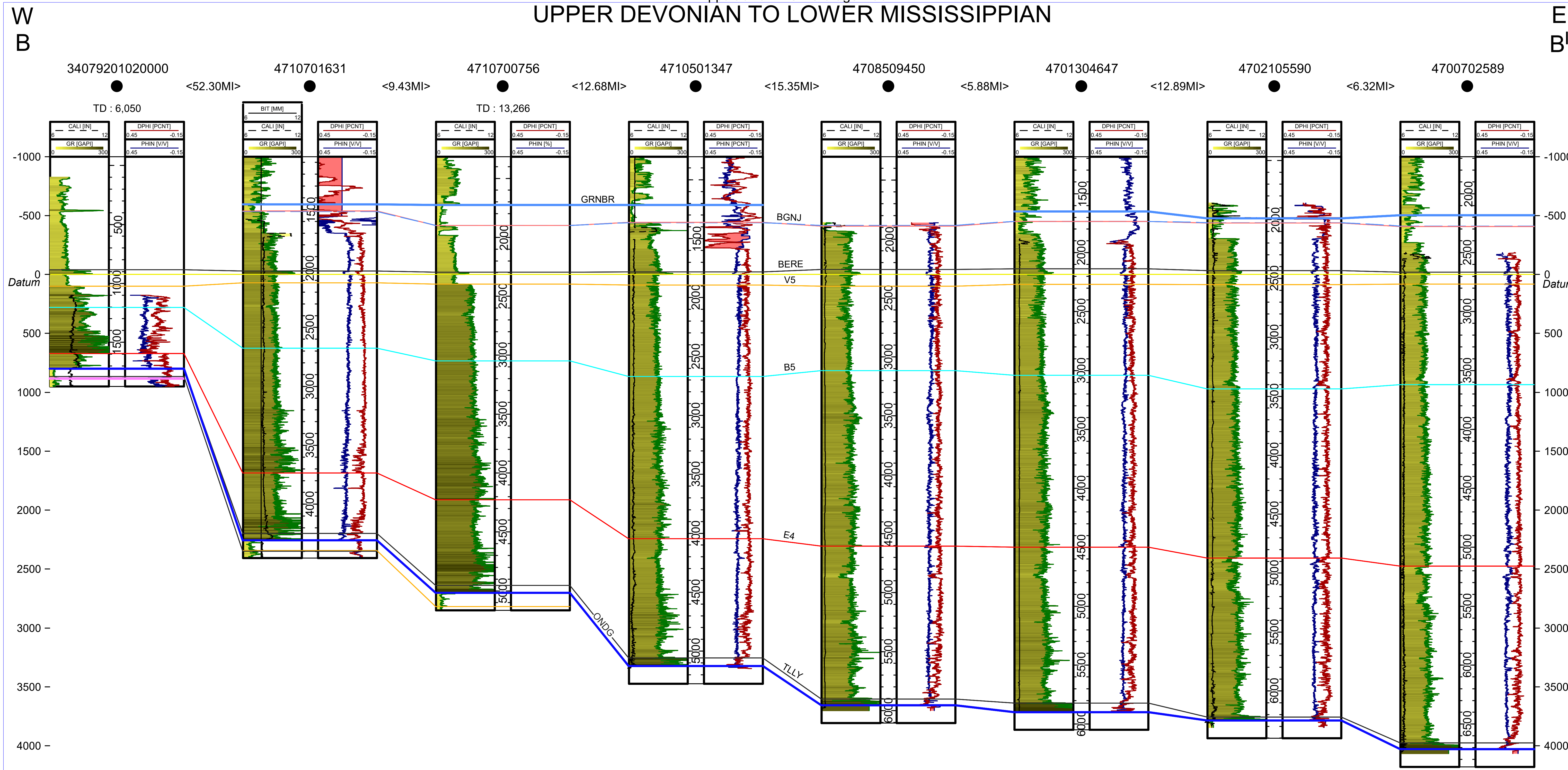
The Study represents the efforts of five different states and fifteen oil and gas industry partners to research all aspects of the Utica Shale Play in the Appalachian basin from basin-scale stratigraphy to nano-porosity textures. The study assessed the lithology, geochemistry, stratigraphy and depositional environment of the reservoir as well as defined the oil and gas fairways and production capabilities in production-based and volumetric resource assessments. The combination of various data-types, analyses, and detailed research including core studies, tracking drilling activities, mineralogy and carbonate analyses, TOC data, thermal maturity evaluations, stratigraphic correlations, SEM analyses and resource assessment provides an extremely detailed account of the Utica Shale Play across the Appalachian basin.

APPENDIX B – REGIONAL GEOLOGIC CROSS SECTION PLATES

UPPER DEVONIAN TO LOWER MISSISSIPPIAN

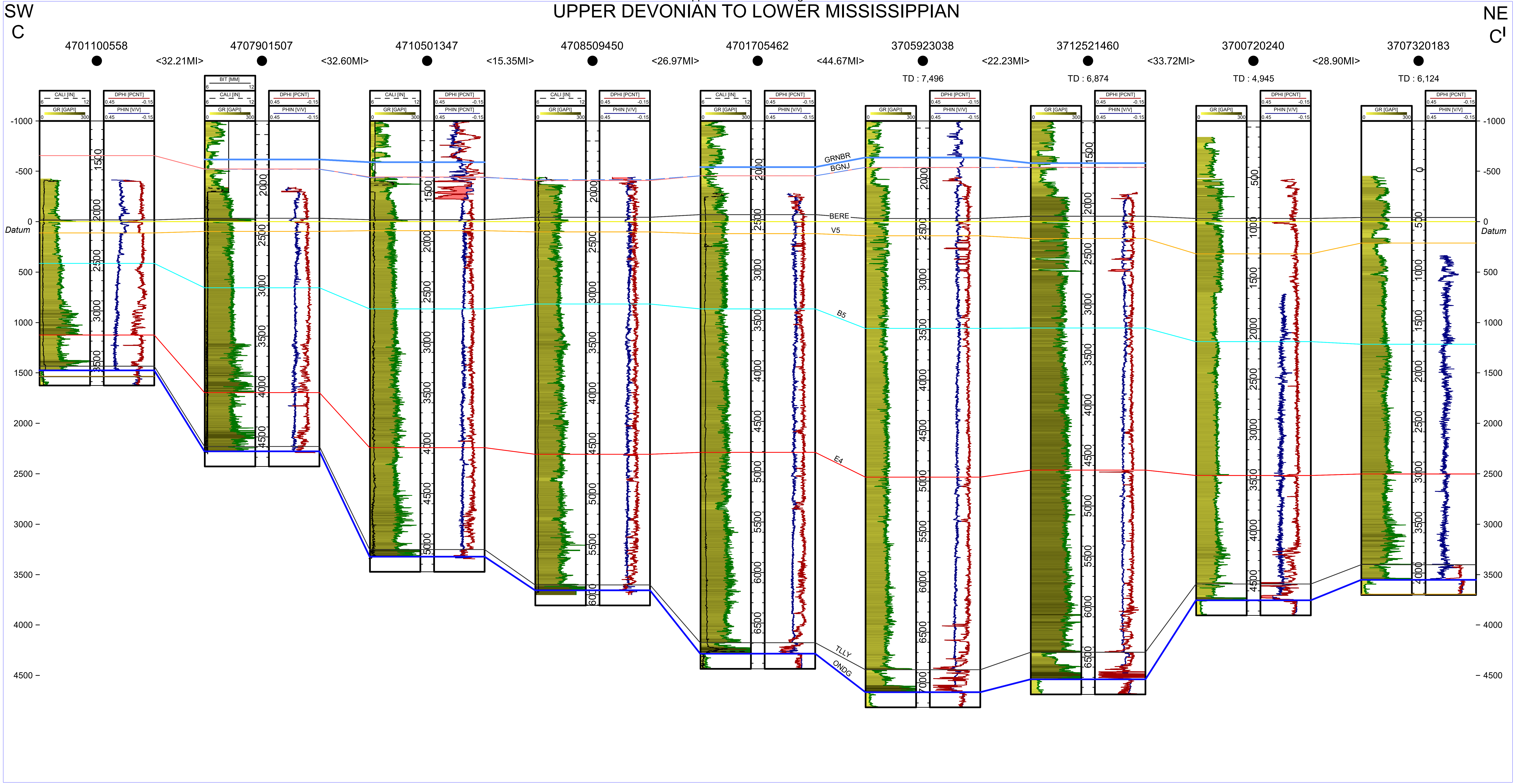


UPPER DEVONIAN TO LOWER MISSISSIPPIAN



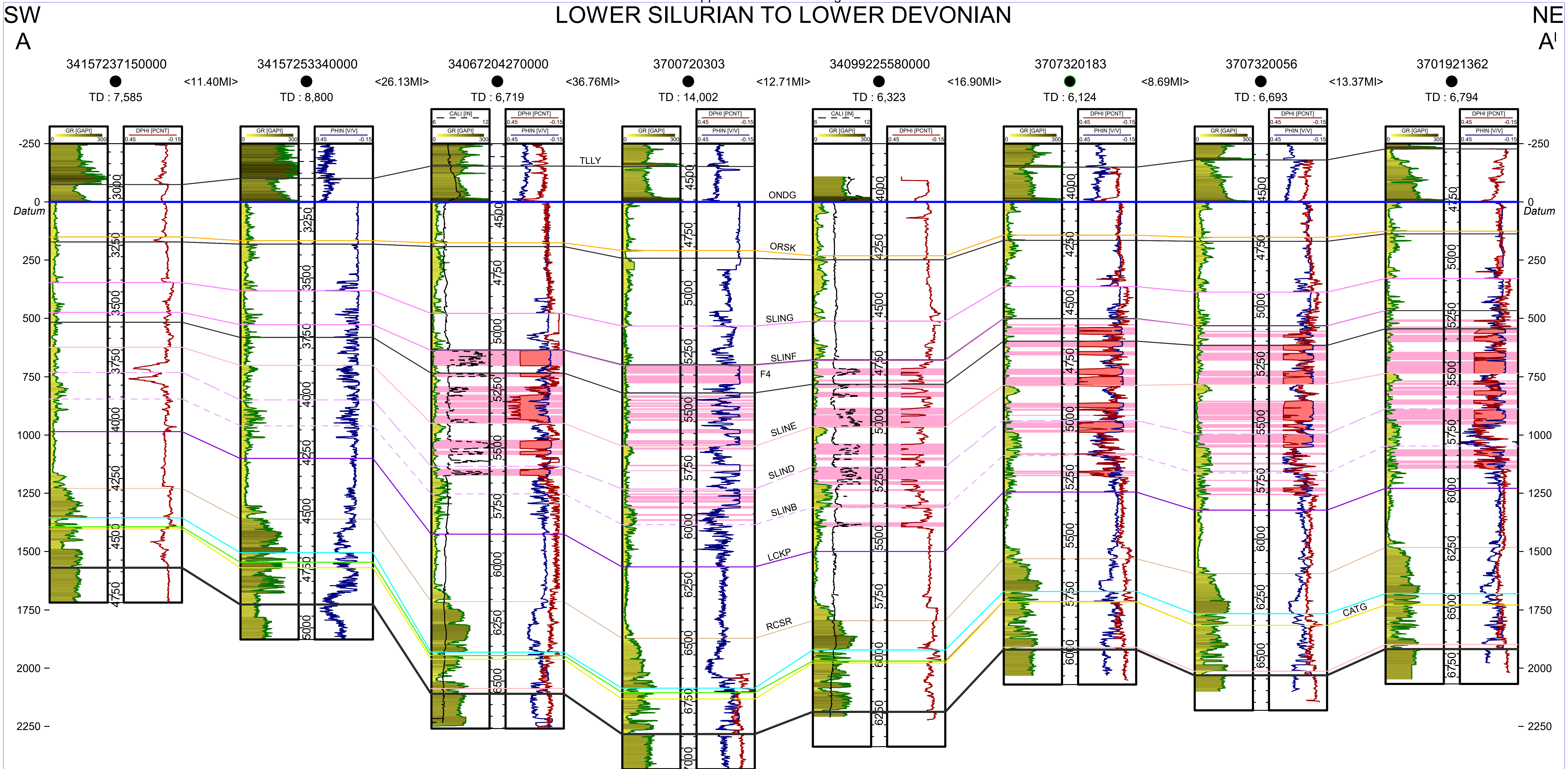
Appalachian NGL Storage Hub

UPPER DEVONIAN TO LOWER MISSISSIPPIAN

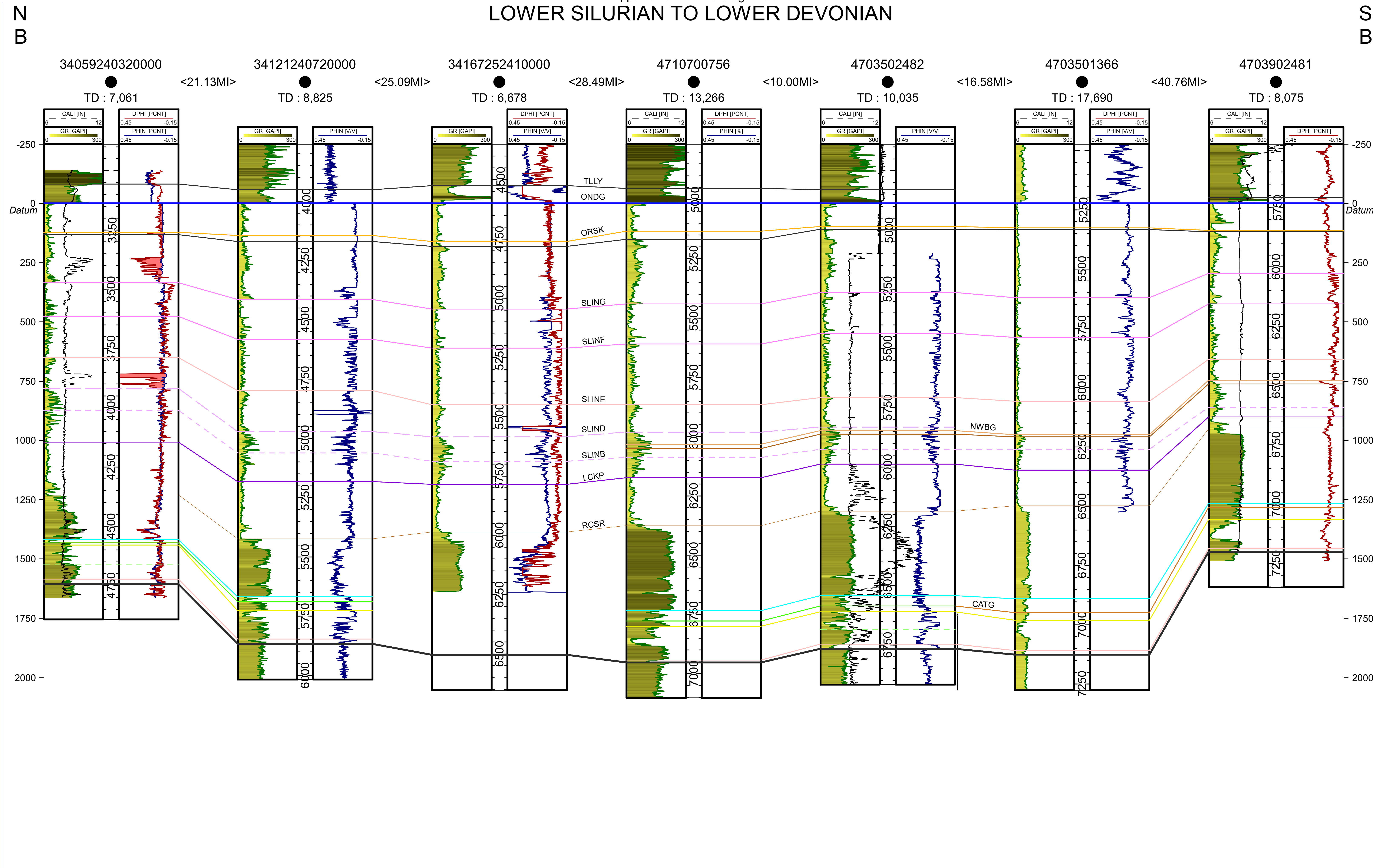


Appalachian NGL Storage Hub

LOWER SILURIAN TO LOWER DEVONIAN

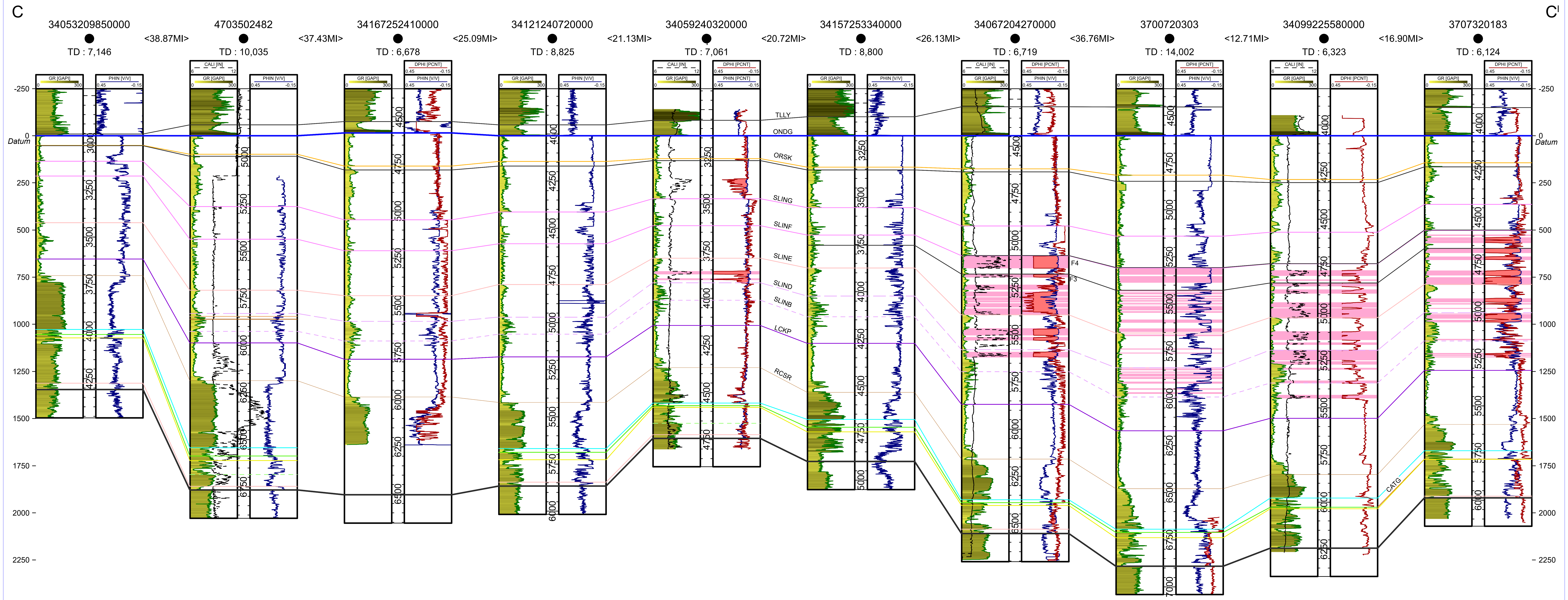


LOWER SILURIAN TO LOWER DEVONIAN

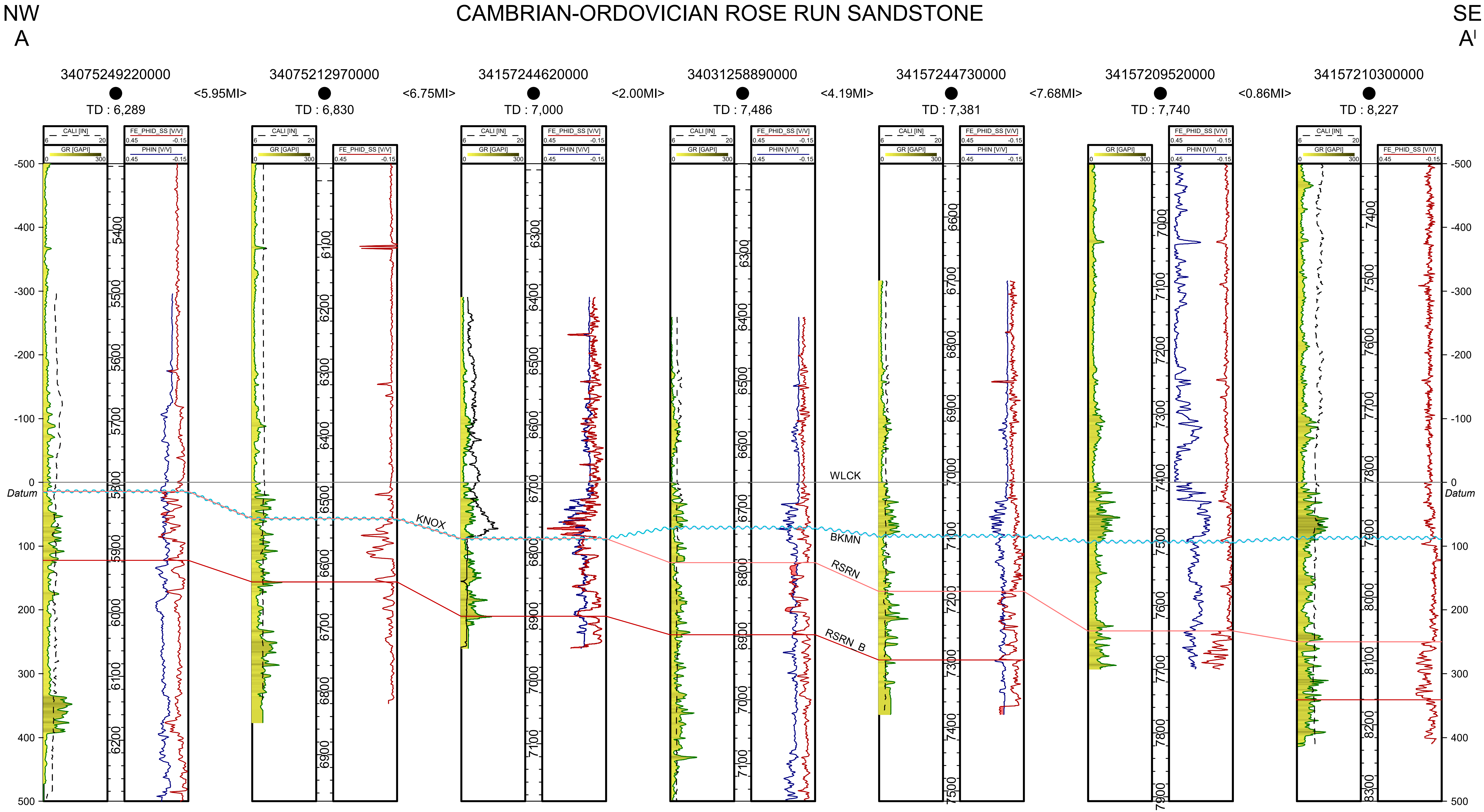


Appalachian NGL Storage Hub

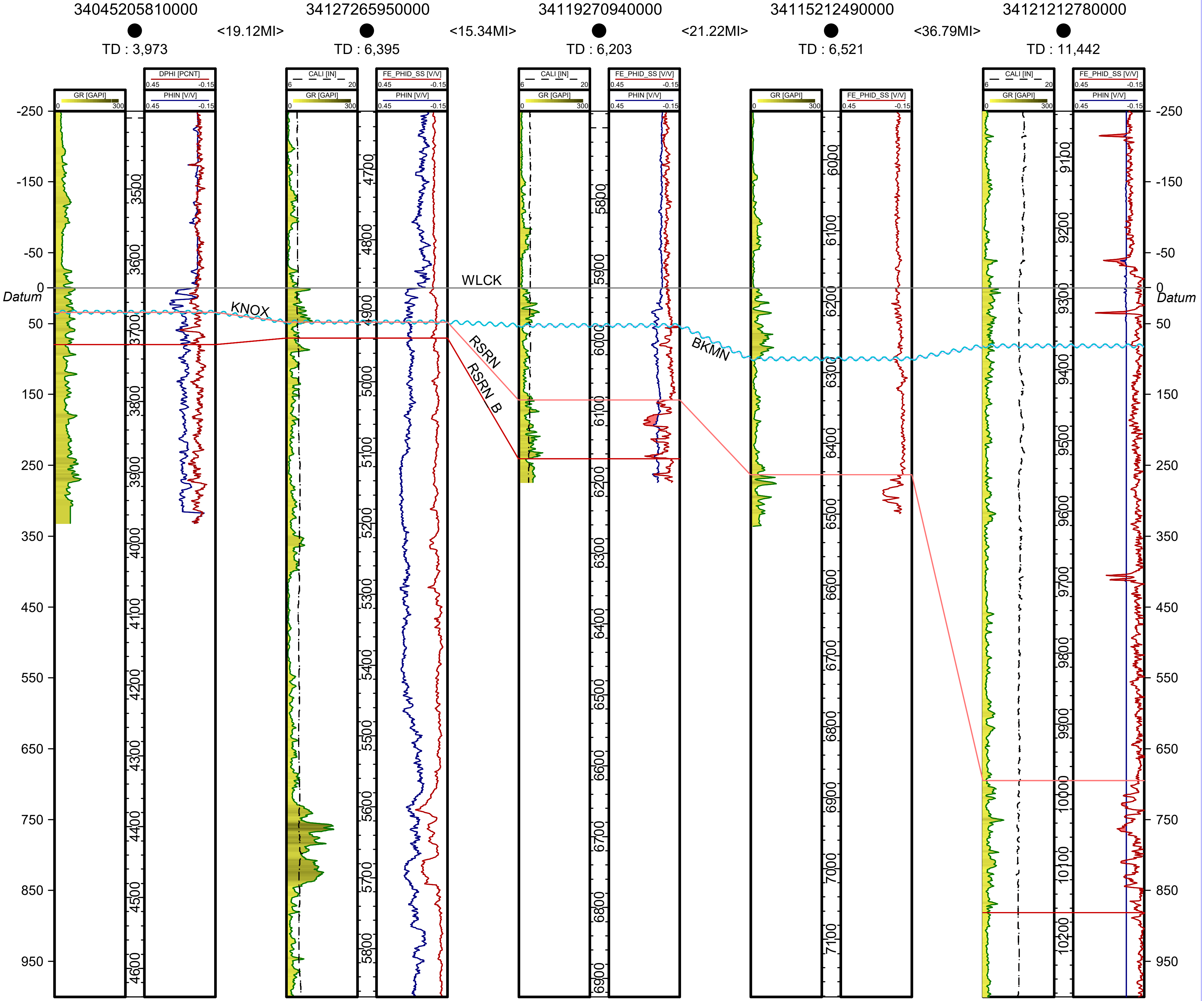
LOWER SILURIAN TO LOWER DEVONIAN



CAMBRIAN-ORDOVICIAN ROSE RUN SANDSTONE

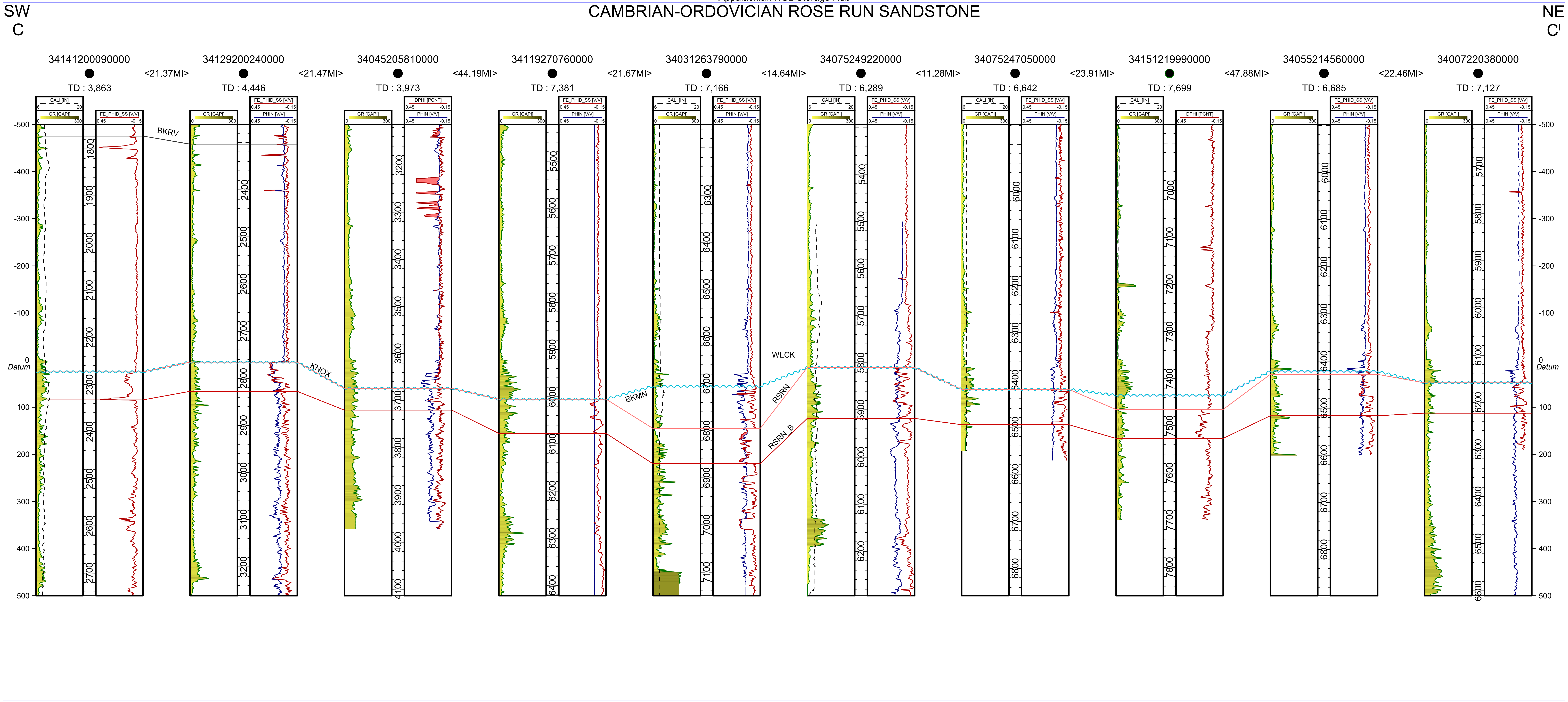


CAMBRIAN-ORDOVICIAN ROSE RUN SANDSTONE



Appalachian NGL Storage Hub

CAMBRIAN-ORDOVICIAN ROSE RUN SANDSTONE



APPENDIX C – PPG INDUSTRIES CORE ANALYSES, MARSHALL COUNTY, WEST VIRGINIA

PPG INDUSTRIES SALT CORE DATA, MARSHALL COUNTY, WEST VIRGINIA

Thirty-four core samples from the PPG36 well were analyzed for 51 different major and trace elements. Major element concentrations were reported in weight percentages (%), and trace element concentrations were reported in parts per million (ppm) or parts per billion (ppb). The samples were grouped into six different groups by the predominant lithology reported in the core description. For example, black shaley siltstone with euhedral halite crystals was grouped into the dark gray to black shaley siltstone category. Tables C-1 and C-2 show the major element and trace element concentrations by lithology, respectively. Elements were not included in these tables if concentrations were reported to be below laboratory detection limits. An additional four elements (barium, cobalt, hafnium and europium) were not included in the trace element table because these were only detected in a single siltstone sample. Detection limits for the various major and trace elements are included in Tables C-3 and C-4, respectively.

Major Element Lithology Table Summary

The halite samples had no iron, while the shaley siltstone and dolomicrite samples had a small amount. As expected, the halite samples had far more sodium than the siltstone or dolomicrite samples. In addition, the siltstone and dolomicrite reported more calcium and magnesium than the predominately halite samples. Titanium, aluminum and potassium concentrations increased in the darker halite samples, which likely get their dark color from dark anhydrite particles. Siltstone samples had the highest concentrations of these three elements. The siltstone and dolomicrite had almost twice as much sulfur as the halite samples.

Trace Element Lithology Table Summary

Halite samples had approximately twice as much bromine than either the siltstone or dolomicrite samples. Scandium concentrations increased in the darker halite samples, which likely get their dark color from dark anhydrite particles. Siltstone samples had the highest concentrations of this element. Lithium concentrations also increased in the darker halite samples, and dolomicrite and siltstone samples had the highest concentrations of lithium. The halite samples contained no molybdenum, thorium or uranium, and the siltstone samples reported higher concentrations of these three elements than the dolomicrite samples. The highest concentrations of the rare-earth elements – lanthanum, cerium, neodymium, samarium and ytterbium – were found in the siltstone samples. These elements were generally reported below detection limits in most of the halite samples, with the exception of detectable levels of lanthanum, neodymium and samarium in the black halite samples and some neodymium in one clear halite sample. Copper was detected in most of the lithologies (gray halite excepted), and dolomicrite samples had the highest concentrations of copper. Lead levels ranged from below detection limits to a few ppm for most lithologies, with the siltstone having the greatest concentration of lead and concentrations remaining below detection limits for the clear halite samples. Zinc and nickel were detected in all six lithologies, with siltstone and dolomicrite lithologies having the highest concentrations of these metals. Manganese and strontium were also present in all six lithologies, but in much greater concentrations than zinc and nickel. Again, siltstone samples had the highest concentrations of these two elements. Yttrium and vanadium were mostly found to be below detection limits, with the exception of a couple ppm in the black halite and dolomicrite samples and 10 to 30 ppm in the siltstone samples.

In conclusion, the shaley siltstone samples have the highest concentrations of most of the elements analyzed for these core samples. Concentrations of several elements increase in the predominantly halite samples as the samples get darker. This probably results from increasing concentrations of non-salt particles such as anhydrite in these core samples. The gray to dark gray, coarsely crystalline halite lithology is shown in Figures 1A, 2 and 3. The dark gray to black, shaley siltstone lithology is illustrated in Figures 1C and 3.

Figure 1. a: Coarse halite crystals with evenly disseminated black anhydrite pieces that give the section a dark gray color; b: post-lithification fracture includes some salt crystals along the fracture zone; c: brown-gray calcareous shale, thinly laminated, sometimes wavy, partially replaced by salt and pepper carbonate(?)-anhydrite mixture. The shale is interbedded with the carbonate-anhydrite beds.

Figure 2. Uniformly coarse (0.25-0.5 inch) halite crystals with evenly disseminated black anhydrite pieces, which give the section a dark gray color.

Figure 3. Mix of gray coarse crystalline halite as above and disoriented large (up to 0.8 ft) clasts of thin bedded anhydrite-carbonate plus calcareous shale. Core base is 6,648 ft.

Major Element Concentrations by Lithology

Lithology	Number of samples	RANGE	Low	High	Low	High	Low	High	Low	High	Low	High
		Element	FE		NA		SN		CA2		P	
		Units	%		%		%		%		%	
		Element Detection Limit	0.01		0.01		0.01		0.01		0.001	
Clear coarsely crystalline halite	4		ND	ND	16.90	21.10	ND	ND	0.08	0.31	ND	ND
Gray, coarsely crystalline halite	4		ND	ND	16.70	21.40	ND	0.08	0.40	5.94	ND	0.001
Dark gray, coarsely crystalline halite	8		ND	ND	13.30	22.70	ND	ND	0.11	4.43	ND	0.003
Black coarsely crystalline halite	6		ND	ND	17.60	22.90	ND	0.10	0.55	6.29	ND	0.005
Dark gray to black, shaley siltstone	4		ND	1.45	0.55	9.45	ND	ND	9.68	15.90	0.002	0.025
Light and dark gray dolomricite	8		ND	0.38	0.82	10.40	ND	ND	9.08	14.80	0.001	0.010

*ND = Not Detected/Below detection limits

Table C-1

Major Element Concentrations by Lithology

Lithology	Number of samples	MG Low	MG High	TI Low	TI High	AL Low	AL High	K Low	K High	S Low	S High
		%		%		%		%		%	
		0.01		0.01		0.01		0.01		0.010	
Clear coarsely crystalline halite	4	ND	0.03	ND	ND	ND	0.02	0.03	0.04	0.030	0.230
Gray, coarsely crystalline halite	4	0.02	0.57	ND	ND	ND	0.08	0.03	0.05	0.300	4.490
Dark gray, coarsely crystalline halite	8	ND	0.44	ND	ND	0.01	0.27	0.02	0.11	0.080	3.670
Black coarsely crystalline halite	6	0.03	1.60	ND	0.02	0.01	0.39	0.03	0.29	0.350	3.520
Dark gray to black, shaley siltstone	4	1.41	9.61	ND	0.14	0.06	2.38	0.11	1.95	0.640	8.000
Light and dark gray dolomricite	8	2.20	6.35	ND	0.03	0.08	0.60	0.09	0.51	2.920	6.070

*ND = Not Detected/Below detection limits

Trace Element Concentrations by Lithology

		RANGE	Low	High	Low	High	Low	High	Low	High	Low	High
		Element	AS		BR		CR		CS		RB	
		Units	PPM		PPM		PPM		PPM		PPM	
Lithology	Number of samples	Element Detection Limit	0.5		0.5		5.0		1.0		15.0	
Clear coarsely crystalline halite	4		ND	ND	54.8	138.0	ND	19.0	ND	ND	ND	ND
Gray, coarsely crystalline halite	4		ND	2.4	58.7	97.7	ND	15.0	ND	ND	ND	33.0
Dark gray, coarsely crystalline halite	8		ND	ND	62.4	135.0	ND	10.0	ND	ND	ND	ND
Black coarsely crystalline halite	6		ND	1.0	83.7	116.0	ND	ND	ND	3.0	ND	ND
Dark gray to black, shaley siltstone	4		ND	15.8	20.7	61.5	ND	36.0	ND	3.0	ND	115.0
Light and dark gray dolomricite	8		ND	6.4	22.6	56.5	ND	18.0	ND	ND	ND	ND

*ND = Not Detected/Below detection limits

** The following elements have been removed from the table because sample PPG36-1-17 was the only sample registering any detection: BA, CO, HF, and EU.

Trace Element Concentrations by Lithology

		SB		SC		TH		U		LA		CE	
		Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
		PPM		PPM		PPM		PPM		PPM		PPM	
Lithology	Number of samples	0.1		0.1		0.2		0.5		0.5		3.0	
Clear coarsely crystalline halite	4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Gray, coarsely crystalline halite	4	ND	ND	ND	1.0	ND	ND	ND	ND	ND	ND	ND	ND
Dark gray, coarsely crystalline halite	8	ND	0.2	ND	0.6	ND	ND	ND	ND	ND	ND	ND	ND
Black coarsely crystalline halite	6	ND	ND	ND	1.2	ND	ND	ND	ND	ND	0.6	ND	ND
Dark gray to black, shaley siltstone	4	ND	0.9	0.9	4.3	ND	4.5	ND	4.9	ND	18.3	ND	39.0
Light and dark gray dolomricite	8	ND	0.3	0.3	3.5	ND	1.4	ND	2.5	ND	3.8	ND	6.0

*ND = Not Detected/Below detection limits

** The following elements have been removed from the table because sample PPG36-1-17 was the only sample registering any detection: BA, CO, HF, and EU.

Table C-2

Trace Element Concentrations by Lithology

		Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
		ND		SM		YB		MO2		CU		PB	
		PPM		PPM		PPM		PPM		PPM		PPM	
Lithology	**Number of samples**	5.0		0.1		0.2		2.00		1.00		4.00	
Clear coarsely crystalline halite	4	ND	10.0	ND	ND	ND	ND	ND	ND	ND	3.00	ND	ND
Gray, coarsely crystalline halite	4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	4.00
Dark gray, coarsely crystalline halite	8	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.00	ND	6.00
Black coarsely crystalline halite	6	ND	11.0	ND	0.2	ND	ND	ND	ND	ND	4.00	ND	6.00
Dark gray to black, shaley siltstone	4	ND	17.0	ND	3.0	ND	1.1	ND	7.00	ND	11.00	ND	16.00
Light and dark gray dolomricite	8	ND	8.0	ND	0.5	ND	0.2	ND	3.00	2.00	21.00	ND	4.00

*ND = Not Detected/Below detection limits

** The following elements have been removed from the table because sample PPG36-1-17 was the only sample registering any detection: BA, CO, HF, and EU.

Trace Element Concentrations by Lithology

		ZN2		NI2		MN		SR2		V		Y		LI	
		Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
		PPM		PPM		PPM		PPM		PPM		PPM		PPM	
Lithology	**Number of samples**	1.00		1.00		1.00		1.00		2.00		2.00		1.00	
Clear coarsely crystalline halite	4	ND	2.00	ND	ND	9.00	16.00	4.00	23.00	ND	ND	ND	ND	ND	ND
Gray, coarsely crystalline halite	4	ND	17.00	ND	1.00	9.00	19.00	27.00	356.00	ND	ND	ND	ND	ND	20.00
Dark gray, coarsely crystalline halite	8	ND	3.00	ND	1.00	7.00	26.00	6.00	799.00	ND	ND	ND	ND	ND	52.00
Black coarsely crystalline halite	6	ND	5.00	ND	3.00	8.00	33.00	26.00	280.00	ND	4.00	ND	2.00	1.00	44.00
Dark gray to black, shaley siltstone	4	2.00	14.00	ND	19.00	19.00	214.00	618.00	5830.00	ND	27.00	ND	10.00	60.00	147.00
Light and dark gray dolomricite	8	3.00	12.00	1.00	6.00	16.00	58.00	502.00	2400.00	ND	9.00	ND	2.00	21.00	159.00

*ND = Not Detected/Below detection limits

** The following elements have been removed from the table because sample PPG36-1-17 was the only sample registering any detection: BA, CO, HF, and EU.

Major Element Detection Limits

Element	Units	Detection Limit
CA	%	0.01
FE	%	0.01
K	%	0.01
NA	%	0.01
P	%	0.001
S	%	0.010
SN	%	0.01
AL	%	0.01
MG	%	0.01
TI	%	0.01

Table C-3

Trace Element Detection Limits

Element	Units	Detection Limit
AG	PPM	0.40
AS	PPM	0.5
AU	PPB	2.0
BA	PPM	50.0
BR	PPM	0.5
CE	PPM	3.0
CO	PPM	1.0
CR	PPM	5.0
CS	PPM	1.0
EU	PPM	0.2
HF	PPM	1.0
HG	PPM	1.0
IR	PPB	5.0
LA	PPM	0.5
LU	PPM	0.05
ND	PPM	5.0
NI	PPM	20.0
RB	PPM	15.0
SB	PPM	0.1
SC	PPM	0.1
SE	PPM	3.0
SM	PPM	0.1
TA	PPM	0.5
TB	PPM	0.5
TH	PPM	0.2
U	PPM	0.5
V	PPM	2.00
W	PPM	1.0
Y	PPM	2.00
YB	PPM	0.2
BE	PPM	2.00
BI	PPM	5.00
CD	PPM	0.5
CU	PPM	1.00
MN	PPM	1.00
PB	PPM	4.00
LI	PPM	1.00
MO	PPM	2.00
NI2	PPM	1.00
SR2	PPM	1.00
ZN2	PPM	1.00

Table C-4

Thin Section Analysis Report

Sample ID:	C-01
Formation/Member Name:	Rose Run
Lithologic Classification:	Sandstone
Depth/Depth Range:	4528.8 ft
Date of Analysis:	6/1/2017
Analyzed by:	L. Ditzler

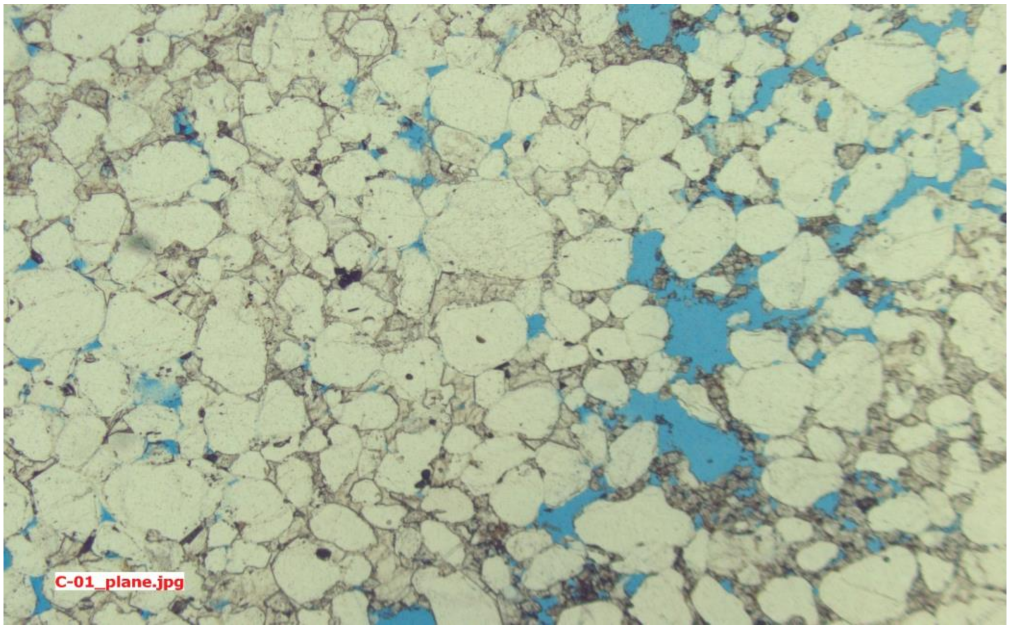
Texture		**Comments**
Grain Size	medium-grained, 350-500µ	
Rounding	well rounded to subrounded	
Sorting	well sorted	

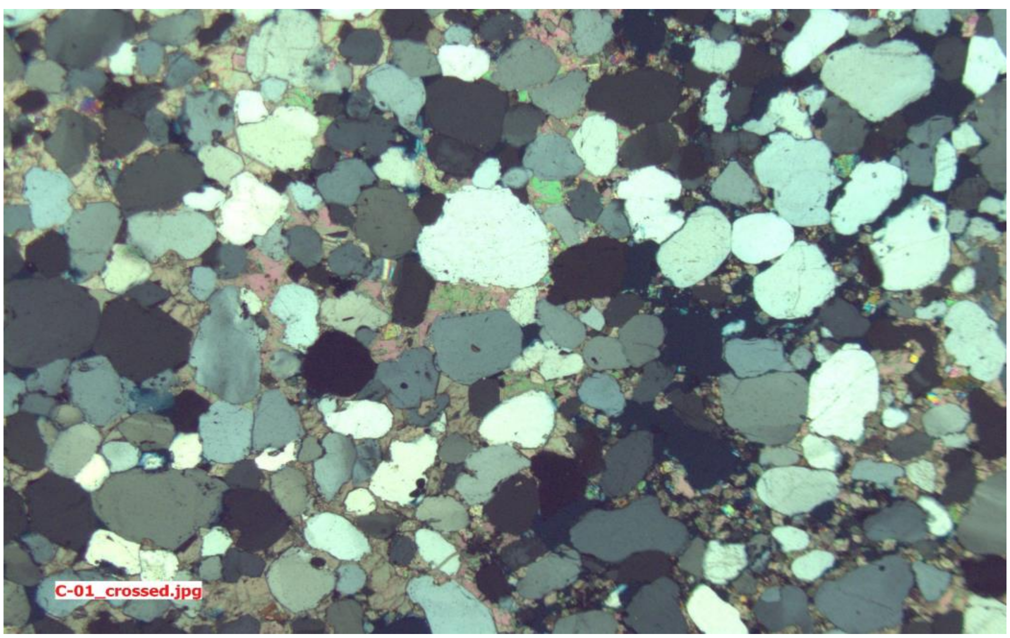
Composition/Detrital Minerals		**Comments**
Quartz		
Polycrystalline	<<1%	
Monocrystalline	79%	grains sometimes with undulose extinction, some quartz overgrowths
Microcrystalline		
Feldspar		
Plagioclase		
Orthoclase		1% total microcline & plag
Microcline		
Carbonate		
Calcite	20%	interstitial cement
Dolomite		
Aragonite		
Clay		
Illite		
Smectite		
Kaolinite		
Muscovite		
Chlorite		
Glauconite		
Rock Fragments		
Sedimentary		
Volcanic		
Metamorphic		
Other (Accessory Minerals)		

Cementing Materials		**Comments**
Quartz	minor	
Feldspar		
Carbonate	most abundant cement, interstitial to quartz grains	
Clay		
Iron Oxide, Hydoxide and/or Sulfide		
Other		

Visual Porosity Estimate	**Comments**
10%	pores between quartz grains

25x magnification, 5mm field of view





Thin Section Analysis Report

Sample ID:	C-02
Formation/Member Name:	Rose Run
Lithologic Classification:	Sandstone
Depth/Depth Range:	4204 ft
Date of Analysis:	6/1/2017
Analyzed by:	L. Ditzler

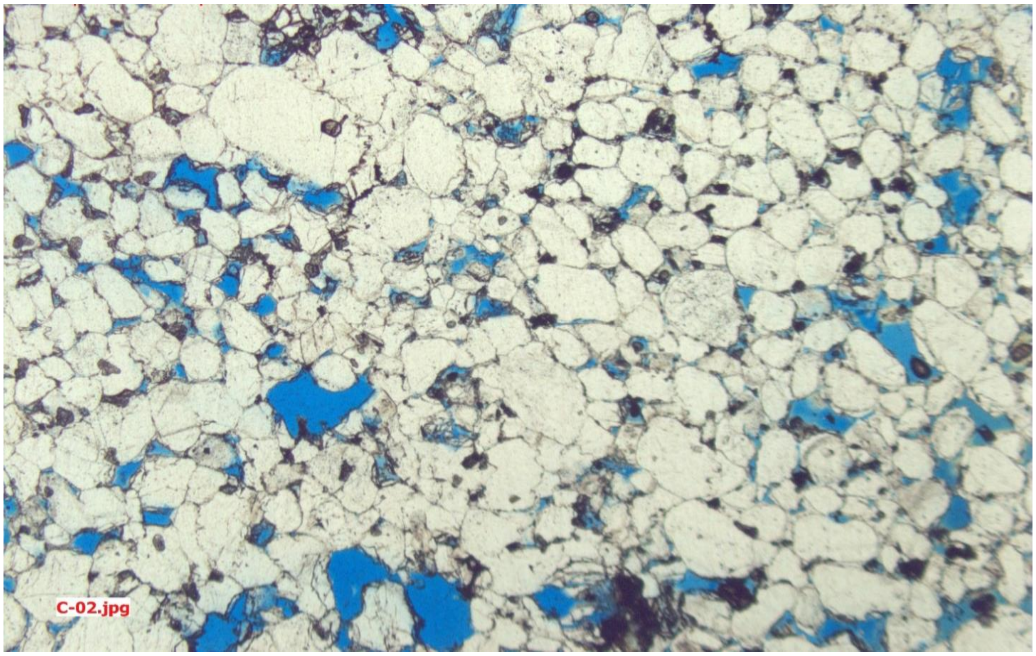
Texture		**Comments**
Grain Size	medium-grained, 350-500µ	
Rounding	rounded to subrounded	
Sorting	well sorted	

Composition/Detrital Minerals		**Comments**
Quartz		
Polycrystalline	<1%	
Monocrystalline	98%	grains sometimes with undulose extinction, quartz overgrowths
Microcrystalline		
Feldspar		
Plagioclase		
Orthoclase		1% total microcline & plag
Microcline		
Carbonate		
Calcite		
Dolomite		
Aragonite		
Clay		
Illite		
Smectite		< 1% total clays
Kaolinite		
Muscovite		
Chlorite		
Glauconite		
Rock Fragments		
Sedimentary		
Volcanic		
Metamorphic		
Other (Accessory Minerals)		

Cementing Materials		**Comments**
Quartz	overgowths on grains	well cemented
Feldspar		
Carbonate	absent	
Clay		
Iron Oxide, Hydoxide and/or Sulfide		
Other		

Visual Porosity Estimate	**Comments**
15%	pores between quartz grains

25x magnification, 5mm field of view



Thin Section Analysis Report

Sample ID:	C-03
Formation/Member Name:	Rose Run
Lithologic Classification:	Breccia
Depth/Depth Range:	6511 ft
Date of Analysis:	6/1/2017
Analyzed by:	L. Ditzler/S. Shank

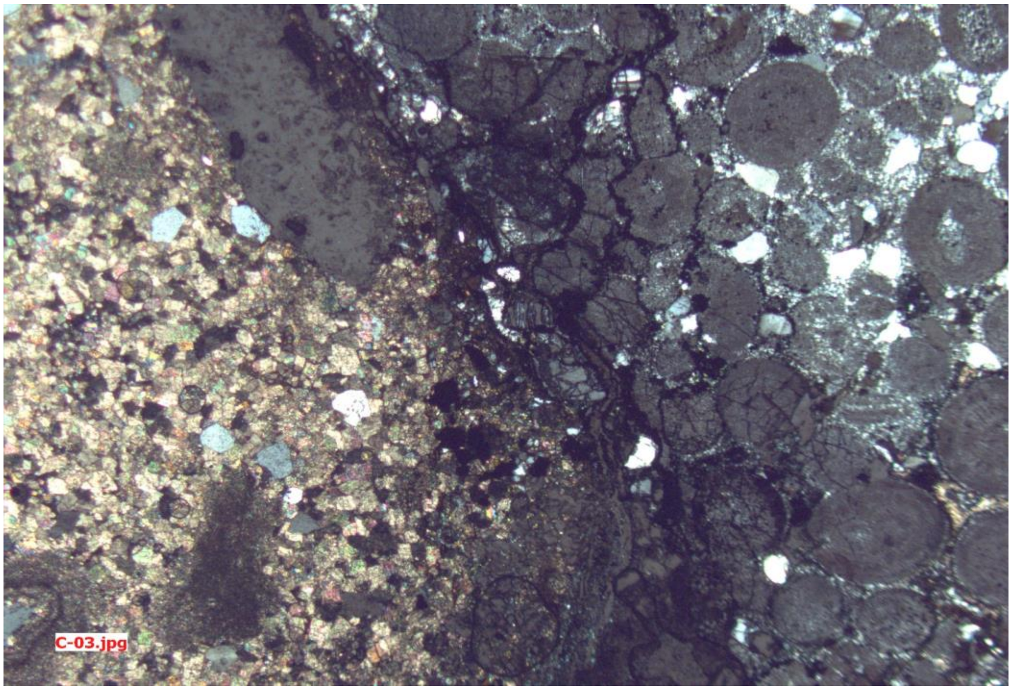
Texture		**Comments**
Grain Size	fragments of silicified oolites in carbonate	scattered quartz grains in carbonate - fine to medium grained, well rounded to subrounded
Rounding		
Sorting		

Composition/Detrital Minerals		**Comments**
Quartz		
Polycrystalline		
Monocrystalline	1%	scattered grains in carbonate
Microcrystalline		
Feldspar		
Plagioclase		
Orthoclase		
Microcline		
Carbonate		
Calcite		
Dolomite	70%	fine-grained (<125 µ), recrystallized (dolomite?) with relic very fine-grained rounded oolites
Aragonite		
Clay		
Illite		
Smectite		
Kaolinite		
Muscovite		
Chlorite	<<1%	trace green in silicified oolites
Glauconite		
Rock Fragments		
Sedimentary	29%	silicified oolites in microcrytalline quartz matrix
Volcanic		
Metamorphic		
Other (Accessory Minerals)		

Cementing Materials		**Comments**
Quartz		
Feldspar		
Carbonate		
Clay		
Iron Oxide, Hydoxide and/or Sulfide		
Other		

Visual Porosity Estimate	**Comments**
1%	thin partially open fracture and voids along silicified oolite/carbonate contact, no blue epoxy

25x magnification, 5mm field of view



Thin Section Analysis Report

Sample ID:	C-06
Formation/Member Name:	Rose Run
Lithologic Classification:	Breccia
Depth/Depth Range:	4191 ft
Date of Analysis:	6/27/2017
Analyzed by:	S. Shank

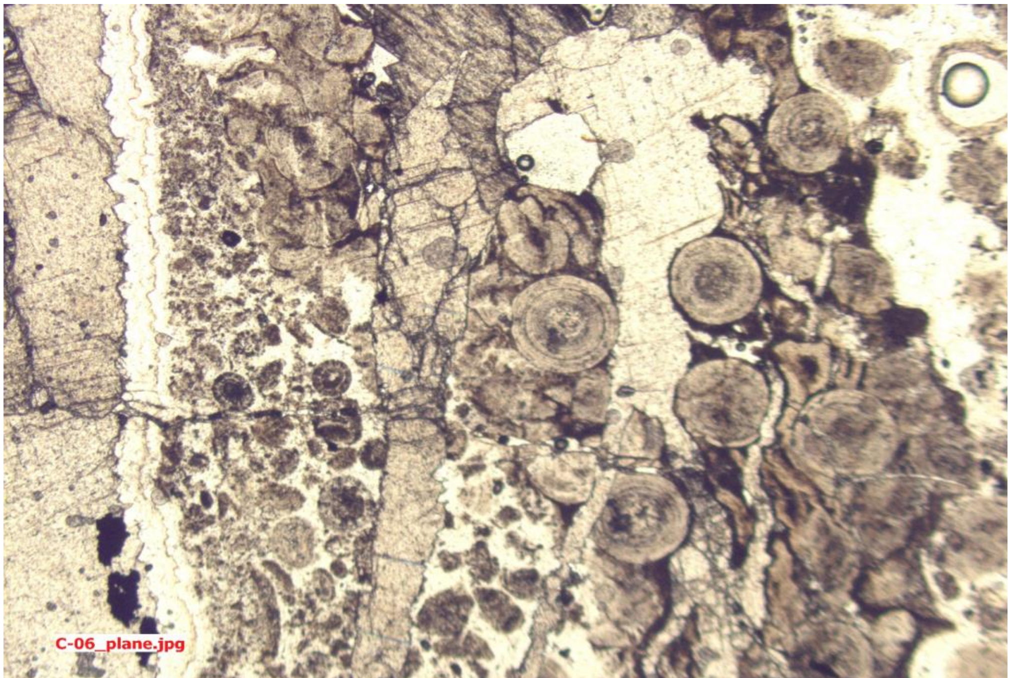
Texture		**Comments**
Grain Size		silicified oolites in microcrystalline quartz matrix, numerous veins of carbonate, quartz and pyrite
Rounding		
Sorting		

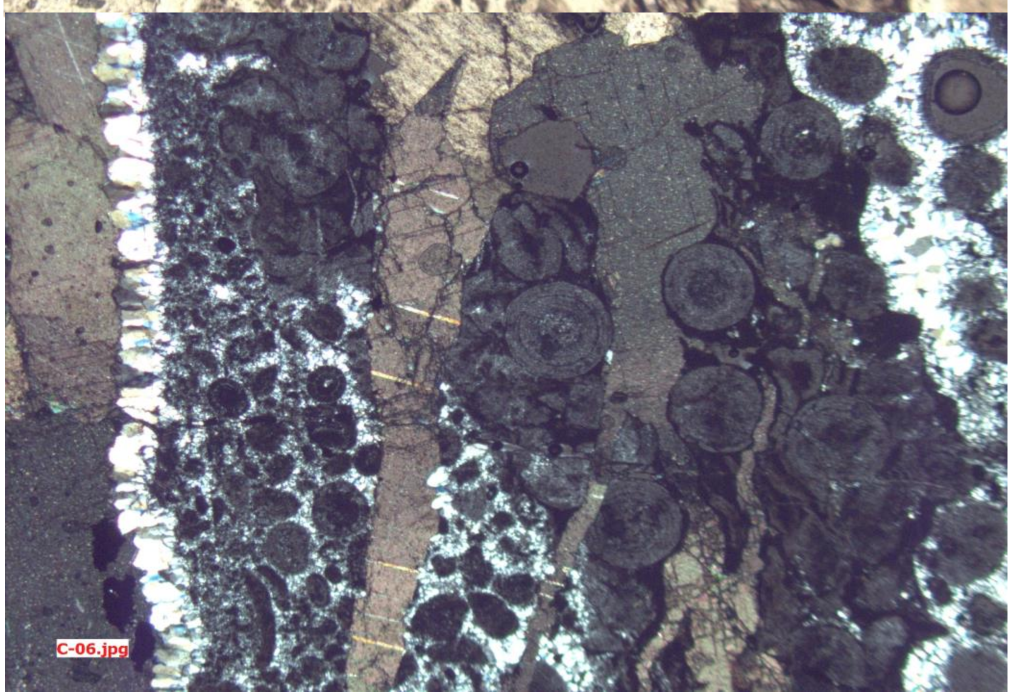
Composition/Detrital Minerals		**Comments**
Quartz		
Polycrystalline		
Monocrystalline		
Microcrystalline		
Feldspar		
Plagioclase		
Orthoclase		
Microcline		
Carbonate		
Calcite		
Dolomite		
Aragonite		
Clay		
Illite		
Smectite		
Kaolinite		
Muscovite		
Chlorite		
Glauconite		
Rock Fragments		
Sedimentary		
Volcanic		
Metamorphic		
Other (Accessory Minerals)		

Cementing Materials		**Comments**
Quartz		
Feldspar		
Carbonate		
Clay		
Iron Oxide, Hydoxide and/or Sulfide	1%	pyrite in fractures
Other		

Visual Porosity Estimate		**Comments**
	<1%	most voids appear to be due to plucking

25x magnification, 5mm field of view





Thin Section Analysis Report

Sample ID: C-07
Formation/Member Name: Rose Run
Lithologic Classification: Sandy Carbonate
Depth/Depth Range: 6500.2 ft
Date of Analysis: 6/27/2017
Analyzed by: S. Shank

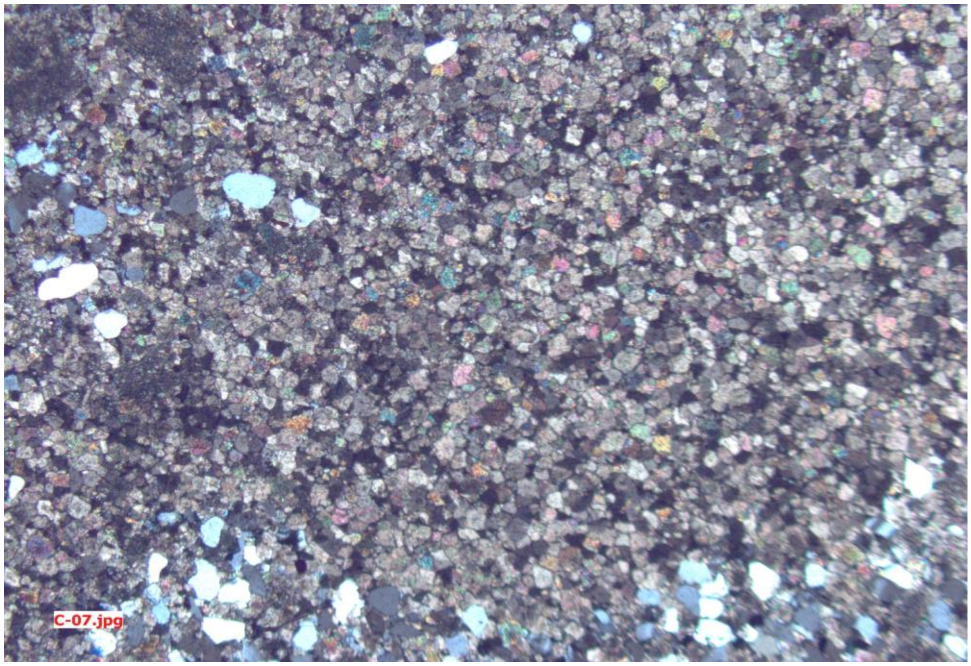
Texture		Comments
Grain Size	fine to medium	scattered quartz grains in recrystallized carbonate matrix, quartz grains locally abundant
Rounding	well-rounded to subangular	
Sorting	well sorted	

Composition/Detrital Minerals		Comments
Quartz		
Polycrystalline	<<1%	
Monocrystalline	10%	
Microcrystalline		
Feldspar		
Plagioclase		
Orthoclase		
Microcline		
Carbonate		
Calcite		
Dolomite	90%	<125µ, equant recrystallized carbonate, dolomite?
Aragonite		
Clay		
Illite		
Smectite		
Kaolinite		
Muscovite		
Chlorite		
Glauconite		
Rock Fragments		
Sedimentary		
Volcanic		
Metamorphic		
Other (Accessory Minerals)		

Cementing Materials		Comments
Quartz		
Feldspar		
Carbonate		
Clay		
Iron Oxide, Hydoxide and/or Sulfide		
Other		

Visual Porosity Estimate	Comments
<1%	voids appear to be due to plucking, no blue epoxy

25x magnification, 5mm field of view



Thin Section Analysis Report

Sample ID:	C-08
Formation/Member Name:	Rose Run
Lithologic Classification:	Carbonate
Depth/Depth Range:	6519 ft
Date of Analysis:	6/28/2017
Analyzed by:	S. Shank

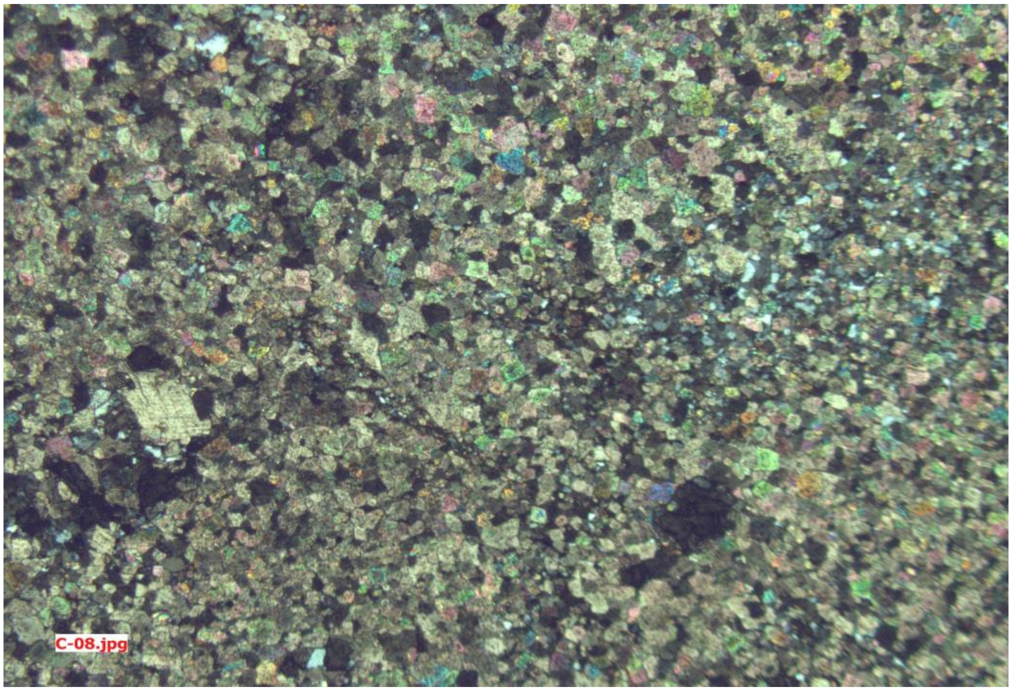
Texture		Comments
Grain Size		recrystallized carbonate with trace very fine-grained quartz
Rounding		
Sorting		

Composition/Detrital Minerals		Comments
Quartz		
Polycrystalline		
Monocrystalline	<1%	trace very fine-grained quartz
Microcrystalline		
Feldspar		
Plagioclase		
Orthoclase		
Microcline		
Carbonate		
Calcite		
Dolomite	100%	equant, recrystallized carbonate, <125µ, few larger rhombs, dolomite?
Aragonite		
Clay		
Illite		
Smectite		
Kaolinite		
Muscovite		
Chlorite		
Glauconite		
Rock Fragments		
Sedimentary		
Volcanic		
Metamorphic		
Other (Accessory Minerals)		

Cementing Materials		Comments
Quartz		
Feldspar		
Carbonate		
Clay		
Iron Oxide, Hydoxide and/or Sulfide		
Other		

Visual Porosity Estimate	Comments
<<1%	voids appear to be due to plucking, no blue epoxy

25x magnification, 5mm field of view



Thin Section Analysis Report

Sample ID:	C-11
Formation/Member Name:	Rose Run
Lithologic Classification:	Sandy Carbonate
Depth/Depth Range:	4219 ft
Date of Analysis:	6/28/2017
Analyzed by:	S. Shank

Texture		**Comments**
Grain Size		coarsely recrystallized carbonate with trace quartz grains, really poor thin section - thin, wedged
Rounding		
Sorting		

Composition/Detrital Minerals		**Comments**
Quartz		
Polycrystalline		
Monocrystalline	1%	scattered, very fine-grained, few larger grains
Microcrystalline		
Feldspar		
Plagioclase		
Orthoclase		
Microcline		
Carbonate		
Calcite		
Dolomite		<500µ, coarse, irregular to rhombic grains, very clouded, dolomite?
Aragonite		
Clay		
Illite		
Smectite		
Kaolinite		
Muscovite		
Chlorite		
Glauconite		
Rock Fragments		
Sedimentary		
Volcanic		
Metamorphic		
Other (Accessory Minerals)		

Cementing Materials		**Comments**
Quartz		
Feldspar		
Carbonate		
Clay		
Iron Oxide, Hydoxide and/or Sulfide		
Other		

Visual Porosity Estimate	**Comments**
5%	angular vugs with carbonate rhombs growing into void

25x magnification, 5mm field of view

Thin Section Analysis Report

Sample ID:	C-13
Formation/Member Name:	Rose Run
Lithologic Classification:	Quartz Sandstone
Depth/Depth Range:	6484 ft
Date of Analysis:	6/28/2017
Analyzed by:	S. Shank

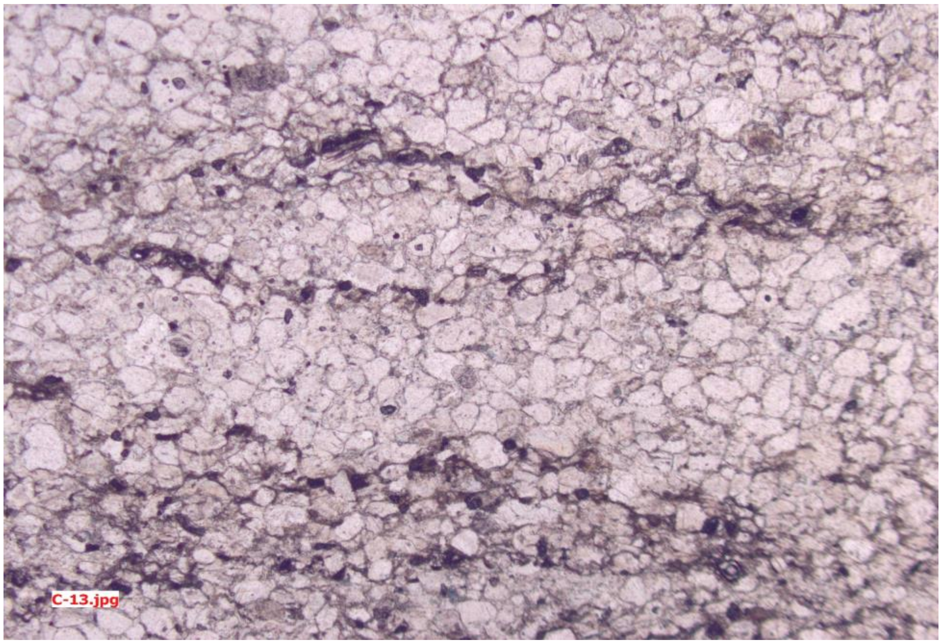
Texture		**Comments**
Grain Size	very fine to medium	
		some lamination based on grain size, section riddled with grit
Rounding	well to poorly rounded	
Sorting	moderately well sorted	

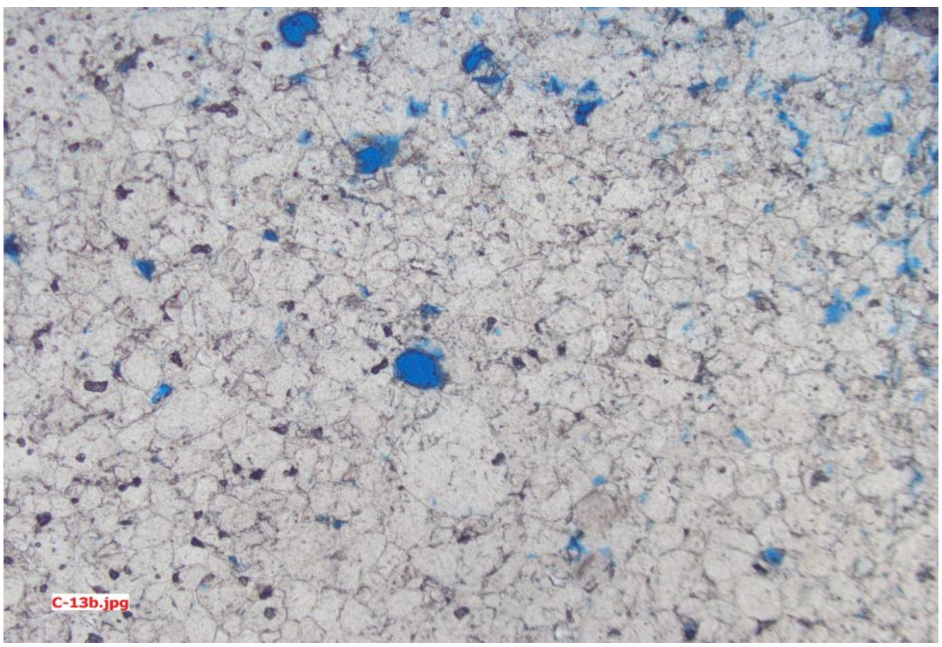
Composition/Detrital Minerals		**Comments**
Quartz		
Polycrystalline		
Monocrystalline	97%	some undulatory extinction
Microcrystalline		
Feldspar		
Plagioclase		
Orthoclase		
Microcline	2%	minor plagioclase
Carbonate		
Calcite		
Dolomite		
Aragonite		
Clay		
Illite		
Smectite		
Kaolinite		
Muscovite		
Chlorite		thin, irregular laminae of very fine-grained brownish green unidentified clay
Glauconite		
Rock Fragments		
Sedimentary		
Volcanic		
Metamorphic		
Other (Accessory Minerals)		

Cementing Materials		**Comments**
Quartz	overgrowths on quartz	well cemented
Feldspar		
Carbonate		
Clay		
Iron Oxide, Hydoxide and/or Sulfide		
Other		

Visual Porosity Estimate	**Comments**
3%	very irregular distribution - restricted to margins of slide, some may be plucked grains, fractures from coring?

25x magnification, 5mm field of view





Thin Section Analysis Report

Sample ID: C-14
Formation/Member Name: Rose Run
Lithologic Classification: Calcareous Sandstone
Depth/Depth Range: 4246 ft
Date of Analysis: 6/2/2017
Analyzed by: L. Ditzler

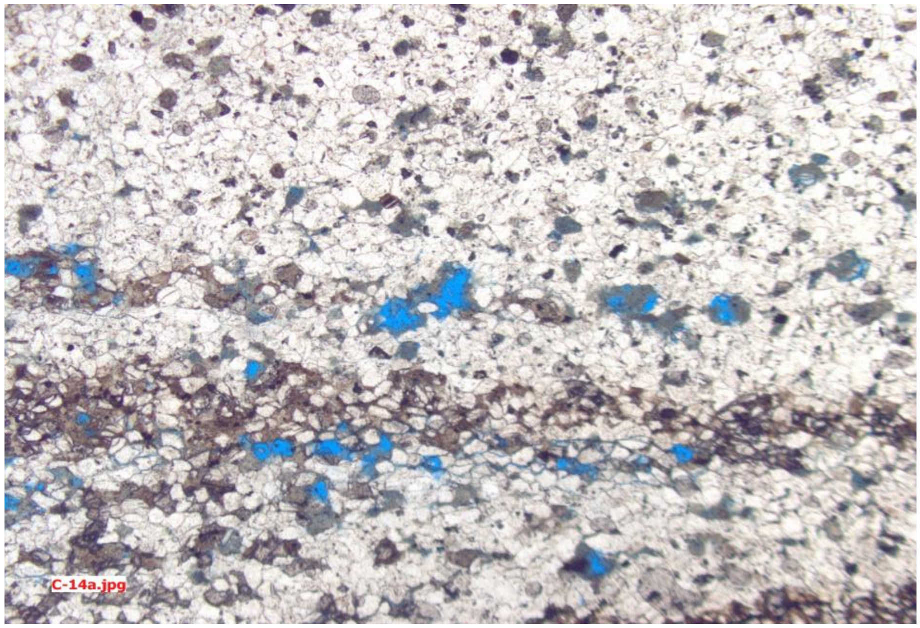
Texture		Comments
Grain Size	fine to very-fine grained, 88-125µ	well laminated based on grain size and mineralogy of coarser quartz layers, finer quartz layers with clay, clay laminae, and carbonate-rich layers
Rounding	poorly rounded	
Sorting	moderately well sorted	

Composition/Detrital Minerals		Comments
Quartz		
Polycrystalline		
Monocrystalline	65%	
Microcrystalline		
Feldspar		
Plagioclase		
Orthoclase		
Microcline	2%	with minor plagioclase
Carbonate		
Calcite		
Dolomite		
Aragonite		
Clay		
Illite		
Smectite		
Kaolinite		
Muscovite		
Chlorite		dull green very fine grained interstitial patches with quartz layers, extremely fine-grained brownish material in thin laminae
Glauconite		
Rock Fragments		
Sedimentary		
Volcanic		
Metamorphic		
Other (Accessory Minerals)		
	very trace opaques	

Cementing Materials	Comments
Quartz	overgrowths on quartz
Feldspar	
Carbonate	
Clay	some interstial material in quartz-rich layers
Iron Oxide, Hydoxide and/or Sulfide	
Other	

Visual Porosity Estimate	Comments
5%	highly variable, in coarser quartz rich layers - open space in clay rich laminae? and replacing greenish clay, no porosity in finer-grained quartz and carbonate layers

25x magnification, 5mm field of view



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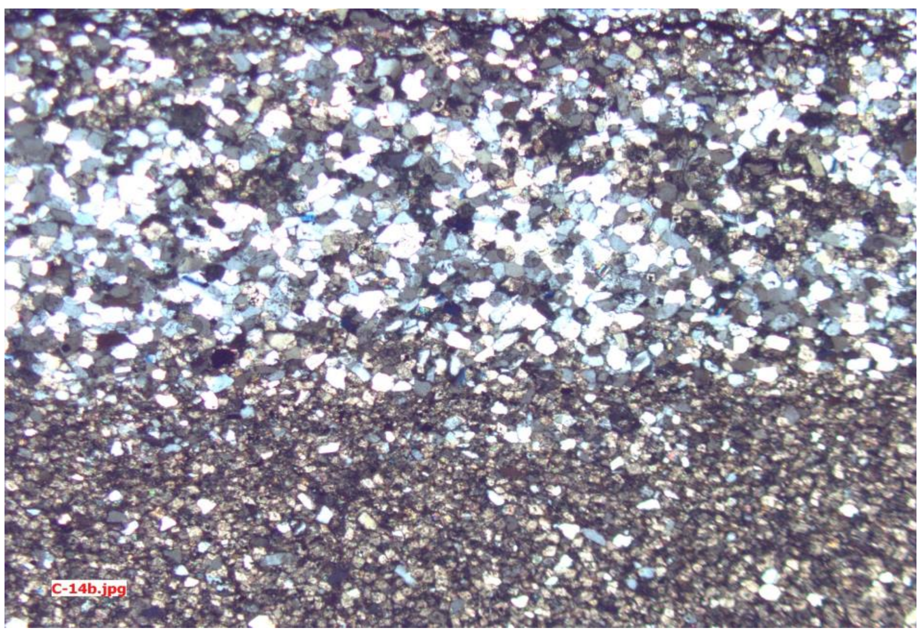


Thin Section Analysis Report

Sample ID: C-15
Formation/Member Name: Rose Run
Lithologic Classification: Sandstone
Depth/Depth Range: 4243.6 ft
Date of Analysis: 6/2/2017
Analyzed by: L. Ditzler/S. Shank

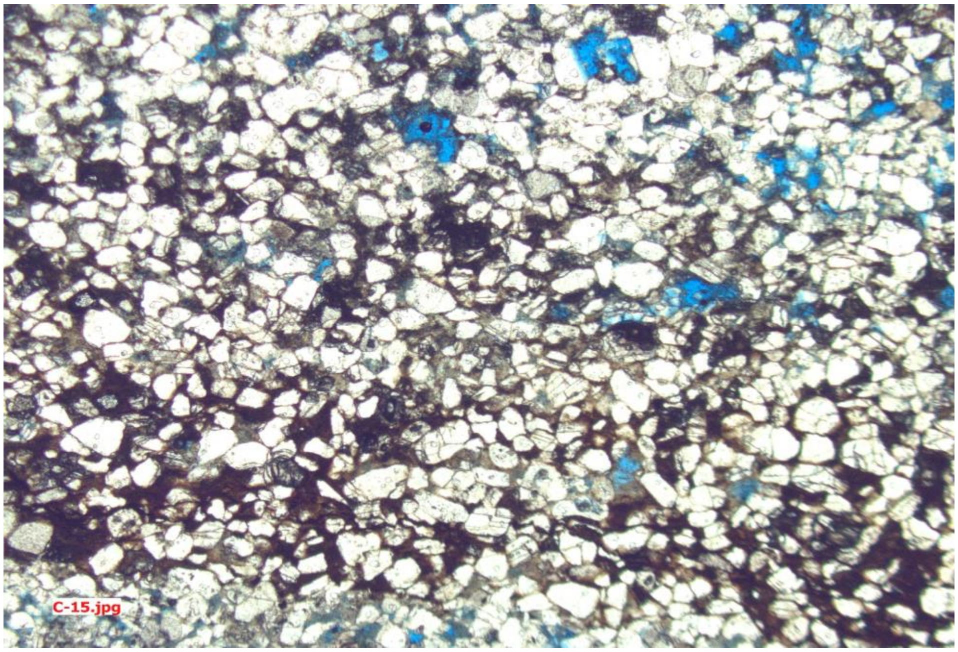
Texture		Comments
Grain Size	very fine-grained	well layered, defined by brown clay rich laminae
Rounding	well rounded to subrounded	
Sorting	well sorted	

Composition/Detrital Minerals		Comments
Quartz		
Polycrystalline		
Monocrystalline	78%	
Microcrystalline		
Feldspar		
Plagioclase	2.5	
Orthoclase		fairly feldspar rich
Microcline	2.5	
Carbonate		
Calcite		
Dolomite		
Aragonite		
Clay		
Illite		
Smectite		
Kaolinite		
Muscovite		
Chlorite	17%	alternating layers of greenish interstitial clay and brownish red interstitial (some hematite?) - Liesegang bands?
Glauconite		
Rock Fragments		
Sedimentary		
Volcanic		
Metamorphic		
Other (Accessory Minerals)		

Cementing Materials		Comments
Quartz		quartz overgrowths, well cemented
Feldspar		
Carbonate		
Clay	17%	greenish insterstitial patches and mm wide bands of brownish clay and hematite? Liesegang bands?
Iron Oxide, Hydoxide and/or Sulfide		
Other		

Visual Porosity Estimate	Comments
10%	restricted to quartz rich layers - replacing green clay but with patchy distribution, minimal porosity in red brown bands

25x magnification, 5mm field of view



Thin Section Analysis Report

Sample ID:	C-16
Formation/Member Name:	Rose Run
Lithologic Classification:	Carbonate
Depth/Depth Range:	4247 ft
Date of Analysis:	6/28/2017
Analyzed by:	S. Shank

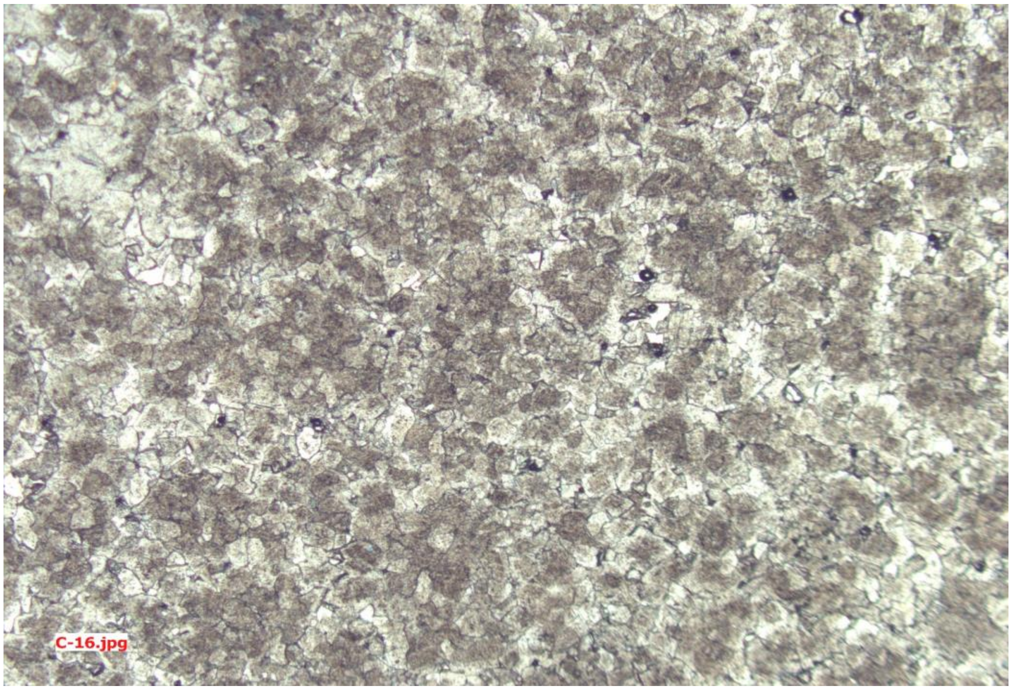
Texture		**Comments**
Grain Size		
Rounding		
Sorting		

Composition/Detrital Minerals		**Comments**
Quartz		
Polycrystalline		
Monocrystalline		
Microcrystalline		
Feldspar		
Plagioclase		
Orthoclase		
Microcline		
Carbonate		
Calcite		
Dolomite		62-250μ, recrystallized, equigranular to rhombic grains, very cloudy, dolomite?
Aragonite		
Clay		
Illite		
Smectite		
Kaolinite		
Muscovite		
Chlorite		
Glauconite		
Rock Fragments		
Sedimentary		
Volcanic		
Metamorphic		
Other (Accessory Minerals)		

Cementing Materials		**Comments**
Quartz		
Feldspar		
Carbonate		
Clay		
Iron Oxide, Hydoxide and/or Sulfide		
Other		

Visual Porosity Estimate		**Comments**
	<<1%	very scattered, small angular voids, no blue epoxy

25x magnification, 5mm field of view



Thin Section Analysis Report

Sample ID:	DN-29
Formation/Member Name:	Gatesburg/Rose Run
Lithologic Classification:	Carbonate
Depth/Depth Range:	N/A
Date of Analysis:	6/12/2017
Analyzed by:	S. Shank

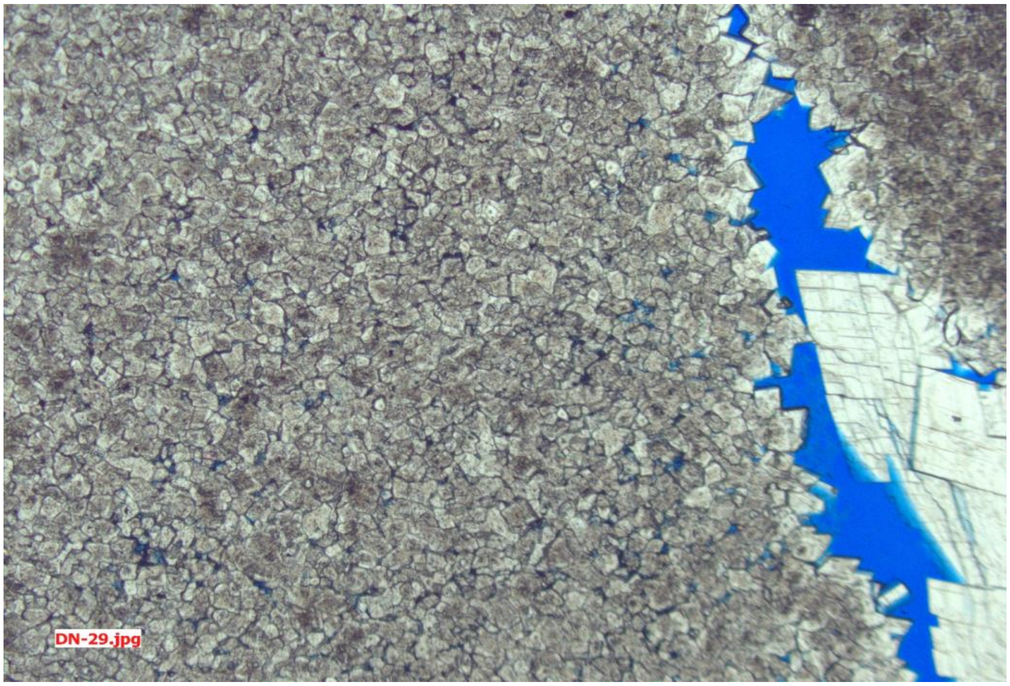
Texture		**Comments**
Grain Size		
Rounding		
Sorting		

Composition/Detrital Minerals		**Comments**
Quartz		
Polycrystalline		
Monocrystalline		
Microcrystalline		
Feldspar		
Plagioclase		
Orthoclase		
Microcline		
Carbonate		
Calcite		
Dolomite	100%	125-250µ, equigranular, recrystallized, very cloudy, common but discontinuous vugs with coarser carbonate rhombs and voids
Aragonite		
Clay		
Illite		
Smectite		
Kaolinite		
Muscovite		
Chlorite		
Glauconite		
Rock Fragments		
Sedimentary		
Volcanic		
Metamorphic		
Other (Accessory Minerals)		

Cementing Materials		**Comments**
Quartz		
Feldspar		
Carbonate		
Clay		
Iron Oxide, Hydoxide and/or Sulfide		
Other		

Visual Porosity Estimate		**Comments**
	1%	almost all in or near vugs, virtually no porosity in matrix

25x magnification, 5mm field of view



Thin Section Analysis Report

Sample ID: DN-32
Formation/Member Name: Gatesburg/Rose Run
Lithologic Classification: Carbonate
Depth/Depth Range: N/A
Date of Analysis: 6/12/2017
Analyzed by: S. Shank

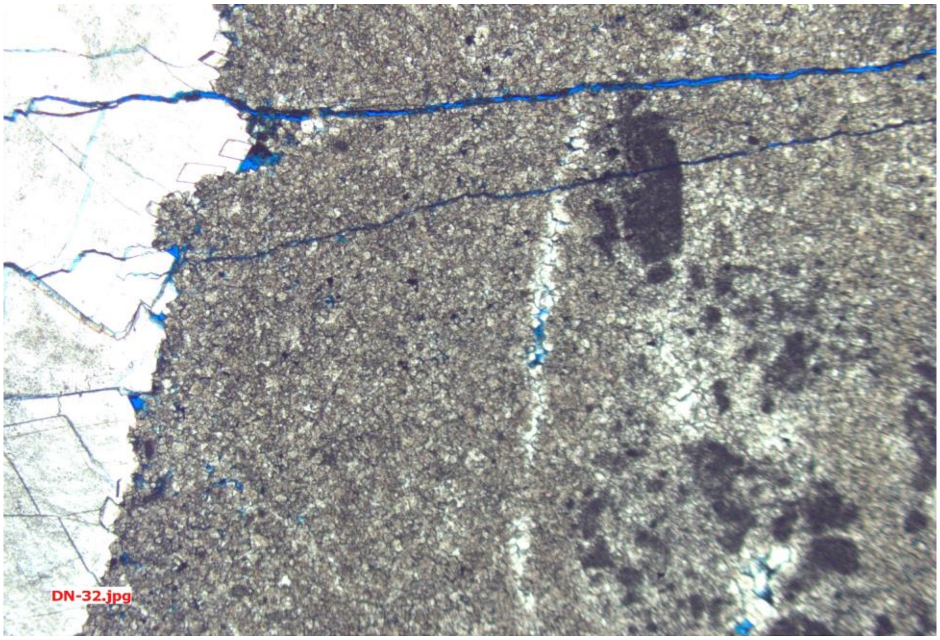
Texture		Comments
Grain Size		
Rounding		
Sorting		

Composition/Detrital Minerals		Comments
Quartz		
Polycrystalline		
Monocrystalline		
Microcrystalline		
Feldspar		
Plagioclase		
Orthoclase		
Microcline		
Carbonate		
Calcite		
Dolomite	100%	very fine-grained, <125μ, equigranular, recrystallized matrix, dolomite, very cloudy, large common vugs with coarse carbonate rhombs, rounded, extremely fine-grained patches - relic peloids?, dolomite?
Aragonite		
Clay		
Illite		
Smectite		
Kaolinite		
Muscovite		
Chlorite		
Glauconite		
Rock Fragments		
Sedimentary		
Volcanic		
Metamorphic		
Other (Accessory Minerals)		

Cementing Materials		Comments
Quartz		
Feldspar		
Carbonate		
Clay		
Iron Oxide, Hydoxide and/or Sulfide		
Other		

Visual Porosity Estimate	Comments
2%	porosity in vugs and thin fractures, almost no porosity in matrix

25x magnification, 5mm field of view



Thin Section Analysis Report

Sample ID:	DN-36
Formation/Member Name:	Gatesburg/Rose Run
Lithologic Classification:	Carbonate
Depth/Depth Range:	N/A
Date of Analysis:	6/13/2017
Analyzed by:	S. Shank

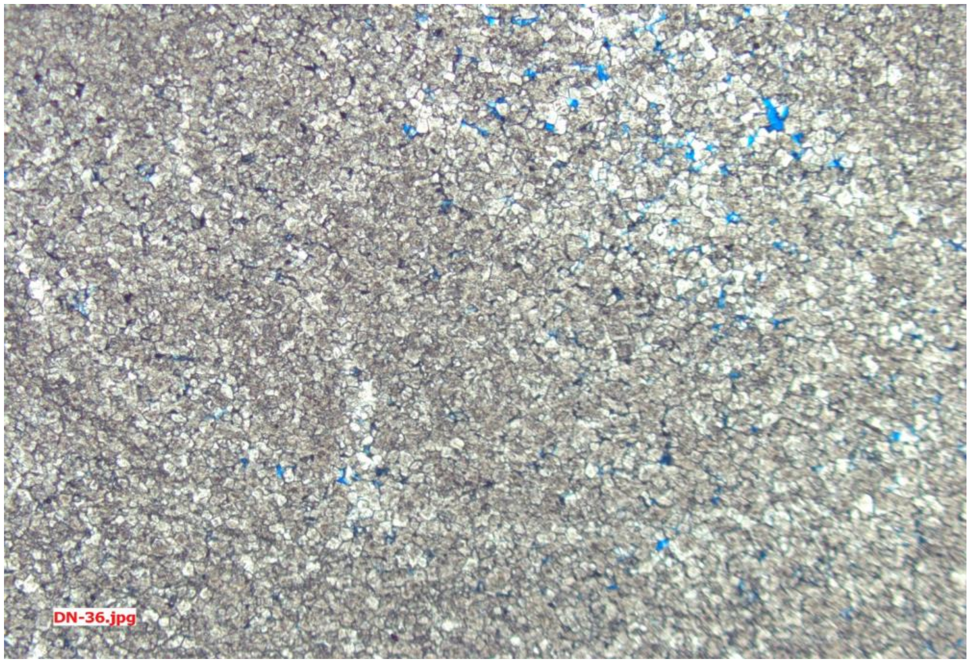
Texture		**Comments**
Grain Size		
Rounding		
Sorting		

Composition/Detrital Minerals		**Comments**
Quartz		
Polycrystalline		
Monocrystalline		
Microcrystalline		
Feldspar		
Plagioclase		
Orthoclase		
Microcline		
Carbonate		
Calcite		
Dolomite	100%	very fine-grained, <125, equigranular, recrystallized, clouded, dolomite? No vugs but a few small patches of slighly coarser carbonate
Aragonite		
Clay		
Illite		
Smectite		
Kaolinite		
Muscovite		
Chlorite		
Glauconite		
Rock Fragments		
Sedimentary		
Volcanic		
Metamorphic		
Other (Accessory Minerals)		

Cementing Materials		**Comments**
Quartz		
Feldspar		
Carbonate		
Clay		
Iron Oxide, Hydoxide and/or Sulfide		
Other		

Visual Porosity Estimate	**Comments**
2%	common, small intergranular, patchy distribution

25x magnification, 5mm field of view



Thin Section Analysis Report

Sample ID:	DN-37
Formation/Member Name:	Gatesburg/Rose Run
Lithologic Classification:	Carbonate
Depth/Depth Range:	N/A
Date of Analysis:	6/13/2027
Analyzed by:	S. Shank

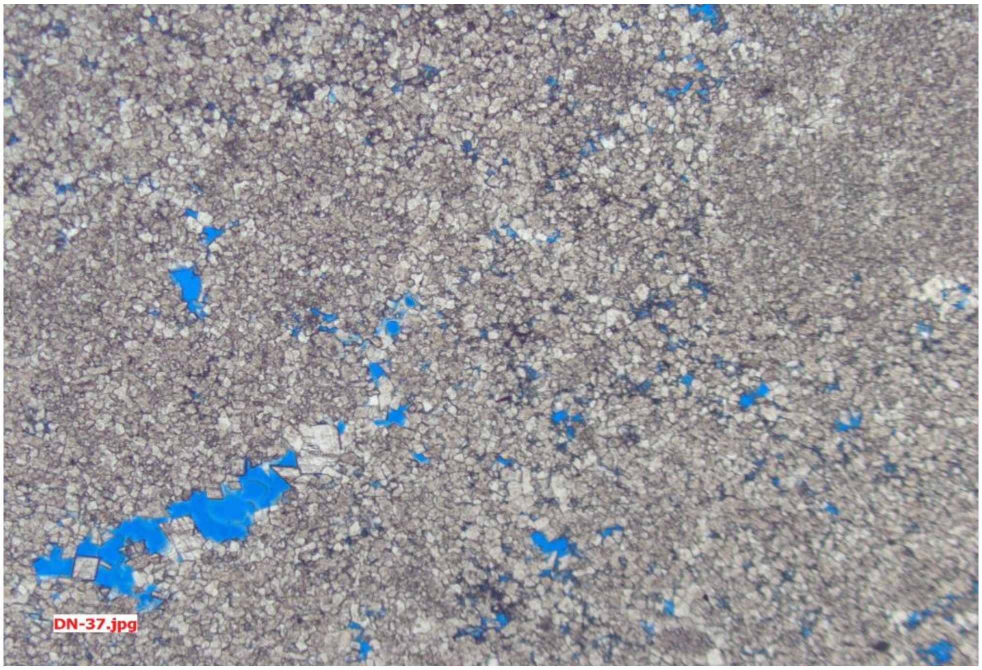
Texture		**Comments**
Grain Size		
Rounding		
Sorting		

Composition/Detrital Minerals		**Comments**
Quartz		
Polycrystalline		
Monocrystalline		
Microcrystalline		
Feldspar		
Plagioclase		
Orthoclase		
Microcline		
Carbonate		
Calcite		
Dolomite	100%	generally fine-grained with veins and patches of coarser carbonate, equigranular, recrystallized, clouded, dolomite?
Aragonite		
Clay		
Illite		
Smectite		
Kaolinite		
Muscovite		
Chlorite		
Glauconite		
Rock Fragments		
Sedimentary		
Volcanic		
Metamorphic		
Other (Accessory Minerals)		

Cementing Materials		**Comments**
Quartz		
Feldspar		
Carbonate		
Clay		
Iron Oxide, Hydoxide and/or Sulfide		
Other		

Visual Porosity Estimate		**Comments**
	5%	common voids in vugs and common intergranular porosity

25x magnification, 5mm field of view



Thin Section Analysis Report

Sample ID:	DN-38
Formation/Member Name:	Gatesburg/Rose Run
Lithologic Classification:	Carbonate
Depth/Depth Range:	N/A
Date of Analysis:	6/13/2017
Analyzed by:	S. Shank

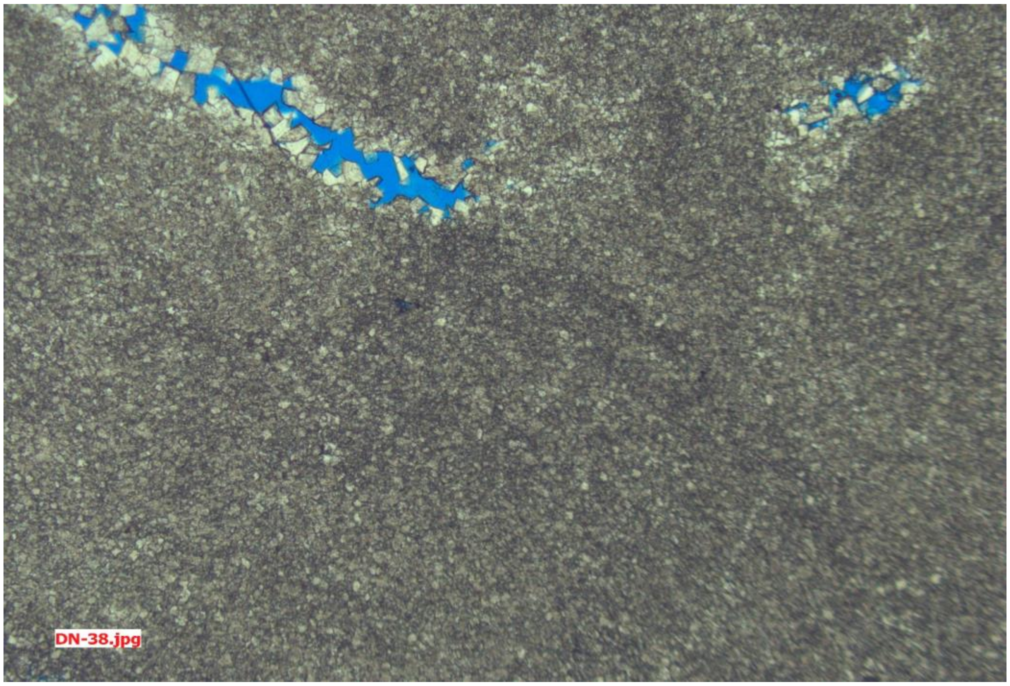
Texture		**Comments**
Grain Size		
Rounding		
Sorting		

Composition/Detrital Minerals		**Comments**
Quartz		
Polycrystalline		
Monocrystalline		
Microcrystalline		
Feldspar		
Plagioclase		
Orthoclase		
Microcline		
Carbonate		
Calcite		
Dolomite	100%	generally very fine-grained, <125µ, clouded, dolomite?, scattered, discontinuous vugs and veins of coarser carbonate rhombs and voids.
Aragonite		
Clay		
Illite		
Smectite		
Kaolinite		
Muscovite		
Chlorite		
Glauconite		
Rock Fragments		
Sedimentary		
Volcanic		
Metamorphic		
Other (Accessory Minerals)		

Cementing Materials		**Comments**
Quartz		
Feldspar		
Carbonate		
Clay		
Iron Oxide, Hydoxide and/or Sulfide		
Other		

Visual Porosity Estimate	**Comments**
2%	virtually no intergranular porosity, almost all in vugs and veins

25x magnification, 5mm field of view



Thin Section Analysis Report

Sample ID: DN-40
Formation/Member Name: Gatesburg/Rose Run
Lithologic Classification: Dolostone
Depth/Depth Range: N/A
Date of Analysis: 6/13/2017
Analyzed by: S. Shank

Texture		Comments
Grain Size		
Rounding		
Sorting		

Composition/Detrital Minerals		Comments
Quartz		
Polycrystalline		
Monocrystalline		
Microcrystalline		
Feldspar		
Plagioclase		
Orthoclase		
Microcline		
Carbonate		
Calcite		
Dolomite	100%	fine to medium grained, <350µ, equigranular to irregular, recrystallized, cloudy dolomite. Dolomite confirmed by SEM.
Aragonite		
Clay		
Illite		
Smectite		
Kaolinite		
Muscovite		
Chlorite		
Glauconite		
Rock Fragments		
Sedimentary		
Volcanic		
Metamorphic		
Other (Accessory Minerals)		

Cementing Materials		Comments
Quartz		
Feldspar		
Carbonate		
Clay		
Iron Oxide, Hydoxide and/or Sulfide		
Other		

Visual Porosity Estimate		Comments
	2%	scattered vugs, extremely limited intergranular porosity

Thin Section Analysis Report

Sample ID:	DN-41
Formation/Member Name:	Gatesburg/Rose Run
Lithologic Classification:	Carbonate
Depth/Depth Range:	N/A
Date of Analysis:	6/13/2017
Analyzed by:	S. Shank

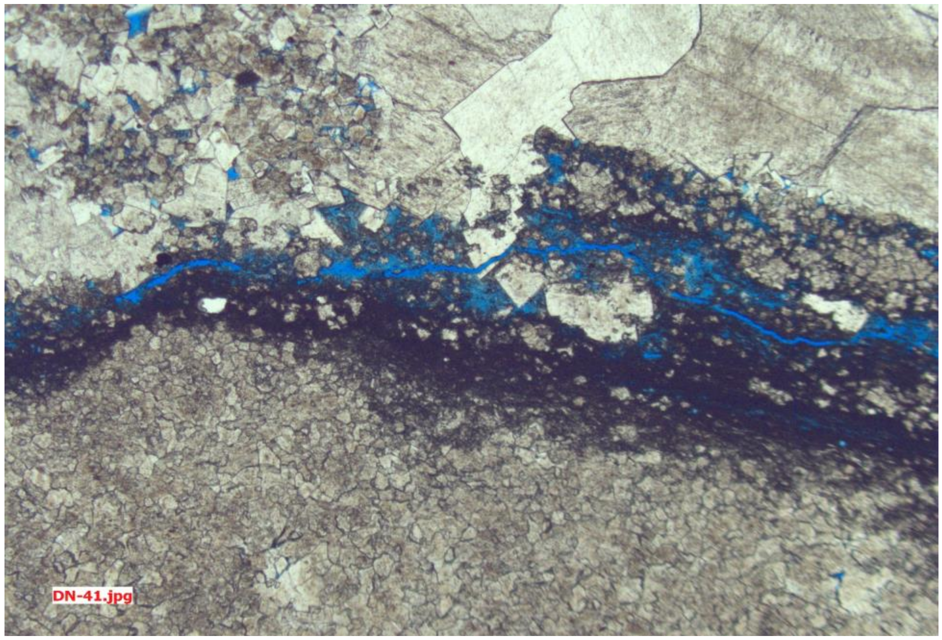
Texture		**Comments**
Grain Size		
Rounding		
Sorting		

Composition/Detrital Minerals		**Comments**
Quartz		
Polycrystalline		
Monocrystalline		
Microcrystalline		
Feldspar		
Plagioclase		
Orthoclase		
Microcline		
Carbonate		
Calcite		
Dolomite	100%	very fine to fine-grained matrix, cloudy, <125µ, with large vugs filled with coarse carbonate. Few thin veins.
Aragonite		
Clay		
Illite		
Smectite		
Kaolinite		
Muscovite		
Chlorite		
Glauconite		
Rock Fragments		
Sedimentary		
Volcanic		
Metamorphic		
Other (Accessory Minerals)		

Cementing Materials		**Comments**
Quartz		
Feldspar		
Carbonate		
Clay		
Iron Oxide, Hydoxide and/or Sulfide		
Other		

Visual Porosity Estimate	**Comments**
1%	scattered voids in vugs and veins, minimal porosity in matrix

25x magnification, 5mm field of view



Thin Section Analysis Report

Sample ID:	DN-42
Formation/Member Name:	Gatesburg/Rose Run
Lithologic Classification:	Carbonate
Depth/Depth Range:	N/A
Date of Analysis:	6/15/2017
Analyzed by:	S. Shank

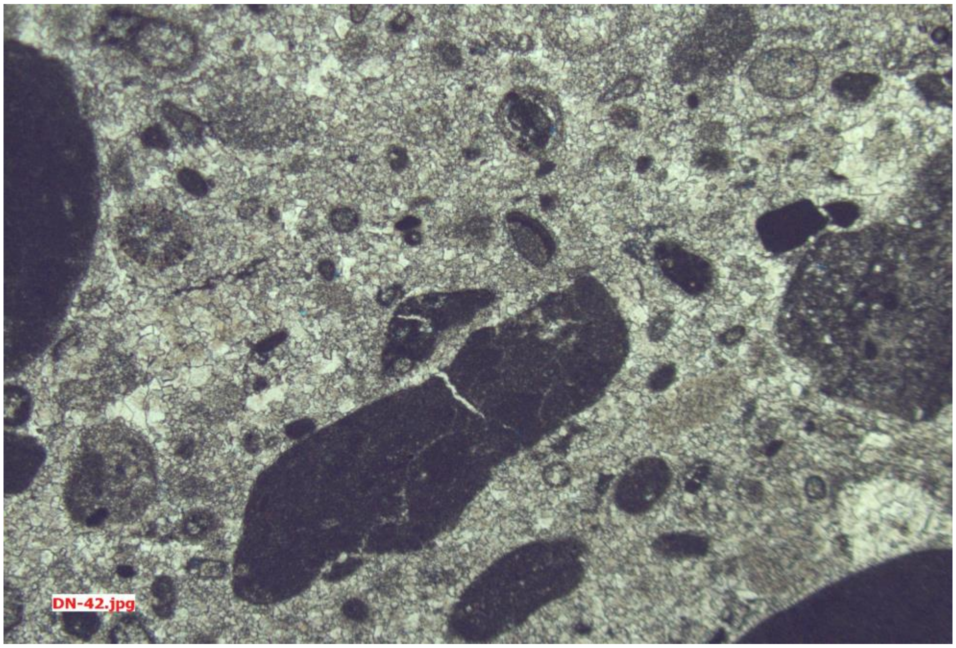
Texture		**Comments**
Grain Size		
Rounding		
Sorting		

Composition/Detrital Minerals		**Comments**
Quartz		
Polycrystalline		
Monocrystalline		
Microcrystalline		
Feldspar		
Plagioclase		
Orthoclase		
Microcline		
Carbonate		
Calcite		
Dolomite	100%	abundant allochems, clasts, relic ooids, peloids? in recrystallized cloudy very fine-grained, <125μ, matrix. Dolomite?
Aragonite		
Clay		
Illite		
Smectite		
Kaolinite		
Muscovite		
Chlorite		
Glauconite		
Rock Fragments		
Sedimentary		
Volcanic		
Metamorphic		
Other (Accessory Minerals)		

Cementing Materials		**Comments**
Quartz		
Feldspar		
Carbonate		
Clay		
Iron Oxide, Hydoxide and/or Sulfide		
Other		

Visual Porosity Estimate	**Comments**
<<1%	No porosity observed except for small discontinuous fracture

25x magnification, 5mm field of view



Thin Section Analysis Report

Sample ID: DN-43
Formation/Member Name: Gatesburg/Rose Run
Lithologic Classification: Carbonate
Depth/Depth Range: N/A
Date of Analysis: 6/16/2017
Analyzed by: S. Shank

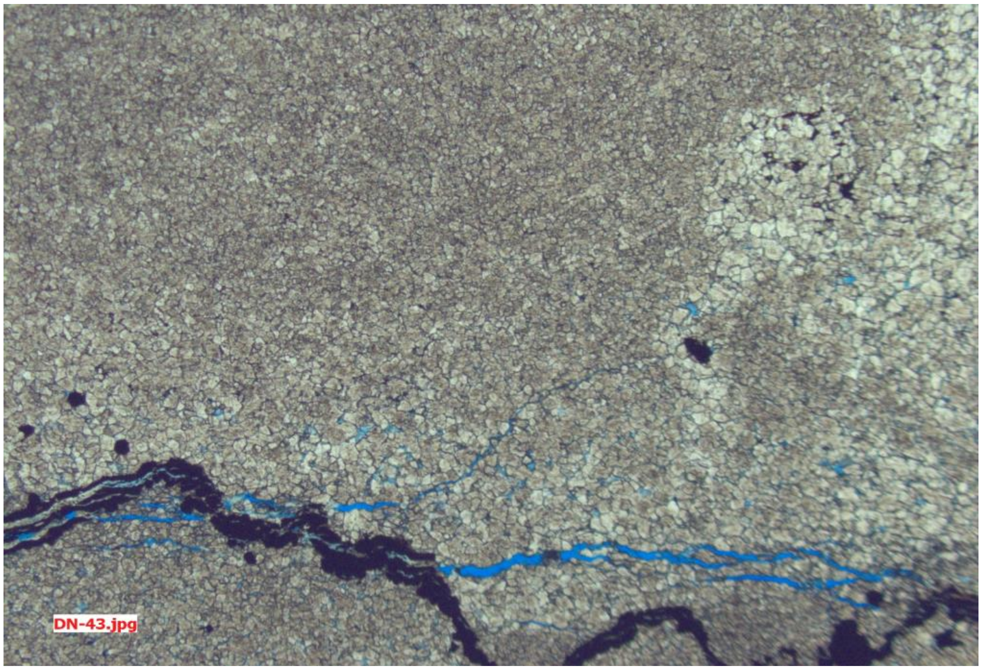
Texture		Comments
Grain Size		
Rounding		
Sorting		

Composition/Detrital Minerals		Comments
Quartz		
Polycrystalline		
Monocrystalline		
Microcrystalline		
Feldspar		
Plagioclase		
Orthoclase		
Microcline		
Carbonate		
Calcite		
Dolomite	100%	very fine-grained, <125µ, recrystallized, cloudy dolomite?, with scattered coarser patches and veins. Cut by thin stylolites and subparallel fracture
Aragonite		
Clay		
Illite		
Smectite		
Kaolinite		
Muscovite		
Chlorite		
Glauconite		
Rock Fragments		
Sedimentary		
Volcanic		
Metamorphic		
Other (Accessory Minerals)		
	<1% opaques	scattered grains and in stylolites

Cementing Materials		Comments
Quartz		
Feldspar		
Carbonate		
Clay		
Iron Oxide, Hydoxide and/or Sulfide		
Other		

Visual Porosity Estimate		Comments
	<1%	virtually no intergranular porosity in very fine-grained matrix, thin fracture along stylolite and scattered porosity in coarser grained patches

25x magnification, 5mm field of view



Thin Section Analysis Report

Sample ID: DN-45
Formation/Member Name: Gatesburg/Rose Run
Lithologic Classification: Breccia
Depth/Depth Range: N/A
Date of Analysis: 6/16/2017
Analyzed by: S. Shank

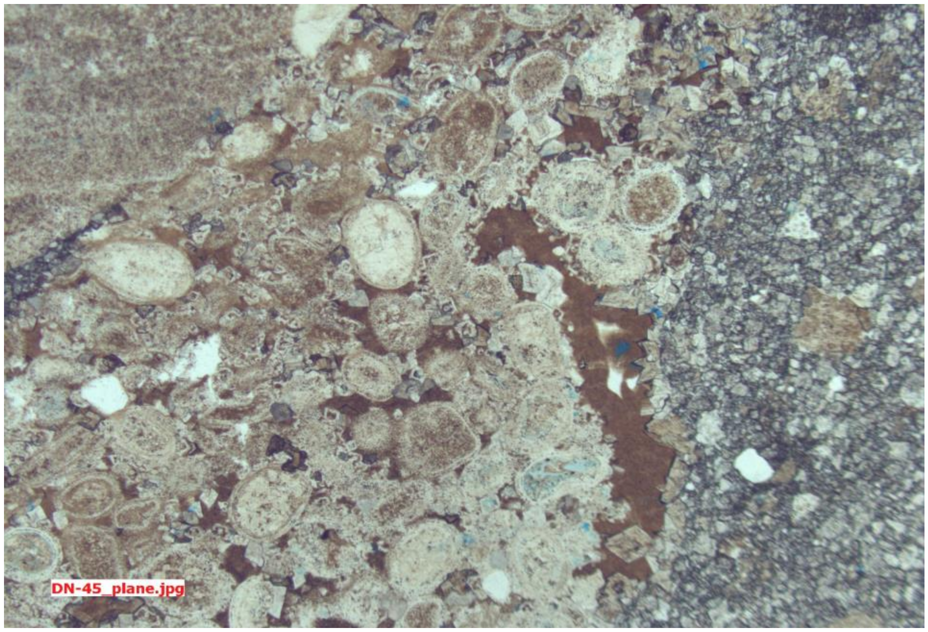
Texture		Comments
Grain Size		matrix supported breccia with angular clasts (~1 cm) of chert and silicified oolites in carbonate
Rounding		
Sorting		

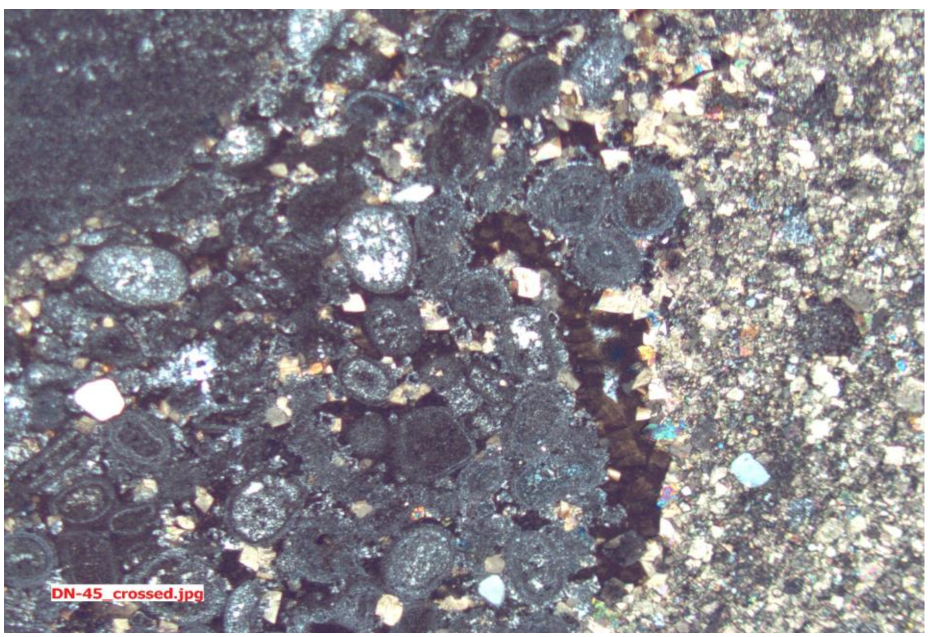
Composition/Detrital Minerals		Comments
Quartz		
Polycrystalline		
Monocrystalline	<1%	few scattered sand grains in silicified oolites and carbonate matrix
Microcrystalline		
Feldspar		
Plagioclase		
Orthoclase		
Microcline		
Carbonate		
Calcite		
Dolomite		
Aragonite		
Clay		
Illite		
Smectite		
Kaolinite		
Muscovite		
Chlorite		
Glauconite		
Rock Fragments		
Sedimentary	75%	chert and silicified oolites
Volcanic		
Metamorphic		
Other (Accessory Minerals)		

Cementing Materials		Comments
Quartz		
Feldspar		
Carbonate	25%	very fine-grained, <125µ, equigranular to rhombic cloudy carbonate, some rhombs of carbonate in silicified oolites
Clay		
Iron Oxide, Hydoxide and/or Sulfide		
Other		

Visual Porosity Estimate	Comments
<1%	extremely limited porosity in very thin veins, fractures along clast margins and scattered voids

25x magnification, 5mm field of view





Thin Section Analysis Report

Sample ID:	H-6-00
Formation/Member Name:	Gordon
Lithologic Classification:	Sandstone
Depth/Depth Range:	2906 ft
Date of Analysis:	7/14/2017
Analyzed by:	L. Ditzler

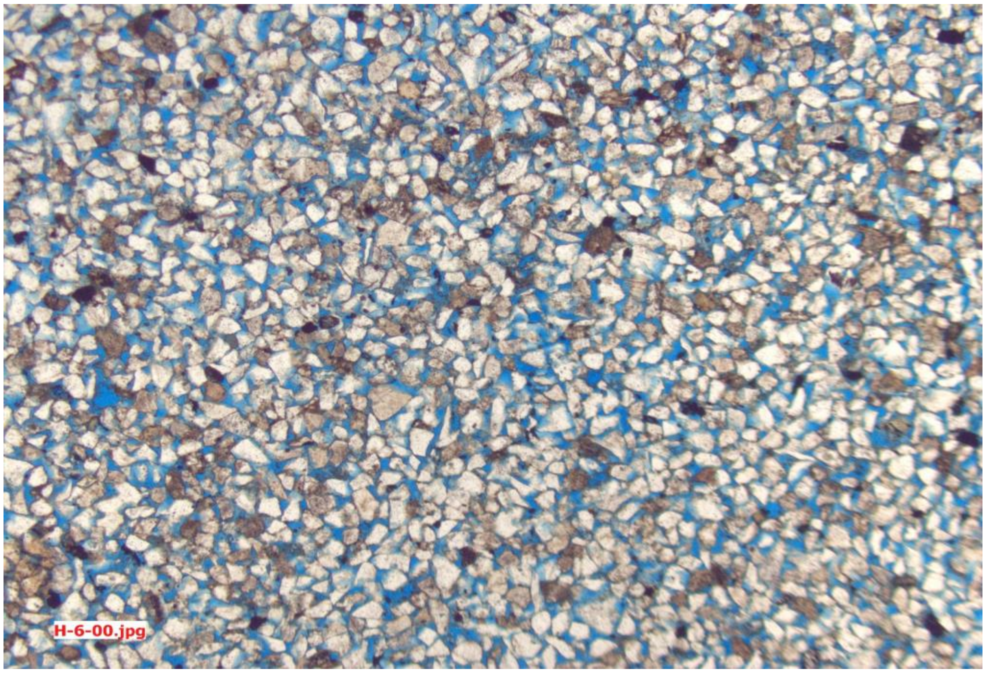
Texture		**Comments**
Grain Size	fine-grained, 177-250µ	
Rounding	Sub-angular to sub-rounded	
Sorting	well sorted	

Composition/Detrital Minerals		**Comments**
Quartz		
Polycrystalline	4%	
Monocrystalline	86%	
Microcrystalline	5%	
Feldspar		
Plagioclase		2% total feldspar
Orthoclase		
Microcline		
Carbonate		
Calcite		
Dolomite		
Aragonite		
Clay		
Illite	<1%	total clay - skattered flakes and patches
Smectite		
Kaolinite		
Muscovite		
Chlorite	<<1%	
Glauconite		
Rock Fragments		
Sedimentary		
Volcanic		
Metamorphic		
Other (Accessory Minerals)		
	Zircon	very minor amount

Cementing Materials		**Comments**
Quartz		very poorly cemented
Feldspar		
Carbonate		
Clay	3%	
Iron Oxide, Hydoxide and/or Sulfide		
Other		

Visual Porosity Estimate	**Comments**
25%	primarily intergranular - evenly dispersed

25x magnification, 5mm field of view



Thin Section Analysis Report

Sample ID:	H-4-99
Formation/Member Name:	Gordon
Lithologic Classification:	Sandstone
Depth/Depth Range:	2894.9 ft
Date of Analysis:	7/14/2017
Analyzed by:	L. Ditzler

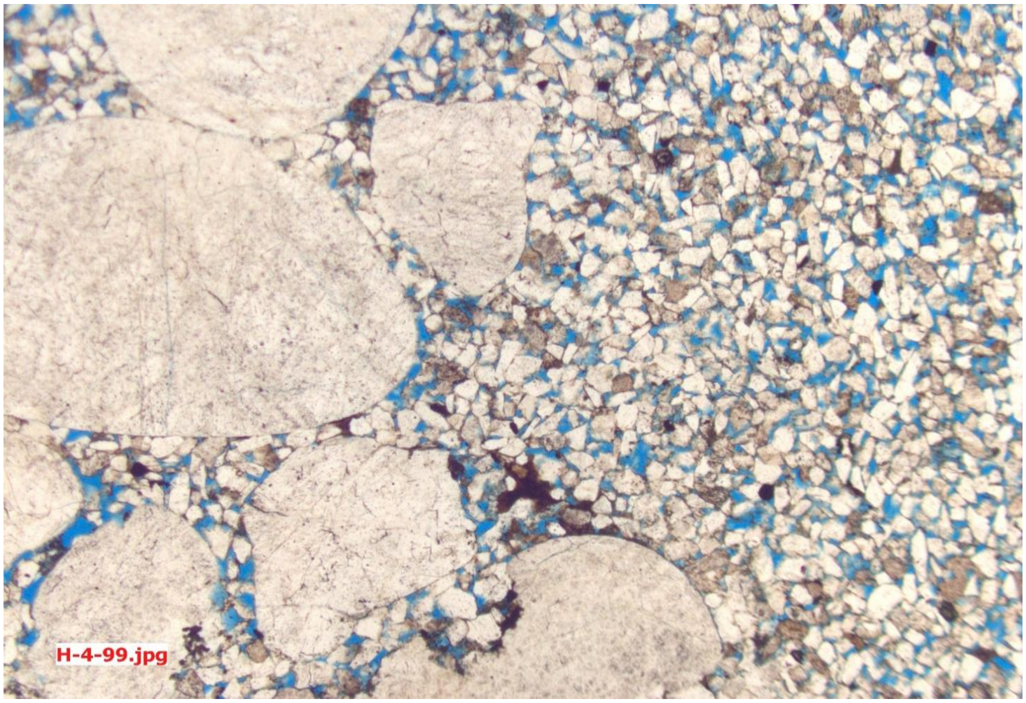
Texture		**Comments**
Grain Size	very-fine (88-125µ) to very-coarse (1410-2000µ)	some lamination based on grain size
Rounding	very-coarse grains are very well rounded while very-fine grains are sub-rounded to	
Sorting	poor	

Composition/Detrital Minerals		**Comments**
Quartz		
Polycrystalline	3%	
Monocrystalline	90%	
Microcrystalline	3%	
Feldspar		
Plagioclase	1%	total feldspar
Orthoclase		
Microcline		
Carbonate		
Calcite		
Dolomite		
Aragonite		
Clay		
Illite		scattered grains
Smectite		
Kaolinite		
Muscovite	<1%	
Chlorite		
Glauconite		
Rock Fragments		
Sedimentary		
Volcanic		
Metamorphic		
Other (Accessory Minerals)		
	Zircon	very minor amount

Cementing Materials		**Comments**
Quartz		Poorly cemented
Feldspar		
Carbonate		
Clay	3%	
Iron Oxide, Hydoxide and/or Sulfide		
Other		

Visual Porosity Estimate	**Comments**
25%	primarily intergranular - evenly dispersed

25x magnification, 5mm field of view



Thin Section Analysis Report

Sample ID: H-2-99
Formation/Member Name: Gordon
Lithologic Classification: Quartz Comglomerate
Depth/Depth Range: 2892.75 ft
Date of Analysis: 7/14/2017
Analyzed by: L. Ditzler

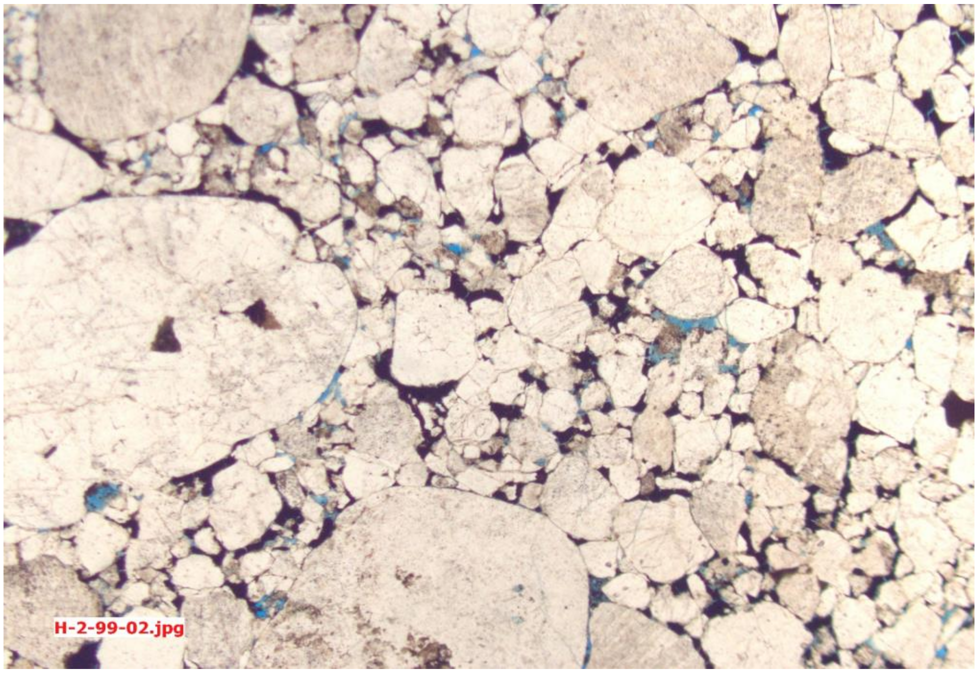
Texture		Comments
Grain Size	very-fine (88-125µ) to granular (2-6mm)	
Rounding	well rounded to subangular	
	very-coarse grains are very well rounded while very-fine grains are sub-rounded to sub-angular	
Sorting		

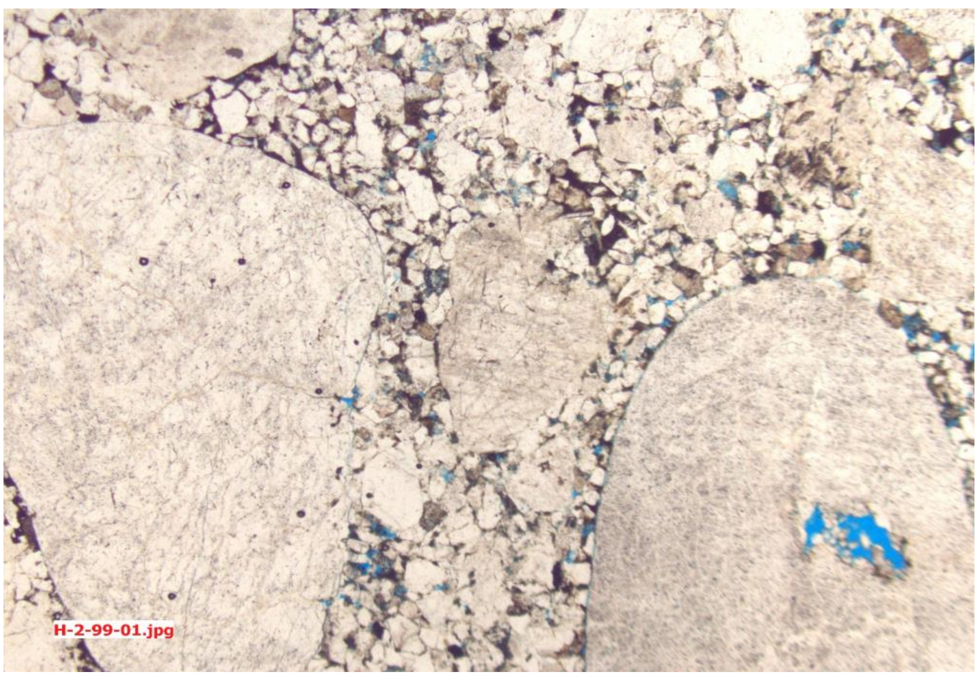
Composition/Detrital Minerals		Comments
Quartz		
Polycrystalline	43%	
Monocrystalline	40%	
Microcrystalline	2%	
Feldspar		
Plagioclase	2%	Total feldspar
Orthoclase		
Microcline		
Carbonate		
Calcite		
Dolomite		
Aragonite		
Clay		
Illite		Scattered grains of muscovite and minor biotite (<<1%)
Smectite		
Kaolinite		
Muscovite	<1%	
Chlorite		
Glauconite		
Rock Fragments		
Sedimentary		
Volcanic		
Metamorphic		
Other (Accessory Minerals)		

Cementing Materials		Comments
Quartz	<1%	some quartz overgrowths
Feldspar		
Carbonate		
Clay	1%	minor, scattered
Iron Oxide, Hydoxide and/or Sulfide	7%	
Other		

Visual Porosity Estimate	Comments
4%	both intergranular and within fractures in grains

25x magnification, 5mm field of view





Thin Section Analysis Report

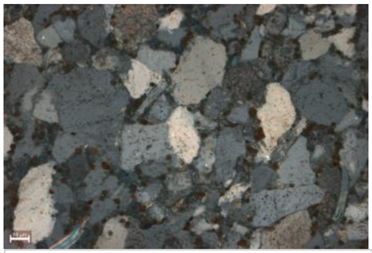
Sample ID:	LH-1-02
Formation/Member Name:	Gordon
Lithologic Classification:	Sandstone
Depth/Depth Range:	3136.75
Date of Analysis:	7/17/2017
Analyzed by:	Ellen Davis

	Texture	**Comments**
		observed at 10x
Grain Size	50-200 µm, average grain size ~125 µm	
Rounding	subangular, subrounded	
Sorting	well sorted	

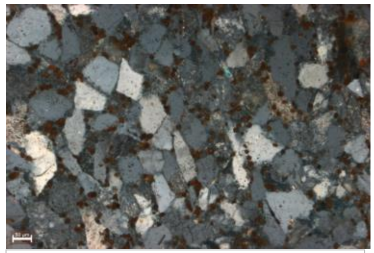
	Composition/Detrital Minerals	**Comments**
	Quartz	
Polycrystalline	·some polycrystalline quartz present	
		images LH-1-02_0002 - LH-1-02_0005, LH-1-02_0007
Monocrystalline	~75% monocrystalline quartz ·smaller, subhedral grains ·not much overgrowth	
Microcrystalline	grains can be easily observed under petroscope	
	XN: black, white, gray PPL: light brown	
	Feldspar	
Plagioclase	·albite twinning present	image LH-1-02_0001
Orthoclase	N/A	
Microcline	N/A	
	Carbonate	
Calcite	~25% calcite ·subhedral grains ·mostly cementing grains	image LH-1-02_0006
	XN: brown, green, pink PPL: light brown	
Dolomite	N/A	
Aragonite	N/A	
	Clay	
Illite	N/A	
Smectite	N/A	
Kaolinite	N/A	
Muscovite	<5% muscovite ·small, subangular grains	images LH-1-02_0010, 0013, 0014, 0019
	XN: blue, purple, orange PPL: gray-green	
Chlorite	N/A	
Glauconite	N/A	
	Rock Fragments	
Sedimentary	·sedimentary rock fragments present	image LH-1-02_0020
Volcanic	N/A	
Metamorphic	N/A	
	Other (Accessory Minerals)	
	images LH-1-02_0009, LH-1-02_0012	

	Cementing Materials	**Comments**
Quartz	·some intergrown quartz grains	
Feldspar		
Carbonate	·some calcite cementing	
Clay		
Iron Oxide, Hydoxide and/or Sulfide		
Other		

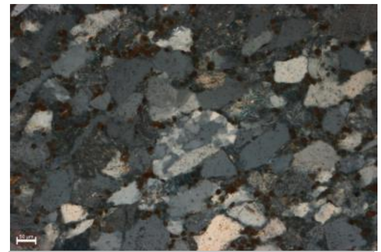
	Visual Porosity Estimate	**Comments**
		images LH-1-02_0015 - LH-1-02_0018



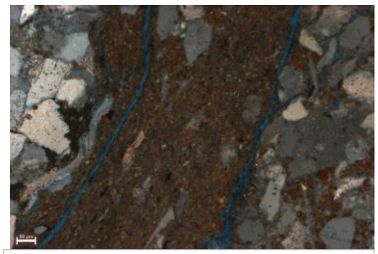
This image shows subhedral, intergrown quartz grains.
(10x, XN)



The subangular and subrounded quartz grains in this image. Some iron is shown here as well.
(10x, XN)



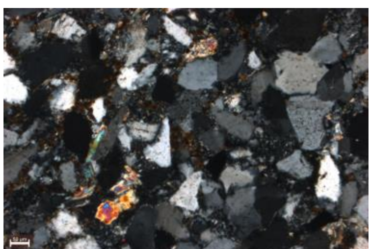
This image shows polycrystalline quartz as well as subhedral, monocrystalline quartz grains.



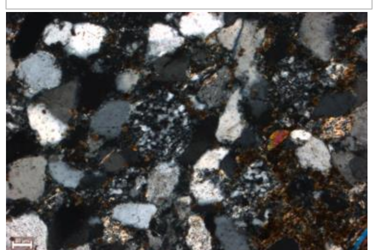
This image shows a large calcite grain.
(10x, XN)

The subhedral quartz grains in this image are cemented by calcite. Some grains of birefringent muscovite are also present.
(10x, XN)

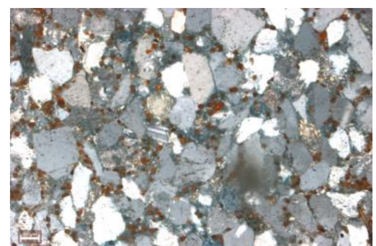
This image shows several grains of birefringent muscovite in a matrix of intergrown quartz.
(10x, XN)



The birefringent subhedral muscovite grains in this image are surrounded by quartz grains.
(10x, XN)

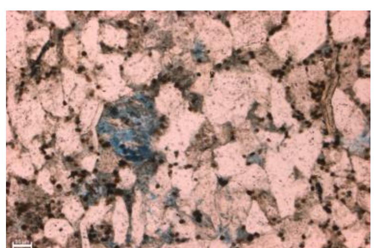


This image shows sedimentary rock fragments and subhedral quartz grains.
(10x, XN)



This image shows a small, subangular grain of plagioclase feldspar with albite twinning in a matrix of quartz grains.
(10x, XN)

This image shows the porosity of this sample.
(10x, PPL)



The blue epoxy in this image shows the pore space in the sample.
(10x, PPL)

The pore space in this image is filled with blue epoxy.
(10x, PPL)

Thin Section Analysis Report

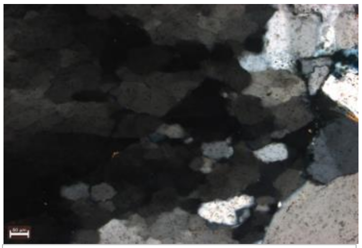
Sample ID: LH-5-02
Formation/Member Name: Gordon
Lithologic Classification: Sandstone
Depth/Depth Range: 3138.8
Date of Analysis: 7/18/2017
Analyzed by: Ellen Davis

	Texture	Comments
		observed at 10x
Grain Size	50-600 µm, average grain size ~100 µm	
Rounding	subangular, subrounded	
Sorting	primarily well sorted	

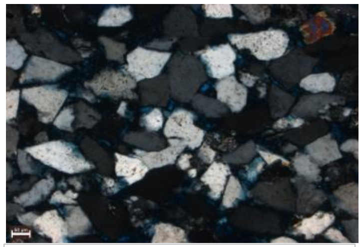
	Composition/Detrital Minerals	Comments
	Quartz	
Polycrystalline	·polycrystalline quartz present in larger grains	images LH-5-02_0003, 0009, 0010
Monocrystalline	~90% monocrystalline quartz ·smaller, subhedral grains with not much overgrowth	
Microcrystalline	grains can be easily observed under petroscope	
	XN: black, white, gray PPL: light brown	
	Feldspar	
Plagioclase	·albite twinning present	images LH-5-02_0002, 0004
Orthoclase	N/A	
Microcline	N/A	
	Carbonate	
Calcite	~<10% calcite ·subhedral grains	images LH-5-02_0006, 0008
	XN: brown, green, pink PPL: light brown	
Dolomite	N/A	
Aragonite	N/A	
	Clay	
Illite	N/A	
Smectite	N/A	
Kaolinite	N/A	
Muscovite	<5% muscovite ·small, subangular and subrounded grains	images LH-5-02_0005, 0007
	XN: blue, purple, orange PPL: gray-green	
Chlorite	N/A	
Glauconite	N/A	
	Rock Fragments	
Sedimentary	·some sedimentary rock fragments present	images LH-5-02_0001, 0014
Volcanic	N/A	
Metamorphic	N/A	
	Other (Accessory Minerals)	

	Cementing Materials	Comments
Quartz	·some intergrown quartz grains	
Feldspar		
Carbonate	·some calcite cementing	
Clay		
Iron Oxide, Hydoxide and/or Sulfide		
Other		

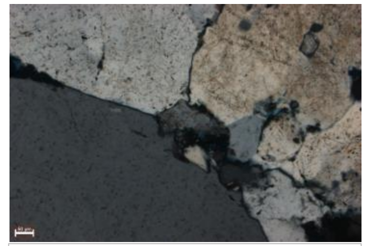
	Visual Porosity Estimate	Comments
	·visual porosity estimate is ~30%	images LH-5-02_0011 - LH-5-02_0015



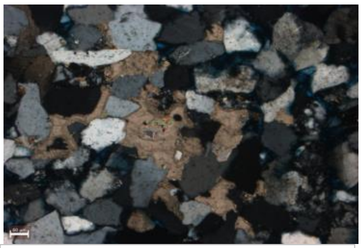
This image shows polycrystalline quartz grains.
(10x, XN)



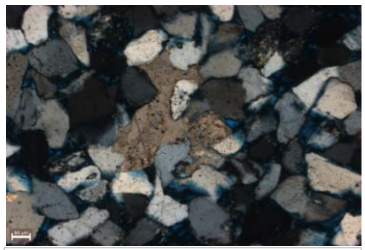
This image shows subrounded and subangular quartz grains with some intergrowth and some pore space visible. Colored muscovite can be seen in the top right corner as well.
(10x, XN)



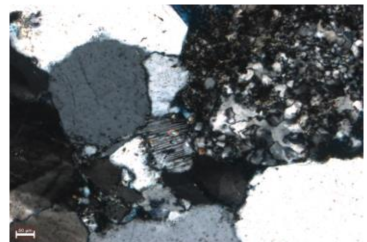
Larger quartz grains with some intergrowth are shown in this image.
(10x, XN)



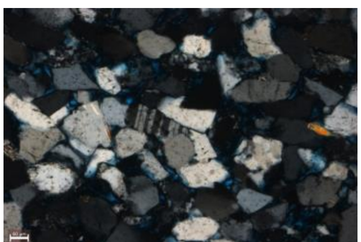
The quartz in this image is cemented by grains of anhedral calcite.
(10x, XN)



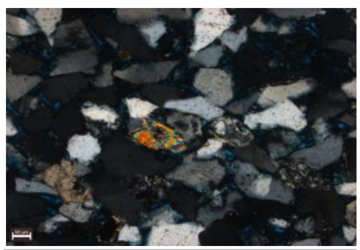
This image shows a grain of anhedral calcite surrounded by smaller, subhedral quartz grains.
(10x, XN)



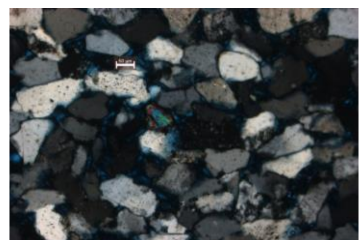
This image shows plagioclase feldspar with albite twinning. Some larger quartz grains and sedimentary rock fragments are present as well.
(10x, XN)



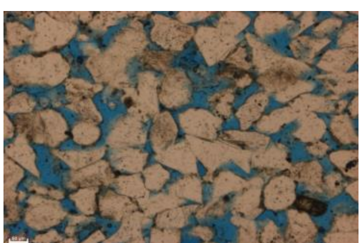
Plagioclase feldspar with albite twinning is shown in this image. Subrounded and subangular quartz grains surround the feldspar.
(10x, XN)



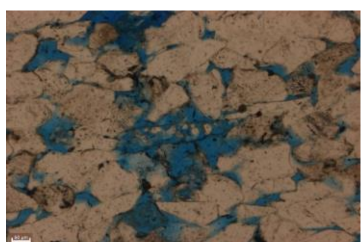
The brightly colored grain in this image is muscovite. The muscovite is surrounded by subangular quartz and some pore space can be seen.
(10x, XN)



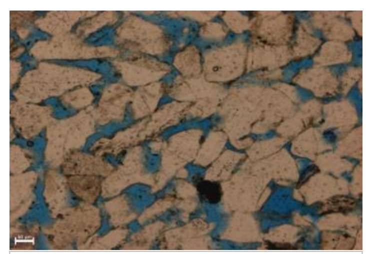
This image shows blue/green muscovite surrounded by subhedral quartz and pore space.
(10x, XN)



This image shows the pore space in the sample. The blue is the epoxy filling the pore space and the brown is the grains.
(10x, PPL)



The blue in this image shows the pore space in this sample.
(10x, PPL)



This image shows pore space in the sample.
(10x, PPL)

Thin Section Analysis Report

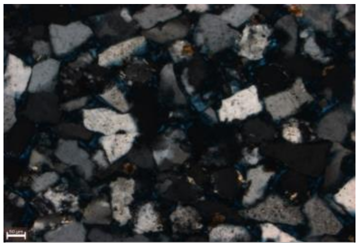
Sample ID:	LH-9-02
Formation/Member Name:	Gordon
Lithologic Classification:	Sandstone
Depth/Depth Range:	3141.40
Date of Analysis:	7/18/2017
Analyzed by:	Ellen Davis

	Texture	**Comments**
		observed at 10x
Grain Size	50-150 µm, average grain size ~100 µm	
Rounding	subangular, subrounded grains	
Sorting	well sorted	

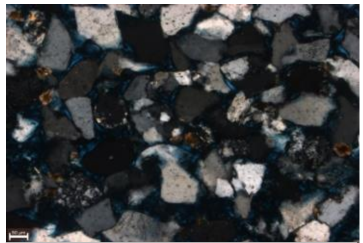
	Composition/Detrital Minerals	**Comments**
	Quartz	
Polycrystalline	·some polycrystalline quartz present	images LH-9-02_0009, 0010, 0012
Monocrystalline	~90% monocrystalline quartz ·smaller, subhedral grains	
Microcrystalline	grains can be easily observed under petroscope	
	XN: black, white, gray PPL: light brown	
	Feldspar	
Plagioclase	·albite twinning present	images LH-9-02_0002, 0004
Orthoclase	N/A	
Microcline	N/A	
	Carbonate	
Calcite	~10% calcite ·mostly subhedral grains	images LH-9-02_0003, 0005
	XN: brown, green, pink PPL: light brown	
Dolomite	N/A	
Aragonite	N/A	
	Clay	
Illite	N/A	
Smectite	N/A	
Kaolinite	N/A	
Muscovite	<5% muscovite ·small, subangular and subrounded grains	images LH-9-02_0001, 0008
	XN: blue, purple, orange PPL: gray-green	
Chlorite	N/A	
Glauconite	N/A	
	Rock Fragments	
Sedimentary	·sedimentary rock fragments present	images LH-9-02_0006, 0011
Volcanic	N/A	
Metamorphic	N/A	
	Other (Accessory Minerals)	
	some iron present	image LH-9-02_0007

	Cementing Materials	**Comments**
Quartz	·intergrown quartz grains	
Feldspar		
Carbonate	·some calcite cementing	
Clay		
Iron Oxide, Hydoxide and/or Sulfide		
Other		

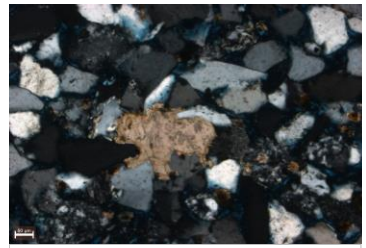
	Visual Porosity Estimate	**Comments**
	·visual porosity estimate is ~30%	images LH-9-02_0013 - LH-9-02_0016



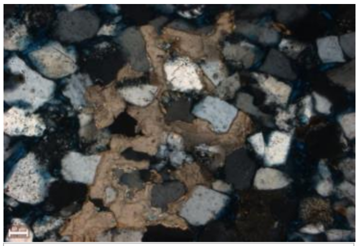
This image shows subangular and subrounded quartz grains with some pore space present as well.
(10x, XN)



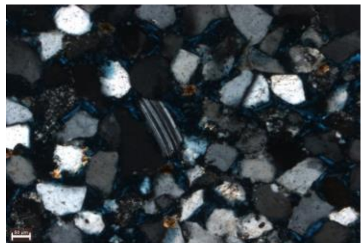
Subhedral quartz grains are shown in this image along with some polycrystalline quartz grains and sedimentary rock fragments.
(10x, XN)



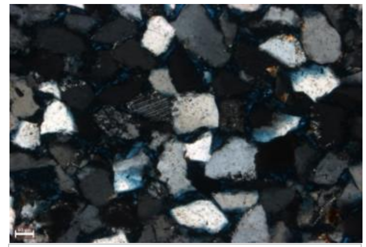
This image shows anhedral calcite and subhedral quartz grains.
(10x, XN)



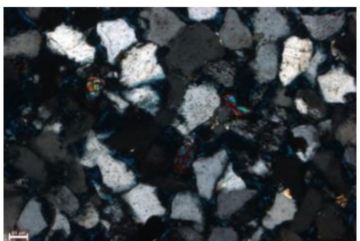
The subangular and subrounded quartz grains in this image are cemented by calcite grains.
(10x, XN)



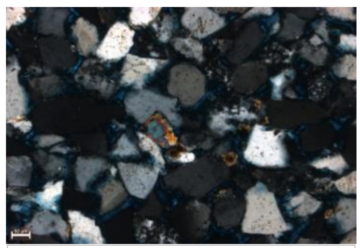
This image shows plagioclase feldspar with albite twinning. Some quartz grains and pore space is shown as well.



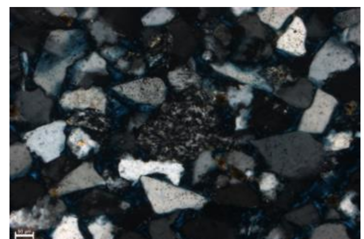
Plagioclase feldspar with albite twinning is surrounded by subhedral quartz grains in this image.
(10x, XN)



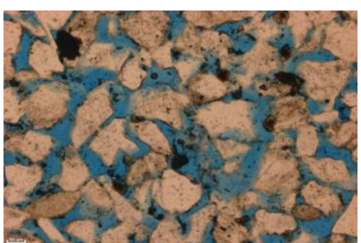
The three brightly colored grains in this image are subhedral muscovite grains. The muscovite is surrounded by quartz grains.
(10x, XN)



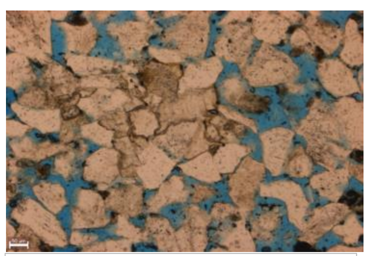
This image shows a colorful grain of muscovite and subhedral quartz grains.
(10x, XN)



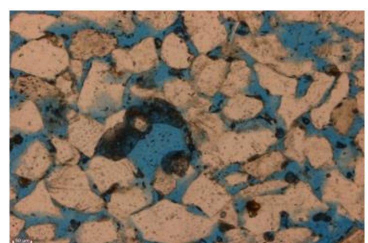
This image shows a sedimentary rock fragment surrounded by quartz grains and pore space.
(10x, XN)



This image shows the pore space present in the sample.
(10x, PPL)



The blue in this image is epoxy used to show pore space in a sample.
(10x, PPL)



This image shows the porosity of this sample.
(10x, PPL)

Thin Section Analysis Report

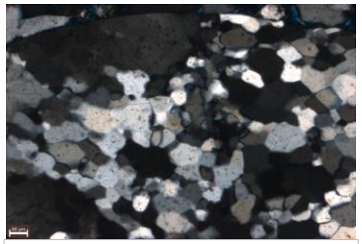
Sample ID: LH-11-02
Formation/Member Name: Gordon
Lithologic Classification: Sandstone
Depth/Depth Range: 3143.85
Date of Analysis: 7/18/2017
Analyzed by: Ellen Davis

Texture		Comments
		observed at 10x
Grain Size	50-150 µm, average grain size ~80 µm	
Rounding	subangular, subrounded grains	
Sorting	well sorted	

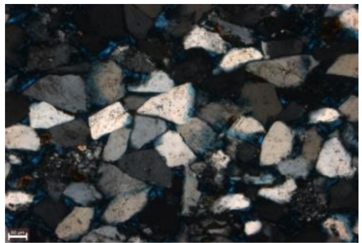
Composition/Detrital Minerals		Comments
Quartz		
Polycrystalline	·polycrystalline quartz present	images LH-11-02_0007, 0008, 0009
Monocrystalline	~90% monocrystalline quartz ·small, mostly subhedral grains	
Microcrystalline	grains can be easily observed under petroscope	
	XN: black, white, gray PPL: light brown	
Feldspar		
Plagioclase	·albite twinning present	images LH-11-02_0004, 0005
Orthoclase	N/A	
Microcline	N/A	
Carbonate		
Calcite	~10% calcite ·mostly subhedral, cementing grains	images LH-11-02_0002, 0006
	XN: brown, green, pink PPL: light brown	
Dolomite	N/A	
Aragonite	N/A	
Clay		
Illite	N/A	
Smectite	N/A	
Kaolinite	N/A	
Muscovite	<5% muscovite ·small, subhedral grains	images LH-11-02_0001, 0003
	XN: blue, purple, orange PPL: gray-green	
Chlorite	N/A	
Glauconite	N/A	
Rock Fragments		
Sedimentary	·sedimentary rock fragments present	images LH-11-02_0003, 0011
Volcanic	N/A	
Metamorphic	N/A	
Other (Accessory Minerals)		
	possibly iron present	image LH-11-02_0010

Cementing Materials		Comments
Quartz	·intergrown quartz grains	
Feldspar		
Carbonate	·some calcite cementing	
Clay		
Iron Oxide, Hydoxide and/or Sulfide		
Other		

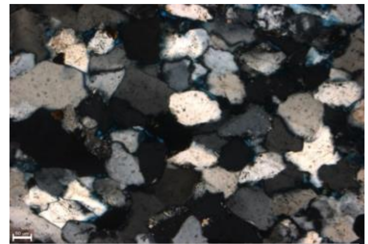
Visual Porosity Estimate	Comments
·visual porosity estimate is ~30%	images LH-11-02_0012 - LH-11-02_0015



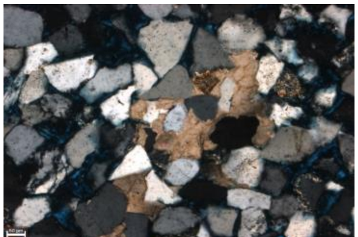
This image shows polycrystalline quartz.
(10x, XN)



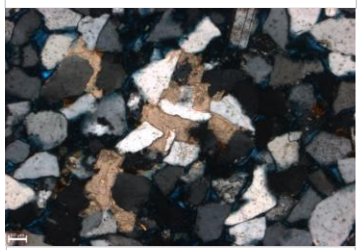
This image shows subangular and subrounded quartz grains with some pore space visible.
(10x, XN)



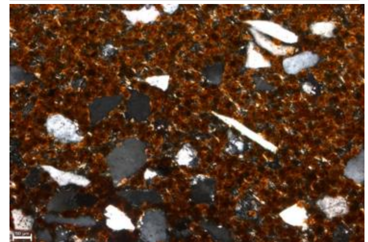
Subhedral quartz is shown in this image, some of which is intergrown.



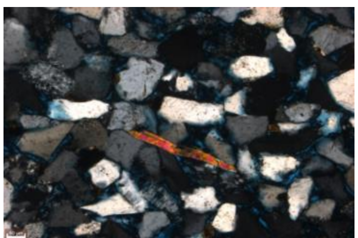
The subhedral quartz in this image is cemented by anhedral calcite.
(10x, XN)



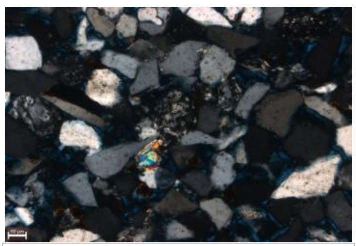
This image shows subhedral calcite along with quartz grains and some pore space.
(10x, XN)



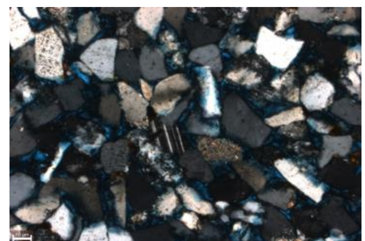
This image shows iron cementing subhedral quartz grains.
(10x, XN)



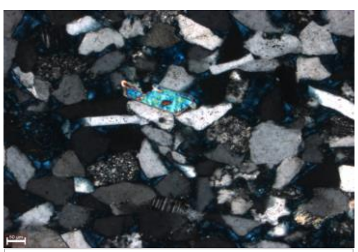
The elongated pink and orange grain in this image is muscovite. The muscovite is surrounded by subhedral quartz.
(10x, XN)



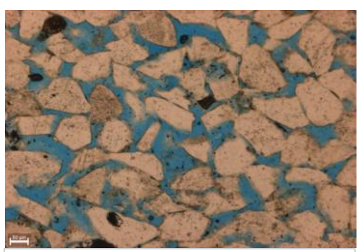
This image shows a grain of subhedral muscovite along with quartz grains, pore space, and sedimentary rock fragments.
(10x, XN)



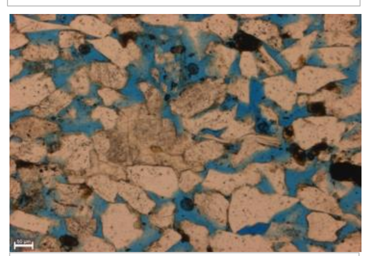
The albite twinning in this image shows the presence of plagioclase feldspar. The feldspar is surrounded by subhedral quartz grains and pore space.



This image shows plagioclase feldspar, a grain of muscovite, sedimentary rock fragments, and subhedral quartz grains.
(10x, XN)



The blue epoxy in this image shows the pore space in the sample.
(10x, PPL)



This image shows the porosity of the sample.
(10x, PPL)

Thin Section Analysis Report

Sample ID: LH-12-02
Formation/Member Name: Gordon
Lithologic Classification: Sandstone
Depth/Depth Range: 3145.25
Date of Analysis: 7/18/2017
Analyzed by: Ellen Davis

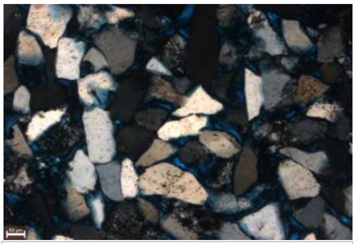
observed at 10x

	Texture	Comments
Grain Size	50-100 µm, average grain size ~80 µm	
Rounding	subangular, subrounded grains	
Sorting	well sorted	

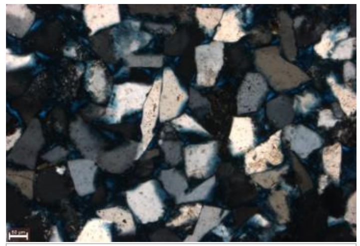
	Composition/Detrital Minerals	Comments
	Quartz	
Polycrystalline		images LH-12-02_0008, 0010
Monocrystalline	~90% monocrystalline quartz ·small, mostly subhedral grains ·not much intergrowth	
Microcrystalline	grains can be easily observed under petroscope	
	XN: black, white, gray PPL: light brown	
	Feldspar	
Plagioclase	·albite twinning present	images LH-12-02_0001, 0003
Orthoclase	N/A	
Microcline	N/A	
	Carbonate	
Calcite	~10% calcite ·mostly subhedral, cementing quartz grains	images LH-12-02_0002, 0004, 0011
	XN: brown, green, pink PPL: light brown	
Dolomite	N/A	
Aragonite	N/A	
	Clay	
Illite	N/A	
Smectite	N/A	
Kaolinite	N/A	
Muscovite	<5% muscovite ·small, subhedral grains	images LH-12-02_0005, 0007
	XN: blue, purple, orange PPL: gray-green	
Chlorite	N/A	
Glauconite	N/A	
	Rock Fragments	
Sedimentary	·sedimentary rock fragments present	images LH-12-02_0006, 0009
Volcanic	N/A	
Metamorphic	N/A	
	Other (Accessory Minerals)	

	Cementing Materials	Comments
Quartz	·some intergrown quartz is present	
Feldspar		
Carbonate	·some calcite cementing	
Clay		
Iron Oxide, Hydoxide and/or Sulfide		
Other		

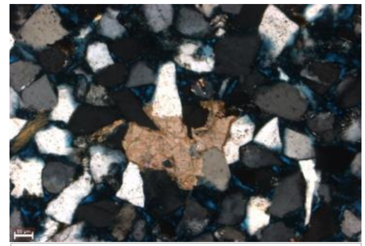
	Visual Porosity Estimate	Comments
	·visual porosity estimate is ~25%	images LH-12-02_0012 - LH-12-02_0015



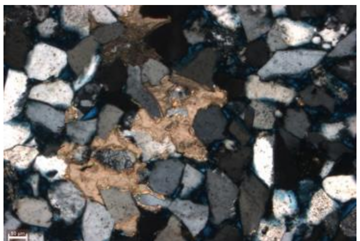
This image shows subhedral quartz grains, some intergrown. Pore space is also shown by blue epoxy.
(10x, XN)



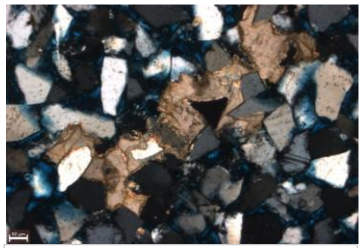
Subangular and subrounded quartz grains are shown in this image.
(10x, XN)



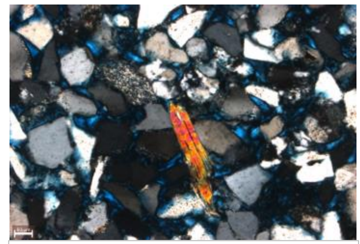
The calcite in this image is surrounded by subhedral quartz grains.
(10x, XN)



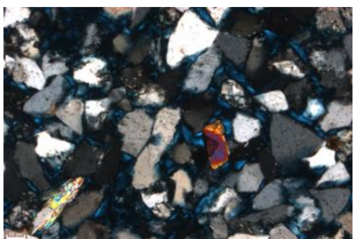
This image shows calcite cementing smaller quartz grains and sedimentary rock fragments.
(10x, XN)



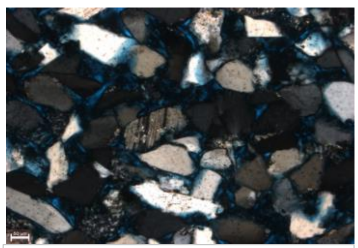
Subangular calcite cements quartz grains in this image. Blue epoxy shows pore space here as well.
(10x, XN)



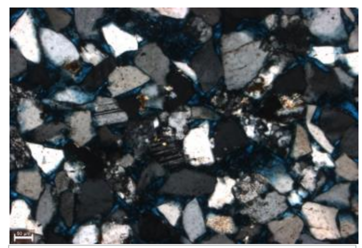
This image shows an elongated piece of birefringent muscovite along with some quartz grains and sedimentary rock fragments.
(10x, XN)



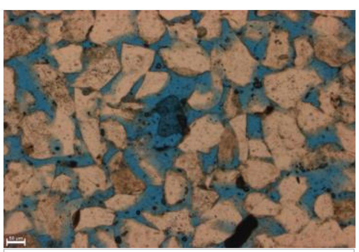
The subhedral, birefringent grains in this image are muscovite, surrounded by pore space and quartz grains.
(10x, XN)



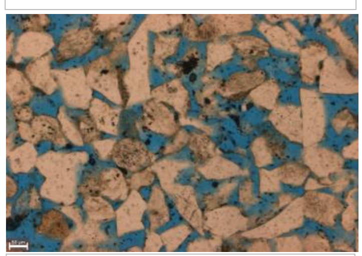
This image shows plagioclase feldspar with albite twinning. Subhedral quartz grains and sedimentary rock fragments surround the feldspar.
(10x, XN)



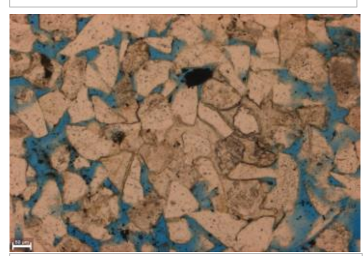
Two grains of plagioclase feldspar, sedimentary rock fragments, and subhedral quartz grains are shown in this image.
(10x, XN)



This image shows the porosity of the sample.
(10x, PPL)



The blue epoxy shows the pore space in this sample.
(10x, PPL)



This image shows the porosity of the sample. The light-brown, subangular grains are surrounded by blue epoxy.
(10x, PPL)

Thin Section Analysis Report

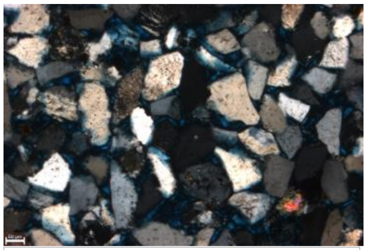
Sample ID:	LH-15-02
Formation/Member Name:	Gordon
Lithologic Classification:	Sandstone
Depth/Depth Range:	3148.00
Date of Analysis:	7/19/2017
Analyzed by:	Ellen Davis

	Texture	Comments
		observed at 10x
Grain Size	50-200 µm, average grain size ~80 µm	
Rounding	subangular, subrounded grains	
Sorting	well sorted	

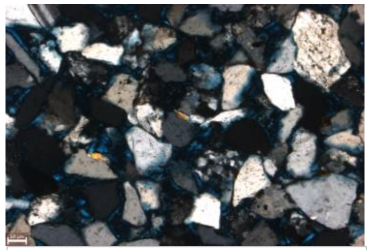
	Composition/Detrital Minerals	Comments
	Quartz	
Polycrystalline		images LH-15-02_0007, 0012
Monocrystalline	~90% monocrystalline quartz ·small, mostly subhedral grains	
Microcrystalline	grains can be easily observed under petroscope	
	XN: black, white, gray PPL: light brown	
	Feldspar	
Plagioclase	~3% feldspar ·albite twinning present	images LH-15-02_0001, 0009, 0010
Orthoclase	N/A	
Microcline	N/A	
	Carbonate	
Calcite	~10% calcite ·subhedral, cementing quartz	images LH-15-02_0002, 0003, 0005
	XN: brown, green, pink PPL: light brown	
Dolomite	N/A	
Aragonite	N/A	
	Clay	
Illite	N/A	
Smectite	N/A	
Kaolinite	N/A	
Muscovite	~3% muscovite ·small, elongated grains	images LH-15-02_0006, 0008, 0010
	XN: blue, purple, orange PPL: gray-green	
Chlorite	N/A	
Glauconite	N/A	
	Rock Fragments	
Sedimentary	·sedimentary rock fragments present	image LH-15-02_0004
Volcanic	N/A	
Metamorphic	N/A	
	Other (Accessory Minerals)	

	Cementing Materials	Comments
Quartz	·some intergrown quartz is present	
Feldspar		
Carbonate	·some calcite cementing	
Clay		
Iron Oxide, Hydoxide and/or Sulfide		
Other		

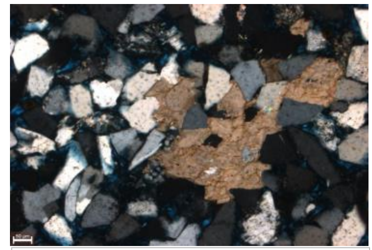
Visual Porosity Estimate	Comments
·visual porosity estimate is ~20%	images LH-15-02_0013 - LH-15-02_0016



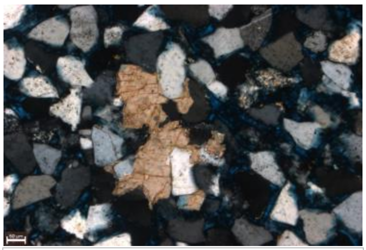
This image shows subangular quartz grains and pore space.
(10x, XN)



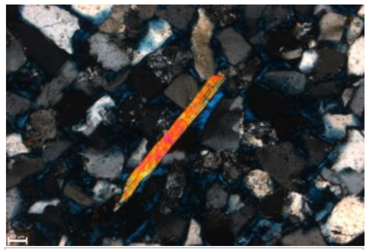
This image shows quartz grains of different sizes. Some sedimentary rock fragments are shown as well.
(10x, XN)



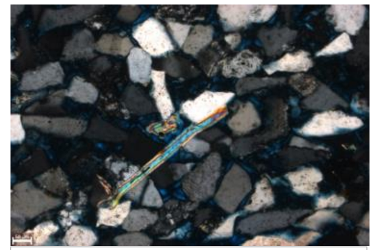
This image shows subangular calcite surrounded by subhedral quartz grains.
(10x, XN)



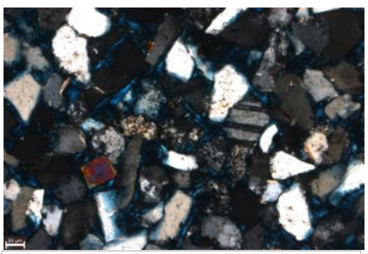
The calcite in this image cements quartz grains.
(10x, XN)



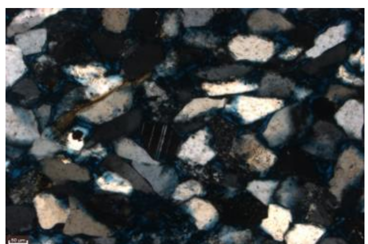
This image shows an elongated grain of birefringent muscovite.
(10x, XN)



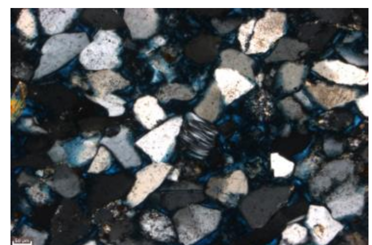
The bright blue grains in this image are muscovite. These grains of muscovite are surrounded by quartz grains.
(10x, XN)



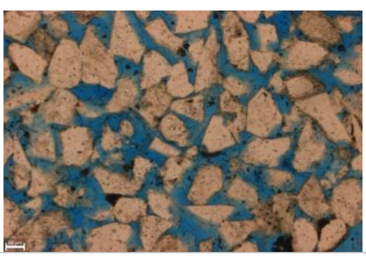
This image shows a grain of birefringent muscovite, a grain of subhedral plagioclase feldspar, and some sedimentary rock fragments.
(10x, XN)



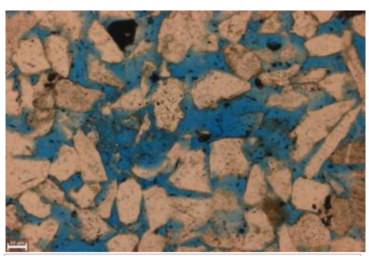
The albite twinning in this image shows plagioclase feldspar surrounded by subhedral quartz grains.
(10x, XN)



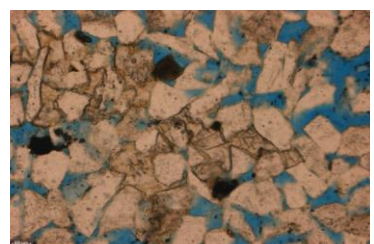
This image shows quartz grains, plagioclase feldspar, sedimentary rock fragments, and birefringent muscovite.
(10x, XN)



The blue epoxy in this image shows the pore space of the sample.
(10x, PPL)



This image shows the porosity of the sample.
(10x, PPL)



The subhedral grains in this image is shown with blue epoxy filling the pore space.
(10x, PPL)

Thin Section Analysis Report

Sample ID: LH-17-02
Formation/Member Name: Gordon
Lithologic Classification: Sandstone
Depth/Depth Range: 3151.90
Date of Analysis: 7/19/2017
Analyzed by: Ellen Davis

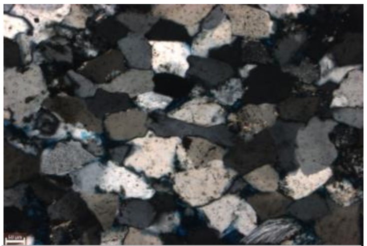
observed at 10x

	Texture	Comments
Grain Size	50-200 µm, average grain size ~100 µm	
Rounding	subangular, subrounded grains	
Sorting	well sorted	

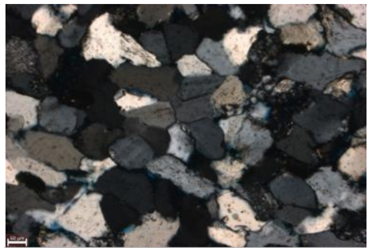
	Composition/Detrital Minerals	Comments
	Quartz	
Polycrystalline	·some polycrystalline quartz present	images LH-17-02_0003, 0007
Monocrystalline	~95% monocrystalline quartz ·small, mostly subhedral grains	
Microcrystalline	grains can be easily observed under petroscope	
	XN: black, white, gray PPL: light brown	
	Feldspar	
Plagioclase	·albite twinning present	images LH-17-02_0001, 0005
Orthoclase	N/A	
Microcline	N/A	
	Carbonate	
Calcite	·almost no calcite	
Dolomite	N/A	
Aragonite	N/A	
	Clay	
Illite	N/A	
Smectite	N/A	
Kaolinite	N/A	
Muscovite	<5% muscovite ·small, subhedral grains	images LH-17-02_0002, 0004, 0006
	XN: blue, purple, orange PPL: gray-green	
Chlorite	N/A	
Glauconite	N/A	
	Rock Fragments	
Sedimentary	·sedimentary rock fragments present	images LH-17-02_0008, 0013
Volcanic	N/A	
Metamorphic	N/A	
	Other (Accessory Minerals)	
	some iron present	

	Cementing Materials	Comments
Quartz	·cementing is primarily intergrown quartz	
Feldspar		
Carbonate		
Clay		
Iron Oxide, Hydoxide and/or Sulfide		
Other		

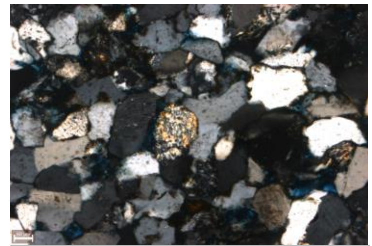
Visual Porosity Estimate	Comments
·visual porosity estimate is ~8%	images LH-17-02_0009 - LH-17-02_0012



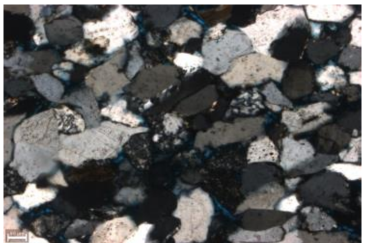
This image shows intergrown quartz grains.
(10x, XN)



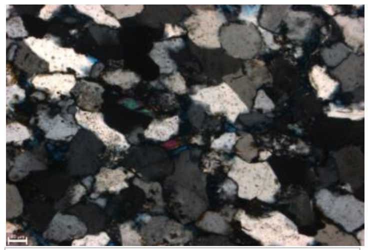
The subhedral quartz grains in this image are intergrown. Some sedimentary rock fragments are also shown.
(10x, XN)



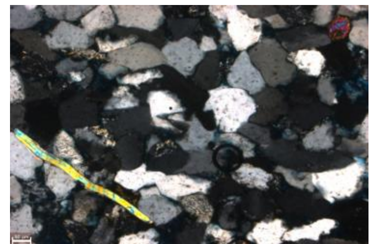
This image shows a sedimentary rock fragment with iron present in the grain. Intergrown quartz grains surround the sedimentary rock fragment.
(10x, XN)



Sedimentary rock fragments are cemented in grains of intergrown quartz.
(10x, XN)

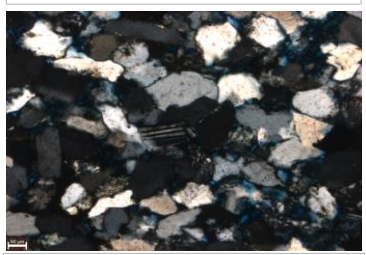


The colorful muscovite grains in this image are surrounded by subhedral intergrown quartz grains.
(10x, XN)

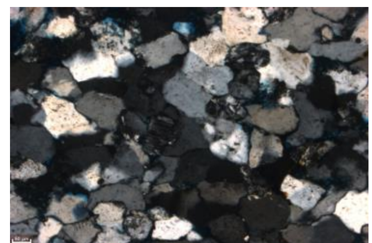


This image shows two grains of birefringent muscovite: one elongated and one subrounded.
(10x, XN)

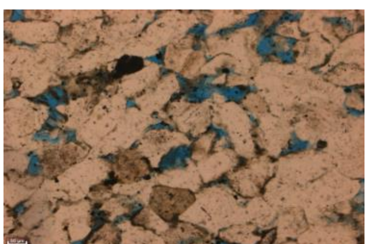
Two grains of birefringent muscovite are embedded in a matrix of intergrown quartz.
(10x, XN)



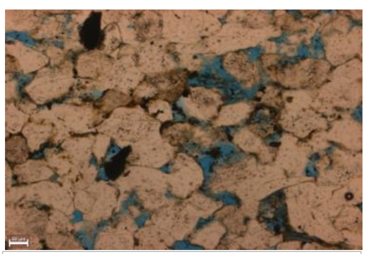
This image shows plagioclase feldspar with albite twinning surrounded by intergrown quartz grains.
(10x, XN)



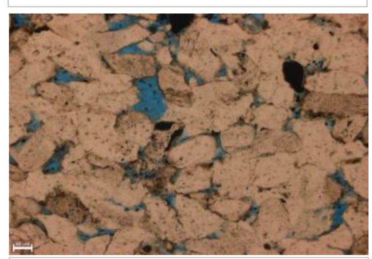
Although slightly difficult to see, this image shows plagioclase feldspar. Intergrown quartz and sedimentary rock fragments are also present in this image.
(10x, XN)



This image shows the porosity of the sample.
(10x, PPL)



Blue epoxy in this image shows the pore space in this sample.
(10x, PPL)



The pore space in these subhedral grains is filled by blue epoxy.
(10x, PPL)

Thin Section Analysis Report

Sample ID: LH-20-02
Formation/Member Name: Gordon
Lithologic Classification: Sandstone
Depth/Depth Range: 3158.30
Date of Analysis: 7/19/2017
Analyzed by: Ellen Davis

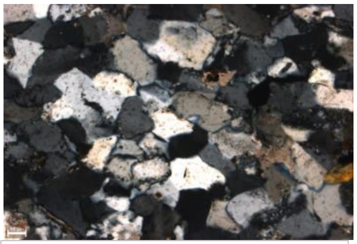
observed at 10x

	Texture	Comments
Grain Size	50-250 µm, average grain size ~150 µm	
Rounding	subangular, subrounded grains	
Sorting	well sorted	

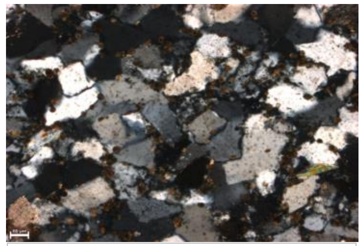
	Composition/Detrital Minerals	Comments
	Quartz	
Polycrystalline		images LH-20-02_0005, 0008, 0009
Monocrystalline	~60% monocrystalline quartz ·subhedral grains ·abundant intergrowth	
Microcrystalline	grains can be easily observed under petroscope	
	XN: black, white, gray PPL: light brown	
	Feldspar	
Plagioclase	·albite twinning present ·small, subhedral grains	images LH-20-02_0001, 0003, 0007
Orthoclase	N/A	
Microcline	N/A	
	Carbonate	
Calcite	~40% calcite ·calcite mostly cementing smaller quartz grains	images LH-20-02_0004, 0009, 0010
Dolomite	N/A	
Aragonite	N/A	
	Clay	
Illite	N/A	
Smectite	N/A	
Kaolinite	N/A	
Muscovite	<5% muscovite ·small, subhedral grains	images LH-20-02_0002, 0006
	XN: blue, purple, orange PPL: gray-green	
Chlorite	N/A	
Glauconite	N/A	
	Rock Fragments	
Sedimentary	·sedimentary rock fragments present	
Volcanic	N/A	
Metamorphic	N/A	
	Other (Accessory Minerals)	
	iron present	

	Cementing Materials	Comments
Quartz	·some intergrown quartz cementing	
Feldspar		
Carbonate	·primarily calcite cementing	
Clay		
Iron Oxide, Hydoxide and/or Sulfide		
Other		

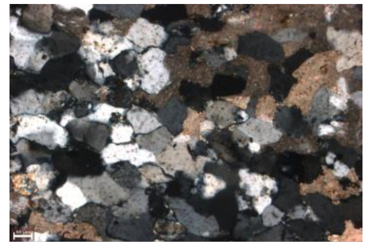
Visual Porosity Estimate	Comments
·visual porosity estimate is ~3%	images LH-20-02_0011 - LH-20-02_0014



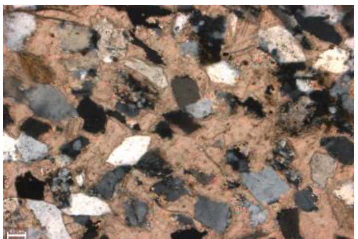
This image shows intergrown, subhedral quartz grains.
(10x, XN)



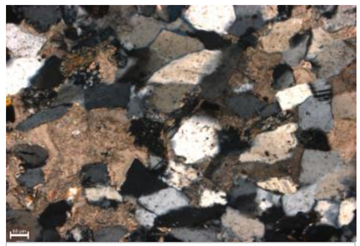
Intergrown quartz grains in this image are covered with iron.
(10x, XN)



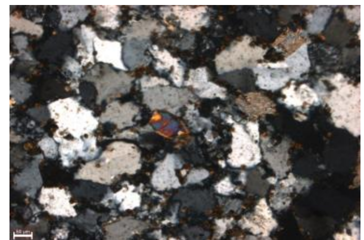
Quartz grains in this image are cemented by calcite. Some polycrystalline quartz is present as well.
(10x, XN)



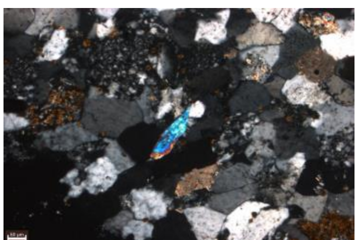
This image shows quartz grains cemented by calcite.
(10x, XN)



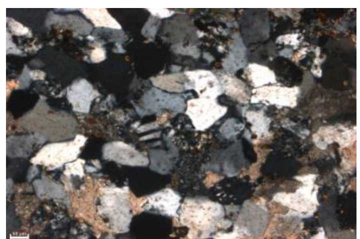
Calcite in this image surrounds intergrown quartz grains and sedimentary rock fragments.
(10x, XN)



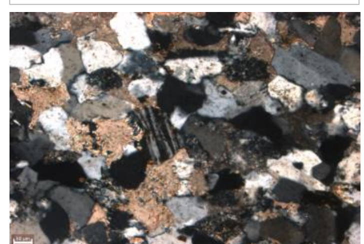
This image shows a grain of subrounded muscovite in a matrix of intergrown quartz.
(10x, XN)



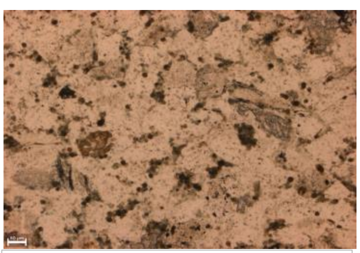
This elongated grain of birefringent muscovite is surrounded by sedimentary rock fragments and intergrown quartz.
(10x, XN)



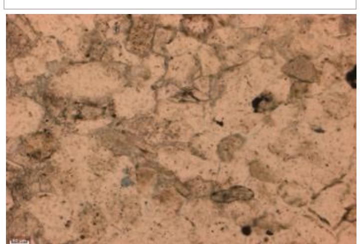
This image shows a subhedral grain of plagioclase feldspar. Sedimentary rock fragments, calcite grains, and intergrown quartz are also shown here.
(10x, XN)



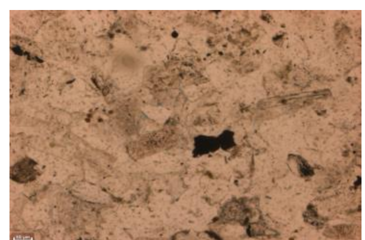
The plagioclase feldspar in this image shows albite twinning surrounded by clacite and intergrown quartz.
(10x, XN)



This image shows the porosity of the sample.
(10x, PPL)



There is hardly any blue epoxy in this image but the blue epoxy that is visible shows the pore space in the sample.
(10x, PPL)



This image shows the porosity of this sample.
(10x, PPL)

Thin Section Analysis Report

Sample ID:	LW-1
Formation/Member Name:	Oriskany
Lithologic Classification:	Calcareous Sandstone
Depth/Depth Range:	6963.1 ft
Date of Analysis:	6/27/2017
Analyzed by:	S. Shank

Texture		**Comments**
Grain Size	very fine to fine-grained	scattered, uncommon rounded medium to coarse sand grains
Rounding	rounded to angular	
Sorting	moderate	

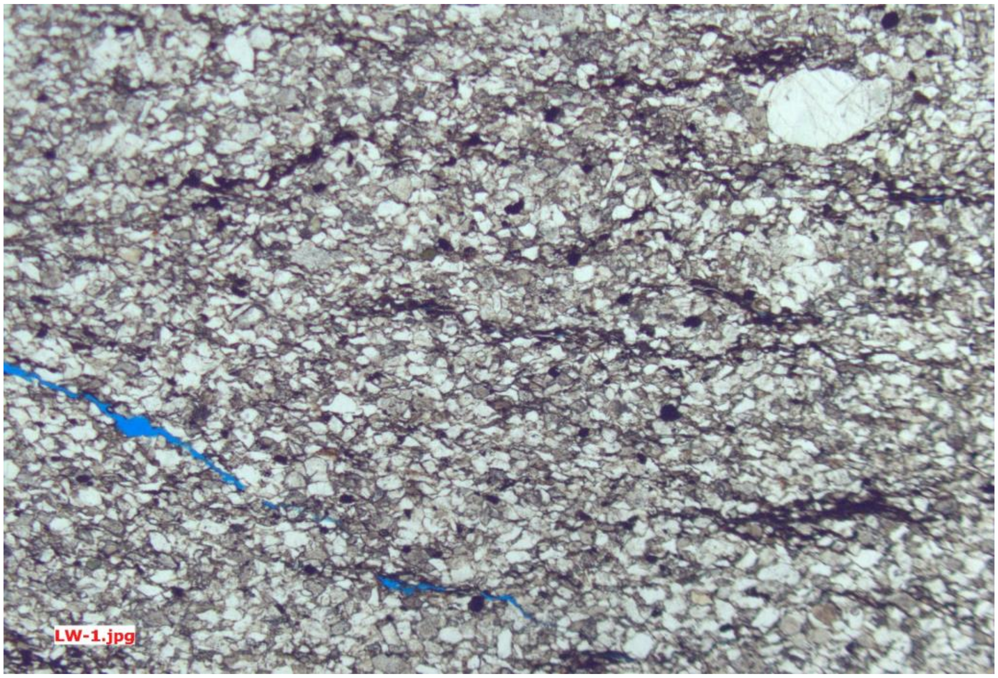
Composition/Detrital Minerals		**Comments**
Quartz		
Polycrystalline	<1%	
Monocrystalline	65%	
Microcrystalline		
Feldspar		
Plagioclase		
Orthoclase		
Microcline	2%	total feldspar
Carbonate		
Calcite	<1%	few fossil fragments - brachiopods
Dolomite		
Aragonite		
Clay		
Illite		
Smectite		
Kaolinite		
Muscovite		
Chlorite		
Glauconite		
Rock Fragments		
Sedimentary		
Volcanic		
Metamorphic		
Other (Accessory Minerals)		
	tourmaline	
	opaques	
	5%	thin discontinuous laminae of unidentified red-brown clay/hematite mix?

Cementing Materials		**Comments**
Quartz		
Feldspar		
Carbonate	28%	
Clay		
Iron Oxide, Hydoxide and/or Sulfide		
Other		

Visual Porosity Estimate		**Comments**
	<1%	no intergranular porosity, few thin fractures - sometimes parallel to laminae

LW-1

25x magnification, 5mm field of view



Thin Section Analysis Report

Sample ID:	LW-2
Formation/Member Name:	Oriskany
Lithologic Classification:	Sandy Limestone
Depth/Depth Range:	6985 ft
Date of Analysis:	6/27/2017
Analyzed by:	S. Shank

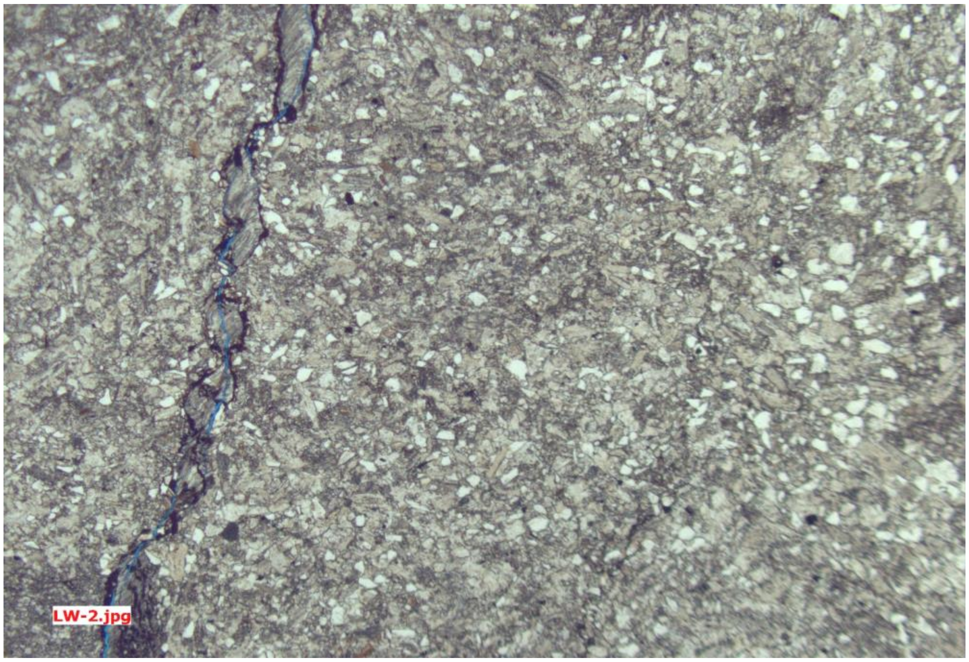
Texture		**Comments**
Grain Size	very fine to fine-grained	
Rounding	rounded to angular	
Sorting	moderate to well sorted	

Composition/Detrital Minerals		**Comments**
Quartz		
Polycrystalline	<1%	
Monocrystalline	15%	scattered, matrix supported
Microcrystalline		
Feldspar		
Plagioclase		
Orthoclase		
Microcline	<1%	total feldspar
Carbonate		
Calcite	80%	highly variable, patchy distribution of fine-grained calcite and coarser=recrystallized calcite, scattered fossil brachiopod fragments
Dolomite		
Aragonite		
Clay		
Illite		
Smectite		
Kaolinite		
Muscovite		
Chlorite		
Glauconite		
Rock Fragments		
Sedimentary		
Volcanic		
Metamorphic		
Other (Accessory Minerals)		
	5%	thin discontinuous laminae of unidentified red-brown clay/hematite mix?

Cementing Materials		**Comments**
Quartz		
Feldspar		
Carbonate		
Clay		
Iron Oxide, Hydoxide and/or Sulfide	5%	secondary, thin discontinuous, wavy laminae of unidentified red-brown clay/hematite mix?
Other		

Visual Porosity Estimate		**Comments**
	<1%	no intergranular porosity, few thin fractures - sometimes parallel to laminae

25x magnification, 5mm field of view



Thin Section Analysis Report

Sample ID: LW-3
Formation/Member Name: Oriskany
Lithologic Classification: Calcareous Sandstone
Depth/Depth Range: 6988.7 ft
Date of Analysis: 6/27/2017
Analyzed by: S. Shank

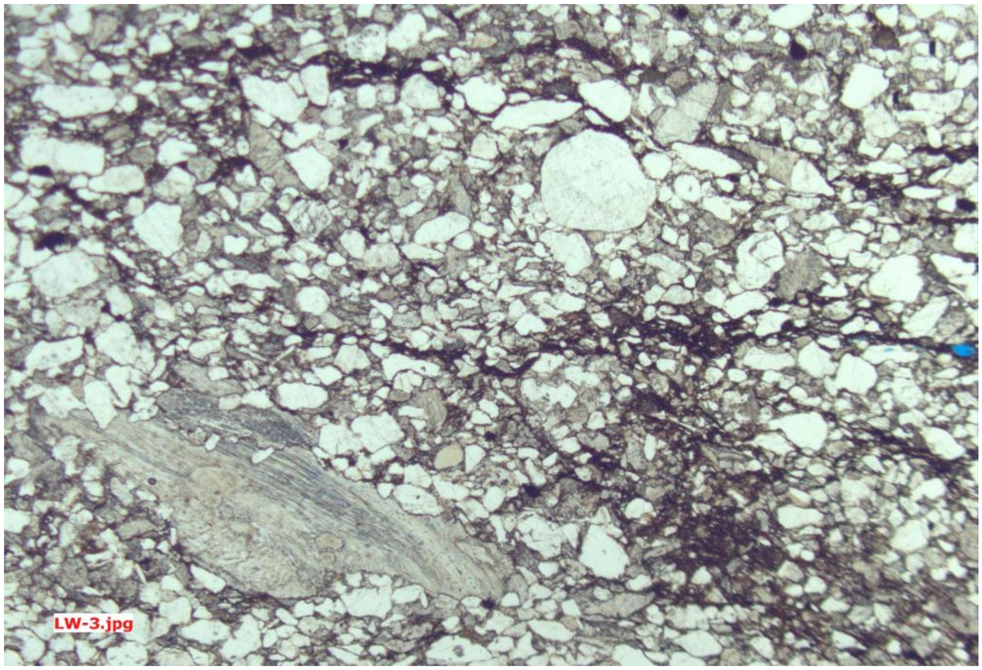
Texture		Comments
Grain Size	very fine to fine-grained	scattered, uncommon rounded medium sand grains
Rounding	rounded to angular	
Sorting	moderate	

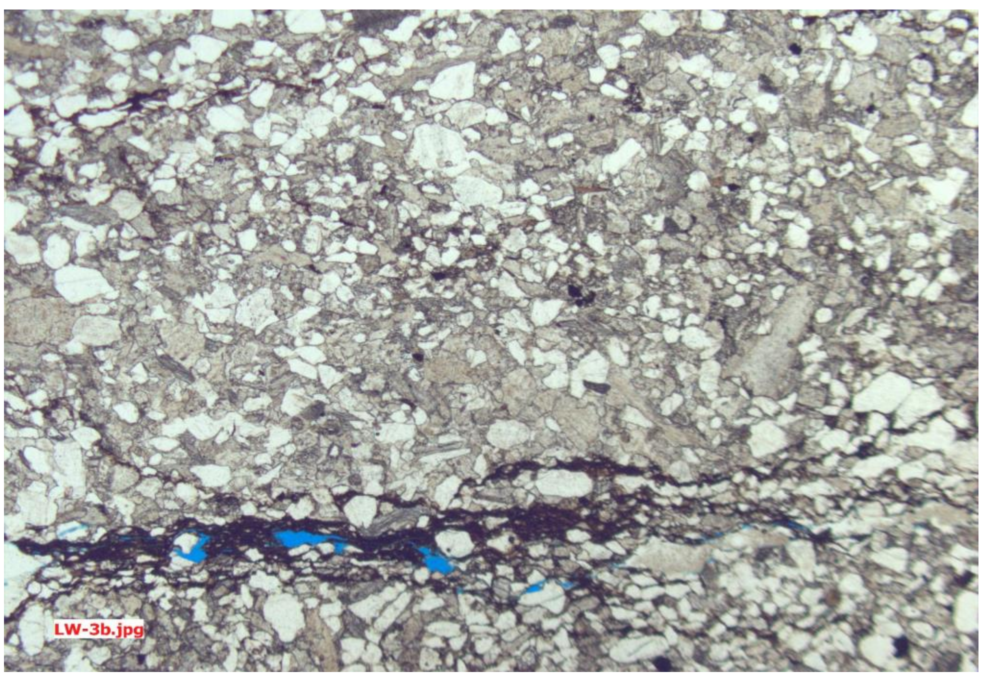
Composition/Detrital Minerals		Comments
Quartz		
Polycrystalline	<1%	
Monocrystalline	48%	
Microcrystalline		
Feldspar		
Plagioclase		
Orthoclase		
Microcline	2%	total feldspar
Carbonate		
Calcite	45%	fine-grained to coarse crystalline, few fossil fragments - brachiopods?
Dolomite		
Aragonite		
Clay		
Illite		
Smectite		
Kaolinite		
Muscovite		
Chlorite		
Glauconite		
Rock Fragments		
Sedimentary		
Volcanic		
Metamorphic		
Other (Accessory Minerals)		
	tourmaline	
	opaques	
	5%	thin discontinuous laminae of unidentified red-brown clay/hematite mix?

Cementing Materials		Comments
Quartz		
Feldspar		
Carbonate		
Clay		
Iron Oxide, Hydoxide and/or Sulfide		
Other		

Visual Porosity Estimate		Comments
	<1%	no intergranular porosity, some porosity associated with laminae

25x magnification, 5mm field of view





Thin Section Analysis Report

Sample ID:	WD-11	4710701266
Formation/Member Name:	Oriskany Sandstone Wood County, WV	
Lithologic Classification:	Sandstone	
Depth/Depth Range:	4225 ft	Observed @ 10x
Date of Analysis:	6/1/2017	
Analyzed by:	Eric Hirschfeld	

	Texture	**Comments**
Grain Size	avg size 250 microns	Clastic
Rounding	subangular-subrounded	Inequigranular
Sorting	moderate- well-sorted	

	Composition/Detrital Minerals	**Comments**
	Quartz	
Polycrystalline	n/a	
	95% composition;predominantly undulose quartz; high relief; intergrown and deformed quartz grains; XN: black/white, PL: transparent	Figure 11.1 through Figure 11.6
Monocrystalline		
Microcrystalline	grains are easily observed via petroscope	
	Feldspar	
Plagioclase	<1% composition; albite twinning, subhedral-anhedral; XN: black/white, PL: transparent; subangular grains.	Figure 11.1 and Figure 11.2
Orthoclase	n/a	
Microcline	n/a	
	Carbonate	
Calcite	subangular fragments; 5% composition; some grains elognated, some slightly globular; XPL: tan-pink, PPL: transparent	Figure 11.1 through Figure 11.6
Dolomite	n/a	
Aragonite	n/a	
	Clay	
Illite	n/a	
Smectite	n/a	
Kaolinite	n/a	
Muscovite	small oblate grains; <1% composition; subhedral; high birefringence, <1% composition; XN: green, pink, blue,orange, PL: transparent	no figure
Chlorite	n/a	
Glauconite	n/a	
	Rock Fragments	
Sedimentary	Predominantly consisted of detrital sedimentary fragments	
Volcanic	possible volcanic fragments present	
Metamorphic		
	Other (Accessory Minerals)	

	Cementing Materials	**Comments**
Quartz	quartz intergrowth apply cementing	Figure 11.1 through Figure 11.6
Feldspar	n/a	
Carbonate	Calcite present and fills in spacing between quartz grains	Figure 11.1 through Figure 11.6
Clay	n/a	
Iron Oxide, Hydoxide and/or Sulfide	n/a	
Other	n/a	

	Visual Porosity Estimate	**Comments**
Visual Porosity Estimate of total thin section	Porosity= 11%	Figure 11.7 through Figure 11.11

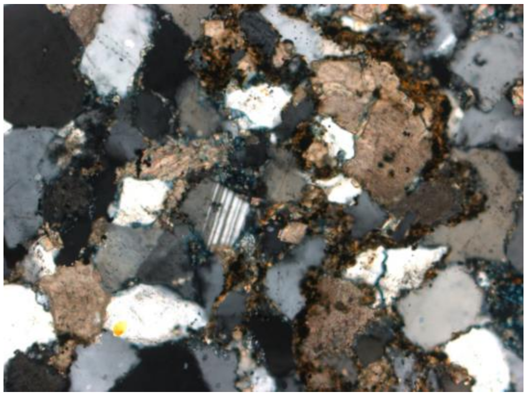


Figure 11.1 Observed at 10x magnification. In XN, intergrown , anhedral and deformed quartz and calcite grains. Also present is a small piece of plagioclase.

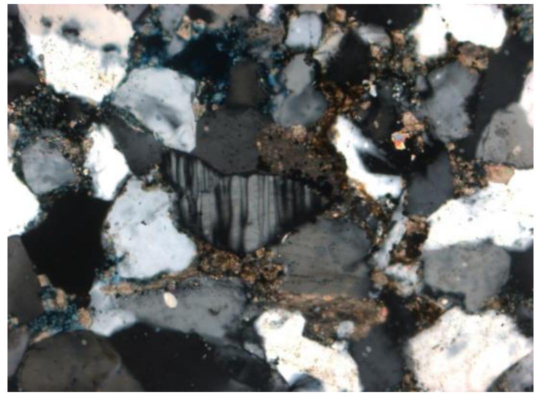


Figure 11.2 Observed at 10x magnification. In XN, anhedral quartz grain with intergrown calcite cementing material. Also present is a anhedral grain of plagioclase exhibiting albite twinning.

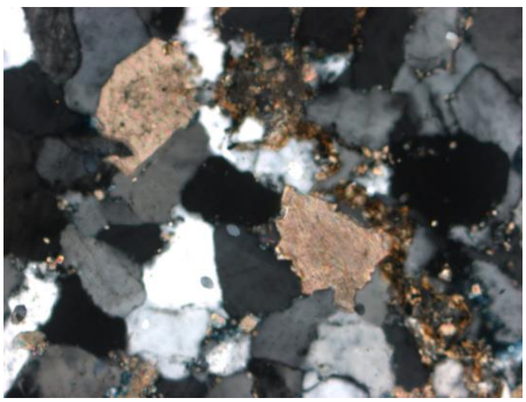


Figure 11.3 Observed at 10x magnification. In XN, anhedral to subhedral, quartz grains with subhedral calcite grains and intergrown calcareous cementing material

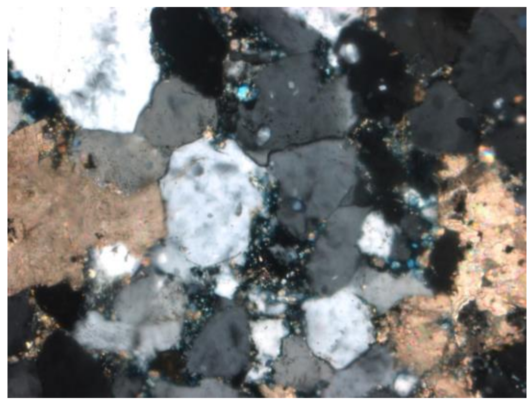


Figure 11.4 Observed at 10x magnification. In XN, subhedral quartz grains grown with anhedral and slightly deformed calcite grains and calcareous cementing material.

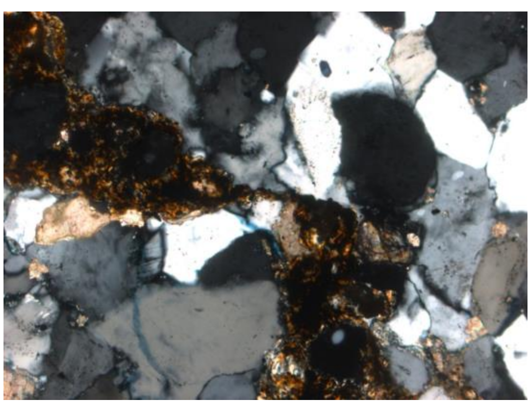


Figure 11.5 Observed at 10x magnification. In XN, interspersed, subhedral to anhedral unduloose quartz grains that are cement calcareous cementing material

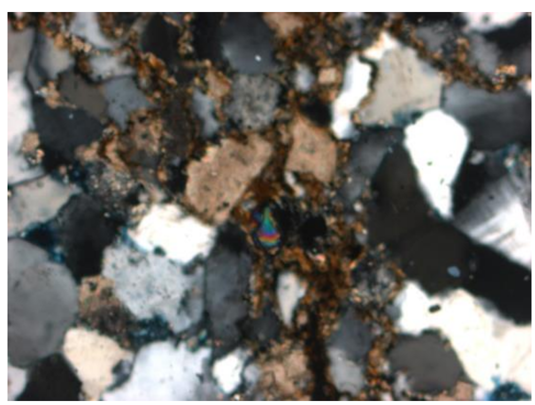


Figure 11.6 Observed at 10x magnification. In XN, subhedral undulose quartz grains overgrown and cemented with calcareous material and calcite in between.

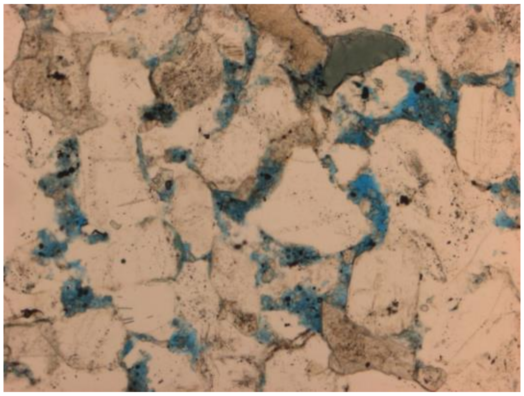


Figure 11.7 Observed at 10x magnification. In PL, the blue dye represents the open pore spaces in the thin section, estimating about 11% porous overall.

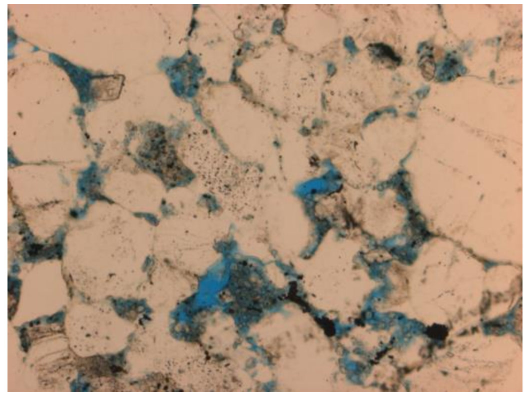


Figure 11.8 Observed at 10x magnification. In PL, the blue dye represents the open pore spaces in the thin section, estimating about 11% porous overall.

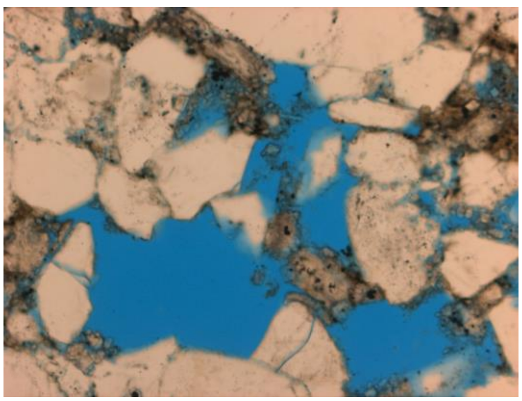


Figure 11.9 Observed at 10x magnification. In PL, the blue dye represents the open pore spaces in the thin section, estimating about 11% porous overall.

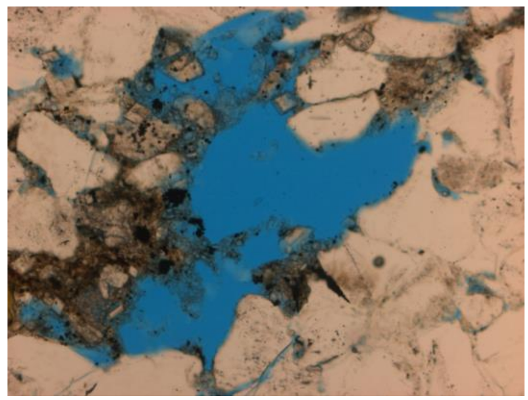


Figure 11.10 Observed at 10x magnification. In PL, the blue dye represents the open pore spaces in the thin section, estimating about 11% porous overall.

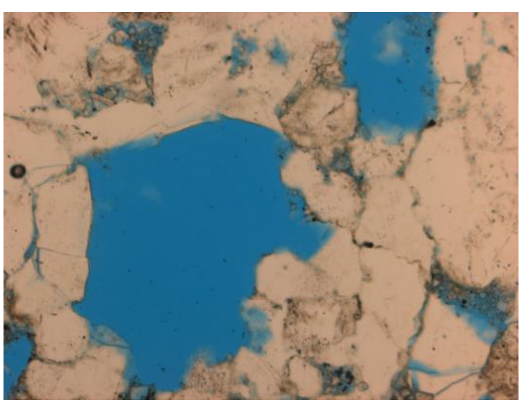


Figure 11.11 Observed at 10x magnification. In PL, the blue dye represents the open pore spaces in the thin section, estimating about 11% porous overall.

Thin Section Analysis Report

Sample ID:	WD-10	4710701266
Formation/Member Name:	Oriskany Sandstone Wood County, WV	
Lithologic Classification:	Sandstone	
Depth/Depth Range:	4222.5 ft	Observed @ 10x
Date of Analysis:	6/2/2017	
Analyzed by:	Eric Hirschfeld	

	Texture	Comments
Grain Size	average grain size is approx 0.5 mm or less	non-homogeneous, Clastic,
Rounding	subangular- subrounded	
Sorting	moderately sorted	

	Composition/Detrital Minerals	Comments
	Quartz	
Polycrystalline	n/a	
Monocrystalline	75% composition; deformed grains; subhedral; evidence of quartz overgrowth	Figure 10.1 through Figure 10.6
Microcrystalline	grains are easily observed via petroscope	
	Feldspar	
Plagioclase	1% or less of composition; albite twinning; subangular; XN: black/white, PL: transparent	no figure
Orthoclase		
Microcline		
	Carbonate	
Calcite	24% composition; massive, globular grains; scattered smaller subangular grains; some lamellar twinning is present; XN: tan/pink, PL: transparent	Figure 10.2 through Figure 10.4, Figure 10.6
Dolomite	n/a	
Aragonite	n/a	
	Clay	
Illite	n/a	
Smectite	n/a	
Kaolinite	n/a	
Muscovite	1% or less composition; high birefringence, rounded oblate grains; XN: pink, blue, green, orange PL: transparent	Figure 10.5
Chlorite	n/a	
Glauconite	n/a	
	Rock Fragments	
Sedimentary	Detrital sedimentary fragments is predominant	
Volcanic	miniscule amount of volcanic fragments	
Metamorphic		
	Other (Accessory Minerals)	

	Cementing Materials	Comments
Quartz	Quartz overgrowth acts as a cememnting material for grains; well cemented	Figure 10.1, Figure 10.3, Figure 10.5
Feldspar	n/a	
Carbonate	Clcite fills in pores between grains as globular cement; moderately cemented	Figure 10.4 and Figure 10.6
Clay	n/a	
Iron Oxide, Hydoxide and/or Sulfide	n/a	
Other	n/a	

	Visual Porosity Estimate	Comments
Visual Porosity Estimate	10% porosity	Figure 10.7 through Figure 10.11

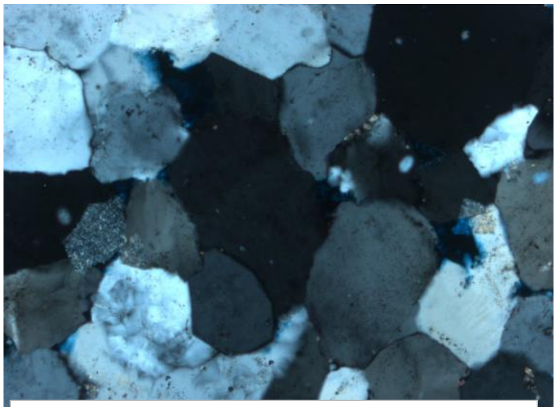


Figure 10.1 Observed at 10x magnification. In XN (unbalanced light), subhedral undulose quartz grains grown and cemented together.

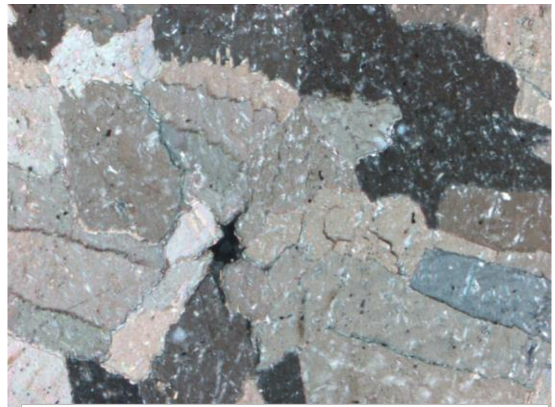


Figure 10.2 Observed at 10x magnification. In XN, elongated and anhedral calcite grains. Grown together acting as cementing material.

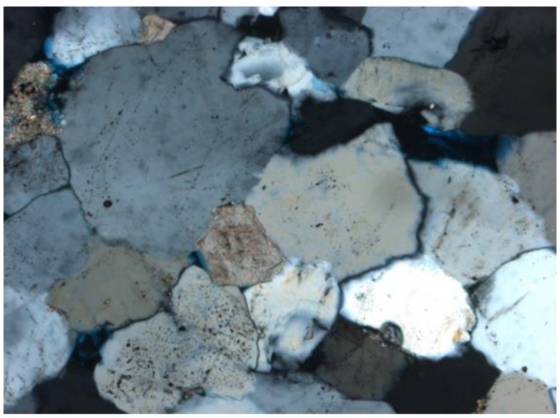


Figure 10.3 Observed at 10x magnification. In XN, subhedral, undulose quartz grains grown and cemented together.

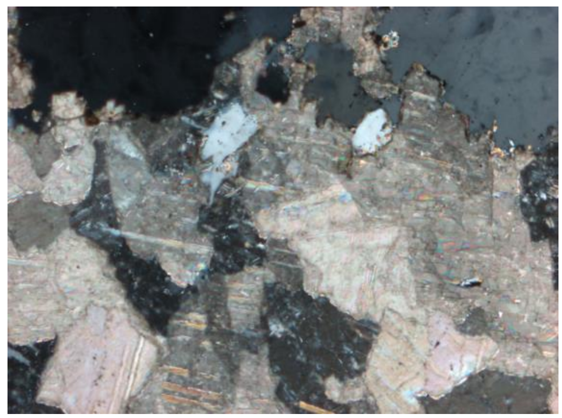


Figure 10.4 Observed at 10x magnification. In XN, globular calcite with lamellar twinning with a few overgrown quartz grains.

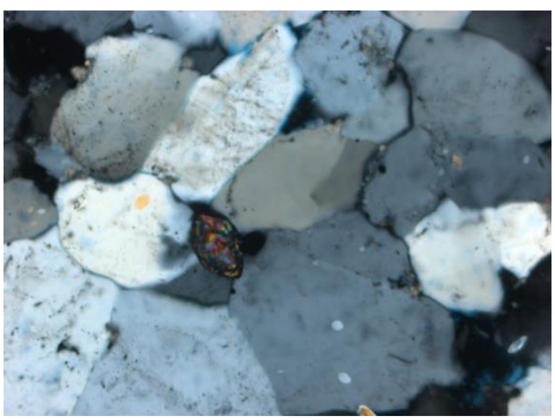


Figure 10.5 Observed at 10x magnification. In XN, subhedral and slightly intergrown quartz grains with a small grain of deformed

Figure 10.6 Observed at 10x magnification. In XN, globular calcite overgrown and interspersedwith subhedral quartz.

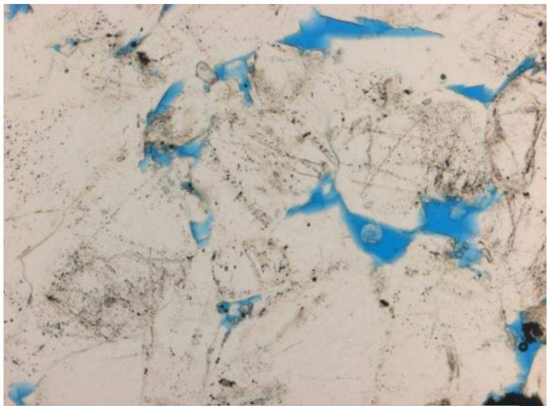


Figure 10.7 Observed at 10x magnification. In PL, the blue dye represents the open pore spaces in the thin section, estimating

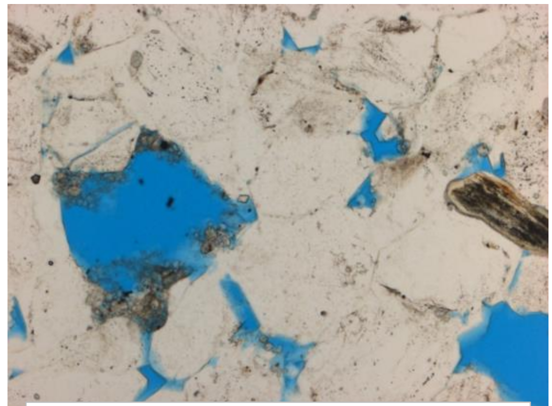


Figure 10.8 Observed at 10x magnification. In PL, the blue dye represents the open pore spaces in the thin section, estimating to about 10% porous overall.

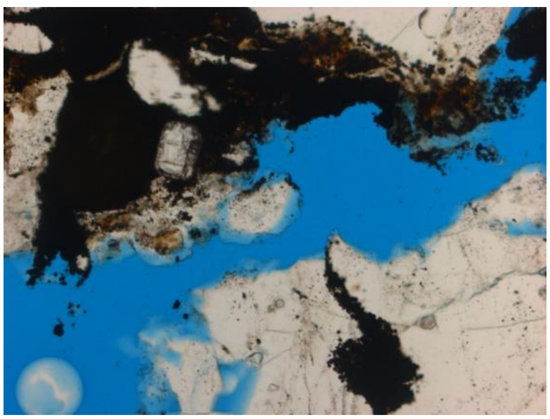


Figure 10.9 Observed at 10x magnification. In PL, the blue dye represents the open pore spaces in the thin section, estimating to about 10% porous overall.

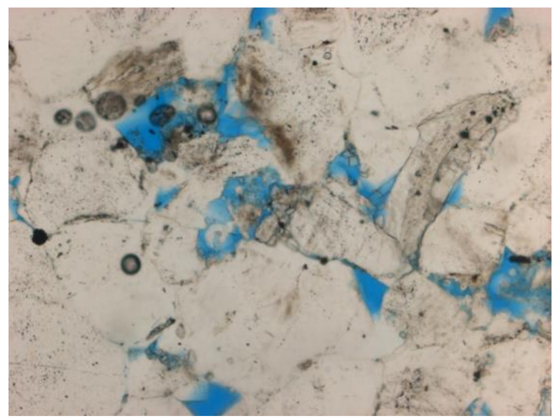


Figure 10.10 Observed at 10x magnification. In PL, the blue dye represents the open pore spaces in the thin section, estimating to about 10% porous overall.

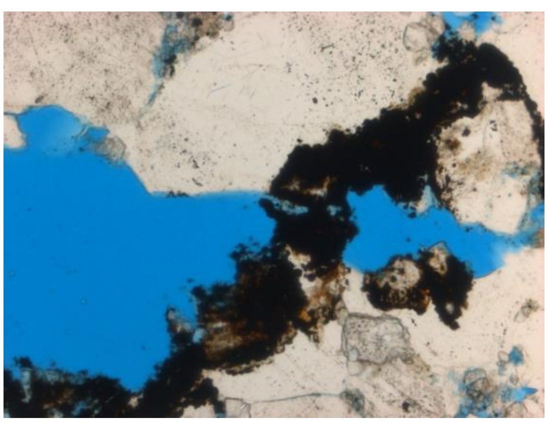


Figure 10.11 Observed at 10x magnification. In PL, the blue dye represents the open pore spaces in the thin section, estimating to about 10% porous overall.

Thin Section Analysis Report

Sample ID:	WD-9	4710701266
Formation/Member Name:	Oriskany Sandstone Wood County, WV	
Lithologic Classification:	Sandstone	
Depth/Depth Range:	4220.1 ft	Observed @ 10x
Date of Analysis:	6/2/2017	
Analyzed by:	Eric Hirschfeld	

	Texture	Comments
Grain Size	average grain size 50 to 600 microns	inequigranular; subhedral; clastic
Rounding	subangularto subrounded	
Sorting	moderately-well sorted	

	Composition/Detrital Minerals	Comments
	Quartz	
Polycrystalline	5% composition; Polycrystalline quartz is less obvious; <50 microns; possibly just quartz overgrowth	
Monocrystalline	70% composition; undulose quartz; XN: black/white, PL: transparent	Figure 9.1, Figure 9.4, Figure 9.6, Figure 9.7
Microcrystalline	grains are easily observed via petroscope	
	Feldspar	
Plagioclase	1% or less composition; subangular; albite twinning, subhedral	no figure
Orthoclase	n/a	
Microcline	n/a	
	Carbonate	
Calcite	25% composition; elongated, fibrous, and globular texture; especially in areas of intergrowth; some massive cumulates of calcite; subangular grains; XN: tan/pink, PL: Tan, transparent	Figure 9.2 through 9.7
Dolomite	n/a	
Aragonite	n/a	
	Clay	
Illite	n/a	
Smectite	n/a	
Kaolinite	n/a	
Muscovite	< 1% composition; olbate shape grains; <100 microns in size; XPL: pink, blue,green,orange, PPL: transparent	no figure
Chlorite	n/a	
Glauconite	n/a	
	Rock Fragments	
Sedimentary	Predominantly detrital sedimentary rock fragments	
Volcanic	n/a	
Metamorphic	n/a	
	Other (Accessory Minerals)	
Biotite?	noticed a few grainsof biotite; deformed; subrounded grain; 450 microns in size; XN: orange, PL: brown	no figure

	Cementing Materials	Comments
Quartz	Quartz intergrowth acts as a cementing material; moderately cemented	Figure 9.1 through Figure 9.7
Feldspar	n/a	
Carbonate	Calcite filling in many of open pores spaces and in between quartz grains; moderately cemented	Figure 9.1 through Figure 9.7
Clay	n/a	
Iron Oxide, Hydoxide and/or Sulfide	n/a	
Other	n/a	

	Visual Porosity Estimate	Comments
Visual Porosity Estimate	10% porosity	Figure 9.8 through Figure 9.12

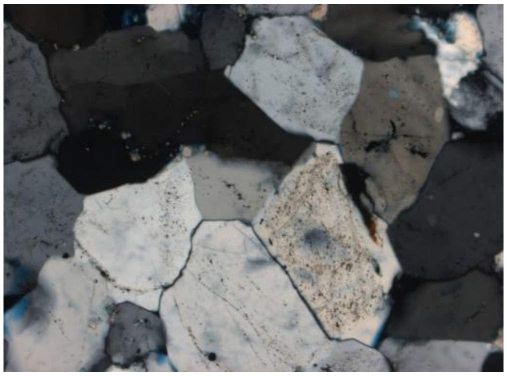


Figure 9.1 Observed at 10x magnification. In XN, subhedral undulose quartz that is also acting as cementing material from growth.

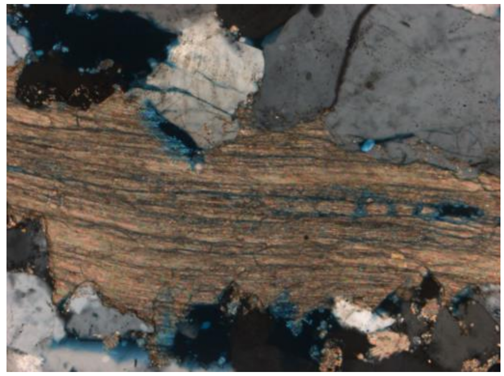


Figure 9.2 Observed at 10x magnification. In XN, deformed elongated grain of calcite grown in between subhedral quartz grains.

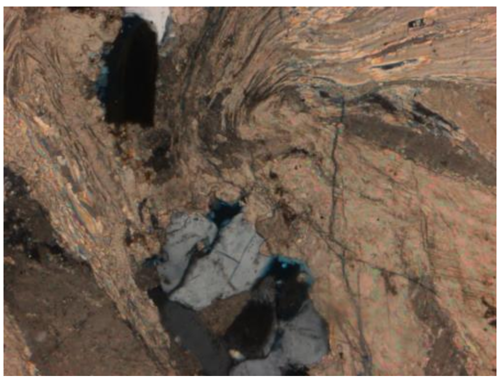


Figure 9.3 Observed at 10x magnification. In XN, large cumulate of deformed clacite, overgrown on quartz grains.

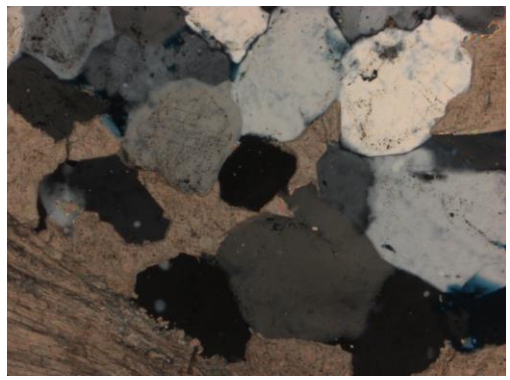


Figure 9.4 Observed at 10x magnification. In XN, grown calcite cementing together subhedral undulose quartz.

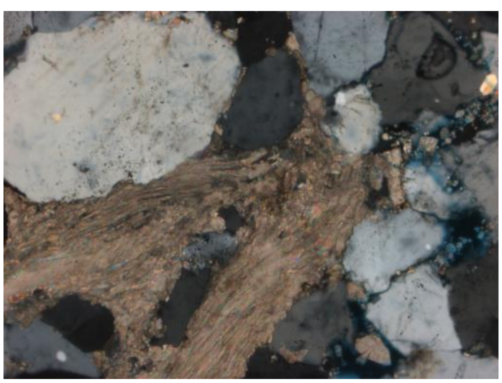


Figure 9.5 Observed at 10x magnification. In XN, interspersed calcite cementing together subhedral undulose quartz.

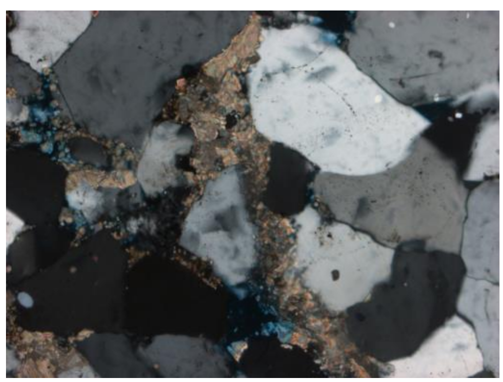


Figure 9.6 Observed at 10x magnification. In XN, intergrown calcite cementing together subhedral undulose quartz. Also quartz overgrowth, cementing grains together.

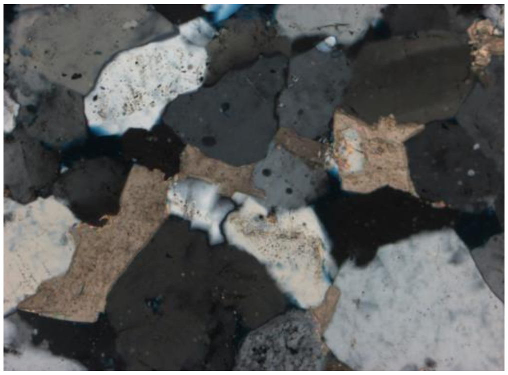


Figure 9.7 Observed at 10x magnification. In XN, interspersed subhedral quartz and calcite grains. Both acting as cementing material.

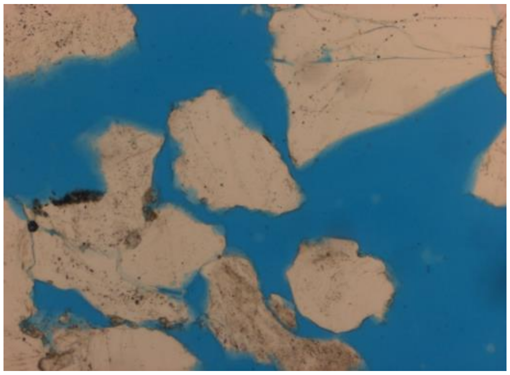


Figure 9.8 Observed at 10x magnification. In PL, blue dye represents the open pore spaces in the thin section, estimating about 10% porous overall

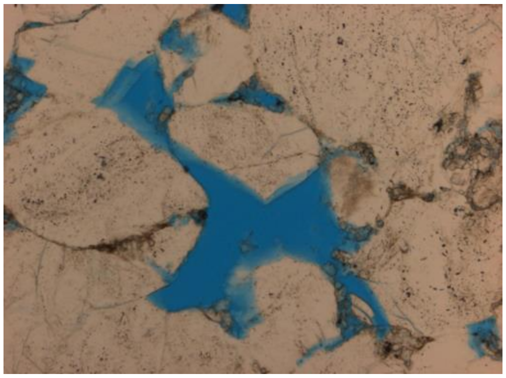


Figure 9.9 Observed at 10x magnification. In PL, blue dye represents the open pore spaces in the thin section, estimating about 10% porous overall

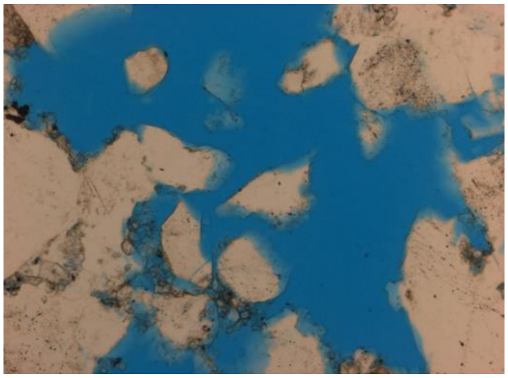


Figure 9.10 Observed at 10x magnification. In PL, blue dye represents the open pore spaces in the thin section, estimating about 10% porous overall

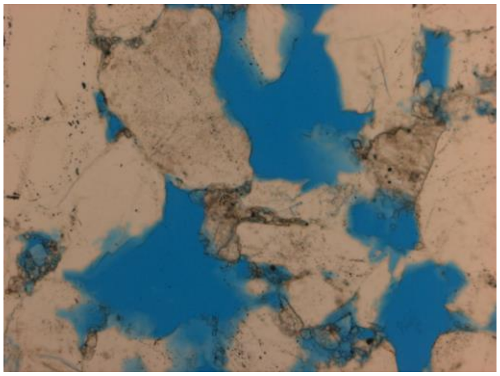


Figure 9.11 Observed at 10x magnification. In PL, blue dye represents the open pore spaces in the thin section, estimating about 10% porous overall

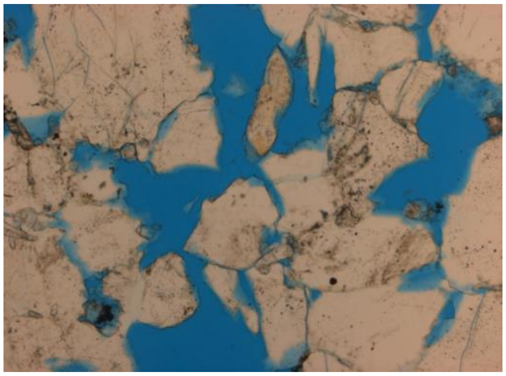


Figure 9.12 Observed at 10x magnification. In PL, blue dye represents the open pore spaces in the thin section, estimating about 10% porous overall

Thin Section Analysis Report

Sample ID:	WD-8	4710701266
Formation/Member Name:	Oriskany Sandstone Wood County, WV	
Lithologic Classification:	Sandstone	
Depth/Depth Range:	4218.7 ft	Observed @ 10x
Date of Analysis:	6/5/2017	
Analyzed by:	Eric Hirschfeld, Ellen Davis	

	Texture	**Comments**
Grain Size	average grain size is approximately 100 microns	Inequigranular; Non-Homogeneous; clastic
Rounding	subangular- subrounded	
Sorting	moderately to well sorted	

	Composition/Detrital Minerals	**Comments**
	Quartz	
Polycrystalline		
Monocrystalline	70% composition; intergrown grains;subangular to subrounded; subhedral	Figures 8.1 through 8.8
Microcrystalline	grains are easily observed via petroscope	
	Feldspar	
Plagioclase	albite twinning; subangular grains; <1% composition; approx. 100 microns in size; subhedral	no figures
Orthoclase		
Microcline	Tartan twinning; subangular grains; <1% composition; approx. 100 microns in size; subhedral	no figures
	Carbonate	
Calcite	Intergrown and interspersed grains; subangular; some elongated grains; slightly deformed; approx. 30% composition	Figures 8.3 through 8.7
Dolomite		
Aragonite		
	Clay	
Illite		
Smectite		
Kaolinite		
Muscovite	small oblated grains; approximately 50 microns in size; XN: green, orange, pink, blue, PL: transparent; <0.5% composition	no figures
Chlorite		
Glauconite		
	Rock Fragments	
Sedimentary	Predominantly sedimentary detrital rock fragments	
Volcanic	n/a	
Metamorphic	n/a	
	Other (Accessory Minerals)	

	Cementing Materials	**Comments**
Quartz	Intergrown and cemented quartz grains that are evenly distributed	Figure 8.1 through 8.6
Feldspar	n/a	
Carbonate	Deformed calcite acting as cementing material between subhedral calcite grains and quartz grains	Figure 8.3 through 8.7
Clay	n/a	
Iron Oxide, Hydoxide and/or Sulfide	n/a	
Other	n/a	

	Visual Porosity Estimate	**Comments**
Visual Porosity Estimate	5% porosity	Figure 8.8 through 8.11

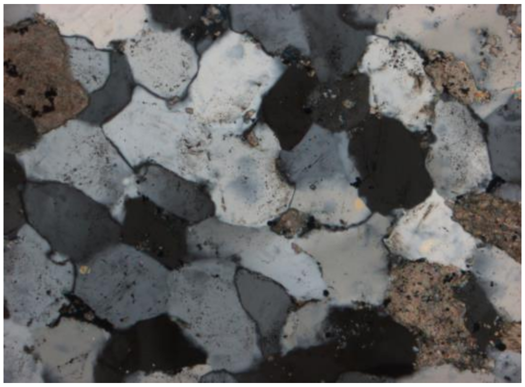


Figure 8.1 Observed at 10x magnification. In XPN subhedral and slightly deformed, undulose quartz. Slightly intergrown.

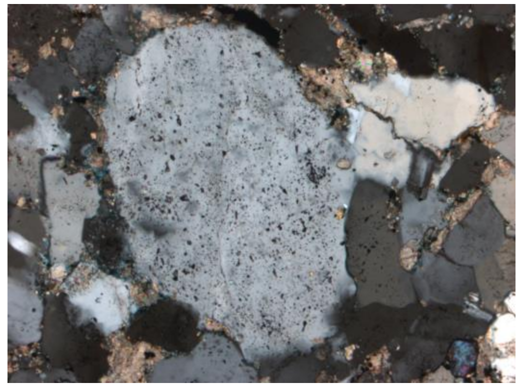


Figure 8.2 Observed at 10x magnification. In XN, large subhedral quartz grain surrounded by anhedral to subhedral quartz and small amounts of deformed calcite.

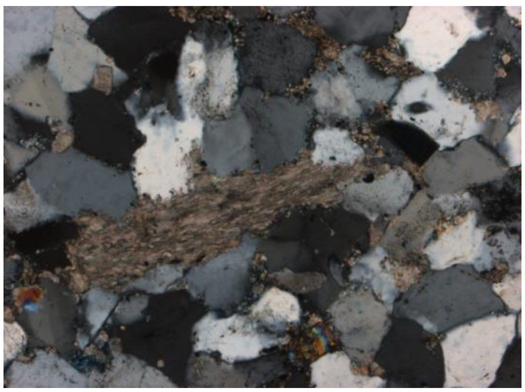


Figure 8.3 Observed at 10x magnification. In XN, deformed elongated calcite surrounded by subhedral quartz.

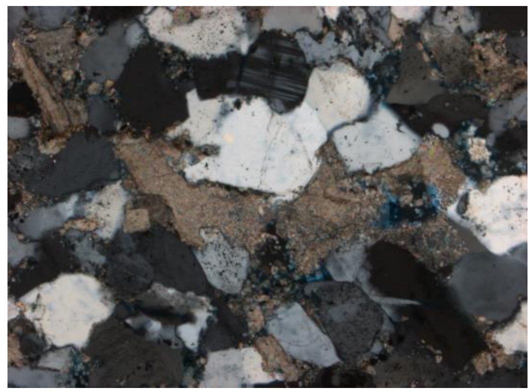


Figure 8.4 Observed at 10x magnification. In XN, deformed calcite grain grown between deformed and subhedral quartz grains.

Figure 8.5 Observed at 10x magnification. In XN, large, elongated, deformed calcite intergrown between subhedral quartz grains.

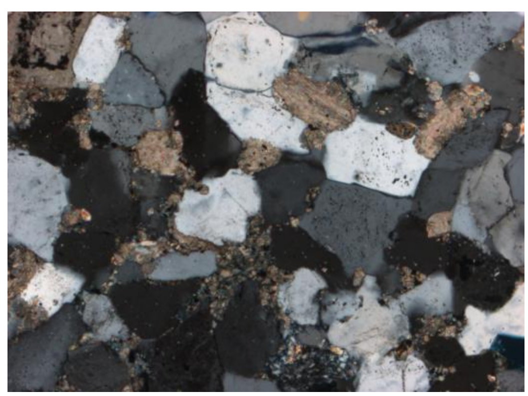


Figure 8.6 Observed at 10x magnification. In XN, subhedral undulose quartz with intergrown deformed calcite grains acting as cementing material.

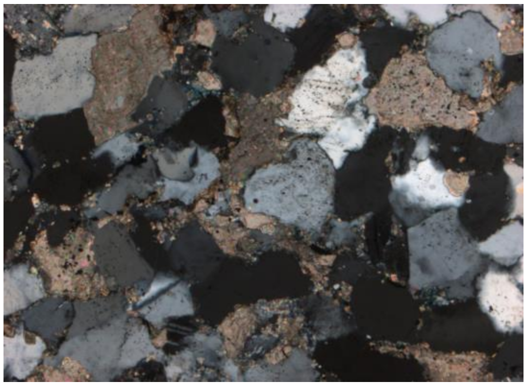


Figure 8.7 Observed at 10x magnification. In XN, deformed calcite grains in between quartz, acting as cementing material. quartz appears to be anhedral to subhedral.

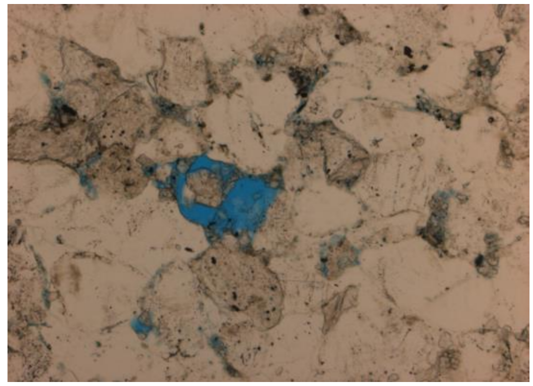


Figure 8.8 Observed at 10x magnification. In PL, blue dye represents the open pore spaces in the thin section, estimating 5% porosity overall.

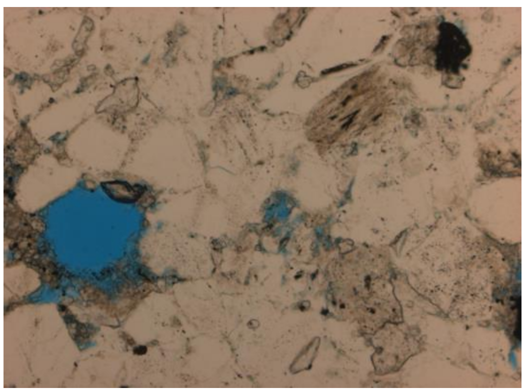


Figure 8.9 Observed at 10x magnification. In PL, blue dye represents the open pore spaces in the thin section, estimating 5% porosity overall.

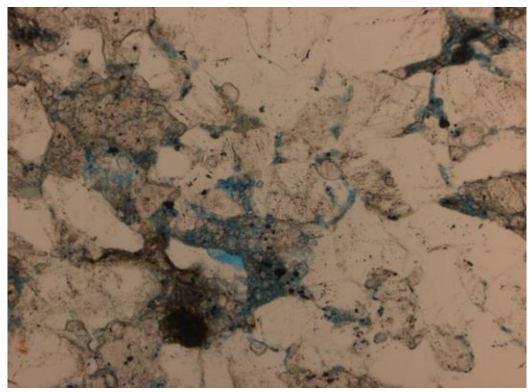


Figure 8.10 Observed at 10x magnification. In PL, blue dye represents the open pore spaces in the thin section, estimating 5% porosity overall.

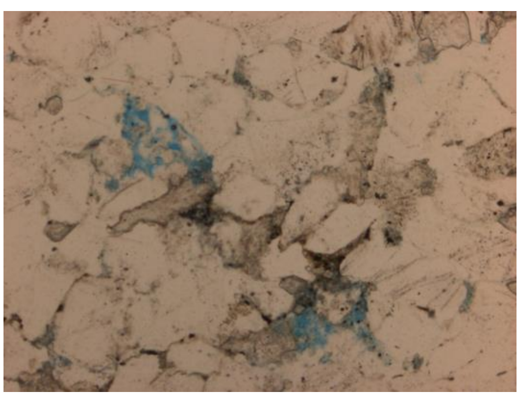


Figure 8.11 Observed at 10x magnification In PL, blue dye represents the open pore spaces in the thin section, estimating 5%

Thin Section Analysis Report

Sample ID:	WD-7	4710701266
Formation/Member Name:	Oriskany Sandstone Wood County, WV	
Lithologic Classification:	Sandstone	
Depth/Depth Range:	4215.8 ft	Observed @ 10x
Date of Analysis:	6/5/2017	
Analyzed by:	Eric Hirschfeld	

	Texture	**Comments**
Grain Size	Average grain size is apporximately 300-400 microns	Inequigranular; Non-homogeneous; Clastic;
Rounding	subangular to subrounded	
Sorting	moderately sorted	

	Composition/Detrital Minerals	**Comments**
	Quartz	
Polycrystalline	n/a	
Monocrystalline	70% composition; undulose quartz; subhedral; intergrown grains; deformed sub-grains but still monocrystalline; few polycrystalline grains but are insignificant to total composition	Figures 7.1 through 7.7
Microcrystalline	grains are easily observed via petroscope	
	Feldspar	
Plagioclase	sunangular grain; albite twinning, <1% composotion; XN: black/white	no figures
Orthoclase	n/a	
Microcline	subangular grain; tartan twinning: <1% composition; XN: black/white	no figures
	Carbonate	
Calcite	29-30% composition; deformed grains; globular, elgongated, intergrown grains between quartz; XN: tan/pink, PL: transparent	Figures 7.4 through 7.7
Dolomite	n/a	
Aragonite	n/a	
	Clay	
Illite	n/a	
Smectite	n/a	
Kaolinite	n/a	
Muscovite	<1% composition; small, oblate grains; XN: green, orange, blue, pink PL: transparent	no figures
Chlorite	n/a	
Glauconite	n/a	
	Rock Fragments	
Sedimentary	Predominantly sedimentary detrital fragments	
Volcanic	n/a	
Metamorphic	n/a	
	Other (Accessory Minerals)	

	Cementing Materials	**Comments**
Quartz	very well cemented intergrown quartz grains;	Figures 7.4 through 7.6
Feldspar	n/a	
Carbonate	Calcite fills in some of the pores spaces and acts as a secondary cementing material	Figures 7.4 through 7.6
Clay	n/a	
Iron Oxide, Hydoxide and/or Sulfide	n/a	
Other	n/a	

	Visual Porosity Estimate	**Comments**
Visual Porosity Estimate	8% porosity	Figures 7.8 thorugh 7.10

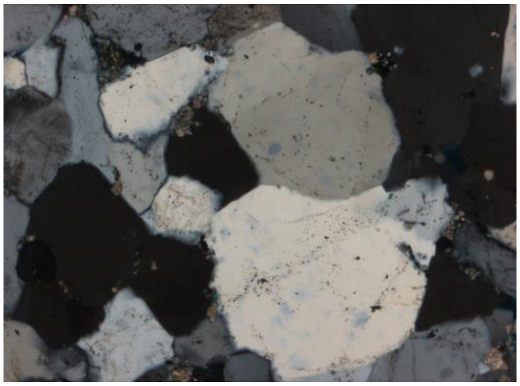


Figure 7.1 Observed at 10x magnification. In XN, subhedral, intergrown undulose quartz grains. Quartz is acting as cementing material. Some deformed grains.

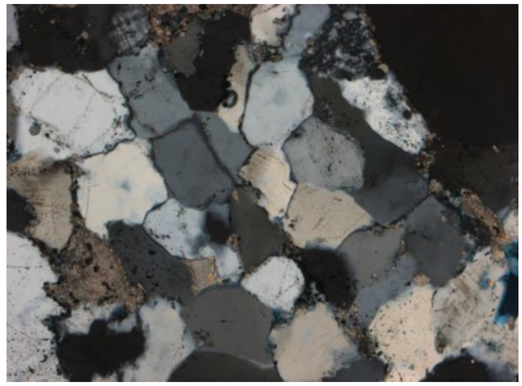


Figure 7.2 Observed at 10x magnification. In XN, subhedral , undulose quartz grains. Overgrown quartz grains. Also present, subhedral to euhedral calcite grains.

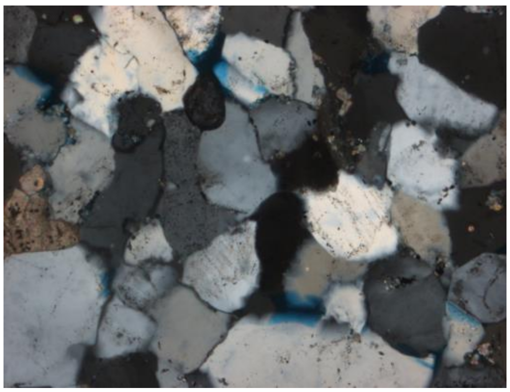


Figure 7.3 Observed at 10x magnification. In XN, anhedral to subhedral , undulose quartz grains. Quartz is the cementing

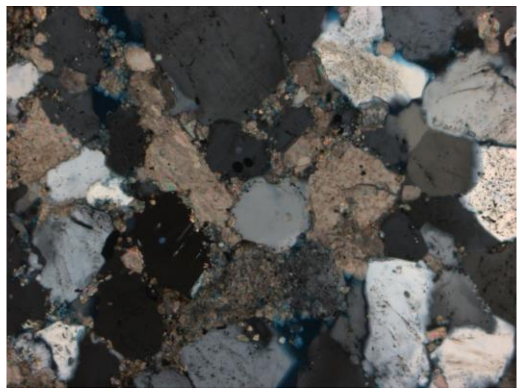


Figure 7.4 Observed at 10x magnification. In XN, Subhedral quartz and slightly globular calcite that is interspersed between quartz grains acting as a cementing material.

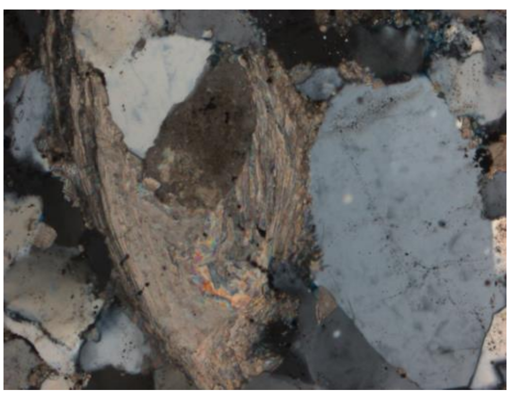


Figure 7.5 Observed at 10x magnification. In XN, globular, deformed calcite grain surrounded by subhedral grains of quartz.

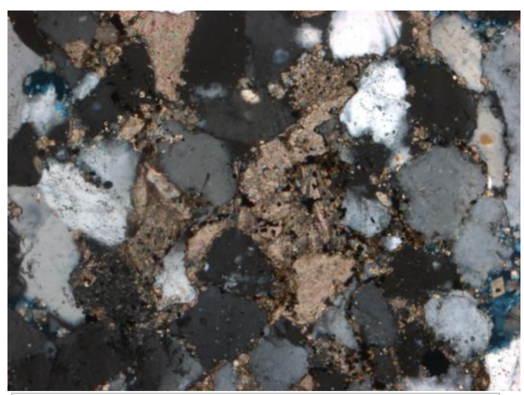


Figure 7.6 Observed at 10x magnification. In XN, interspersed calcite in between quartz grains. Subhedral quartz grains with calcite cement.

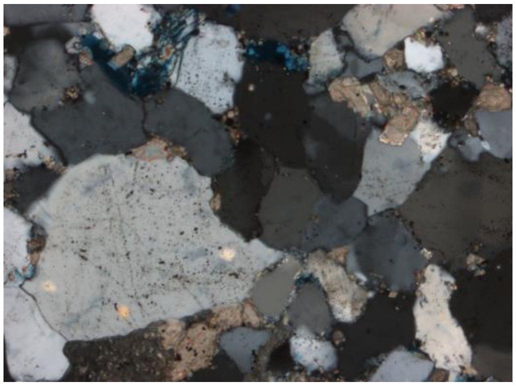


Figure 7.7 Observed at 10x magnification. In XN, anhedral to subhedral quartz grains. some slight deformation from quartz growth.

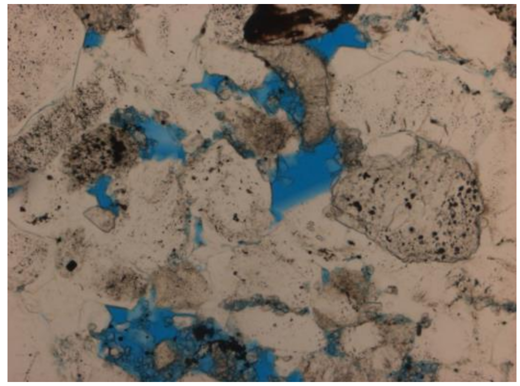


Figure 7.8 Observed at 10x magnification. In PL, the blue dye represents the open spaces in the thin section, estimating to about 8% porosity overall.

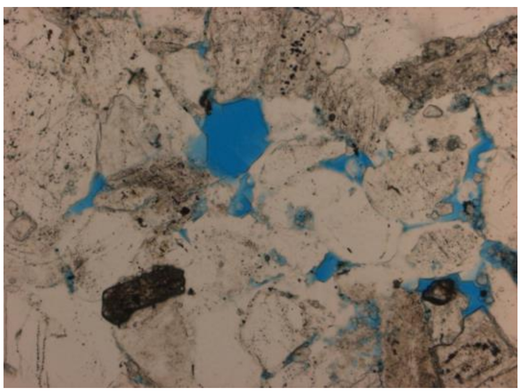


Figure 7.9 Observed at 10x magnification. In PL, the blue dye represents the open spaces in the thin section, estimating to about 8% porosity overall.

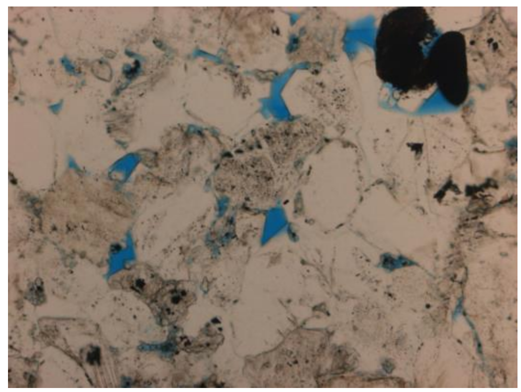


Figure 7.10 Observed at 10x magnification. In PL, the blue dye represents the open spaces in the thin section, estimating to about 8% porosity overall.

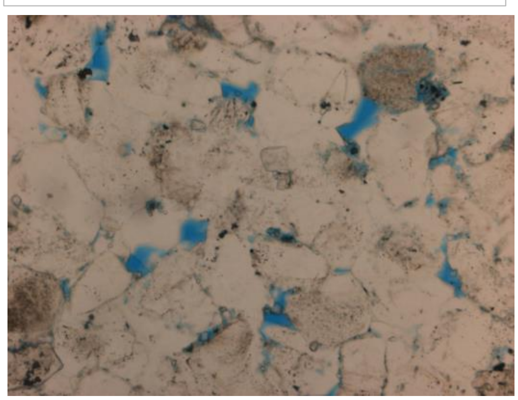


Figure 7.11 Observed at 10x magnification. In PL, the blue dye represents the open spaces in the thin section, estimating to about 8% porosity overall.

Thin Section Analysis Report

Sample ID:	WD-6		4710701266
Formation/Member Name:	Oriskany Sandstone Wood County, WV		
Lithologic Classification:	Sandstone		
Depth/Depth Range:	4213.5 ft	Observed @ 10x	
Date of Analysis:	6/6/2017		
Analyzed by:	Eric Hirschfeld		

	Texture	Comments
Grain Size	average grain size= approx. 0.5 to 0.75 mm	clastic; Homogeneous
Rounding	subangular to subrounded; mostly subrounded	
Sorting	moderately to well sorted	

	Composition/Detrital Minerals	Comments
	Quartz	
Polycrystalline	n/a	
Monocrystalline	80% composition; undulose quartz; subhedral; intergrown grains; some deformed grains; moderate relief; most grains are large ranging from 0.5 to 1mm	Figure 6.1
Microcrystalline	grains are easily observed via petroscope	
	Feldspar	
Plagioclase	n/a	
Orthoclase	n/a	
Microcline	<0.1% composition, tartan twinning, subrounded; subhedral	no figure
	Carbonate	
Calcite	20% composition; globular texture; anhedral but some grains appear to be subhedral; moderate birefringence; XN: tan/pink	Figure 6.2 through Figure 6.5 and Figure 6.7
Dolomite	n/a	
Aragonite	n/a	
	Clay	
Illite	n/a	
Smectite	n/a	
Kaolinite	n/a	
Muscovite	<0.1% composition; approx <100 microns in size; deformed grains; XPL: green, blue,ornage	no figure
Chlorite	n/a	
Glauconite	n/a	
	Rock Fragments	
Sedimentary	Predominantly sedimentary rock fragements	
Volcanic	n/a	
Metamorphic	n/a	
	Other (Accessory Minerals)	

	Cementing Materials	Comments
Quartz	Quartz intergrowth present are the cementing material; moderate to well cemented	
Feldspar	n/a	
Carbonate	calcite deformed between grains also acts as cementing material in between quartz grains; moderate to well cemented	Figure 6.4, Figure 6.6, Figure 6.7
Clay	n/a	
Iron Oxide, Hydoxide and/or Sulfide	n/a	
Other	n/a	

	Visual Porosity Estimate	Comments
Visual Porosity Estimate	9% porosity	Figure 6.8 through Figure 6.12

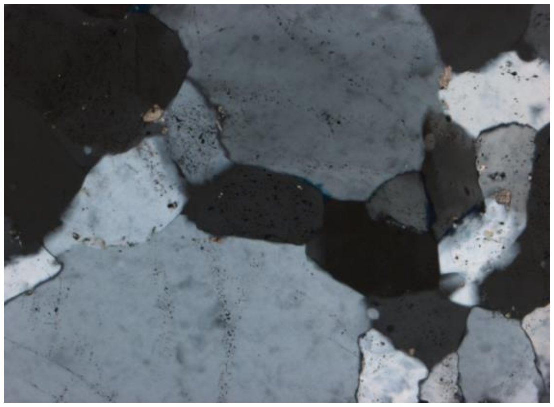


Figure 6.1 Observed at 10x magnification. In XPN subhedral, intergrown, undulose quartz grains. Quartz is the acting cementing material.

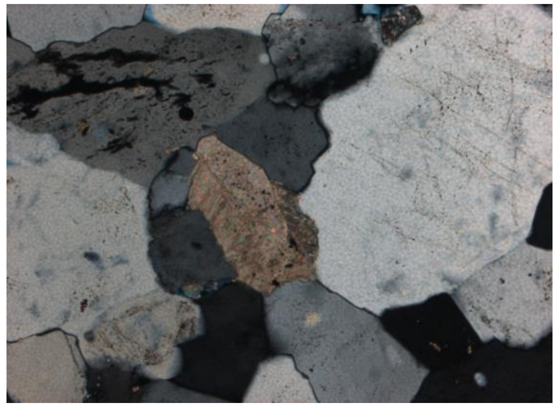


Figure 6.2 Observed at 10x magnification. In XPL, subhedral undulose quartz grains and a subhedral calcitee grain.

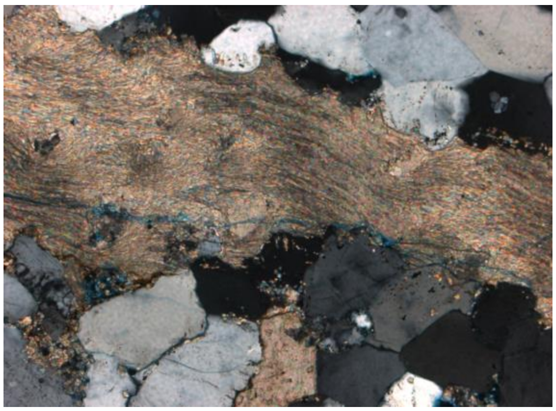


Figure 6.3 Observed at 10x magnification. In XN, globular grain of calcite with subhedral, subrounded undulose quartz grains.

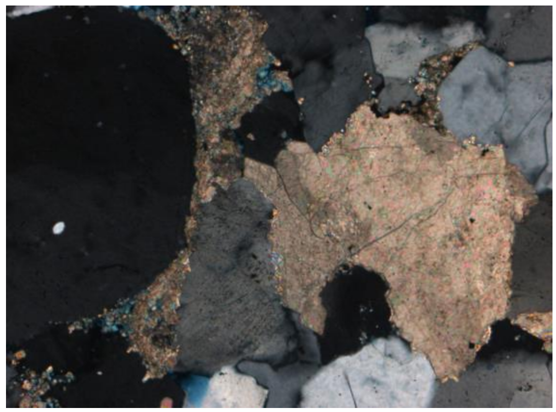


Figure 6.4 Observed at 10x magnification. In XN, globular calcite grain and calcite cementing material in between subhedral quartz grains.

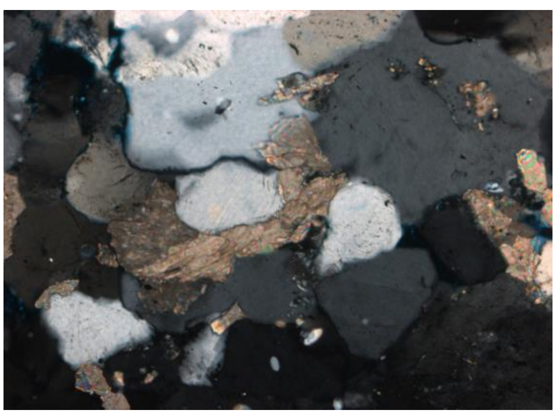


Figure 6.5 Observed at 10x magnification. In XN, Deformed quartz grains with some globular calcite grains.

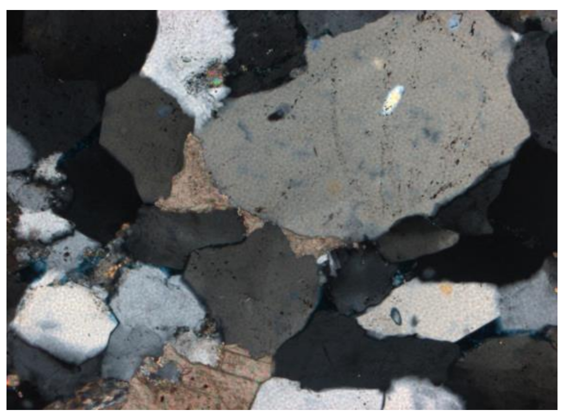


Figure 6.6 Observed at 10x magnification. In XN, quartz grains being cemented by both quartz growth and carbonate material calcite**.**

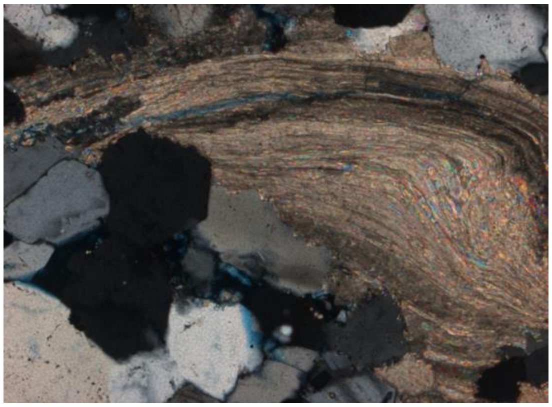


Figure 6.7 Observed at 10x magnification. In XN, massive globular calcite grain with some slightly deformed undulose quartz grains.

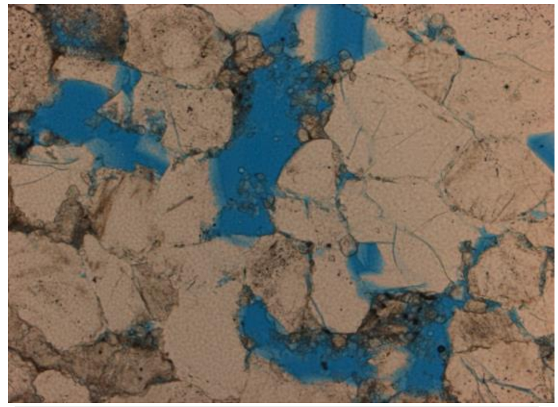


Figure 6.8 Observed at 10x magnification.In PL, the blue dye indicates the open pores spaces in the thin section. This thin section has an estimated 9% porosity overall.

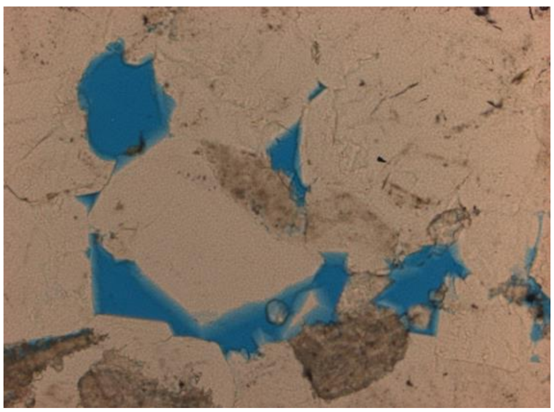


Figure 6.9 Observed at 10x magnification. In PL, the blue dye indicates the open pores spaces in the thin section. This thin section has an estimated 9% porosity overall.

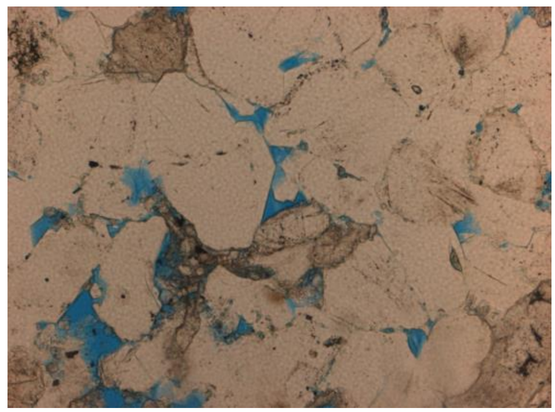


Figure 6.10 Observed at 10x magnification. In PL, the blue dye indicates the open pores spaces in the thin section. This thin section has an estimated 9% porosity overall.

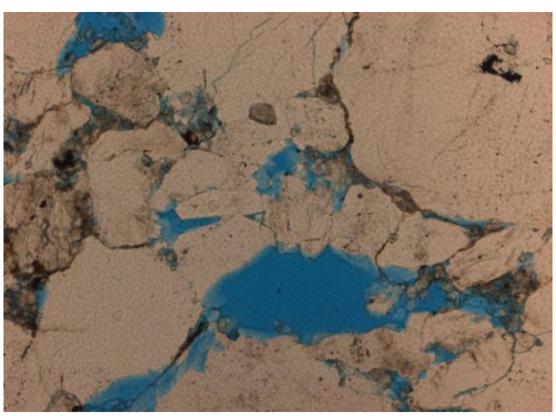


Figure 6.11 Observed at 10x magnification. In PL, the blue dye indicates the open pores spaces in the thin section. This thin section has an estimated 9% porosity overall.

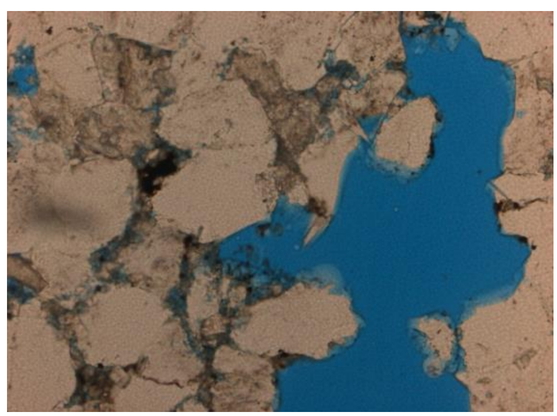


Figure 6.12 Observed at 10x magnification. In PL, the blue dye indicates the open pores spaces in the thin section. This thin section has an estimated 9% porosity overall

Thin Section Analysis Report

Sample ID:	WD-5	4710701266
Formation/Member Name:	Oriskany Sandstone Wood County, WV	
Lithologic Classification:	Sandstone	
Depth/Depth Range:	4212.1 ft	Observed @ 10x
Date of Analysis:	6/8/2017	
Analyzed by:	Eric Hirschfeld	

	Texture	Comments
Grain Size	range of grain size = approx. 0.01 mm to 1mm	clastic
Rounding	subangular	
Sorting	moderately sorted	

	Composition/Detrital Minerals	Comments
	Quartz	
Polycrystalline	n/a	
Monocrystalline	75% composition; undulose quartz; anhedral to subhedral; interspersed grains; deformed grains	Figure 5.1 through Figure 5.6
Microcrystalline	grains are easily observed via petroscope	
	Feldspar	
Plagioclase	albite twinning; small; subhedral; <0.1% composition	no figure
Orthoclase	n/a	
Microcline	tartan twinning; small; subhedral; <0.1% composition	no figure
	Carbonate	
Calcite	25% composition; globular texture; fills in pores in between quartz grains; some subangular grains; semi-elongated texutre on some grains; deformation structures	Figure 5.1 through Figure 5.6
Dolomite	n/a	
Aragonite	n/a	
	Clay	
Illite	n/a	
Smectite	n/a	
Kaolinite	n/a	
Muscovite	n/a	
Chlorite	n/a	
Glauconite	n/a	
	Rock Fragments	
Sedimentary	Predominantly sedimentary rock fragments; detrital sediments of quartz	Figure 5.1 through Figure 5.6
Volcanic	n/a	
Metamorphic	n/a	
	Other (Accessory Minerals)	
???	WD5_0036, WD5_0037	

	Cementing Materials	Comments
Quartz	Quartz normal Growth and intergrowth of grains act as cementing material; moderately to well cemented	
Feldspar	n/a	
Carbonate	Calcite acts as carbonate cement material, fillin in pore spaces between quartz grains; globular texture; irregularshaped, possibly from deformation	Figure 5.1 through Figure 5.6
Clay	n/a	
Iron Oxide, Hydoxide and/or Sulfide	n/a	
Other	n/a	

	Visual Porosity Estimate	Comments
Visual Porosity Estimate	11% porosity	Figure 5.7 through 5.12

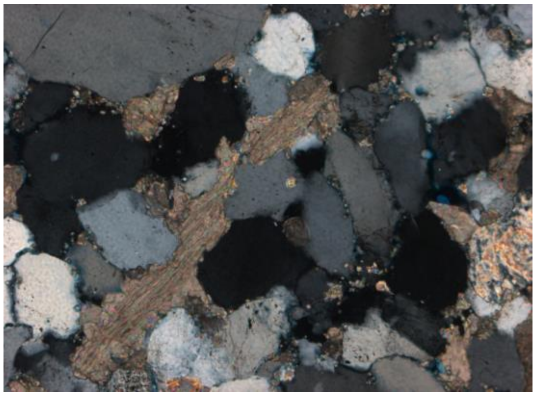


Figure 5.1 Observed at 10x magnification. In XN, Slightly deformed undulose quartz grains with semi-elongated calcite grain

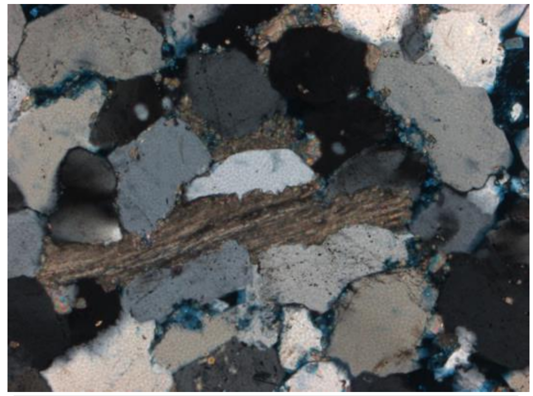


Figure 5.2 Observed at 10x magnification. In XN, anhedral and slightly deformed undulose quartz with a elongated calcite grain deformed from quartz growth, acting as cementing material.

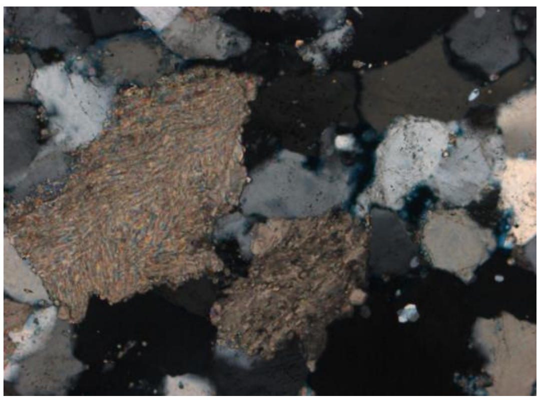


Figure 5.3 Observed at 10x magnification. In XN, anhedral calcite grain with anhedral to subhedral undulose quartz grains. Quartz intergrowth is evident

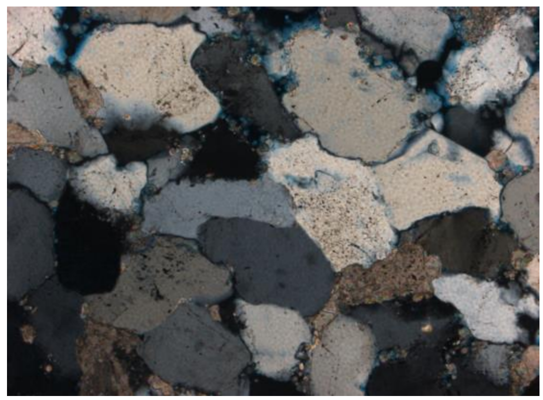


Figure 5.4 Observed at 10x magnification. In XN, subhedral and slightly deformed undulose quartz. Some interspersed grains.

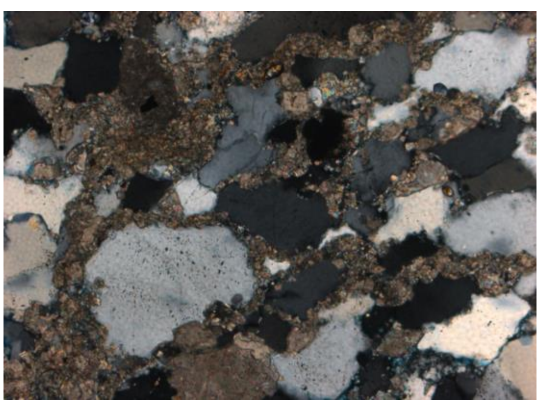


Figure 5.5 Observed at 10x magnification. In XN, subhedral undulose quartz grains cemented together by deformed calcite

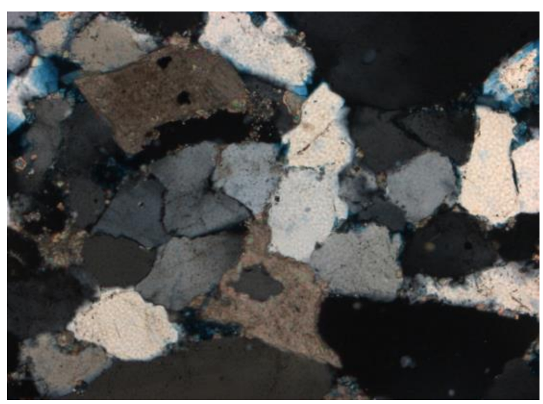


Figure 5.6 Observed at 10x magnification. In XPL, subhedral and slightly deformed quartz grains with quartz cementing. Also a few deformed calcite grains.

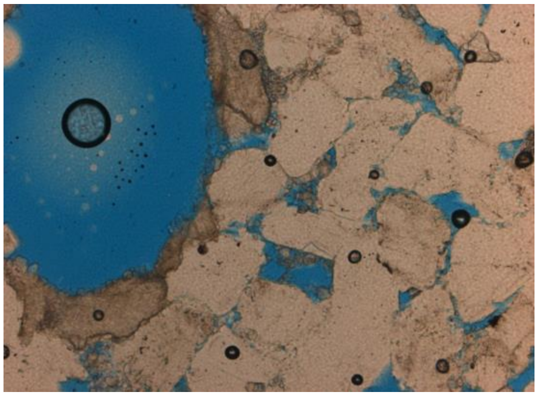


Figure 5.7 Observed at 10x magnification. In PL, blue dye exhibts the open pore spaces in the thin section. the estimated porosity of the thin section is 11% overall

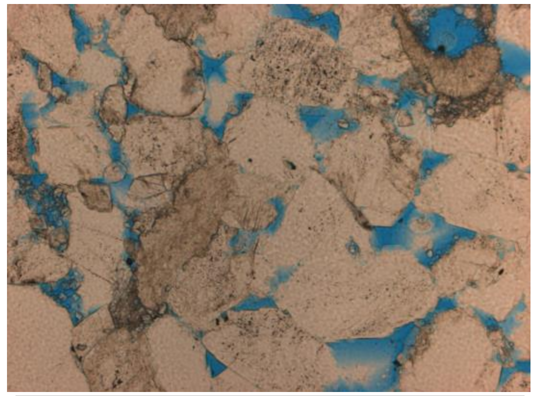


Figure 5.8 Observed at 10x magnification. In PL, blue dye exhibts the open pore spaces in the thin section. the estimated porosity of the thin section is 11% overall

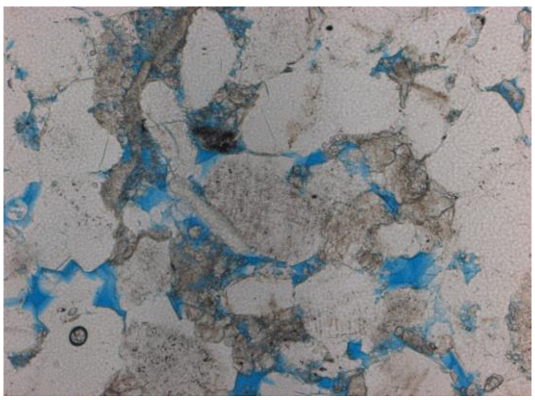


Figure 5.9 Observed at 10x magnification. In PL, blue dye exhibts the open pore spaces in the thin section. The estimated porosity of the thin section is 11% overall.

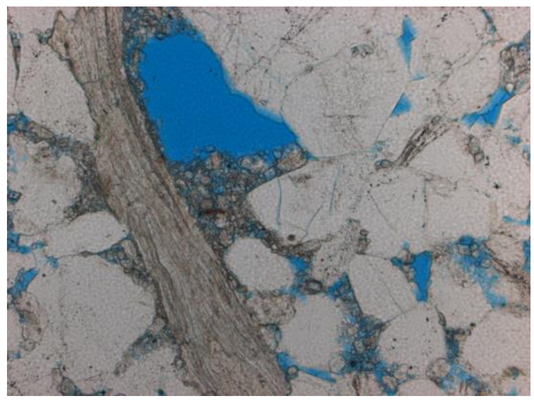


Figure 5.10 Observed at 10x magnification. In PL, blue dye exhibts the open pore spaces in the thin section. The estimated porosity of the thin section is 11% overall.

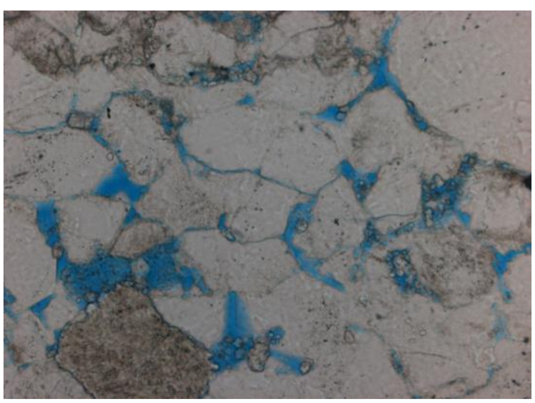


Figure 5.11 Observed at 10x magnification. In PL, blue dye exhibts the open pore spaces in the thin section. The estimated porosity of the thin section is 11% overall

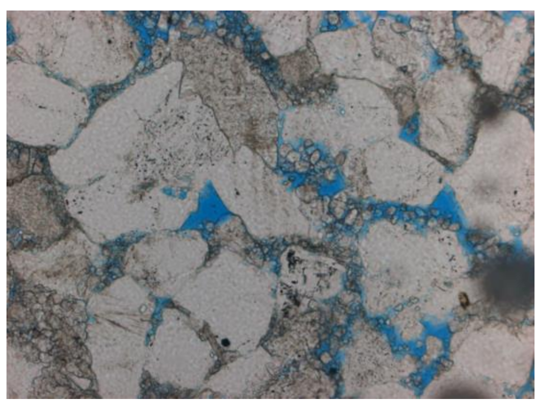


Figure 5.12 Observed at 10x magnification. In PL, blue dye exhibts the open pore spaces in the thin section. The estimated porosity of the thin section is 11% overall

Thin Section Analysis Report

Sample ID:	WD-4	4710701266
Formation/Member Name:	Oriskany Sandstone Wood County, WV	
Lithologic Classification:	Sandstone	
Depth/Depth Range:	4209 ft	Observed @ 10x
Date of Analysis:	6/9/2017	
Analyzed by:	Eric Hirschfeld	

	Texture	**Comments**
Grain Size	average grain size= approx. 150 microns	clastic
Rounding	subangular to subrounded	
Sorting	moderately sorted	

	Composition/Detrital Minerals	**Comments**
	Quartz	
Polycrystalline	n/a	
Monocrystalline	80% composition; anhedral to subhedral grains; deformed grains from growth, undulose quartz	Figure 4.1 through Figure 4.8
Microcrystalline	grains are easily observed via petroscope	
	Feldspar	
Plagioclase	<1% composition; subhedral; subangular; albite twinning	no Figure
Orthoclase	n/a	
Microcline	n/a	
	Carbonate	
Calcite	20% composition; anhedral, deformed grains; XPL; pink/tan, PPL: transparent; moderate birfringence	Figure 4.3 through Figure 4.8
Dolomite	n/a	
Aragonite	n/a	
	Clay	
Illite	n/a	
Smectite	n/a	
Kaolinite	n/a	
Muscovite	n/a	
Chlorite	n/a	
Glauconite	n/a	
	Rock Fragments	
Sedimentary	Detrital sedimentary fragements are dominant in the thin section and is mostly quartz	
Volcanic	n/a	
Metamorphic	n/a	
	Other (Accessory Minerals)	
	n/a	

	Cementing Materials	**Comments**
Quartz	Normal quartz growth, overgrowth, and intergrowth of the grains cement each other together; moderately cemented	Figure 4.3 through Figure 4.8
Feldspar	n/a	
Carbonate	calcite deformations and globular textured grains act as cementing materials	Figure 4.3 through Figure 4.8
Clay	n/a	
Iron Oxide, Hydoxide and/or Sulfide	n/a	
Other	n/a	

	Visual Porosity Estimate	**Comments**
Visual Porosity Estimate	13% porosity	Figure 4.9 through Figure 4.12

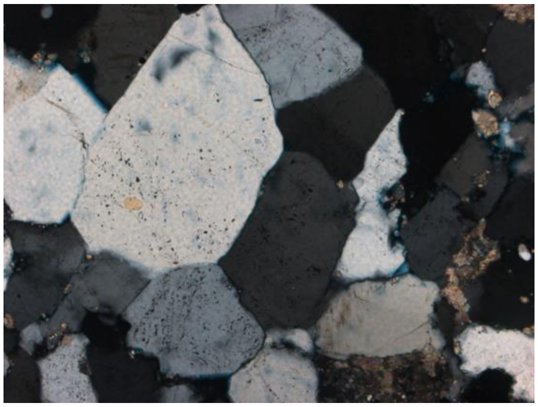


Figure 4.1 Observed at 10x magnification. In XPL, subhedral, undulose quartz gains. Exhibits quartz growth that results in slight deformation.

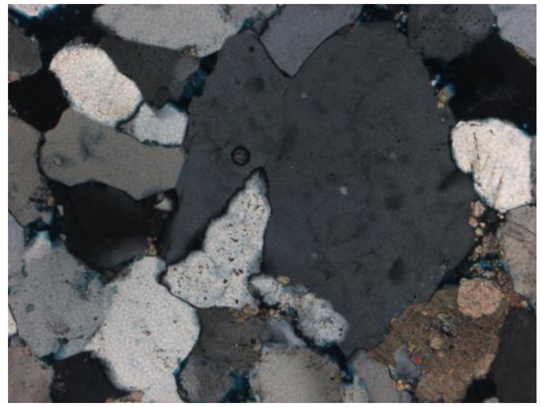


Figure 4.2 Observed at 10x magnification. In XPL, anhedral to subhedral, undulose quartz. Exhibits quartz intergrowth. Also some deformed calcite grains.

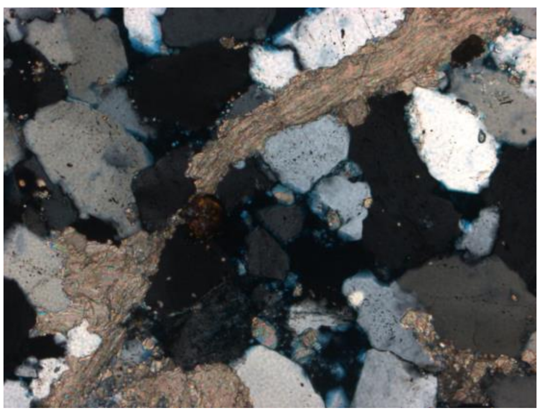


Figure 4.3 Observed at 10x magnification. In XPL, Anhedral and subhedral undulose quartz . some deform grains from interspersion. Elongated and deformed calcite grains.

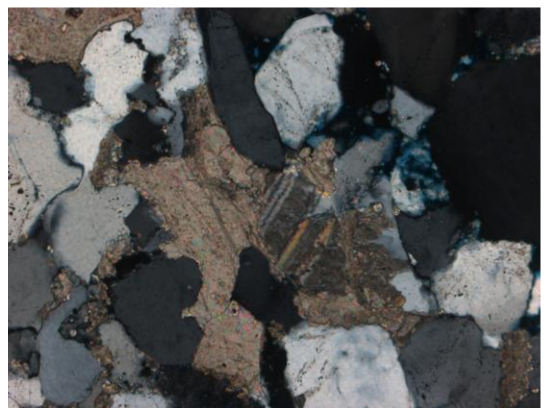


Figure 4.4 Observed at 10x magnification. Deformed undulose quartz grains with deformed calcite grains acting as cementing material. Calcite exhibits some lamellar twinning.

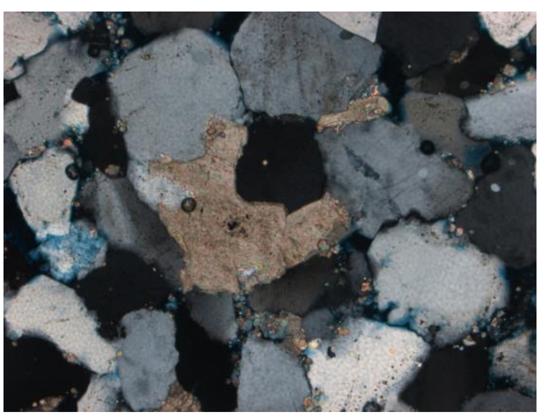


Figure 4.5 Observed at 10x magnification. In XPL, subhedral undulose quartz grains with some deformation growth with a few deformed calcite grains. Exhibits both quartz and carbonate

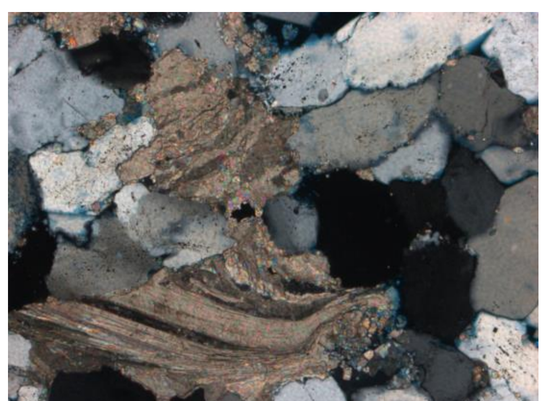


Figure 4.6 Observed at 10x magnification. In XPL, deformed, globular calcite grain cementing together subhedral, undulose quartz grains..

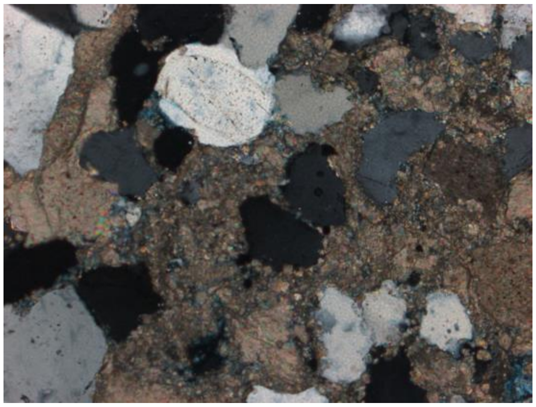


Figure 4.7 Observed at 10x magnification. In XPL, deformed calcite grain and calcareous cement with subrounded, subhedral, undulose quartz grains. Some grains are slightly deformed from growth.

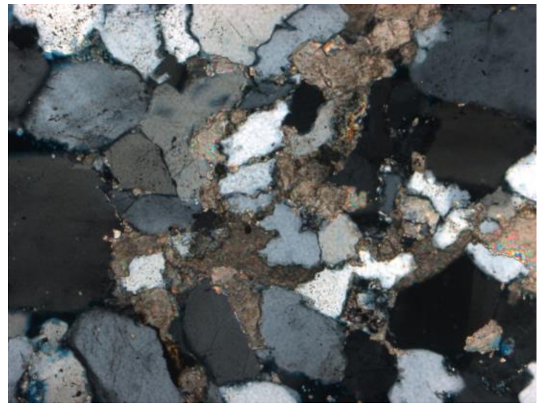


Figure 4.8 Observed at 10x magnification. In XPL, Deformed, undulose quartz grains with calcareous cementing materials.

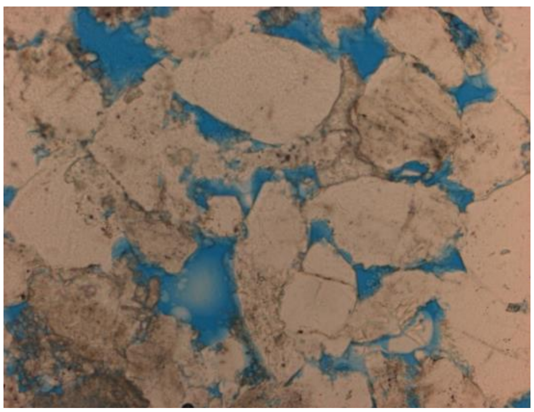


Figure 4.9 Observed at 10x magnification. In PPL, the blue dye exhibits the open pore spaces in the thin section. Visual estimate

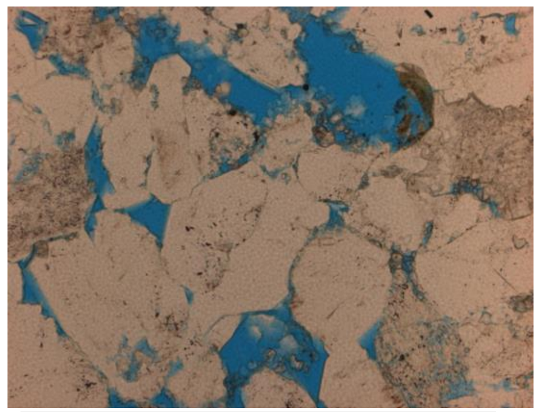


Figure 4.10 Observed at 10x magnification. In PPL, the blue dye exhibits the open pore spaces in the thin section. Visual estimate of porosity is 13% porous.

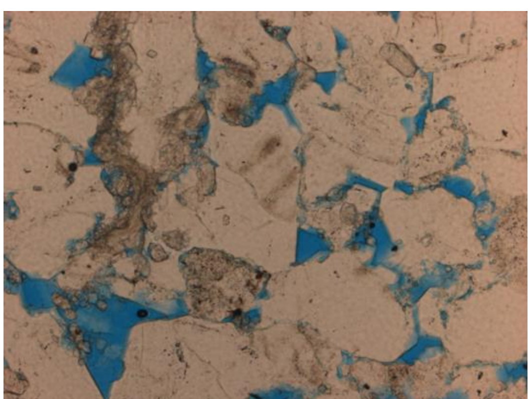


Figure 4.11 Observed at 10x magnification. In PPL, the blue dye exhibits the open pore spaces in the thin section. Visual estimate of porosity is 13% porous.

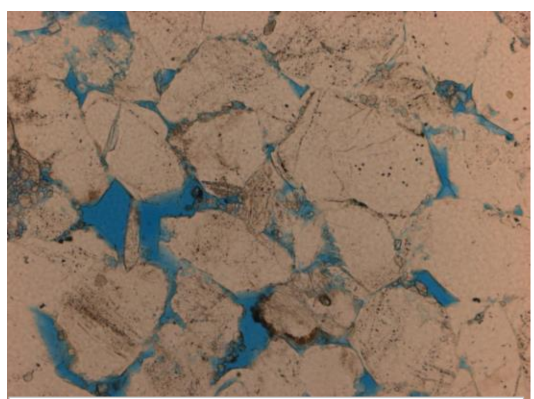


Figure 4.12 Observed at 10x magnification. In PPL, the blue dye exhibits the open pore spaces in the thin section. Visual estimate of porosity is 13% porous.

Thin Section Analysis Report

Sample ID:	WD-3	4710701266
Formation/Member Name:	Oriskany Sandstone Wood County, WV	
Lithologic Classification:	Sandstone	
Depth/Depth Range:	4206 ft	Observed @ 10x
Date of Analysis:	6/9/2017	
Analyzed by:	Eric Hirschfeld	

	Texture	**Comments**
Grain Size	average grain size ranges from 50 microns to 2 mm	clastic
Rounding	subangular to subrounded	
Sorting	poorly sorted	

	Composition/Detrital Minerals	**Comments**
	Quartz	
Polycrystalline	n/a	
Monocrystalline	60% composition; anhedral to subhedral; undulose quartz; quartz overgrowth and intergrowth; deformed grains	Figure 3.1 and Figure 3.2
Microcrystalline	grains are easily observed via petroscope	
	Feldspar	
Plagioclase	n/a	
Orthoclase	n/a	
Microcline	n/a	
	Carbonate	
Calcite	40% composition; deformed grains; semi-fibrous; some subangular grains; anhedral to euhedral; texture in some locations appear to be lamellar twinning; mostly deformed globular grains; one massive deforemed grain of calcite, >3mm	Figure 3.3 through Figure 3.9
Dolomite	n/a	
Aragonite	n/a	
	Clay	
Illite	n/a	
Smectite	n/a	
Kaolinite	n/a	
Muscovite	n/a	
Chlorite	n/a	
Glauconite	n/a	
	Rock Fragments	
Sedimentary	Predominantly sedimentary detrital minerals and rock fragments with a miniscule traces of volcanic fragments	Figure 3.9
Volcanic		
Metamorphic	n/a	
	Other (Accessory Minerals)	
???	unidentifiable mineral	Images: WD3_0011 and WD3_0012

	Cementing Materials	**Comments**
Quartz	Some quartz cementing of grains; moderately cemented	Figure 3.1 through Figure 3.8
Feldspar	n/a	
Carbonate	Predominantly calcite cementing material; calcite fills in pores between quartz grains; acting as main cementing material; moderately to well cemented	Figure 3.1 through Figure 3.8
Clay	n/a	
Iron Oxide, Hydoxide and/or Sulfide	n/a	
Other	n/a	

	Visual Porosity Estimate	**Comments**
Visual Porosity Estimate	7 to 10% porosity	Figure 3.10 through Figure 3.12

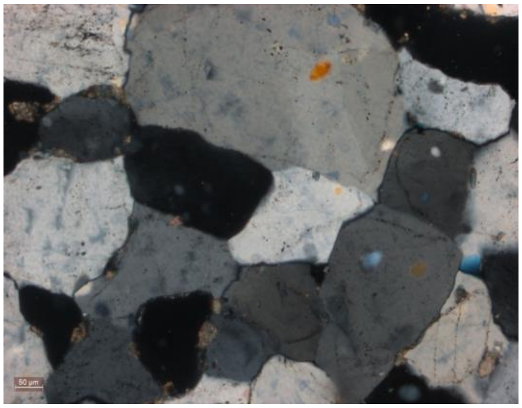


Figure 3.1 Observed at 10x magnification. In XN, subhedral undulose quartz grains cemented together by quartz growth

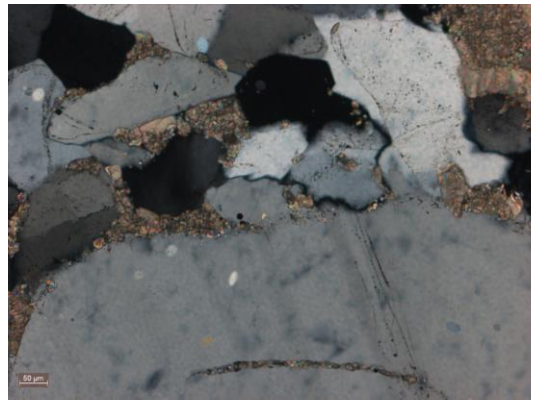


Figure 3.2 Observed at 10x magnification. In XN, anhedral, undulose quartz grains that is calcareously cemented. Also quartz grains show example of overgrowth.

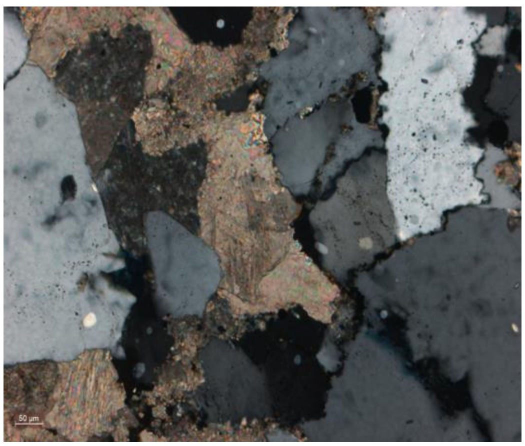


Figure 3.3 Observed at 10x magnification. In XN, Anhedral, undulose quartz grains grown with and cemented by anhedral, deformed calcite grains. Also quartz grains exhibit quartz intergrowth. Slight

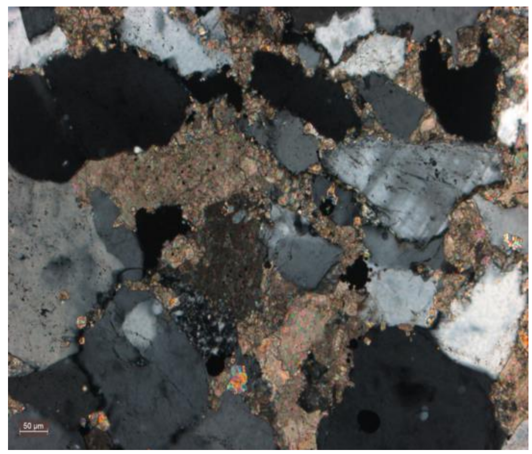


Figure 3.4 Observed at 10x magnification. In XN, anhedral, deformed undulose quartz grains cemented together by both quartz growth and deformed calcite or calcareous material.

Figure 3.5 Observed at 10x magnification. In XN, large andhedral, undulose quartz grains that are cemented together by quartz growth. Also an euhedral clacite grain.

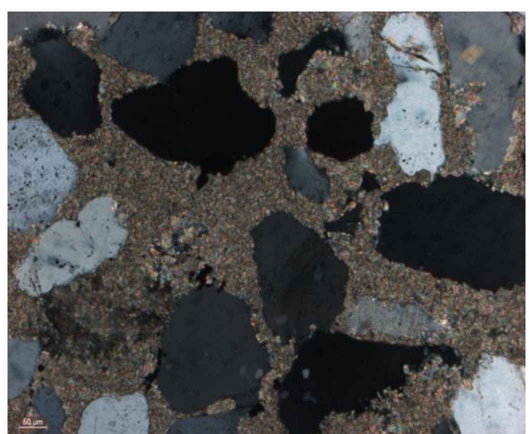


Figure 3.6 Observed at 10x magnification. In XN,subrounded, anhedral quartz grains in a calcareous cement material.

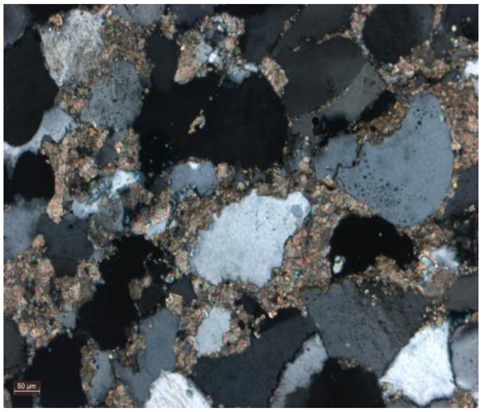


Figure 3.7 Observed at 10x magnification. In XN, anhedral, slighlty deformed quartz grains that are cemented mostly by deformed calcite.

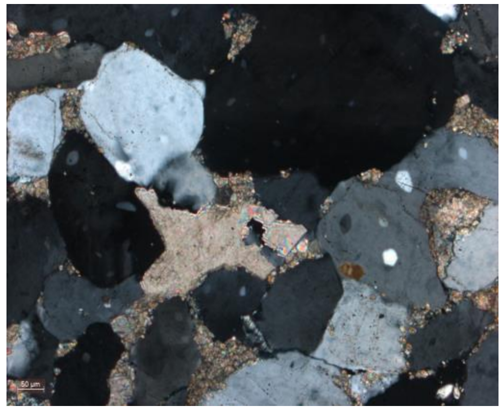


Figure 3.8 Observed at 10x magnification. In XN, subhedral undulose monocrystalline quartz grains cemented together along with cemented of deformed calcite grains.

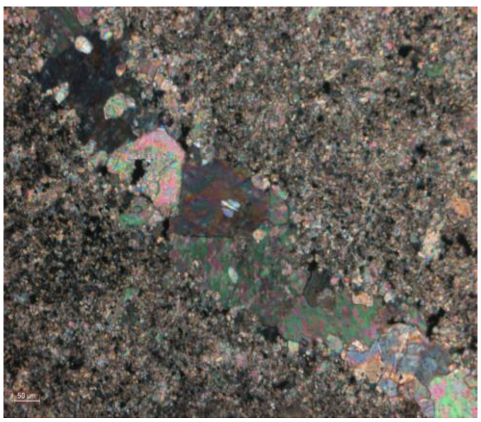


Figure 3.9 Observed at 10x magnification. In XN, portion of massive deformed calcite grain. Exhibits small sedimentary rock fragments and anhedral to subhedral calcite grains.

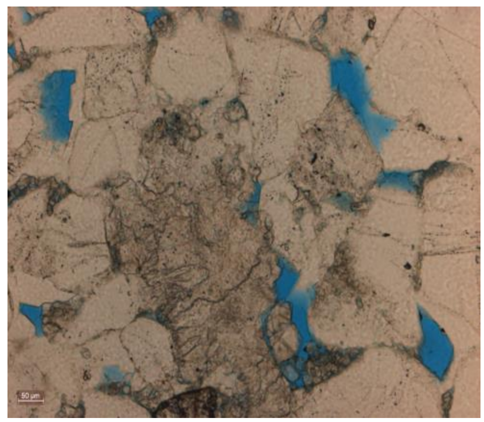


Figure 3.10 Observed at 10x magnification. In PL, blue dye represents the open pores spaces in the thin section,

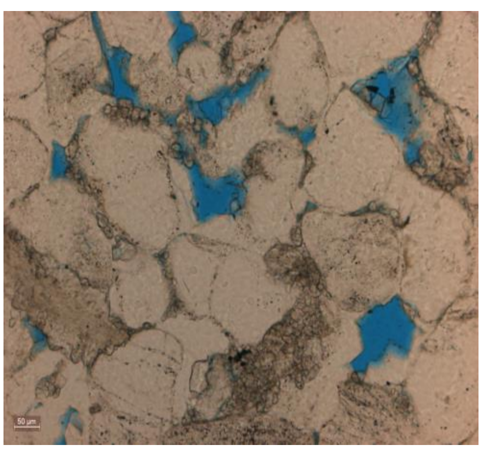


Figure 3.11 Observed at 10x magnification. In PL, blue dye represents the open pores spaces in the thin section, estimating of about 7% porous

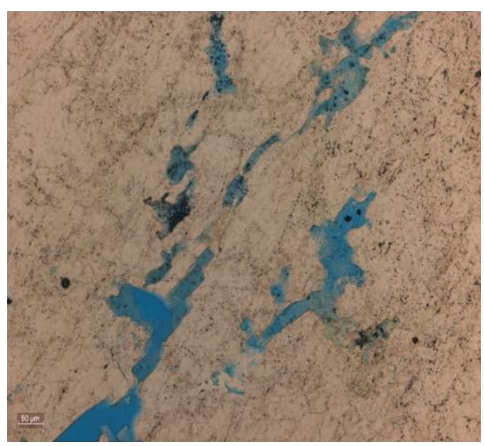


Figure 3.12 Observed at 10x magnification. In PPL blue dye represents the open pores spaces in the thin section, estimating of about 7% porous

Thin Section Analysis Report

Sample ID:	WD-2		4710701266
Formation/Member Name:	Oriskany Sandstone Wood County, WV		
Lithologic Classification:	Sandstone		
Depth/Depth Range:	4200.2 ft	Observed @ 10x	
Date of Analysis:	6/9/2017		
Analyzed by:	Eric Hirschfeld		

	Texture	**Comments**
Grain Size	grain size range = approx 50 microns to 500 microns	homogeneous; massive texture; clastic
Rounding	subangular	
Sorting	very well sorted	

	Composition/Detrital Minerals	**Comments**
	Quartz	
Polycrystalline	n/a	
Monocrystalline	1% composition; subrounded; subhedral; undulose quartz	Figure 2.1 through Figure 2.3 and Figure 2..8
Microcrystalline	most grains are visible under the petroscope	
	Feldspar	
Plagioclase	n/a	
Orthoclase	n/a	
Microcline	n/a	
	Carbonate	
Calcite	97% composition; massively grained, some elongated grains; deformation structures; Euhedral to anhedral; grain size 500 microns to 500 microns; dominant mineral in thin section	Figure 2.6, Figure 2.7
Dolomite	n/a	
Aragonite	n/a	
	Clay	
Illite	n/a	
Smectite	n/a	
Kaolinite	n/a	
Muscovite	n/a	
Chlorite	n/a	
Glauconite	2% composition; small subangular; anhedral to subhedral; XN: dark green, PL: light green/light olive	
	Rock Fragments	
Sedimentary	Predominantly sedimentary fragments of detrital rocks	Figure 2.6, Figure 2.9 through Figure 2.12
Volcanic	some volcanic rock fragments dispersed	
Metamorphic		
	Other (Accessory Minerals)	

	Cementing Materials	**Comments**
Quartz	n/a	
Feldspar	n/a	
Carbonate	completely carbonate cementing; entire smaple is deformed calcite with some residual grains	
Clay	n/a	
Iron Oxide, Hydoxide and/or Sulfide	n/a	
Other	n/a	

	Visual Porosity Estimate	**Comments**
Visual Porosity Estimate	0% Porosity	

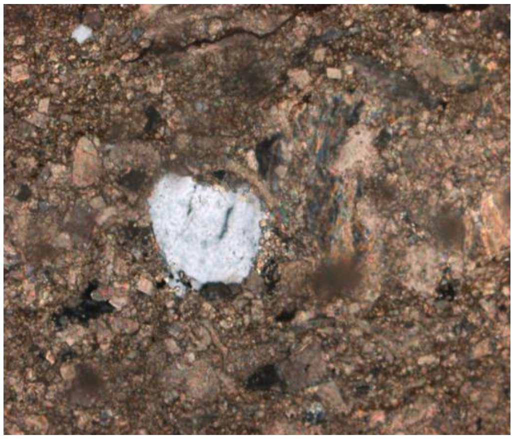


Figure 2.1 Observed at 10x magnification. In XN (unbalanced lighting), subhedral, undulose quartz grain surrounded by deformed calcite grains and calcareous cement

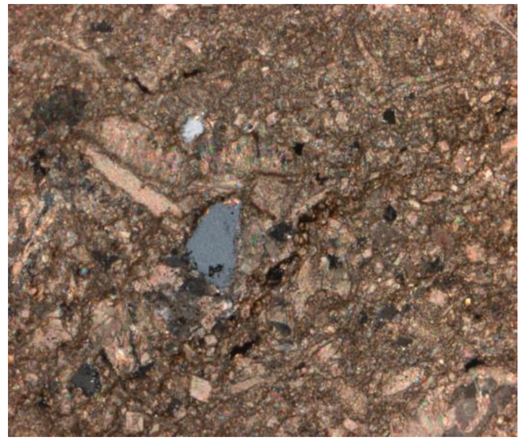


Figure 2.2 Observed at 10x magnification. In XN (unbalanced lighting), subhedral, undulose quartz grain surrounded by elongated, defromed calcite grains, subhedral calcite grains and calcareous cement

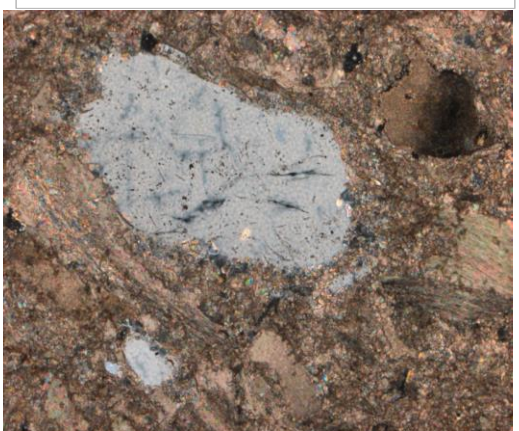


Figure 2.3 Observed at 10x magnification. In XN (unbalanced lighting), anhedral, undulose quartz grain surrounded by anhedral and deformed calcite grains.

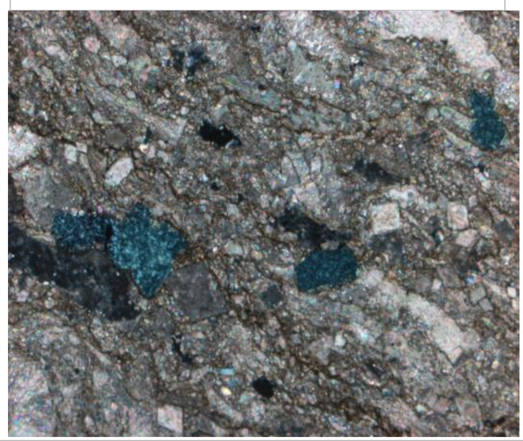


Figure 2.4 Observed at 10x magnification. In XN (balanced lighting), anhedral, greenish glauconite grains with deformed calcite growth and some euhedral calcite grains.

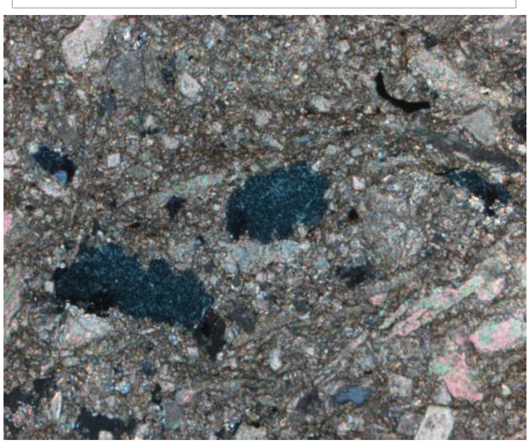


Figure 2.5 Observed at 10x magnification. In XN (balanced lighting), anhredal grains of greenish glauconite grown with deformed calcite grains and a few anhedral calcite grains all within a calcareous cement.

Figure 2.6 Observed at 10x magnification. In XN (balanced lighting), few euhedral calcite grains, deformed calcite growths and the black dots are detrital sedimentary rock fragments.

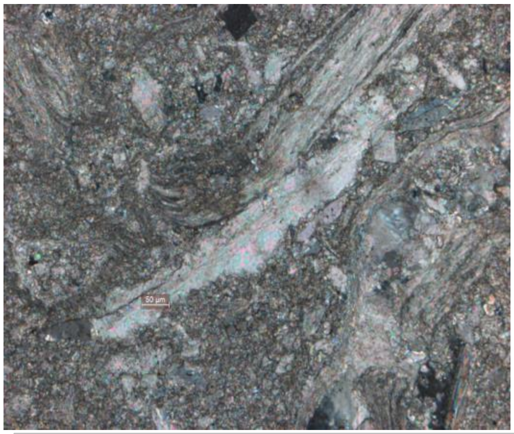


Figure 2.7 Observed at 10x magnification. In XN (balanced lighting) elongated, deformed calcite grains within a calcareous cement

Figure 2.8 Observed at 10x magnification. In XN (unbalanced lighting), anhedral, undulose quartz grain surrounded by multiple euhedral to anhedral calcite grains, all within a calcareous cement.

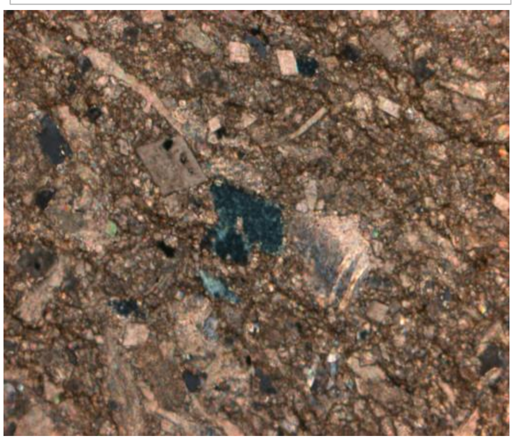


Figure 2.9 Observed at 10x magnification. In XN (unbalanced light) deformed glauconite, black sedimnetary rock fragments, and euhedral and deformed calcite grains winth a calcareous cement.

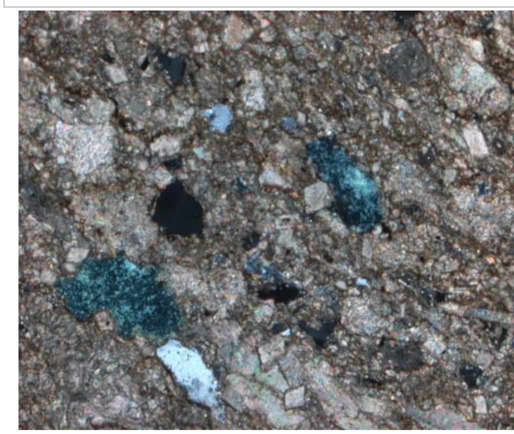


Figure 2.10 Observed at 10x magnification. In XN (balanced lighting), anhedral grains of glauconite (green), sedimentary rock fragments (black) and calcite, all in a calcareous

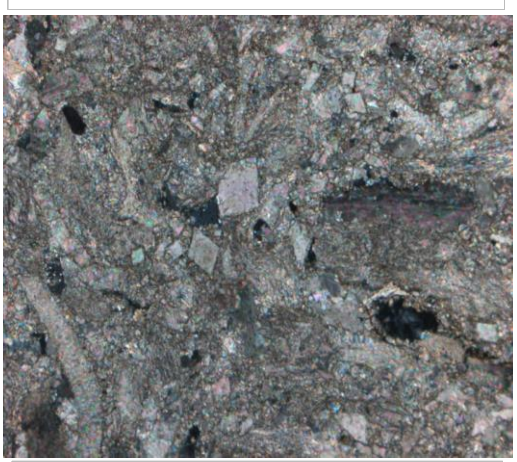


Figure 2.11 Observed at 10x magnification. In XN (balanced lighting) subedral to eudhedral calcite grains, deformed, slightly elongated calcite grains and sedimentary rock fragments.

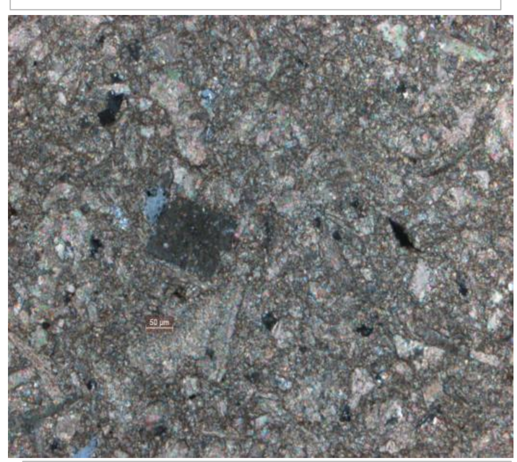


Figure 2.12 Observed at 10x magnification. In XN (balanced lighting), euhedral clacite grain surounded by deformed calcite growth, sedimnetary rock fragments and calcareous

Thin Section Analysis Report

Sample ID:	WD-1		4710701266
Formation/Member Name:	Oriskany Sandstone Wood County, WV		
Lithologic Classification:	Sandstone		
Depth/Depth Range:	4197.1 ft	Observed @ 10x	
Date of Analysis:	6/9/2017		
Analyzed by:	Eric Hirschfeld		

	Texture	**Comments**
Grain Size	average grain size= Approx. 50 microns	homogeneous; massive texure
Rounding	angular to subangular	
Sorting	well sorted	

	Composition/Detrital Minerals	**Comments**
	Quartz	
Polycrystalline	n/a	
Monocrystalline	n/a	
Microcrystalline	most grains are visible under petroscope	
	Feldspar	
Plagioclase	n/a	
Orthoclase	n/a	
Microcline	n/a	
	Carbonate	
Calcite	100% composition; low birefringence; euhedral to anhedral grains; deformation structures of calcite grains; some grains globular; some grains semi-fibrous; XN: tan-pink, light brown, PL: light brown, tan white	Figures 1.1 through 1.12
Dolomite	n/a	
Aragonite	n/a	
	Clay	
Illite	n/a	
Smectite	n/a	
Kaolinite	n/a	
Muscovite	n/a	
Chlorite	n/a	
Glauconite	n/a	
	Rock Fragments	
Sedimentary	Multiple remnants of detrital sedimentary rock fragments	Figures 1.1 through 1.12
Volcanic	n/a	
Metamorphic	n/a	
	Other (Accessory Minerals)	
	n/a	
	n/a	
	n/a	

	Cementing Materials	**Comments**
Quartz	n/a	
Feldspar	n/a	
Carbonate	Deformed calcite grains; calcareous mud acting as the cementing material; entire sample is calcite; very well cemented	Figures 1.1 through 1.12
Clay	n/a	
Iron Oxide, Hydoxide and/or Sulfide	n/a	
Other	n/a	

	Visual Porosity Estimate	**Comments**
Visual Porosity Estimate	0% porosity	Images: WD1_0001 through WD1_0020

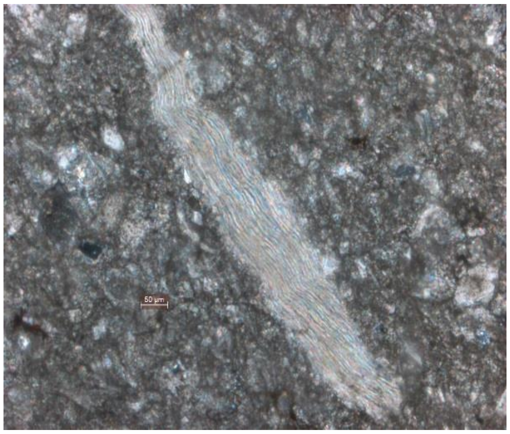


Figure 1.1 Observed at 10x magnificationIn XN, deformed calcite grains, calcite cement semi-fibrous texture.

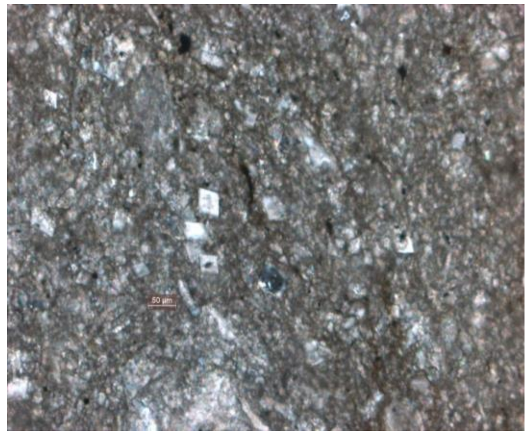
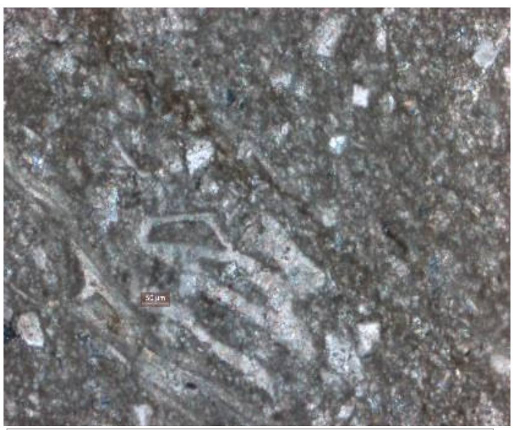


Figure 1.2 Observed at 10x magnification. In XN, euhedral calcite grains and deformed calcite grains in a calcareous cement.



Figrue 1.3 Observed at 10x magnification. In XN, highly deformed calcite grains intergrown and some subhedral calcite grains

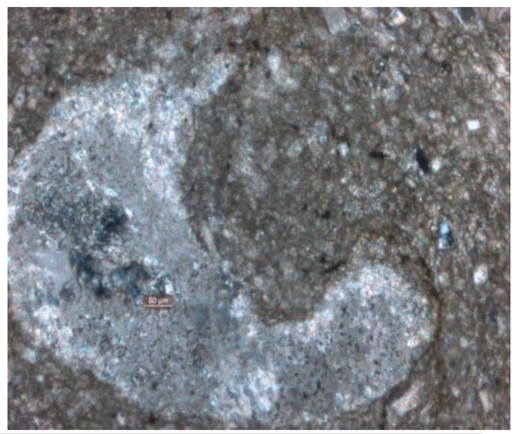


Figure 1.4 Observed at 10x magnification. In XN, masssive, globular calcite grain, some anhedral calcite grains

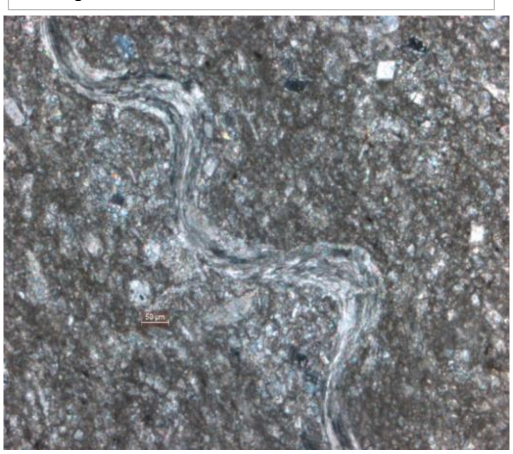


Figure 1.5 Observed at 10x magnification. In XN, deformed semi-fibrous calcite grain, anhedral and subhedral calcite grains. Calcareous cement

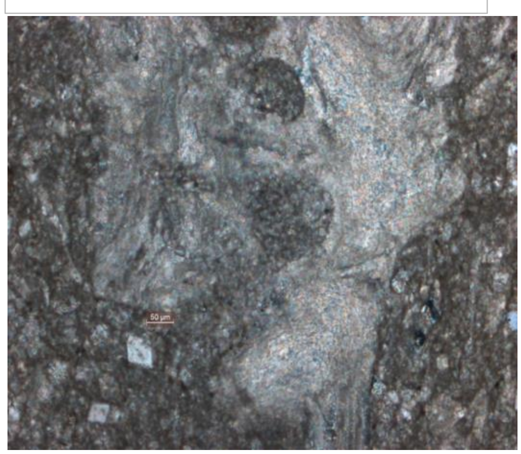


Figure 1.6 Observed at 10x magnification. In XN, massive, deformed calcite growth. Euhedral and subhedral calcite grains. Few remnants of detrital sedimnetray rock fragments

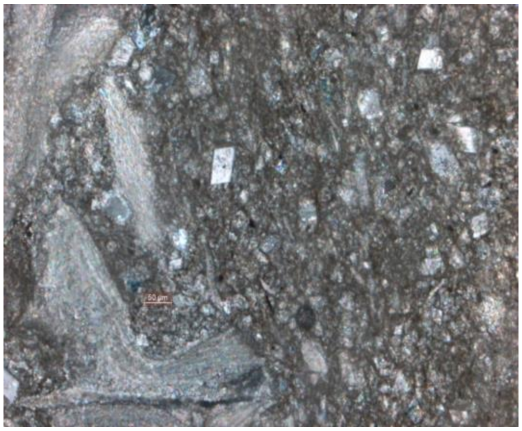


Figure 1.7 Observed at 10x magnification. In XN, massive, semi-globular, deformed calcite growth, euhedral and subhedral clacite grains, calcareous cement.

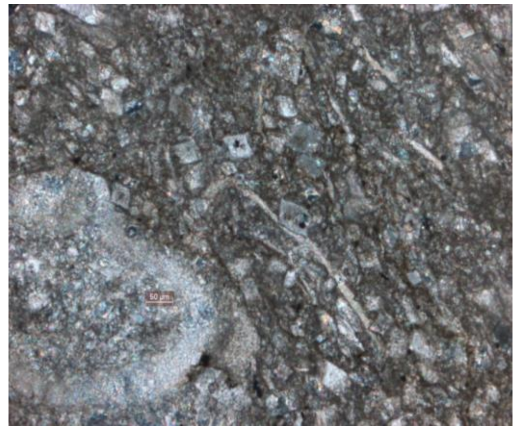


Figure 1.8 Observed at 10x magnification. In XN,many euhedral to anhedral calcite grains. Large deformed calcite growth

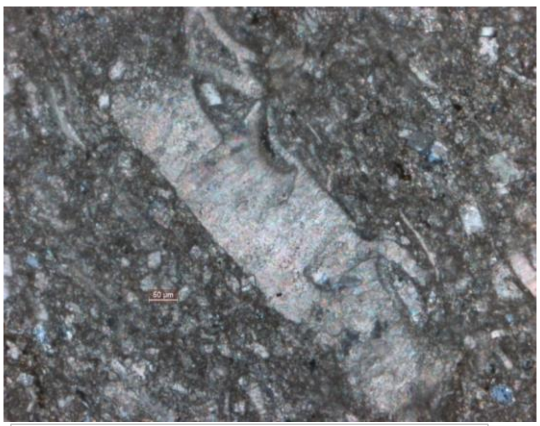


Figure 1.9 Observed at 10x magnification. In XN**,** massive, subhedral calcite grain surrounded by smaller anhedral to subhedral calcite grains. All within a calcareous cement.

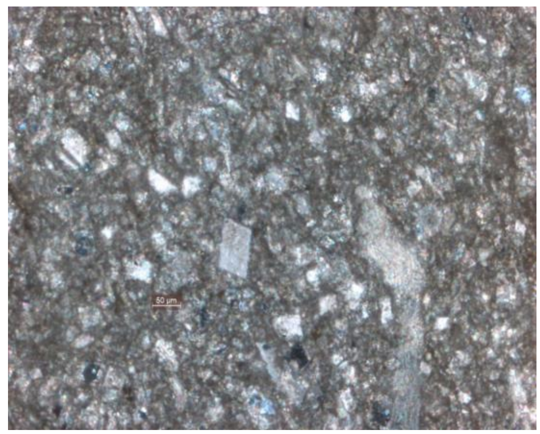


Figure 1.10 Observed at 10x magnification. In XN, subhedral to euhedral calcite grains. Some deformation of grains within calcareous cement

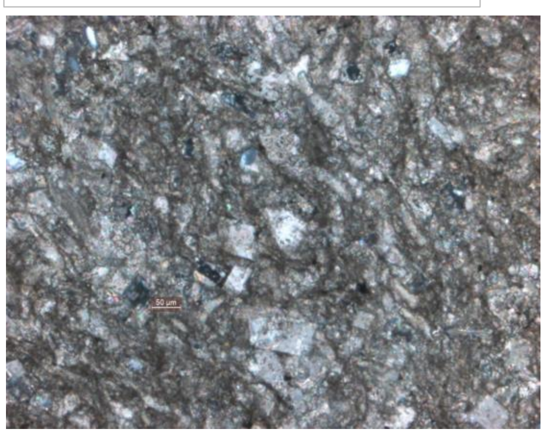


Figure 1.11 Observed at 10x magnification.In XN**,** anhedral to subhedral grains of calcite in calcareous cement. Few sedimentary rock fragments

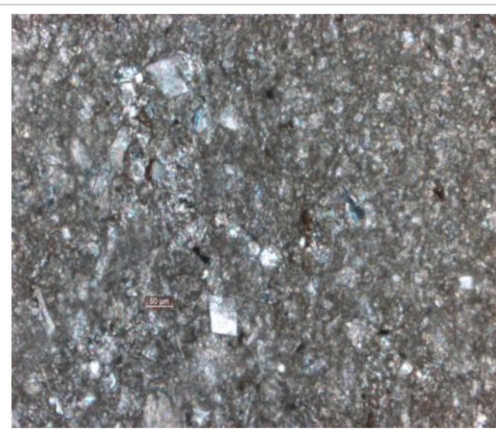


Figure 1.12 Observed at 10x magnification. In XN, euhedral calcite grains and deformed grains within calareous cement. Also present is a few sedimentary rock fragments.

Thin Section Analysis Report

Sample ID: WZ-1
Formation/Member Name: Weir
Lithologic Classification: Sandstone/Graywacke
Depth/Depth Range: 2462.7 ft
Date of Analysis: 6/28/2017
Analyzed by: S. Shank

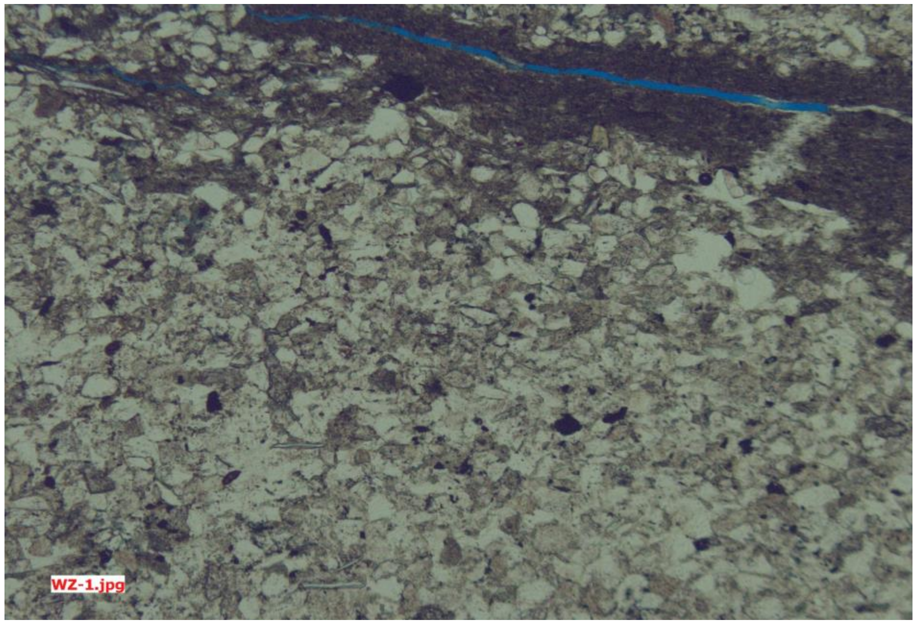
Texture		Comments
Grain Size	very fine-grained, 62-125µ	very fine-grained dirty sandstone, clays appear to be from alteration of feldspar, detrital and cement?, sparse carbonate
Rounding	subangular	
Sorting		

Composition/Detrital Minerals		Comments
Quartz		
Polycrystalline	<<1%	
Monocrystalline	65%	
Microcrystalline		
Feldspar		
Plagioclase	10%	
Orthoclase		rough estimates, now strongly altered to sericite
Microcline	10%	
Carbonate		
Calcite		
Dolomite		
Aragonite		
Clay		
Illite		
Smectite		
Kaolinite		
Muscovite	<1%	few scattered flakes, biotite also?
Chlorite	5%	scattered greenish grunge
Glauconite		
Rock Fragments		
Sedimentary		
Volcanic		
Metamorphic		
Other (Accessory Minerals)		

Cementing Materials		Comments
Quartz		minimal, difficult to observe because very fine-grained
Feldspar		
Carbonate	2%	scattered patches
Clay	8%	rough guess, hard to distinguish from detrital clay, altered feldspar
Iron Oxide, Hydoxide and/or Sulfide		
Other		

Visual Porosity Estimate	Comments
<<1%	no porosity except for thin discontinuous fracture

50x magnification, 2.5 mm field of view



Thin Section Analysis Report

Sample ID:	WZ-2
Formation/Member Name:	Weir
Lithologic Classification:	Sandstone/Graywacke
Depth/Depth Range:	2474.9 ft
Date of Analysis:	6/28/2017
Analyzed by:	S. Shank

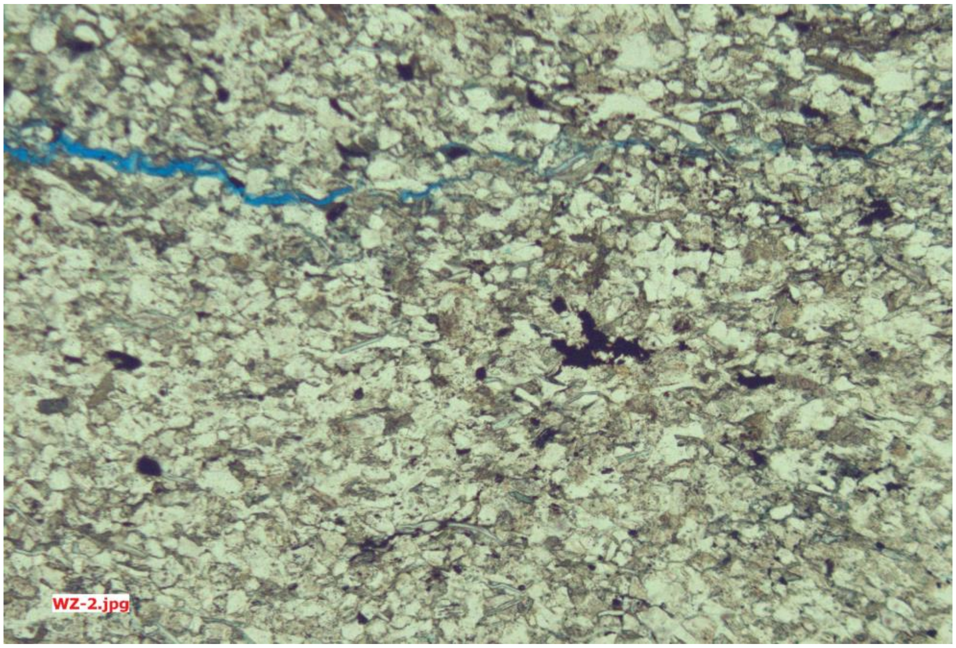
Texture		**Comments**
Grain Size	very fine-grained, 62-125µ	very fine-grained dirty sandstone, clays appear to be from alteration of feldspar, detrital and cement?, sparse carbonate
Rounding	subangular to subrounded	
Sorting	well sorted	

Composition/Detrital Minerals		**Comments**
Quartz		
Polycrystalline		
Monocrystalline	65%	
Microcrystalline		
Feldspar		
Plagioclase	10%	
Orthoclase		rough estimates, now strongly altered to sericite, alteration to carbonate also?
Microcline	10%	
Carbonate		
Calcite	2%	scattered grains and patches
Dolomite		
Aragonite		
Clay		
Illite		
Smectite		
Kaolinite		
Muscovite	<1%	few scattered flakes, biotite also?
Chlorite	5%	scattered greenish grunge
Glauconite		
Rock Fragments		
Sedimentary	<1%	1 mm shale clast
Volcanic		
Metamorphic		
Other (Accessory Minerals)		
	opaques	

Cementing Materials		**Comments**
Quartz		minimal, difficult to observe because very fine-grained
Feldspar		
Carbonate	2%	scattered patches
Clay	8%	rough guess, hard to distinguish from detrital clay, altered feldspar
Iron Oxide, Hydoxide and/or Sulfide		
Other		

Visual Porosity Estimate	**Comments**
<<1%	virtually no porosity except for thin discontinuous fractures

50x magnification, 2.5 mm field of view



Thin Section Analysis Report

Sample ID:	WZ-3
Formation/Member Name:	Weir
Lithologic Classification:	Sandstone/Graywacke
Depth/Depth Range:	2482.5 ft
Date of Analysis:	6/28/2017
Analyzed by:	S. Shank

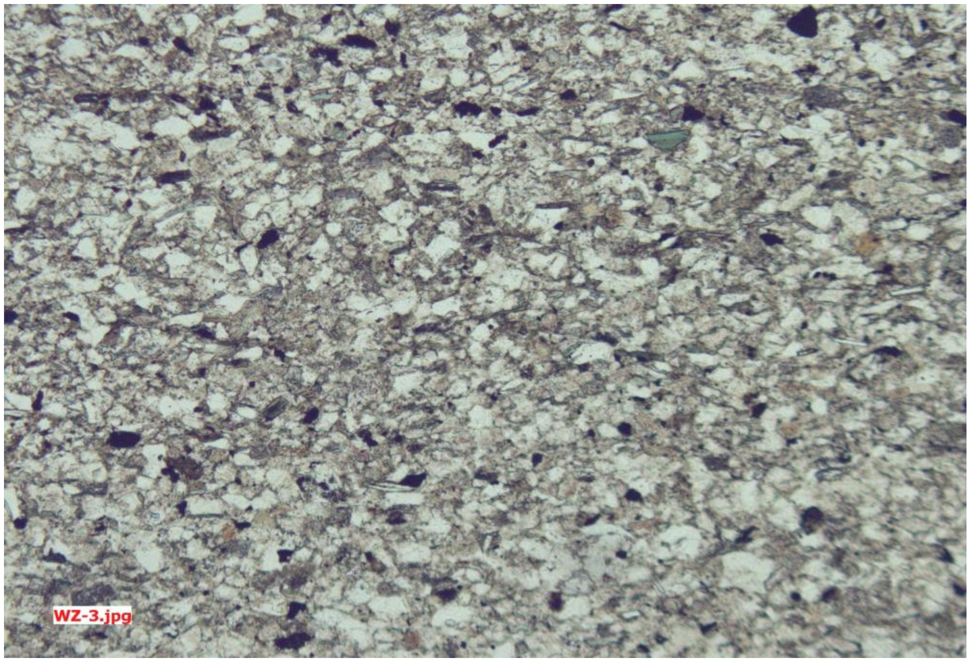
Texture		**Comments**
Grain Size	very fine-grained, 62-125µ	very fine-grained dirty sandstone, clays appear to be from alteration of feldspar, detrital and cement?, sparse carbonate
Rounding	subangular to subrounded	
Sorting	well sorted	

Composition/Detrital Minerals		**Comments**
Quartz		
Polycrystalline		
Monocrystalline	65%	
Microcrystalline		
Feldspar		
Plagioclase	10%	
Orthoclase		rough estimates, now strongly altered to sericite, alteration to carbonate also?
Microcline	10%	
Carbonate		
Calcite	2%	scattered grains and patches
Dolomite		
Aragonite		
Clay		
Illite		
Smectite		
Kaolinite		
Muscovite	<1%	few scattered flakes, biotite also?
Chlorite	5%	scattered greenish grunge
Glauconite		
Rock Fragments		
Sedimentary		
Volcanic		
Metamorphic		
Other (Accessory Minerals)		
	opaques	

Cementing Materials		**Comments**
Quartz		minimal, difficult to observe because very fine-grained
Feldspar		
Carbonate	2%	scattered patches
Clay	8%	rough guess, hard to distinguish from detrital clay, altered feldspar
Iron Oxide, Hydoxide and/or Sulfide		
Other		

Visual Porosity Estimate	**Comments**
<<1%	virtually no porosity

50x magnification, 2.5 mm field of view



Thin Section Analysis Report

Sample ID: WZ-4
Formation/Member Name: Weir
Lithologic Classification: Sandstone/Graywacke
Depth/Depth Range: 2489.8 ft
Date of Analysis: 6/28/2017
Analyzed by: S. Shank

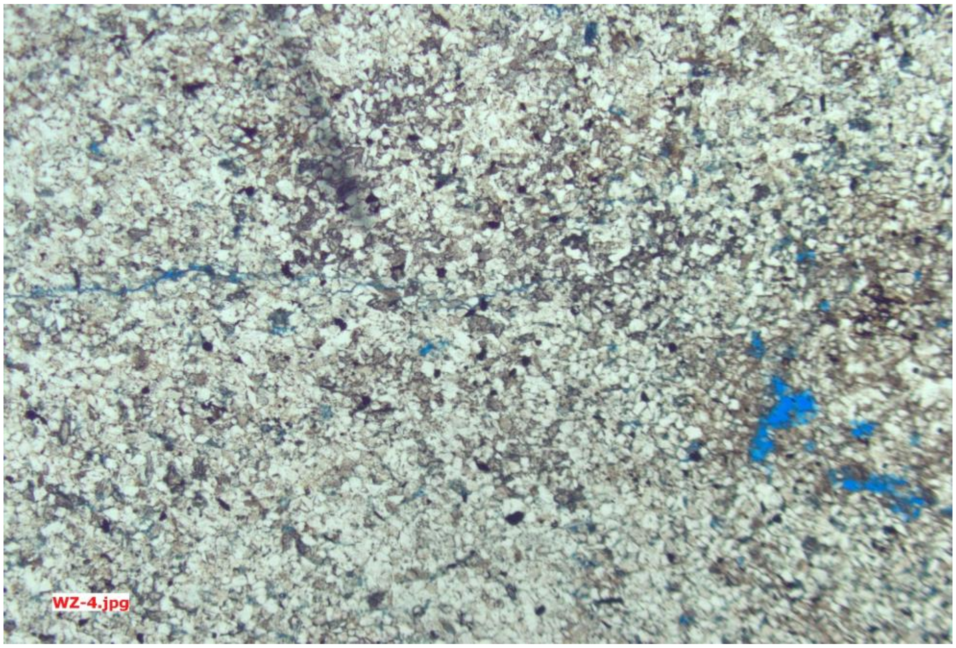
Texture		Comments
Grain Size	very fine-grained, 62-125µ	very fine-grained dirty sandstone, clays appear to be from alteration of feldspar, detrital and cement?, carbonate
Rounding	subangular to subrounded	
Sorting	well sorted	

Composition/Detrital Minerals		Comments
Quartz		
Polycrystalline		
Monocrystalline	75%	
Microcrystalline		
Feldspar		
Plagioclase	5%	
Orthoclase		rough estimates, now strongly altered to sericite, alteration to carbonate also?
Microcline	5%	
Carbonate		
Calcite	2%	scattered grains and patches
Dolomite		
Aragonite		
Clay		
Illite		
Smectite		
Kaolinite		
Muscovite	<1%	few scattered flakes, biotite also?
Chlorite	5%	scattered greenish grunge
Glauconite		
Rock Fragments		
Sedimentary		
Volcanic		
Metamorphic		
Other (Accessory Minerals)		
	opaques	

Cementing Materials		Comments
Quartz		minimal, difficult to observe because very fine-grained
Feldspar		
Carbonate	2%	scattered patches
Clay	8%	rough guess, hard to distinguish from detrital clay, altered feldspar
Iron Oxide, Hydoxide and/or Sulfide		
Other		

Visual Porosity Estimate	Comments
1%	some intergranular porosity, patchy occurrence, few thin fractures

25x magnification, 5mm field of view



Thin Section Analysis Report

Sample ID:	WZ-5
Formation/Member Name:	Weir
Lithologic Classification:	Sandstone/graywacke
Depth/Depth Range:	2492.4 ft
Date of Analysis:	7/2/2017
Analyzed by:	S. Shank

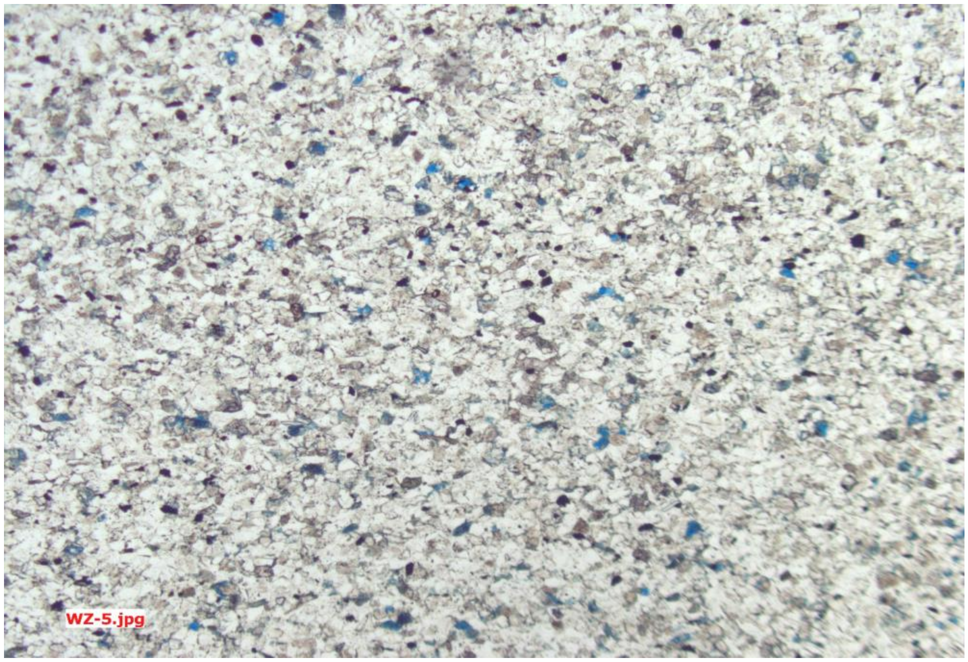
Texture		**Comments**
Grain Size	very fine-grained, 62-125µ	very fine-grained dirty sandstone, clays appear to be from alteration of feldspar, detrital and cement?, carbonate
Rounding	subangular to subrounded	
Sorting	well sorted	

Composition/Detrital Minerals		**Comments**
Quartz		
Polycrystalline		
Monocrystalline	75%	
Microcrystalline		
Feldspar		
Plagioclase	5%	
Orthoclase		rough estimates, now strongly altered to sericite, alteration to carbonate also?
Microcline	5%	
Carbonate		
Calcite	2%	scattered grains and patches
Dolomite		
Aragonite		
Clay		
Illite		
Smectite		
Kaolinite		
Muscovite	<1%	few scattered flakes, biotite also?
Chlorite	5%	scattered greenish grunge
Glauconite		
Rock Fragments		
Sedimentary		
Volcanic		
Metamorphic		
Other (Accessory Minerals)		
	opaques	

Cementing Materials		**Comments**
Quartz		minimal, difficult to observe because very fine-grained
Feldspar		
Carbonate	2%	scattered patches
Clay	8%	rough guess, hard to distinguish from detrital clay, altered feldspar
Iron Oxide, Hydoxide and/or Sulfide		
Other		

Visual Porosity Estimate	**Comments**
1%	some intergranular porosity

25x magnification, 5mm field of view



Thin Section Analysis Report

Sample ID: WZ-6
Formation/Member Name: Weir
Lithologic Classification: Sandstone/Graywacke
Depth/Depth Range: 2497.5 ft
Date of Analysis: 7/2/2017
Analyzed by: S. Shank

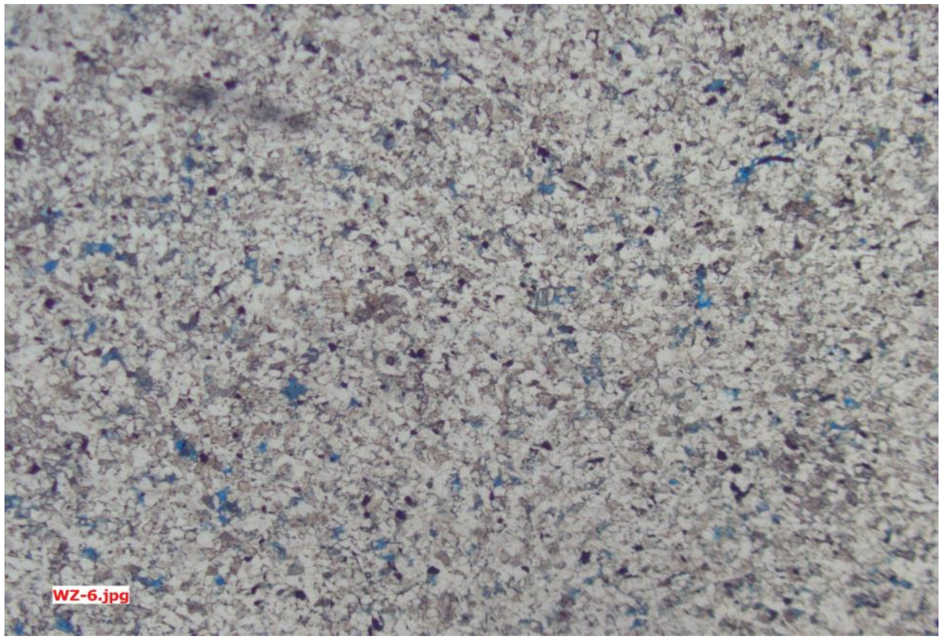
Texture		Comments
Grain Size	very fine-grained, 62-125µ	very fine-grained dirty sandstone, clays appear to be from alteration of feldspar, detrital and cement?, carbonate
Rounding	subangular to subrounded	
Sorting	well sorted	

Composition/Detrital Minerals		Comments
Quartz		
Polycrystalline		
Monocrystalline	75%	
Microcrystalline		
Feldspar		
Plagioclase	5%	
Orthoclase		rough estimates, now strongly altered to sericite, alteration to carbonate also?
Microcline	5%	
Carbonate		
Calcite	2%	scattered grains and patches
Dolomite		
Aragonite		
Clay		
Illite		
Smectite		
Kaolinite		
Muscovite	<1%	few scattered flakes, biotite also?
Chlorite	5%	scattered greenish grunge
Glauconite		
Rock Fragments		
Sedimentary		
Volcanic		
Metamorphic		
Other (Accessory Minerals)		
	opaques	

Cementing Materials		Comments
Quartz		minimal, difficult to observe because very fine-grained
Feldspar		
Carbonate	2%	scattered patches
Clay	8%	rough guess, hard to distinguish from detrital clay, altered feldspar
Iron Oxide, Hydoxide and/or Sulfide		
Other		

Visual Porosity Estimate	Comments
2%	some intergranular porosity

25x magnification, 5mm field of view



Thin Section Analysis Report

Sample ID: WZ-3
Formation/Member Name: Weir
Lithologic Classification: Sandstone/Graywacke
Depth/Depth Range: 2502.8 ft
Date of Analysis: 7/2/2017
Analyzed by: S. Shank

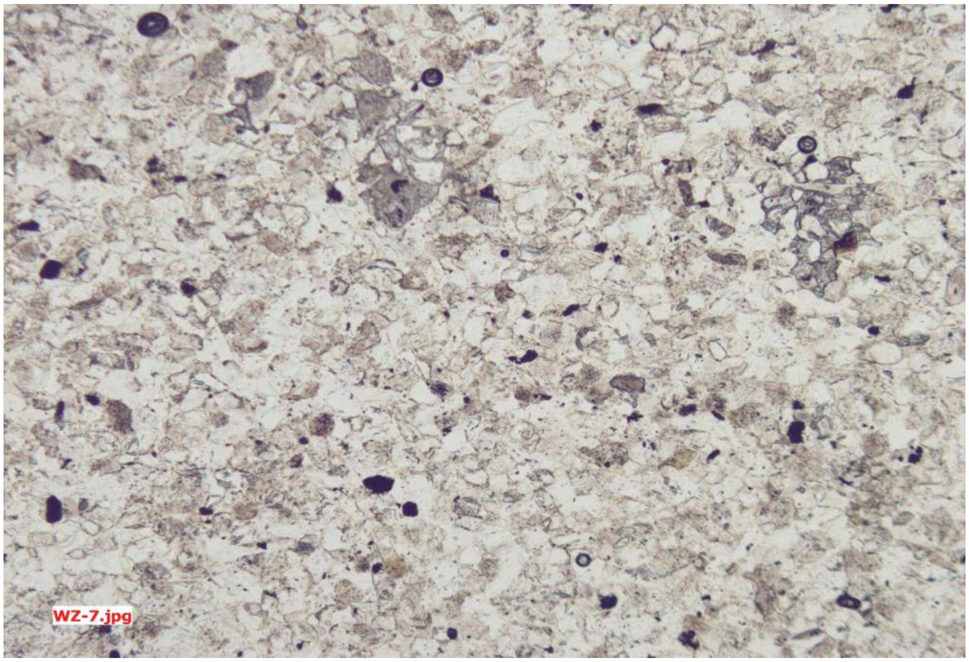
Texture		Comments
Grain Size	very fine-grained, 62-125µ	very fine-grained dirty sandstone, clays appear to be from alteration of feldspar, detrital and cement?, sparse carbonate
Rounding	subangular to subrounded	
Sorting	well sorted	

Composition/Detrital Minerals		Comments
Quartz		
Polycrystalline		
Monocrystalline	65%	
Microcrystalline		
Feldspar		
Plagioclase	10%	
Orthoclase		rough estimates, now strongly altered to sericite, alteration to carbonate also?
Microcline	10%	
Carbonate		
Calcite	2%	scattered grains and patches
Dolomite		
Aragonite		
Clay		
Illite		
Smectite		
Kaolinite		
Muscovite	<1%	few scattered flakes, biotite also?
Chlorite	5%	scattered greenish grunge
Glauconite		
Rock Fragments		
Sedimentary		
Volcanic		
Metamorphic		
Other (Accessory Minerals)		
	opaques	

Cementing Materials		Comments
Quartz		minimal, difficult to observe because very fine-grained
Feldspar		
Carbonate	2%	scattered patches
Clay	8%	rough guess, hard to distinguish from detrital clay, altered feldspar
Iron Oxide, Hydoxide and/or Sulfide		
Other		

Visual Porosity Estimate	Comments
<<1%	virtually no porosity

50x magnification, 2.5 mm field of view



Thin Section Analysis Report

Sample ID:	WZ-8
Formation/Member Name:	Weir
Lithologic Classification:	Sandstone/Graywacke
Depth/Depth Range:	2516.8 ft
Date of Analysis:	7/2/2017
Analyzed by:	S. Shank

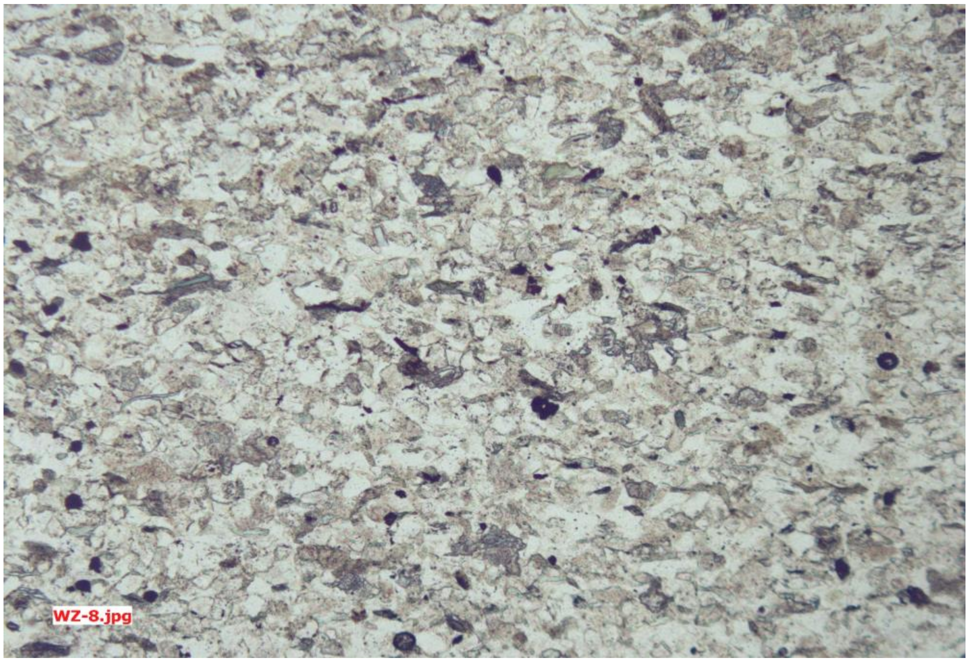
Texture		**Comments**
Grain Size	very fine-grained, 62-125µ	very fine-grained dirty sandstone, clays appear to be from alteration of feldspar, detrital and cement?, carbonate
Rounding	subangular to subrounded	
Sorting	well sorted	

Composition/Detrital Minerals		**Comments**
Quartz		
Polycrystalline		
Monocrystalline	70%	
Microcrystalline		
Feldspar		
Plagioclase	8%	
Orthoclase		rough estimates, now strongly altered to sericite, alteration to carbonate also?
Microcline	8%	
Carbonate		
Calcite	2%	scattered grains and patches
Dolomite		
Aragonite		
Clay		
Illite		
Smectite		
Kaolinite		
Muscovite	<1%	few scattered flakes, biotite also?
Chlorite	5%	scattered greenish grunge
Glauconite		
Rock Fragments		
Sedimentary		
Volcanic		
Metamorphic		
Other (Accessory Minerals)		
	opaques	

Cementing Materials		**Comments**
Quartz		minimal, difficult to observe because very fine-grained
Feldspar		
Carbonate	2%	scattered patches
Clay	5%	rough guess, hard to distinguish from detrital clay, altered feldspar
Iron Oxide, Hydoxide and/or Sulfide		
Other		

Visual Porosity Estimate	**Comments**
0%	no apparent porosity, no blue epoxy?

50x magnification, 2.5 mm field of view



Thin Section Analysis Report

Sample ID:	WZ-9
Formation/Member Name:	Weir
Lithologic Classification:	Clayey Sandstone
Depth/Depth Range:	2536.8 ft
Date of Analysis:	6/22/2017
Analyzed by:	L. Ditzler

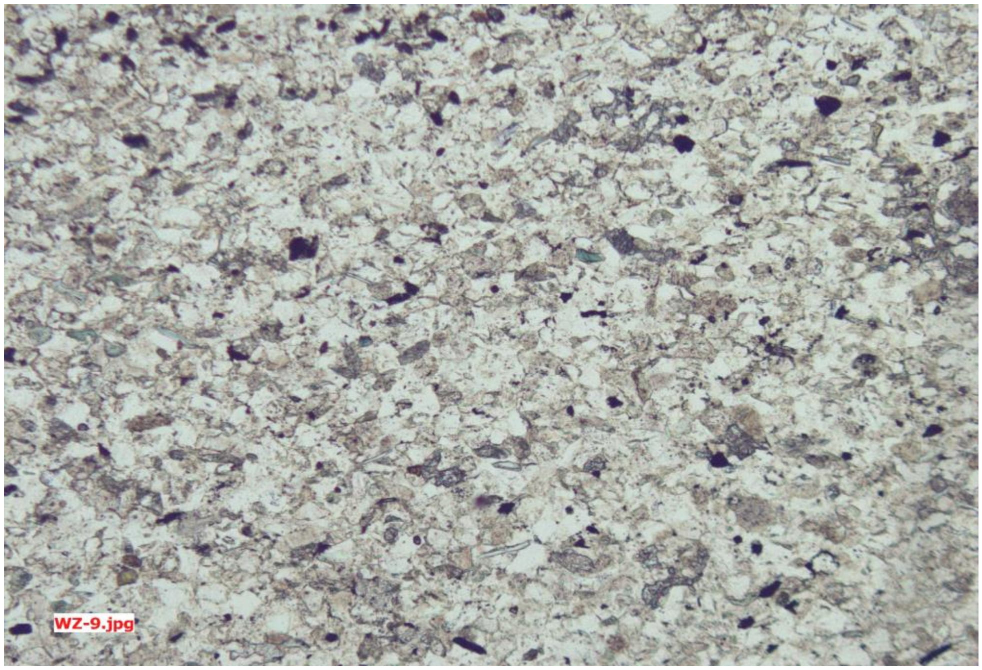
Texture		**Comments**
Grain Size	very fine-grained, 62-125µ	
Rounding	subrounded	
Sorting	very well sorted	

Composition/Detrital Minerals		**Comments**
Quartz		
Polycrystalline		
Monocrystalline	77%	
Microcrystalline		
Feldspar		
Plagioclase	1%	total feldspar
Orthoclase		
Microcline		
Carbonate		
Calcite	1%	scattered grains and patches
Dolomite		
Aragonite		
Clay		
Illite		
Smectite		
Kaolinite		
Muscovite		
Chlorite		
Glauconite		
Rock Fragments		
Sedimentary		
Volcanic		
Metamorphic		
Other (Accessory Minerals)		
	2%	opaques

Cementing Materials		**Comments**
Quartz		
Feldspar		
Carbonate	1%	scattered patches
Clay	18%	grains of muscovite and chlorite exist, but clays occur mostly as a cement
Iron Oxide, Hydoxide and/or Sulfide		
Other		

Visual Porosity Estimate		**Comments**
	1%	but no blue epoxy?

50x magnification, 2.5 mm field of view



Thin Section Analysis Report

Sample ID: WZ-10
Formation/Member Name: Weir
Lithologic Classification: Clayey Sandstone
Depth/Depth Range: 2539.7 ft
Date of Analysis: 6/22/2017
Analyzed by: L. Ditzler

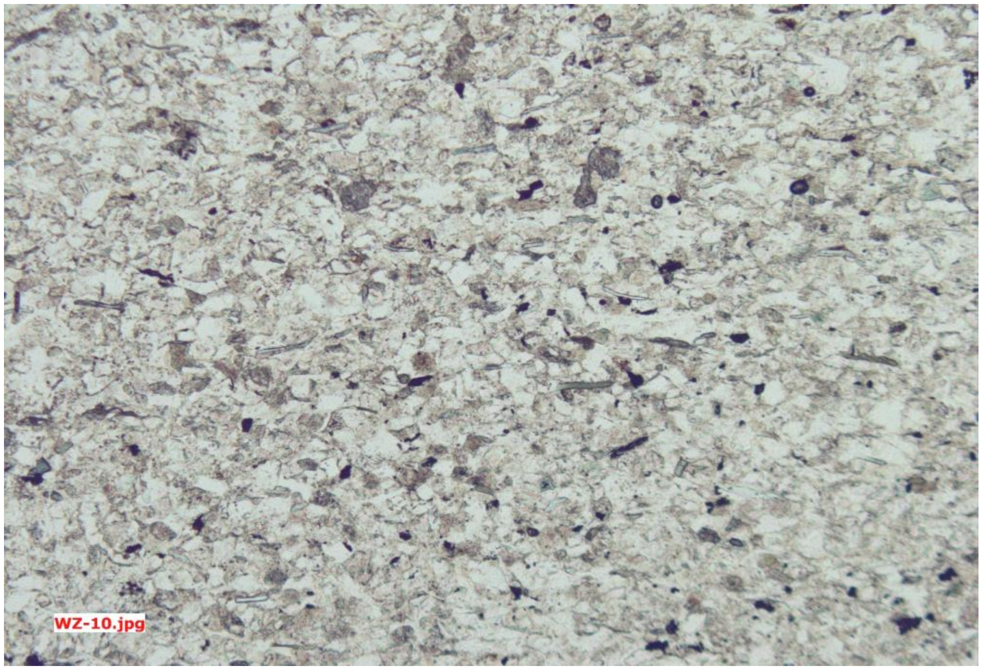
Texture		Comments
Grain Size	very fine-grained, 62-125µ	
Rounding	subrounded	
Sorting	very well sorted	

Composition/Detrital Minerals		Comments
Quartz		
Polycrystalline		
Monocrystalline	78%	
Microcrystalline		
Feldspar		
Plagioclase	1%	total feldspar
Orthoclase		
Microcline		
Carbonate		
Calcite	<1%	scattered grains and patches
Dolomite		
Aragonite		
Clay		
Illite		
Smectite		
Kaolinite		
Muscovite		
Chlorite		
Glauconite		
Rock Fragments		
Sedimentary		
Volcanic		
Metamorphic		
Other (Accessory Minerals)		
	1%	opaques

Cementing Materials		Comments
Quartz		
Feldspar		
Carbonate		
Clay	20%	grains of muscovite and chlorite exist, but clays occur mostly as a cement
Iron Oxide, Hydoxide and/or Sulfide		
Other		

Visual Porosity Estimate	Comments
2%	but no blue epoxy?

50x magnification, 2.5 mm field of view



Thin Section Analysis Report

Sample ID: WZ-11
Formation/Member Name: Weir
Lithologic Classification: Clayey Sandstone
Depth/Depth Range: 2545.4 ft
Date of Analysis: 6/19/2017
Analyzed by: L. Ditzler

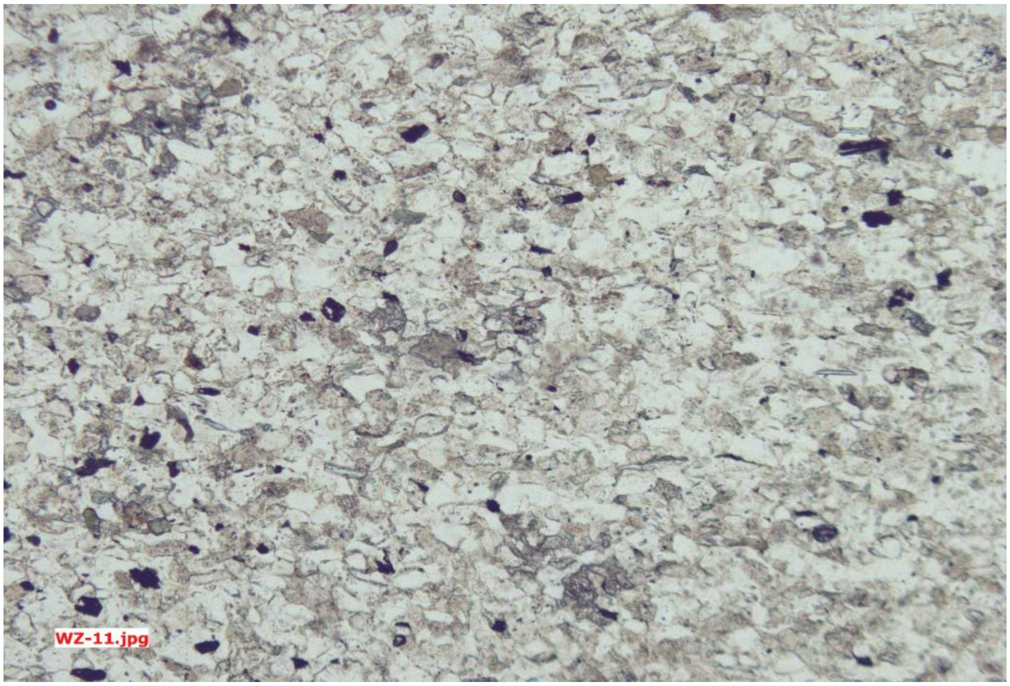
Texture		Comments
Grain Size	very fine-grained, 62-125µ	
Rounding	poorly rounded	
Sorting	very well sorted	

Composition/Detrital Minerals		Comments
Quartz		
Polycrystalline		
Monocrystalline	87%	
Microcrystalline		
Feldspar		
Plagioclase	2%	total feldspar
Orthoclase		
Microcline		
Carbonate		
Calcite	<1%	scattered grains and patches
Dolomite		
Aragonite		
Clay		
Illite		
Smectite		
Kaolinite		
Muscovite		
Chlorite		
Glauconite		
Rock Fragments		
Sedimentary		
Volcanic		
Metamorphic		
Other (Accessory Minerals)		
	1%	opaques

Cementing Materials		Comments
Quartz		
Feldspar		
Carbonate	2%	scattered patches
Clay	8%	cement
Iron Oxide, Hydoxide and/or Sulfide		
Other		

Visual Porosity Estimate		Comments
	<1%	but no blue epoxy?

50x magnification, 2.5 mm field of view



Thin Section Analysis Report

Sample ID:	WZ-12
Formation/Member Name:	Weir
Lithologic Classification:	Clayey Sandstone
Depth/Depth Range:	2550.5 ft
Date of Analysis:	6/19/2017
Analyzed by:	L. Ditzler

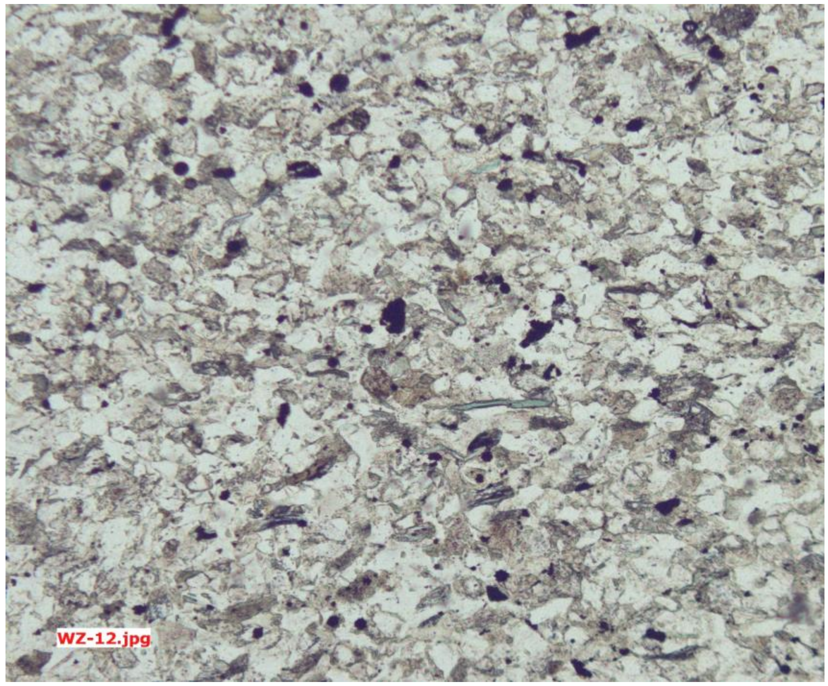
Texture		**Comments**
Grain Size	very fine-grained, 62-125µ	
Rounding	subangular	
Sorting	very well sorted	

Composition/Detrital Minerals		**Comments**
Quartz		
Polycrystalline	2%	
Monocrystalline	84%	
Microcrystalline		
Feldspar		
Plagioclase	2%	total feldspar
Orthoclase		
Microcline		
Carbonate		
Calcite		
Dolomite		
Aragonite		
Clay		
Illite		
Smectite		
Kaolinite		
Muscovite		
Chlorite		
Glauconite		
Rock Fragments		
Sedimentary		
Volcanic		
Metamorphic		
Other (Accessory Minerals)		
	2%	opaque, dark red brown

Cementing Materials		**Comments**
Quartz		
Feldspar		
Carbonate	2%	scattered patches
Clay	8%	grains of muscovite and chlorite exist, but clays occur mostly as a cement
Iron Oxide, Hydoxide and/or Sulfide		
Other		

Visual Porosity Estimate	**Comments**
1%	but no blue epoxy?

50x magnification, 2.5 mm field of view



Thin Section Analysis Report

Sample ID: WZ-13
Formation/Member Name: Weir
Lithologic Classification: clayey sandstone
Depth/Depth Range: 2560.2 ft
Date of Analysis: 6/19/2017
Analyzed by: L. Ditzler

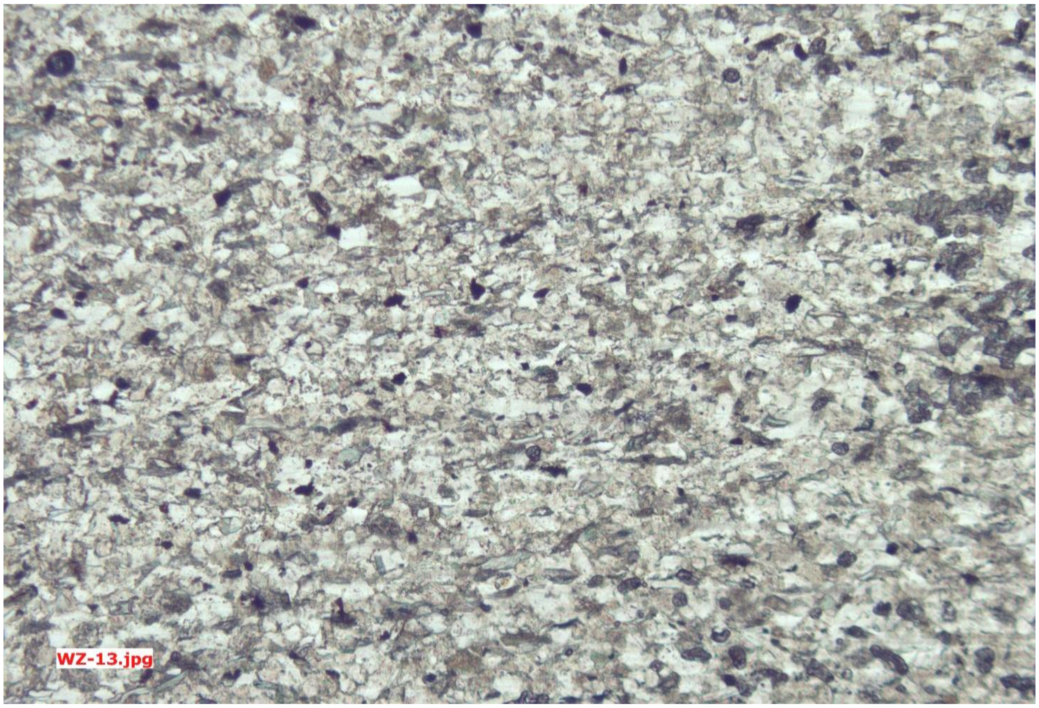
Texture			Comments
Grain Size	very fine-grained, 62-125µ		
Rounding	subangular		
Sorting	well sorted		

Composition/Detrital Minerals			Comments
Quartz			
Polycrystalline			
Monocrystalline		50%	
Microcrystalline			
Feldspar			
Plagioclase	<1%		total feldspar
Orthoclase			
Microcline			
Carbonate			
Calcite			
Dolomite			
Aragonite			
Clay			
Illite			
Smectite			
Kaolinite			
Muscovite	<1%		
Chlorite	<1%		
Glauconite			
Rock Fragments			
Sedimentary			
Volcanic			
Metamorphic			
Other (Accessory Minerals)			
		1%	opaque, dark red brown

Cementing Materials			Comments
Quartz			
Feldspar			
Carbonate	<1%		scattered patches
Clay		49%	some clay and mica grains, some clay cement
Iron Oxide, Hydoxide and/or Sulfide			
Other			

Visual Porosity Estimate			Comments
		1%	but no blue epoxy?

50x magnification, 2.5 mm field of view



Thin Section Analysis Report

Sample ID: WZ-14
Formation/Member Name: Weir
Lithologic Classification: clayey sandstone
Depth/Depth Range: 2685 ft
Date of Analysis: 6/19/2017
Analyzed by: L. Ditzler

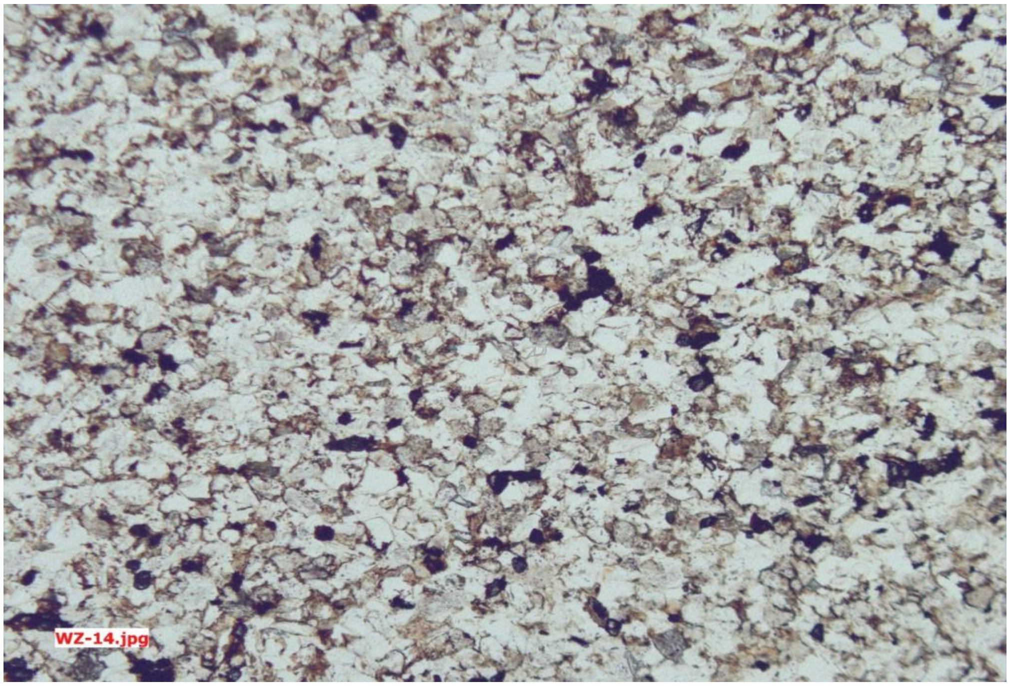
Texture			Comments
Grain Size	very fine-grained, 62-125µ		
Rounding	subangular		
Sorting	well sorted		

Composition/Detrital Minerals			Comments
Quartz			
Polycrystalline			
Monocrystalline		85%	
Microcrystalline			
Feldspar			
Plagioclase	<1%		total feldspar
Orthoclase			
Microcline			
Carbonate			
Calcite			
Dolomite			
Aragonite			
Clay			
Illite			
Smectite			
Kaolinite			
Muscovite		1%	
Chlorite			
Glauconite			
Rock Fragments			
Sedimentary			
Volcanic			
Metamorphic			
Other (Accessory Minerals)			
		5%	opaque, dark red brown

Cementing Materials			Comments
Quartz			
Feldspar			
Carbonate	<1%		scattered patches
Clay		9%	
Iron Oxide, Hydoxide and/or Sulfide	<1%		some Fe-oxide cement
Other			

Visual Porosity Estimate	Comments
<1%	but no blue epoxy?

50x magnification, 2.5 mm field of view



Thin Section Analysis Report

Sample ID: 39-2112-2
Formation/Member Name: Newburg
Lithologic Classification: Sandstone
Depth/Depth Range: 5426.5 ft
Date of Analysis: 6/2/2017
Analyzed by: L. Ditzler

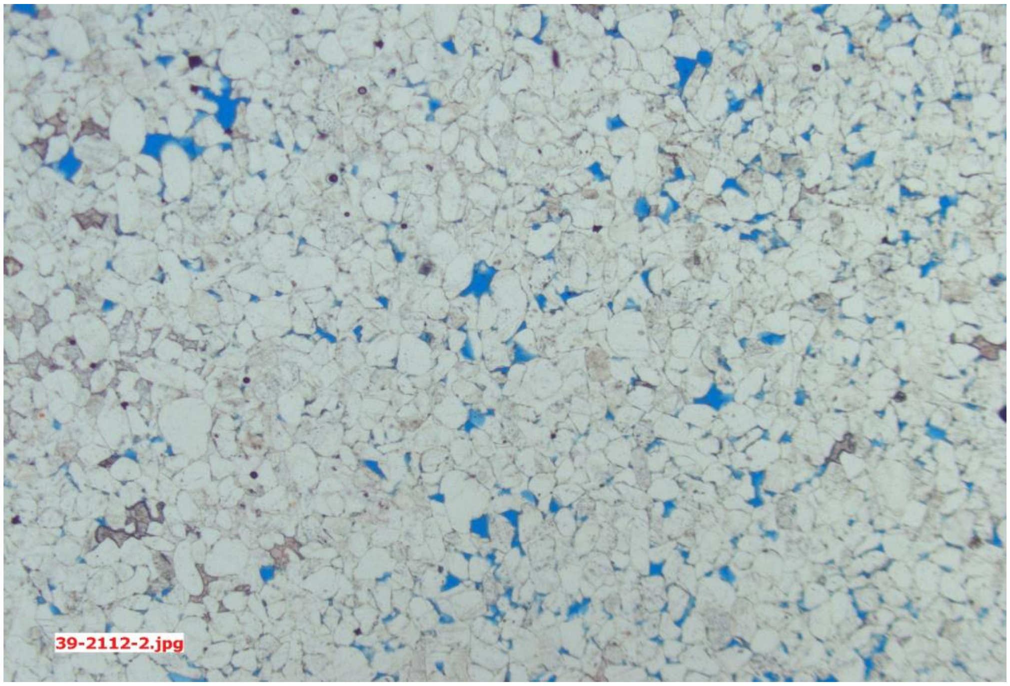
Texture		Comments
Grain Size	fine-grained, 125-177µ	
Rounding	well rounded to subrounded	
Sorting	very well sorted	

Composition/Detrital Minerals		Comments
Quartz		
Polycrystalline		
Monocrystalline	93%	
Microcrystalline		
Feldspar		
Plagioclase		
Orthoclase		
Microcline	<1%	
Carbonate		
Calcite		
Dolomite		
Aragonite		
Clay		
Illite		
Smectite		
Kaolinite		
Muscovite		
Chlorite		
Glauconite		
Rock Fragments		
Sedimentary		
Volcanic		
Metamorphic		
Other (Accessory Minerals)		
	tourmaline	
	zircon	

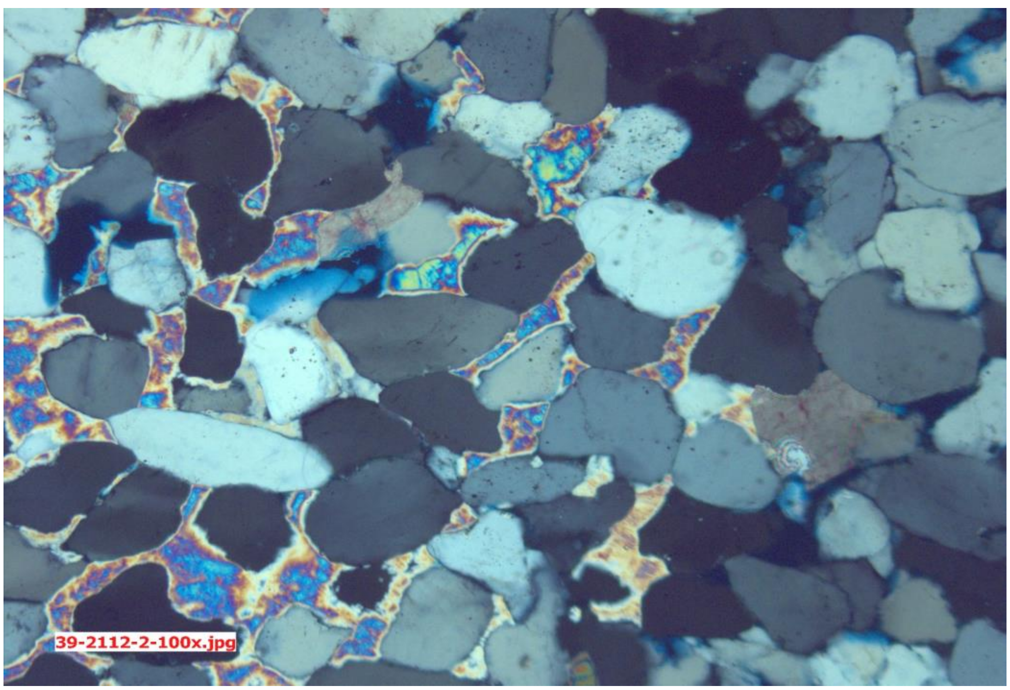
Cementing Materials		Comments
Quartz		overgrowths and intergranular
Feldspar		
Carbonate	2%	scattered patches
Clay		
Iron Oxide, Hydoxide and/or Sulfide		
Other	5%	mystery mineral, moderate relief, colorless, low to moderate birefringence, optically continuous patches, patchy distribution - locally abundant

Visual Porosity Estimate	Comments
3%	intergranular, patchy distribution

25x magnification, 5mm field of view



100x magnification, 1.25mm field of view



Thin Section Analysis Report

Sample ID:	39-2112-4
Formation/Member Name:	Newburg
Lithologic Classification:	Calcareous Sandstone
Depth/Depth Range:	5428.2 ft
Date of Analysis:	6/13/2017
Analyzed by:	S. Shank

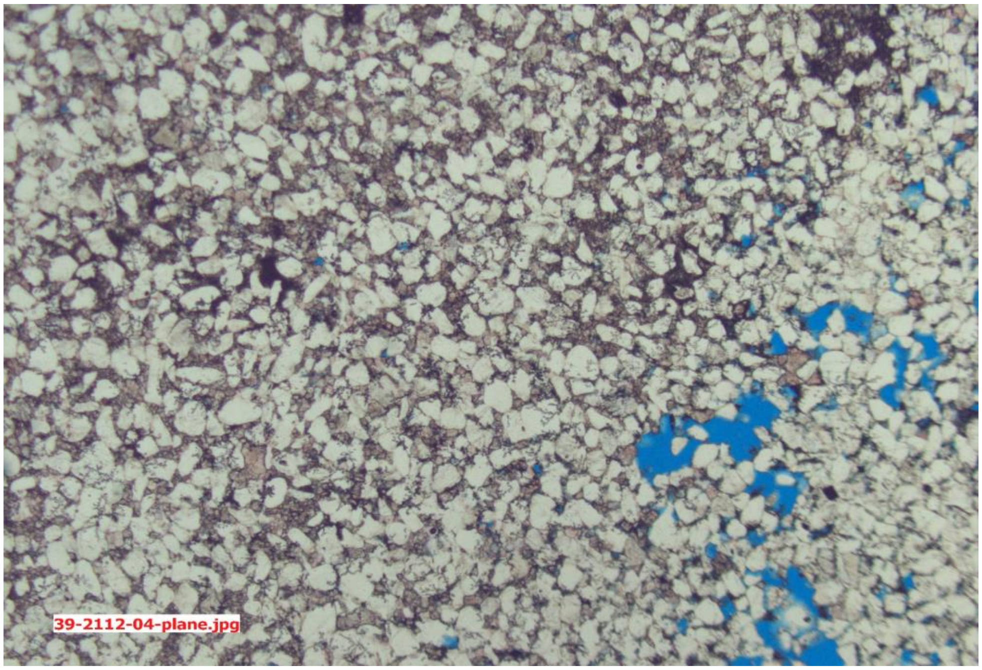
Texture		**Comments**
Grain Size	fine-grained, 125-177µ	
Rounding	well rounded to subrounded	
Sorting	well sorted	

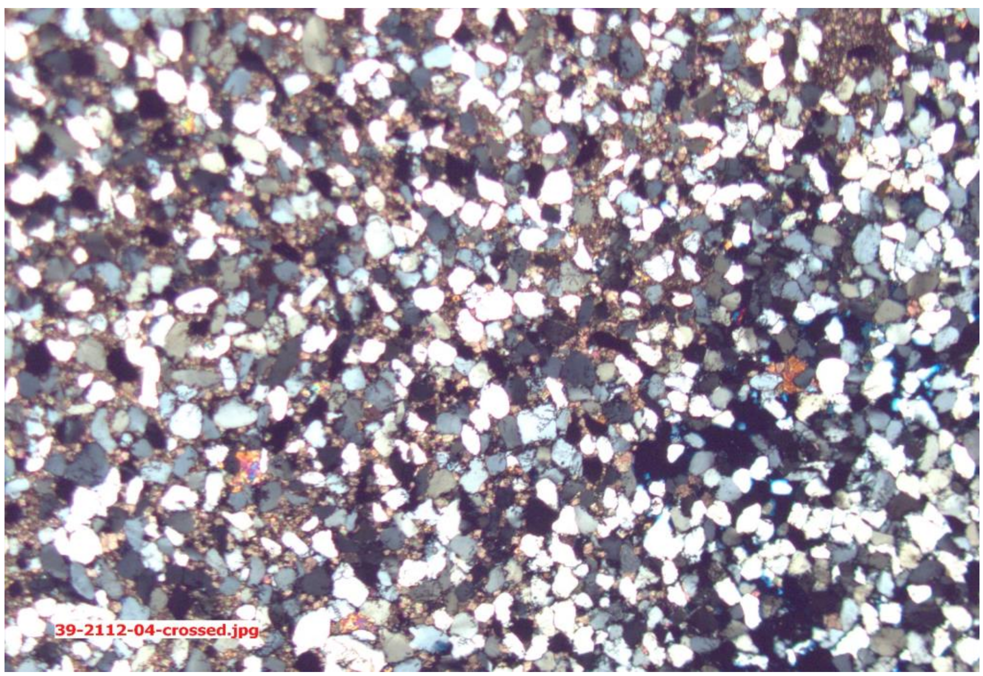
Composition/Detrital Minerals		**Comments**
Quartz		
Polycrystalline		
Monocrystalline	75%	
Microcrystalline		
Feldspar		
Plagioclase		
Orthoclase		
Microcline		
Carbonate		
Calcite		
Dolomite		
Aragonite		
Clay		
Illite		
Smectite		
Kaolinite		
Muscovite		
Chlorite		
Glauconite		
Rock Fragments		
Sedimentary		
Volcanic		
Metamorphic		
Other (Accessory Minerals)		
	tourmaline	

Cementing Materials		**Comments**
Quartz		
Feldspar		
Carbonate	25%	
Clay		
Iron Oxide, Hydoxide and/or Sulfide		
Other	<1	mystery mineral, colorless, moderate relief

Visual Porosity Estimate	**Comments**
2%	very patchy distribution, most of section of almost no porosity

25x magnification, 5mm field of view





Thin Section Analysis Report

Sample ID:	39-2112-6	
Formation/Member Name:	Newburg	
Lithologic Classification:	Quartz Sandstone	
Depth/Depth Range:	5430 ft	
Date of Analysis:	6/13/2017	
Analyzed by:	S. Shank	25x magnification, 5mm field of view

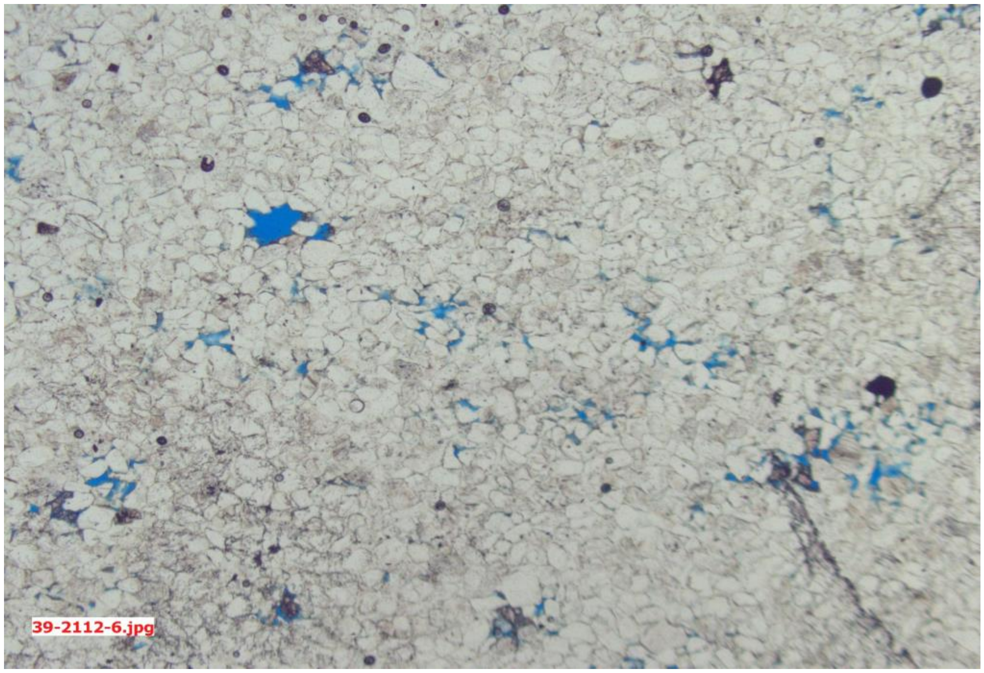
Texture		**Comments**
Grain Size	fine-grained, 125-177µ	
Rounding	well rounded to subrounded	
Sorting	well sorted	

Composition/Detrital Minerals		**Comments**
Quartz		
Polycrystalline		
Monocrystalline	99%	
Microcrystalline		
Feldspar		
Plagioclase		
Orthoclase		
Microcline		
Carbonate		
Calcite		
Dolomite		
Aragonite		
Clay		
Illite		
Smectite		
Kaolinite		
Muscovite		
Chlorite		
Glauconite		
Rock Fragments		
Sedimentary		
Volcanic		
Metamorphic		
Other (Accessory Minerals)		
	tourmaline	well rounded grains not uncommon

Cementing Materials		**Comments**
Quartz	overgrowths and intertitial patches	well cemented
Feldspar		
Carbonate	<1%	
Clay		
Iron Oxide, Hydoxide and/or Sulfide		
Other	<1%	one patch of colorless, moderate relief mystery mineral

Visual Porosity Estimate	**Comments**
5%	common intergranular and larger voids

25x magnification, 5mm field of view



Thin Section Analysis Report

Sample ID:	39-2112-9
Formation/Member Name:	Newburg
Lithologic Classification:	Calcareous Sandstone
Depth/Depth Range:	5432.5 ft
Date of Analysis:	6/13/2017
Analyzed by:	S. Shank

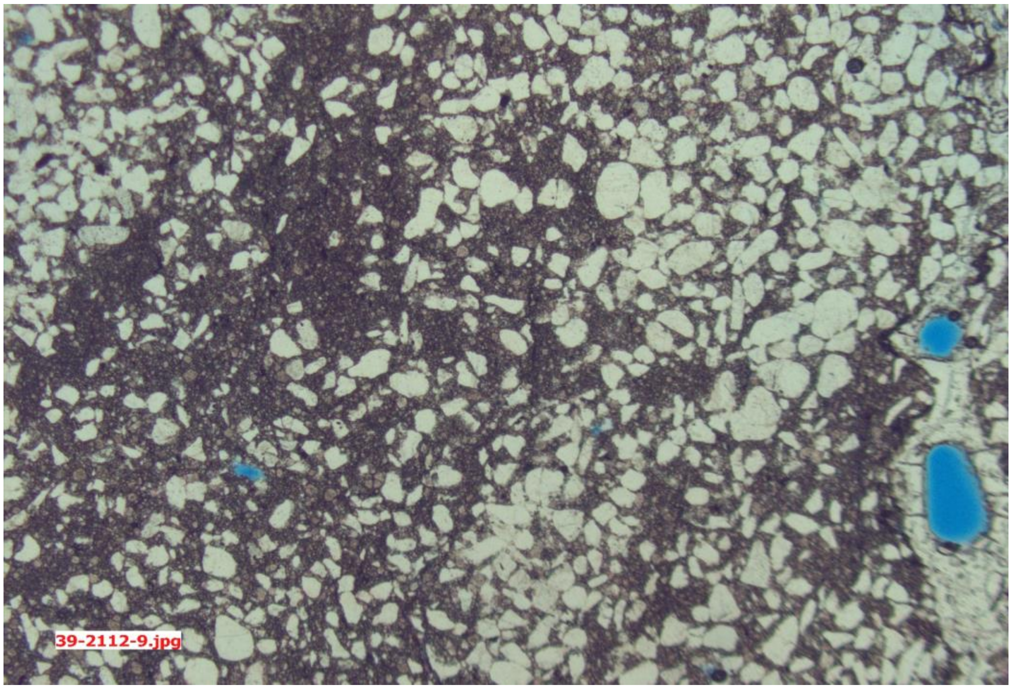
Texture		**Comments**
Grain Size	fine-grained, 125-250µ	
Rounding	well rounded to subangular	
Sorting	well sorted	

Composition/Detrital Minerals		**Comments**
Quartz		
Polycrystalline		
Monocrystalline	70%	
Microcrystalline		
Feldspar		
Plagioclase		
Orthoclase		
Microcline		
Carbonate		
Calcite		
Dolomite		
Aragonite		
Clay		
Illite		
Smectite		
Kaolinite		
Muscovite		
Chlorite		
Glauconite		
Rock Fragments		
Sedimentary		
Volcanic		
Metamorphic		
Other (Accessory Minerals)		

Cementing Materials		**Comments**
Quartz		
Feldspar		
Carbonate	30%	well cemented, locally abundant - matrix supported patches
Clay		
Iron Oxide, Hydoxide and/or Sulfide		
Other		

Visual Porosity Estimate	**Comments**
<1%	almost no intergranular porosity, some along thin fracture

25x magnification, 5mm field of view



	Geologic Interval - Greenbrier Limestone	**1**	**2**	**3**	**4**	**5**	**Area**
Range of Values	**Criteria**						**Explanation:**
	Distance to infrastructure	1	3	2	3	3	distance to Kanawha R used if closer than Ohio R
0	>30 mi						
1	>20 mi but <=30 mi						
2	>5 mi but <=20 mi						
3	<=5 mi						
	Average depth	3	3	3	3	3	
0	<1,800 ft						
3	>=1,800 ft but <=2,000 ft						
	Acreage	3	3	3	3	3	
0	< 25,000	174,000	365,000	452,140	533,745	173,735	ac of Net > 40 ft Greenbrier Lime Mudstone Facies
1	25,000 - 75,000						
2	75,000 - 125,000						
3	> 125,000						
	Average net thickness	3	3	3	3	3	
0	<40 ft						
3	>=40 ft						
	Trap integrity	2	0	1	1	3	
0	No data	44%	0%	9%	11%	81%	% of mud facies in footprint overlain & underlain by grainstone facies
1	Limited data on trap characteristics						
2	Inferred lithologic and/or structural closure						
3	Documented lithologic and/or structural closure						
	Legacy well penetrations	1	0	0	1	2	
0	No data or >=20 wells per 1,000 ac	11.23922	36.84658	23.64533	5.989752	2.664978	wells/1000 ac
1	>=5 wells per 1,000 ac but <20 wells per 1,000 ac	1044					# PA wells
2	>=2 wells per 1,000 ac but<5 wells per 1,000 ac	8	21		67	29	GB wells
3	<2 well per ac	1814	13428	10691	3130	434	WV wells
		2866	13449	10691	3197	463	wells
		81000					PA ac
		255	365	452.14	533.745	173.735	1000 acres
	Stacked opportunity?	1	3	2	2	2	
0	No other intervals in same footprint						
1	1 other interval in same footprint						
2	2 or 3 other intervals in same footprint						
3	4 or more intervals in same footprint						

FID	TEST_ID_1	FIELD_NAME	Formation	Lithology	Geo_Age	DISC_YEAR	State	Pi	Pmax	MMP	Pi_MMP	Pmax_MMP	AvgProdDep
66	11256	Big Run-Burchfield	BGIJ, PRIC	Sandstone	Mississippian	1902	WV	975.982	1803.2	415.9422	560.0398	1387.2578	2254
47	11018	Burdett-St. Albans	Berea	Sandstone	Devonian-Mississippian	1906	WV	959.961	1773.6	414.505	545.456	1359.095	2217
150	11553	Cameron-Garner	Weir	Sandstone	Mississippian	1977	WV	1075.139	1986.4	424.7996	650.3394	1561.6004	2483
60	11249	Condit-Ragtown	BGIJ, PRIC	Sandstone	Mississippian	1898	WV	881.155	1628	401.2759	479.8791	1226.7241	2035
99	11361	Hendershot-Ogdin	Berea	Sandstone	Devonian-Mississippian	1895	WV	954.332	1763.2	422.5391	531.7929	1340.6609	2204
58	11247	Maple-Wadestown	BGIJ, PRIC, SQUW	Sandstone	Mississippian	1905	WV	1015.385	1876	405.4541	609.9309	1470.5459	2345
202	11733	Sidney	Berea	Sandstone	Devonian-Mississippian	1959	WV	1724.206	3185.6	481.3137	1242.8923	2704.2863	3982
156	11561	Stanley	Weir	Sandstone	Mississippian	1966	WV	971.652	1795.2	424.2368	547.4152	1370.9632	2244
201	11732	Whites Creek-Gragston	Berea	Sandstone	Devonian-Mississippian	1930	WV	1659.689	3066.4	475.8018	1183.8872	2590.5982	3833
154	11559	Wilbur	Weir	Sandstone	Mississippian	1971	WV	990.704	1830.4	426.1016	564.6024	1404.2984	2288

NETTHICK	PRESS	POROSITY	Perm	Area_sqft	acreage	store_mode	legacy well count	Revised distance rank	acreage	average depth	porosity	thickness	permeability	pressure
17	1000	0.11	0	469713557	10,783	2798511.513	322	3	3	2	3	2	0	3
21	1000	0.1	0	2165371660	49,710	7684749.364	597	3	3	2	2	3	0	3
49	1100	0.07	0	69935520	1,605	870057.3166	77	3	2	2	2	3	0	3
25	1000	0.176	0	324234255	7,443	1433750.88	552	2	3	2	3	3	0	3
5	1000	0.15	15	156095261	3,583	182836.258	130	3	2	2	3	1	2	3
47	1000	0.11	0	705884336	16,205	13133290.29	419	3	3	2	3	3	0	3
21	1700	0.9	0	570792619	13,104	4890733.603	78	3	3	3	3	3	0	2
59	1000	0.07	0	296201192	6,800	1702426.452	339	2	3	2	2	3	0	3
30	1700	0.9	0	675060539	15,497	5721032.308	215	3	3	3	3	3	0	2
49	1000	0.07	0	246926966	5,669	1184558.647	231	2	3	2	2	3	0	3

Stacked opportunity rank	mode CO2	Cum_Prod_BCF	Avg_Perm_mD	Trap-Type	Res_Cont	Prod rank	wells per 1000 acres	Legacy well penetrations rank
0	3	0.0662		Structural/Stratigraphic	2	1	30	0
0	3	8.7794		Stratigraphic	3	2	12	1
0	2		2	Structural/Stratigraphic	4	1	48	0
1	3	0.0073		Structural/Stratigraphic	2	1	74	0
0	2	1.3074		Stratigraphic	3	2	36	0
1	3	0.0759		Structural/Stratigraphic	2	1	26	0
0	3	0		Stratigraphic	3	1	6	1
2	3	0.0595		Stratigraphic	4	1	50	0
0	3	0.1362		Stratigraphic	3	1	14	1
1	3	0.0395		Stratigraphic	4	1	41	0

FIELD_NAME	Formations	Lithology	Geo_Age	DISC_YEAR	STATE	Pi	Pmax	MMP	Pi_MMP	Pmax_MMP	AvgProdDep	NETTHICK	PRESS	POROSITY	Perm	Area_sqft	Acreage
Abbott-French Creek	DVNN, TRTF, GRDNS, GRDN, FRTH, FFTH, BYRD, ELZB, WRRN	Sandstone	Devonian	1977	WV	950.435	1756	422.1568	528.2782	1333.8432	2195	31	1000	0.09	0	1808783130	41,524
Antram Run	VNNG, BDFD	Sandstone	Devonian	1907	PA	1082.5	2000	430.8356	651.6644	1569.1644	2500	11.17	926	0.11	0	335125521	7,693
Aspinall-Finster	BNSN, ELK, BRLR, ALXD, ELKP	Sandstone, Siltstone	Devonian	1947	WV	2064.111	3813.6	527.16	1536.951	3286.44	4767	22	2100	0.08	0	1178845920	27,063
Aspinall-Finster	BDFD, SPCL, BLTN, RILY	Sandstone	Devonian	1975	WV	1548.408	2860.8	479.5256	1068.8824	2381.2744	3576	32	1500	0.08	0	1180466230	27,100
Auburn	BNSN, ELK, ALXD, ELKP	Sandstone, Siltstone	Devonian	1973	WV	2090.524	3862.4	529.5592	1560.9648	3332.8408	4828	60	2100	0.07	0	241329429	5,540
Auburn	DVNN, GNTZ, FFTF, TRTF, GRDN, FFTH, WRRN	Sandstone, Siltstone	Devonian	1968	WV	1324.547	2447.2	458.34	866.207	1988.86	3059	26	1300	0.07	0	435392488	9,995
Beason Run	BNSN, ELK, ALXD, ELKP	Sandstone, Siltstone	Devonian	1979	WV	2104.813	3888.8	530.8556	1573.9574	3357.9444	4861	49	2100	0.07	0	756783028	17,373
Bridgeport-Pruntytown	BDFD, SPCL, BLTN, RILY	Sandstone	Devonian	1912	WV	1546.676	2857.6	465.9887	1080.6873	2391.6113	3572	38	1500	0.09	0	1799612250	41,313
Brown-Lumberport	BDFD, SPCL, BLTN, RILY, SPCL	Sandstone	Devonian	1902	WV	1440.158	2660.8	469.3222	970.8358	2191.4778	3326	69	1400	0.08	0	2203901700	50,595
Buckhannon-Century	BNSN, ELK, BRLR, ALXD, ELKP, HVRT, FOX	Sandstone, Siltstone	Devonian	1916	WV	1764.042	3259.2	486.4509	1277.5911	2772.7491	4074	26	1800	0.09	0	3181413330	73,035
Campbells Run-Miracle Run	FFTF, TRTF, GRDNS, GRDN, FRTH, FFTH, BYRD	Sandstone	Devonian	1929	WV	1393.394	2574.4	452.813	940.581	2121.587	3218	80	1400	0.09	0	409476011	9,400
Coburn-Earnshaw	DVNN, FFTF, TRTF, GRDNS, GRDN, FRTH, FFTH, BYRD	Sandstone, Siltstone	Devonian	1913	WV	1347.063	2488.8	448.7726	898.2904	2040.0274	3111	60	1300	0.09	0	622282020	14,286
Condit-Ragtown	GNTZ, FFTF, TRTF, GRDNS, GRDN, FRTH, FFTH, BYRD, ELZB	Sandstone	Devonian	1914	WV	1381.703	2552.8	450.2505	931.4525	2102.5495	3191	90	1400	0.09	0	723520415	16,610
Conings	BNSN, ELK, ALXD, LPLD, BLCK, ELKP	Sandstone, Siltstone	Devonian	1962	WV	2111.741	3901.6	531.4837	1580.2573	3370.1163	4877	90	2100	0.07	0	234252654	5,378
Elk Creek (Overfield)	BDFD, SPCL, BLTN, RILY	Sandstone	Devonian	1917	WV	1693.463	3128.8	493.0826	1200.3804	2635.7174	3911	49	1700	0.08	0	1550603480	35,597
Elk Creek (Overfield)	DVNN, GNTZ, FFTF, GRDNS, FRTH, FFTH, BYRD, ELZB, WRRN	Sandstone, Siltstone	Devonian	1921	WV	1000.23	1848	427.0329	573.1971	1420.9671	2310	21	1000	0.09	0	1672241240	38,389
Farmington	GNTZ, FFTF, TRTF, GRDNS, GRDN, FRTH, FFTH, BYRD, WRRN	Sandstone	Devonian	1909	WV	1149.182	2123.2	427.7405	721.4415	1695.4595	2654	28	1100	0.09	0	2153027930	49,427
Frvw-Statler Rn-Mt Morrs	FFTF, GRDN, FRTH, FFTH, BYRD, ELZB	Sandstone	Devonian	1913	WV	1318.052	2435.2	444.1278	873.9242	1991.0722	3044	100	1300	0.09	0	428278401	9,832
Glade Run	BDFD, SPCL, BLTN, RILY	Sandstone	Devonian	1962	WV	1577.852	2915.2	482.288	1095.564	2432.912	3644	62	1600	0.08	0	473084772	10,861
Glenville North	BNSN, ELK, BRLR, ALXD, BLCK, ELKP	Sandstone, Siltstone	Devonian	1957	WV	2024.708	3740.8	523.574	1501.134	3217.226	4676	81	2000	0.08	0	1755729840	40,306
Glenville South	DVNN, GNTZ, GRDNS, GRDN, FRTH, FFTH, BYRD, WRRN	Sandstone, Siltstone	Devonian	1930	WV	1140.522	2107.2	440.6693	699.8527	1666.5307	2634	30	1100	0.09	0	635846970	14,597
Grantsville-Arnoldsburg	BNSN, ELK, BRLR, ALXD	Sandstone, Siltstone	Devonian	1992	WV	2145.082	3963.2	534.5031	1610.5789	3428.6969	4954	75	2100	0.07	0	459346104	10,545
Greenwood	BNSN, ELK, BRLR, ALXD, ELKP	Sandstone, Siltstone	Devonian	1979	WV	2148.113	3968.8	534.7773	1613.3357	3434.0227	4961	52	2100	0.07	0	530143329	12,170
Hazel Green-Lawford-Berea	BNSN, ELK, ALXD	Sandstone, Siltstone	Devonian	1980	WV	2083.596	3849.6	528.9303	1554.6657	3320.6697	4812	58	2100	0.07	0	537280459	12,334
Heaters	BNSN, ELK, ALXD, ELKP	Sandstone, Siltstone	Devonian	1968	WV	1996.563	3688.8	521.0073	1475.5557	3167.7927	4611	35	2000	0.09	0	557965364	12,809
Heaters	BDFD, SPCL, BLTN, RILY, SPCL	Sandstone	Devonian	1973	WV	1243.576	2297.6	450.5942	792.9818	1847.0058	2872	36	1200	0.09	0	628589494	14,430
Hundred	HMPR, GNTZ, FFTF, TRTF, GRDNS, GRDN, FRTH, FFTH, BYRD	Sandstone	Devonian	1904	WV	1339.269	2474.4	448.0917	891.1773	2026.3083	3093	60	1300	0.09	0	660485390	15,163
Jarvisville	BDFD, SPCL, BLTN, RILY, SPCL	Sandstone	Devonian	1901	WV	1367.414	2526.4	462.4225	904.9915	2063.9775	3158	33	1400	0.08	0	2259984560	51,882
Jefferson	VNNG, CNMG	Sandstone	Devonian-Pennsylvanian	1889	PA	1366.981	2525.6	460.722	906.259	2064.878	3157	11.17	980	0.11	0	785178189	18,025
Llewellyn Run-Plum Run	DVNN, FFTF, TRTF, GRDNS, GRDN, FRTH, FFTH, BYRD	Sandstone, Siltstone	Devonian	1925	WV	1299.866	2401.6	455.9838	843.8822	1945.6162	3002	90	1300	0.09	0	277971674	6,381
Logansport	GNTZ, FFTF, TRTF, GRDNS, GRDN, FFTH, BYRD	Sandstone	Devonian	1914	WV	1225.823	2264.8	448.8899	776.9331	1815.9101	2831	80	1200	0.09	0	280287709	6,435
Lorentz	BNSN, ELK, ALXD	Sandstone, Siltstone	Devonian	1940	WV	1980.542	3659.2	519.5443	1460.9977	3139.6557	4574	23	2000	0.09	0	523374122	12,015
Lorentz	BDFD, SPCL, BLTN, RILY	Sandstone	Devonian	1937	WV	1588.244	2934.4	483.2617	1104.9823	2451.1383	3668	40	1600	0.08	0	252142265	5,788
Lorentz	GNTZ, FFTF, GRDNS, GRDN, FFTH, BYRD, ELZB, WRRN	Sandstone	Devonian	1977	WV	1120.171	2069.6	438.7002	681.4708	1630.8998	2587	25	1100	0.09	0	540880368	12,417
Mahone (Smithville)	BNSN, ELK, ALXD, ELKP	Sandstone, Siltstone	Devonian	1981	WV	2095.72	3872	530.0307	1565.6893	3341.9693	4840	51	2100	0.07	0	313251515	7,191
Mannington	DVNN, GNTZ, FFTF, TRTF, GRDNS, GRDN, FRTH, FFTH, BYRD	Sandstone, Siltstone	Devonian	1893	WV	1217.163	2248.8	448.0577	769.1053	1800.7423	2811	88	1200	0.09	0	456715822	10,485
Maple-Wadestown	DVNN, GNTZ, FFTF, TRTF, GRDNS, GRDN, FRTH, FFTH, BYRD	Sandstone, Siltstone	Devonian	1905	WV	1347.496	2489.6	435.1238	912.3722	2054.4762	3112	85	1300	0.09	0	891187468	20,459
Masontown	VNNG, BRGN	Sandstone	Devonian-Mississippian	1889	PA	1246.607	2303.2	448.1598	798.4472	1855.0402	2879	31.19	960	0.11	0	211818446	4,863
Mcgraw	GRDNS ,GRDN	Sandstone	Devonian	1985	WV	1729.402	3195.2	496.4216	1232.9804	2698.7784	3994	21	1700	0.07	0	3267562990	75,013
McKeesport	SPCL	Sandstone	Devonian	1919	PA	1385.6	2560	450.6245	934.9755	2109.3755	3200	17.17	1400	0.11	0	305164182	7,006
Meathouse Fork-Bristol	GNTZ, FFTF, TRTF, GRDNS, GRDN, FRTH, FFTH, BYRD, WRRN	Sandstone	Devonian	1985	WV	1235.782	2283.2	449.8463	785.9357	1833.3537	2854	26	1200	0.09	0	533973099	12,258
Mooresville	DVNN, GNTZ, GRDNS, GRDN, FFTH, BYRD, ELZB	Sandstone, Siltstone	Devonian	1901	WV	1338.403	2472.8	446.0885	892.3145	2026.7115	3091	100	1300	0.1	0	250299125	5,746
Murphy Creek	BDFD, SPCL, BLTN, RILY, SPCL	Sandstone	Devonian	1906	WV	1384.734	2558.4	464.0685	920.6655	2094.3315	3198	34	1400	0.08	0	2361016070	54,201
Murphy Creek	BNSN, ELK, BRLR, ALXD, SCMR, LPLD, ELKP	Sandstone, Siltstone	Devonian	1917	WV	1945.469	3594.4	516.3366	1429.1324	3078.0634	4493	21	1900	0.08	0	1692492830	38,854
New Milton South	BNSN, ELK, ALXD, LPLD	Sandstone, Siltstone	Devonian	1962	WV	2158.938	3988.8	535.7562	1623.1818	3453.0438	4986	33	2200	0.07	0	386399585	8,870
Porto Rico	BNSN, ELK, ALXD, LPLD	Sandstone, Siltstone	Devonian	1978	WV	2156.773	3984.8	535.5605	1621.2125	3449.2395	4981	84	2200	0.07	0	346267479	7,949
Porto Rico	GNTZ, TRTF, GRDN, WRRN	Sandstone	Devonian	1901	WV	1320.65	2440	457.9682	862.6818	1982.0318	3050	32	1300	0.08	0	450687254	10,346
Prunty	BNSN, ELK, ALXD	Sandstone, Siltstone	Devonian	1980	WV	2069.74	3824	527.6717	1542.0683	3296.3283	4780	36	2100	0.07	0	484233371	11,116
Rural Ridge	VNNG, BDFD	Sandstone	Devonian	1912	PA	1379.105	2548	437.911	941.194	2110.089	3185	31.19	934	0.11	0	127940605	2,937
Salem	BDFD, SPCL, BLTN, RILY	Sandstone	Devonian	1979	WV	1834.621	3389.6	506.1533	1328.4677	2883.4467	4237	62	1800	0.08	0	252716644	5,802
Shiloh-Wick Area	TRTF, GRDNS, GRDN, FFTH, WRRN	Sandstone	Devonian	1979	WV	1174.296	2169.6	443.9304	730.3656	1725.6696	2712	24	1200	0.08	0	691705149	15,879
Shinnston	FFTF, TRTF, GRDN, FRTH, FFTH, BYRD	Sandstone	Devonian	1964	WV	1075.572	1987.2	434.3744	641.1976	1552.8256	2484	25	1100	0.08	0	357019980	8,196
Smithfield	DVNN, HMPR, FFTF, GRDNS, GRDN, FRTH, FFTH	Sandstone	Devonian	1909	WV	1303.763	2408.8	456.3561	847.4069	1952.4439	3011	40	1300	0.09	0	394964024	9,067
Smithton-Flint-Sedalia	BDFD, SPCL, BLTN, RILY	Sandstone	Devonian	1936	WV	1744.99	3224	497.8674	1247.1226	2726.1326	4030	24	1700	0.07	0	896856705	20,589
South Burns Chapel	SPCL, BLTN	Sandstone	Devonian	1968	WV	1080.335	1996	430.6055	649.7295	1565.3945	2495	56	1100	0.12	0	164532369	3,777
Stanley	GNTZ, TRTF, GRDN, FFTH, WRRN	Sandstone	Devonian	1971	WV	1372.61	2536	462.9165	909.6935	2073.0835	3170	35	1400	0.07	0	411904436	9,456
Straight Fk-Bluestone Ck	BNSN, ELK, BRLR, ALXD, LPLD, BLCK, ELKM	Sandstone, Siltstone	Devonian	1977	WV	2135.123	3944.8	533.6018	1601.5212	3411.1982	4931	33	2100	0.07	0	1283721340	29,470
Straight Fk-Bluestone Ck	TRTF, GRDNS, GRDN, FFTH, WRRN	Sandstone	Devonian	1930	WV	1230.153	2272.8	449.3058	780.8472	1823.4942	2841	26	1200	0.07	0	1272655710	29,216
Stumptwn-Normantwn-Shock	BNSN, ELK, BRLR, ALXD, BLCK, ELKP	Sandstone, Siltstone	Devonian	1977	WV	2139.453	3952.8	533.9938	1605.4592	3418.8062	4941	50	2100	0.07	0	1044320410	23,974
Stumptwn-Normantwn-Shock	GNTZ, FFTF, GRDNS, GRDN, FFTH, BYRD, ELZB, WRRN	Sandstone	Devonian	1985	WV	1158.708	2140.8	442.4263	716.2817	1698.3737	2676	30	1200	0.08	0	938207965	21,538
Thursday	BNSN, ELK, BRLR, ALXD, ELKP	Sandstone, Siltstone	Devonian	1980	WV	2103.947	3887.2	530.777	1573.17	3356.423	4859	76	2100	0.07	0	231698236	5,319
Wallace-Folsom	GNTZ, FFTF, TRTF, GRDNS, GRDN, FRTH, FFTH	Sandstone	Devonian	1903	WV	1327.145	2452	458.5878	868.5572	1993.4122	3065	60	1300	0.09	0	659098954	15,131
Weston-Jane Lew	BDFD, SPCL, BLTN, RILY	Sandstone	Devonian	1913	WV	1376.507	2543.2	463.2869	913.2201	2079.9131	3179	77	1400	0.08	0	2448116640	56,201
Weston-Jane Lew	BNSN, ELK, BRLR, ALXD, SCMR, LPLD, ELKP	Sandstone, Siltstone	Devonian	1909	WV	1877.488	3468.8	510.0997	1367.3883	2958.7003	4336	66	1900	0.08	0	2777449160	63,761
White Ash	VNNG, BDFD	Sandstone	Devonian	1910	PA	1328.011	2453.6	445.0876	882.9234	2008.5124	3067	31.19	1035	0.11	0	120378835	2,764
Wolf Summit	FFTF, TRTF, GRDNS, GRDN, FRTH, FFTH, BYRD	Sandstone	Devonian	1898	WV	1149.182	2123.2	441.5062	707.6758	1681.6938	2654	40	1100	0.09	0	268280272	6,159

store_mode	legacy well count	Revised distance rank	Acreage	Average depth	porosity	net thickness	permeability	pressure	Stacked opportunity rank	Cum_Prod_BCF	Trap-Type	Res_Cont	Mode CO2	Prod rank	wells per 1000 acres	Legacy well penetrations rank
6321557.392	4	2	3	2	2	3	0	3	0	32.6406	Stratigraphic	2	3	3	0	3
1196237.94	285	2	3	2	3	2	0	3	0		Stratigraphic	3	3	0	37	0
8483007.931	1083	3	3	3	2	3	0	2	0	25.1796	Stratigraphic	2	3	3	40	0
13169907.51		3	3	3	2	3	0	3	0	16.6803	Stratigraphic	2	3	3	0	3
3519097.197	441	2	3	3	2	3	0	2	1	5.4395	Stratigraphic	2	3	2	80	0
2869762.602		2	3	2	2	3	0	3	1	0.1974	Stratigraphic	2	3	1	0	3
9177142.114	918	2	3	3	2	3	0	2	1	13.4582	Stratigraphic	2	3	3	53	0
23432680.87	1408	1	3	3	2	3	0	3	0	51.2586	Stratigraphic	2	3	3	34	0
44555857.02	2729	2	3	2	2	3	0	3	1	105.1931	Stratigraphic	2	3	3	54	0
29486166.82	0	1	3	3	2	3	0	2	0	71.3801	Stratigraphic	2	3	3	0	3
12929238.9	864	2	3	2	2	3	0	3	0	0.498	Stratigraphic	2	3	1	92	0
14474706.25	465	3	3	2	2	3	0	3	0	0.8535	Stratigraphic	2	3	1	33	0
25412730.81	888	2	3	2	2	3	0	3	1	0.2246	Stratigraphic	2	3	1	53	0
5310166.133	136	2	3	3	2	3	0	2	2	1.8273	Stratigraphic	2	3	2	25	0
21891921.06	414	2	3	3	2	3	0	2	0	10.4916	Stratigraphic	2	3	3	12	1
4809094.11		2	3	2	2	3	0	3	0	4.9117	Stratigraphic	2	3	2	0	3
22817738.08	1575	2	3	2	2	3	0	3	1	3.838	Stratigraphic	2	3	2	32	0
16654003.37	919	2	3	2	2	3	0	3	1	3.0461	Stratigraphic	2	3	2	93	0
8253438.3	319	1	3	3	2	3	0	2	0	16.6103	Stratigraphic	2	3	3	29	0
45051466.31	1473	2	3	3	2	3	0	2	2	70.2819	Stratigraphic	2	3	3	37	0
6434533.401	51	2	3	2	2	3	0	3	1	1.7106	Stratigraphic	2	3	2	3	2
8835267.475	410	1	3	3	2	3	0	2	1	2.5915	Stratigraphic	2	3	2	39	0
6950697.87	960	3	3	3	2	3	0	2	1	3.4257	Stratigraphic	2	3	2	79	0
7436756.341	497	2	3	3	2	3	0	2	1	1.0556	Stratigraphic	2	3	2	40	0
7279259.449	19	1	3	3	2	3	0	2	0	4.3728	Stratigraphic	2	3	2	1	3
7538696.484		2	3	2	2	3	0	3	0	7.0682	Stratigraphic	2	3	2	0	3
15353100.03	604	3	3	2	2	3	0	3	0	1.101	Stratigraphic	2	3	2	40	0
21706305.19	2817	2	3	2	2	3	0	3	1	94.5968	Stratigraphic	2	3	3	54	0
2891192.42	312	3	3	2	3	2	0	3	0		Stratigraphic	3	3	0	17	1
9330188.307	211	2	3	2	2	3	0	3	1	0.3599	Stratigraphic	2	3	1	33	0
8277706.417	279	2	3	2	2	3	0	3	1	0.1717	Stratigraphic	2	3	1	43	0
4551466.174	28	1	3	3	2	3	0	2	0	7.7796	Stratigraphic	2	3	2	2	2
2986716.24		2	3	3	2	3	0	2	0	1.204	Stratigraphic	2	3	2	0	3
4538770.96		2	3	2	2	3	0	3	0	3.7117	Stratigraphic	2	3	2	0	3
3952640.404	382	2	3	3	2	3	0	2	1	3.934	Stratigraphic	2	3	2	53	0
14816481.07	914	2	3	2	2	3	0	3	0	0.026	Stratigraphic	2	3	1	87	0
30336172.37	604	3	3	2	2	3	0	3	1	0.8291	Stratigraphic	2	3	1	30	0
2157018.375	129	2	2	2	3	3	0	3	0				3	0	27	0
17330822.13	0	1	3	3	2	3	0	2	0	0.3162	Stratigraphic	2	3	1	0	3
1785558.003	128	3	3	2	3	2	0	3	0	17	Structural/Stratigraphic	3	3	3	18	1
4839713.74	649	2	3	2	2	3	0	3	1	1.7841	Stratigraphic	2	3	2	53	0
10672932.64	162	2	3	2	2	3	0	3	1	0.3507	Stratigraphic	2	3	1	28	0
24554576.93	1931	3	3	2	2	3	0	3	2	22.4262	Stratigraphic	2	3	3	36	0
11404551.43	1222	3	3	3	2	3	0	2	2	33.9081	Stratigraphic	2	3	3	31	0
3215978.787	245	2	3	3	2	3	0	2	2	10.1658	Stratigraphic	2	3	3	28	0
7335461.043	809	3	3	3	2	3	0	2	1	3.1174	Stratigraphic	2	3	2	102	0
4313472.016		3	3	2	2	3	0	3	1	1.2128	Stratigraphic	2	3	2	0	3
4234035.064	456	2	3	3	2	3	0	2	1	0.9281	Stratigraphic	2	3	1	41	0
1397316.275	173	2	2	2	3	3	0	3	0		Stratigraphic	3	3	0	59	0
4621078.937	436	2	3	3	2	3	0	2	1	1.4723	Stratigraphic	2	3	2	75	0
5167439.913	939	3	3	2	2	3	0	3	1	0.5435	Stratigraphic	2	3	1	59	0
2749115.697	516	2	3	2	2	3	0	3	0	4.6303	Stratigraphic	2	3	2	63	0
5810597.498	746	3	3	2	2	3	0	3	0	0.4815	Stratigraphic	2	3	1	82	0
5348236.877	1309	3	3	3	2	3	0	2	1	2.5491	Stratigraphic	2	3	2	64	0
4751959.286	31	0	2	2	3	3	0	3	0				3	0	8	1
3793800.63	512	3	3	2	2	3	0	3	2	2.9367	Stratigraphic	2	3	2	54	0
10493114.86	2010	3	3	3	2	3	0	2	1	29.8571	Stratigraphic	2	3	3	68	0
8420570.614		3	3	2	2	3	0	3	1	7.0298	Stratigraphic	2	3	2	0	3
14750790.09	823	1	3	3	2	3	0	2	1	0.4602	Stratigraphic	2	3	1	34	0
8081968.425		1	3	2	2	3	0	3	1	1.2458	Stratigraphic	2	3	2	0	3
4204873.336	257	1	3	3	2	3	0	2	1	1.3343	Stratigraphic	2	3	2	48	0
14795624.61	1191	3	3	2	2	3	0	3	1	0.1112	Stratigraphic	2	3	1	79	0
73818353.77	2584	3	3	2	2	3	0	3	1	15.1306	Stratigraphic	2	3	3	46	0
59573062.89	896	3	3	3	2	3	0	2	1	55.0673	Stratigraphic	2	3	3	14	1
1275379.894	22	3	2	2	3	3	0	3	0				3	0	8	1
3794286.568	747	2	3	2	2	3	0	3	1	0.9506	Stratigraphic	2	3	1	121	0

State	Thickness	Porosity	Reported_P	Permeability	Working_Gas_Capacity_MCF	Area	Acreage	Modal_Stor	Depth_of_R	legacy well count	Acreage
WV	20	0.91	1900	0	23,504,769	265773264.2	6,101	17,275,627	5858	321	3
WV	20	0.91	1670	0	8,540,000	110683949.9	2,541	7,159,667	5325	214	2
WV	15	0.087	1000	0		1974277920	45,323	2,657,298	2050	1840	3
WV	11	0.087	941	0	2,221,000	52629084.65	1,208	63,679	2174	86	2
PA	17.17	0.11	1400	0		31249858.34	717	182,847	3200	1	1
PA	12	0.16	0	0		171874394.4	3,946	1,996,113	2486	157	2
WV	13	0.087	1000	0	4,446,000	476884287.8	10,948	1,925,347	2400	464	3
WV	20	0.091	1835	0	10,553,000	405236463.4	9,303	2,611,318	4980	205	3
WV	50	0.091	1875	0	3,811,000	134271152.1	3,082	2,166,744	5126	69	2
WV	19	0.09	2200	0	3,811,000	428480561.5	9,837	2,597,995	5105	104	3
WV	20	0.107	680	0	3,811,000	368056388.5	8,449	708,962	2037	196	3
WV	20	0.107	710	0		1256638010	28,848	8,640,276	2313	1365	3

average depth	porosity	net thickness	permeability	pressure	mode CO2	distance	Stacked opportunity rank	wells per 1000 acres	Legacy well penetrations rank
1	3	2	0	2	3	2	1	53	0
1	3	2	0	2	3	2	1	84	0
2	2	2	0	3	3	3	2	41	0
2	2	2	0	3	1	2	1	71	0
2	3	2	0	3	2	3	1	1	3
2	3	2	0	0	3	3	0	40	0
2	2	2	0	3	3	2	2	42	0
3	2	2	0	2	3	3	2	22	0
1	2	3	0	2	3	3	0	22	0
1	2	2	0	2	3	3	1	11	1
2	3	2	0	1	2	3	0	23	0
2	3	2	0	1	3	3	1	47	0

FID	TEST_ID_1	FIELD_TYPE	FIELD_NAME	Formation	Lithology	Geo_Age	DISC_YEAR	State	Pi	Pmax	MMP	Pi_MMP	Pmax_MMP
4	827	Gas	ROCK CAMP	Oriskany	Sandstone	Devonian	1936	OH	1905.2	3520	531.316	1373.884	2988.684
7	961	Gas	PUTNAM	Oriskany	Sandstone	Devonian	1951	OH	1775.3	3280	500.6747	1274.6253	2779.3253
10	964	Gas	LAUREL RUN	Oriskany	Sandstone	Devonian	1989	OH	1688.7	3120	492.6394	1196.0606	2627.3606
26	11118	Gas	Glenville North	MLTI	Chert, Dolomite, Limestone	Devonian	1972	WV	2875.553	5312.8	599.276	2276.277	4713.524
27	11119	Gas	Dekalb	MLTI	Limestone, Sandstone	Devonian	1985	WV	2678.538	4948.8	582.0531	2096.4849	4366.7469
33	11134	Gas	Kanawha Forest	Oriskany	Sandstone	Devonian	1966	WV	1988.336	3673.6	520.2562	1468.0798	3153.3438
34	11135	Gas	Campbell Creek	Oriskany	Sandstone	Devonian	1935	WV	2089.225	3860	529.4413	1559.7837	3330.5587
36	11137	Gas	Blue Ck (Falling Rk)	Oriskany	Sandstone	Devonian	1944	WV	2269.786	4193.6	545.745	1724.041	3647.855
37	11138	Gas	Red House	Oriskany	Sandstone	Devonian	1954	WV	1962.356	3625.6	517.8819	1444.4741	3107.7181
39	11140	Gas	Elk-Poca (Sissonville)	Oriskany	Sandstone	Devonian	1967	WV	2178.856	4025.6	537.5557	1641.3003	3488.0443
41	11143	Gas	New England	Oriskany	Sandstone	Devonian	1952	WV	1825.528	3372.8	505.3149	1320.2131	2867.4851
48	11150	Gas	Hurricane Creek	Oriskany	Sandstone	Devonian	1940	WV	1884.416	3481.6	494.9085	1389.5075	2986.6915

AvgProdDep	NETTHICK	PRESS	POROSITY	Perm	Area_sqft	acreage	store_mode	legacy well count	Revised distance rank	acreage	average depth	porosity	thickness
4400	22	1500	0.08	0	58890404	1,352	307357.6636	42	3	2	3	2	3
4100	20	1410	0.06	0	284757075	6,537	1047095.679	64	3	3	3	2	2
3900	24	1300	0.08	0	128311755	2,946	751753.1752	112	2	2	3	2	3
6641	30	2900	0.13	0	407121910	9,346	5502218.77	349	2	3	1	3	3
6186	40	2700	0.08	0	325008982	7,461	3593176.79	330	1	3	1	2	3
4592	11	2000	0.09	0	402087510	9,231	1402187.139	116	3	3	3	2	2
4825	15	2100	0.09	0	823957610	18,915	3930794.164	193	3	3	3	2	2
5242	23	2300	0.09	0	817180858	18,760	6006895.235	1260	2	3	1	2	3
4532	10	2000	0.09	0	379766518	8,718	1202877.338	58	3	3	3	2	1
5032	18	2200	0.14	0	10668353200	244,911	95245552.39	3515	3	3	1	3	2
4216	15	1800	0.04	0	777247960	17,843	1260302.512	166	3	3	3	1	2
4352	11	1900	0.06	0	251396100	5,771	441617.4277	49	3	3	3	2	2

permeability	pressure	Stacked opportunity rank	mode CO2	Cum_Prod_BCF	Trap-Type	Res_Cont	Prod rank	wells per 1000 acres	Legacy well penetrations rank
0	3	1	2				0	31	0
0	3	0	3		Stratigraphic	3	1	10	1
0	3	1	2				0	38	0
0	2	2	3	1.6525	Structural	3	2	37	0
0	2		3	0.1766	Structural	3	1	44	0
0	2	1	3		Structural/Stratigraphic	4	0	13	1
0	2	1	3	24.75	Structural/Stratigraphic	4	3	10	1
0	2	1	3	66.55	Structural/Stratigraphic	4	3	67	0
0	2	1	3	1.1238	Structural/Stratigraphic	4	2	7	1
0	2	1	3	962.207	Structural/Stratigraphic	4	3	14	1
0	2	1	3	5.4067	Stratigraphic	3	2	9	1
0	2	1	2	0.0172	Stratigraphic	3	1	8	1

	Geologic Interval – Salina F4 Salt	**1**	**2**	**3**	**4**	**Area**	
Range of Values	**Criteria**					**Explanation**	
	Distance to infrastructure	3	3	3	3	Ohio River	
0	>30 mi						
1	>20 mi but <=30 mi						
2	>5 mi but <=20 mi						
3	<=5 mi						
	Average depth	2	2	1	1	from structure map	
0	<=2,000 ft						
1	>5,000 ft but <=7,000 ft						
2	>3,000 ft but <=5,000 ft						
3	>2,000 ft but <=3,000 ft						
		2	3	2	1	Net Acreage	
	Acreage	2	3	2	1	Gross Acreage	
0	<25,000	83,775	129,016	80,867	40,952	acreage per F4 net salt polygons	GROSS AC
1	25,000-50,000	16,266	27,627	16,590	2,395	cities + river	
2	50,000-100,000	67,509	101,389	64,277	38,557	F4 acreage minus cities	
3	>100,000	0	700	0	750	laterals	
		83,025	128,316	80,867	40,202	F4 acreage minus laterals	
		16,266	28,327	16,590	3,145	laterals, cities + rivers	
		67,509	100,689	64,277	37,807	F4 acreage minus cities + laterals	NET AC
	Average net thickness	3	3	3	3	F4 polygons = 100 ft min	
0	<=10 ft						
1	>10 ft but <=50 ft						
2	>50 ft but <=100 ft						
3	>100 ft						
	Pressure	0	0	0	2	Ben's Run data for polygon 4	
0	No data						
1	>0 psi but <=900 psi						
2	>900 psi but <=1,500 psi						
3	>1,500 psi						
	Trap integrity	3	3	3	3		
0	No data						
1	Limited data on trap characteristics						
2	Inferred lithologic and/or structural closure						
3	Documented lithologic and/or structural closure						
		1	1	1	0	wells/NET 1000 ac	
	Legacy well penetrations	1	1	1	0	wells/GROSS 1000 ac	
0	No data or >=20 wells per 1,000 ac	725	1615	528	1877	well penetration	
1	>=5 wells per 1,000 ac but <20 wells per 1,000 ac	83,775	129,016	80,867	40,952	gross ac	GROSS
2	>=2 wells per 1,000 ac but <5 wells per 1,000 ac	16,266	27,627	16,590	2,395	city + river ac	
3	<2 well per ac	67,509	101,389	64,277	38,557	ac- cities	
		0	700	0	750	lateral ac	
		83,775	128,316	80,867	40,202	ac - laterals	
		16,266	28,327	16,590	3,145	ac- city, river + lateral	
		67,509	100,689	64,277	37,807	ac- (cities + laterals)	NET
		8.654133	12.51783	6.529239	45.83415	wells per 1000 ac, net acreage	
		10.73931	16.03949	8.214447	49.64689	wells per 1000 ac, gross acreage	
	Stacked opportunity?	1	0	0	2		
0	No other intervals in same footprint						
1	1 other interval in same footprint						
2	2 or 3 other intervals in same footprint						
3	4 or more intervals in same footprint						

FID	TEST_ID_1	FIELD_TYPE	FIELD_NAME	Formation	Lithology	Geo_Age	DISC_YEAR	STATE	Pi	Pmax	MMP	Pi_MMP	Pmax_MMP	AvgProdDep	NETTHICK
1	11735	Gas	Groundhog Creek	Newburg	Sandstone	Silurian	1969	WV	2127.329	3930.4	532.8961	1594.4329	3397.5039	4913	8
3	11737	Gas	North Ripley	Newburg	Sandstone	Silurian	1969	WV	2329.107	4303.2	551.0648	1778.0422	3752.1352	5379	77
4	11738	Gas	Wheaton Run	Newburg	Sandstone	Silurian	1971	WV	2398.387	4431.2	557.2554	1841.1316	3873.9446	5539	5
7	11741	Gas	Rocky Fork	Newburg	Sandstone	Silurian	1966	WV	2434.759	4498.4	560.4961	1874.2629	3937.9039	5623	140
8	11742	Gas	Cooper Creek	Newburg	Sandstone	Silurian	1968	WV	2491.482	4603.2	565.5371	1925.9449	4037.6629	5754	30
9	11743	Gas	Kanawha Forest	Newburg	Sandstone	Silurian	1964	WV	2328.674	4302.4	551.026	1777.648	3751.374	5378	48

PRESS	POROSITY	Perm	Area_sqft	acreage	store_mode	legacy well count	Revised distance rank	acreage	average depth	porosity	thickness	permeability	pressure
2100	0.11	0	110413232	2,535	458319.0539	13	3	2	3	3	1	0	2
2300	0.14	0	837237403	19,220	35473678.35	201	3	3	1	3	3	0	2
2400	0.13	0	70266226	1,613	182644.8922	89	3	2	1	3	1	0	2
2400	0.18	0	1830852180	42,031	204839637.1	653	3	3	1	3	3	0	2
2500	0.15	0	373834312	8,582	7161427.579	109	2	3	1	3	3	0	2
2300	0.11	0	1204570710	27,653	33330365.64	285	3	3	1	3	3	0	2

Stacked opportunity rank	mode CO2	Cum_Prod_BCF	Avg_Perm_mD	Trap-Type	Res_Cont	Prod rank	wells per 1000 acres	Legacy well penetrations rank
0	2	10.177		Structural/Stratigraphic	4	3	5	1
2	3	86.654		Stratigraphic	4	3	10	1
1	2	1.1		Structural/Stratigraphic	3	2	55	0
2	3	136.451	46	Structural/Stratigraphic	4	3	16	1
1	3	17.752		Structural	4	3	13	1
2	3	49.185	14	Structural/Stratigraphic	3	3	10	1

FID	TEST_ID_1	FIELD_TYPE	FIELD_NAME	FMTN_CODE	Lithology	Geo_Age	DISC_YEAR	STATE	Pi	Pmax	MMP	Pi_MMP	Pmax_MMP	AvgProdDep
36	649	Gas	PHILO CONSOLIDATED	CLNN, MDIN	Sandstone	Silurian	1928	OH	2013.45	3720	539.1473	1474.3027	3180.8527	4650
63	1005	Gas	CANTON CONSOLIDATED	CLNN	Sandstone	Silurian	1921	OH	1983.14	3664	523.3013	1459.8387	3140.6987	4580
65	1060	Gas	CANTON CONSOLIDATED	CLNN	Sandstone	Silurian	1921	OH	1983.14	3664	523.3013	1459.8387	3140.6987	4580
110	1543	Gas	NORTH ELLSWORTH CONSOLIDATED	CLNN	Sandstone	Silurian	1963	OH	2208.3	4080	563.461	1644.839	3516.539	5100
124	1981	Gas	CANTON CONSOLIDATED	CLNN	Sandstone	Silurian	1921	OH	1983.14	3664	523.3013	1459.8387	3140.6987	4580
141	2048	Gas	CANTON CONSOLIDATED	CLNN	Sandstone	Silurian	1921	OH	1983.14	3664	523.3013	1459.8387	3140.6987	4580
189	2216	Gas	TRIADELPHIA CONSOLIDATED	CLNN, MDIN	Sandstone	Silurian	1927	OH	1723.34	3184	495.8589	1227.4811	2688.1411	3980
198	2240	Gas	TRIADELPHIA CONSOLIDATED	CLNN, MDIN	Sandstone	Silurian	1927	OH	1723.34	3184	495.8589	1227.4811	2688.1411	3980
258	2342	Gas	RAVENNA-BEST CONSOLIDATED	CLNN	Sandstone	Silurian	1949	OH	2100.05	3880	552.0548	1547.9952	3327.9452	4850
259	2343	Gas	SUFFIELD-SMITH	CLNN	Sandstone	Silurian	1960	OH	2152.01	3976	557.5398	1594.4702	3418.4602	4970

NETTHICK	PRESS	POROSITY	Perm	Area_sqft	acreage	store_mode	legacy well count	Revised distance rank	acreage	average depth	porosity	thickness	permeability	pressure
18	1400	0.065	0	258448763	5,933	1268564.437	34	3	3	3	2	2	0	3
15	1400	0.07	0	3445312460	79,093	16655292.91	276	3	3	3	2	2	0	3
15	1400	0.07	0	330975566	7,598	1599998.566	22	3	3	3	2	2	0	3
50	1500	0.078	0	4740884540	108,836	88346392.13	1509	3	3	1	2	3	0	3
15	1400	0.07	0	376286626	8,638	1819040.812	8	3	3	3	2	2	0	3
15	1400	0.07	0	429948805	9,870	2078453.947	158	3	3	3	2	2	0	3
21	1200	0.079	0	247246866	5,676	1504614.33	141	2	3	3	2	3	0	3
21	1200	0.079	0	218920059	5,026	1332232.288	291	2	3	3	2	3	0	3
40	1500	0.083	0	2986159320	68,553	44314865.27	745	3	3	3	2	3	0	3
45	1400	0.08	0	307148619	7,051	3298574.757	188	3	3	3	2	3	0	3

Stacked opportunity rank	mode CO2	Cum_Prod_BCF	Avg_Perm_mD	Trap-Type	Res_Cont	Prod rank	wells per 1000 acres	Legacy well penetrations rank
0	3	31.215	2.3	Stratigraphic	4	3	6	1
0	3	58.847		Stratigraphic	4	3	3	2
0	3	58.847		Stratigraphic	4	3	3	2
0	3					0	14	1
0	3	58.847		Stratigraphic	4	3	1	3
0	3	58.847		Stratigraphic	4	3	16	1
0	3	15.59	6.2	Stratigraphic	3	3	25	0
0	3	15.59	6.2	Stratigraphic	3	3	58	0
0	3	33.457	2	Stratigraphic	3	3	11	1
0	3	12.833		Structural	3	3	27	0

FID	TEST_ID_1	FIELD_TYPE	FIELD_NAME	Formation	Lithology	Geo_Age	DISC_YEAR	STATE	Pi	Pmax	MMP	Pi_MMP	Pmax_MMP	AvgProdDep
1	2	Gas	KIRKERSVILLE	Rose Run	Sandstone	Cambrian	1992	OH	1610.76	2976	458.156	1152.604	2517.844	3720
3	5	Gas	DUMM RIDGE	Rose Run	Sandstone	Cambrian	1992	OH	1580.45	2920	455.3367	1125.1133	2464.6633	3650
4	6	Gas	DUMM RIDGE	Rose Run	Sandstone	Cambrian	1992	OH	1580.45	2920	469.0019	1111.4481	2450.9981	3650
5	7	Gas	ROCKBRIDGE	Rose Run	Sandstone	Cambrian	1993	OH	1874.89	3464	494.1037	1380.7863	2969.8963	4330
6	9	Gas	ROCKBRIDGE	Rose Run	Sandstone	Cambrian	1993	OH	1874.89	3464	494.1037	1380.7863	2969.8963	4330
7	10	Gas	DUMM RIDGE	Rose Run	Sandstone	Cambrian	1992	OH	1580.45	2920	455.3367	1125.1133	2464.6633	3650
8	11	Gas	DUMM RIDGE	Rose Run	Sandstone	Cambrian	1992	OH	1580.45	2920	455.3367	1125.1133	2464.6633	3650
15	116	Gas	FRAZEYBURG	Rose Run	Sandstone	Cambrian	1990	OH	2524.39	4664	555.8541	1968.5359	4108.1459	5830
28	161	Gas	ROCKBRIDGE	Rose Run	Sandstone	Cambrian	1993	OH	1874.89	3464	494.1037	1380.7863	2969.8963	4330
57	219	Gas	RANDOLPH	Rose Run	Sandstone	Cambrian	1990	OH	3074.3	5680	628.3089	2445.9911	5051.6911	7100

NETTHICK	PRESS	POROSITY	Perm	Area_sqft	acreage	store_mode	legacy well count	Revised distance rank	acreage	average depth	porosity	thickness
35	1300	0.08	0	37830589	868	340358.1197	10	1	1	3	2	3
35	1300	0.08	0	24474155	562	220036.3612	8	0	1	3	2	3
35	1300	0.08	0	72771945	1,671	636957.2799	29	0	2	3	2	3
35	1500	0.08	0	71038170	1,631	630034.0489	34	0	2	3	2	3
35	1500	0.08	0	22632338	520	200725.0967	27	0	1	3	2	3
35	1300	0.08	0	136366663	3,131	1226012.678	23	0	2	3	2	3
35	1300	0.08	0	73985424	1,698	665170.4003	8	0	2	3	2	3
30	2000	0.08	0	373427707	8,573	4000720.153	269	3	3	1	2	3
35	1500	0.08	0	44112044	1,013	391227.5567	16	0	2	3	2	3
30	2400	0.08	0	233475675	5,360	2441340.943	135	2	3	1	2	3

permeability	pressure	Stacked opportunity rank	mode CO2	Cum_Prod_BCF	Avg_Perm_mD	Trap-Type	Res_Cont	Prod rank	wells per 1000 acres	Legacy well penetrations rank
0	3	0	2					0	12	1
0	3	0	2					0	14	1
0	3	0	2					0	17	1
0	3	0	2					0	21	0
0	3	0	2					0	52	0
0	3	0	3					0	7	1
0	3	0	2					0	5	2
0	2	0	3					0	31	0
0	3	0	2					0	16	1
0	2	0	3	0.425		Structural	2	1	25	0

Unweighted Ranking	Container Type	FID	Test_ID	Field/Location	Normalized Rating	Distance to infrastructure	Acreage	Average depth	Net thickness	Trap integrity	Legacy well penetrations	Stacked opportunity?
1	mined-rock cavern			M-R5	19	3	3	3	3	3	2	2
2	depleted Newburg Sandstone	3	11737	North Ripley	16	3	3	1	3	3	1	2
2	depleted Newburg Sandstone	7	11741	Rocky Fork	16	3	3	1	3	3	1	2
2	depleted Newburg Sandstone	9	11743	Kanawha Forest	16	3	3	1	3	3	1	2
2	mined-rock cavern			M-R4	16	3	3	3	3	1	1	2
3	depleted Oriskany Sandstone	34	11135	Campbell Creek	15	3	3	3	2	2	1	1
3	mined-rock cavern			M-R2	15	3	3	3	3	0	0	3
3	salt cavern			S-1	15	3	2	2	3	3	1	1
3	salt cavern			S-2	15	3	3	2	3	3	1	0
2	depleted Upper Devonian sands	553	11104	Weston-Jane Lew	14	3	3	3	3	0	1	1
4	depleted Clinton/Medina Group	124	1981	CANTON CONSOLIDATED	14	3	3	3	2	0	3	0
4	depleted Newburg Sandstone	8	11742	Cooper Creek	14	2	3	1	3	3	1	1
4	depleted Upper Devonian sands	643	11223	Abbott-French Creek	14	2	3	2	3	1	3	0
4	gas storage field	14		Ripley	14	3	3	3	2	1	0	2
5	depleted Keener-Berea	58	11247	Maple-Wadestown	13	3	3	2	3	1	0	1
5	depleted Oriskany Sandstone	39	11140	Elk-Poca (Sissonville)	13	3	3	1	2	2	1	1
5	gas storage field	12		Racket-Newberne (Sinking Creek)	13	2	3	2	2	2	0	2
5	salt cavern			S-4	13	3	1	1	3	3	0	2
4	depleted Clinton/Medina Group	63	1005	CANTON CONSOLIDATED	13	3	3	3	2	0	2	0
5	depleted Clinton/Medina Group	65	1060	CANTON CONSOLIDATED	13	3	3	3	2	0	2	0
5	depleted Clinton/Medina Group	258	2342	RAVENNA-BEST CONSOLIDATED	13	3	3	3	3	0	1	0
6	depleted Keener-Berea	47	11018	Burdett-St. Albans	12	3	3	2	3	0	1	0
6	depleted Keener-Berea	60	11249	Condit-Ragtown	12	2	3	2	3	1	0	1
7	depleted Rose Run-Gatesburg Ss	8	11	DUMM RIDGE	11	0	2	3	3	1	2	0
7	depleted Rose Run-Gatesburg Ss	15	116	FRAZEYBURG	11	3	3	1	3	1	0	0
8	depleted Rose Run-Gatesburg Ss	1	2	KIRKERSVILLE	10	1	1	3	3	1	1	0
8	depleted Rose Run-Gatesburg Ss	4	6	DUMM RIDGE	10	0	2	3	3	1	1	0
8	depleted Rose Run-Gatesburg Ss	7	10	DUMM RIDGE	10	0	2	3	3	1	1	0
8	depleted Rose Run-Gatesburg Ss	28	161	ROCKBRIDGE	10	0	2	3	3	1	1	0
8	depleted Rose Run-Gatesburg Ss	57	219	RANDOLPH	10	2	3	1	3	1	0	0

Mined-Rock Caverns	Rating_Norm
1	14
2	15
3	14
4	16
5	19

Salt Caverns	Rating_Norm
1	15
2	15
3	13
4	13

Depleted Gas Reservoirs

FID	Gas Storage Fields	Rating_Norm
26	Coco "A"	11
28	Coco "C"	10
5	Fink-Kennedy-Lost Creek (Murphy Creek)	13
7	Logansport	11
32	McKeesport	13
56	Mehaffy	12
12	Racket-Newberne (Sinking Creek)	13
14	Ripley	14
13	Rockport	10
1	Rockport (Deep)	12
8	Victory "A" (Kausooth-Cameron)	12
9	Victory "B" (Kausooth-Cameron)	13

FID	Test_ID	Keener-Berea	Rating_Norm
66	11256	Big Run-Burchfield	11
47	11018	Burdett-St. Albans	12
150	11553	Cameron-Garner	10
60	11249	Condit-Ragtown	12
99	11361	Hendershot-Ogdin	8
58	11247	Maple-Wadestown	13
202	11733	Sidney	13
156	11561	Stanley	12
201	11732	Whites Creek-Gragston	13
154	11559	Wilbur	11

FID	Test_ID	Upper Devonian sandstones	Rating_Norm
643	11223	Abbott-French Creek	14
1165	15592	Antram Run	9
412	10841	Aspinall-Finster	12
447	10921	Aspinall-Finster	12
556	11107	Auburn	12
632	11211	Auburn	11
547	11098	Beason Run	12
371	10740	Bridgeport-Puntytown	10
364	10732	Brown-Lumberport	11
399	10804	Buckhannon-Century	10
477	10981	Campbells Run-Miracle Run	10
481	10985	Coburn-Earnshaw	11
597	11171	Condit-Ragtown	11
400	10805	Conings	13
429	10881	Elk Creek (Overfield)	13
626	11205	Elk Creek (Overfield)	13
601	11175	Farmington	11
476	10980	Frvw-Statler Rn-Mt Morrs	11
425	10876	Glade Run	12
407	10836	Glenville North	13
649	11233	Glenville South	13
417	10848	Grantsville-Arnoldsburg	11
539	11088	Greenwood	13
560	11112	Hazel Green-Lawford-Berea	12
381	10753	Heaters	13
521	11067	Heaters	13
598	11172	Hundred	11
423	10873	Jarvisville	11
1166	15594	Jefferson	11
483	10987	Llewellyn Run-Plum Run	11
462	10940	Logansport	11
402	10808	Lorentz	13
516	11061	Lorentz	13
638	11218	Lorentz	12
551	11102	Mahone (Smithville)	12
459	10936	Mannington	10
596	11170	Maple-Wadestown	12
1156	15547	Masontown	9
469	10949	Mcgraw	10
847	13828	McKeesport	11
619	11197	Meathouse Fork-Bristol	11
595	11169	Mooresville	11
443	10896	Murphy Creek	13
559	11111	Murphy Creek	14
555	11106	New Milton South	13
550	11101	Porto Rico	13
624	11203	Porto Rico	12
557	11108	Prunty	12
1074	14887	Rural Ridge	9
372	10741	Salem	12
465	10943	Shiloh-Wick Area	12
605	11180	Shinnston	10
461	10939	Smithfield	11
424	10874	Smithton-Flint-Sedalia	13
363	10731	South Burns Chapel	8
612	11188	Stanley	14
543	11094	Straight Fk-Bluestone Ck	13
620	11199	Straight Fk-Bluestone Ck	12
379	10750	Stumptwn-Normantwn-Shock	11
648	11231	Stumptwn-Normantwn-Shock	10
403	10809	Thursday	11
464	10942	Wallace-Folsom	12
436	10888	Weston-Jane Lew	12
553	11104	Weston-Jane Lew	14
1145	15401	White Ash	11
616	11193	Wolf Summit	11

FID	Test_ID	Oriskany Sandstone	Rating_Norm
4	827	ROCK CAMP	14
7	961	PUTNAM	13
10	964	LAUREL RUN	12
26	11118	Glenville North	13
27	11119	Dekalb	10
33	11134	Kanawha Forest	15
34	11135	Campbell Creek	15
36	11137	Blue Ck (Falling Rk)	11
37	11138	Red House	13
39	11140	Elk-Poca (Sissonville)	13
41	11143	New England	15
48	11150	Hurricane Creek	14

FID	Test_ID	Newburg Sandstone	Rating_Norm
1	11735	Groundhog Creek	13
3	11737	North Ripley	16
4	11738	Wheaton Run	11
7	11741	Rocky Fork	16
8	11742	Cooper Creek	14
9	11743	Kanawha Forest	16

FID	Test_ID	Clinton/Medina Group	Rating_Norm	FID	Test_ID	Rose Run - Gatesburg sandstones	Rating_Norm
36	649	PHILO CONSOLIDATED	12	1	2	KIRKERSVILLE	10
63	1005	CANTON CONSOLIDATED	13	3	5	DUMM RIDGE	9
65	1060	CANTON CONSOLIDATED	13	4	6	DUMM RIDGE	10
110	1543	NORTH ELLSWORTH CONSOLIDATED	11	5	7	ROCKBRIDGE	8
124	1981	CANTON CONSOLIDATED	14	6	9	ROCKBRIDGE	7
141	2048	CANTON CONSOLIDATED	12	7	10	DUMM RIDGE	10
189	2216	TRIADELPHIA CONSOLIDATED	11	8	11	DUMM RIDGE	11
198	2240	TRIADELPHIA CONSOLIDATED	11	15	116	FRAZEYBURG	11
258	2342	RAVENNA-BEST CONSOLIDATED	13	28	161	ROCKBRIDGE	10
259	2343	SUFFIELD-SMITH	12	57	219	RANDOLPH	10

Range of Values	Criteria	Coco "A"	Coco "C"	Fink-Kennedy-Lost Creek (Murphy Creek)	Logansport	McKeesport	Mehaffy	Racket-Newberne (Sinking Creek)	Ripley	Rockport	Rockport (Deep)	Victory "A" (Kausooth-Cameron)	Victory "B" (Kausooth-Cameron)
	FID	25	27	4	6	31	55	11	13	12	0	7	8
	Test_ID	26	28	5	7	32	56	12	14	13	1	8	9
	Distance to infrastructure												
0	>30 mi	2	2	3	2	3	3	2	3	3	3	3	3
1	>20 mi but <=30 mi												
2	>5 mi but <=20 mi												
3	<=5 mi												
	Acreage	3	2	3	2	1	2	3	3	2	3	3	3
0	<=500 ac												
1	>500 ac but <=1,000 ac												
2	>1,000 ac but <=5,000 ac												
3	>5,000 ac												
	Average depth												
0	<=2,000 ft	1	1	2	2	2	2	2	3	1	1	2	2
1	>5,000 ft												
2	>2,000 ft but <=3,500 ft												
3	>3,500 ft but <=5,000 ft												
	Net thickness	2	2	2	2	2	2	2	2	3	2	2	2
0	<=1 ft												
1	>1 ft but <=10 ft												
2	>10 ft but <=20 ft												
3	>20 ft												
	Trap integrity	2	2	1	2	1	3	2	1	1	1	2	2
0	No data												
1	Limited data on trap characteristics												
2	Inferred lithologic and/or structural closure												
3	Documented lithologic and/or structural closure												
	Legacy well penetrations	0	0	0	0	3	0	0	0	0	1	0	0
0	No data or >=20 wells per 1,000 ac												
1	>=5 wells per 1,000 ac but <20 wells per 1,000 ac												
2	>=2 wells per 1,000 ac but<5 wells per 1,000 ac												
3	<2 well per ac												
	Stacked opportunity?	1	1	2	1	1	0	2	2	0	1	0	1
0	No other intervals in same footprint												
1	1 other interval in same footprint												
2	2 or 3 other intervals in same footprint												
3	4 or more intervals in same footprint												
	Totals	11	10	13	11	13	12	13	14	10	12	12	13

Range of Values	Criteria: Geologic Interval – Salina F4 Salt	1	2	3	4
	Distance to infrastructure	3	3	3	3
0	>30 mi				
1	>20 mi but <=30 mi				
2	>5 mi but <=20 mi				
3	<=5 mi				
	Average depth	2	2	1	1
0	<=2,000 ft				
1	>5,000 ft but <=7,000 ft				
2	>3,000 ft but <=5,000 ft				
3	>2,000 ft but <=3,000 ft				
	Acreage	2	3	2	1
0	<25,000 ac				
1	>=25,000 ac but <50,000 ac				
2	>=50,000 ac but <100,000 ac				
3	>=100,000 ac				
	Average net thickness	3	3	3	3
0	<=10 ft				
1	>10 ft but <=50 ft				
2	>50 ft but <=100 ft				
3	>100 ft				
	Trap integrity	3	3	3	3
0	No data				
1	Limited data on trap characteristics				
2	Inferred lithologic and/or structural closure				
3	Documented lithologic and/or structural closure				
	Legacy well penetrations	1	1	1	0
0	No data or >=20 wells per 1,000 ac				
1	>=5 wells per 1,000 ac but <20 wells per 1,000 ac				
2	>=2 wells per 1,000 ac but<5 wells per 1,000 ac				
3	<2 well per ac				
	Stacked opportunity?	1	0	0	2
0	No other intervals in same footprint				
1	1 other interval in same footprint				
2	2 or 3 other intervals in same footprint				
3	4 or more intervals in same footprint				
	Totals	15	15	13	13

Range of Values	Geologic Interval - Greenbrier Limestone Criteria	1	2	3	4	5
	Distance to infrastructure	1	3	2	3	3
0	>30 mi					
1	>20 mi but <=30 mi					
2	>5 mi but <=20 mi					
3	<=5 mi					
	Average depth	3	3	3	3	3
0	<1,800 ft					
3	>=1,800 ft but <=2,000 ft					
	Acreage	3	3	3	3	3
0	<25,000 ac					
1	>=25,000 ac but <75,000 ac					
2	>=75,000 ac but <125,000 ac					
3	>=125,000 ac					
	Average net thickness	3	3	3	3	3
0	<40 ft					
3	>=40 ft					
	Trap integrity	2	0	1	1	3
0	No data					
1	Limited data on trap characteristics					
2	Inferred lithologic and/or structural closure					
3	Documented lithologic and/or structural closure					
	Legacy well penetrations	1	0	0	1	2
0	No data or >=20 wells per 1,000 ac					
1	>=5 wells per 1,000 ac but <20 wells per 1,000 ac					
2	>=2 wells per 1,000 ac but<5 wells per 1,000 ac					
3	<2 well per ac					
	Stacked opportunity?	1	3	2	2	2
0	No other intervals in same footprint					
1	1 other interval in same footprint					
2	2 or 3 other intervals in same footprint					
3	4 or more intervals in same footprint					
	Totals	14	15	14	16	19

	Geologic Interval –	Geologic Interval – Keener_Berea										Geologic Interval – Upper Devonian			
		Field													
	FID	66	47	150	60	99	58	202	156	201	154	643	1165	412	447
	Test_ID	11256	11018	11553	11249	11361	11247	11733	11561	11732	11559	11223	15592	10841	10921
Range of Values	**Criteria**	Big Run-Burchfield	Burdett-St. Albans	Cameron-Garner	Condit-Ragtown	Hendershot-Ogdin	Maple-Wadestown	Sidney	Stanley	Whites Creek-Gragston	Wilbur	Abbott-French Creek	Antram Run	Aspinall-Finster	Aspinall-Finster
	Distance to infrastructure														
0	>30 mi	3	3	3	2	3	3	3	2	3	2	2	2	3	3
1	>20 mi but <=30 mi														
2	>5 mi but <=20 mi														
3	<=5 mi														
	Acreage	3	3	2	3	2	3	3	3	3	3	3	3	3	3
0	<=500 ac														
1	>500 ac but <=1,000 ac														
2	>1,000 ac but <=5,000 ac														
3	>5,000 ac														
	Average depth	2	2	2	2	2	2	3	2	3	2	2	2	3	3
0	<=2,000 ft														
1	>5,000 ft														
2	>2,000 ft but <=3,500 ft														
3	>3,500 ft but <=5,000 ft														
	Net thickness	2	3	3	3	1	3	3	3	3	3	3	2	3	3
0	<=1 ft														
1	>1 ft but <=10 ft														
2	>10 ft but <=20 ft														
3	>20 ft														
	Trap integrity	1	0	0	1	0	1	0	0	0	0	1	0	0	0
0	No data														
1	Limited data on trap characteristics														
2	Inferred lithologic and/or structural closure														
3	Documented lithologic and/or structural closure														
	Legacy well penetrations	0	1	0	0	0	0	1	0	1	0	3	0	0	0
0	No data or >=20 wells per 1,000 ac														
1	>=5 wells per 1,000 ac but <20 wells per 1,000 ac														
2	>=2 wells per 1,000 ac but<5 wells per 1,000 ac														
3	<2 well per 1000 ac														
	Stacked opportunity?	0	0	0	1	0	1	0	2	0	1	0	0	0	0
0	No other intervals in same footprint														
1	1 other interval in same footprint														
2	2 or 3 other intervals in same footprint														
3	4 or more intervals in same footprint														
	Totals	11	12	10	12	8	13	13	12	13	11	14	9	12	12

Geologic Interval –

Range of Values	Criteria	Auburn	Auburn	Beason Run	Bridgeport-Pruntytown	Brown-Lumberport	Buckhannon-Century	Campbells Run-Miracle Run	Coburn-Earnshaw	Condit-Ragtown	Conings	Elk Creek (Overfield)	Elk Creek (Overfield)	Farmington
	FID	556	632	547	371	364	399	477	481	597	400	429	626	601
	Test_ID	11107	11211	11098	10740	10732	10804	10981	10985	11171	10805	10881	11205	11175
	Distance to infrastructure													
0	>30 mi	2	2	2	1	2	1	2	3	2	2	2	2	2
1	>20 mi but <=30 mi													
2	>5 mi but <=20 mi													
3	<=5 mi													
	Acreage	3	3	3	3	3	3	3	3	3	3	3	3	3
0	<=500 ac													
1	>500 ac but <=1,000 ac													
2	>1,000 ac but <=5,000 ac													
3	>5,000 ac													
	Average depth	3	2	3	3	2	3	2	2	2	3	3	2	2
0	<=2,000 ft													
1	>5,000 ft													
2	>2,000 ft but <=3,500 ft													
3	>3,500 ft but <=5,000 ft													
	Net thickness	3	3	3	3	3	3	3	3	3	3	3	3	3
0	<=1 ft													
1	>1 ft but <=10 ft													
2	>10 ft but <=20 ft													
3	>20 ft													
	Trap integrity	0	0	0	0	0	0	0	0	0	0	1	1	0
0	No data													
1	Limited data on trap characteristics													
2	Inferred lithologic and/or structural closure													
3	Documented lithologic and/or structural closure													
	Legacy well penetrations	0	0	0	0	0	0	0	0	0	0	1	2	0
0	No data or >=20 wells per 1,000 ac													
1	>=5 wells per 1,000 ac but <20 wells per 1,000 ac													
2	>=2 wells per 1,000 ac but<5 wells per 1,000 ac													
3	<2 well per 1000 ac													
	Stacked opportunity?	1	1	1	0	1	0	0	0	1	2	0	0	1
0	No other intervals in same footprint													
1	1 other interval in same footprint													
2	2 or 3 other intervals in same footprint													
3	4 or more intervals in same footprint													
	Totals	12	11	12	10	11	10	10	11	11	13	13	13	11

Geologic Interval –

Range of Values	Criteria	Frvw-Statler Rn-Mt Morrs	Glade Run	Glenville North	Glenville South	Grantsville-Arnoldsburg	Greenwood	Hazel Green-Lawford-Berea	Heaters	Heaters	Hundred	Jarvisville	Jefferson	Llewellyn Run-Plum Run
	FID	476	425	407	649	417	539	560	381	521	598	423	1166	483
	Test_ID	10980	10876	10836	11233	10848	11088	11112	10753	11067	11172	10873	15594	10987
	Distance to infrastructure													
0	>30 mi	2	1	2	2	1	3	2	1	2	3	2	3	2
1	>20 mi but <=30 mi													
2	>5 mi but <=20 mi													
3	<=5 mi													
	Acreage	3	3	3	3	3	3	3	3	3	3	3	3	3
0	<=500 ac													
1	>500 ac but <=1,000 ac													
2	>1,000 ac but <=5,000 ac													
3	>5,000 ac													
	Average depth	2	3	3	2	3	3	3	3	2	2	2	2	2
0	<=2,000 ft													
1	>5,000 ft													
2	>2,000 ft but <=3,500 ft													
3	>3,500 ft but <=5,000 ft													
	Net thickness	3	3	3	3	3	3	3	3	3	3	3	2	3
0	<=1 ft													
1	>1 ft but <=10 ft													
2	>10 ft but <=20 ft													
3	>20 ft													
	Trap integrity	0	2	0	0	0	0	0	0	0	0	0	0	0
0	No data													
1	Limited data on trap characteristics													
2	Inferred lithologic and/or structural closure													
3	Documented lithologic and/or structural closure													
	Legacy well penetrations	0	0	0	2	0	0	0	3	3	0	0	1	0
0	No data or >=20 wells per 1,000 ac													
1	>=5 wells per 1,000 ac but <20 wells per 1,000 ac													
2	>=2 wells per 1,000 ac but<5 wells per 1,000 ac													
3	<2 well per 1000 ac													
	Stacked opportunity?	1	0	2	1	1	1	1	0	0	0	1	0	1
0	No other intervals in same footprint													
1	1 other interval in same footprint													
2	2 or 3 other intervals in same footprint													
3	4 or more intervals in same footprint													
	Totals	11	12	13	13	11	13	12	13	13	11	11	11	11

	Geologic Interval –														
	FID	462	402	516	638	551	459	596	1156	469	847	619	595	443	559
	Test_ID	10940	10808	11061	11218	11102	10936	11170	15547	10949	13828	11197	11169	10896	11111
Range of Values	**Criteria**	Logansport	Lorentz	Lorentz	Lorentz	Mahone (Smithville)	Mannington	Maple-Wadestown	Masontown	Mcgraw	McKeesport	Meathouse Fork-Bristol	Mooresville	Murphy Creek	Murphy Creek
	Distance to infrastructure														
0	>30 mi	2	1	2	2	2	2	3	2	1	3	2	2	3	3
1	>20 mi but <=30 mi														
2	>5 mi but <=20 mi														
3	<=5 mi														
	Acreage	3	3	3	3	3	3	3	2	3	3	3	3	3	3
0	<=500 ac														
1	>500 ac but <=1,000 ac														
2	>1,000 ac but <=5,000 ac														
3	>5,000 ac														
	Average depth	2	3	3	2	3	2	2	2	3	2	2	2	2	3
0	<=2,000 ft														
1	>5,000 ft														
2	>2,000 ft but <=3,500 ft														
3	>3,500 ft but <=5,000 ft														
	Net thickness	3	3	3	3	3	3	3	3	3	2	3	3	3	3
0	<=1 ft														
1	>1 ft but <=10 ft														
2	>10 ft but <=20 ft														
3	>20 ft														
	Trap integrity	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	No data														
1	Limited data on trap characteristics														
2	Inferred lithologic and/or structural closure														
3	Documented lithologic and/or structural closure														
	Legacy well penetrations	0	3	2	2	0	0	0	0	0	1	0	0	0	0
0	No data or >=20 wells per 1,000 ac														
1	>=5 wells per 1,000 ac but <20 wells per 1,000 ac														
2	>=2 wells per 1,000 ac but<5 wells per 1,000 ac														
3	<2 well per 1000 ac														
	Stacked opportunity?	1	0	0	0	1	0	1	0	0	0	1	1	2	2
0	No other intervals in same footprint														
1	1 other interval in same footprint														
2	2 or 3 other intervals in same footprint														
3	4 or more intervals in same footprint														
	Totals	11	13	13	12	12	10	12	9	10	11	11	11	13	14

Geologic Interval –

Range of Values	Criteria	New Milton South	Porto Rico	Porto Rico	Prunty	Rural Ridge	Salem	Shiloh-Wick Area	Shinnston	Smithfield	Smithton-Flint-Sedalia	South Burns Chapel	Stanley	Straight Fk-Bluestone Ck	Straight Fk-Bluestone Ck	Stumptwn-Normantwn-Shock	Stumptwn-Normantwn-Shock	Thursday	Wallace-Folsom
	FID	555	550	624	557	1074	372	465	605	461	424	363	612	543	620	379	648	403	464
	Test_ID	11106	11101	11203	11108	14887	10741	10943	11180	10939	10874	10731	11188	11094	11199	10750	11231	10809	10942
	Distance to infrastructure																		
0	>30 mi	2	3	3	2	2	2	3	2	3	3	0	3	3	3	1	1	1	3
1	>20 mi but <=30 mi																		
2	>5 mi but <=20 mi																		
3	<=5 mi																		
	Acreage	3	3	3	3	2	3	3	3	3	3	2	3	3	3	3	3	3	3
0	<=500 ac																		
1	>500 ac but <=1,000 ac																		
2	>1,000 ac but <=5,000 ac																		
3	>5,000 ac																		
	Average depth	3	3	2	3	2	3	2	2	2	3	2	2	3	2	3	2	3	2
0	<=2,000 ft																		
1	>5,000 ft																		
2	>2,000 ft but <=3,500 ft																		
3	>3,500 ft but <=5,000 ft																		
	Net thickness	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
0	<=1 ft																		
1	>1 ft but <=10 ft																		
2	>10 ft but <=20 ft																		
3	>20 ft																		
	Trap integrity	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
0	No data																		
1	Limited data on trap characteristics																		
2	Inferred lithologic and/or structural closure																		
3	Documented lithologic and/or structural closure																		
	Legacy well penetrations	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
0	No data or >=20 wells per 1,000 ac																		
1	>=5 wells per 1,000 ac but <20 wells per 1,000 ac																		
2	>=2 wells per 1,000 ac but<5 wells per 1,000 ac																		
3	<2 well per 1000 ac																		
	Stacked opportunity?	2	1	1	1	0	1	1	0	0	1	0	2	1	1	1	1	1	1
0	No other intervals in same footprint																		
1	1 other interval in same footprint																		
2	2 or 3 other intervals in same footprint																		
3	4 or more intervals in same footprint																		
	Totals	13	13	12	12	9	12	12	10	11	13	8	14	13	12	11	10	11	12

Range of Values	Criteria																			
	Geologic Interval –					**Geologic Interval – Oriskany**												**Geologic Interval – Newburg**		
	FID	436	553	1145	616	4	7	10	26	27	33	34	36	37	39	41	48	1	3	4
	Test_ID	10888	11104	15401	11193	827	961	964	11118	11119	11134	11135	11137	11138	11140	11143	11150	11735	11737	11738
Range of Values	**Criteria**	Weston-Jane Lew	Weston-Jane Lew	White Ash	Wolf Summit	ROCK CAMP	PUTNAM	LAUREL RUN	Glenville North	Dekalb	Kanawha Forest	Campbell Creek	Blue Ck (Falling Rk)	Red House	Elk-Poca (Sissonville)	New England	Hurricane Creek	Groundhog Creek	North Ripley	Wheaton Run
	Distance to infrastructure																			
0	>30 mi	3	3	3	2	3	3	2	2	1	3	3	2	3	3	3	3	3	3	3
1	>20 mi but <=30 mi																			
2	>5 mi but <=20 mi																			
3	<=5 mi																			
	Acreage	3	3	2	3	2	3	2	3	3	3	3	3	3	3	3	3	2	3	2
0	<=500 ac																			
1	>500 ac but <=1,000 ac																			
2	>1,000 ac but <=5,000 ac																			
3	>5,000 ac																			
	Average depth	2	3	2	2	3	3	3	1	1	3	3	1	3	1	3	3	3	1	1
0	<=2,000 ft																			
1	>5,000 ft																			
2	>2,000 ft but <=3,500 ft																			
3	>3,500 ft but <=5,000 ft																			
	Net thickness	3	3	3	3	3	2	3	3	3	2	2	3	1	2	2	2	1	3	1
0	<=1 ft																			
1	>1 ft but <=10 ft																			
2	>10 ft but <=20 ft																			
3	>20 ft																			
	Trap integrity	0	0	0	0	2	1	1	2	2	2	2	1	1	2	2	1	3	3	3
0	No data																			
1	Limited data on trap characteristics																			
2	Inferred lithologic and/or structural closure																			
3	Documented lithologic and/or structural closure																			
	Legacy well penetrations	0	1	1	0	0	1	0	0	0	1	1	0	1	1	1	1	1	1	0
0	No data or >=20 wells per 1,000 ac																			
1	>=5 wells per 1,000 ac but <20 wells per 1,000 ac																			
2	>=2 wells per 1,000 ac but<5 wells per 1,000 ac																			
3	<2 well per 1000 ac																			
	Stacked opportunity?	1	1	0	1	1	0	1	2		1	1	1	1	1	1	1	0	2	1
0	No other intervals in same footprint																			
1	1 other interval in same footprint																			
2	2 or 3 other intervals in same footprint																			
3	4 or more intervals in same footprint																			
	Totals	12	14	11	11	14	13	12	13	10	15	15	11	13	13	15	14	13	16	11

Range of Values	Criteria	Rocky Fork	Cooper Creek	Kanawha Forest	PHILO CONSOLIDATED	CANTON CONSOLIDATED	CANTON CONSOLIDATED	NORTH ELLSWORTH CONSOLIDATED	CANTON CONSOLIDATED	CANTON CONSOLIDATED	TRIADELPHIA CONSOLIDATED	TRIADELPHIA CONSOLIDATED	RAVENNA-BEST CONSOLIDATED	SUFFIELD-SMITH
	Geologic Interval –				**Geologic Interval – Clinton-Medina**									
	FID	7	8	9	36	63	65	110	124	141	189	198	258	259
	Test_ID	11741	11742	11743	649	1005	1060	1543	1981	2048	2216	2240	2342	2343
	Distance to infrastructure													
0	>30 mi	3	2	3	3	3	3	3	3	3	2	2	3	3
1	>20 mi but <=30 mi													
2	>5 mi but <=20 mi													
3	<=5 mi													
	Acreage	3	3	3	3	3	3	3	3	3	3	3	3	3
0	<=500 ac													
1	>500 ac but <=1,000 ac													
2	>1,000 ac but <=5,000 ac													
3	>5,000 ac													
	Average depth	1	1	1	3	3	3	1	3	3	3	3	3	3
0	<=2,000 ft													
1	>5,000 ft													
2	>2,000 ft but <=3,500 ft													
3	>3,500 ft but <=5,000 ft													
	Net thickness	3	3	3	2	2	2	3	2	2	3	3	3	3
0	<=1 ft													
1	>1 ft but <=10 ft													
2	>10 ft but <=20 ft													
3	>20 ft													
	Trap integrity	3	3	3	0	0	0	0	0	0	0	0	0	0
0	No data													
1	Limited data on trap characteristics													
2	Inferred lithologic and/or structural closure													
3	Documented lithologic and/or structural closure													
	Legacy well penetrations	1	1	1	1	2	2	1	3	1	0	0	1	0
0	No data or >=20 wells per 1,000 ac													
1	>=5 wells per 1,000 ac but <20 wells per 1,000 ac													
2	>=2 wells per 1,000 ac but<5 wells per 1,000 ac													
3	<2 well per 1000 ac													
	Stacked opportunity?	2	1	2	0	0	0	0	0	0	0	0	0	0
0	No other intervals in same footprint													
1	1 other interval in same footprint													
2	2 or 3 other intervals in same footprint													
3	4 or more intervals in same footprint													
	Totals	16	14	16	12	13	13	11	14	12	11	11	13	12

	Geologic Interval –	Geologic Interval – Rose Run									
	FID	1	3	4	5	6	7	8	15	28	57
	Test_ID	2	5	6	7	9	10	11	116	161	219
Range of Values	**Criteria**	KIRKERSVILLE	DUMM RIDGE	DUMM RIDGE	ROCKBRIDGE	ROCKBRIDGE	DUMM RIDGE	DUMM RIDGE	FRAZEYBURG	ROCKBRIDGE	RANDOLPH
	Distance to infrastructure										
0	>30 mi	1	0	0	0	0	0	0	3	0	2
1	>20 mi but <=30 mi										
2	>5 mi but <=20 mi										
3	<=5 mi										
	Acreage	1	1	2	2	1	2	2	3	2	3
0	<=500 ac										
1	>500 ac but <=1,000 ac										
2	>1,000 ac but <=5,000 ac										
3	>5,000 ac										
	Average depth	3	3	3	3	3	3	3	1	3	1
0	<=2,000 ft										
1	>5,000 ft										
2	>2,000 ft but <=3,500 ft										
3	>3,500 ft but <=5,000 ft										
	Net thickness	3	3	3	3	3	3	3	3	3	3
0	<=1 ft										
1	>1 ft but <=10 ft										
2	>10 ft but <=20 ft										
3	>20 ft										
	Trap integrity	1	1	1	0	0	1	1	1	1	1
0	No data										
1	Limited data on trap characteristics										
2	Inferred lithologic and/or structural closure										
3	Documented lithologic and/or structural closure										
	Legacy well penetrations	1	1	1	0	0	1	2	0	1	0
0	No data or >=20 wells per 1,000 ac										
1	>=5 wells per 1,000 ac but <20 wells per 1,000 ac										
2	>=2 wells per 1,000 ac but<5 wells per 1,000 ac										
3	<2 well per 1000 ac										
	Stacked opportunity?	0	0	0	0	0	0	0	0	0	0
0	No other intervals in same footprint										
1	1 other interval in same footprint										
2	2 or 3 other intervals in same footprint										
3	4 or more intervals in same footprint										
	Totals	10	9	10	8	7	10	11	11	10	10

APPENDIX G – CORE AND THIN SECTION DATA FOR JONES & LAUGHLIN #1, BEAVER COUNTY, PENNSYLVANIA

Sample Number	Formation	Depth (ft)	Earlougher Engineering		PAGS	
			Permeability (mD)	Porosity (%)	Permeability (mD)	Porosity (%)
1	Huntersville Chert	5250	0.01	0.14	0.174	0.074
10	Huntersville Chert	5258	0	0.14	0.19	0.025
20	Huntersville Chert	5268	0	0.43	0.671	0.228
30	Huntersville Chert	5346	0	0.58	0.185	0.052
40	Huntersville Chert	5356	0	0.14	0.188	0.144
49	Huntersville Chert	5366	0	0.14	0.196	0.039
60	Oriskany Sandstone	5385	0	0.43	0.192	0.199
61	Oriskany Sandstone	5386			0.199	0.026
62	Oriskany Sandstone	5387			0.199	0.367
63	Oriskany Sandstone	5388	0.04		0.191	0.605
64	Oriskany Sandstone	5389	0		0.218	0.029
65	Oriskany Sandstone	5390	0.07		0.314	1.04
66	Oriskany Sandstone	5391	0		0.221	1.03
67	Oriskany Sandstone	5392	0.2		0.323	2.61
68	Oriskany Sandstone	5393	3.3		1.27	4.38
69	Oriskany Sandstone	5394	0.94		2.23	5.19
70	Oriskany Sandstone	5395	1.2	4.8	1.74	4.36
71	Oriskany Sandstone	5396	0.68		1.04	4.26
	Oriskany Sandstone Oriskany Sandstone	5397- 5403	No core samples			
72	Oriskany Sandstone	5404	2.3		1.94	4.73
73	Oriskany Sandstone	5405	3		3.27	4.88
74	Oriskany Sandstone	5406	4.2		4.59	5.36
75	Oriskany Sandstone	5407	2.7	5.5	3.15	4.35
76	Oriskany Sandstone	5408	1.9		2.07	5.03
77	Oriskany Sandstone	5409	3.4		4.56	5.44
78	Oriskany Sandstone	5410	1.8		2.66	6.44
79	Oriskany Sandstone	5411	3.1		3.83	5.6
80	Oriskany Sandstone	5421	0.01	2.0	0.251	0.865
81	Oriskany Sandstone	5422	0.08		0.333	3.1
82	Oriskany Sandstone	5423	0.03		0.295	2.31
83	Oriskany Sandstone	5424	0.02		0.243	1.01
84	Oriskany Sandstone	5425	0.02		0.285	1.02
85	Oriskany Sandstone	5426	0.01	1.2	0.248	1.81

Core No.	Formation	Depth (ft)	Dry Weight (g)	Wet Weight (g)	Difference (g)	Bulk Volume (cc)	Pore Volume (cc)	Porosity (%)
41	Huntersville Chert	5357	34.7149	34.7162	0.0013	12.95	0.00173	0.013
42	Huntersville Chert	5358	25.14	25.1425	0.0025	9.311	0.00333	0.036
43	Huntersville Chert	5359	30.4366	30.4421	0.0055	11.345	0.00733	0.065
44	Huntersville Chert	5360	32.4891	32.493	0.0039	12.033	0.00919	0.043
45	Huntersville Chert	5361	35.2397	35.2419	0.0022	12.95	0.00293	0.023
46	Huntersville Chert	5363	31.8703	31.8725	0.0022	11.8038	0.00293	0.025
47	Huntersville Chert	5364	14.4666	14.4798	0.0032	5.358	0.00426	0.08
48	Huntersville Chert	5365	31.2625	31.2665	0.004	11.746	0.00533	0.045
49	Huntersville Chert	5366	32.0247	32.0282	0.0035	11.861	0.00966	0.039
50	Huntersville Chert	5367	15.4	15.4058	0.0058	6.303	0.00773	0.123
51	Huntersville Chert	5368	30.6315	30.6377	0.0062	11.345	0.00826	0.073
52	Huntersville Chert	5369	29.8562	29.8581	0.0019	11.303	0.00253	0.023
53	Huntersville Chert	5370	18.1427	18.1447	0.002	6.818	0.00266	0.039
54	Huntersville Chert	5371	34.398	34.4038	0.005	12.692	0.00666	0.052
55	Huntersville Chert	5380	17.3848	17.3874	0.0026	6.532	0.00346	0.053
56	Huntersville Chert	5381	29.1627	29.1665	0.0038	10.801	0.0051	0.047
57	Huntersville Chert	5382	33.3341	33.34	0.0059	12.549	0.00786	0.063
58	Huntersville Chert	5383	18.9513	18.9544	0.0031	7.019	0.00413	0.059
59	Oriskany Sandstone	5384	27.6939	27.6979	0.004	10.257	0.00533	0.052
60	Oriskany Sandstone	5385	32.7926	32.8109	0.0183	12.262	0.02437	0.199
61	Oriskany Sandstone	5386	37.6074	37.6101	0.0027	13.809	0.0036	0.026
62	Oriskany Sandstone	5387	33.5575	33.5919	0.0344	12.491	0.0458	0.367
63	Oriskany Sandstone	5388	29.7823	29.8391	0.0568	11.059	0.0757	0.685
64	Oriskany Sandstone	5389	37.5406	37.5436	0.003	13.695	0.004	0.029
65	Oriskany Sandstone	5390	28.9666	29.0516	0.085	10.881	0.113	1.04
66	Oriskany Sandstone	5391	33.9981	34.0976	0.0995	12.778	0.132	1.03
67	Oriskany Sandstone	5392	34.5054	34.7628	0.2574	13.112	0.3429	2.61
68	Oriskany Sandstone	5393	33.7255	34.1572	0.4317	13.112	0.575	4.38
69	Oriskany Sandstone	5394	34.491	35.0187	0.5277	13.551	0.7029	5.19
70	Oriskany Sandstone	5395	34.2145	34.6511	0.4366	13.351	0.5816	4.36
71	Oriskany Sandstone	5396	34.0314	34.4534	0.422	13.208	0.5621	4.26
			2 feet, unmarked cores					
72	Oriskany Sandstone	5404	34.3839	34.8603	0.4764	13.408	0.6346	4.73
73	Oriskany Sandstone	5405	30.5221	31.0323	0.5102	12.033	0.6796	4.82
74	Oriskany Sandstone	5406	32.6152	33.1301	0.5149	12.807	0.6859	5.36
75	Oriskany Sandstone	5407	33.9678	34.4769	0.5091	13.294	0.6781	4.35
76	Oriskany Sandstone	5408	30.7374	31.1907	0.4533	12.004	0.6038	5.03
77	Oriskany Sandstone	5409	31.6332	32.1394	0.5062	12.405	0.6743	5.44
78	Oriskany Sandstone	5410	33.364	34.0002	0.6362	13.15	0.8474	6.44
79	Oriskany Sandstone	5411	34.3147	34.8811	0.5664	13.466	0.7544	5.6
80	Oriskany Sandstone	5421	35.1305	35.2165	0.086	13.236	0.1145	0.856

Thin Section Analysis Report

Sample ID: 0-2 JL-1-A
Formation/Member Name: Oriskany Sandstone Beaver County, PA
Lithologic Classification: Sandstone
Depth/Depth Range: 5383 ft
Date of Analysis: 6/7/2017
Analyzed by: Ellen Davis

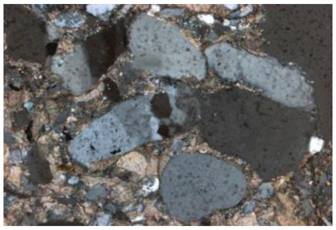
observed at 10x

	Texture	**Comments**
Grain Size	50-800 µm, average grain size ~300 µm	
Rounding	subangular, subrounded	
Sorting	moderately to poorly sorted	

	Composition/Detrital Minerals	**Comments**
	Quartz	
Polycrystalline		images 02_0002, 02_0004, 02_0009 - 02_0013
Monocrystalline	~80% monocrystalline quartz ·larger, subrounded to rounded grains ·many smaller subangular grains ·not much overgrowth ·primarily subhedral with moderate relief	
Microcrystalline	grains can be easily observed under petroscope	
	XN: black, white, gray PPL: light brown	
	*small holes present; could just be the image	
	Feldspar	
Plagioclase	·albite twinning present	images 02_0001, 02_0006, 02_0007
Orthoclase	N/A	
Microcline	·tartan twinning present	image 02_0008
	Carbonate	
Calcite	~20% calcite ·moderate relief ·primarily cementing material/overgrowth ·primarily anhedral	images 02_0017 - 02_0023
	XN: brown, green, pink PPL: light brown	
Dolomite	N/A	
Aragonite	N/A	
	Clay	
Illite	N/A	
Smectite	N/A	
Kaolinite	N/A	
Muscovite	<1% muscovite ·small, subrounded to rounded grains	
	XN: blue, purple, orange PPL: gray-green	
Chlorite	N/A	
Glauconite	N/A	
	Rock Fragments	
Sedimentary		
Volcanic	N/A	
Metamorphic	N/A	
	Other (Accessory Minerals)	
Uncertainties	image 02_0005	

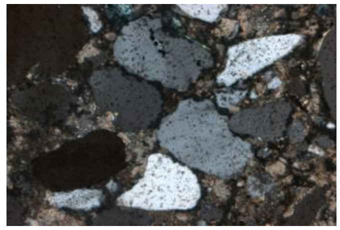
	Cementing Materials	**Comments**
Quartz		
Feldspar		
Carbonate	·primarily carbonate cementing	images 02_0025 - 02_0030
Clay		
Iron Oxide, Hydoxide and/or Sulfide		
Other		

	Visual Porosity Estimate	**Comments**
	difficult to determine porosity due to absence of dye	



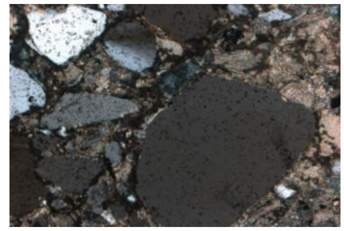
This XN image shows subangular quartz grains varying from smaller to larger grain sizes. The image also contains polycrystalline quartz although it makes up a small percentage of the sample's composition.

(10x, XN)



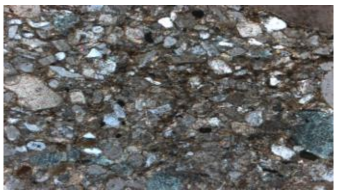
This image shows subangular and subrounded quartz grains with medium relief. The quartz is in a matrix of calcite and does not show much overgrowth.

(10x, XN)



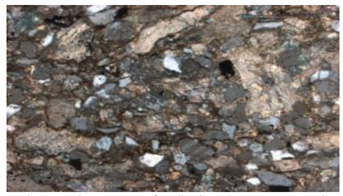
This is a larger quartz grain, embedded in a matrix of calcite and smaller quartz grains.

(10x, XN)



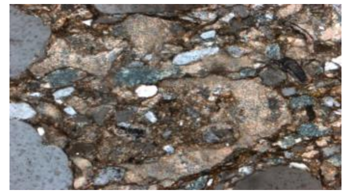
This image shows much smaller quartz grains surrounded by cementing calcite.

(10x, XN)



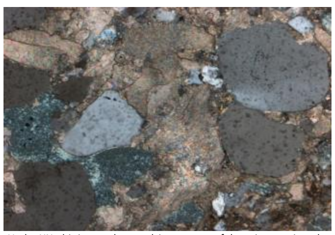
This image shows a matrix of small, subangular quartz grains and calcite.

(10x, XN)



A large section of calcite is shown in this image. Here, smaller quartz grains are cemented by the calcite.

(10x, XN)



Under XN, this image shows calcite as a one of the primary minerals in the sample as well as the predominant cementing material.

(10x, XN)

This image shows a large grain of calcite surrounded by cementing calcite and larger quartz grains.

(10x, XN)

This image shows subangular birefringent muscovite in a matrix of small quartz grains and calcite cement.

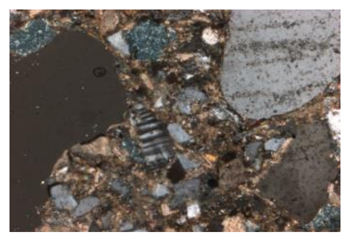
(10x, XN)

The small, brightly-colored minerals in this XN image are grains of muscovite.

(10x, XN)

The tartan twinning in this image shows the presence of microcline feldspar.

(10x, XN)



This image of plagioclase feldspar shows albite twinning. The striped pattern is visible under XN.

(10x, XN)

Thin Section Analysis Report

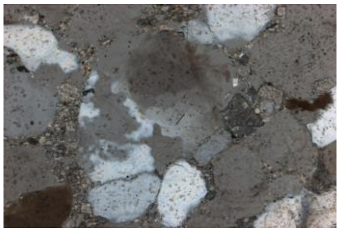
Sample ID: 0-3-A JL-1-A
Formation/Member Name: Oriskany Sandstone Beaver County, PA
Lithologic Classification: Sandstone
Depth/Depth Range: 5384 ft
Date of Analysis: 6/7/2017
Analyzed by: Ellen Davis

	Texture	**Comments**
		observed at 10x
Grain Size	100-700 µm, average grain size ~350µm	
Rounding	subrounded to rounded	
Sorting	well sorted	

	Composition/Detrital Minerals	**Comments**
	Quartz	
Polycrystalline		images 03A_0002 - 03A_0004, 03A_0006 - 03A_0009
Monocrystalline	~95% quartz ·mostly large, subrounded to rounded grains ·small holes present in grains ·overgrowth is present some polycrystalline as well) ·subhedral with moderate relief	
Microcrystalline	grains can be easily observed under petroscope XN: black, white, gray PPL: light brown	
	Feldspar	
Plagioclase	N/A	
Orthoclase	N/A	
Microcline	·tartan twinning present	image 03A_0015
	Carbonate	
Calcite	~5% calcite ·primarily cementing material/overgrowth ·anhedral grains XN: brown, green, pink PPL: light brown/gray	images 03A_0010 - 03A_0014
Dolomite	N/A	
Aragonite	N/A	
	Clay	
Illite	N/A	
Smectite	N/A	
Kaolinite	N/A	
Muscovite	<1% muscovite ·small grains ·subrounded to rounded grains XN: blue, green, orange, pink PPL: green/gray	images 03A_0016, 03A_0017
Chlorite	N/A	
Glauconite	N/A	
	Rock Fragments	
Sedimentary		
Volcanic		
Metamorphic		
	Other (Accessory Minerals)	
Uncertainties	image 03A_0005	

	Cementing Materials	**Comments**
Quartz	·overgrown quartz and calcite present	images 03A_0018 - 03A_0023
Feldspar		image 03A_0001
Carbonate		
Clay		
Iron Oxide, Hydoxide and/or Sulfide		
Other	·possibly mud present?	

	Visual Porosity Estimate	**Comments**
	absence of dye limited accuracy of porosity estimate	



This image shows the primary composition of this sample: overgrown quartz. With XN, polycrystalline grains can be seen among the overgrowth.

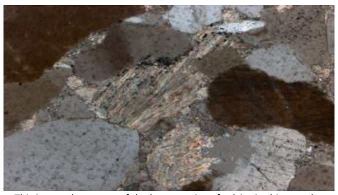
(10x, XN)

The quartz grains in this image are overgrown, forming a cementing material. There is some calcite present but the matrix is primarily quartz.

(10x, XN)

This is a particularly large quartz grain and other large, overgrown quartz grains. Some cementing calcite is also shown.

(10x, XN)



This image shows one of the larger grains of calcite in this sample under XN. Smaller bits of calcite can also be seen between the quartz grains in this image.

(10x, XN)

The large grain of calcite in this image is embedded in overgrown quartz and some smaller grains of calcite.

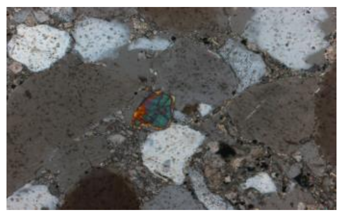
(10x, XN)

Although the compostion of this sample is primarily overgrown quartz, this image shows a large grain of calcite cemented by overgrown quartz.

(10x, XN)

The tartan twinning in this image shows the presence of microcline feldspar, here cemented by quartz grains.

(10x, XN)



This image shows a grain of brightly colored muscovite in a matrix of overgrown quartz and calcite.

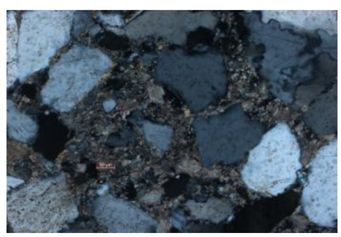
(10x, XN)

*****

(10x, XN)

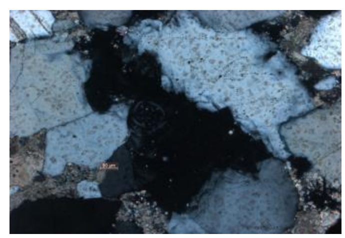
This image shows calcite separating subrounded and subanglar quartz grains.

(10x, XN)



These are small quartz grains embedded in calcite. Some overgrown quartz is also present in the top-left of this image.

(10x, XN)



This overgrown quartz is the predominant mineral in the sample. The overgrowth cements larger grains of calcite.

(10x, XN)

Thin Section Analysis Report

Sample ID: 0-3-B JL-1-A
Formation/Member Name: Oriskany Sandstone Beaver County, PA
Lithologic Classification: Sandstone
Depth/Depth Range: 5384 ft
Date of Analysis: 6/9/2017
Analyzed by: Ellen Davis

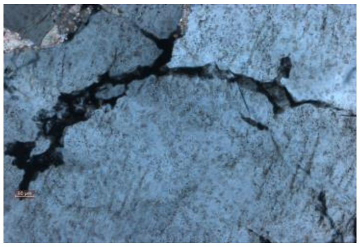
observed at 10x

	Texture	Comments
Grain Size	50-900 µm, average grain size ~450 µm	
Rounding	subangular to subrounded	
Sorting	moderately to well sorted	

	Composition/Detrital Minerals	Comments
	Quartz	
Polycrystalline		images 03B_0003 - 03B_0009, 03B_0012
Monocrystalline	~85% quartz ·subangular to subrounded grains ·primarily larger than the other grains ·large amounts of overgrowth ·mostly subhedral grains ·small holes are present in grains	
Microcrystalline	grains can be easily observed under petroscope XN: black, white, gray PPL: light brown	
	Feldspar	
Plagioclase	<1% feldspar ·albite twinning ·small, subhedral grains	images 03B_0001, 03B_0010, 03B_0020
Orthoclase	N/A	
Microcline	N/A	
	Carbonate	
Calcite	~15% calcite ·primarily anhedral cementing material XN: brown, green, pink PPL: light brown/gray	images 03B_0011, 03B_0013 - 03B_0018
Dolomite	N/A	
Aragonite	N/A	
	Clay	
Illite	N/A	
Smectite	N/A	
Kaolinite	N/A	
Muscovite	<1% muscovite ·small, rounded grains XN: blue, orange, pink, green PPL: yellow-green/brown	images 03B_0019, 03B_0021, 03B_0024
Chlorite	N/A	
Glauconite	N/A	
	Rock Fragments	
Sedimentary		
Volcanic		
Metamorphic		
	Other (Accessory Minerals)	

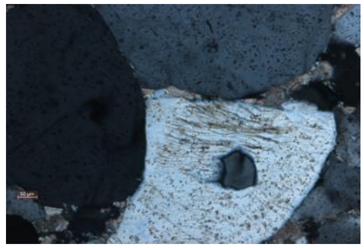
	Cementing Materials	Comments
Quartz	·overgrown quartz and calcite cementing	images 03B_0002, 03B_0023, 03B_0025 - 03B_0029
Feldspar		
Carbonate		
Clay		
Iron Oxide, Hydoxide and/or Sulfide		
Other	·mud possibly present(?)	

Visual Porosity Estimate	Comments
no dye made it difficult to determine porosity	



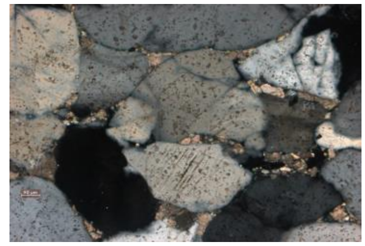
This image shows large, subhedral quartz grains. Quartz comprises 85% of this sample.

(10x, XN)



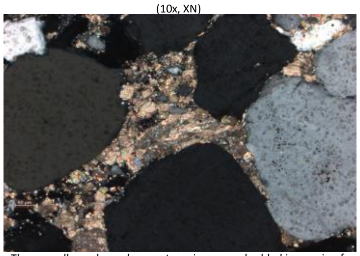
These quartz grains are large, subhedral and subrounded. Some quartz overgrowth is shown as well.

(10x, XN)



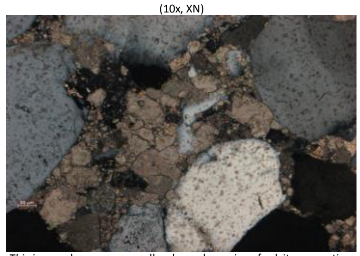
This image shows overgrown quartz and some smaller grains of calcite embedded in it.

(10x, XN)



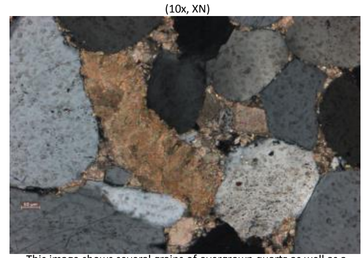
These smaller, subangular quartz grains are embedded in a grain of calcite. Larger, subrounded quartz grains are also shown.

(10x, XN)



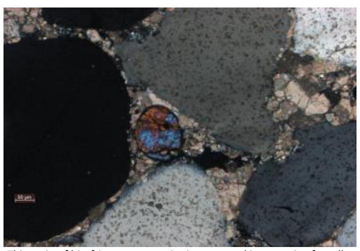
This image shows many small, subangular grains of calcite cementing quartz grains.

(10x, XN)



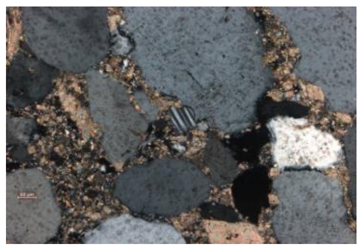
This image shows several grains of overgrown quartz as well as a large grain of calcite. Some smaller grains of calcite cement the overgrown quartz.

(10x, XN)



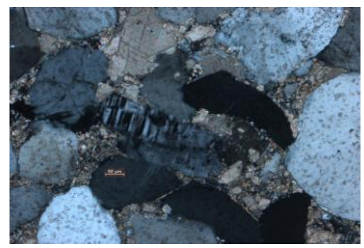
This grain of birefringent muscovite is cemented in a matrix of small, subangular calcite and large grains of quartz.

(10x, XN)



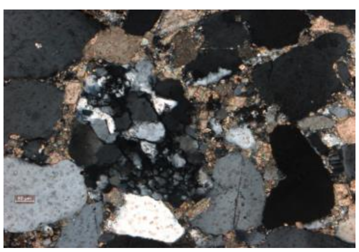
The albite twinning shown in this image is due to plagioclase feldspar. The feldspar is cemented in a matrix of quartz and calcite.

(10x, XN)



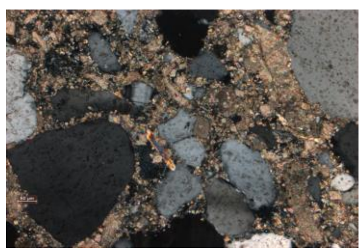
This image shows plagioclase feldspar with albite twinning surrounded by calcite and large, subrounded quartz.

(10x, XN)



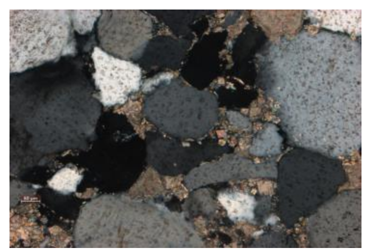
This is an image of polycrystalline quartz. Small grains of calcite and larger grains of monocrystalline quartz surround the polycrystalline quartz.

(10x, XN)



These subangular and subrounded quartz grains are in a matrix of calcite and smaller quartz grains. There is also a small grain of muscovite in the center of the image.

(10x, XN)



Overgrown quartz is shown in this image, surrounded by calcite.

(10x, XN)

Thin Section Analysis Report

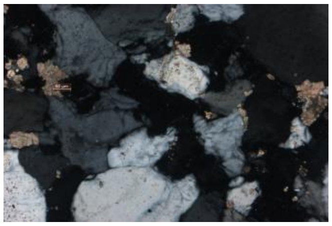
Sample ID:	0-4 JL-1-A
Formation/Member Name:	Oriskany Sandstone Beaver County, PA
Lithologic Classification:	Sandstone
Depth/Depth Range:	5387 ft
Date of Analysis:	6/12/2017
Analyzed by:	Ellen Davis

	Texture	Comments
		observed at 10x
Grain Size	50-800 µm, average grain size ~300 µm	
Rounding	subangular to subrounded, subhedral	
Sorting	moderately to well sorted	

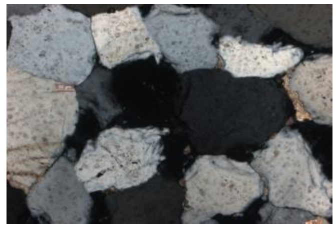
	Composition/Detrital Minerals	Comments
	Quartz	
Polycrystalline		images 04_0001 - 04_0005, 04_0007 - 04_0009
Monocrystalline	~95% quartz ·subangular to subrounded grains ·medium grain size ·abundant overgrowth; polycrystalline grains	
Microcrystalline	grains can be easily observed under petroscope	
	XN: black, white, gray PPL: light brown	
	Feldspar	
Plagioclase	·albite twinning present	image 04_0016
Orthoclase	N/A	
Microcline	·tartan twinning present	image 04_0015
	Carbonate	
Calcite	<5% calcite ·medium, subhedral grains ·mostly anhedral	images 04_0011 - 04_0014, 04_0018, 04_0019
	XN: brown, green, pink PPL: light brown/gray	
Dolomite		
Aragonite		
	Clay	
Illite	N/A	
Smectite	N/A	
Kaolinite	N/A	
Muscovite	<1% muscovite ·small, subrounded to rounded grains	image 04_0017
	XN: blue, orange, pink PPL: yellow-green/gray	
Chlorite	N/A	
Glauconite	N/A	
	Rock Fragments	
Sedimentary	some sedimentary rock fragments present	image 04_0006 (SRF?)
Volcanic		
Metamorphic		
	Other (Accessory Minerals)	
Uncertainties	04_0010 (right side), 04_0023 (unknown circles)	

	Cementing Materials	Comments
Quartz	·mostly overgrown quartz	images 04_0020 - 04_0022, 04_0024 - 04_0025
Feldspar		
Carbonate	·some calcite present	
Clay		
Iron Oxide, Hydoxide and/or Sulfide		
Other		

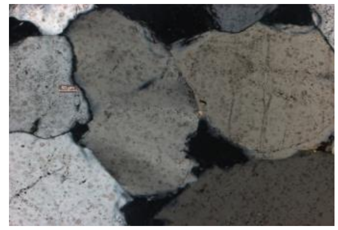
	Visual Porosity Estimate	Comments
	difficult to determine porosity due to absence of dye	


This sample is about 95% quartz and this image shows subhedreal, overgrown quartz grains. Some grains of calcite are also present.

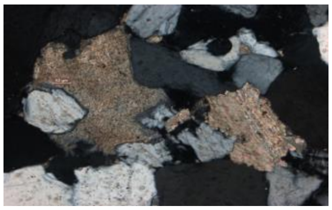
(10x, XN)

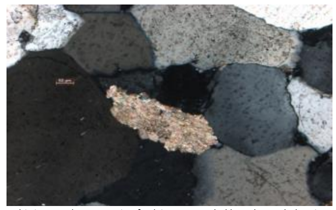

This image shows subangular, overgrown quartz cementing several smaller grains of calcite.

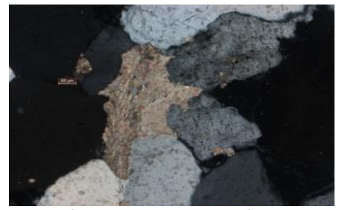
(10x, XN)


These large, subrounded/subangular quartz grains are overgrown with only some void space separating the grains.

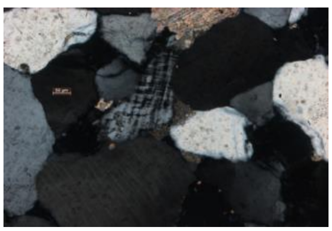
(10x, XN)


These two large grains of subhedral calcite are cemented by overgrown quartz.
(10x, XN)

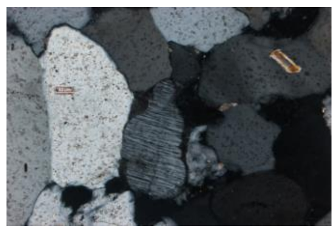

This image shows a grain of calcite surrounded by subrounded grains of overgrown quartz.
(10x, XN)


A matrix of overgrown quartz surrounds a grain of ahedral calcite.

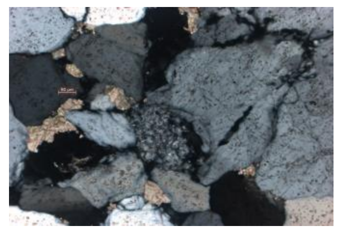
(10x, XN)


This is an image of microcline feldspar with tartan twinning in a matrix of overgrown quartz. Some calcite is also shown in this image.

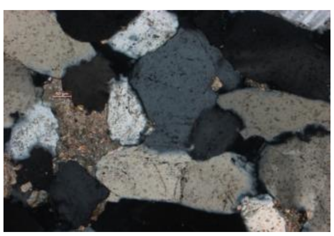
(10x, XN)


This image shows a subrounded grain of plagioclase feldspar with albite twinning. A small grain of muscovite is in the top right corner.

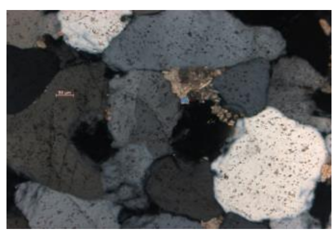
(10x, XN)


This sedimentary rock fragment is embedded in overgrown quartz grains with some small grains of calcite also present.

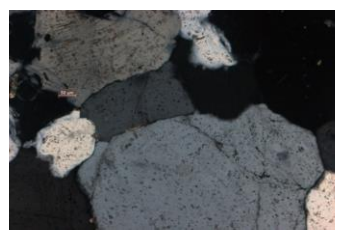
(10x, XN)


This image shows overgrown quartz cementing grains of calcite.

(10x, XN)


These small grains of calcite are surrounded by subrounded and subangular overgrown quartz. Some void space is shown as well.

(10x, XN)


This image shows subhedral, overgrown quartz grains along with some void space.

(10x, XN)

Thin Section Analysis Report

Sample ID:	0-5 JL-1-A
Formation/Member Name:	Oriskany Sandstone Beaver County, PA
Lithologic Classification:	Sandstone
Depth/Depth Range:	5388 ft
Date of Analysis:	6/12/2017
Analyzed by:	Ellen Davis

	Texture	**Comments**
		observed at 10x
Grain Size	100-800 µm, average grain size ~300 µm	
Rounding	subangular to subrounded grains; subhedral	
Sorting	moderately to poorly sorted grains	

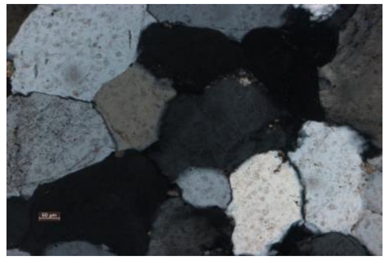
	Composition/Detrital Minerals	**Comments**
	Quartz	
Polycrystalline		images 05_0003 - 05_0009
Monocrystalline	~90% quartz ·abundant overgrowth ·subangular to subrounded grains ·mostly subhedral	
Microcrystalline	grains can be easily observed under petroscope	
	XN: black, white, gray PPL: light brown	
	Feldspar	
Plagioclase	N/A	
Orthoclase	N/A	
Microcline	N/A	
	Carbonate	
Calcite	~10% calcite	images 05_0010 - 05_0013, 05_0015 - 05_0016
	XN: brown, green, pink PPL light brown/gray	
Dolomite		
Aragonite		
	Clay	
Illite	N/A	
Smectite	N/A	
Kaolinite	N/A	
Muscovite	<5% muscovite ·small, angular-subangular grains	images 05_0006
	XN: blue, orange, pink PPL: gray-brown	
Chlorite	N/A	
Glauconite	N/A	
	Rock Fragments	
Sedimentary	sedimentary rock fragments present in thin section	images 05_0001 (SRF)
Volcanic		
Metamorphic		
	Other (Accessory Minerals)	
Uncertainties	05_0014	

	Cementing Materials	**Comments**
Quartz	·primarily overgrown quartz	images 05_0018 - 05_0023
Feldspar		
Carbonate	·some (not much) calcite cementing	
Clay		
Iron Oxide, Hydoxide and/or Sulfide		
Other	·possibly mud	

Visual Porosity Estimate	**Comments**
lack of dye makes it difficult to determine porosity	

This image shows large, subrounded quartz grains. This comprises about 90% of the sample.

(10x, XN)



This image shows subangular and subrounded overgrown quartz grains.

(10x, XN)

This is a large quartz grain with other overgrown quartz grains surrounding it.

(10x, XN)

This larger grain of subhedral calcite is in a matrix of overgrown quartz.

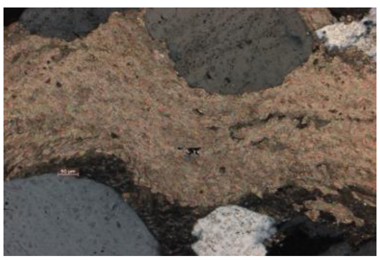
(10x, XN)

This image shows a strained grain of calcite surrounded by subround and subangular overgrown quartz.

(10x, XN)

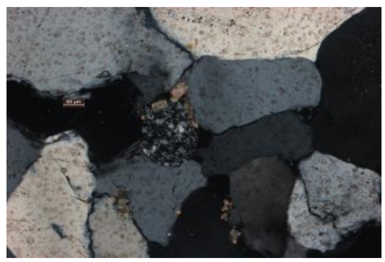
In this image, overgrown quartz surrounds a grain of calcite.

(10x, XN)



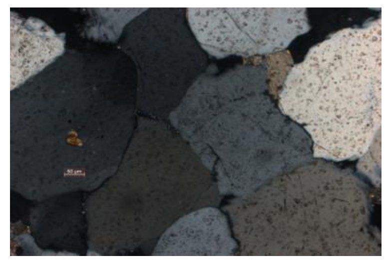
This image shows a matrix of calcite among several subrounded quartz grains.

(10x, XN)



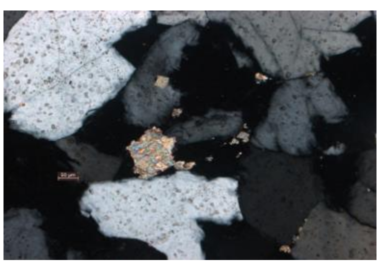
This image shows a sedimentary rock fragment in a matrix of overgrown quartz.

(10x, XN)



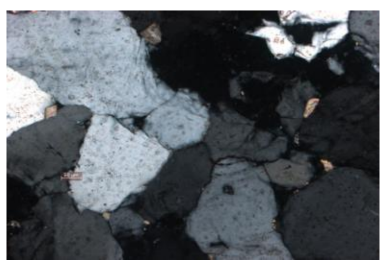
Although only about 50 µm large, this grain of birefringent muscovite is embedded in a grain of quartz. Other overgrown grains of quartz are present in this image.

(10x, XN)



This image shows overgrown quartz, subangular calcite, and pore space in between the grains.

(10x, XN)



This subhedral overgrown quartz is the primary cementing material in this image but some pore space can be seen separating the quartz.

(10x, XN)

This image shows a good example of the overall composition of this sample. A grain of calcite is shown with overgrown quartz and void space.

(10x, XN)

Thin Section Analysis Report

Sample ID: 0-6 JL-1-A
Formation/Member Name: Oriskany Sandstone Beaver County, PA
Lithologic Classification: Sandstone
Depth/Depth Range: 5404 ft
Date of Analysis: 6/13/2017
Analyzed by: Ellen Davis

observed at 10x

	Texture	Comments
Grain Size	50-700 µm, average grain size ~350 µm	
Rounding	subangular to subrounded grains; mostly subhedral	
Sorting	moderately sorted	

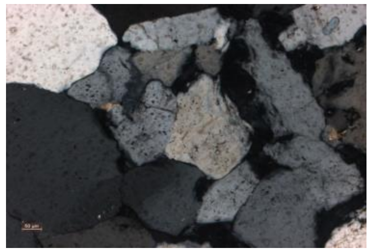
	Composition/Detrital Minerals	Comments
	Quartz	
Polycrystalline		images 06_0004 - 06_0010, 06_0012
Monocrystalline	~90% quartz ·large amounts of overgrowth ·subangular to subrounded grains ·mostly subhedral grains ·some polycrystalline quartz	
Microcrystalline	grains can be easily observed under petroscope	
	XN: black, white, gray PPL: light brown	
	Feldspar	
Plagioclase	·albite twinning present	image 06_0001
Orthoclase	N/A	
Microcline	·tartan twinning present	image 06_0014
	Carbonate	
Calcite		images 06_0013, 06_0015, 06_0017 - 06_0021
	<10% calcite ·medium sized, subhedral grains ·some small grains present	
	XN: brown, green, pink PPL: light brown	
Dolomite	N/A	
Aragonite	N/A	
	Clay	
Illite	N/A	
Smectite	N/A	
Kaolinite	N/A	
(?) Muscovite	·small, subangular grains	image 06_0068
	XN: blue, yellow, green PPL: gray-brown	
Chlorite	N/A	
Glauconite	N/A	
	Rock Fragments	
Sedimentary	some sedimentary rock fragments	06_0002 (SRF?)
Volcanic		
Metamorphic		
	Other (Accessory Minerals)	
Uncertainties	images 06_0026 (4:00), 06_0011 (small, clear/ blue)	
	06_0016 (clear, yellow)	

	Cementing Materials	Comments
Quartz	·primarily overgrown quartz	images 06_0022 - 06_0025, 06_0027, 06_0029
Feldspar		
Carbonate	·small amounts of calcite	
Clay		
Iron Oxide, Hydoxide and/or Sulfide		
Other	·some mud (?)	image 06_0003 (mud)

	Visual Porosity Estimate	Comments
	difficult to estimate porosity due to lack of dye	


This image shows a range of differently sized overgrown quartz grains.

(10x, XN)


The subhedral quartz grains in this image are overgrown, cementing grains of calcite.

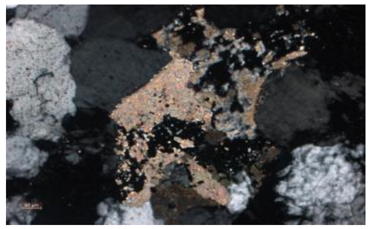
(10x, XN)


This image shows larger, overgrown quartz grains.

(10x, XN)


Overgrown quartz surrounds a subhedral grain of calcite.

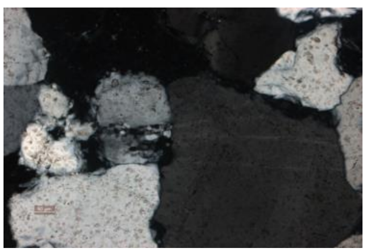
(10x, XN)


This image shows calcite in a matrix of overgrown quartz and smaller grains of calcite. Some void space can be seen here as well.

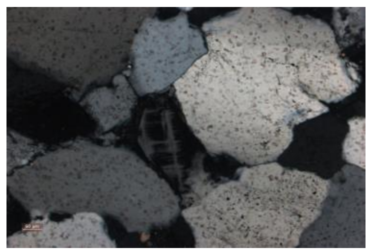
(10x, XN)


These grains of calcite are embedded in subrounded, overgrown quartz grains.

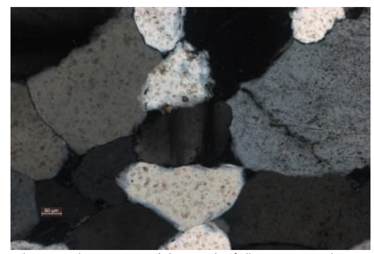
(10x, XN)


This polycrystalline quartz is in a matrix of overgrown quartz.

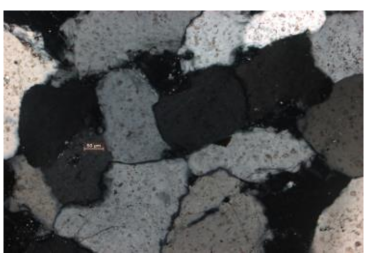
(10x, XN)


This microcline feldspar with tartan twinning is cemented between subangular and subrounded overgrown quartz.

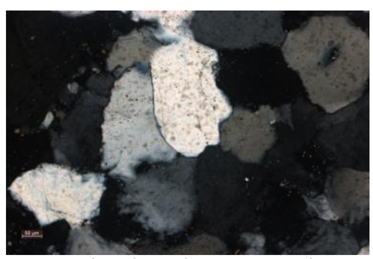
(10x, XN)


This image shows a more subtle example of albite twinning indicating the presence of plagioclase feldspar. The feldspar is cemented in overgrown quartz.

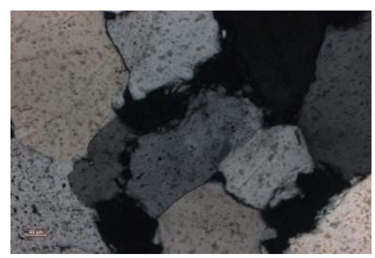
(10x, XN)


This image shows overgrown quartz as well as pore space inbetween the quartz grains.

(10x, XN)


Pore space can be seen between the overgrown quartz in this image.

(10x, XN)


This image shows subhedral overgrown quartz grains and pore space.

(10x, XN)

Thin Section Analysis Report

Sample ID: 0-7-A JL-1-A
Formation/Member Name: Oriskany Sandstone Beaver County, PA
Lithologic Classification: Sandstone
Depth/Depth Range: 5418 ft
Date of Analysis: 6/13/2017
Analyzed by: Ellen Davis

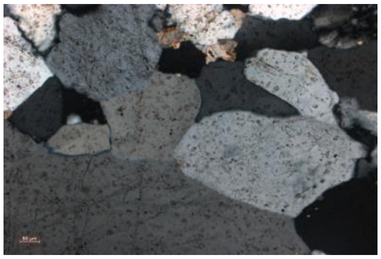
observed at 10x

	Texture	Comments
Grain Size	50-500 µm, average grain size ~350 µm	
Rounding	subangular to subrounded	
Sorting	poorly to moderately sorted	

	Composition/Detrital Minerals	Comments
	Quartz	
Polycrystalline	N/A	images 07A_0007 - 07A_0013
Monocrystalline	~60% quartz ·medium sized, overgrown grains ·mostly monocrystalline	
Microcrystalline	grains can be easily observed under petroscope	
	XN: white, black, gray PPL: light brown	
	Feldspar	
Plagioclase	·albite twinning present	images 07A_0001, 07A_0002, 07A_0014
Orthoclase	N/A	
Microcline	·tartan twinning present	image 07A_0003 (?)
	Carbonate	
Calcite		
	~40% caclite ·large line of calcite running down top of slide ·medium sized grains ·primarily euhedral	images 07A_0015 - 07A_0021
	XN: brown, green, pink PPL: light brown/gray	
Dolomite		
	N/A	
Aragonite	N/A	
	Clay	
Illite	N/A	
Smectite	N/A	
Kaolinite	N/A	
Muscovite	<1% muscovite ·small, subangular to subrounded grains	images 07A_0004 - 07A_0006
	XN: orange, blue, pink PPL: green-brown	
Chlorite	N/A	
Glauconite	N/A	
	Rock Fragments	
Sedimentary		
Volcanic		
Metamorphic		
	Other (Accessory Minerals)	
Uncertainties	images 07A_0022, 07A_0023 (black & white, low relief, crystalline)	
	image 07A_0024 (black with calcite, no extinction, smooth PPL, pores?)	

	Cementing Materials	Comments
Quartz	·about 50% overgrown quartz	images 07A_0025 - 07A_0030
Feldspar		
Carbonate	·50% calcite	
Clay		
Iron Oxide, Hydoxide and/or Sulfide		
Other		

	Visual Porosity Estimate	Comments
	no dye, difficult to determine porosity	

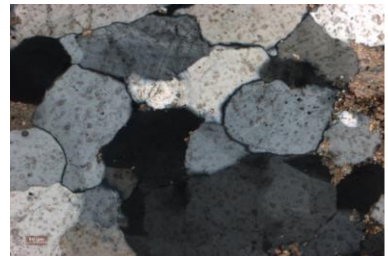


This image shows subrounded overgrown quartz grains ranging in size.

(10x, XN)

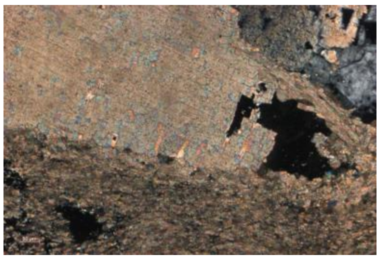
These monocrystalline, overgrown quartz grains cement about 60% of the sample.

(10x, XN)



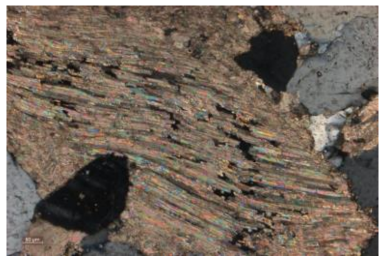
This overgrown quartz cements some smaller grains of calcite.

(10x, XN)



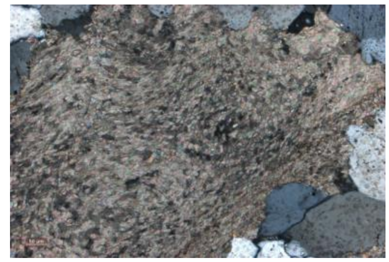
There is a large grain of calcite stretching across part of the sample. This image shows part of that line of calcite. Some pore space is also shown.

(10x, XN)



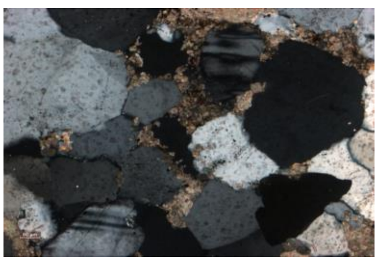
This is another image of calcite in the sample. This calcite is more striated and some quartz grains are also present in the image.

(10x, XN)



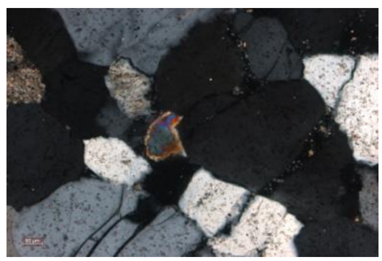
This is also an image of calcite in this sample. The grains are small and there is overgrown quartz embedded in the calcite.

(10x, XN)



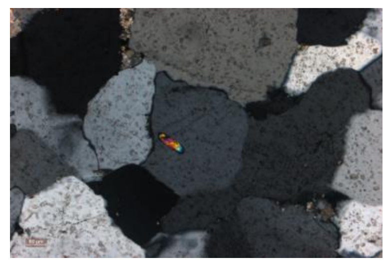
This image shows two grains of plagioclase feldspar with albite twining in a matrix of calcite and overgrown quartz.

(10x, XN)



This subangular grain of birefringent muscovite is embedded in a matrix of overgrown quartz.

(10x, XN)

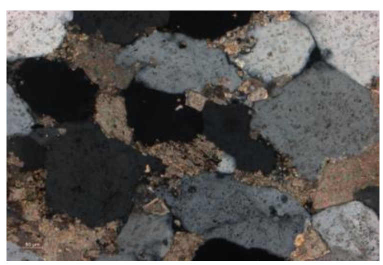


This image shows a small, subrounded grain of birefringent muscovite cemented by overgrown quartz.

(10x, XN)

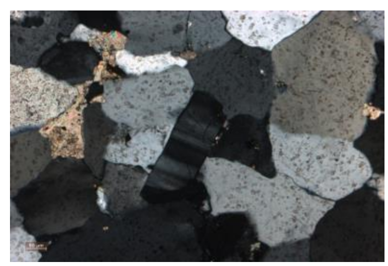
This image shows polycrystalline quartz, a sedimentary rock fragment. It is surrounded by overgrown quartz.

(10x, XN)



This image is an example of the diverse composition of this sample. Some overgrown quartz is shown and calcite is cementing other quartz grains.

(10x, XN)



Plagioclase feldspar with albite twinning is shown in this image. The feldspar is embedded in a matrix of overgrown quartz.

(10x, XN)

Thin Section Analysis Report

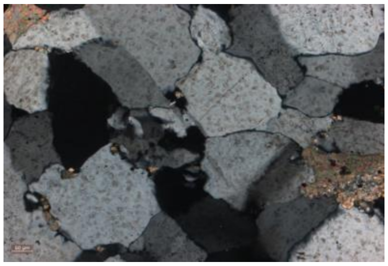
Sample ID:	0-7-B JL-1-A
Formation/Member Name:	Oriskany Sandstone Beaver County, PA
Lithologic Classification:	Sandstone
Depth/Depth Range:	5418 ft
Date of Analysis:	6/13/2017
Analyzed by:	Ellen Davis

	Texture	**Comments**
		observed at 10x
Grain Size	50-500 µm, average grain size ~300 µm	
Rounding	subangular to subrounded	
Sorting	moderately to well mixed	

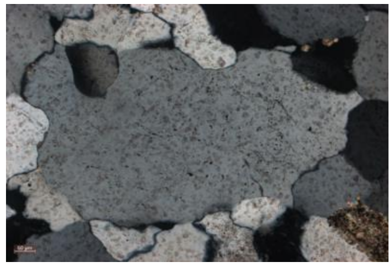
	Composition/Detrital Minerals	**Comments**
	Quartz	
Polycrystalline		images 07B_0007 - 07B_0013
Monocrystalline	~50% quartz ·wide range of sizes ·overgrowth present ·primarily monocrystalline quartz	
Microcrystalline	grains can be easily observed under petroscope	
	XN: white, black, gray PPL: light brown	
	Feldspar	
Plagioclase	·albite twinning	images 07B_0001, 07B_0006
Orthoclase	N/A	
Microcline	·tartan twinning	images 07B_0002, 07B_0004
	Carbonate	
Calcite	~50% calcite ·medium sized, anhedral grains	images 07B_0014 - 07B_0019
	XN: brown, green, pink PPL: brown-gray	
Dolomite	N/A	
Aragonite	N/A	
	Clay	
Illite	N/A	
Smectite	N/A	
Kaolinite	N/A	
(?) Muscovite	<1% muscovite ·subrounded	images 07B_0003, 07B_0005
	XN: orange, red, yellow, purple	
Chlorite	N/A	
Glauconite	N/A	
	Rock Fragments	
Sedimentary		
Volcanic		
Metamorphic		
	Other (Accessory Minerals)	

	Cementing Materials	**Comments**
Quartz	·primarily overgrown quartz	images 07B_0020 - 07B_0026
Feldspar		
Carbonate	·some calcite present	
Clay		
Iron Oxide, Hydoxide and/or Sulfide		
Other		

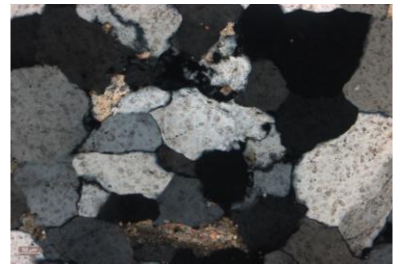
	Visual Porosity Estimate	**Comments**
	difficult to determine porosity, no dye	


This image shows polycrystalline quartz among overgrown monocrystalline quartz grains.

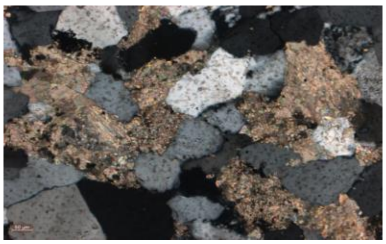
(10x, XN)


This large grain of quartz is overgrown with smaller quartz grains, cementing grains of calcite.

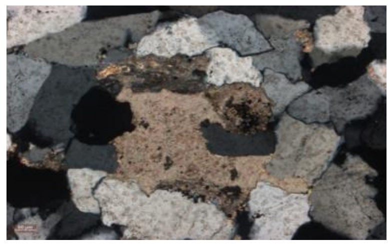
(10x, XN)


This image shows different sized quartz grains, overgrown with each other and cementing calcite.

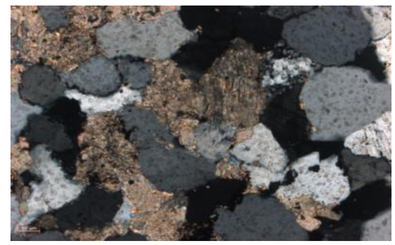
(10x, XN)


Overgrown quartz in this image is cemented by calcite.

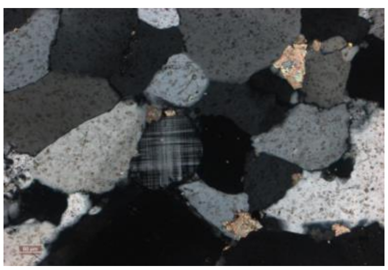
(10x, XN)


This image shows calcite embedded in grains of subangular, overgrown quartz.

(10x, XN)


This image shows overgrown quartz in a matrix of calcite.

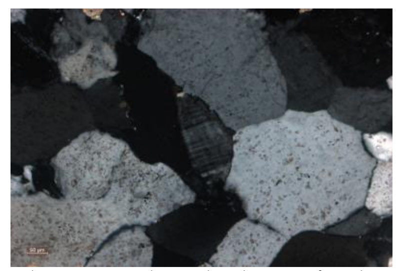
(10x, XN)


This microcline feldspar with tartan twinning is surrounded by overgrown quartz.

(10x, XN)


This image shows plagioclase feldspar with albite twinning and is in a matrix of overgrown quartz and calcite.

(10x, XN)


The tartan twinning in the image shows the presence of microcline feldspar. This feldspar is embedded in overgrown quartz.

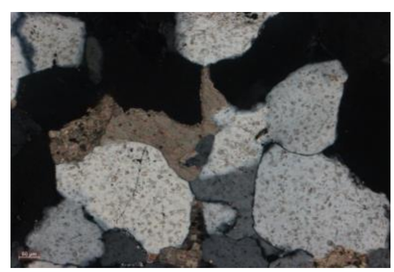
(10x, XN)


This image shows a grain of orange and purple muscovite in a matrix of overgrown quartz, calcite, and some pore space.

(10x, XN)

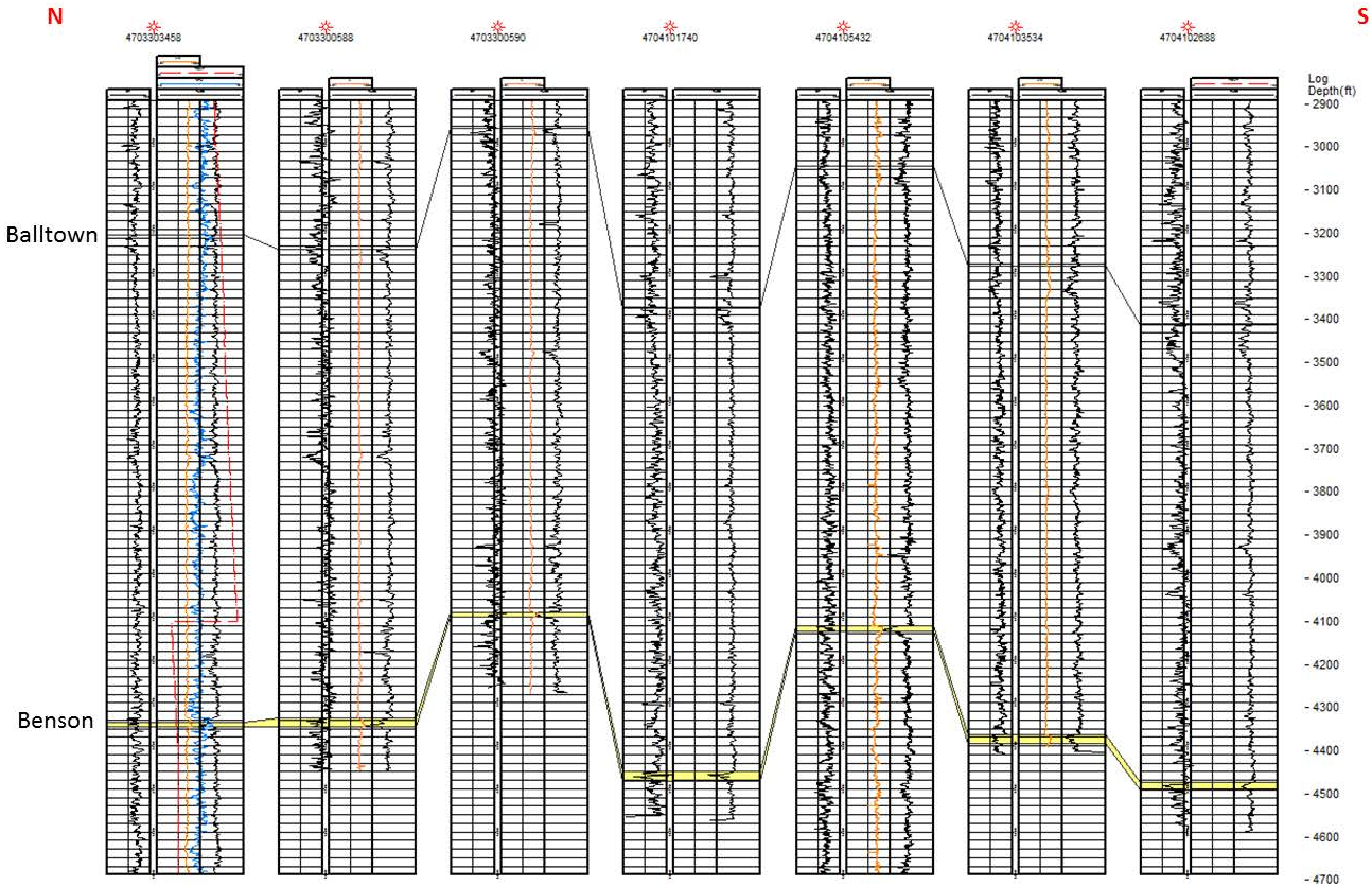

This image shows two subangular grains of birefringent muscovite surrounded by subrounded grains of quartz and calcite.

(10x, XN)

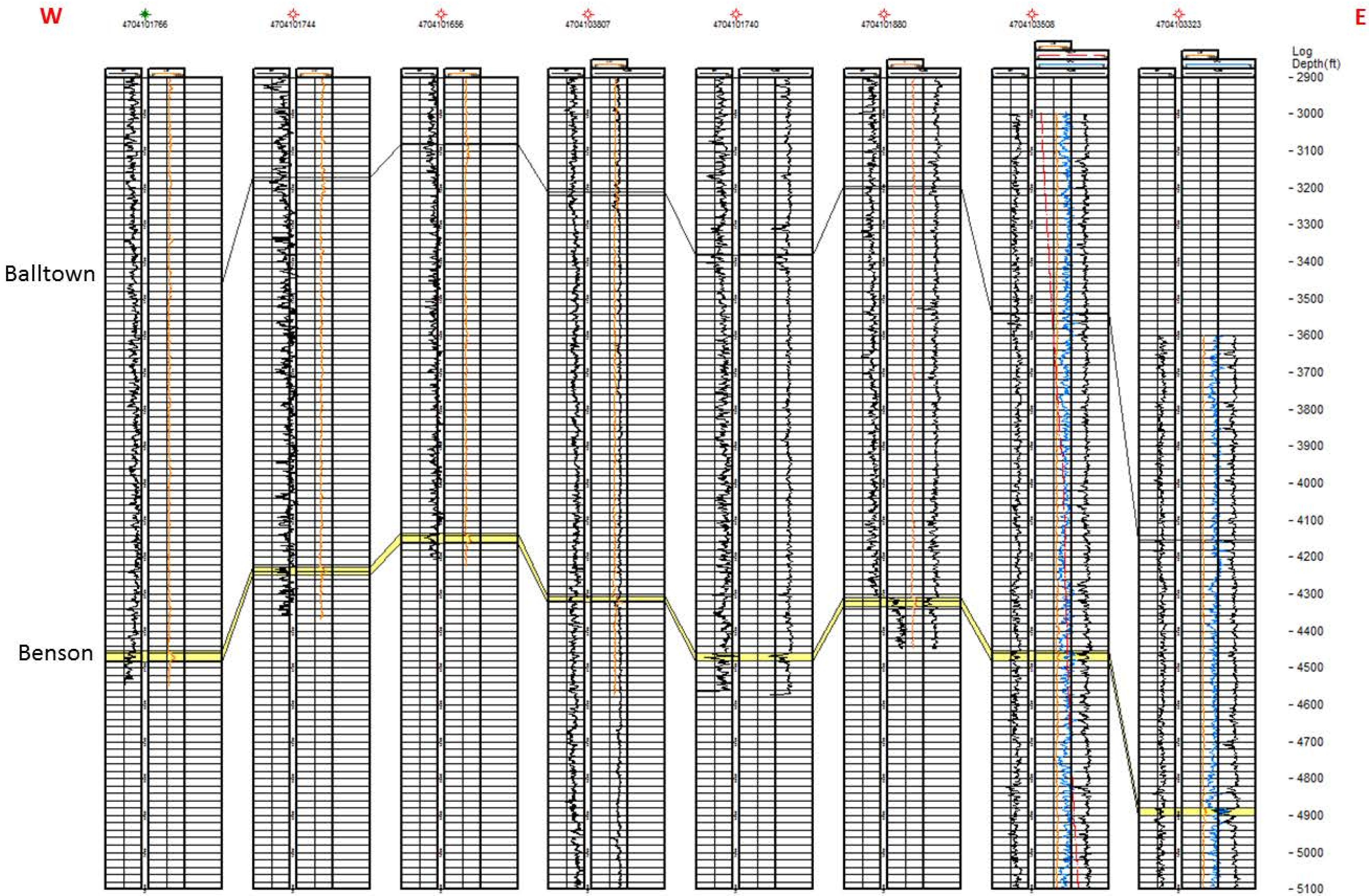

Both the calcite and the overgrown quartz act as cementing materials in this image. Some pore space can also be seen.

(10x, XN)

APPENDIX H – WESTON-JANE LEW FIELD CROSS SECTION PLATES



N
S
4703303458
4703300588
4703300590
4704101740
4704105432
4704103534
4704102688
Log Depth(ft)
2900
3000
3100
3200
3300
3400
3500
3600
3700
3800
3900
4000
4100
4200
4300
4400
4500
4600
4700
Balltown
Benson


W
E
4704101766
4704101744
4704101656
4704103807
4704101740
4704101880
4704103508
4704103323
Log Depth(ft)
- 2900
- 3000
- 3100
- 3200
- 3300
- 3400
- 3500
- 3600
- 3700
- 3800
- 3900
- 4000
- 4100
- 4200
- 4300
- 4400
- 4500
- 4600
- 4700
- 4800
- 4900
- 5000
- 5100
Balltown
Benson

APPENDIX I – ORISKANY SANDSTONE PETROGRAPHY, WOOD COUNTY, WEST VIRGINIA

ORISKANY SANDSTONE PETROGRAPHY, WOOD COUNTY, WEST VIRGINIA

The Darrell Matheny #2 (API No. 4710701266) is located about 25 mi north of the Southern Prospect in Wood County, West Virginia (Figure 1). In the Southern Prospect, the Elk-Poca (Sissonville) Field (highlighted yellow in Figure 1) produced natural gas for decades before a portion of the area (Ripley Field – highlighted orange in Figure 1) was converted to natural gas storage.

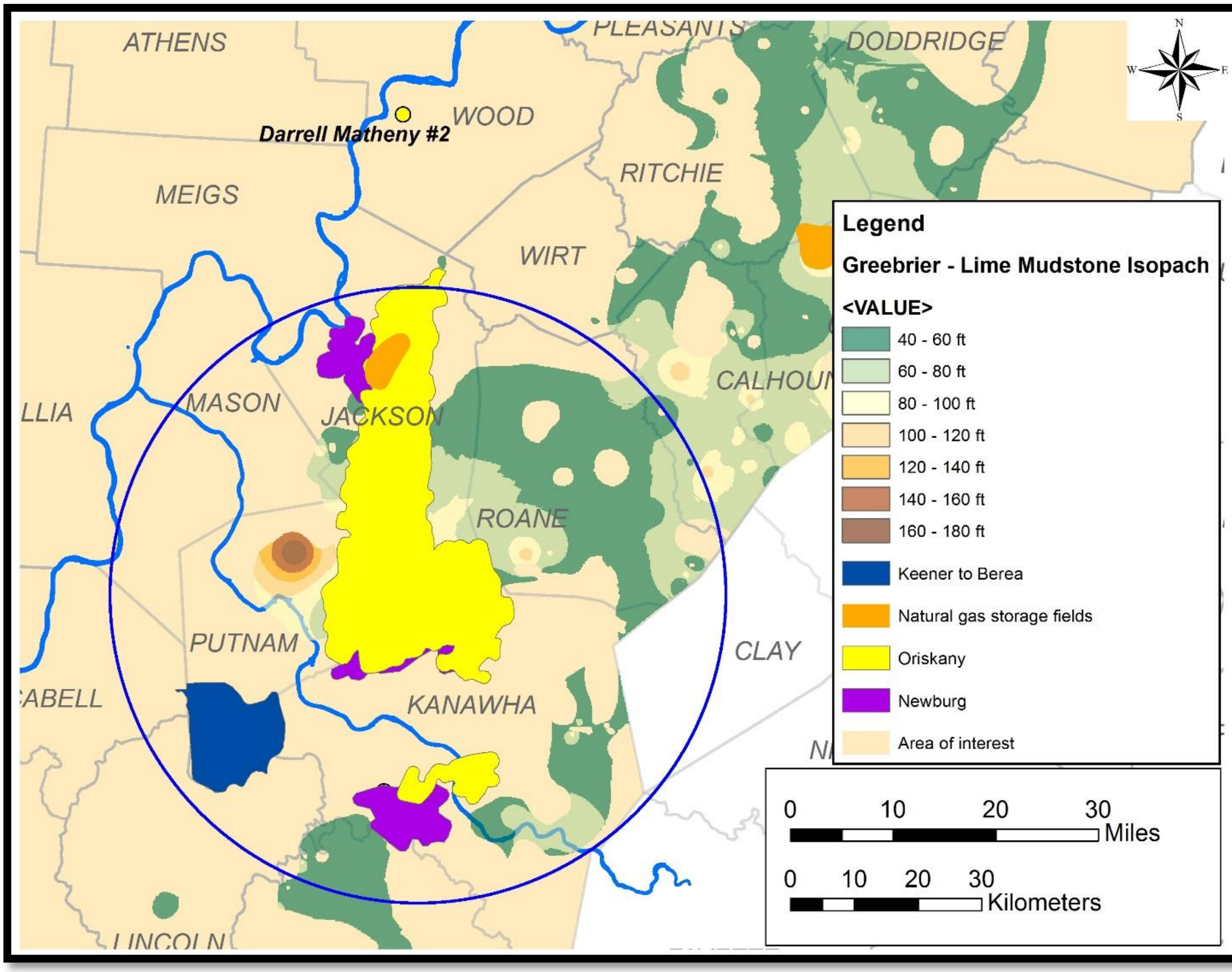


Figure 1. Location of the Darrell Matheny #2 relative to the Southern Prospect.

Thin sections were analyzed using a Leica DM 4500 P microscope, fitted with a Leica DFC400 camera, using a magnification of 10x power under both plane and polarized light (PL and XN, respectively). Photomicrographs were taken using the Leica DCF400 camera affixed to the microscope. The analysis included the following steps: (1) identify and estimate the percentage of mineral groups present; (2) examine textures and grain properties; (3) analyze the cementing materials that hold the rock matrix together; and (4) prepare a visual estimate of porosity

(porosity is indicated with blue epoxy in these sections). Observations were made using Ulmer-Scholle and others (2014) as a guide, and visual estimates of mineral composition and porosity were based on the comparison chart for visual percentage estimation by Terry and Chilingar (1955).

Thin section WD-1 was sampled from the Onondaga Limestone, the caprock above the Oriskany Sandstone (Figure 2). Notable are the lack of porosity and abundance of calcite cement. Homogeneous calcite grains are approximately 50 microns in size. Larger grains exhibit minor deformity.

Figure 2. Thin section WD-1, 4197.1 ft (PL).

Thin section WD-5 is typical of the Oriskany Sandstone (Figures 3 and 4). Grains are subangular to subrounded, moderately sorted and are comprised of monocrystalline quartz. Both quartz and calcite cement are present. Porosity in this thin section is intergranular and estimated at about 11 percent.

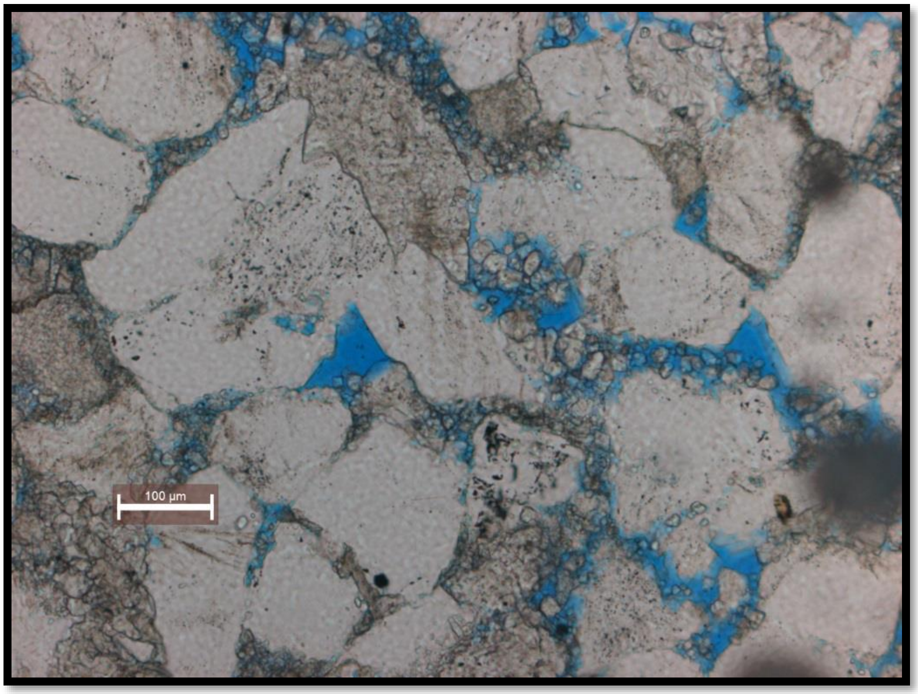


Figure 3. Thin section WD-5, 4212.1 ft (PL).

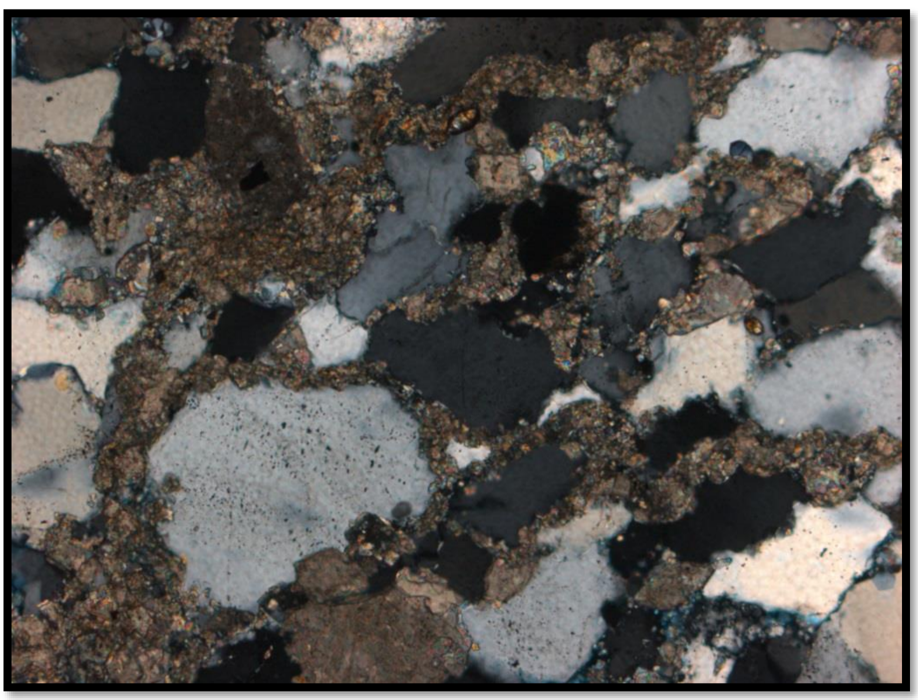


Figure 4. Thin section WD-5 (XN). Note the calcite cement between quartz grains.

Thin section WD-7 (Figure 5) exhibits lower intergranular porosity (approximately 8 percent) than the previously presented sample (WD-5), due to more complete cementation of quartz grains. Both quartz and carbonate cement are present. Grain size remains fairly uniform at 300-400 microns.

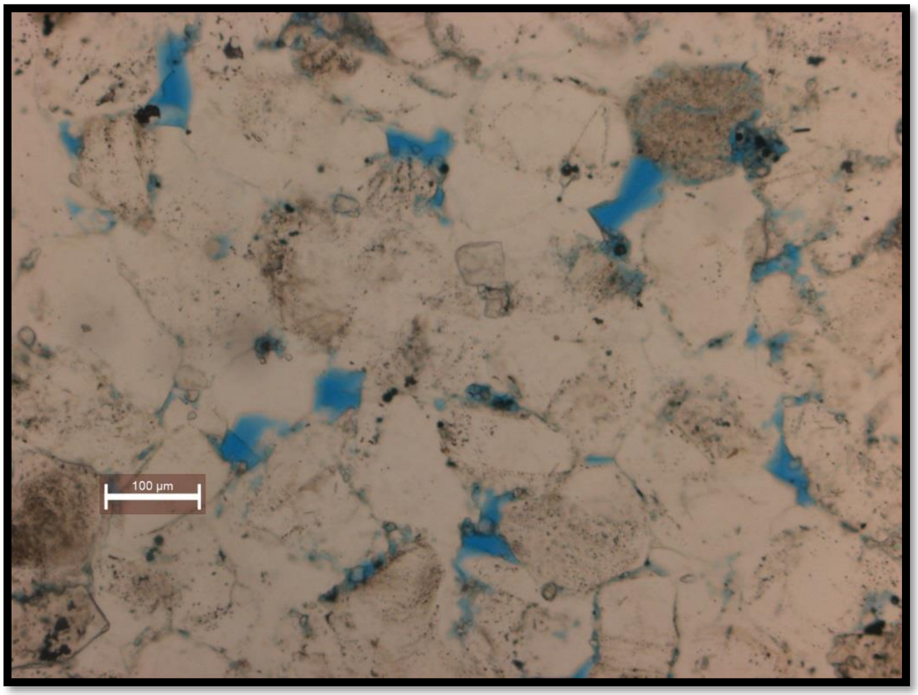


Figure 5. Thin Section WD-7, 4215.8 ft (PL).

Thin section WD-10 shows quartz overgrowths (Figures 6 and 7). Grains are subangular to subrounded, moderately sorted and comprised of monocrystalline quartz. Quartz grains average 500 microns in size. Intergranular porosity in this thin section is partially occluded by quartz cementation, but still estimated to be about 10 percent.

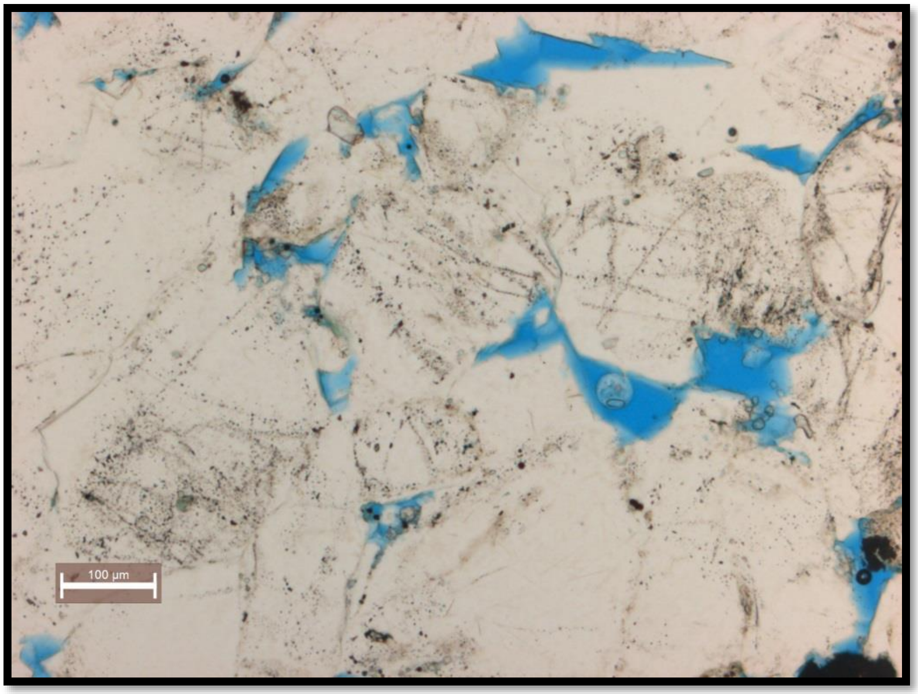


Figure 6. WD-10, 4222.5 ft (PL).

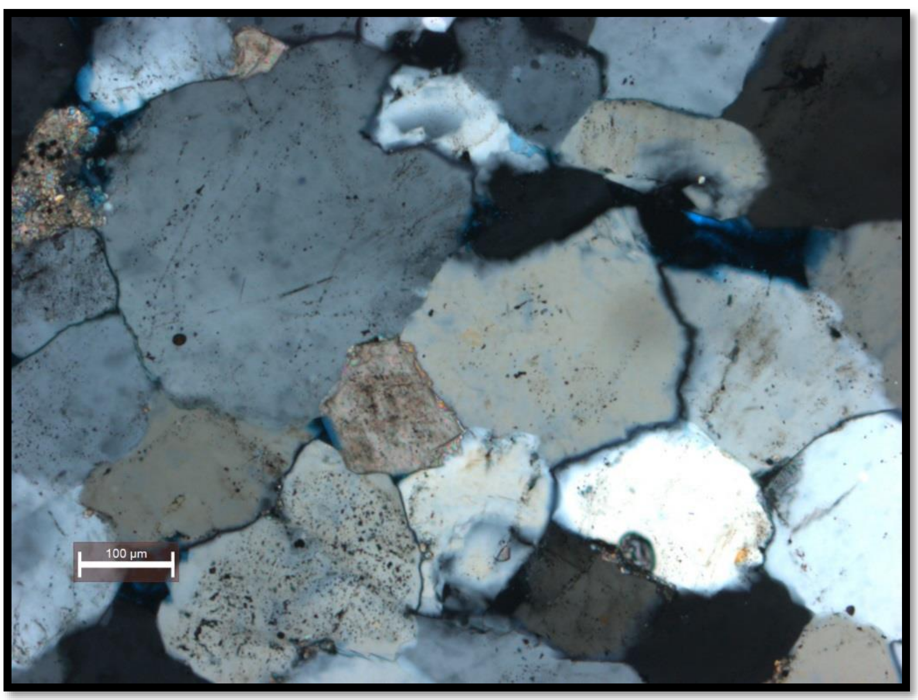


Figure 7. WD-10, 4222.5 ft (XN).

Overall, the Oriskany Sandstone thin sections from the Darrell Matheny #2 (API No. 4710701266) were observed to contain clean quartz sand (70 percent or more) with uniform grain size and shape and minimal inclusions. Calcite was observed as the primary cementing material.

APPENDIX J – ENGINEERING DESIGN CONSIDERATIONS

ENGINEERING DESIGN CONSIDERATIONS

1.0 MINED-ROCK CAVERNS

1.1 Infrastructure Requirements, Timeline and Anticipated Costs

Significant infrastructure requirements exist for construction of mined-rock caverns. These include power (5.0 MVA or greater) to enable use of hoists, ventilation fans and water pumps; road access; and labor, as "the required skilled construction labor force is greater for mined-rock caverns than either salt caverns or oil and gas reservoir storage" (Nelson and others, 2011). Mined-rock caverns have several characteristics that make them a more environmentally benign process; namely, a smaller footprint, decreased water requirements, and minimal waste production. In addition, the limestone produced from mining may be of suitable lithology for use in other aspects of the storage hub network, such as pipeline corridors, access roads, or site construction.

Mined-rock storage caverns in the United States are constructed in several different lithologies. Most are built in extremely low-permeability shales, with others constructed in dolomite, limestone and granite. Hard-rock cavern storage volumes range from 20,000 to 1,400,000 barrels (BBL) (average of 320,000 BBL). Worldwide, the maximum volume is 5 million BBL. A potential mined-rock cavern project has a step economic of scale curve; costs are fixed with regard to initial activities, such as geological investigation, shaft sinking, and initial development mining, so overall project cost per barrel decreases with increasing cavern volume. Nelson and others (2011) estimated a mined-rock cavern in the Greenbrier could host a volume between 2.0 and 2.5 million BBL.

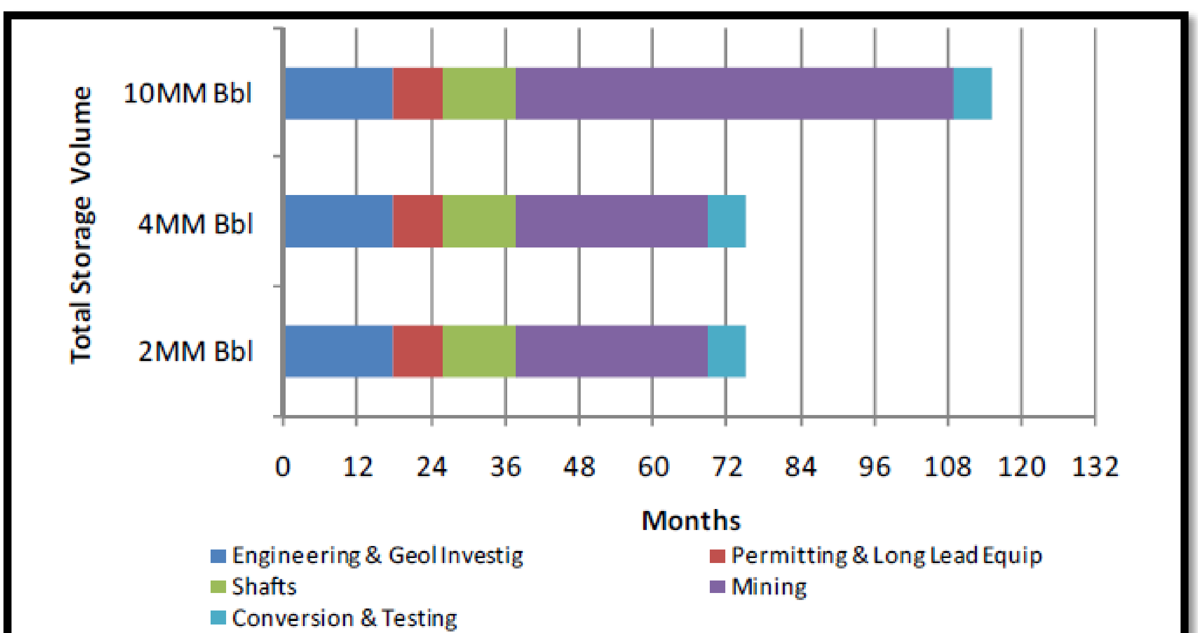


Figure 1. Rough Order of Magnitude (ROM) timeline for construction of a mined-rock cavern.

Item	Option 1	Option 2	Option 3
Storage Volume (millions of barrels)	2	4	10
Number of Caverns	1	2	4
Fixed Costs ($ millions)			
Engineering	$1.5	$1.5	$1.5
Geological Investigation	$2.0	$2.0	$2.0
Mainshaft	$9.0	$18.0	$36.0
Mainshaft Conversion	$2.0	$4.0	$8.0
Pump/Vent Wells	$8.4	$16.8	$33.6
Hoist and Headframe	$5.0	$10.0	$10.0
Breakout Mining	$2.0	$4.1	$8.1
Variable Costs ($ millions)			
Production Mining	$150.0	$300.0	$750.0
Convert and Outfit	$9.0	$15.0	$33.0
Test and Purge	$1.6	$3.1	$7.7
Total Cost	**$190.5**	**$374.5**	**$889.9**
Unit Cost ($/barrel)	**$95.3**	**$93.6**	**$89.0**
Lower Range ($/barrel)	**$79.0**	**$78.0**	**$74.0**
Upper Range ($/barrel)	**$114.0**	**$112.0**	**$107.0**

Figure 2. Mined rock cavern details and estimated costs (Nelson and others, 2011).

1.2 Host Rock Requirements and Cavern Design

Structural stability and low permeability to groundwater flow are the two main host rock criteria for a mined-rock cavern. The cavern operates under hydraulic containment – the surrounding natural hydrostatic pressure must be greater than the pressure of the stored product. This ensures containment of the product; a leak path will result in water flowing in, rather than flowing out and causing product to escape.

Modern mined-rock caverns are typically equipped with three shafts. An 8- to 14- foot (ft) diameter main shaft serves as an access point during initial construction and waste disposal tasks. Upon completion, this shaft is used for the cavern's instrumentation, piping and pump systems. A smaller set of two 36- to 48-inch (in) vent/pump shafts are used for ventilation in the construction phases and are then recompleted to serve as submersible pump wells in the production phase (Figure 3).

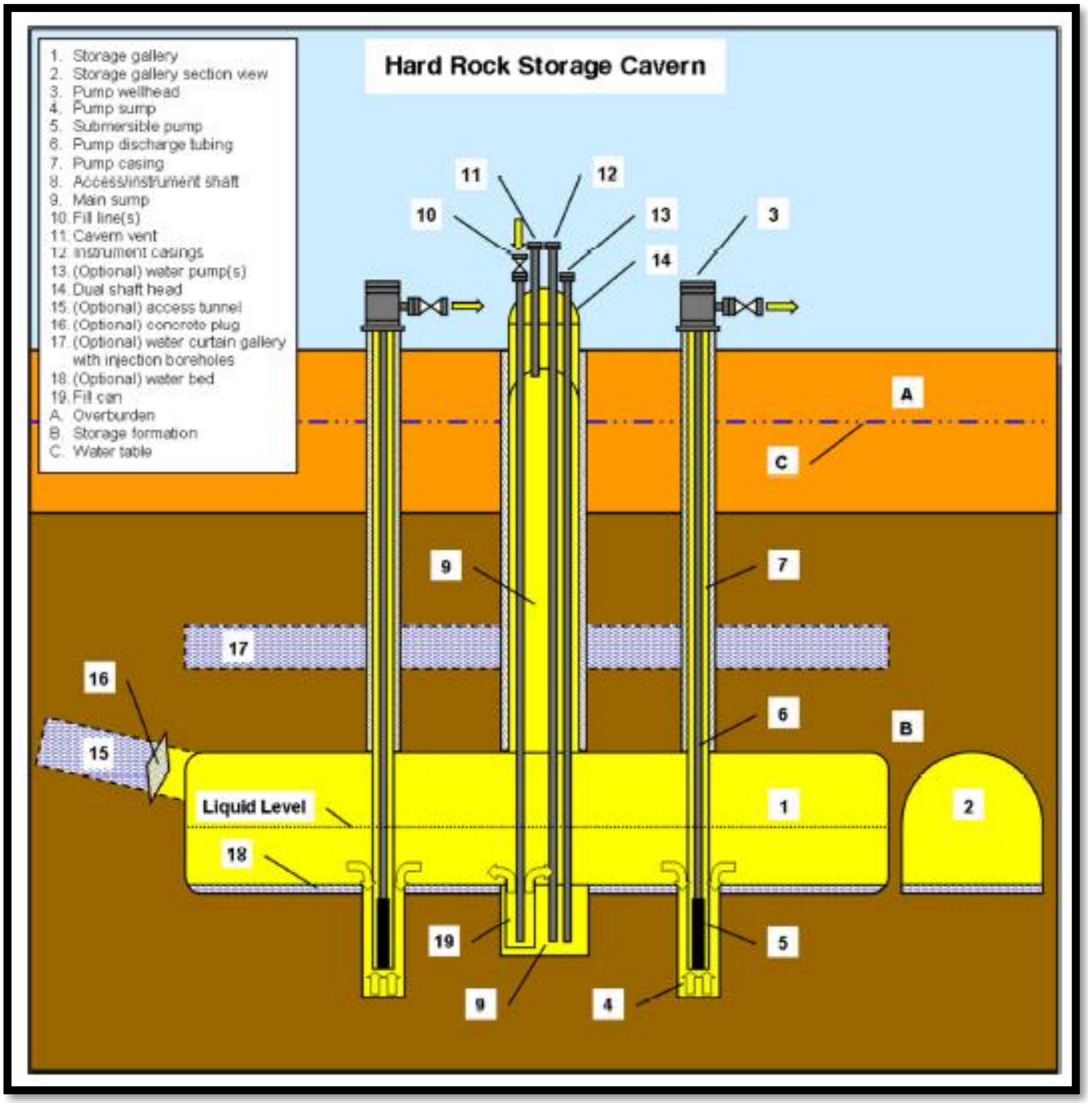


Figure 3. Schematic (cross section view) design of a mined-rock cavern.

A typical hard-rock cavern design operates using a brine-compensated style. This type of cavern remains full of liquid at all times. During product injection, the brine is displaced and the brine is re-injected to deliver the product and to regulate reservoir pressure. Nelson and others (2011) estimates the following pressure ranges:

- Minimum ethane wellhead pressure to ensure product remains liquid = 900 to 1,200 pounds per square inch (psi)
- Operating pressure gradients = 0.55 to 0.85 psi per ft
- Brine pressures for hydrocarbon storage caverns = 25 to 100 psi

Given these pressure ranges the authors suggest a cavern depth of 1,000 to 3,000 ft and warn that construction of a cavern at depths shallower than 1,000 ft would require higher brine pressures to maintain minimum ethane wellhead pressure.

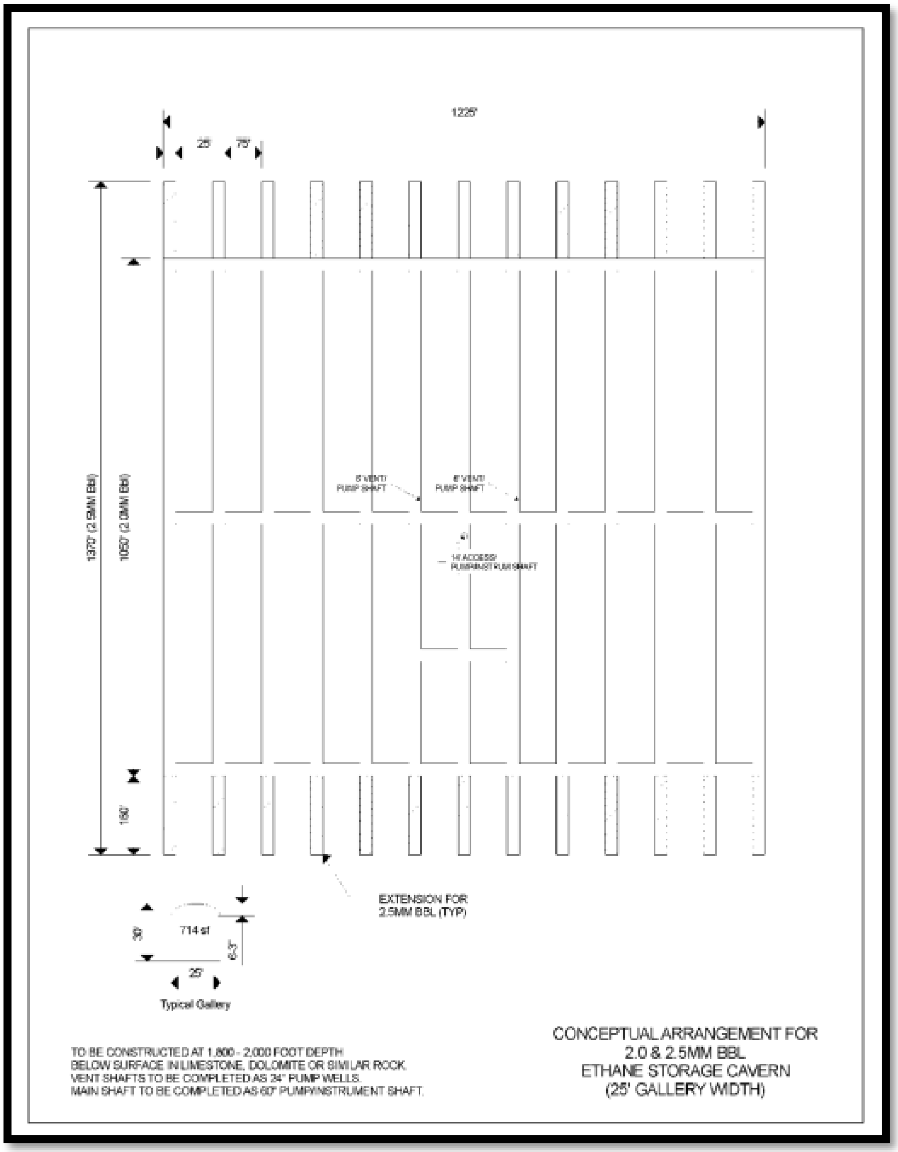


Figure 4. Plan view conceptual design for a mined-rock cavern (Nelson and others, 2011).

In a "brine-compensated storage" cavern, brine is injected when product is withdrawn and vice versa. Therefore, surface storage (brine ponds) must be provided for the product-displacement brine. Subsurface brine storage (in caverns with a nitrogen surcharge) is possible. However, roughly 3 BBL of cavern space is required for every barrel of stored brine to ensure that the nitrogen pressure (following brine withdrawal) is sufficient for cavern structural support.

The following equation can be used to compute the gross volume of a mined-rock cavern, where cross-sectional area of a room [length (l) * width (w)] is multiplied by its (height (h) to determine volume in cubic feet (ft^3). The volume is divided by 5.615 to convert units of cubic ft^3 to BBL.

$$V = (l \times w \times h)/5.615$$

Additional factors or corrections (not given here) will need to be applied to this equation to account for the pressure-dependence of ethane or other NGLs at reservoir depth, as well as the portion of the cavern's volume used for product vs. brine.

2.0 SALT CAVERNS

2.1 Infrastructure requirements, Timeline and Anticipated Costs

The main infrastructure requirements for salt cavern construction are related to transportation corridors for water and brine, brine disposal requirements, fresh water source(s) to leach the cavern, and 2.0 to 5.0 MVA capacity electrical service. Many of these requirements are already in-place in the region surrounding the Ohio River. This is especially true in the tri-state region of eastern Ohio, northern West Virginia and western Pennsylvania where the thickest salt intervals are observed. The maximum thickness of the Salina F4 salt in the ASH area of interest typically does not exceed 100 ft. Given a cavern width of 200 ft, a typical cavern volume is approximately 200,000 BBL. Therefore, multiple caverns would be necessary to obtain overall storage volumes of a million barrels or more. Figure 5 shows the Rough Order of Magnitude (ROM) timeline for construction of a salt-brine cavern complex (Nelson and others, 2011).

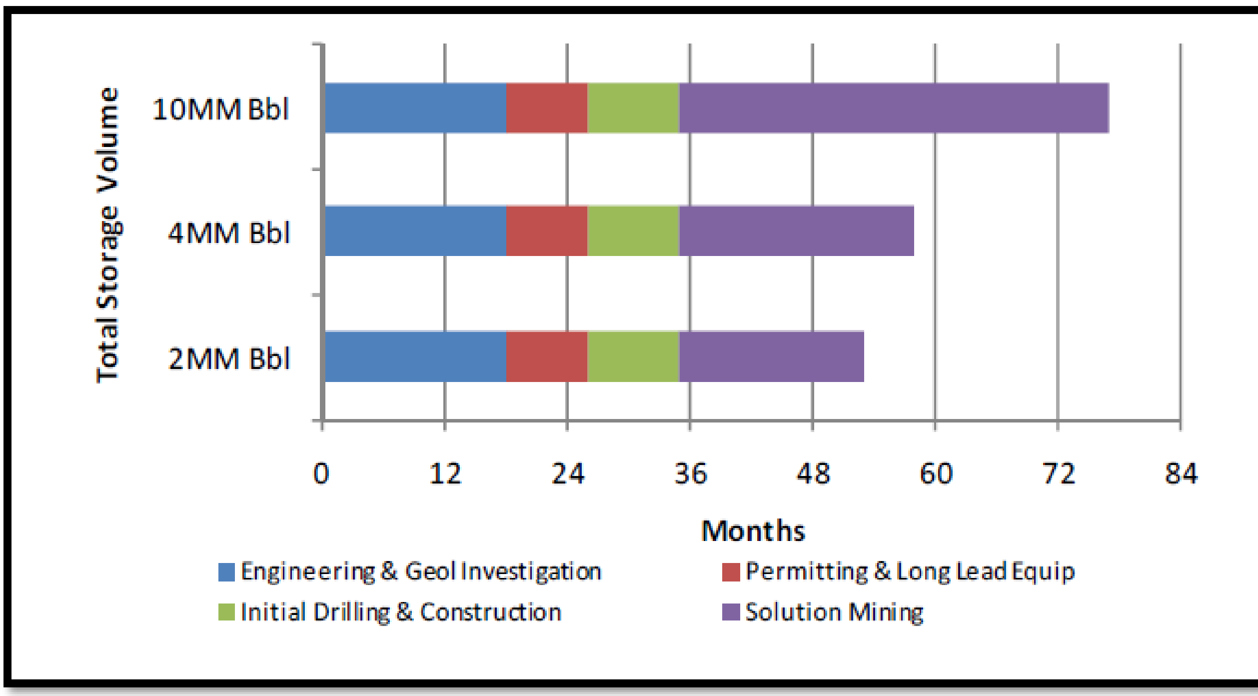


Figure 5. ROM timeline for construction of a salt-brine cavern complex.

Estimated costs for a salt brine cavern (Figure 6) depend on cavern depth (the cost generally increases with depth), as well as the volume of brine disposal necessary to complete the project. Figure 6 gives an estimate (Nelson and others, 2011) of costs assuming brine disposal into a saline aquifer.

Item	Option 1	Option 2	Option 3
Storage Volume (millions of barrels)	2	4	10
Number of Caverns	10	20	50
Number of Brine Disposal Wells	35	53	71
Leach Rate (gpm)	1,000	1,500	2,000
Leach Pumping (days)	412	550	1,031
Overall Leaching Duration (months)	18	23	42
Fixed Costs ($ millions)			
Engineering	$2.0	$2.0	$2.0
Geological Investigation	$2.0	$2.0	$2.0
Leach Plant	$3.0	$3.0	$3.0
Leach Headers	$0.6	$0.6	$0.6
Brine Disposal Wells	$157.5	$238.5	$319.5
Variable Costs ($ millions)			
Storage Wells (13⅜ inch)	$85.0	$170.0	$425.0
Brine Ponds	$10.0	$20.0	$50.0
Leach Plant	$6.0	$8.0	$12.0
Leaching Pipelines	$8.1	$13.1	$21.8
Leaching O&M	$3.0	$6.0	$15.0
Conversion	$4.3	$8.5	$21.3
Total Cost	**$281.5**	**$471.7**	**$872.1**
Unit Cost ($/barrel)	**$140.7**	**$117.9**	**$87.2**
Lower Range ($/barrel)	**$117**	**$98**	**$73**
Upper Range ($/barrel)	**$169**	**$142**	**$105**

Figure 6. Estimate of costs associated with salt cavern construction assuming brine disposal into a saline aquifer (Nelson and others, 2011).

2.2 Host Rock Requirements and Cavern Design

In terms of cavern development, a very important consideration is the nature of salt bed accumulation in a potential location. As opposed to storage in a pure salt column or diapir, the Salina F4 and associated units are bedded salts; that is, interlayered evaporite and non-evaporite units of varying "purity." Therefore, the targeted salt bed must be of a thickness to allow cavern dissolution of the desired height while allowing for accumulation of the insoluble lithologies at the cavern's base. These insoluble/impure materials tend to expand as they are immersed and accumulate at the cavern base; this "bulking factor" is typically around 50 percent of the initial material volume.   A final consideration for the target salt bed is that it must be of adequate thickness to allow for sufficient preservation of roof material (often referred to as a 'saltback').

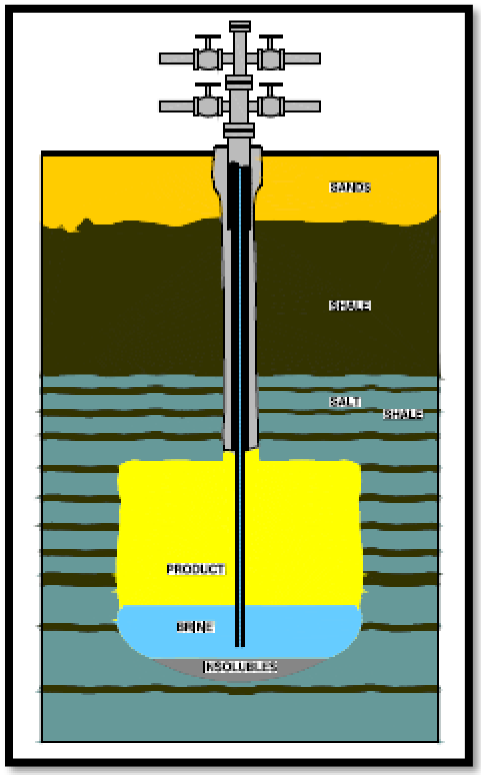


Figure 7. Schematic diagram of a salt cavern (Nelson and others, 2011).

Parameters	Value		
Volume (thousands of barrels)	200	200	200
Well Diameter (inches)	13⅜	13⅜	13⅜
Leaching Tubulars (inches)	7 × 4½	10¾ × 7	10¾ × 7
Leach Rate (gpm)	500	1,000	1,500
Max Injection/Delivery Rate (gpm)	1,300	1,300	1,300
Injection/Delivery Rate (barrels per day)	44,600	44,600	44,600
Overall Leaching Duration (days)	132	77	59
Approx. Leach Injection Pressure (psi)	2,000	1,550	2,750
Assumed Brine Injection Pressure (psi)	1,200	1,200	1,200
Approx. Leaching Power (horsepower)	1,400	2,500	5,200
Approx. Leaching Power Usage (Megawatt hours)	2,400	2,150	3.000

[10] Salt concentration at saturation increases with temperature.

Figure 8. Design parameters for a salt cavern (Nelson and others, 2011).

The following equation can be used to compute the gross volume of a solution-mined salt cavern, where cross-sectional area is circular [π * radius (r)^2] is multiplied by its (height (h) to determine volume in ft^3. The volume is divided by 5.615 to convert units of ft^3 to BBL.

$$V = (\pi \times r^2 \times h)/5.615$$

Additional factors or corrections (not given here) will need to be applied to this equation to account for the pressure-dependence of ethane or other NGLs at reservoir depth, as well as the portion of the cavern's volume used for product vs. brine.

3.0 RESERVOIR STORAGE

3.1 Infrastructure requirements, Timeline and Anticipated Costs

Main infrastructure requirements for reservoir storage will depend on the type, age and depth of the target field. Existing gas storage fields represent the lowest infrastructure requirements, as it is assumed much of the necessary infrastructure is in-place and field limits (trap integrity) considerations have already been addressed. Depleted fields that have not been converted to storage will have varying infrastructure needs, including (but not limited to) access roads, pipeline rights-of-ways and mitigation costs associated with identification and mitigation/plugging of legacy wells. Given the decreased infrastructure and construction requirements associated with reservoir storage, timeline for development is shorter than for either mined-rock or salt cavern construction (Figure 9). The estimated costs are also significantly lowered (Figure 10).

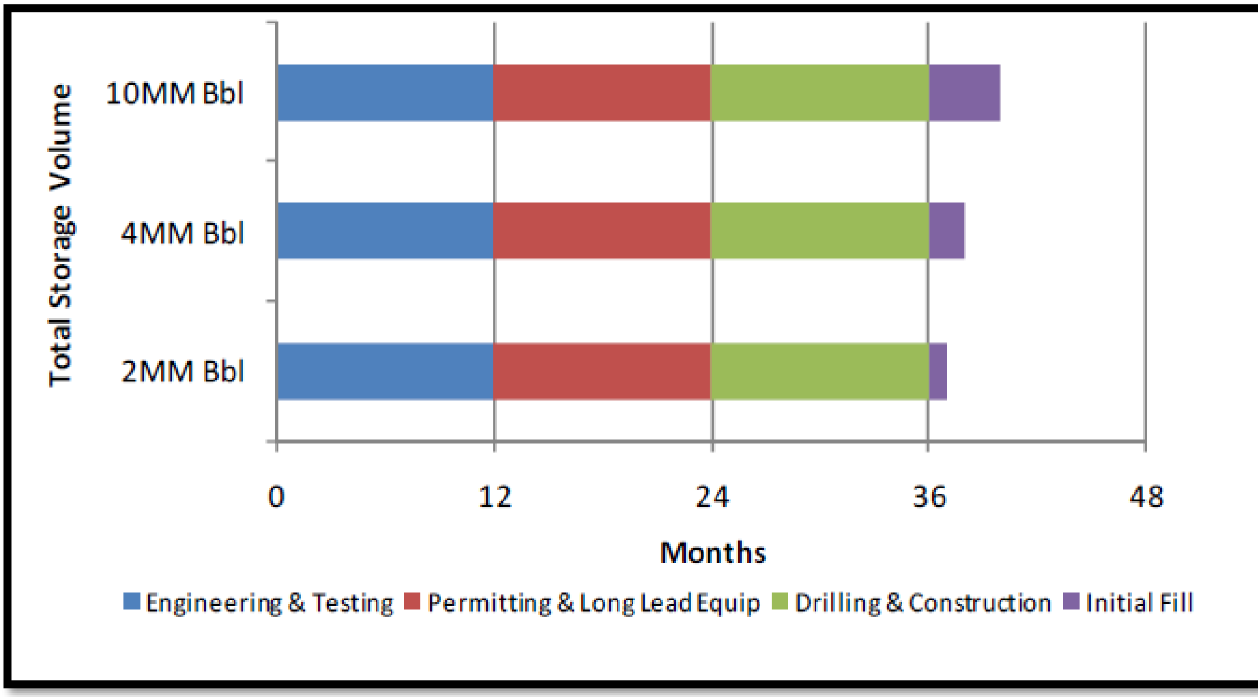


Figure 9. ROM timeline for construction of reservoir storage (Nelson and others, 2011).

Item	Small	Medium	Large
Storage Volume (millions of barrels)	2	4	10
Number of Horizontal Wells	6	6	6
Fixed Costs ($ millions)			
Engineering	$1.0	$1.0	$1.0
Reservoir Test/Characterize	$0.5	$0.5	$0.5
Pipeline (20 mi, 10 inch)	$29.6	$29.6	$29.6
Compression	$6.1	$6.1	$6.1
Gas Processing	$2.0	$2.0	$2.0
Variable Costs ($ millions)			
New Horizontal Wells	$36.0	$36.0	$36.0
Gas in Place ($/MMbbl/Ethane)	$1.0	$2.0	$5.0
Total Cost	**$76.2**	**$77.2**	**$80.2**
Unit Cost ($/barrel)	**$38.1**	**$19.3**	**$8.0**
Lower Range ($/barrel)	**$25.1**	**$12.8**	**$5.4**
Upper Range ($/barrel)	**$67.6**	**$34.0**	**$13.9**

Figure 10. Estimate of costs associated with reservoir construction (Nelson and others, 2011).

In order to compute the storage capacity of a depleted reservoir to store ethane, the produced volume and reservoir pressure conditions must be known for the area being converted to storage. As reported by Nelson and others (2011), the storage capacity can be estimated by dividing the cumulative production of natural gas from the reservoir by the ratio of reservoir pressure to atmospheric pressure (i.e., at standard temperature and pressure conditions). The resulting volume is divided by 5.615 to convert units of ft^3 to BBL.

4.0 PROJECT COMPARISON

Each of these three potential storage options has relative strengths and weaknesses when compared to one another. For example, deliverability is highest in mined-rock and salt cavern options; these options also require the highest capital investment costs. Figure 11 lists the advantages and disadvantages of the various storage options. The costs associated with each design option also vary with overall storage volume; a comparison of these relative costs is provided in Figure 12.

Storage Option	Advantages	Disadvantages
Salt Caverns Without Brine Takeaway	• Ability to meet a very high deliverability (80,000 bbls/day per well).	• Generally the largest unit cost. • Significant brine disposal cost. • Large acreage requirement. • Requires large surface brine ponds. • Cavern depth outside industry experience. • Limited site options.
Salt Caverns With Brine Takeaway	• Ability to meet a very high deliverability (80,000 bbls/day per well).	• Large unit cost. • Considerable brine disposal cost for 4 and 10 MMbbls of storage. • Large acreage requirement. Requires large surface brine ponds. • Cavern depth outside industry experience. • Limited site options.
Mined-Rock Caverns	• Ability to meet a very high deliverability. • Least risk of environmental impact. • Smallest acreage requirement.	• Large unit cost. • Longest development time.
Oil and Gas Reservoir	• Lowest unit cost: $38.1, $19.3, and $8.0/bbl for 2, 4, and 10 MMbbls of storage. • Shortest development time: 37, 38, and 40 months for 2, 4, and 10 MMbbls of storage. • Greatest flexibility of site options.	• Would require processing to separate hydrocarbons.

Figure 11. Comparison of various NGL storage options (Nelson and others, 2011).

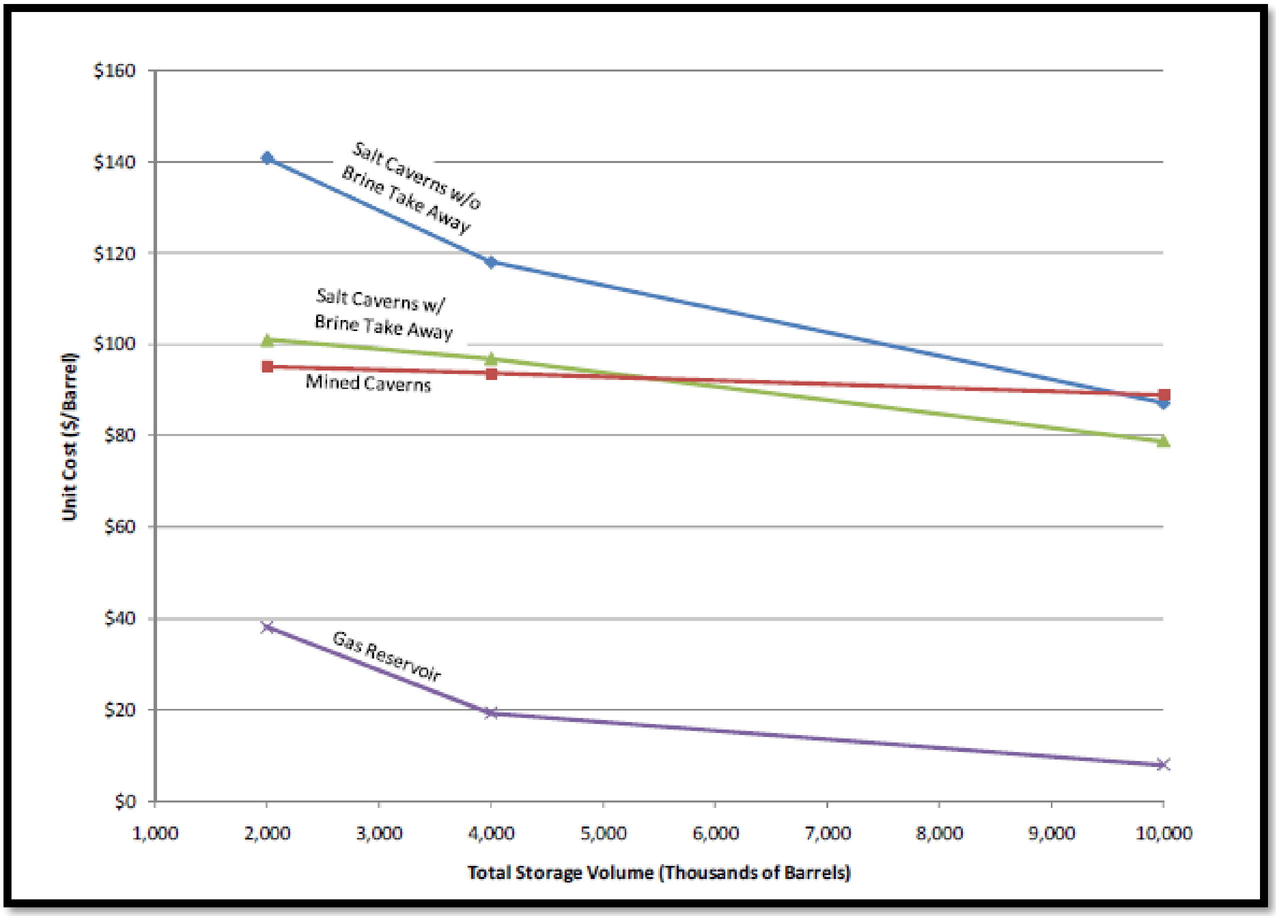


Figure 11. Comparison of unit costs associated with different storage types and volumes (Nelson and others, 2011).