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.