2021 Eastern Section AAPG Abstracts

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Oral Session Abstracts

Speaker is first author unless indicated by an asterisk (*).

“Super basin thinking”: Methods to explore and revitalize the world’s greatest petroleum basins

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The AAPG Super Basin initiative creates an action plan to help geoscientists revisit the world's most productive petroleum basins by providing resources through conferences, online presentations, and publications like the Bulletin's special issues. Understanding Super Basins better enables us to apply technologies that can reveal each unique Super Basin's full resource development potential. By studying the world's most significant petroleum Super Basins, we document concepts to find and produce hydrocarbons more economically in all basins.

Between 2000 and 2015, game-changing technologies reinvigorated many of the world's greatest onshore and offshore basins. Workflows that caused production peaks to reach new heights included horizontal drilling and hydraulic fracturing in unconventional onshore reservoirs and enhanced seismic imaging in conventional offshore reservoirs. Improved understanding of source rocks, petroleum systems, oil habitats, stratigraphy, rock properties, and clinoform architecture enhances the exploration and development toolkit. Commercial aspects like reduced costs, improved processes, and multidisciplinary teams bolstered a new golden age in many Super Basins.

Super Basin Thinking forms a new paradigm useful in directing actions. Super Basins foster new technology because they possess key geologic factors and a basin-level economy of scale that fuels innovation. New concepts, techniques, and methodologies developed in Super Basins benefit the entire ecosystem of hydrocarbon recovery. As geoscientists, global thinking improves our ability to provide abundant and affordable energy choices, and when done correctly, can also benefit our environment and local, state, federal, and global economies. Super Basins, the Appalachian Basin, and geoscientists play vital roles in this noble effort.

The Appalachian Unconventional “Super Basin” – A Discussion of Past, Present, and Future Exploration Trends

William A. Zagorski, Vice President, Chief Geologist, Range Resources - Appalachia LLC

The Appalachian Basin, once considered a legacy basin, has re-emerged as a “Super Basin” largely due to the horizontal commercialization of the expansive Upper Devonian Age Marcellus Shale play in 2007 followed by deeper Ordovician Utica Point Pleasant play in 2011. The Appalachian Basin has long been in the forefront of unconventional resources development in North America with historic activity dating back to 1825. At present the Marcellus itself produces over 24 BCFEPD and provides a significant portion of the US natural gas supply. The Marcellus play is one of, if not the, world's largest gas field. This presentation will provide an overview of some key historic production trends in the Appalachian Basin and discuss the evolution of the Marcellus shale play, its core producing areas, and reservoir characteristics across this expansive play.

The Appalachian "Super Basin" – Utica-Point Pleasant Play Update

Michael Jarvis, Range Resources – Appalachia, LLC

The Utica-Point Pleasant play has been an active horizontal exploration and development target in the Appalachian Basin since the play begin commercialization in 2010. Rig activity targeting the Utica-Point Pleasant peaked in 2014, and although the play appears to extend over a significant geographic area, current drilling activity is predominantly focused in areas exhibiting the highest Point Pleasant reservoir quality in eastern Ohio, northern West Virginia, and southwest Pennsylvania. Another area of development exists in north central Pennsylvania, where operators have exploited a thicker interval of Utica and Point Pleasant rocks, which has similar estimated volumes of gas in place when compared to the active portion of the southwest region of the play.

As of July 2021, production from the Utica-Point Pleasant play was 7.2 BCFE/d, after peaking in late 2019 at 8.2 BCFE/d (EIA). The roots of the modern play were focused on development in portions of Ohio where higher BTU gas and natural gas liquids are produced, but current drilling activity has focused eastward in Ohio and into West Virginia and Pennsylvania, targeting high-rate dry gas results. In these areas, operators leverage higher pressure gradients (>0.75 psi/ft), increased gas in place (>100 BCF/section), higher levels of TOC and porosity in the Point Pleasant, and a contrast in reservoir quality of the Utica and Point Pleasant, which aids hydraulic fracture containment in the deeper Point Pleasant target. In the last 4 years, operators have delineated the Point Pleasant to vertical depths over 13,750 feet and at pore pressure gradients >0.95 psi/ft., further evidence that the extents and potential of the Utica-Point Pleasant play are still evolving.

The Marcellus Shale: Geologic controls on reservoir quality and geochemical aspects of future potential resources

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The Middle Devonian Marcellus Shale is present in vast portions of the geographically extensive Appalachian Basin. Indeed, the Marcellus is found in the subsurface and/or outcrop of New York, Pennsylvania, West Virginia, and Ohio. Mineralogic, depositional, sequence stratigraphic, reservoir pressure, and thermal maturity models explain the variability in lithostratigraphic expression and reservoir development in the Marcellus Shale. Clay-poor, overpressured condensed sections rich in organic-matter describe reservoir facies in existing core development areas in the condensate and dry gas windows. Moreover, such facies are present in large portions of the Marcellus basin that are not currently economic but could be exploited under certain economic conditions. In 2019, the Potential Gas Committee (PGC) estimated that the technically recoverable resource in the Atlantic Region, which is largely driven by the Marcellus, is 1,311 TCF of gas which encompasses large areas that have not been developed indicating a vast remaining resource. In addition to abundant hydrocarbons, the Marcellus shale hosts as yet unknown quantities of critical minerals that may be extracted from drilling waste streams. Current government sponsored critical mineral research is focused on coal and coal mining by-products; yet the geologic parameters conducive to critical mineral deposition and enrichment in certain coals are also present in shales: clays, organic matter, phosphate grains/beds, and exposure to hydrothermal fluids. Understanding the distribution of these critical minerals, including rare earth elements, and how they align with sequence stratigraphic and thermal maturity trends in the basin, could be an important tool for developing a domestic source of critical minerals for future supply in the United States.

A proposed model for quantifying critical mineral occurrence from unconventional sources: An example from the Marcellus Shale, Appalachian Basin, USA

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The United States has seen a burgeoning demand for energy derived from renewable resources. Vehicle manufactures are producing electric vehicles, countries and corporations have pledged to achieve net zero carbon emissions, and an increasing amount of electricity is generated from wind and solar. Integral to these technologies is the use of critical minerals (CMs) including Rare Earth Elements (REEs). Indeed, the demand for REEs is expected to grow by 5% - 9% per year over the next 25 years. Such growth in demand has led to a renewed focus on CMs exploration and extraction technologies. Moreover, as occurred in the oil and gas industry with the “shale boom”, rising commodity prices and a lack of domestic high yield deposits may force companies to explore unconventional sources of CMs such as black shale waste streams. For example, approximately 15,000 Marcellus wells have been drilled with an estimated 120,000 remaining locations. Assuming an 8 ¾ in drill hole, average length of 7,000 feet, and rock density of 2.5 gm/cc, drilling will generate approximately 30 million tons of cuttings. The Marcellus Shale in Chenango County, NY, has an average vanadium concentration of 340 ppm. At this concentration drilling waste could provide a resource of greater than 10,000 tons of vanadium. To date, resource assessments and exploration of unconventional sources of CMs are lacking. Here we report on our initial model for such an assessment using the Middle Devonian Marcellus Shale as an example. Many CMs, including Co, Cu, Ni, and V accumulate in shale under anoxic conditions. Moreover, they can accumulate in placer-like lag deposits. Such deposits often occur in sediment-starved transgressive systems tracts and condensed sections.

Thus, detailed assessment of the sequence stratigraphy and sedimentology allows us to predict the stratigraphic and basin-scale occurrence of shale-hosted CMs.

Statistical methods for collection, measurement, and analysis of critical minerals in fine grained clastic rocks: Case study of the Dunkirk Shale, NY

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Global demand for critical minerals (CM) is projected to increase under all scenarios modeled by the International Energy Agency (IEA). Several organizations including the IEA and the U.S. Geological Survey have underscored the importance of defining the abundance and geographic distribution of these minerals. Key elements such as lithium, nickel, cobalt, manganese, and graphite are required materials for Li-ion battery development, many of which are found in black shale deposits.

The statistical methods described in this paper are one component of a larger study focused on assessing the distribution and abundance of critical minerals in the Devonian aged Dunkirk shale. The expectation is that these methods will be largely transferable to other basins containing fine grained clastic rocks. The fundamental objectives of the Dunkirk case study are:

- To develop a workflow for sampling, measurement, and analysis of CMs
- To identify the processes that concentrate the CMs
- To define abundance and distribution of CMs

Firstly, this paper will present a largely open-source approach to this research that will be organized for public access. This will be primarily managed using web-based dashboards that allow users to view descriptions of the methods and results alongside dynamic plots and downloadable data. Next, the current state and upcoming plans for statistical analyses related to this work will be discussed.

To date, completed work includes an estimation of the appropriate sample size to lend statistical significance to the analyses, determination of the ideal measurement windows for the XRF tool, comparison of handheld and benchtop XRF measurements, and a k-means method for calibration of XRF measurements, all of which will be reported in the web-based dashboard. Immediate upcoming plans include an assessment of elemental variance within a fixed lithologic interval, assessment of elemental distribution by lithology, a comparison of black shale CMs relative to crustal abundances, and an evaluation of the reliability correlating elemental signatures across the study area. All these steps are critical for supporting the subsequent objectives and will ultimately lead to an assessment of the abundance and distribution of CMs in the Dunkirk shale.

Energy in transition, the hunt for lithium in North America

Lindell C. Bridges, Pure Earth Resources

The energy industry is in transition which offers new opportunities for geoscientists. The demand for critical minerals is on the rise as the need for batteries increases due to the push to electrify our transportation and energy storage technology. One of the critical minerals is lithium. Lithium does not occur as the metal in nature, but is found in unusual lithium pegmatites, clay-rich sediments, and in high-lithium brine deposits, in both playas and oilfield produced water. The United States ranks 7th in lithium production globally with only 1.2% of the total production. Our 630,000 metric tons of known reserves ranks 5th in the world. As new extraction technologies emerge, we expect lithium reserves in the United States to increase.

Work at Pure Earth Resources is focused on high-lithium brine deposits, primarily water produced from oil and gas wells. Currently, the most active area for lithium extraction research from oilfield produced water is the Smackover formation of southern Arkansas. The lithium-rich waters are not ubiquitous; there are localized areas of high content along most of the Smackover Trend. Other trends with high lithium produced water occur in other basins, including the Appalachian basin. Work is underway on the most promising of these prospects, including mapping geochemistry, porosity and permeability, mineralogy, and petrophysical analysis.

Lithium has many uses besides batteries. These include lubricants, aluminum, glass and ceramics, air conditioners, medication, and chemicals. However, according to Statista.com, batteries make up 71% of the end-usage worldwide. Demand is expected to continue its upward trend for the foreseeable future.

Feasibility and potential of Compressed Air Energy Storage (CAES) using salt caverns in Michigan

Kyle Cox and Matthew Rine, Consumers Energy

1000’s of MWs of solar and wind generation will be added to Michigan’s electrical grid in the coming decades. These renewable energy sources require long duration energy storage (LDES) to support their intermittent nature. A variety of existing and emerging LDES technologies are available but there will be no one size fits all solution. The environmental, social, and economic impacts/sustainability must be considered for each LDES deployment.

Compressed Air Energy Storage (CAES) is one promising storage technology capable of providing grid scale LDES. CAES is a proven method with decades of commercial operation demonstrating its grid-scale storage capabilities. Recent DOE reports indicate CAES is the most economic form of grid scale storage. CAES stores energy in the form of pressurized air within a reservoir. While a variety of reservoirs are plausible, solution mined salt caverns are the only option with commercial demonstration. Creating such caverns requires the presence of thick and relatively pure salt formations at sufficient depth to support the storage pressures of CAES, which severely restricts the geographic range of CAES.

In this study, the ability of Michigan's Silurian salt formations to support salt caverns capable of providing significant energy storage via CAES was investigated. Existing solution mined salt caverns in Michigan were compared with the estimated storage density of CAES facilities. This comparison showed that Michigan's salt beds have the capability to house caverns that could provide GWhs of storage. To identify where new caverns capable of grid scale LDES are feasible, maps of the salt units were used to estimate potential cavern volume and operating pressure based on in state proxies and published guidelines for CAES cavern design. It was found that CAES facilities capable of providing significant energy storage are feasible throughout much of Michigan's Lower Peninsula.

Echoes of a giant: the Utica/TBR conventional play

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The world's first giant oil field, Lima-Indiana, was reservoired in prolific, high-porosity fractured & hydrothermally-altered rocks of the Ordovician Trenton/Black River Formation (TBR), sealed by shales and tight carbonates of the overlying Utica/Pt Pleasant. Sporadic further exploration in subsequent decades has continued to affirm the prolific nature of the TBR, but the play has remained immature, due to its relative subtlety and reliance on good quality seismic data. However, massive Marcellus/Utica seismic datasets acquired in the early 2010s provide new insights. These data, integrated with Utica drilling & geologic information, now strongly suggest that in specific areas, the Utica and TBR are both part of one conventional play, ie the Utica-TBR (UTBR). Facts that support this idea are :

1. The highest Utica productivity is often associated with wrench-related structures very similar to known TBR discoveries. The biggest shale gas well ever, EQT Scotts Run, is such an example.
2. Variations in mineral/metals composition & thermal maturities along Utica laterals, suggesting hydrothermal activity, have been observed to correlate with TBR-like structural anomalies
3. Huge gas kicks, zero weight on bit, and mud losses while drilling Utica laterals often correlate to TBR-like seismic features. These wells are almost always more prolific than wells lacking them.

This updated understanding has huge implications for the size and further potential of the UTBR. First, it changes how we map sweetspots in the combined play. "Rock quality" may no longer be the primary driver for a huge well, but rather, the specific structural features susceptible to fracturing & alteration, *which are widespread and largely untested*. Second, it suggests that in places where UTBR conventional features are present, Utica operators are probably missing highly-prolific TBR reservoirs beneath their laterals.

Moundsville Monster: The history and geology of West Virginia's most productive shale gas well

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The MND6HHS horizontal Point Pleasant shale well, located in Marshall County, WV, has produced over 17 Bcf of natural gas since it began production in 2015, making it the most productive shale well to be drilled in the State of West Virginia and possibly the most productive well ever to be drilled in the state's storied history. This talk will combine the historical recollections of geologists involved in the well's discovery with a review of the regional geology of the Utica/Point Pleasant play and wellbore specific characteristics of the Point Pleasant formation that helped to make the well such a prolific producer.

Identifying repeated reservoir intervals geospatially using open-hole geophysical logs

Dave Boyer, Mudrock Energy

Thrust and reverse faults throughout the Appalachian Basin often produce regions of increased stratigraphic section. Within oil and gas wells, there are segments where targeted reservoirs repeat within the wellbore. Open-hole logs allow for the definition of characteristics to interpret and map the repeated sections repeatedly.

Within a study area surrounding the Hiram Anticline in northern West Virginia, an analysis of open-hole logs from numerous Upper Devonian wells was completed. Repeated sections and structural marker beds were interpreted and mapped. Cross-section diagrams and locations of potential shallow faults were added. Following the completion of the analysis, the study identified regions of expected repeated reservoirs.

Application of similarity analysis to predict performance of new wells in old fields using geologic variables

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Predicting a well's potential performance is critical for informed decision making and planning. However, when drilling new wells in old fields, it can be challenging to estimate due to limited data and sporadic coverage. This study aims to explore and apply a similarity analysis approach to a newly drilled well in an old, plugged oil field in the southern Michigan Basin, to predict potential performance based on geologic variables and historical production data.

A catalog of geologic variables, including text and numerical types, was developed for 47 wells in the North Scipio Pool in the Albion-Scipio field in southern Michigan. Variables included indicators for porosity type, well type, well position, depth, and petrophysical derived characteristics of the reservoir. Gower's distance methodology was applied to the dataset, which compares each set of variables between wells, and produces a dissimilarity metric. The dissimilarity was used to weight the importance of each well against the newly drilled well, to identify the top wells with greatest similarity.
The results of the similarity analysis was used in two ways; 1) the well weights were multiplied by cumulative production values and summed for all wells to estimate potential cumulative production in the new well, and 2) the top five wells with greatest similarity were modeled against the production test in the new well to determine a production trend. The analysis yielded a range of potential production values for the new well.

The similarity analysis was successfully applied to a mixed set of variables to understand the potential performance of a new well in an old oil field. The results were used to inform project decisions and ensure the success of the test well. The methodology can be broadly applicable to other wells and fields.

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Mapping depletion using drilling data to gain insights into fracture growth and reservoir drainage

Jason Glascock and Kevin Wutherich, Drill2Frac

With the continuing increase in the number of infill wells being drilled, it is inevitable that many of these new wells will intersect areas of depletion caused by the legacy offsets which can have huge implications on reservoir drainage and resultant well productivity. Within the multiple producing intervals of the Marcellus play, this becomes even more relevant when trying to understand for example whether a lateral completed in the Upper Marcellus may have caused significant drainage in the Lower Marcellus.

This talk will focus on a new technology that uses drilling data to detect localized depletion around fractures in infill wells with a high degree of accuracy. It will present several case studies in the Appalachian basin as well as other shale formations which will demonstrate some of these effects of changing drilling targets as wells as giving some additional insight on fracture growth and drainage in the basin using this technology. In addition, workflows will be presented that will show how the use of this technology has the ability to significantly mitigate fracture interactions as well as their detrimental effects on production.

How the humanities can teach us to improve our interpretation skills; Geosteering techniques from examples in several basins

Chad Koury, Koury Geosteering, LLC

A highly analytical approach towards geologic operations while drilling horizontal wells is comprised of quantitative and qualitative methods. Quantitative methods are constrained and rigorous and require education in many facets of all professional disciplines involved in the drilling process. Qualitative methods exist in the philosophical and artistic domain. Both approaches require one to think critically and maintain concentration on the spectrum of foci from microscopic to macroscopic.

While drilling, specific techniques can be employed to aide in effectively correlating MWD gamma to vertical offsets. MWD gamma ray signatures measured within common strata exhibit different levels of continuity along the path of a horizontal wellbore. While some signatures will remain consistent, others will change drastically, depending on mineralogical, depositional, and structural conditions. Moreover, data is often taken at face-value and assumed to be accurate; maintaining skepticism towards all sources of data is crucial in avoiding pitfalls. Most importantly, running multiple iterations on the same data and maintaining thorough communication with all involved parties will ensure that no stone is left unturned.

Artistry and philosophy are beneficial tools in the mind of a geoscientist when interpreting data and following operational procedures. Removing our perceptions from the concrete world and thinking on abstraction facilitates our ability to expand the possibilities that we can conceive in our own mind. In a more avant-garde vein, interpreting and understanding the motivation and message behind impressionism and cubism in visual art exemplifies these qualitative methods. While painters like Monet and Picasso created two-dimensional works of art in the physical domain, the observation and interpretation of these specimen are multi-dimensional beyond the canvas. Integrating all sources of data from reservoir attributes and drilling performance metrics will enhance the resolution of perception of the subsurface and the optimal manner in which we can exploit the underlying resources.

Carbon in the Cambrian Rome Trough: Insights from the Rogersville Shale

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Buried beneath proven unconventional reservoirs of the Appalachian Basin lies the Rogersville Shale of the Middle-Upper Cambrian Conasauga Group confined within the Rome Trough. The Rogersville Shale is composed of primarily dark, laminated terrigenous mudstone with intervals of thinly bedded, bioturbated very fine grained sandstone. Mudstones typically show low TOC (≤1%) except in the Exxon Jay Smith #1 well (Wayne Co. WV), where TOC values range from 1.2% to 4.4%. To investigate the controls of organic richness of the Rogersville Shale, we evaluate the elemental and stable carbon isotope composition of 40 samples from the Exxon # 1 Jay Smith core at 0.5-1 ft resolution. Major element abundances and XRD mineralogy shows strong influence of siliciclastic input of clay, feldspars and detrital phosphorus, and to a lesser extent rutile, through positive correlations of SiO_2 with Al_2O_3 ($r^2 = 0.59$), K_2O ($r^2 = 0.51$), Na_2O ($r^2 = 0.34$), P_2O_5 ($r^2 = 0.33$), and TiO_2 ($r^2 = 0.26$). Redox-sensitive major and trace elements (MnO, MgO and Fe_2O_2, V, Ni, Mo, U, Cu, Cr, and Cd) suggest bottom waters were rarely hypoxic. Sedimentary organic matter yields highly negative $\delta^{13}C$ values ranging from -15.3 to -41.3‰, with a median $\delta^{13}C$ value of -33.7‰, which is -3‰ lower than average $\delta^{13}C$ values reported for sedimentary organic matter from the overlying Upper Cambrian Nolichucky and Eu Clair Formations. Two Middle Cambrian negative isotope excursions are documented globally, one at ~506 Ma, known as the Drumian isotopic carbon excursion and another at 510 Ma, known as Redlichiid-Olenellid extinction carbon isotope excursion. We postulate that the highly negative carbon isotopic signature of the Rogersville Shale reflects one of these excursions, both of which are linked to trilobite extinctions, and was possibly driven by short-lived upwelling of hypoxic waters enriched in light carbon isotopes.

Preliminary evaluation of Rogersville Shale well completions and performance

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The deep Rogersville Shale exploratory play in northeastern Kentucky and West Virginia had a strong start with competitive land leasing, followed by six wells being drilled in the play between 2014 and 2017. But only one well had limited commercial production, and all have been plugged and abandoned. Nevertheless, operators of the Rogersville wells provided robust datasets for the Department of Energy–supported Conasauga Shale Research Consortium to evaluate in order to better delineate the play and improve well performance. The Rogersville has low TOC content, < 2.5 percent overall, and XRD mineralogy indicates the presence of freshwater-sensitive illite/smectite expandable clays. Pre-fracture treatment tests of well cuttings indicated that the Rogersville's freshwater sensitivity could be mitigated with clay stabilizers in the treatment water. A pretreatment mini-fracture test of the Rogersville found a fracture gradient of 1.02 psi/ft and a calculated pressure-falloff permeability in the Rogersville of 230 nanoDarcys. Four wells, two horizontal and two vertical, were treated with fresh slickwater fractures. One horizontal well was treated in 27 stages using 301,239 BW and 12,113,340 pounds of sand, whereas the second was treated in 11 stages using 107,116 BW and 3,513,180 pounds of sand. The vertical well had a much smaller fracture treatment. After fracturing, initial production averaged 28 BOPD and 616 Mcfgpd from the horizontal wells. Neither of these wells produced all of the treatment water before being shut in and abandoned. Expandable clays in the Rogersville and freshwater fracture treatments may have combined to damage the reservoir permeability and compromise oil and gas production. Lessons learned from these Rogersville test wells indicate that fracture treatments could be designed to mitigate the expandable clays problem. The costs of these deep wells, however, may negate improvements in well-completion technologies.

Resolving biogeochemical feedback mechanisms using a quantitative, statistical approach in the Late Ordovician Utica-Point Pleasant Formation: Implications for source rock deposition and absolute proxy values

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The Middle to Late Ordovician was a dynamic interval as the Earth system transitioned toward a steady state in which the geosphere and biosphere became more intimately linked. This time also saw widespread deposition of organic-rich shales, many serving as source rocks for prolific petroleum systems or are themselves being exploited as source rock reservoirs (SRRs). Here, we utilize the Katian Utica and Point Pleasant (U-PP) Formations of the Appalachian basin to explore the record of biogeochemical feedback mechanisms and extent to which these feedbacks influence organic matter availability, preservation potential, and SRR development using a quantitative, integrated approach.

Core material from the western basin margin was analyzed for Fe-speciation, trace elemental composition, TOC contents, and biomarker composition/abundance. Preliminary results suggest that the U-PP can be characterized by a distinct facies progression, interpreted to reflect carbonate platform drowning and development of a clastic-dominated foreland basin. Across the U-PP, Fe-speciation data indicate a broad transition from oxic to ferruginous (anoxic, Fe-replete) conditions while redox-sensitive trace elements sustain near-crustal values, supporting a local control on redox. Early organic geochemical analyses reveal an abundance of lipid biomarkers that suggest a dominance of eukaryotic primary producers. Intriguingly, the composition of some samples includes characteristic carotenoid biomarkers that may be evidence of photic zone euxinia (anoxic, sulfide-replete), perhaps implying a more complicated water column redox architecture.

This work represents the first SRR-specific study to apply multivariate statistical techniques to organic and inorganic geochemical data within a stratigraphic framework, such that correlations between parameters and facies may reveal enigmatic mechanistic relationships between biological communities and their environments. Ultimately, understanding these complex interactions – e.g., the role of terrestrialization on organic matter burial via intermediate processes of weathering, clay formation, Fe-cycling, and microbial community turnover – is crucial to interpret these signals preserved in the sedimentary record more completely.

Comparing and contrasting deposits of the Late Ordovician "Point Pleasant" and Dolgeville Formations

David R. Blood, DRB Geological Consulting

Deposits of the Late Ordovician, including upper portions of the Trenton Group, "Point Pleasant" Limestone, Dolgeville Formation, and Utica Shale, often collectively referred to as the 'Utica Play" are the target of unconventional oil and gas development in the Appalachian Basin. In general, the section comprises basal carbonates of the Trenton passing upward into a unit of interbedded carbonates and shales, the Point Pleasant/Dolgeville, overlain by organic-rich shale of the Utica. The series represents the drowning of the Trenton carbonate platform resulting from widespread transgression associated with the Taconic Orogeny. The transgression culminates in the basal portion of the Utica shale before giving rise to regressive systems tract deposits of overlying Utica Shale sediments, and shale and siltstone of the Kope and Lorraine/Reedsville formations. The similarity of geophysical well log response of the "Point Pleasant" and Dolgeville, that is, decimeter-scale interbedded limestone and organic-rich shale directly overlying the Trenton Limestone, and underlying the Utica Shale makes it tempting to equate these two deposits. However, there are several important observations which suggest that these units are distinct and accumulated under markedly different conditions. The term "Point Pleasant" is applied to subsurface deposits in eastern Ohio and southwestern Pennsylvania. Interbedded organic-rich mudstone obrution layers and organic-lean carbonate shell beds of Mohawkian to early Cincinnatian age characterize these deposits. Shell beds represent largely in-situ, occasionally storm disturbed and reworked, time-rich intervals interrupted by rapid deposition of organic-rich muds. The Dolgeville Formation, occurring in eastern New York and northeastern Pennsylvania, consists of interbedded organic-rich mudstone, and organic-lean, turbiditic calcisiltites of Cincinnatian age. Here, time-rich organic muds were deposited by suspension settling and interrupted by rapid deposition of calcisiltite turbidites. Therefore, while these units look similar on well logs, detailed comparisons demonstrate that the two units accumulated under markedly different conditions at different times.

Produced gas and condensate geochemistry of the Marcellus Formation: Insights into petroleum maturity, migration, and alteration in an unconventional shale reservoir

Christopher D. Laughrey, Stratum Reservoir

The Middle Devonian Marcellus Formation is the most prolific hydrocarbon play in the Appalachian basin. Regional differences in Marcellus fluid chemistry reflect variations in thermal maturity and hydrocarbon alteration. These variations define specific dry gas and wet gas/condensate production in the basin. This paper integrates results from more than a decade of study of Marcellus natural gas chemical and isotope composition, including noble gas systematics for dry gases. Geochemical interpretation of associated wet gases is supported by High Resolution Gas Chromatography and API gravity data.

Dry Marcellus gases produced in northeast Pennsylvania and northcentral West Virginia are mixtures of over-mature methane, mostly cracked from refractory kerogen, and ethane and propane cracked from light oil and wet gas. Natural gas plots reveal reversed carbon and hydrogen isotope trends which reflect (1) mixing of hydrocarbons of different thermal maturities, (2) Rayleigh fractionation of wet gas during redox reactions with formation water at high temperatures, and (3) isotope exchange between methane and formation water. Noble gas systematics support the interpretation of hydrocarbon-formation water interactions. Noble gas data constrain the maturity of the hydrocarbon gases and provide a method of quantifying gas retention versus expulsion in the reservoirs.

Marcellus gases co-produced with condensate in southwest Pennsylvania and northwest West Virginia are mixtures of residual associated gases generated in the late oil window and post-mature hydrocarbons generated from oil cracking in the wet gas window. The $\delta^{13}C$ of ethane and propane are congruent and reflect effective maturation trends within the source rocks. Correlation of API gravity and C_7 expulsion temperatures, high heptane and isoheptane ratios, and the gas geochemical data confirm that the Marcellus condensates formed through oil cracking. Respective low toluene/nC_7 and high nC_7/methylcyclohexane ratios indicate selective depletion of low-boiling point aromatics and cyclic light saturates in all samples, suggesting that water washing and gas stripping have altered the fluids. These alterations may be related to deep migration of hot basinal brines.

Variations in produced water chemistry and relation to regional geology and production in the Marcellus Shale, Northcentral West Virginia

Jonathan Brady, The Thrasher Group, Inc.

An investigation of 74 Marcellus Shale wells across northcentral West Virginia indicates changes in produced water chemistry and quantity can be related to geologic conditions based on well logs and core data. These changes are determined by reviewing multiple produced water analyses for individual wells for periods up to ten years. Results show variations among the areas in this study. From west to east across central Harrison County to central Taylor County, then north into Monongalia County, gamma-ray logs show increasing intensity, especially in the middle and lower Marcellus. XRD mineralogy from core data shows increasing clay content from west to east with associated decreases in quartz. Produced water analyses show increases in barium concentrations from west to east, typically associated with increasing shale/clay minerals. Additionally, produced water samples show decreasing calcium and strontium concentrations moving west to east, suggesting that increased carbonate content, possibly as carbonate cement, is present in the western-most study areas. These geological differences across the area results in variations in produced water behaviors. Total dissolved solids (TDS) concentrations typically reach their maximum value during the second year of production. After this time, areas in Harrison County showed both increasing and decreasing TDS concentrations, while areas in Taylor and Monongalia showed almost exclusively decreasing concentrations over time. With TDS concentrations dropping below the maximum values, relative ratios of formation water vs. fracturing fluid can be determined in a given well as it ages. Normalized, cumulative gas production for these wells showed that the geologic differences observed in the produced water are reflected in different production rates across the study area.

Organic content, distribution, and thermal maturity in the Cambrian Rogersville Shale

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The Rogersville Shale unconventional oil and gas play in the Rome Trough of eastern Kentucky and West Virginia consists of six wells drilled by four companies between 2014 and 2017. Although all the wells encountered hydrocarbons, only the Cabot #50 Amherst Industries in Putnam County, West Virginia, was put on production. The DOE-funded Conasauga Shale Research Consortium (the Kentucky and West Virginia geological surveys and the West Virginia University Departments of Petroleum & Natural Gas Engineering and Geology and Geography) formed in 2019 to study the possible production potential of this emerging resource. The consortium received donations of cores, cuttings, and data from the key wells. Using a combination of these donated samples and data, along with legacy data held at the Kentucky and West Virginia surveys, the consortium compiled or conducted 2,067 analyses of % TOC, 696 of programmed pyrolysis, and 21 of petrographic microscopy for the Conasauga Group, primarily in the Rogersville Shale. The entire shale sequence was then analyzed.

Although the Rogersville Shale is up to 1,750 ft thick in eastern Kentucky, the zone with TOC content greater than 1 wt. % (i.e., potential source rock) is less than 120 ft thick. Two stacked intervals (of approximately ~40 and 10 ft in thickness) of calcareous siltstone and shales with 1–4 percent TOC occur in this organic zone near the middle of the formation. The top of this zone is interpreted as sequence boundary C3-2, which may explain the organic preservation. As in parts of the Utica Shale play in Ohio, here the highest TOC zones occur not in higher gamma-ray intervals as in most organic shales; instead, TOC is correlated with higher carbonate content. In the core area of the play, the Rogersville has a thermal maturity (%Ro equivalent) of around 1.7.

Seismic stratigraphy, oil & gas, and CCUS potential of the Illinois Wabash Fault Zone and Kentucky Rough Creek Graben using High-Quality Mega-Regional 2D seismic lines

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The Fairfield sub-basin in the southern area of Illinois, combined with the northwest area of western Kentucky in the Rough Creek Graben, forms an intriguing area for scientific and economic investigation. Integrating deep Knox well penetrations with high-quality 2D seismic provides valuable insights into multiple petroleum systems for oil and gas exploration, future carbon capture and storage projects, and assessment of rare earth deposits associated with "Hicks Dome", a late Permian-age intrusive feature created by rising ultramafic magma.

Our regional 2D seismic reinterpretation crosses productive fields, and important igneous basement tests, and investigated prospect and trap geometries of multiple petroleum systems (including the upper Devonian New Albany and Ordovician Maquoketa). Deep strata of Cambrian-Ordovician and Pre-Cambrian overlying billion-year-old Mid-Continent Rift (MCR) sediments may contain oil and gas in significant stratigraphic traps. Cambrian petroleum systems exist in adjacent basins in neighboring states. Regional assessment of petroleum migration from the Cambrian-Ordovician highlights areas where the oil and gas Industry might find future petroleum accumulations.

In addition to hydrocarbon resources, an integrated regional study has other applications. Illinois and Kentucky are proving grounds for Carbon Capture and Sequestration research. Our 2D megaregional seismic shows that future CO2 CCUS storage sites might include post-Permian age structures drilled by 1980s era wells into water-filled porous reservoirs, in porous reservoir facies of the St. Peter Sandstone, Knox, Potosi Dolomite, Eau Claire, and Mt. Simon found in the deep, southern, Fairfield Basin. Seismic data included in this study show the Illinois "Hicks Dome" in two directions on separate seismic lines of interest to the search for critical rare earth minerals. And finally, this seismic study shows faults that coincide with recordings of modern earthquakes and this may be useful in environmental and earthquake research.

Evaluating the liquids potential and distribution of West Virginia's Marcellus Liquids Fairway

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The distribution of liquid hydrocarbon (HC) resources in the Marcellus Formation throughout West Virginia (WV) is a matter of economic importance for the State of West Virginia and Marcellus operators. Herein, the West Virginia Geological and Economic Survey (WVGES) and Advanced Hydrocarbon Stratigraphy (AHS) have undertaken a project to map the composition and quantities of liquid gasoline range HCs present in drilling cuttings from counties in and neighboring the WV liquids fairway using Rock Volatiles Stratigraphy (RVStrat). Cuttings were analyzed from 12 wells, including air drilled wells, from Doddridge, Marshall, Ritchie, Tyler, Harrison, and Wetzel counties; spud dates range from 1953-2013. Insights into the geographical distribution of liquids quantities and compositions and the regional petroleum system were gained with a focus on the Devonian-aged shales, i.e. the upper and lower Marcellus Formation and the West River and Geneseo shale members of the Genesee Formation. Major results were identification of apparent thermal maturity trends embedded in the liquids composition across the basin where there is a trend of increasing paraffin (alkane) and decreasing naphthene (cycloalkane) content as a function of depth. A trend of decreasing size (number of carbon atoms) of the liquid molecules vs depth was observed in the West River, Geneseo, and upper Marcellus indicative of thermal maturity. The liquids distribution across the Marcellus fits within expectations from production data showing a trend of increasing content moving westward from northcentral WV towards the Ohio River; liquid saturations measured were likely ≤1% of the original subsurface saturation. The liquids content in the Marcellus shows an apparent declining exponential vs depth trend likely linked to the progression of catagenesis. An anomalous well that may have undergone a significant gas migration/expulsion event, resulting in less liquid content and a preferential depletion of the more volatile liquid HC species was identified. There is also a trend of increasing mechanical strength of the cuttings vs depth likely due to compaction; there are differences in mechanical strength as function of when the well was drilled, before or after 2009 (likely due to PDC [polycrystalline diamond compact drill bits); this was the only bias identified due to the age of the sample or mud system used. The value of being able to collect usable and meaningful geochemical data from air drilled wells where the cuttings are several decades old with minimal cuttings material by RVStrat should not be understated; it allows using samples that are typically considered unsuitable and offers unique opportunities for petroleum system assessments.

The war for porosity: competition for underground storage in the Appalachian Basin

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The Appalachian Basin is not only a Super Basin, but arguably the oldest and most populous Super Basin. Productive portions of the basin span part of New York, Pennsylvania, Ohio, West Virginia, Maryland, Virginia, Kentucky, and Tennessee and within or nearby the population centers one thinks of when mentioning these states. All those people can be difficult to drill around, but they also provide an opportunity for this "mature" Super Basin. All those people require energy in some form or fashion and meeting those energy demands will require underground storage in many formations for differing products.

The shale revolution in Appalachia continues and as we find more natural gas, we will need underground natural gas storage, allowing for natural gas withdrawal on demand when furnaces are turned up or when used to produce electricity. But as we move into the future and consider the increased availability of natural gas liquids produced from shales, even more storage is needed. Shell's mammoth ethane cracker plant is being built in Beaver County, PA right now, and so the need for ethane storage opportunities is now. Further, as the energy industry reaches toward the use of alternative fuels, for example, hydrogen energy, additional storage facilities will need to be considered and discovered for that hydrogen. Also, new storage will continue to be needed for electric generation plants that can capture and sequester carbon dioxide. Finally, as we continue to drill, to provide the energy for the above opportunities, we will need to find places to dispose of water and underground saltwater disposal wells are one tool for disposing flowback and produced water.

You can boil down a petroleum geologist's job as looking for porosity and permeability (hopefully with hydrocarbon in it). It tends to be the engineer's job to try to get the hydrocarbon out of the ground. We need to turn that thinking upside down and Appalachian petroleum geologists need to be looking for porosity and permeability for storage and disposal opportunities …… to inject product into, not pull product out of. The end of the productive life of the Appalachian Basin is long ahead of us, but to keep that "end of days" well into the future, we need to find storage opportunities for the energy we are producing today and will discover in the future.

Regional EOR potential of the Utica/Point Pleasant in Ohio

James McDonald, Christopher B.T. Waid, Michael P. Solis, Samuel R.W. Hulett, Erika M. Danielsen, Ohio Department of Natural Resources, Division of Geological Survey

Over the past decade, the Utica Shale/Point Pleasant Formation unconventional shale play has been a prolific oil, gas, and natural gas liquids producer, primarily in the Ohio portion of the Appalachian Basin. As part of the Utica Consortium Playbook, Hickman and others (2015) delineated an oil assessment area for the Utica/Point Pleasant unconventional shale play. Current oil production from the Point Pleasant Formation is in the extreme southeastern portion of the oil assessment area, showing that most of the oil assessment area first delineated in 2015 is nonproductive. This study is a regional characterization of the Utica/Point Pleasant interval for enhanced oil recovery (EOR) techniques. EOR techniques may allow for the opening of the oil assessment area, extending the life of the play, and possibly play a role in usage of CO_2 EOR techniques.

The methods employed in this study include new mapping of the geologic units in the Utica/Point Pleasant interval, along with examining existing and newly submitted data for the rock and reservoir properties since the publication of the Utica Consortium Playbook. The new structure and isopach maps show much more detail than was published previously. Using the mineralogy data, Mineral Brittleness Indices (MBI) were computed for each of the geologic units in Utica/Point Pleasant interval. New reservoir pressure mapping by Trotter (2018) shows that the primary production is from the overpressure area. Most of the oil assessment area is slightly above or at hydrostatic pressure. Any EOR activity will require additional energy being added to the reservoir, through repressurizing of the reservoir, for oil to be driven to collection wellbores. These new maps and analyses provide guidance to operators for future EOR operations in the Utica/Point Pleasant unconventional shale play.

Evaluating seal capacity to super critical CO_2 ($scCO_2$) as an aid in risk assessment and carbon storage site characterization

Donna Caraway Willette, Illinois State Geological Survey

Estimation of seal capacity is generally derived from membrane capillary pressure behavior of the caprock using mercury injection capillary-pressure (MICP) analyses. Wettability parameters (interfacial tension (s) and contact angle (q)) are used to convert to a $scCO_2$/brine system. There are complexities in utilizing reasonable wettability parameters. Recent experimental studies using various substrates with $scCO_2$ immersed in brine indicate that they become less water-wet in the presence of $scCO_2$, i.e. contact angles varying from 0^o to 40^o and with higher pressures up to 20mPa (2900 psi), can range up to 60^o. An additional complication arises as MICP data is point-sourced, MICP data may not be available, and there is variation in lab protocols in establishing threshold pressures. Given these issues, there are methodologies to assist in constraining seal capacity.

An approximation of sealing capacity can be evaluated using permeability estimates derived from petrophysical analysis. This estimate is determined from a statistically significant relationship between air permeability (md) and air threshold pressure (psi) such that the mean pressure of $scCO_2$ is 42.7% of that measured in relation to air or N_2. This formulation overestimates the column height but can be useful in evaluations. MICP examples from caprock with a permeability range from 10^{-4} to 10^{-5} md suggest that for clay-rich intervals under high pressure (> 2000psi), a reasonable estimate for seal capacity is 25% - 30% of the column height derived from permeability formulation only. Clay-rich caprocks under pressures < 1500 psi, seal capacity may range between 40% - 48% of estimates derived from a similar permeability range. This difference is due to the change in $scCO_2$ wettability (contact angle) under differing pressure regimes. It is best practice to use MICP data which span the range of contact angles between 0^o – 60^o, vary the sample threshold pressure by 20% - 25% to account for complex lithology, and calculate minimum and maximum capacity for risk assessment inputs.

A holistic assessment of development of electric power generation in the United States; Surface impacts of wind, solar and natural gas in the Appalachian Basin

Tim Carr, Department of Geology and Geography, West Virginia University

In addition to positive health, economic and societal impacts, all energy sources have negative impacts on our environment at multiple stages in their development and use. Negative impacts can include air and water pollution, damage to public health, wildlife and habitat loss, water use, and global warming emissions. This talk concentrates on the impact of natural gas compared to non-hydro renewables on land use and habitat loss.
A natural gas well requires clearing and leveling an area around the well site and laying pipelines. Solar and wind require significant surface modifications and power lines. Both forms of energy can have significant impact on land use and habitat loss.

Costs for natural gas, solar and wind power have significantly decreased over the last decade. However, power density of solar and wind measured as energy generation rate per time per unit ground area ($W_e\ m^{-2}$) appears to be stagnant, while the power density from multi-well shale gas pads is increasing.
Using power density, the rate of energy generation per unit of land surface area occupied by an energy system, lower power densities mean larger land and environmental footprints. Data from published sources for generation efficiency, analysis of satellite imagery, and regional and local data across the Appalachian basin provides a better understand surface impacts. Power

density derived for multi-well shale gas pads with laterals in excess of 3,000 meters, and electricity generated with combined cycle gas turbines is two orders of magnitude greater power density than non-hydro renewables.

Electric generation from renewable solar and wind sources will reduce global warming emissions. However, much lower power density coupled with low efficiency (dispatch availability) will result in larger environmental consequences in terms of changing land use and loss of critical habitat measured in millions of acres compared to electricity generated from natural gas.

Poster Session Abstracts

Alphabetical according to lead presenter

Lateral variability of the Marcellus Shale

Bruno Abersold, Department of Geology and Geography, West Virginia University

The Marcellus Formation, a large shale gas reservoir located within in the Appalachian basin, produces the energy that fuels the economy across the United States. Well data and rock core for the Coastal 1H well, found in Fayette County, Pennsylvania, provides the basis to understand reservoir characteristics and depositional processes of the Marcellus Formation across the basin. The well is located near along the eastern edge of the productive fairway and adjacent to the Allegheny mountain front. We used characteristics, such as total organic carbon (TOC), geomechanical properties, and lithology, to integrate with ten other available wells across the basin. The Marcellus Formation was divided into five informal units - three shale layers (upper, middle, and lower), separated by two limestone beds. Ternary diagrams visualize the mineralogical composition of the Marcellus Formation. Consistently they indicate that carbonate and silica content increases with depth and clay decreases. Total organic carbon, however, increases with depth in only certain wells. Geomechanical properties vary the most when looking at the individual units of a well and brittleness decrease upwards with increased clay content. Overall, the Marcellus Formation is weak and brittle compared to adjacent units. The Coastal 1H shares similar lithological properties with the nearby wells, however, it is less organic rich and less brittle in comparison to the other study wells. In general, it seems that the lower Marcellus is the optimal unit for hydraulic fracturing, as it is the most brittle and organic rich.

Phase associations of rare earths and critical minerals in Marcellus and Haynesville Shale: Implications on release and recovery strategies

Shailee Bhattacharya, Vikas Agrawal, Bennington Opdahl, and Shikha Sharma, West Virginia University

The focus on clean energy transmission and rapid advancement of technological devices has resulted in high demand for rare earth elements (REEs) and critical minerals (CM). Hydrocarbon rich shales that have been major supplier of natural gas in US over the last decade have the potential to serve as source of some of the REE's and CM's. However, there is little understanding of the geological and geochemical processes that lead to enrichment REEs and CMs in these shale reservoirs. To develop economically viable extraction techniques there is a need to build better geochemical models for enrichment. The goal of our study is to investigate the distribution of REEs and CMs in the different fractions of shale, namely, exchangeable, acidsoluble, pyritic, organic and silicate phases. A sequential leaching experiment was performed on Marcellus shale and Haynesville shale samples to compare the differences in phase associations of REEs and CMs. Results show that REY are mostly concentrated in the acid-soluble fraction. Critical minerals, such as Al, As, Cr, Cu, Co, Li, Mn, V, Ti, and U are found widely distributed among all the phases. The Haynesville shale has elemental abundances majorly in acid-soluble and silicate phases, while the Marcellus shale has relatively higher contribution of critical elements from the pyritic fraction followed by acid-soluble and organic phases. The Marcellus shale is at least ten times more enriched in As, Li and U than the upper continental crustal average. Additionally, although the individual concentrations of Platinum group elements are considerably low, there is a significant difference in the nature of associations between Marcellus and Haynesville shale. These preliminary results help us understand the mechanisms that caused the phase associations. The study is critical as it also will help improve strategies to increase extraction efficiency and economics of REE and CM recovery from shales.

Preliminary high-resolution mapping of organic carbon distribution in the lower Huron Member of the Ohio Shale

Erika M. Danielsen, Ohio Department of Natural Resources, Division of Geological Survey

The Devonian shales of the Appalachian Basin have been studied extensively in terms of hydrocarbon resource potential; however, the increasing demand for carbon capture, utilization, and storage calls for continued reassessment of the properties of the Devonian shale formations at a finer scale. This project aims to estimate and map total organic carbon (TOC) distribution in the lower Huron Member of the Ohio Shale in Ohio at a high geographic and stratigraphic resolution using geophysical logs to estimate TOC. The Eastern Gas Shales Project (EGSP) of the 1970s and 1980s funded the drilling of several cores in Ohio with accompanying TOC lab analyses. These data have been used for TOC mapping previously, but core data only covers a narrow geographic area and the data is scattered through several of the Devonian shale formations. These TOC data from the EGSP and other cores were used to develop an equation for this project that uses gamma-ray and bulk density logs to estimate TOC in wells that penetrate the lower Huron. This project builds on previous work by the Ohio Geological Survey that increased the stratigraphic resolution of the upper Devonian shale mapping in Ohio, particularly in the lower Huron Member. TOC estimates were mapped across eight depositional cycles within the lower Huron to determine if changes in basin morphology during deposition impacted the distribution of high TOC zones.

Leveraging state system resources for a collaborative, comprehensive geologic field camp

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Geology is inherently a field science. A transformative experience for students on their paths to careers in geology is through "field camp." In these unique courses, students receive hands-on training and apply geological tools. Unfortunately, the availability of geological field camps has declined and have become cost prohibitive. This is a challenge for undergraduate students seeking careers in geology, lacking demonstrable, comprehensive field experiences on their resume. It is a challenge to our discipline as well, which has long relied upon a robust, field-based capstone for entrants into the workforce, graduate school, and professional licensure. In Pennsylvania, particularly the State System (PASSHE), most geology programs require or recommend field camp. Currently, the 11 Geoscience programs within PASSHE operate independently, many struggling to offer field instruction due to limitations on faculty time, campus resources, and enrollment. Consequently, students shop for alternatives, often attending camps with high, out-of-state tuition and expensive travel. This is burdensome for students and families and a barrier for underserved and marginalized populations. In Summer 2022, a PASSHE-wide option launches with its first cohort. Designed by PASSHE geology faculty for PASSHE students, the participants will travel to system campuses each summer. Students are housed on campus and investigate the geology with local professionals and faculty from those institutions. Field activities include surficial and bedrock mapping, geophysical surveys, and geochemical sampling. Projects will be designed to using current technologies and develop communication and problem-solving skills in a group setting. The program includes outreach to engage pre-college students and teachers, and service-learning activities with the community. As we develop the course, we seek input and ideas from industry professionals. This field camp will be the first of its kind and will benefit from forethought and recommendations from hiring managers aware of workforce needs in the energy and environmental sectors.

Lithofacies, depositional setting, and sequence framework of the Cambrian Rogersville Shale, Rome Trough, Kentucky

Dave C. Harris, and John B. Hickman, Kentucky Geological Survey, University of Kentucky

Cores and related data from the Cambrian Rogersville Shale in the Rome Trough, Lawrence and Johnson Counties, Kentucky, were analyzed in a regional study recently completed by the Conasauga Shale Research Consortium. More than 900 feet of Rogersville Shale from two wells, and almost 400 feet of Nolichucky Shale from a single well, were provided to the consortium. These cores constitute an important sedimentologic record for the deep Cambrian formations in the subsurface of the Appalachian Basin.

The Rogersville Shale in the cored intervals is composed of heterolithic intervals of thinly bedded calcareous siltstones to very fine-grained sandstones, interbedded with medium to dark gray shale. Calcite-cemented siltstones and sandstones occur in beds up to 6 cm thick, and commonly occur as millimeter-scale laminations separated by shale partings. The coarser layers commonly have sharp, erosional bases and low-angle to hummocky cross-stratification. Lenticular siltstone beds with climbing or starved ripple lamination, and flat-pebble conglomerates composed of siltstone intraclasts are common. Bioturbation is abundant throughout the Rogersville in both shale and siltstone beds. Carbonate content varies in the coarser-grained beds, both as transported grains and cement.

The thin-bedded and heterolithic nature of the Rogersville suggests deposition in a distal marine setting with intermittent silt-sized sediment supply. Siltstones and sandstones are interpreted as discrete event beds, deposited by storm currents in a deeper basinal environment below normal wave base. Hummocky crossbedded siltstones with erosional basal contacts also support storm deposition. Individual event beds cannot be correlated between the cored wells.

The Rogersville Shale comprises parts of two third-order depositional sequences based on outcrop exposures. The mid-Rogersville sequence boundary marked by the shallow-water Craig Limestone Member in outcrop has been interpreted in the basin as a correlative conformity and helps to explain the distribution of organic-rich shale in the play area.

Qualitative REE analysis of Ohio underclays by pXRF

Samuele R.W. Hulett, Franklin L. Fugitt, and Christopher E. Wright, Ohio Department of Natural Resources, Division of Geological Survey

Aluminum-rich clays and claystones associated with Pennsylvanian-age coal horizons can be found throughout eastern Ohio. Similar clays from Pennsylvania and West Virginia have been recognized as a potential low-grade, large-volume source of Rare Earth Elements (REE). Samples were gathered samples from 66 sites, with subsamples taken at regular intervals throughout the clay. Samples were prepared and analyzed via portable X-Ray Fluorescence (pXRF) in order to qualitatively assess REE content. While the pXRF can only measure four of the REEs (Lanthanum, Cerium, Praseodymium and Neodymium), some associations emerge. Total REE content ranges from about 50 ppm to over 350 ppm, with an average of 210 ppm. Average clay/shale REE content over these four elements is 183 ppm. The greatest concentrations occur in the Lower Kittanning underclay and red Conemaugh Group shale. The lowest concentration comes from the Middle Mercer underclay. Preliminary data does not show any correlation between total REE concentration and proximity of the subsample to the overlying coal. A comparison of total REE vs other major element concentrations show a direct correlation with iron. This association coupled with a weak aluminum correlation suggests the possibility that the REEs are not adsorbed onto the clay minerals but instead may be hosted in iron minerals in the clay. Future analysis via tabletop XRF and XRD will aid in confirming these results. If accurate, these associations may be able to help target intervals with the greatest potential for future economic use and give an insight into the origins of these REE rich units.

Organic source characterization of the Utica, Marcellus and Burkett Shales

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We present new geochemical data from the Ordovician Utica shale (n=3) and Devonian Marcellus (n=8 plus 6 previously published data) and Burkett shales (n=2) – some of the biggest producers of natural gas in North America in recent times. The <1 to 9% organic carbon contents in Burkett and Marcellus shales were typical for mature shales. Total lipid extracts (TLE) from the NY Marcellus samples were nearly 2x the average TLE of the Utica shales. TLEs from the hydrothermally altered PA samples were generally lower, except one Burkett sample. The n-alkane distributions from three Marcellus and one Burkett shale samples show a single peak centered on C-26-C-27. Other samples have a bimodal distribution with a secondary, sometimes dominant, peak, centered on C-15 to C-16. The abundance of longer chain n-alkanes along with ⍰13Corg values <-22‰ indicate terrestrial inputs in both these shales. Negative Cerium anomalies from Marcellus and Burkett samples point to anoxic condition during deposition. The ⍰13Corg values further indicate that deposition took place in shallower water and not in anoxic deep water setting. Presence of medium to long chain n-alkanes (C23-C33) in the Ordovician Utica shale also likely indicate shallower water deposition with input from terrestrial bryophyte and fungi. The high (>1 for n = 11) Terrestrial to Aquatic ratio and Carbon Preference Index values of ~1 farther point to mature terrestrial or type III kerogen that are gas-prone. The geochemical signature suggests that deposition of the gas rich black shales were linked to development of shallow anoxic water with high terrestrial sediment supply during both the Taconic and Acadian orogenies.

Vug and fracture characterization of Trenton-Black River reservoirs through CT scan and image log analysis in the southern Michigan Basin

Laura Keister, Amber Conner, Autumn Haagsma, and Srikanta Mishra, Battelle

A comprehensive evaluation of chemically enabled CO_2-EOR in the Southern Michigan Basin Trenton-Black River (TBR) reservoirs is underway as part of work supported by the U.S. DOE under DOE-FOA-0001988. The TBR consists of complex, multi-porosity and/or hydrothermally altered dolomite (HTD) reservoirs with secondary porosity (i.e., vugs and fractures), which contributes significantly to total porosity, permeability, and storage potential throughout the reservoirs. These reservoirs are especially challenging for enhanced oil recovery due to heterogeneities, compartmentalization, and presence of thief zones. As a result, there is a heightened need to understand and predict these potential reservoir features for satisfactory incremental oil recovery.

To address these challenges, a database of image logs and 3D computed tomography (CT) scans that depict secondary porosity features were compiled. Image logs provide high-resolution, 360-degree wellbore images that can be used to derive planar structural and sedimentary features for detailed reservoir characterization, such as faults, fractures, bedding, stress fields, and pores. Flags were developed to identify and classify vugs and fractures, and the frequency and orientations were analyzed. The 3D CT scans capture high-resolution images of whole core that represent variations in density, indicating changes in composition and porosity. We developed a technique which isolates specific rock density ranges, quantifies the percent of each feature, and creates 3D visualizations. Image logs and CT scans were compared for wells that had both datasets.

The results produced quantitative size, orientation, and distribution for thousands of secondary porosity features in the TBR. The features varied greatly from well to well but had the highest concentration within dolomitic intervals. Total porosity increased where features were present, indicating an important role in reservoir quality. Overall, this study quantitatively detailed the distribution of these complex porosity networks. The results will be used to inform 3D modeling to assess the CO_2-EOR feasibility in the TBR.

Northern Bohemian Massif: an example fo multi-phase tectonic reactivation recorded by Late Paleozoic–Mesozoic basins

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The northern Bohemian Massif (BM) experienced a complex Late Paleozoic–Mesozoic intra-plate tectonosedimentary evolution. Processes that led to current basin configuration have recently been explored through facies analysis, lithostratigraphic correlation of sedimentary formations and provenance analysis (U–Pb geochronology; heavy minerals). The provenance data point to multiple sources, both local and distant within the BM, or exotic sources (Baltica). Temporal and spatial evolution of source areas and juxtaposition of preserved basin fills suggest that least four generations of basins developed in the study area:

(1) Extensional early Permian basins, formed by reactivation of SSW-NNE normal faults;

(2) Permian outliers within the Elbe Zone and the Döhlen Basin (Germany) . We interpret them as remnants of a series of pull-apart basins governed by NW-SE faults (the Elbe Zone);

(3) Middle-Upper Jurassic outliers within the Elbe Zone, interpreted as a trace of now completely eroded Late Jurassic-Early Cretaceous basin;

(4) Upper Cretaceous of the Bohemian Cretaceous Basin, interpreted as either transtensional (Uličný 2001) or intraplate foreland basin (Voigt et al. 2021).

Provenance of the Upper Jurassic and Upper Cretaceous indicates two-stage deposition, interrupted by reactivation of basement faults and shift of depositional and source areas. Certain Upper fromations received a substantial portion of Baltica-derived siliciclastic material interpreted to be recycled from the hypothetic Lower Cretaceous during unroofing of the adjacent source area. A reconstruction of Mesozoic tectoinosedimentary evolution and paleogeography of the northern BM shows that the mentioned phases of basin development were interrupted by major non-depositional intervals (Middle Triassic-Early Jurassic, mid-Cretaceous, post-early Campanian). This was caused by reactivation of Variscan NW-SE faults due to stress transfer from the North Atlantic Rift (Jurassic-Early Cretaceous), which was overridden by far-field effect of the convergence of Iberia, Africa, and Europe during Late Cretaceous times.

Vein evolution and hydrocarbon migration in the Marcellus Shale across the Appalachian Basin

Natalie Odegaarden and Tim Carr, West Virginia University

Four cored wells of the entire Middle Devonian Marcellus Shale from Ohio and West Virginia were used to investigate the distribution and morphological evolution of natural fractures with cement when kerogen matured to different burial depths. The cores from west to east across the Appalachian basin have increasing VRo (1.21 to >2.0 %), depths and thicknesses, along with changes in clay composition and redox environment. Each core has a decreasing upwards trend in total organic carbon and multiple organic-rich units. Examination of spectral GR logs (U, Th/U, and Th/K ratio), cores and thin sections were used to determine vein composition and crystal morphology related to kerogen maturation, vein orientation, abundance, and length. Veins were classified based on angle to bedding: horizontal, horizontal swarm, oblique, and vertical.

Bitumen and calcite were the main vein composition, where calcite cement morphologies include fibrous and granular calcite. Horizontal fibrous calcite veins with bitumen inclusions throughout the vein width and along inclusion bands formed during early oil generation. Granular calcite formed during the peak oil window because it mainly occurred between fibrous calcite veins with vertical orientation; contained a plethora of bitumen inclusions giving it a dark color in comparison the adjoining white fibrous calcite; and developed when partially cross-cutting bitumen veins supplied fluids. Vein abundance increased with increasing thermal maturity, while redox condition became more cyclical and clay type became less illitic across the Appalachian basin. Horizontal/horizontal swarm bitumen and fibrous calcite veins dominate the westernmost well, whereas eastward vertical bitumen and calcite veins containing fibrous and granular crystals increase. Based on calcite and bitumen vein abundance and length, fractures propagated from the lower organic-rich units to upper units, thereby promoting hydrocarbon migration throughout the shale. Natural fracture studies provide insight to shale as a store for carbon-dioxide.

Effects of an igneous intrusion on the Devonian Millboro Shale, Sugar Grove, West Virginia

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The Devonian Millboro Shale crops out near Sugar Grove, West Virginia, where an Eocene basalt sill-dike complex intruded the shale. We collected seventeen samples along a 100-foot transect to the south of the intrusion, starting at the center of the intrusion and moving out into the surrounding shale. Seven of the samples were collected within the first ten feet of the transect, and the remainder were collected at ten-foot intervals. Petrographic and scanning electron microscopy were used to characterize shale mineralogy, texture, diagenetic/alteration features, and reservoir quality as a function of distance from the intrusion.

Avary and Dennison (2013) describe a phyllitic sheen within a three-foot zone of the intrusion caused by contact metamorphism. We observe slate between three and ten feet, followed by shale containing alteration features for the remainder of the outcrop. For all samples, SEM results indicate the presence of period 3 and 4 elements (e.g., aluminum, calcium, potassium) in addition to an expected abundance of silicon and oxygen. Yttrium, thorium, titanium, and phosphorus were also present within the first five feet of the phyllite and slate surrounding the intrusion.

Pyrite framboids, veins, and organic material are ubiquitous throughout the samples. Within the first ten feet immediately south of the intrusion/Millboro contact, 1) euhedral pyrite occurs, 2) vein frequency is higher, and 3) bedding/laminations are not observed. The framboids show signs of deformation and alteration within a 40-foot zone of the contact. Further understanding these features will provide insight into alteration processes caused by

the intrusion, as well as effects of Appalachian Basin intrusions on organic-rich shale reservoir quality.

Mapping update of the Middle to Upper Ordovician Black River Group to Utica Shale interval, Ohio

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As part of a study to characterize the Point Pleasant/Utica Play for potential EOR in Ohio, the Ohio Geological Survey remapped, in stratigraphic order, the Middle to Upper Ordovician Black River Group; Trenton Limestone; the Curdsville, Logana, and upper Lexington members of the Lexington Limestone; Point Pleasant Formation; and Utica shale. This study used 1,033 wells to map the interval.

The structure contours for each mapped unit roughly parallel each other. Variations in dip for each surface are primarily a result of differing thicknesses of each unit. Structural features common to each unit are a low associated with the faults bounding the Bellefontaine Outlier and a north-plunging anticline east of the Bowling Green Fault.

The isopach map of the Curdsville Member show that it is continuous with the basal Trenton Limestone across the region. The Logana Member is more shaley, it thins and becomes indistinguishable from shales in the Sebree Trough, while cleaner carbonates continued to be deposited on the Trenton and Galena shelf. The upper Lexington Member thins in the Utica/Point Pleasant sub-Basin and pinches out in the Sebree Trough. The combined Trenton/Lexington isopach shows the axis of the Sebree Trough and some localized structural thickening of the interval. The Point Pleasant Formation is thickest in southern Ohio and is not continuous across the Sebree Trough. The Utica shale is thickest along the Sebree Trough and pinches out along the northern margin of the Lexington Platform. The isopach maps of the interval show the shales of the Point Pleasant were deposited in low-energy areas while carbonates were deposited in higher-energy areas and during higher-energy events. As the basin evolved, the low-energy Utica shale was deposited over the Trenton Limestone and Point Pleasant Formation.

New maps showing dolomitization extent and mineralogical brittleness index in the Utica Shale, Point Pleasant Formation, and Lexington Limestone in Ohio

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To facilitate enhanced oil recovery (EOR) in the oil-bearing Utica shale/Point Pleasant formation, the Ohio Geological Survey performed an assessment of the Utica/Point Pleasant interval in Ohio. This project included quality controlling and using source rock and geochemical data from previous studies in new ways. This poster focuses on a new map of percent dolomitization of the Utica shale through Lexington/Trenton limestones (undifferentiated) and mineral brittleness index (MBI) maps of the Lexington/Trenton limestones, Point Pleasant formation, and Utica shale.

X-ray diffraction data from previous studies was compiled, quality controlled, and assigned to the three geological units. The percent of dolomitization of total carbonate material within each unit was averaged for each well and mapped using Esri ArcGIS. These data indicate that dolomitization was minor throughout the eastern half of Ohio (3–15%), with regions of higher dolomitization (20–45%) localized to basement faults. Dolomitization generally increases westward, where much of the dolomitization occurred along extensive basement faulting in northwestern Ohio.

MBI was calculated and mapped for the three units within each well. Several brittleness trends are consistent from Lexington deposition to Point Pleasant deposition. One is the north–south high-brittleness zone in central Ohio. In the Lexington, this zone extends from Pickaway and Hocking Counties in the south to Huron County in the north. During Point Pleasant deposition, this trend was reduced and extended northwards into Richland County. High brittleness values in this trend are reduced further to only Pickaway County in the Utica shale. Another area with consistent MBI values in each formation is eastern Washington County (eastern Ohio), which shows low brittleness values in both the Lexington and Point Pleasant maps. In general, brittleness in the Utica is uniform (0.45-0.55) across the study area, except for high values in Pickaway County and northeastern Harrison County (eastern Ohio).

Regional correlation and depositional history using well log and core data of the Middle Devonian Marcellus Poseidon 8M Well, Westmoreland County, PA, USA

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Natural gas producers have invested billions in Pennsylvania Ohio and West Virginia to establish significant gas production from the Marcellus Shale and the deeper Ordovician Utica-Point Pleasant intervals. The Marcellus Shale is the largest natural gas play in the United States producing and together with the Utica-Point Pleasant account for more than 28% of current total US gas production. Commercial gas production has been reported from several other Devonian shale units in the Appalachian region, including the Rhinestreet, Levanna and Geneseo-Burket units. However, these younger and shallower shale units remain underdeveloped and represent future opportunities.

The Geneseo-Burket shale similar to the Marcellus is one of the most highly radioactive and organic-rich of the Devonian shale units, yet little is in the public domain as to its stratigraphic distribution, depositional history, geomechanical properties, and geologic controls on gas production.

The main objective of the research is to examine the geologic characteristics of the Geneseo-Burket Shale from wells in southeast Pennsylvania and northern West Virginia. A complete core of the Geneseo-Burket from a well in Westmoreland County, Pennsylvania is integrated with CT-scans, geochemical data and well logs. The results provide an improved understanding of the lithology, vertical and regional depositional patterns, contacts with the underlying Tully Limestone and overlying Penn Yan Shale, the stratigraphic distribution across the Appalachian basin and ultimately the potential resources.

Statistical and economic assessment of rare earth elements in West Virginia Coals

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Rare earth elements (REEs) are critical to essential technologies, including those used for renewable energy production, communication, transportation, and national defense. Recent research has suggested that specific coal seams and coal byproducts are enriched in these elements and may be a promising resource due to an abundance of domestic supply and pre-existing mining infrastructure. With one of the largest coal reserves in the country, West Virginia can play a key role in maintaining the nation's supply of REEs. However, to identify economically viable reserves and develop efficient extraction techniques, it is important to understand patterns of occurrence and concentration of REEs in different coal seams. Additionally, understanding statistical relationships between REE concentrations and potential predictor variables can reduce the need for expensive laboratory analysis of the full suite of elements when quantifying resources within seams. We utilized coal chemistry data from the U.S. Geological Survey's CoalQUAL database to help identify viable REE reserves and gain insight into elemental and mineral relationships that can enhance prediction and extraction of rare earth elements in West Virginia coals. Linear regression was used to evaluate the relationship between light, medium, heavy, and total rare earth content and proxies for the mineral fraction of coal, including ash yield and aluminum. Regression was also used to assess the suitability of using yttrium, thorium, and aluminum as predictor variables to estimate rare earth concentrations. Results indicate that the strength of these statistical relationships varies between coal seams. The proportion of economically promising samples and their spatial distribution will be evaluated on a seam-by-seam basis to assist in developing West Virginia coal reserves as a resource for REEs.