Regional Correlation and Depositional History using Well Log and Core Data of the Geneseo-Burket from the Poseidon 8M Well, Westmoreland County PA, USA

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Regional Correlation and Depositional History using Well Log and Core Data of the Geneseo-Burket from the Poseidon 8M Well, Westmoreland County PA, USA

Spencer Williams

Thesis submitted
To the Eberly College of Arts & Sciences
At West Virginia University

In partial fulfillment of the requirements for the degree of
Master of Science in
Geology

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Morgantown, West Virginia
2021

Keywords: Geneseo Formation, Marcellus Formation, Natural Gas, Well Log Analysis, Core Analysis

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Abstract

Regional Correlation and Depositional History using Well Log and Core Data of the Geneseo-Burket from the Poseidon 8M Well, Westmoreland County PA, USA

Spencer Williams

Natural gas producers have invested billions of dollars in Pennsylvania and West Virginia to establish significant gas production from the Devonian Marcellus Shale and the deeper Ordovician Utica-Point Pleasant interval. In addition, commercial gas production has been reported from several other Devonian shale units in the Appalachian region, including the Rhinestreet, Levanna, and Geneseo-Burket. The Marcellus Shale is the largest natural gas play in the United States. The Marcellus is located directly under the Mahantango and Tully Limestone formations with a gross thickness of organic-rich shale in the subsurface from less than 10 feet in eastern Ohio to around 100 feet in north-central West Virginia and several hundred feet in central and northeastern Pennsylvania.

The Geneseo-Burket shale is similar to the Marcellus as one of the most highly radioactive and organic-rich of the Devonian shale units, yet little is known of the stratigraphic distribution, depositional history, and gas production. In the future, the Geneseo-Burket could be an explicit exploration target.

The main objective of this research is to examine the geologic characteristics of the Geneseo-Burket shale that will ultimately allow an assessment of the depositional history, the stratigraphic distribution across the basin and ultimately the potential hydrocarbon resources.

This study uses several well logs to conduct a petrophysical evaluation of the Geneseo-Burket shale, primarily located in West Virginia and Pennsylvania. The contact of the Geneseo-Burket shale is examined with the underlying Tully Limestone and the overlying contact with the Lodi Limestone and organic-lean Penn Yan Shale. These contacts are compared to a similar and more widely examined stratigraphy located deeper in the subsurface between the organic-rich Marcellus Shale and the overlying organic-lean Mahantango Shale and underlying Onondaga Limestone. In this research we find that in the Poseidon 8M well, the organic-rich Geneseo-Burket shale is similar in mineralogy to that of the Marcellus Shale, and may be the result of geochemical changes in the water column.
Acknowledgements

I would like to thank my advisor, Dr. Timothy Carr, who has supported me and had a massive influence on my thinking and who has worked extensively with me in my studies of the Appalachian Basin. What an incredible experience it has been to be a part of your research group. I would also like to thank my committee members Drs. Dengliang Gao and Jaime Toro for advice and support throughout this process. Thank you to Olympus Energy for donating the Poseidon 8M well core and log data, and to MSEEL for contributing log data that was used extensively throughout this research.

Lastly, I am grateful for the advice and friendship of my research lab group members and WVU’s Department of Geology and Geography whose insights and critique have made me more competent in my studies.
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1.0 Introduction

The Appalachian basin is an elongated depression in the crystalline basement complex, which contains a great volume of predominantly sedimentary rocks. The Geneseo-Burket is a Middle Devonian black shale of the Genesee Group that overlies the Tully Limestone and Hamilton Group. The Hamilton Group includes the organic-rich Marcellus Shale with its prolific gas production (Figure 1). The Burket Formation is the stratigraphic term used over most of Pennsylvania and West Virginia, while the Geneseo black shale member of the Genesee Group is used in northeast Pennsylvania and southern New York. The Burket Shale member of the Harrell Formation in Pennsylvania is correlative to the Geneseo Shale of the Genesee Formation (Group) of New York (Butts, 1918). The Geneseo-Burket contains an Upper Givetian conodont fauna characterized by the *disparilis* Zone, which places it in the Middle Devonian (Over, 2007). The Burket and Geneseo are lithologically similar and occupy the same stratigraphic position above the Tully Limestone (de Witt et al., 1993). For this study, the unit is referred to as the Geneseo-Burket shale.

The distribution and depositional controls on the Geneseo-Burket shale is poorly known. Although it is producing from several wells in southwest Pennsylvania and north-central West Virginia, it is currently unclear the degree to which the Geneseo-Burket shale is prospective as a major gas-shale resource. The Geneseo-Burket extends throughout the northern Appalachian basin and thicknesses can exceed 150 feet in eastern Pennsylvania.

Natural gas producers have invested billions in Pennsylvania and West Virginia to establish significant gas production from the Marcellus Shale and the deeper Ordovician Utica-Point Pleasant intervals. In addition to the Geneseo-Burket, commercial gas production has been reported from the various Devonian shale units of the Appalachian basin, including the Rhinestreet, and Levanna (Van Tyne, 1983). Natural gas is an essential US primary energy resource for electric generation, chemicals, and direct use (e.g., space heating). Since the natural shale gas boom began in 2007, the Marcellus Formation has proven to be the largest producer of dry shale gas (EIA, 2021, Figure 2). Marcellus production took off after 2011 and current U.S. shale gas production is just over 75 billion cubic feet per day (Bcf/d). In October 2021, the Marcellus Shale is producing nearly 25.4 Bcf/d double that of the second most productive shale
gas play, the Permian Basin (EIA, 2021). Also located within the Appalachian basin is the deeper Utica Formation, which is the third highest producing unit of shale gas in the United States at (7.1 Bcf/d). The two Appalachian basin shale gas reservoirs combined produce almost 43.2% of total US shale gas production.

![Devonian Stratigraphy](image)

**Figure 1** - Devonian stratigraphy with examined cored interval from Poseidon 8M well displayed in red box.

The Marcellus is located directly under the Mahantango and Tully Limestone formations with a gross thickness of organic-rich shale in the subsurface of less than 10 feet in eastern Ohio to around 100 feet in north-central West Virginia, and several hundred feet in central and northeastern Pennsylvania.

The Geneseo-Burket shale is similar to the Marcellus as it is one of the most highly radioactive and organic-rich of the Devonian shale units. However little of the stratigraphic distribution, depositional history, and gas production is known where the Geneseo-Burket could be an explicit exploration target. Based on data from the West Virginia Geologic and Economic Survey (WVGES, 2021), in West Virginia only 27 horizontal wells were completed in the Geneseo-
Burket while 3,122 wells horizontal wells were completed in the Marcellus Shale (Table 1). As normalized per 1,000 feet of lateral, the average Genesee-Burket well does not appear to have as high of the gas production as the Marcellus and dwarfed by the Utica (Table 1). However, the shallower Genesee-Burket does produce significant quantities of gas and liquids (oil and natural gas liquids).

**Table 1** - Horizontal shale gas wells completed in West Virginia from the Genesee-Burket, Marcellus, and Utica. Average production is only for wells reporting gas or liquids (oil and natural gas liquids) production in 2020. Data acquired online from the WVGES (2021).
The main goal of this research is to examine the geologic characteristics of the Geneseo-Burket Shale that will ultimately allow an assessment of the depositional history, the stratigraphic distribution across the basin and ultimately the potential resources.

I examined the contacts of the Geneseo-Burket with the underlying Tully Limestone and the overlying transition to the organic-lean Penn Yan Shale. The well and core of this study is from the Huntley and Huntley Poseidon 8M well is located in Westmoreland County, Pennsylvania. To execute this study, I used a variety of data including: the integration of logs CT Scans, XRD data, and thin sections, in order to understand depositional and environmental changes. Stratigraphy, TOC values, and other parameters have been utilized to better characterize the Geneseo-Burket shale and to better understand the depositional environment processes.

Detailed descriptions, characterizations, and stratigraphic analysis of the Geneseo-Burket and adjoining units are largely not available. The study is an effort to shed light on an otherwise (or historically) overlooked and undervalued shale unit in the Appalachian basin. This study will discuss core descriptions, estimate TOC values from the logs, and tie it to core data. I will also utilize the Schmoker equation to extrapolate TOC values in other wells and execute a regional analysis and correlation across the basin. Geomechanics of the Poseidon 8M well will be considered as well. In addition, a comparison of the Penn Yan/Geneseo-Burket/Tully and the Mahantango/Marcellus/Onondaga sequences discusses the differences and similarities in mineralogy and hydrocarbon production potential will be addressed. Having the opportunity to explore, analyze, and add to general information about the Geneseo-Burket section of the core in the subsurface is exciting because it is new and widely uncharted territory.

1.1 Geologic Background

The stratigraphic units on the surface of western New York including the organic-rich Geneseo-Burket and Tully Limestone have been discussed in detail by numerous authors (e.g., Grabau, 1917; Heckel, 1966; de Witt and Colton, 1978; Ettensohn, 1985) (Figures 3, 4, and 5). The basal Tully Limestone characterizes the base of the depositional sequence (Figure 2). A sequence-bounding unconformity and flooding surfaces has been described capping the limestone and succeeded by dark shale-dominated strata of the Geneseo-Burket that coarsen upward to the base of the overlying sequence (Ver Straeten and Brett, 1995). The Tully Limestone is one of two
major carbonate units in the Devonian clastic wedge, the other being the Onondaga Limestone. In general, the Tully is a dark gray to black, fossiliferous limestone, composed of lime silt and fine mud. The grains of non-uniform shape and size, along with their mono- and polycrystalline structures, were interpreted as skeletal lamellae (Heckel, 1966). Postulated synorogenic structures were interpreted to prevent the elastic influx from overwhelming the carbonate shoal with westward thinning of the Tully, and increasing shale content in the south, suggesting the lime mud was derived from an algal or coral reef in the north (Heckel, 1966). The interval characterized by deposition of the Tully Limestone terminated in the western basin by either lack of sedimentation or subsequent uplift and erosion.

**Figure 3** - Middle and Upper Devonian stratigraphy of western New York, showing major black shale units. The Geneseo Shale would be the equivalent of the Geneseo-Burket interval used in this study (Van Tyne, 1983).
The organic-rich deposits of the Geneseo-Burket overlie the Tully Limestone throughout the basin. The Geneseo-Burket shale is primarily composed of grayish-black, brownish-black, and black shale and dark-medium gray, laminar to wavy bedded siltstone layers that range from 0.25-10 inches occur sparingly. The number of siltstone beds in the Geneseo-Burket has been reported to increase towards the east in the vicinity of Keuka Lake, NY (de Witt and Colton, 1978). The unit grades upward into a prograding wedge of deltaic clastic deposits. Previous surface maps (de Witt and Colton, 1978) indicate that the Geneseo-Burket thickness ranges from 130 ft (39.6m), near Cayuga Lake, to 44 ft (13.4m) in western New York. East of Cayuga Lake, the Geneseo-Burket interfingers the Tully Limestone in a zone that increases in thickness up to 15 ft (4.6m). This zone consists of 1 to 6 inches of brownish-black, slightly calcareous shale beds, intercalated with 3 to 18 inches of argillaceous, brownish-black nodular limestone beds (de Witt and Colton, 1978). In contrast, the Geneseo-Burket lies uncomfortably above the Tully in the west (Ettensohn, 1985). Overlying the Geneseo-Burket is the Lodi Limestone followed by the Penn Yan Shale (Figure 4). In New York, the Lodi Limestone consists of silty argillaceous limestone nodules intercalated in calcareous argillaceous siltstone (deWitt and Colton, 1978). The Penn Yan Shale can directly overlie the Geneseo Burket in outcrops across New York and is reported as a slightly silty mudrock and shale with scattered beds of brownish-black iron stained shale and argillaceous limestone nodules and scattered calcareous and argillaceous layers (deWitt and Colton, 1978). Very little is known of the distribution of the Geneseo-Burket and associated units in the subsurface of western Pennsylvania and north-central West Virginia and eastern Ohio, and is one of the subjects of this research.
The Middle-Upper Devonian black shale units, including the Marcellus and Geneseo-Burket have been interpreted as a direct manifestation of the Acadian Orogeny (Ettensohn, 1985). Pulses of crustal loading have been interpreted as the cause rapid subsidence, which coupled with eustasy led to deposition of organic-rich black shale in four stages (Figure 5) (Ettensohn, 1985). The first stage was initiation of tectonic loading and formation of a basin through rapid
subsidence. These shale units are interpreted as deposited in a deep basinal setting characterized as a transgressive systems tract. Stage 2 was characterized by southern migration of deformation and a decrease in subsidence rate along the eastern and western side of the basin (Ettensohn, 1985). This deposits a regressive systems tract and clastic influx increases. During stage three, additional collision and widespread uplift creates a regional disconformity in association with a peripheral bulge (Ettensohn, 1985). Stage four consists of a period of tectonic quiescence with widespread carbonate deposition. In the absence of stage four, the depositional cycle returns to stage one (Ettensohn, 1985). The Middle and Late Devonian are divided into four intervals called tectophases (Ettensohn, 1985). The Needmore and Esopus black shale units, as well as the Oriskany Sandstone (Figure 5) represent the first interval. The second tectophase is represented by the Hamilton Group, which is composed of the Marcellus and other siltstone and shale units along with the Onondaga Limestone (Figures 4 and 5). The Tully Limestone, which directly underlies the Geneseo-Burket, is representative of the last stage in the second tectophase, while the Geneseo-Burket marks the beginning of the first stage of the third depositional cycle (Ettensohn, 1985). This third tectophase began with stage one, where tectonic loading was reinitiated. This stage is interpreted as characterized by the organic-rich black Geneseo-Burket shale and is related to a period of global transgression and cratonic submergence (Sloss and Speed, 1974; Johnson, 1970; Baird and Brett, 1986).
Figure 5 - Four tectophases associated with black shale deposition (Ettensohn, 1994).

The application of sequence stratigraphic methods to basin evolution studies permits chronostratigraphic subdivision of the rock record into cyclic, unconformity bound, genetically related, successions of strata (Van Wagoner et al., 1988). A depositional sequence is the fundamental unit of sequence stratigraphy. They are coherent packages of strata that are bound at the bottom and top by unconformities or their correlative conformities (Mitchum et al., 1977). Sequences are formed by cyclic changes in relative sea level through interaction of tectonics, eustasy, and sedimentation (Allen and Allen, 1990).

They are divided into system tracts: Lowstand (LST), Transgressive (TST) and Highstand (HST), composed of smaller sequences (parasequences) deposited during a transgressive-regressive cycle. A transgressive-regressive cycle (T-R cycle) is characterized by sedimentary
rocks deposited during the time between the beginning of one relative deepening event and the beginning of the next (Johnson et al., 1985). Twelve post-Lochkovian T-R cycles have been recognized and dated using standard conodont zonation. Evidence from three midcontinent areas demonstrates that these relative deepening events are simultaneous in several or all of the following five regions: western US, western Canada, New York, Belgium, and Germany (Johnson et al., 1985). The Genesee Group including the Geneseo-Burket shale and underlying Tully Limestone belong to a TR cycle (Johnson, 1985). Surfaces most beneficial to identifying depositional and T-R sequences are subaerial unconformities, shoreface ravinements, and the maximum flooding surface (Embry 2002). The marine flooding surface defines the change from the TST to the regressive system tract (highstand systems tract), which is not necessarily a record of the base level maximum. Base level rise-induced transgressions are characterized by associated increased accommodation space, reduced clastic influx and changes in water chemistry, and may correspond with a condensed section (Emery and Myers, 1996; Van Wagoner et al., 1988; Partington et al., 1993).

Condensed sections are spatially extensive, can have high total organic carbon (TOC) and authigenic/diagenetic minerals such as phosphatic, glauconitic, or pyritic material (Sarg 1988; Liro et al 1994; Emery and Myers, 1996). Transgressive system tract deposits, especially the condensed section, have significant source rock potential (Emery and Myers, 1996; Vail, 1987). The reduced clastic flux that is associated with a base level high favors concentration of oil-prone organic matter (Creaney and Passey, 1990).

In this study, a sequence stratigraphic framework is adopted to investigate the regional variation of the Geneseo-Burket and adjacent formations. This will include a cross section of other surrounding wells in the region to show trends and common occurrences in this section of the Appalachian. In this model, I will be primarily using log signatures such as bulk density and gamma ray to describe and identify depositional sequences, their associated system tracts and sequence boundary surface developments.
2.0 Methods and Materials

The project integrates a core study and with log analysis for the Poseidon 8M well in County Pennsylvania. The Poseidon well was placed within a regional framework using select available wells across Pennsylvania, West Virginia, and Ohio. Specific logs were incorporated into the core study, in addition to CT scans, thin sections, and core photos logs. Fracture characterization and geomechanics were grouped to better visualize the properties at play in the Poseidon 8M well.

2.1 Available Geophysical Logs

Several geophysical well logs are used to evaluate the petrophysical characteristics of the Geneseo-Burket shale, including resistivity, sonic, neutron porosity, gamma ray, and density logs. Table 1 below shows the data that we have available for not only my study well, Poseidon 8m, but for several surrounding wells for the purpose of building a regional correlation.

Table 2 - Available data from the Poseidon 8M well in addition to the data from the pre-existing wells covering the Burket-Geneseo selected for study.

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*Spectral Gamma Ray Log* - In the early 20th century, geologists began using natural gamma ray logging in formation evaluations for hydrocarbon recovery when it was recognized that natural gamma ray peaks vary with lithology. Natural gamma ray spectrum logging devices and total gamma ray are used to record potassium, uranium, and thorium. Natural gamma ray logging devices are scintillation spectrometers used to find and measure natural gamma ray readings. When determining the elemental concentrations of K, U, and Th, one uses gamma ray count rates...
from multiple energy windows. Usually, these measured concentrations are corrected for the effects of spectral interference and Compton scattering. Other methods for filtering data are also used. Natural gamma ray logging devices have many uses. They can be individually run or in combination with neutron, compensated neutron, or density.

Organic-rich, black and gaseous shales are very radioactive. These shales are important because they are potential source rocks. Their high hydrocarbon output potential is due to natural fractures systems in the otherwise impermeable rock. Typically, these natural fracture systems are found in interbedded, brittle, calcareous, cherty, or silty regions. Calcareous and silty zones are characterized by the log values of potassium and thorium. However, large amounts of uranium are easily located with natural gamma ray logs.

Typically, radioactivity of a formation is measured using gamma ray logs. We know that there are specific gamma ray intensities that occur frequently for each major sedimentary rock class. Generally, shale will have higher gamma ray values than sandstone and limestone. Natural gamma ray spectrum logging devices, in addition to total gamma ray counts, record the individual contributions of potassium-40 isotope, uranium series nuclide, bismuth-214, and thorium series nuclide, thallium-208. The gamma ray signature in the Geneseo-Burket formation is obvious in well logs because it usually exceeds 180 API units. Moreover, a gamma ray spectrum method show that in organic-rich black shale variations in uranium correlate best with variations in the total gamma ray count and total organic content (TOC).

To explain, In the Geneseo-Burket interval in Allegany County, NY the gamma ray spectral log response displays high uranium concentrations (Figure 6). Organic compounds in a rock play a large role in uranium accumulation (Fertl and Chilinagar, 1988). Several factors, including carbonate content, sedimentation rate, and primary uranium content of sea water govern the precipitation of uranium from sea water onto the surface of organic particles under anoxic or euxinic conditions. Marine shale usually contains 15-60 ppm of uranium. Depending on the formation, excessive amounts of uranium are found in the rocks containing the most organic matter (McKelvey and Nelson, 1949). Therefore, gamma ray logs are used as a gage to estimate organic richness in Devonian shales.
Figure 6 – Spectral gamma ray log across the Geneseo-Burket shale from Allegany, NY showing association of uranium, potassium, thorium to total gamma ray. The highly fractured zone is associated with high uranium concentrations. Figure modified from Fertl and Chilingar (1988) with the addition of stratigraphic nomenclature used in this study.

Density Log and Total Organic Content. To measure the overall formation density, we use bulk density logs. Solid matrix and fluid enclosed pores are typically used to take formation density measurements. The Geneseo-Burket interval is characterized by a number of low bulk density layers. If the bulk density relies on fluid density and matrix density, then the porosity is inferred. Other attributes of the Geneseo-Burket shale that affect bulk density include organic matter and pyrite. Often highly, organic-rich intervals will have a density less than 2.6 gm/cc due to the presence of lighter kerogen (1.0-1.2 gm/cc) intermixed with higher density matrix such as quartz (2.65 gm/cc) and/or carbonate (2.71 gm/cc). A porosity curve (derived from sonic, bulk density, neutron porosity) cannot be exclusively used to estimate organic richness, because it is impossible to distinguish the porosity response from the organic matter response, without assuming constant porosity throughout the interval. (Passey et al., 1990). If we wish to make quantifiable total organic carbon estimations, measured TOC must be ready to be calibrated. The corresponding porosity may be calculated when the volume of organic matter is calculated, and the correct bulk density is retrieved.
The significance of organic content in gas production is supported by the common division of shale into black and gray facies (Schmoker, 1980). The darker shales, with higher organic content are usually more productive than the lighter (gray) shales. Organic matter is the source of natural gas in the Devonian shales (Schmoker, 1980). In addition, organic content affects the design and effectiveness of well stimulations and concentrates trace metals of economic and environmental importance. For these reasons, it is useful to examine the spatial distribution of organic matter. This was achieved previously in Ohio, Kentucky, and West Virginia using aggregated organic rich zones of the western Appalachian basin (Schmoker, 1979). Continual exploration and production in the basin over the past 30 years have led to better well control, including more wireline logs. When total organic carbon (TOC) is present in a formation it is a signal that influences the probability of natural gas availability in organic rich shales and other rocks (Passey et al., 1990). This is why TOC logs are often used to determine the availability of hydrocarbons in a well. LECO carbon analyzer system methods and other pyrolysis equipment are frequently used to measure TOC. In this study TOC analysis was conducted previously by an outside laboratory (WVDG). This lab used LECO carbon analyzer system and the ROCKEval 6 programmed-pyrolysis (Schmoker, 1979) to create a means of calculating total organic carbon. This method uses density logs to determine organic content in Devonian black shales. The equation (using density, ρ) for calculating TOC is:

\[
TOC \text{ (wt\%)} = \frac{154.497}{\rho} - 57.261,
\]

Full-wave Form Sonic Logs and Geomechanical Moduli. Geomechanics is the study of how subsurface rocks deform or fail in response to changes of stress, pressure and temperature a vital part of drilling and completion process (geoexpro.com). Due to the need to enhance through fracture stimulation permeability in shale reservoirs, geomechanics is an essential aspect of horizontal drilling and completion in shale gas reservoirs. As the Poseidon 8m well in Westmorland, County PA was drilled numerous geochemical properties were used. Some properties that can be derived from the sonic scanner during the drilling process include Young’s Modulus (YME), Poisson’s Ratio (PR), Unconfined Compressive Strength (UCS) and Shear modulus. Young’s Modulus is generally associated with stress and strain and can be calculated with this equation.
\[ YME = \frac{\rho v_s^2 (3v_p^2 - 4v_s^2)}{v_p^2 - v_s^2}, \]

Rho (\(\rho\)) is characterized by formation density, \(v_s\) is velocity in the shear direction and \(v_p\) is velocity in the compressional direction.

Poisson’s Ratio (PR) however has no units and is defined generally as the fraction of expansion divided by the fraction of compression. PR is an elastic constant that is a measure of compressibility of material perpendicular to applied stress (E.J. HEARN Ph.D., B.Sc. (Eng.) Hons., C.Eng., F.I.Mech.E., F.I.Prod.E., F.I.Diag.E., in Mechanics of Materials 1 (Third Edition), 1997) Poisson’s ratio is calculated by the following equation.

\[ PR = \frac{v_p^2 - 2v_s^2}{2(v_p^2 - v_s^2)}. \]

**Mineralogical Logs.** We used RhoMaa-Umaa cross plots that were introduced to utilize measurements of the photoelectric index, neutron porosity, and bulk density for matrix mineral evaluation. RHOMaa is the estimate of density (RHO) of the mineral matrix (ma), where the final ‘a’ is for “apparent,” because it is estimated from the logs, and not measured from the core. RHOMaa has units of gm/cc. Umaa is the bulk photoelectric absorption (U) of the mineral matrix (ma) estimated from the logs. Umaa has units of barns/cc (kgs.ku.edu). RhoMaa is calculated using RhoZ or RhoB as the bulk density and Phia as the average density in this equation: \(RHOMAA = (RHOZ - PHIA)/(1 - PHIA)\). When calculating Umaa we use PEFZ as the photoelectric factor in the following equation: \(UMAA = ((RHOZ * PEFZ) - PHIA)/(1 - PHIA)\). When RhoMaa vs UMa are plotted against each other data points are plotted in relation to carbonate & calcite, silicate & quarts, and dolomite. When neutron porosity and density porosity logs are plotted, we can see our formations lithology quite clearly. These lithologies may include the likes of sandstone, limestone, dolomite, etc.
2.2 POSEIDON 8M CORE

A total of 737.5 ft (224.8 m) of Poseidon 8M well core was available for study, however, the core interval utilized for this study covered the Geneseo-Burkett shale and portions of the adjacent Tully Limestone and Penn-Yan Shale (Figure 1). The interval ranged from core depth of 7375 – 7608 ft (2247.9–2318.92 m), for a total of 233 ft (71.02 m). The top of the Geneseo-Burkett shale from the core is at 7560 ft, and the core ends below the top of the Tully Limestone at 7608 ft. The focus of the study is the Geneseo-Burkett shale; however, the overlying lower Penn-Yan Shale and the underlying Tully Limestone were included to determine the nature of the upper and lower contacts of the Geneseo-Burkett (Figure 1). The total thickness of core from the Geneseo-Burkett shale present in Poseidon 8M is 47.62 ft (14.51 m).

The core study focused on two main aspects: core description and integration with the well logs to understand the deposition environment of the Geneseo-Burkett shale. Core descriptions and fracture characterizations were completed based on a one linear-foot interval scale.

High-resolution gamma ray and density logging of the core at a 0.033 ft (1 cm) resolution significantly improved our ability to discriminate the lithology of thin beds, while spectral gamma ray core logging added information of the primary radioactive elements of potassium, uranium, and thorium (Figure 7). These elements determined from the spectral gamma ray log are used to improve depositional and lithologic interpretations. Locations for selected thin-sections concentrated on the upper and lower contacts of the Geneseo-Burkett with the overlying Penn-Yan Shale and underlying Tully Limestone.
Figure 7 - High resolution (0.033 ft, or ~1cm) core logs across the Geneseo-Burket interval in the Poseidon 8M including: gamma ray (API), density (gm/cc) and spectral gamma ray showing thorium (Th ppm), potassium (K%) and uranium (U ppm). Density less than 2.6 gm/cc indicates relatively high kerogen is highlighted in red, and density greater than 2.7 indicates carbonate is highlighted in blue.
3.0 Results

3.1 Poseidon Lithological Data Analysis

This section includes a series of ternary plots using the logging solutions to illustrate lithology of the Lower to Middle Devonian stratigraphic sequence (Figure 1). The sequence consists of various lithologies such as the quartz rich Huntersville Chert and carbonate-rich Tully and Onondaga limestones (Figure 8). The lithologic log solutions for the stratigraphic sequence were checked against the limited X-Ray Diffraction (XRD) data, and show reasonable congruence (Figure 9). The XRD shows that Geneseo-Burket is composed of mostly clay minerals and silicates. The XRD provides confidence in the log solutions.

This ternary diagram shows that the Geneseo-Burket shale is a quartz and clay mix (Figure 10). In general, it is more quartz than clay with a few scattered carbonate-rich intervals. Both the Geneseo Burket and Marcellus Shale units are generally composed mostly of siliceous clay, about 50% siliceous material and 50% clay (Figure 11). The Geneseo-Burket intervals plot closer to the carbonate end-member than the Marcellus. Calcite-filled fractures and other carbonates contribute to Geneseo-Burket intervals trending towards the left end of the diagram (e.g., shown in core photograph from 7594.6 to 7596.2 in the Appendix).

The Tully and Onondaga both plot closer together toward the carbonate corner of the diagram (Figure 8). The Onondaga Limestone is carbonate-heavy with about 10% clay and 10% quartz. The Tully Limestone, while still carbonate-dominated, contains more quartz and clay components than the Onondaga does. The Huntersville Chert plots at about 80 to 90% quartz with just a little bit of clay (Figure 8). The ternary plots show a clear distinction in lithology between these Lower and Middle Devonian formations. Huntersville is approximately 90% quartz, 10% carbonate, 0% clay (Figure 8).
Figure 8 - Ternary plot from wireline log data of the Lower and Middle Devonian stratigraphic sequence from the Huntersville Chert to the Penn Yan Shale in the Poseidon 8M well (Figure 1). The sequence includes the organic-rich Geneseo-Burket and Marcellus Shale units. Log minerology is plotted here showing how much carbonate, clay and quartz is contained in each formation.

Figure 9 - Ternary plot using XRD from core plugs of the Lower and Middle Devonian stratigraphic sequence from the Huntersville Chert to the Penn Yan Shale in the Poseidon 8M well. The distribution of lithologies is similar to the lithologies determined from logs (Figures 8).
Figure 10 - Ternary plot from wireline log data of the Geneseo-Burket shale in the Poseidon 8M well showing that quartz dominates with lesser amount of clay. Some log readings indicate some carbonate-rich intervals.

Figure 11 - Ternary plot from wireline log data of the Geneseo-Burket and Marcellus Shale units in the Poseidon 8M well showing that quartz and clay dominate. In both units, some log readings indicate some carbonate-rich intervals. The Marcellus Shale is slightly more clay-rich than the Geneseo-Burket.
3.2 Total Organic Carbon Analysis

The determination of total organic carbon (TOC) is an important parameter for evaluation of shale gas resources. Analyzing variations in TOC can identify zones that may have the highest log-term productivity. Various methods are employed by industry to measure total organic carbon, including pyrolysis (LECO) of core plugs, which are available from Poseidon 8M, and various well logging methods such as proposed by Schmoker (1979, 1981) using the density or gamma-ray tools. The Schmoker’s method utilizing the bulk density log to estimate TOC is plotted against the limited core plug pyrolysis data and displays a reasonable correlation (Figure 12), and follow the variations in TOC through the organic-rich and organic-lean intervals including the Geneseo-Burket and Marcellus (Figures 13, 14).

The spectral gamma-ray logs of uranium, potassium, and thorium show the same variations. With high uranium, indicating high organic rich shale also confirmed with relatively low bulk density less than 2.6 gm.cc (Figure 7).

In the Poseidon 8M, the Marcellus and the Geneseeo Burket have a similar computed mean value of TOC (3.8 and 3.6 weight percent respectively). However, the maximum value is over 10 weight percent in the base of the Marcellus versus a maximum of 6.8 weight percent in the base of the Geneseeo-Burket. In addition, the Marcellus is much thicker at 170 feet (52m) compared to only 20 feet (6m) for the Geneseeo-Burket. This may explain some of the observed higher productivity of horizontal wells in the Marcellus Shale compared the Geneseeo-Burket shale (Table 1).

3.3 Stratigraphic Patterns

It is important to note patterns and repetitive cycles that occurred during the deposition of the Marcellus and Geneseeo-Burket shale units. The first item to note is that subsurface wireline logs have relatively low resolution of 1 to 5 feet and do not show the sharp contacts at the base and top of the Geneseeo-Burket shale that are evident on the higher resolution core logs (Figure 7).
compared to Figure 13). These sharp contacts are confirmed with the core observations in section 3.5.

The general pattern of the Lower and Middle Devonian strata is a carbonate such as the Onondaga Limestone or Tully Limestone overlain by the organic-rich shale of either the Marcellus or Geneseo-Burket overlain by organic-lean shale (figures 13, 14). The surfaces on top of the carbonate units have been interpreted as unconformities marking the top of a tectonically driven cycle (e.g., de Witt and Colton, 1978; Ettensohn, 1985; Ver Straeten and Brett, 1995). Immediately above the limestone, the highest gamma ray values and highest TOC values occur at the base of both the Marcellus and Geneseo-Burket shale intervals and organic content decreases upwards through the shale (figures 13, 14). This pattern has been interpreted as a flooding surface and the initiation of progradation during high-stand deposits resulting from a tectonic or eustatic event. However, in contrast the rapid change could be interpreted as sudden onset of anoxia with a gradual return to more aerobic conditions due to chemical changes in the water column.

Within the Marcellus Shale several carbonate-rich units separating organic-rich shale occur, which in some instances have been assigned stratigraphic member designation, such as the Purcell and Cherry Valley Limestone. These carbonate-rich intervals are visible in the Poseidon 8M (Figure 14). Traditional wireline logs do not resolve internal carbonate-rich intervals in the Geneseo-Burket shale in the Poseidon 8M (Figure 13). However, the high-resolution core logs with a density greater than 2.71 gm/cc strongly suggest a carbonate-rich interval separating two organic-rich shale intervals with high uranium content (Figure 7 at 7492 ft core depth).

Finally, the Marcellus and especially the Geneseo-Burket shale units are capped by a more carbonate rich interval indicated by bulk density greater than 2.7 gm/cc (Figures 7, 13, 14). In the case of the Geneseo-Burket, this interval could be interpreted as the Lodi Limestone member, which is observed in New York outcrops (Figures 4, 6). The overlying organic-lean shale units of the Mahantango and Pen Yan show relatively low TOC with thin carbonate and slightly organic enriched intervals (e.g. 7562 ft in Figure 7).
Figure 12 - Cross-plot of total organic carbon (TOC) measured from Poseidon 8M core samples by LECO pyrolysis versus TOC estimated from density log using the Schmoker equation (1979). Measured correlation is 0.733. Differences are potentially the result of core to log shifts and sample resolution.
Figure 13 - Wireline logs through from the upper Tully Limestone through the Geneseo-Burket shale, the limestone interval designated the Lodi Limestone, and into the lower Penn Yan Shale. The logs include: gamma-ray (Track 1), bulk density, density and neutron porosities (Track 2), computed TOC using Schmoker (1979) from bulk density and TOC from core plugs (Track 3), and mineralogy generated from pulsed-neutron well logs (ELAN) (Track 4).
Figure 14a - Wireline logs through from the upper interval from above the Mahantango Shale and Marcellus Shale contact to 7960. The logs include gamma-ray (Track 1), bulk density, density and neutron porosities (Track 2), computed TOC using Schmoker (1979) from bulk density and TOC from core plugs (red dots) (Track 3), and mineralogy generated from pulsed-neutron well logs (ELAN) (Track 4).
Figure 15 – Continuation from 7960 in the Marcellus Shale to just below the Marcellus Shale and Onondaga contact. The logs include gamma-ray (Track 1), bulk density, density and neutron porosities (Track 2), computed TOC using Schmoker (1979) from bulk density and TOC from core plugs (Track 3), and mineralogy generated from pulsed-neutron well logs (ELAN) (Track 4).
3.4 Fractures and Geomechanics Interpretation

The compressional-wave and shear-wave travel time sonic logs were used to generate Young’s Modulus (YME) and Poisson’s Ratio (PR) from the upper Onondaga Limestone through the Marcellus and Geneseo-Burket shale units and ending in the lower Penn Yan Shale (Figure 15). The two moduli were cross-plotted using the approach proposed by Grieser and Bray (2007). Plotting YME vs PR crossplot gives a graphical representation of regions of rock brittleness and malleability, which often is labelled as ductility in the literature (Figures 16 – 19).

The Geneseo-Burket overall has a low YME and PR values and is similar to the Marcellus Shale (Figures 15 and 18). While the Tully, Onondaga, and Huntersville have high (> 6 GPa) YME and low to mid PR values (Figure 15 and 16). Plotting YME against PR (Figures 17 and 18) shows that the Geneseo-Burket shale interval primarily falls within the weak brittle region, while the Tully, Onondaga, and Huntersville fall within the strong region in the top half of the graph (Figures 16 and 19). The upper Marcellus has a greater range of YME/PR values than the middle and lower Marcellus. The Huntersville is the most isolated/grouped formation, falling completely within the strong-brittle region. The Onondaga is less tightly clustered but stays within the top half (> 6 GPa) of the graph. The Onondaga could be more variable because it has a transitional contact with the Marcellus; the shale could be giving some of the lower PR values.

The Onondaga is less tightly clustered but stays within the top half (> 6 GPa) of the graph. The Onondaga could be more variable because it has a transitional contact with the Marcellus; the shale could be giving some of the lower PR values.

The Huntersville Chert is the most isolated/grouped formation, falling completely within the strong and brittle region. It has been noted that in the absence of the Onondaga Limestone, which occurs south of central West Virginia, it is relatively easy to have uncontrolled fractures due to stimulation travel downwards into the formation and reach the saline aquifer (Peter Sullivan, pers. comm.). The carbonate-rich lithology in the Poseidon 8M of the Tully and Onondaga, and possibly even Lodi limestone intervals can explain why they form a good fracture barriers (Figure 20). The Poisson’s Ratio for the Tully and Onondaga is high; meaning the Onondaga generally should exhibit more ductile/malleable characteristics (Figure 19). While the higher
Young’s or elastic modulus signifies an overall rock “toughness.” An analogy would be trying to fracture a tire as opposed to a relatively brittle but strong material such as wood.

**Figure 16** – Addition of geomechanical logs to logs included in Figure 7. Interval is from the upper Huntersville Chert through the organic-rich Marcellus and Genesee shale units into the lower Penn Yan Shale. Logs include Young’s Modulus (YME) and Poisson’s Ratio (PR) (Track 6) generated from the compressional-wave and shear-wave travel times from sonic logs (DTCO and DTSM – Track 5).
Figure 17 - Crossplot of Young’s Modulus (YME) and Poisson’s Ratio (PR) for all the units from the Huntersville Chert through the organic-rich Marcellus and Geneseo shale units into the lower Penn Yan Shale. Showing the weak-strong and brittle-malleable axes defining quadrants modified from Grieser and Bray (2007).

Figure 18 - Crossplot of Young’s Modulus (YME) and Poisson’s Ratio (PR) with the Geneseo-Burket organic-rich shale unit highlighted. The Geneseo-Burket shale plots
mainly in the weak and brittle region, and it should be relatively easy to fracture stimulate. Showing the weak-strong and brittle-malleable axes defining quadrants modified from Grieser and Bray (2007).

**Figure 19** - Crossplot of Young’s Modulus (YME) and Poisson’s Ratio (PR) with the Geneseo-Burket and Marcellus organic-rich shale units highlighted. The Geneseo-Burket shale has a slightly higher YME and PR than the Marcellus Shale. Both units should be relatively easy to fracture stimulate. Showing the weak-strong and brittle-malleable axes defining quadrants modified from Grieser and Bray (2007).
Figure 20 – Crossplot of Young’s Modulus (YME) and Poisson’s Ratio (PR) with the Tully and Onondaga limestone units highlighted. The Tully Limestone has a higher YME and similar PR to the Onondaga Limestone. Both units should be strong barriers to inhibit fracture propagation. Showing the weak-strong and brittle-malleable axes defining quadrants modified from Grieser and Bray (2007).
**Figure 21** – The Tully and the Onondaga limestone units are lithologically similar carbonate units. The Onondaga Limestone is 80-90% carbonate while the Tully at 70-80% carbonate contains slightly more clay and quartz.

3.5 Genesee-Burket Core Analysis

After performing in depth analysis of the well core at various depths, we concluded that it would be best to integrate the log analysis data with a core assessment. The primary components of this study include gamma ray, porosity, spectral logs, CT scans and thin sections. Changes in gamma ray logs indicate shifts of natural radioactivity in formations and can identify lithologies. When shale content increases in a formation the gamma ray log response increases because of radioactive material in the shale. CT scans provide a way to make observations and measurements in a three-dimensional format. Thin sections were used to investigate the core composition and structure of sediments. Logs, core photos, CT scans and thin section images were combined to provide a visual integration of core and log analysis.
The upper Tully Limestone is a burrow-mottled carbonate mudstone (Figure 21 and Appendix) with scattered bioclasts. In the core, a very sharp contact occurs at 7600 ft between the Geneseo-Burket shale and the underlying Tully Limestone (Figure 20, Appendix A at 7600 ft core depth). In core and thin sections, we see that the surface was a carbonate hard-ground with small-scale relief on the surface, a lag composed of bioclasts, and the overlying black Geneseo-Burket shale filling in fissures in the underlying Tully (Figure 20). There is also what appears to be pyritic material that has precipitated at the contact boundary between the Geneseo-Burket and the Tully Limestone which could be caused by anoxia after the time of deposition. The sharpness of the contact is delineated by the high-resolution core logs (Figure 7), but is not as evident on the typical low-resolution wireline logs (Figure 13 at 7602 ft log depth). The gamma ray log response increases rapidly on logs from a base level of 50 API in the Tully Limestone to over 200 API. The gamma-ray response is primarily composed of uranium reflecting the organic-rich natural of the Geneseo-Burket shale (Figure 7).

Using CT scans and core photos one can see abundant pyrite in the upper Tully Limestone (bright areas in CT scan of Figure 21). Core photos also show what looks like wispy layers of shale-rich material imbedded that indicates that the Tully Limestone could be more of a limestone and shale mix (Appendix). The Tully Limestone plots in ternary diagrams as more clay-rich than the Onondaga Limestone (Figure 19). Taking a further step into the optics of this core we cut thin sections along the contact boundary that provides further visualization as to what has occurred in this core section at 7600.76 ft. In these thin sections, the sharp nature of contact boundaries are clearly visible. In addition, abundant pyrite minerals are visible. The rapid change from the Tully to the Geneseo-Burket with a surface showing relief and shale-filled fractures extending from the contact into the Tully Limestone supports an interpretation of a carbonate hardground. It is also important to note that there is an angular relationship of shale laminae and pyrite bands in the shale relative to the “flat” contact (Figure 21). Shown in the thin section photos (Figure 21) these angular bands could be caused by currents suggesting shallow water at or after the time of deposition.
The sharp contact of Geneseo-Burket with the underlying Tully Limestone indicates a carbonate hardground with small-scale relief, shale infilling the underlying Tully carbonate and a bioclastic lag at the base of the Geneseo-Burket shale.

In Figure 22, we use the same analysis components as Figure 21 as we do a log to core comparison. This is the contact of the carbonate-rich bed at the top of the Geneseo-Burket with the overlying organic-lean Penn Yan Shale. The core photos at Appendix A at a depth 7581ft shows a well-defined thin layer of limestone at the base of the Penn Yan Shale. This limestone could be interpreted as the Lodi Limestone member that in New York was deposited between the Penn Yann shale and the Geneseo-Burket shale (Figures 4 and 6). However, this unit has not been extensively recognized in the subsurface of Pennsylvania and West Virginia. This may be a result of lack of Geneseo-Burket core and high-resolution core logs. This carbonate unit is evident in core and the high-resolution logs with a density greater than 2.7 gm/cc (Figure 7 and 22). What is also visible is the sharp nature of the contacts of the organic-rich shale of the Geneseo-Burket and the Lodi Limestone with the overlying Penn Yan Shale. Additionally, there are not many minerals that are visual at this depth aside from what looks to be calcite crystals on the lower end of the core slab.
**Figure 23** – The sharp contact of the overlying Penn Yan Shale with the carbonate-rich bed assigned to the Lodi Limestone. In thin-section, the limestone interval is rich in bioclasts and a cement crust is visible at the contact.

In Figure 23, which is just 7 feet above the contact of the organic-lean Penn Yan Shale and organic-rich Geneseo-Burket shale units shown in the previous figure, gives us a look into log/core analysis the Penn Yan Shale only. At this depth organic richness continues to be on the low, as indicated by the gamma ray response, TOC log and uranium content (Figures 7, 13). CT scans show us that there are several strands of pyrite that move horizontally in the core. There is also minor horizontal lamination. Density and neutron porosity are high and similar in comparison to the porosities that we saw in Figure 21. Our thin sections indicate lamination with possible pyrite minerals imbedded and numerous bioclasts.

The high-resolution core logs clearly show the contact between the Penn Yan Shale and the Geneseo-Burket shale (Figure 7). Decreases in gamma ray especially in uranium component in the logs indicate that the Penn Yan Shale contains less organic richness then the underlying Geneseo-Burket shale.
There is a slight peak in gamma ray just above the contact line at 7570ft, which may indicate a thin organic-rich bed. There are visible horizontal lamination patterns that can be seen throughout the core along with a couple calcite filled fractures. The thin sections in this figure indicate potential fossils and/or mineral detections.

Figure 24 - Penn Yan Shale unlike the Genesee-Burket and Marcellus Shale is not very organic rich resulting in a medium-gray core. Pyritic minerals and carbonate laminations are visible at this core depth.

3.6 Regional Interpretation

The thicknesses of the Genesee-Burket in the Poseidon 8M well and seven other wells we referenced in this region are as follows: Cold Stream: 32ft, Poseidon 8m: 26ft, Whipkey: 30ft, Infinity Coastal: 20ft, Boggess 17H: 24ft, MIP-3H: 21ft, Armstrong #1: 21ft and Goff #55: 26ft. In all wells examined, the thickness of the Genesee-Burket is very consistent and almost an order
of magnitude less than the thickness of the Marcellus Shale. There do not appear to be any regional trends of change in thickness of the Geneseo-Burket across the study area. The relatively thinness of the Geneseo-Burket compared to the Marcellus could contribute to the comparatively lower production (Table 1).

Figure 25 – Regional cross-section shows the variations in thickness, the correlation that occurred between the Poseidon 8m well, and other wells in the Appalachian region
3.7 Depositional History

The Genesee Group has been described extensively in outcrop and extends from southwestern NY and western PA into eastern OH and northern WV (de Witt and others, 1993). The Genesee Formation comprises the Penn Yan Shale member, the overlying Genundewa Limestone Member, and the West River shale Member above the Geneseo shale member (Geneseo-Burket of this study). For both the Geneseo and Penn Yan shale members, the stratigraphic data that we have available is primarily from New York. This study extends the description of the Geneseo-Burket and Penn Yan to the subsurface in the Poseidon 8M located in southwestern Pennsylvania.

In outcrop, the Penn Yan consists mainly of dark- to medium-gray shale or mudrock and some beds of black shale, abundant limestone nodules, and a few thin beds of dark-gray siltstone (de Witt and others, 1993).

Genesee sediments have been interpreted as deposited in the deeper part of an epicontinental sea west of the Late Devonian Catskill Delta. The interpretation is that a euxinic environment occurred in the deeper part of the sea and the upper waters of the sea were relatively clear with high oxygen levels. During this time, depositional energy was low and only fine-grained sediments accumulated in the calm waters. Turbidites from the growing delta in west-central New York began to accumulate and intermingle with brown/black organic-rich muds. In outcrop, this region lacks evidence of fossils in the Geneseo shale member (Geneseo-Burket of this study), however in an area in the eastern part of the study area a small fauna of thin-shelled brachiopod *Orbiculoidea lodiensis* was reported. This fauna is reported in the Lodi Limestone of the uppermost beds of the Geneseo and the basal gray beds of the overlying Penn Yan shale Member.

In the Poseidon 8M located in southwest Pennsylvania, one sees a very similar pattern as described from the outcrop belt of New York State with the organic-rich Genesee-Burket overlying the Tully Limestone with a very sharp contact (Figures 3, 4 and 6). The core and high-resolution logs both show the same sharp stratigraphic contact between the Tully and Genesee-Burket, which is interpreted in the Poseidon 8M as a carbonate hardground and significant hiatus.
(Figures 7, 21 and Appendix at 7600 feet). The contact in the Poseidon 8M of the relatively thin organic-rich Geneseo-Burket with the organic-lean Penn Yan is also similar to the pattern observed in various locations across New York. This includes the thin bioclastic-rich carbonate bed labelled the Lodi Limestone. In the Poseidon 8M this upper contact is also very sharp. The high degree of stratigraphic continuity between New York outcrops and the subsurface of southwest Pennsylvania was not expected.

4.0 Discussion and Conclusions

The following conclusions are listed and discussed based on the examination of the Poseidon 8M well:

- In the Poseidon 8M, the organic-rich Geneseo-Burket shale is similar in mineralogy to the Marcellus Shale. Both units are composed mainly of quartz and clay mixture with scattered intervals of higher carbonate content. Average total organic carbon (TOC) approaches 4 weight percent in both shale units. However, the Marcellus Shale has a significantly higher TOC, approaching 12 weight percent at its base, than the Geneseo-Burket.
- The Geneseo-Burket shale shows a similar pattern to the Marcellus Shale with the highly organic-rich shale at the base. In general, the organic richness decreases upwards through both shale units. In the case of the Marcellus Shale, there are several carbonate rich units within the unit, which in some cases have been designated members (e.g., the Purcell or Cherry Valley). The high-resolution core logs suggest that the much thinner Geneseo-Burket has a slightly more carbonate-rich interval in the middle of the unit.
- The Poseidon 8M core has a well-developed carbonate hard ground at the top of the Tully Limestone that is observed in core and in high-resolution logs. The shale of the Geneseo-Burket fills fissures in the Tully and there is a well develop bioclastic lag deposit at the base. This surface is interpreted as a significant hiatus.
- Both shale units are capped by a carbonate-rich interval, which in the case of the Geneseo-Burket is interpreted as the Lodi Limestone member.
- Overlying both organic-rich shale units of the Marcellus and Geneseo-Burket are organic-lean shale units of the Mahantango and Penn Yan Shale units.
• The geomechanical properties in the Poseidon 8M of the Marcellus Shale and the Geneseo-Burket shale and surrounding units are similar as well.

• In the Poseidon 8M, the Geneseo-Burket at 20 feet (6 m) is significantly (nearly an order of magnitude) thinner than the Marcellus Shale at 170 feet (52 m). In all the wells examined in southwest Pennsylvania and north-central West Virginia, the Geneseo-Burket is thin with a consistent thickness from 20-30 feet (6-9 m).

• While the Geneseo-Burket organic-rich shale is productive, the relatively thin nature of the unit and lower maximum TOC compared to the Marcellus Shale could explain the lower productivity.

• The rapid, significant and repetitive shifts in depositional environments suggests that changes from intervals that were accumulated under aerobic/oxic conditions such as the Tully Limestone and organic-rich shale such as the Geneseo-Burket accumulated under euxinic conditions may not have been driven directly by tectonic/eustatic events and changes in water depth. Instead, these changes in depositional environment could have been influenced by subtle changes in circulation and/or productivity that affect the water column.
5.0 References Cited


Fertl, W.H. and Chilingar, G.V., Total organic carbon content determined from well logs. SPE 15612 (1986).


Mitchum, RM, Jr., P.R. Vail, and S. Thompson III, 1977, Seismic stratigraphy and global changes of sea level, 2: the depositional sequences as a basic unit for stratigraphic analysis.


6.0 Appendix Core Photos

Figure 26 - Core photos with visible light with contacts of stratigraphic units highlighted.