DETERMINING STRUCTURAL INFLUENCE ON DEPOSITIONAL SEQUENCES IN CARBONATES USING CORE-CALIBRATED WIRELINE LOGS: MISSISSIPPIAN, MID-CONTINENT, U.S.A

By

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Abstract:

Identifying stratigraphic surfaces and correlating depositional packages is problematic in proximal ramp settings where argillaceous carbonates with distinct wireline log signatures are absent due to non-deposition or post depositional erosion. In southern Kansas, packages were defined based on petrophysical similarities as expressed by the neutron and density porosity logs. Based on the examination of core-calibrated wireline logs, depositional packages were established that could be correlated up to 25 miles (~40 km). Examination of the geometry of these packages indicated that they prograded to the south and thinned both landward and basinward. The apparent direction of progradation changed near the Pratt Anticline from southwesterly to southeasterly. Furthermore, packages thinned and terminate against the Pratt Anticline and Central Kansas Uplift. This thinning and apparent change in direction of progradation is interpreted as evidence of syndepositional uplift of both features during Mississippian deposition.

Attempts to tie packages in the Bartel #1-16 core in Reno County, Kansas to the Bann #1-14 core in Woods County, Oklahoma were not successful. The predominantly log-based correlation was interpreted to show that most packages in the Bartel #1-16 core terminate before the Kansas-Oklahoma border. The packages/sequences in the Bann #1-14 are interpreted to be younger and more distal as increases in gamma-ray signature interpreted as flooding surfaces become apparent. Establishing a method for correlating depositional packages in proximal settings and understanding the relative ages of packages in a regional context increases our understanding of the complex Mississippian carbonate section. Considering the influence of uplift on the direction of package progradation could be useful in aligning horizontal wellbores to intersect reservoir facies.

Full sized cross sections are available as supplementary files.

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CHAPTER I

INTRODUCTION

SUMMARY OF THE PROBLEM

Mississippian sequence stratigraphy is not well defined in southern Kansas and northern Oklahoma. In particular, electrofacies-defined units, as utilized during the recent wave of unconventional drilling (horizontal well bores) in Kansas and Oklahoma, are typically not core constrained. While Mississippian strata have been drilled both Kansas and Oklahoma, there has been a high concentration of horizontal drilling activity around the Pratt Anticline and southern Central Kansas Uplift due to the frequency and variety of traps. Prior studies that included the Pratt Anticline addressed regional scale paleo-depositional modeling (Lane and DeKyser, 1980) and lithostratigraphic specific topics (Goebel, 1968a, Harris, 1975, Watney et al., 2008; Mazzullo et al., 2009) Studies that address the specific influence of the Pratt Anticline and the Central Kansas Uplift on depositional processes and facies distribution are not known, but the influence of structure on a carbonate systems is generally understood (Tucker and Wright, 1990). It was believed the Pratt Anticline and the Central Kansas Uplift became tectonically active post-Mississippian time (Merriam, 1963), but when more closely examined, the structural-stratigraphic complexities examined in this study suggested that it was active either continually or sporadically during Mississippian deposition. If the Pratt Anticline or Central Kansas Uplift was uplifting during Mississippian deposition, these features could have influenced depositional geometries and scale, evolution and distribution of facies and ultimately reservoir potential. As a result of the uplift of the Pratt Anticline and Central Kansas Uplift, Mississippian strata dip easterly, southerly, and westerly off the anticline, to form a high concentration of pre-Pennsylvanian subcrops in southern Kansas.

FUNDAMENTAL QUESTIONS AND HYPOTHESES

The primary hypothesis is that the Pratt Anticline and Central Kansas Uplift were positive structural features during Mississippian deposition and influenced depositional processes. In a carbonate system, a relative sea level change of only a few meters in shallow water carbonates, regardless of the mechanism, can significantly influence depositional facies and their distribution (Grammer, 2014). This has an impact on the location and size of reservoirs that are tied to facies.

The fundamental questions to be answered by this research are as follows:

1) Are the top and bottom of sequence/packages identified within Mississippian core expressed as clearly definable log signatures?
2) Can these log signatures be traced in multiple wells distributed across tens of miles to allow correlation of these package sequences and establish package geometry and scale?
3) Do the geometries of sequence/packages in the area of the Central Kansas Uplift and the Pratt Anticline provide evidence of structural uplift concurrent with deposition?

OBJECTIVES

The principal objective of the thesis is to better understand if syndepositional uplift of the Pratt Anticline or Central Kansas Uplift influenced deposition of Mississippian sediments. The goal of this project is to examine the geometry of depositional sequences to determine if evidence of uplift is expressed in sequence geometry, thickness, and distribution around the Pratt Anticline or Central Kansas Uplift. This will be accomplished by identifying sequences in cores and using this information to see if depositional surfaces that mark the boundaries of sequences are expressed on wireline logs as clearly definable log signatures. If so, surfaces that can be correlated will then be traced on cross-sections until they terminate. The resulting geometry of each sequence will then be used to determine a direction of sequence progradation as an indication of paleotopography and structural influence in the area during deposition. Understanding this relationship between structure and deposition will improve the ability to predict the occurrence of reservoirs by refining the expected distribution of facies belts.

GEOLOGIC BACKGROUND

REGIONAL GEOLOGY AND DEPOSITIONAL FACTORS

Deposition of Mississippian sediments in the Mid-Continent was aerially extensive and is represented predominantly as a carbonate system comprised of limestone, dolomite, chert, and shale (Merriam, 1963). The Mississippian depositional system of the Mid-Continent spanned thousands of square miles and comprises parts or all of the present states of Kansas, Oklahoma, Nebraska, Missouri, Colorado, Texas, and Arkansas (Fig 1). Depositional strike of the Mid-Continent Mississippian carbonate system trends approximately east-west with shallow water facies found in Kansas and progressively deeper water facies occurring southward in Oklahoma (Lane and DeKyser, 1980) (Fig. 2). The system is bounded to the east by the Ozark Uplift, the south by the ancestral Anadarko and Arkoma (Oklahoma) Basins, and the north and northwest by the Transcontinental Arch. (Fig 1) The system was oriented between approximately between 20-30° south of the paleo-equator (Gutschick and Sandberg, 1983, Witzke, 1990) (Fig. 3). Prevailing winds and surface currents are interpreted to have been from a present-day east-northeast direction (Witzke, 1990). The earth at the time of Mississippian deposition was in a transitional period going from the greenhouse conditions of the Devonian to icehouse conditions in the upper Mississippian, Pennsylvanian and Permian (Read, 1995).

The Mississippian depositional system of the Mid-Continent was described by Lane (1978) and Lane and DeKyser (1980) as a shelf like environment with a clearly definable shelf margin (Fig 2). The term "shelf" has continued to be used as a label for the system even after

Gutschick and Sandberg (1983) described a broad gentle foreslope at the margin grading into deep water starved facies (Fig 3). While many depositional systems can be labeled differently depending on the orientation of proximal to distal transects, this Mississippian system in the recent literature is described as a distally steepened ramp even though the term “shelf” is still used (Mazullo et. al.,2009)

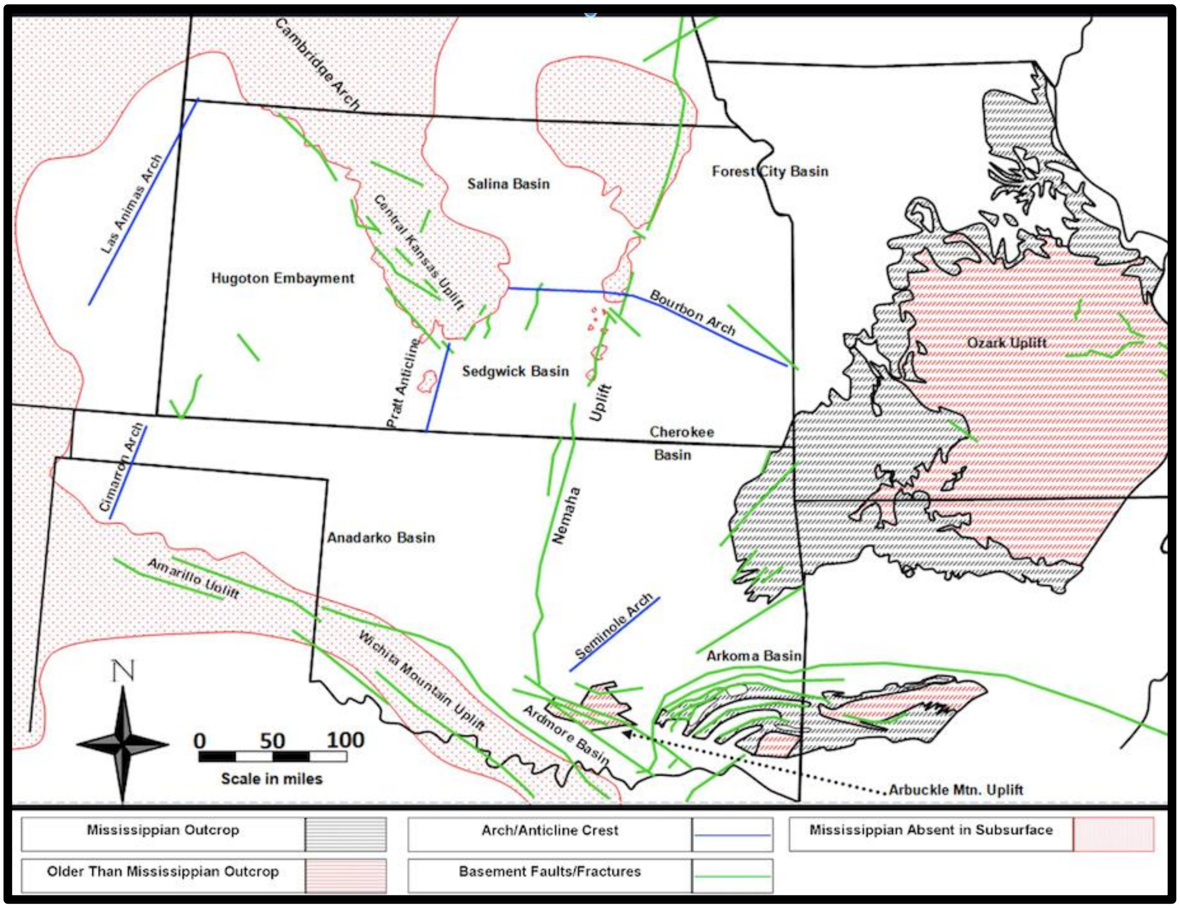


Figure 1: Illustration of the Mid-Continent region showing the major structural features and the present day aerial extent of the Mississippian in both the subsurface and surface. (Image modified from Reed, 1948; Merriam, 1983; Adler, 1971; Haley et al, 1993; Johnson, 2008)

Biostratigraphic (conodont) zonation shows that prograding sediment wedges built out across the ramp towards the basin in the Lower to Middle Mississippian (Boardman et al., 2010). This recognition of time-transgressive lithofacies within the Mississippian carbonate system supports the ramp model and clarified lateral facies relationships within prograding wedges. These prograding wedges resulted in evolution of the geometry of the system from a nearly homoclinal ramp during the early Mississippian to a distally steepened ramp during the middle Mississippian (Wilhite et al., 2011). The morphologic change of geometry over time is not uncommon within carbonate dominated systems. Unlike siliciclastic sediments, carbonate sediments cement quickly both in water and when subaerially exposed, thus they are able to resist erosion and result in packages of sediments that are resistant to reworking during low sea levels (Grammer, 2014).

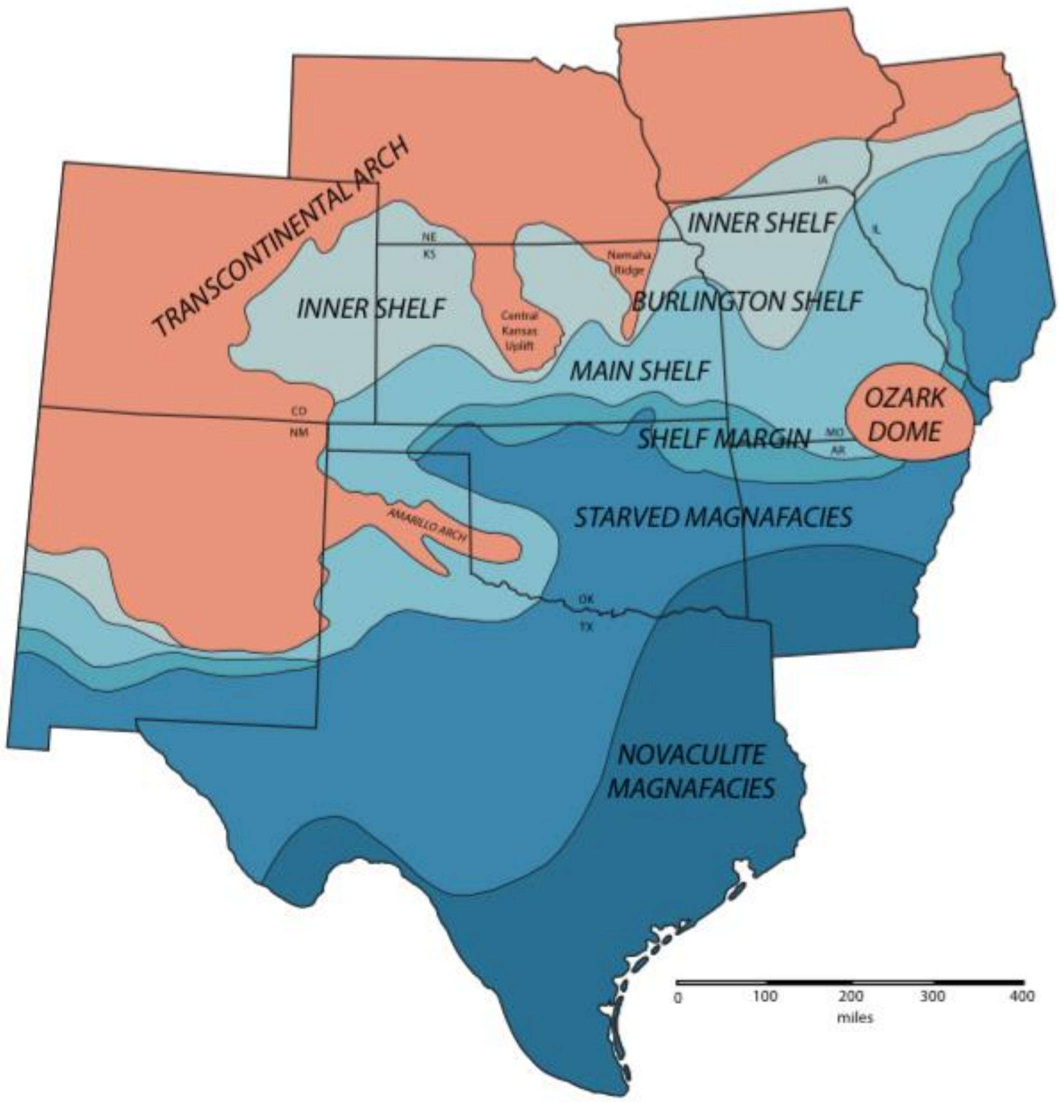


Figure 2: Generalized Early Mississippian depositional model of the Mid-Continent. This overgeneralized model is labeled with terms for a shelf carbonate depositional environment. This figure is still commonly referenced even though it is generally accepted that deposition of Mississippian carbonates occurred in a distally steepened ramp setting. Modified from Lane and DeKyser (1980).

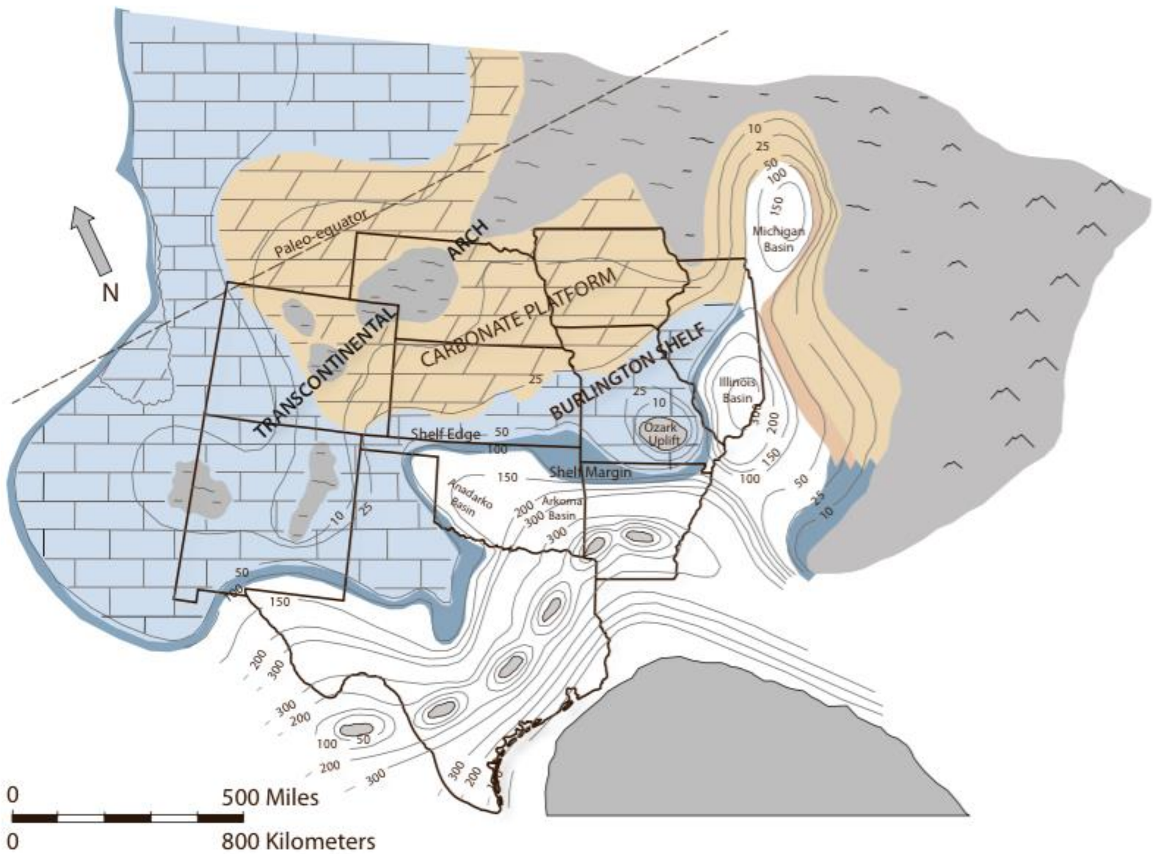


Figure 3: Paleodepositional model of the Mid-Continent representative of the Early Mississippian time. The system trends west-east in Kansas, with shallower water environments to the north and progressively deeper water settings to the south. Carbonate system geometries are highly dynamic through time. Models like this can only represent a carbonate system for a single slice of time and do not represent the changes a carbonate system undergoes with time. Modified from Gutschick and Sandberg (1983).

SEA LEVEL CONTROLLING CARBONATE CYCLICITY

Second, third, fourth and fifth order cycles in carbonates are controlled by cyclicity in the rise and fall of sea level and different driving forces for each cycle order control these fluctuations in sea level (Read, 1995). The frequency for each subsequent cycle is shorter than its predecessor. The frequency of 2nd order cycles range 10-15 million years. Driven by tectonics, ocean volumes, and occasionally glacial fluctuations, they create packages of rock hundreds to several thousands of meters thick that can be regionally correlated (Read, 1995). Found within the

2^{nd} order cycles are smaller scale 3^{rd} order cycles. The 3^{rd} order cycles are not as well understood compared to the 2^{nd} order cycles. There is still debate between researchers over the driving force behind the 3^{rd} order cycles. Plint, et. al. (1992) attributed the driving force to tectonics and sea floor spreading. Read (1995) attributed the driving force to the more plausible advance and retreat of large continental ice sheets. As a result, the frequency is very broad ranging from one to ten million years (Plint, et. al., 1992).

Milankovitch cyclicity is the attributed driving force behind the shorter duration, higher frequency 4^{th} and 5^{th} order cycles (Read, 1995). Milankovitch cycles are the most predictable of all the cycles because they result from three predictable variations of the earth's position around the sun; eccentricity, obliquity, and precession (Fig 4). These three movements affect the amount of solar radiation received by the Earth. Variability in the amount of solar radiation is shown to dramatically affect global climate and glaciation (Read, 1995). Eccentricity is change in the shape of the earth's orbit around the sun and controls glaciation over the corresponding 100 – 400 thousand year 4^{th} order cycles (Read, 1995). Obliquity is the change in the earth's axis controlling seasonal variability over 40 thousand year 5^{th} order cycles (Read, 1995). Precession is the wobble of the earth's axis and produces 5^{th} order cycles with frequencies of approximately 21 thousand years (Read, 1995).

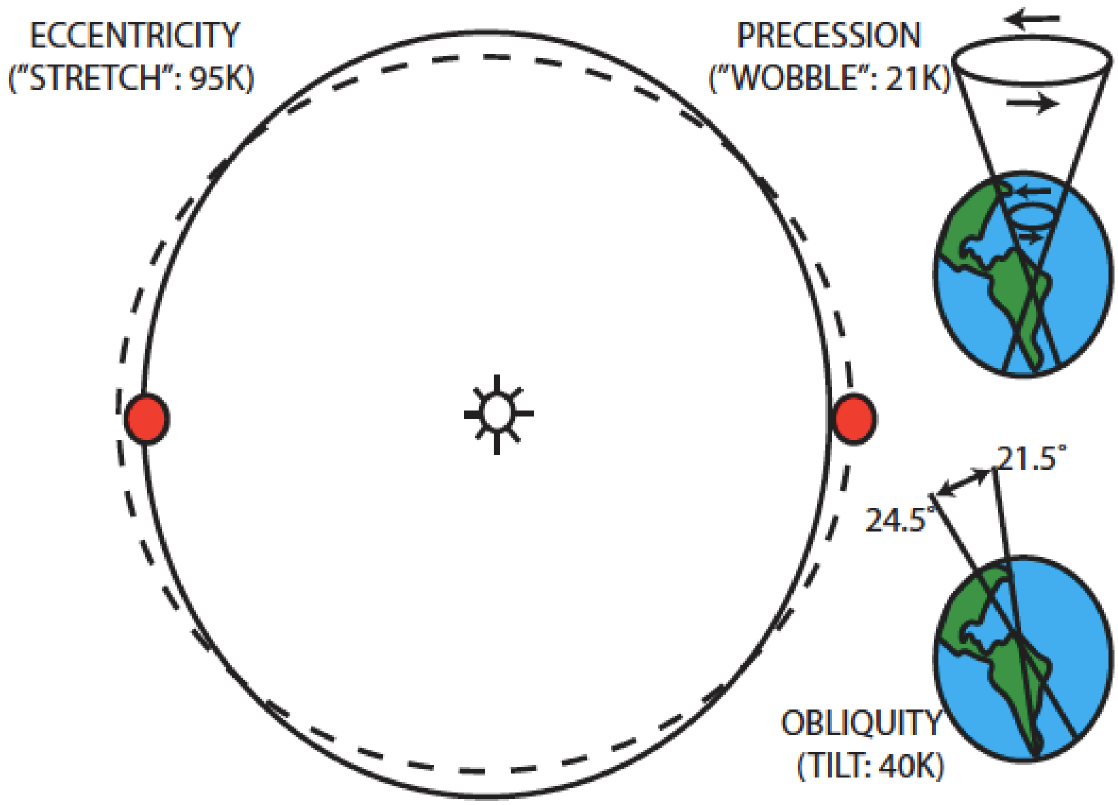


Figure 4: Visualization of the variations in the Earth's orbit and axis that create Milankovitch cyclicity. Modified from Kerans and Tinker (1997).

Greenhouse and icehouse conditions for the Earth determine which Milankovitch variable is dominant and the amount of sea level change that is to be expected. As mentioned above, these changes in the amount of glaciation are associated with eccentricity. During greenhouse times with low continental ice volumes, precession dominated cycles result in sea level variations of 10m or less (Read, 1995). Icehouse conditions are times when higher frequency sequential glaciation and deglaciation events dominate Earth's climate. The resulting large removal of water from the ocean to the land and subsequent replacement of that water back into the ocean can create sea level changes as large as 100m (Read, 1995). Deglaciation happens much more rapidly than glaciation and results in rapid transgression and gradual regression of sequences (Read, 1995). Obliquity appears to be the dominant cycle during icehouse times as well as transitional times between icehouse and greenhouse conditions (Read, 1995). Since the Earth at the time of Mississippian deposition is interpreted to be in a transitional period going from the greenhouse conditions of the Devonian to established icehouse conditions of the Pennsylvanian, it is expected that the frequency and magnitude of sea level change in the early Mississippian would differ from those of the late Mississippian (Fig. 5).

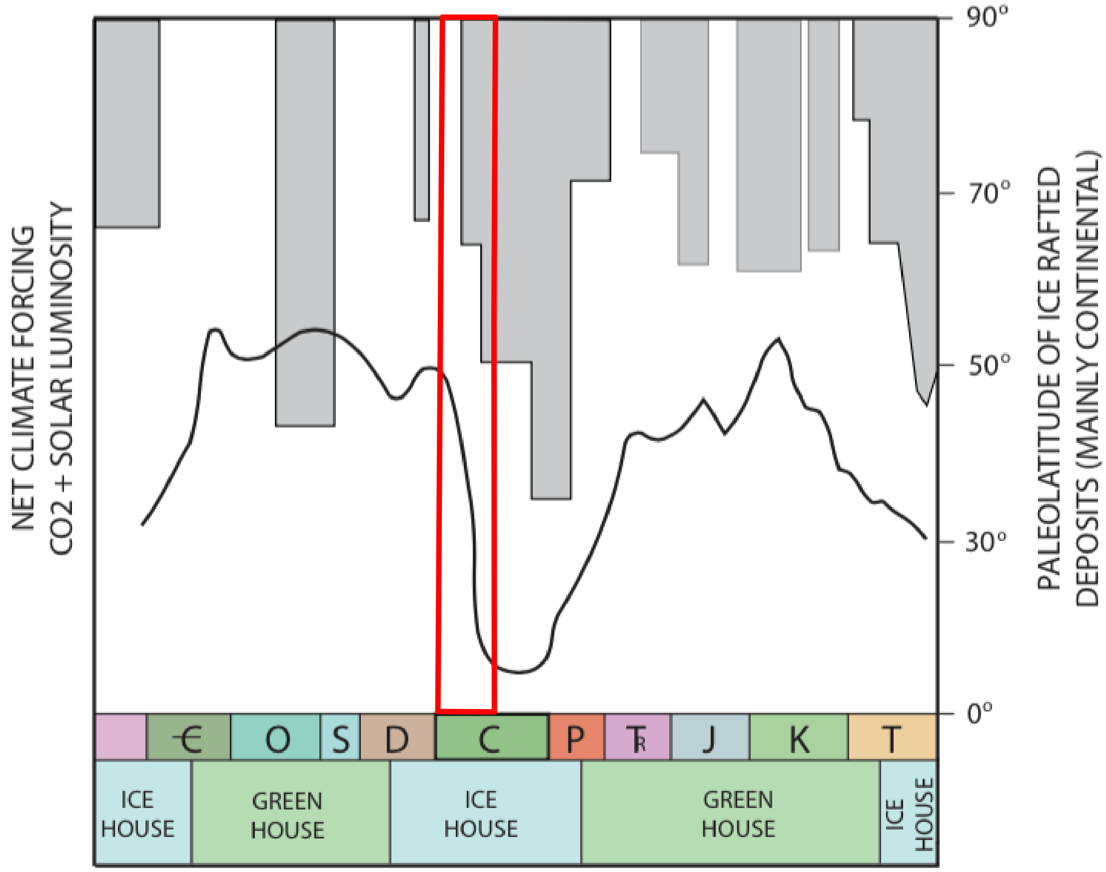


Figure 5: Diagram illustrating the distribution of icehouse and greenhouse conditions. Paleo-latitudes of ice-rafted glacial deposits data (gray boxes with black outline) and marine ice-rafted deposits data (gray boxes with no outline) coupled with climatic change due to variation in CO_2 and solar intensity data (solid line) indicate that the Mississippian represents a transitional period from greenhouse conditions that existed during the Devonian to icehouse conditions that were well established by the Pennsylvanian. Modified from Read (1995).

POTENTIAL PROBLEMS IN CORRELATING CYCLES USING WIRELINE LOG EXPRESSIONS

While it is common practice to use wireline log expressions to correlate carbonate sections, many characteristics of carbonates make this practice inherently difficult and prone to many false correlations. One of the more notable issues is the scale of subsurface studies. Carbonates are characterized by both lateral and vertical heterogeneity (Tucker and Wright, 1990). Studies of modern day carbonates show that facies changes can occur over short (tens of feet) and that facies can phase in and out over a distance of less than 660 feet, a distance equivalent to the distance between well bores at standard 10 acre well spacing (Fig 6) The result is that although the same facies may occur in two wells 660 feet apart, it is possible that they are not continuous (Grammer, 2013). With this type of complexity, it is easy to visualize how much detail cannot be resolved using data from wells drilled on tight 10 acre well spacing patterns.

While using log expressions to correlate cycles has serious shortcomings, it can still be valuable. Some of the issues mentioned above can be mitigated by using core to identify cycle boundaries and tying those surfaces to log expressions. This method helps to reduce the risk of correlating a meaningless “phantom” log expression that has no geologic value. The confidence in the correlation does however decrease rapidly with distance from the core. It is important to keep these issues in perspective and not over represent results based on log correlations.

Figure 6: Google image of the Lighthouse Reef System near Belize, Central America with simulated ~10 acre (660') well spacing (red dots) and ~40 acre (1320') well spacing (orange dots) and the likely depositional facies encountered at the surface. Even with extremely tight 10 acre well spacing, the petrophysical or core data that would be acquired from each well would be insufficient to create an accurate image of the distribution of facies. Modified from Grammer, (2015).

STRATIGRAPHY

The lowermost boundary of the Mississippian system in the Mid-Continent occurs within the Late Devonian to Early Mississippian Woodford Shale. This boundary is not discernible on logs or in core and must be obtained using conodont biostratigraphy. The lower boundary of the Mississippian carbonate section is characterized on wireline gamma-ray logs as a change from the highly radioactive Woodford Shale or less radioactive Kinderhookian "Shale" to the very low radioactive (low gamma-ray value) Mississippian carbonate. The Mississippian-Pennsylvanian unconformity separates the Mississippian from the overlying Pennsylvanian section, which is shale dominated and provides an easily recognized boundary. This boundary is characterized on gamma-ray logs as an abrupt change from the "clean" gamma-ray signature of the Mississippian carbonate to the more radioactive shale of the Pennsylvanian.

Mississippian stratigraphic nomenclature is not uniform across the Mid-Continent. Subsurface nomenclature is different from outcrop nomenclature and both change across state boundaries. To further complicate stratigraphy, informal terms such as “Miss Lime”, “Miss Chat”, and “Miss Solid” are used extensively in industry. The subsurface Mississippian nomenclature in Kansas was set by Goebel (1968a, 1968b) and is still used today with minor changes (Fig 7). The Mississippian is broken into four stages; Kinderhookian, Osagean (spelled Osagian by the Kansas Geological Survey {see Kansas Geological Survey, 2015}), Meramecian, and Chesterian. The Kinderhookian and Osagean Stages comprise the Lower Mississippian Series and the Meramecian and Chesterian Stages comprise the Upper Mississippian Series. The Kinderhookian Stage contains the Chouteau Limestone (called the Compton in southeast Kansas), Sedalia Dolomite (Northview Shale equivalent), and the Gilmore City Limestone. The Osagean Stage contains the Fern Glen Limestone, which has two members, the St. Joe Limestone Member and the Reeds Spring Limestone Member, and the Burlington Limestone and Keokuk Limestone undifferentiated (Geobel, 1968b). The Meramecian Stage is subdivided into the Warsaw Limestone, Salem Limestone, St. Louis Limestone, and St. Genevieve Limestone. The Chesterian Stage is not subdivided and is only present in southwestern Kansas and western Oklahoma (Geobel, 1968b).

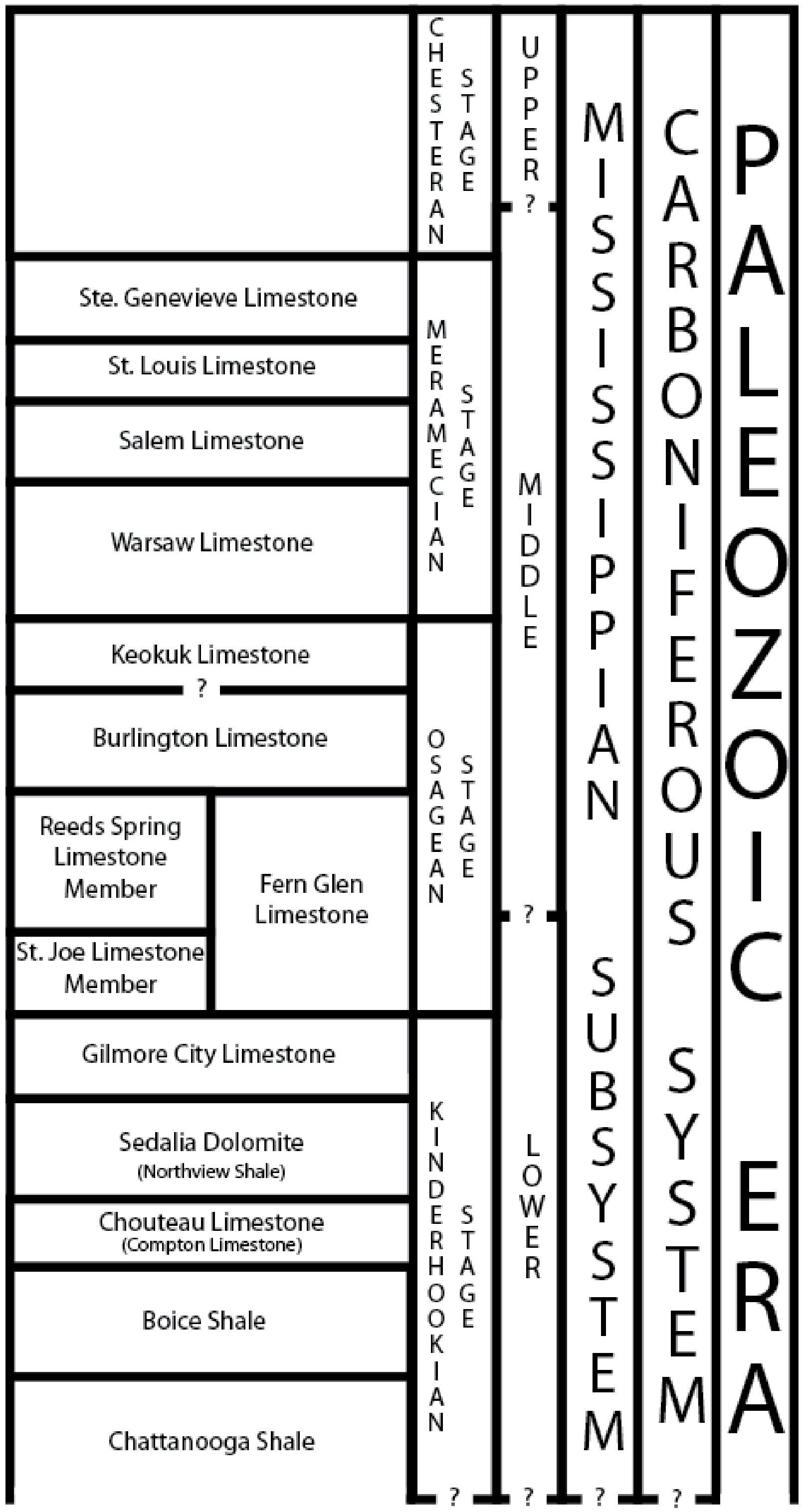


Figure 7: The current accepted stratigraphic nomenclature for subsurface Mississippian rocks in Kansas. This nomenclature is different from the nomenclature of the Mississippian outcrops in the Tri State Region of southeastern Kansas, northwestern Arkansas, and northeastern Oklahoma. Modified from the Kansas Geological Survey (2015).

CHAPTER II

METHODOLOGY AND RESULTS

INTRODUCTION

The primary goal of this study is to determine whether core-calibrated depositional sequences/packages identified on wireline logs can be traced far enough laterally to observe the effects of structural influence on depositional geometry and scale. To test the principal hypothesis, two cores were utilized, one each from a proximal and distal position on what has been interpreted as a regionally extensive ramp. Both cores are near either the Pratt Anticline or Central Kansas Uplift (Fig. 8). The interpretation of these cored intervals and the consistency or variability in the geometry of depositional packages represented in cross sections will be crucial to determining whether structural uplift was concurrent with Mississippian deposition. Furthermore, the methodology is designed to determine the influence these uplifts may have had on the direction of sequence/package progradation and change the expected trend of facies.

DATA AND METHODS

CORE

Two cores were used to establish depositional facies and correlate depositional surfaces to wireline logs. Both cores are four inches in diameter and were cut and polished as library samples, which facilitated the description. The Blueridge Petroleum Corporation’s Bartel #1-16, which contains 225 feet of Mississippian section, is located in S16-T24S-R4W, Reno County, Kansas (Fig 8). Based on the wireline logs, the Bartel #1-16 core is missing 2 feet of Mississippian section at the top and 9 feet of Mississippian section at the base of the core. The second core is the Chesapeake Energy Corporation's Bann #1-14 contains 147 feet of Mississippian section and is located in S14-T28N-R14W, Woods County, Oklahoma (Fig 8). The Bann #1-14 captures the Mississippian-Pennsylvanian contact, but is missing 295 feet of Mississippian below the core. It is also missing approximately 15 feet of the core near the top that was unable to be recovered.

These cores were chosen based on their north/south alignment, distance from each other and position near the Pratt Anticline and the Central Kansas Uplift (Fig. 8). Their proximity to the structures and completeness should allow core-calibration to wireline logs, the ability to trace internal surfaces in the Mississippian sequences and to test the hypothesis that the Pratt Anticline and/or Central Kansas Uplift influenced Mississippian deposition. The cores are also located in an area that has historical Mississippian production and in recent years has been a focal point for the application of unconventional drilling techniques to Mississippian reservoirs. This historical and recent activity provided the large number of wireline logs necessary to generate cross-sections.

WIRELINE LOGS

It is common practice in the Mid-Continent to run an open hole wireline log suite for every well drilled. For this reason there are abundant wireline logs available for data acquisition in a mature region like the Mid-Continent. For regional correlation purposes, gamma-ray logs are the dominant type used and were preferred for this study. The quality of the data produced by wireline logs has increased significantly over the years and the modern (post 2000) logs provide the best data for this type of work since they contain combinations of gamma-ray curves with other curves (i.e. neutron/density porosity, resistivity, caliper, etc.) (Schlumberger, 2015).

Gamma-ray tools measure the amount of natural radiation emitted by sedimentary rocks (Beaty, 2014). This radiation occurs from the presence of radioactive potassium (K), thorium (Th), and/or uranium (U). Radiation is typically measured in American Petroleum Institute (API) units with a scale from 0 – 200 or 0 - 150. For correlation purposes, the actual quantitative measurement of radiation is ignored in favor of looking for repetition of patterns created by the relative difference in natural radioactivity. Carbonates and sandstones generally present a “clean” or low API reading (15 API -40 API), whereas shales typically present a “hot” or higher API value (40 API or higher). While the above is generally true, this tool cannot be used to determine lithology. Most gamma-ray tools measure approximately 6-12 inches into the rock surrounding the borehole and have a vertical resolution of approximately 2-3 feet (Schlumberger, 2015). Older gamma-ray tools (pre 1960’s) did not measure as deep and averaged a larger package of rock; if a well was logged in the 1960’s and today, the results from the older tool would show less gamma-ray variation and a smoother curve. Besides the age of the wireline log, both the depth of investigation and vertical resolution are dependent on the logging speed (Beaty, 2014).

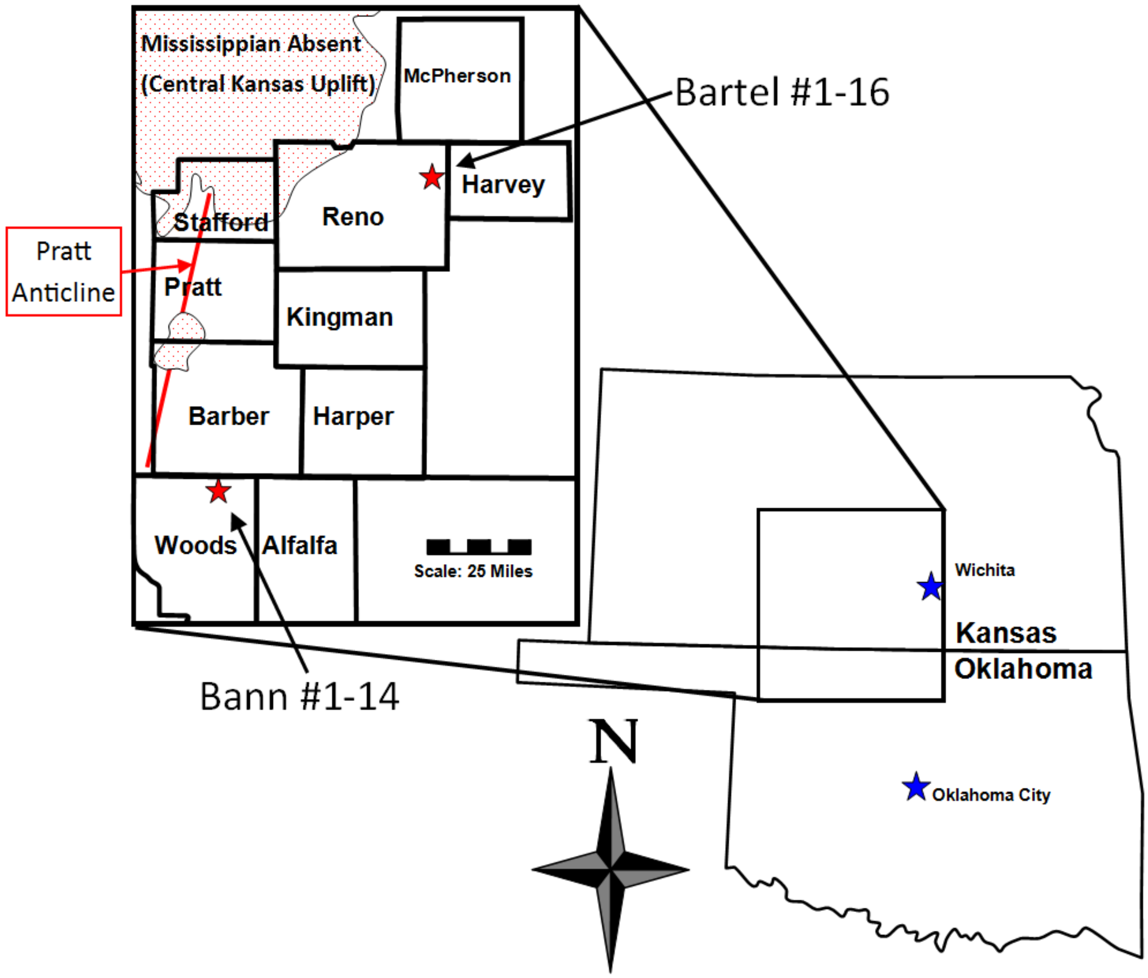


Figure 8: Map depicting the study area that includes eight Kansas counties and two Oklahoma counties that are outlined and labeled in the inset box. The two cored wells, the Bartel #1-16 and the Bann #1-14, are indicated with red stars. The inset view shows the study area in relationship to the Central Kansas Uplift where Mississippian strata are currently absent and the Pratt Anticline.

Wireline logs are considered petrophysical data and as with any petrophysical data there are limitations to the quality of data for a specific use based on how the tools take measurements (Beaty, 2014). Potential problems with carbonates in particular include very low gamma-ray readings over tens to hundreds of feet and insufficient vertical resolution of the logging tools. If a carbonate presents a very low gamma-ray reading with little to no variation over the entire formation, it is difficult or impossible to correlate internal surfaces. Another potential problem arises when brines flow through the rock and precipitate mineral deposits including uranium salts that leave portions of the rock artificially "hotter" (i.e. higher total GR) than the original sediment. While this phenomenon could indicate porosity in that section of the rock, it may not have value for correlations unless it reflects a porous facies, which in turn could be correlatable. This is why correlating increases in gamma-ray readings as boundaries in carbonates without tying that increase to an actual surface in a core could lead to correlating "phantom" features. Thin-section analysis is valuable in visualizing finer-scale rock properties that define boundaries or stratigraphic surfaces. However, with the highest resolution gamma-ray tool having a minimal vertical resolution of 1 foot to 3 feet in most cases, it becomes impractical to use this tool to correlate high-order surfaces such as fourth or fifth order sequences in some cases if the thickness of the packages are thinner than the vertical resolution of the tools. Third-order depositional packages are generally thick enough and have adequately distinct surfaces to be useful for gamma-ray wireline log correlation as shown by Bertalott (2014).

Log data was acquired from the Kansas Geological Survey and the Oklahoma Corporation Commission. Forty three wells were selected from a larger data set to generate four cross sections. These logs consist mostly of density/neutron porosity logs with gamma ray curves.

BARTEL #1-16

Blueridge Petroleum Corporation drilled the Bartel #1-16 in December of 2011 in the Burrton field in S16-T24S-R4W of Reno County, Kansas (Fig 9). The well was cored from 3292 feet to 3517 feet (225 feet/68.6 meters). The entirety of the core is in the Mississippian carbonate section. Based on correlations to the open-hole logs, it is interpreted that the Bartel #1-16 is missing 2 feet of Mississippian section on the top and 9 feet of the lowermost Mississippian carbonate above the Kinderhookian Shale section (Fig 10). The Mississippian carbonate section is 235 feet thick in this well and spans from 3525 feet to 3290 feet. Superior Well Services, Hays, Kansas, logged the well and ran four open hole logs: compensated density/neutron log, sonic log, micro log, and dual induction log. All logs were run in conjunction with a gamma-ray tool.

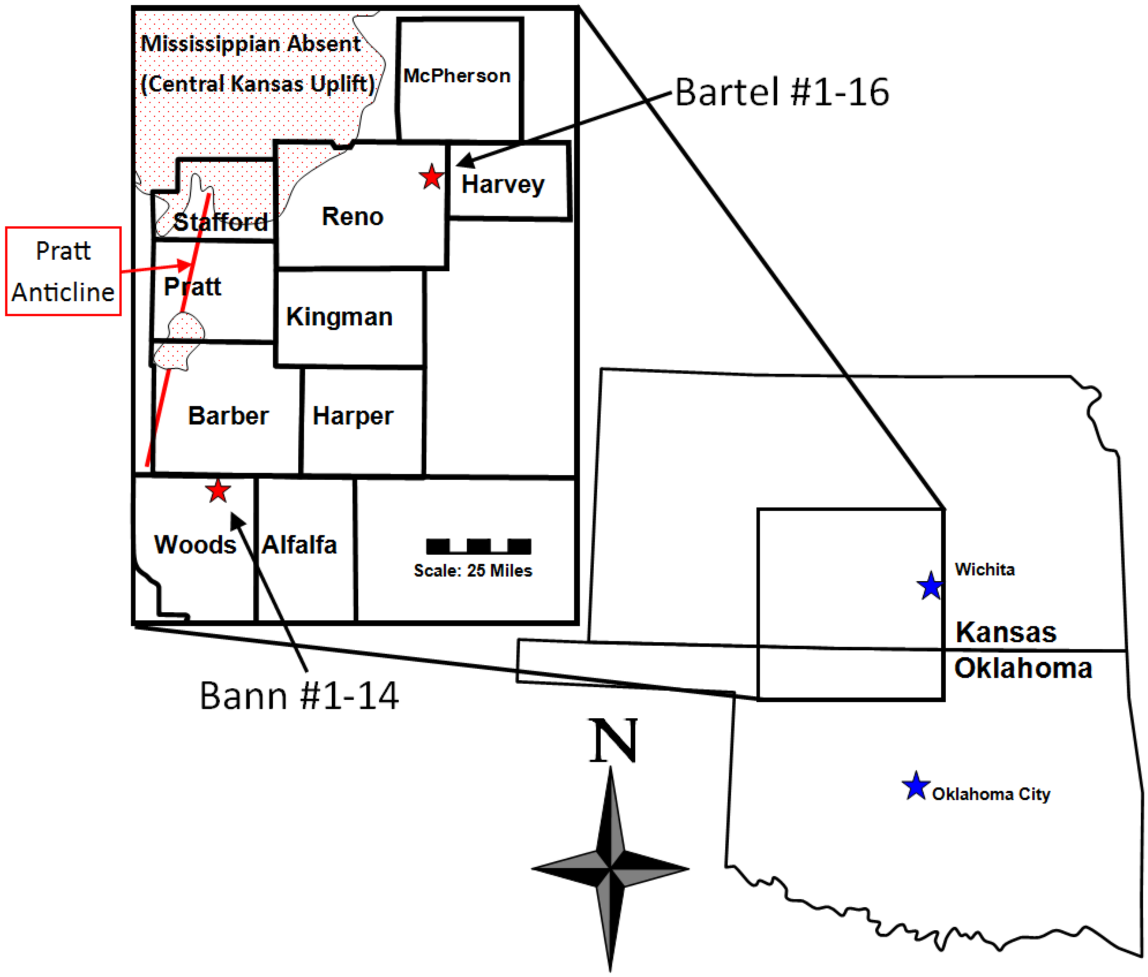


Figure 9: Map showing the location of the Bartel #1-16 in relationship to Pratt Anticline and the Central Kansas Uplift.

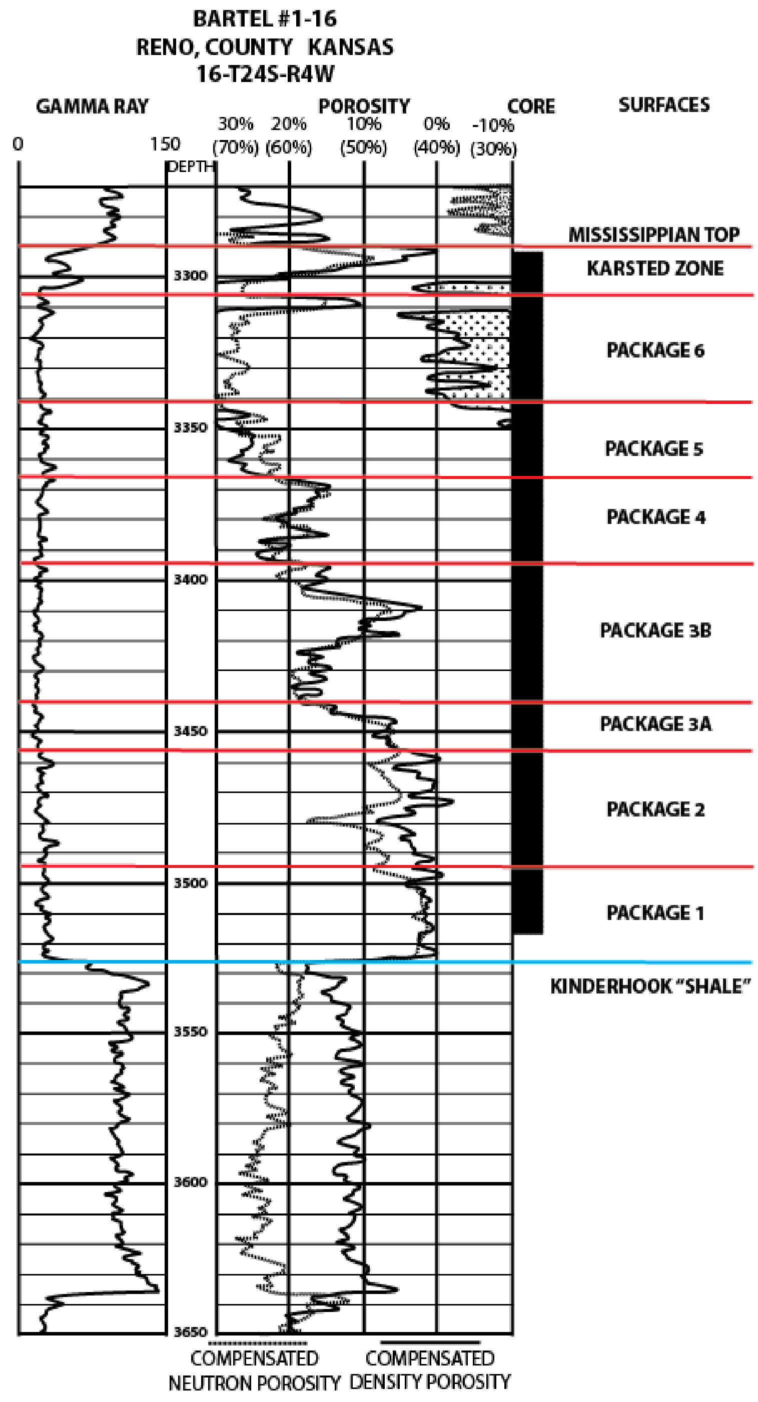


Figure 10: Section of the wireline log for the Blueridge Petroleum Bartel #1-16. The gamma-ray curve is in track one to the left of the depth track. The density/neutron curve is located on the right in track two. The box right of the log indicates the cored interval. The top of the Mississippian carbonate and the surfaces within the carbonate interval are indicated with red lines and labeled to the right. The bottom of the Mississippian carbonate/top of the Kinderhookian "Shale" is indicated with a blue line. Gamma-ray curves typically used to establish depositional boundaries for regional correlations are not apparent in this well on a proximal position of the ramp. Distinct packages of similar porosity do occur and can be used as a proxy for correlations over short distances (tens of miles).

DESCRIPTION

The core was described as eight large petrophysically distinct packages separated by stratigraphic surfaces. The core description was obtained by examining the polished library set using a hand lens. The gamma-ray log survey across the Mississippian carbonate displayed no distinctive increase in radioactivity that could be used to identify stratigraphic surfaces. Package boundaries on logs were established using the compensated density/neutron curves. Using the density/neutron logs for regional correlations proved to be effective in the proximal ramp setting (Fig. 11). In recent Mid-Continent Mississippian studies, Leblanc (2014) and Bertalott (2014) demonstrated that well to well correlation of sequence boundaries were accomplished using gamma-ray curves. The study areas of both Leblanc (2014) and Bertalott (2014) were located in areas interpreted as being in distal ramp settings, with deeper water facies, on a distally steepened ramp where correlations can be performed with gamma-ray (Fig. 12). In more proximal positions, higher energy facies have proven to hinder the ability for flooding surfaces to form (Price, 2014).The outcrop study produced no variations in gamma-ray usable for regional correlation purposes (Price, 2014).

Package one is the lowermost package in the core and covers the footages 3517-3494.2 feet. It consists of approximately 17 higher frequency packages that fine upwards and are approximately one foot thick. Each smaller package is bounded at the top and the bottom by a sharp contact (Fig. 13). From the base up each smaller package is dark grey, grain-rich matrix with centimeter to millimeter scale crinoid fragments and centimeter to millimeter scale slightly darker grey rounded clasts that grade upward into a dark grey muddy matrix (Fig. 13). Grains, other than crinoid grains, were not discernable in the matrix using the hand lens. The dark grey clasts only occur in the lowermost portions of the higher frequency packages and no grains could be identified in the clasts by hand lens. There are no visible burrows or porosity in package one. There is also little variability between the smaller packages and they are not detected on wireline logs. Package one is characterized on porosity logs as the lowest porosity of the Mississippian carbonate section and has density/neutron porosity values that generally range from 1-3% (Fig. 14).

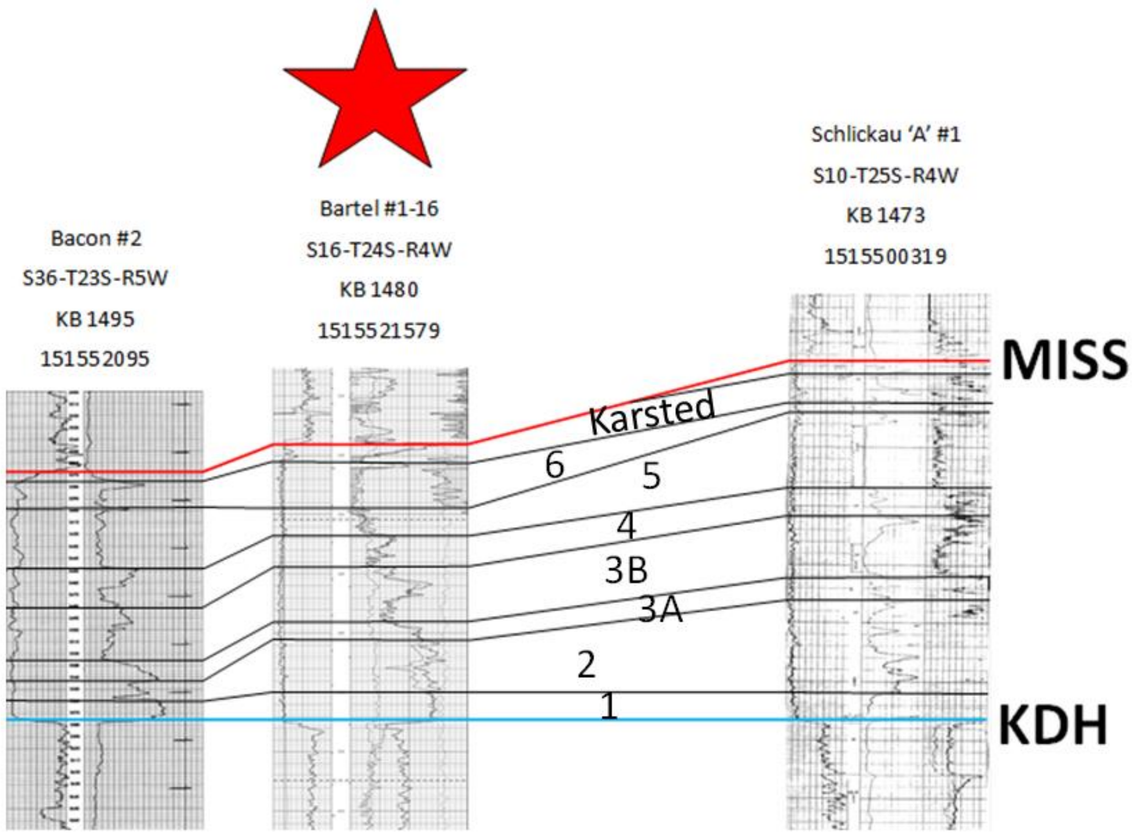


Figure 11: A short cross section showing how the density/neutron porosity curves were able to be used to correlate the packages described in the Bartel #1-16.

Package two covers the footage 3494.2-3455.6 feet. It is a mud-rich matrix to grain-rich, matrix and consists of light tan and green to olive green carbonate with fine to medium sand sized carbonate grains and millimeter to rare centimeter scale crinoid fragments (Fig. 15). Package two also contains grey to blue-grey chert and rare white chert that consists of less than 5% of the package. There are no visible burrows or porosity evident in hand sample. Package two exhibits 1-10% density/neutron porosity which is an increase in the upper range of the porosity measured in package one (Fig. 16).

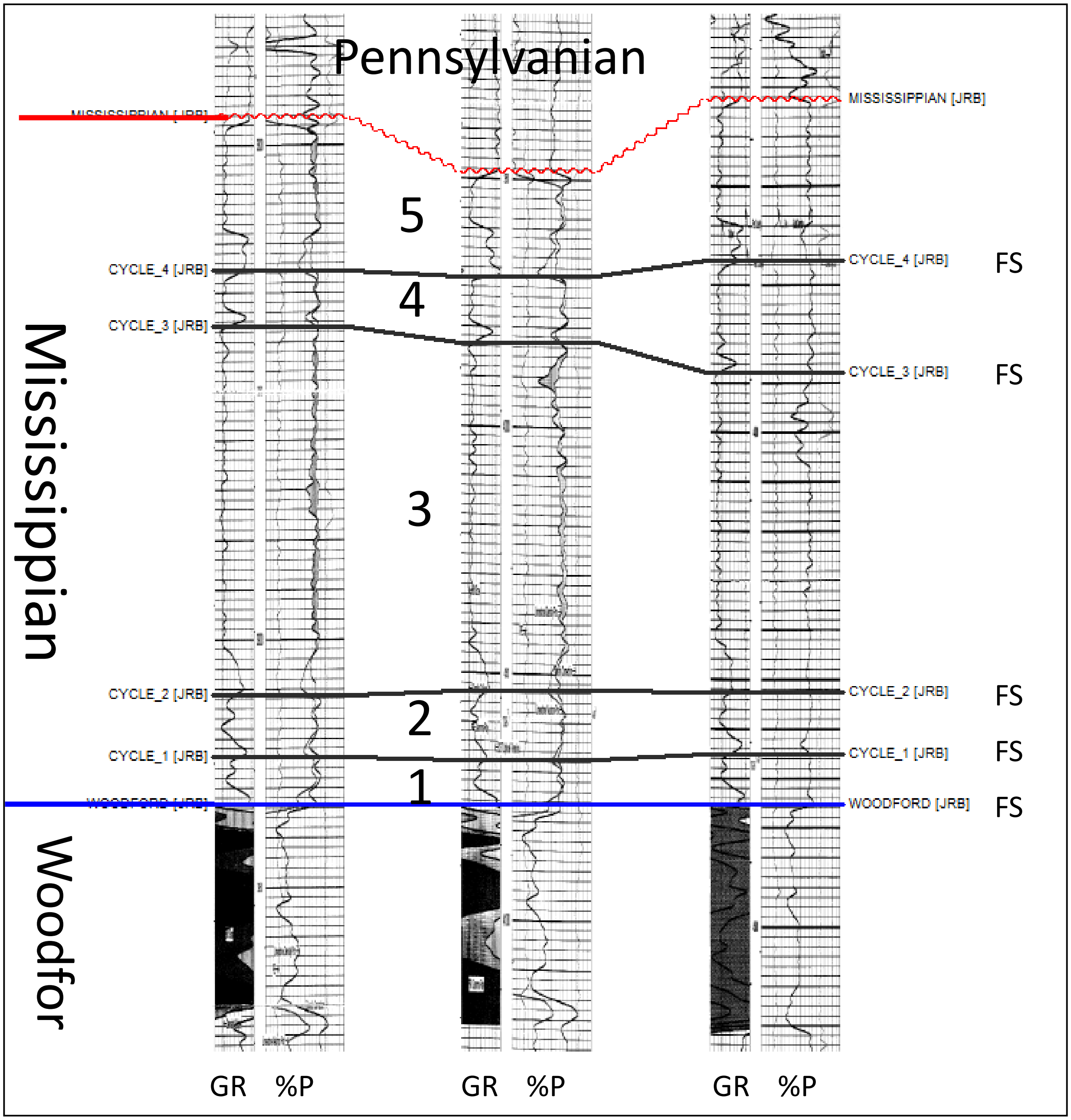


Figure 12: Cross section from Bertalott (2014) showing correlations based on increases in gamma-ray signatures at flooding surfaces.

Package three is divided into package 3A and package 3B. Package 3A is from 3455.6-3439.5 feet and varies from a dark tan to brown mud-rich to grain-rich matrix and contains fine- to medium-sand-sized carbonate grains and a several millimeter-scale crinoids (Fig. 17). Package 3A contains blue-grey chert with a centimeter to millimeter scale dark tan alteration rind. Package 3A is about 50% chert and has no visible burrows or porosity. Porosity curves on wireline logs indicate a marked increase in porosity from approximately 8% at the bottom to near 18% at the top (Fig. 20).

Package 3B extends from 3439.5-3395.8 feet. It varies from a light tan to off white grain-rich matrix and contains fine to coarse sand sized carbonate grains and sub millimeter scale to rare centimeter scale crinoid fragments (Fig 18). It also contains white-light grey chert with occasional crinoid fragments preserved within the chert. The distribution of silicification in package 3B indicates that chert preferentially replaced the grain-rich portions. Package 3B is approximately 40% chert and has no visible burrows or obvious porosity, but exhibits an increase in the range of wireline log porosity across the package and peaks around 20% (Fig. 20).

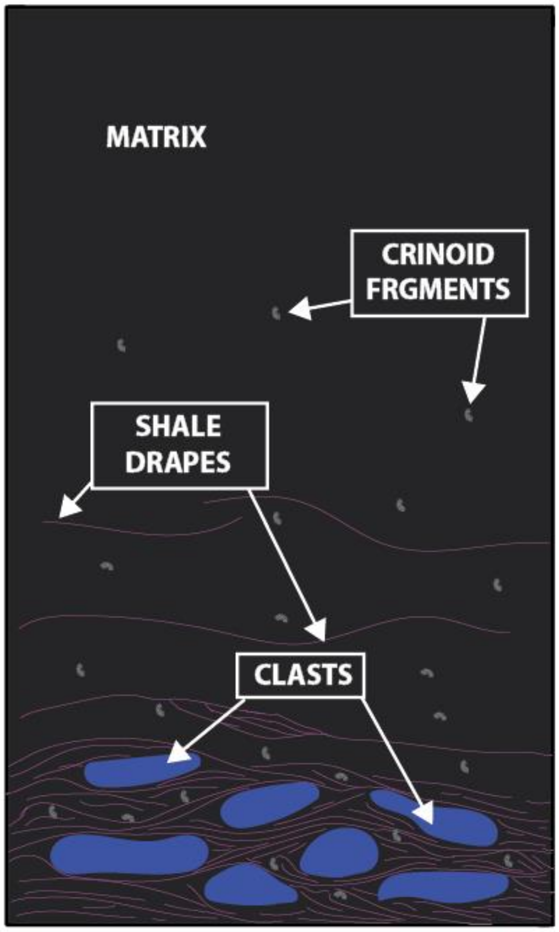


Figure 13: An annotated drawing (left) and core photograph (right) of a representative cycle found in package one. No grains are discernible other than crinoid fragments and clasts in the lower portions of the smaller cycles. Blueridge Petroleum, Bartel #1-16. Depth 3515.

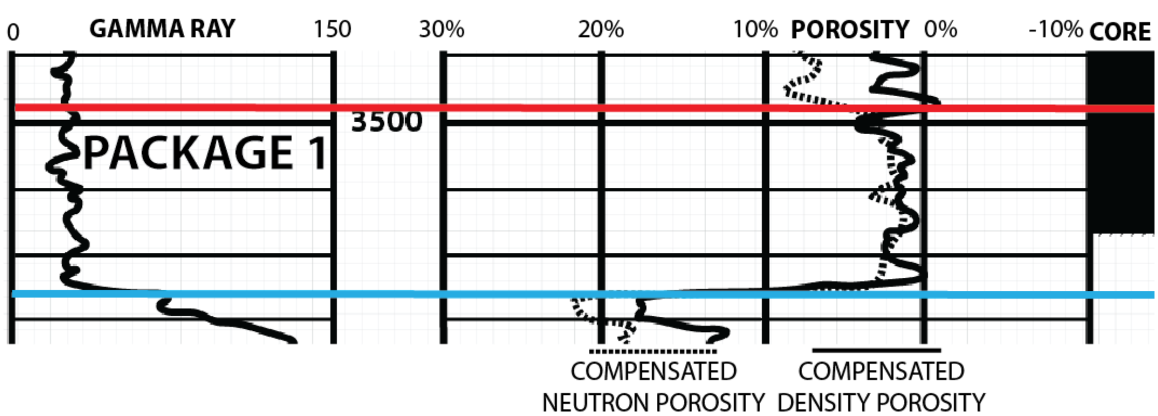


Figure 14: Gamma-ray and density/neutron porosity curves for package one in Blueridge Petroleum Corporation, Bartel #1-16. Contact between package one and the underlying Kinderhook "Shale" (blue line) is characterized by a steep decrease in gamma-ray values from ~70 API to ~30 API in package one. Contact between package one and two (red line) is sharp.

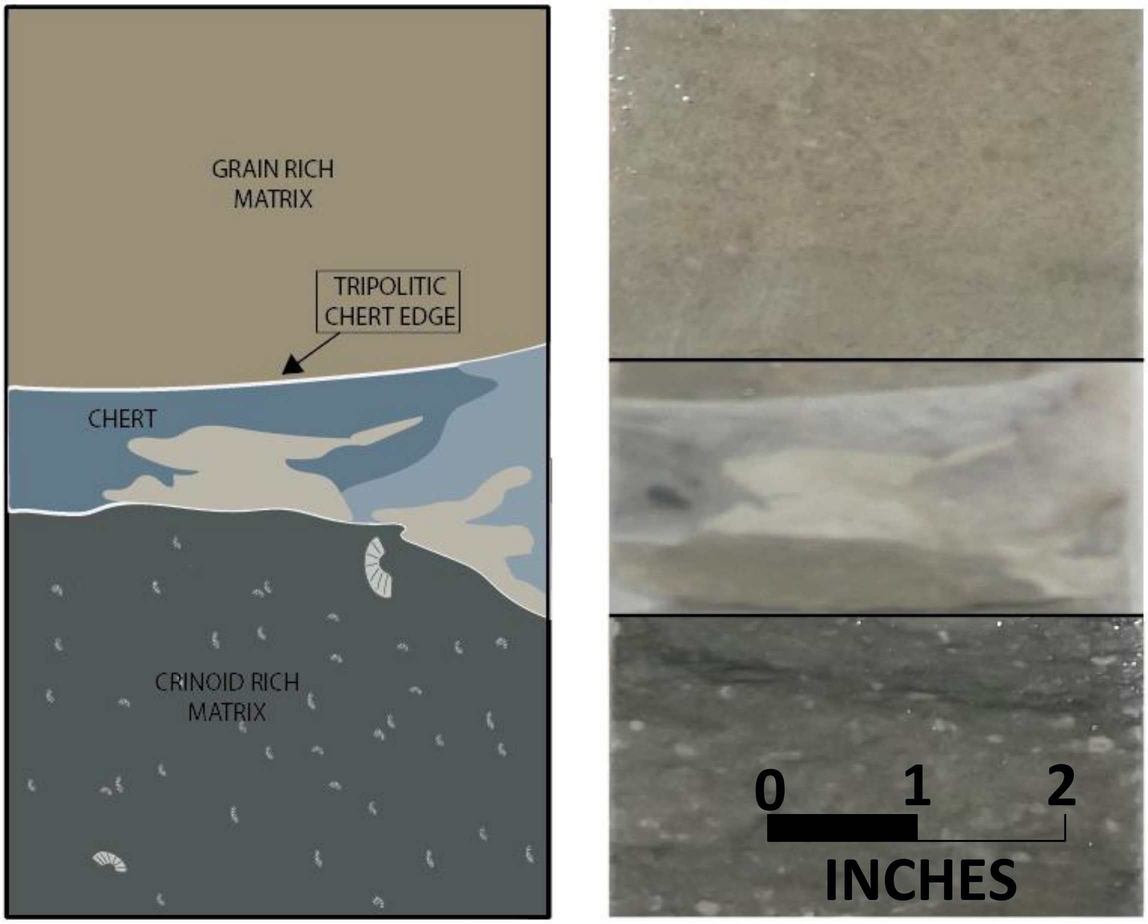


Figure 15: Stylized representation (left) and three core photographs (right) showing variation found in package two. Note the abundance of crinoid fragments in the darker carbonate matrix at the bottom of the figure and grain rich, cemented carbonate at the top. Blueridge Petroleum, Bartel #1-16. Top photo depth 3462 feet, middle photo depth 3477 feet, bottom photo depth 3483 feet.

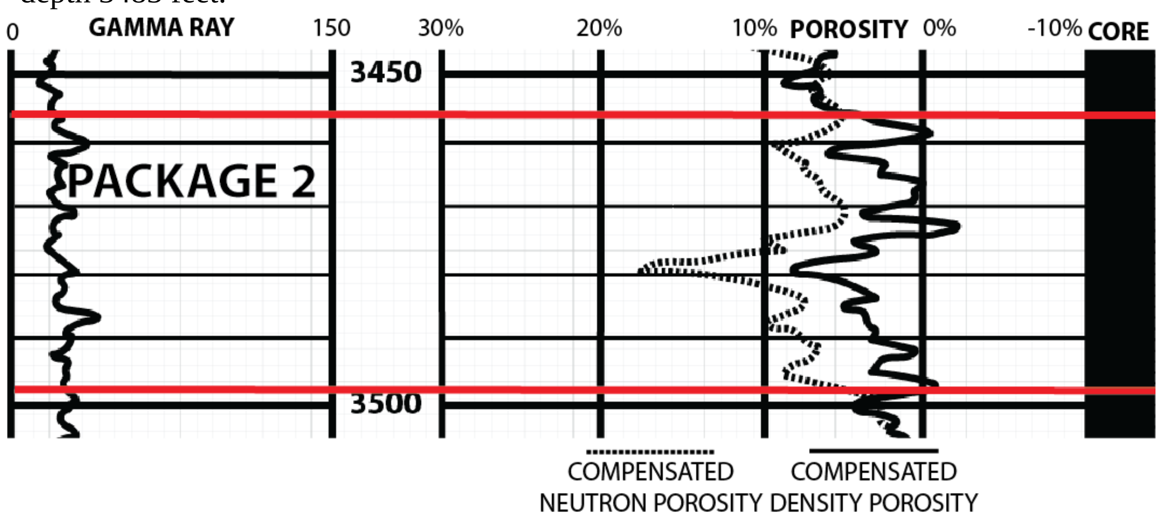


Figure 16: Gamma-ray and density/neutron porosity curves for package two in Blueridge Petroleum Corporation, Bartel #1-16. Package two shows an overall higher porosity signature compared to package one; 2-6% increase in density porosity and 4-15% increase in neutron density. Upper and lower boundary of package two is represented by red lines.

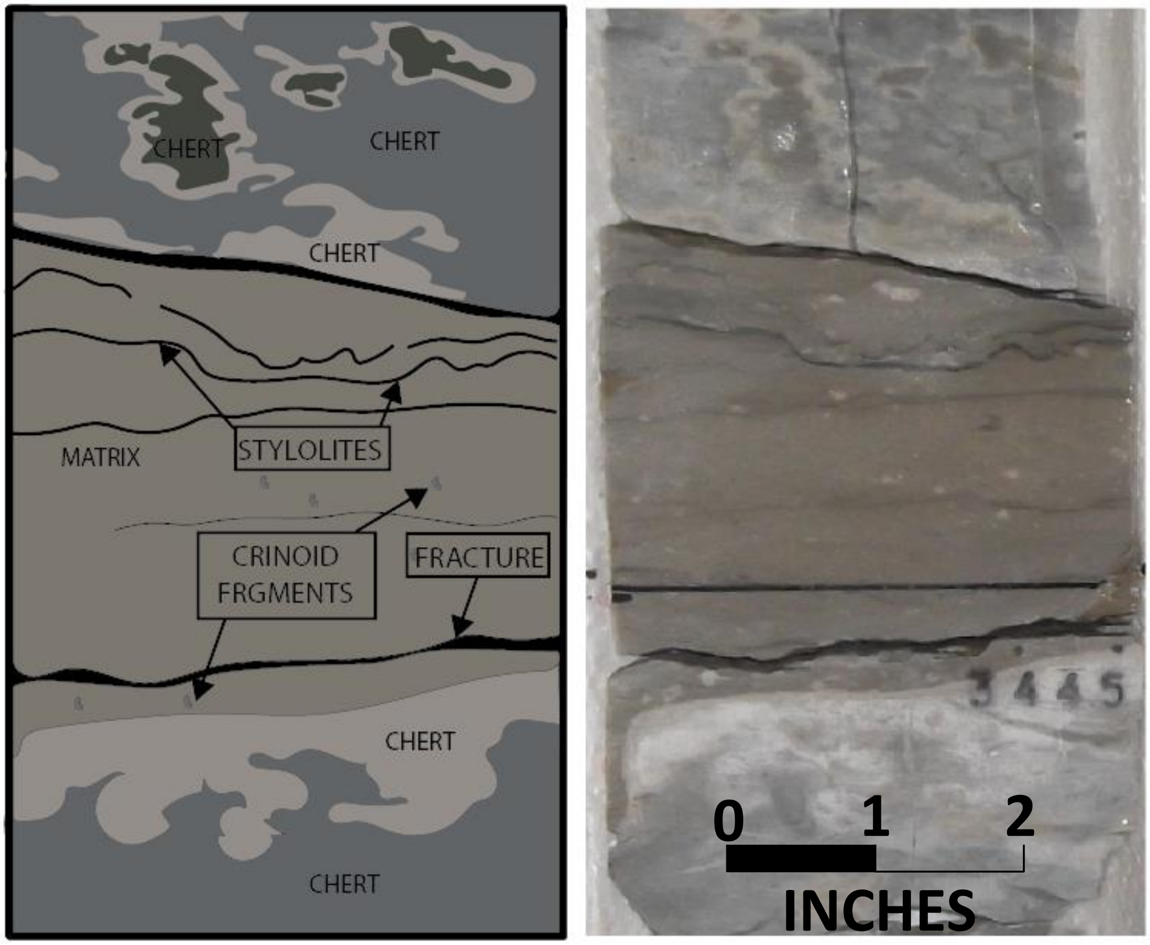
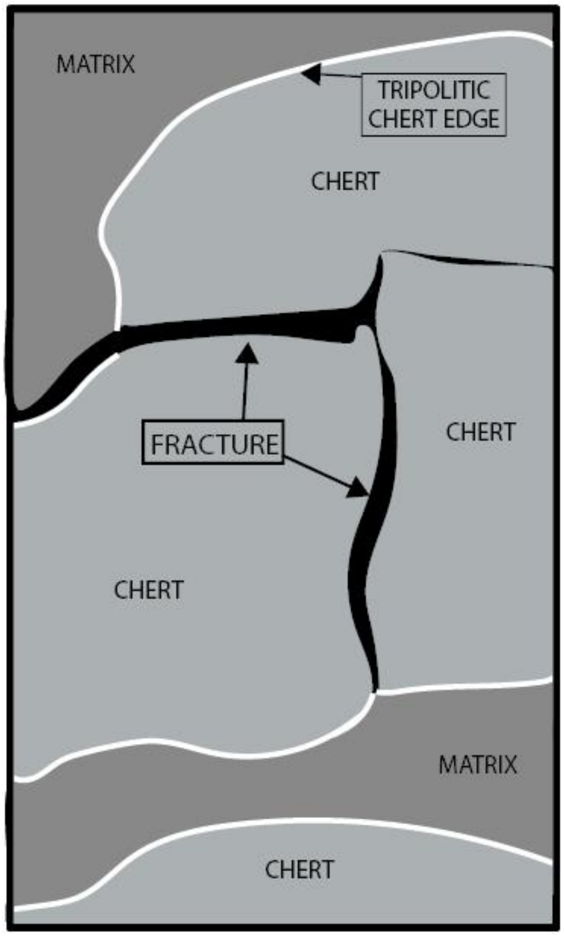


Figure 17: Stylized representation (left) and core photograph (right) of a representative section of package 3A. This package is characterized by approximately 40% chert. Blueridge Petroleum, Bartel #1-16. Depth 3445 feet.

Package four covers the footages 3395.8-3365.1 feet. It varies from a white to off-white grain-rich matrix with fine to coarse (rare) sand-sized grains and rare horizontal burrows that are millimeter scale wide by sub millimeter scale tall (burrows are not evident in core photographs) (Fig. 19). White to pale grey chert comprises approximately 30% of package four. Visible interparticle porosity and millimeter scale dissolution porosity are evident. Light oil staining occurs predominantly in the sections that contain small (millimeter-scale) burrows. The oil staining glows dull yellow under ultraviolet light. There are no visible fossil fragments in this package. On wireline logs, package four is marked by a large increase in porosity over the values observed for package 3B with the lowermost portion of package four having 22-24%

density/neutron porosity that decreases towards the top where porosity values range from 15-17% (Fig. 20).



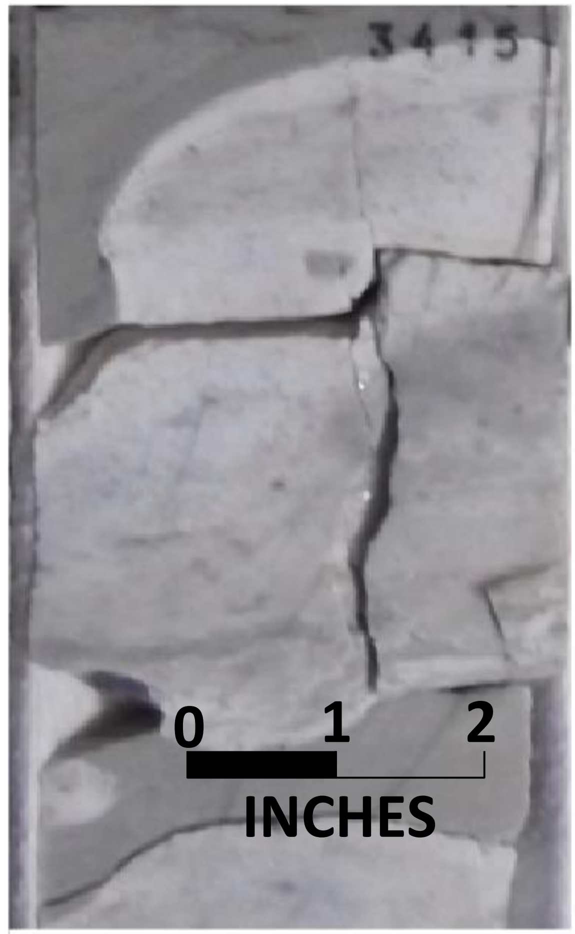


Figure 18: Stylized representation (left) and core width photograph (right) of a representative section of package 3B. Note the large amount light-colored chert and what appears to be the beginning of a tripolitic rind on the outside edge. Crinoid fragments become rare and decrease in size compared to pervious packages. Blueridge Petroleum, Bartel #1-16. Depth 3415 feet.

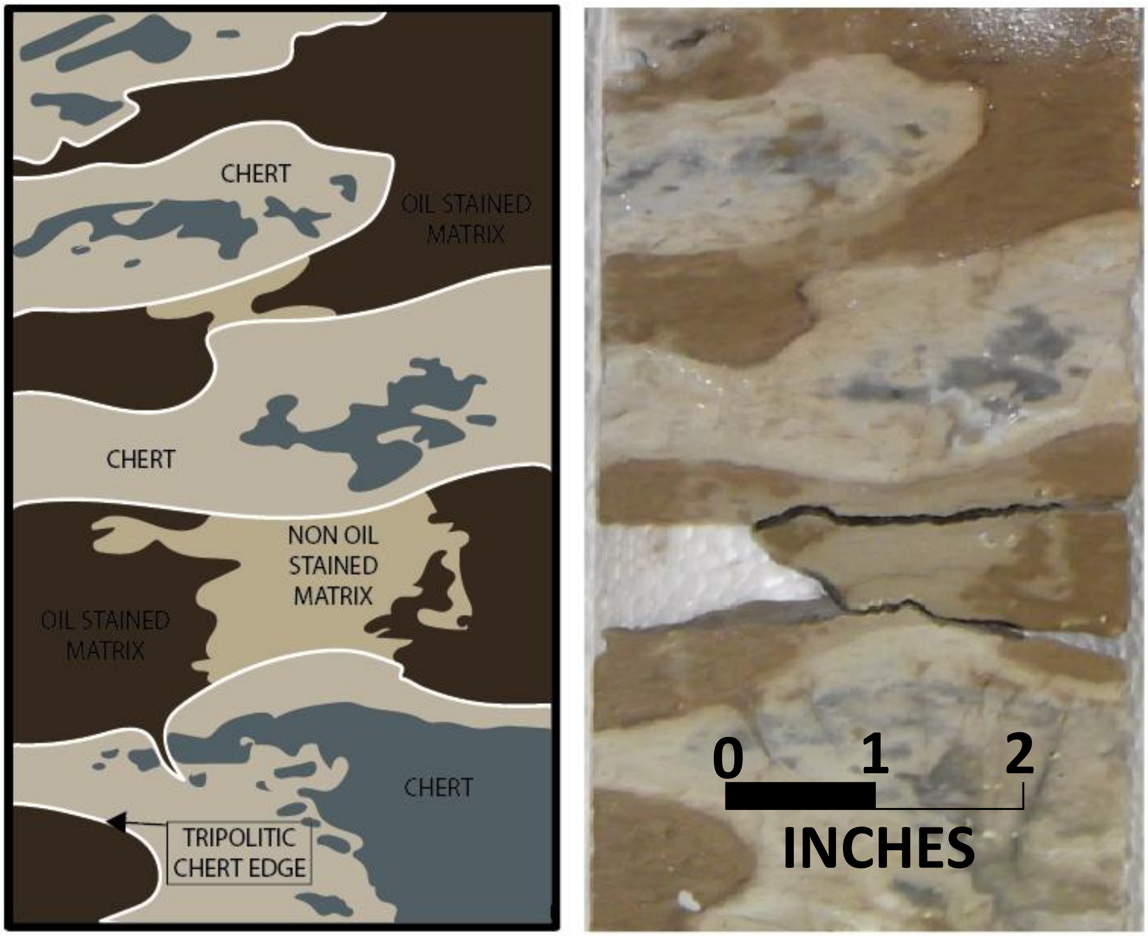


Figure 19: Stylized representation (left) and core width photograph (right) of a representative section of package 4. Note the oil stained carbonate matrix. Small (mm-scale) horizontal burrows are seen in this package with a hand lens but are not apparent in core photographs. Blueridge Petroleum, Bartel #1-16. Depth 3375 feet.

Package five covers the footages 3365.1-3340 feet. It is tan with light green wisps and is a grain-rich matrix (Fig 21). There is also white to light grey chert that composes approximately 30-40% of the package and contains interparticle porosity. Interparticle porosity occurs throughout package five in the grain-rich matrix. Oil staining is associated with both types of porosity found in package five and glows dull yellow under ultraviolet light. Porosity in package five ranges between 30% and 40% (Fig. 22).

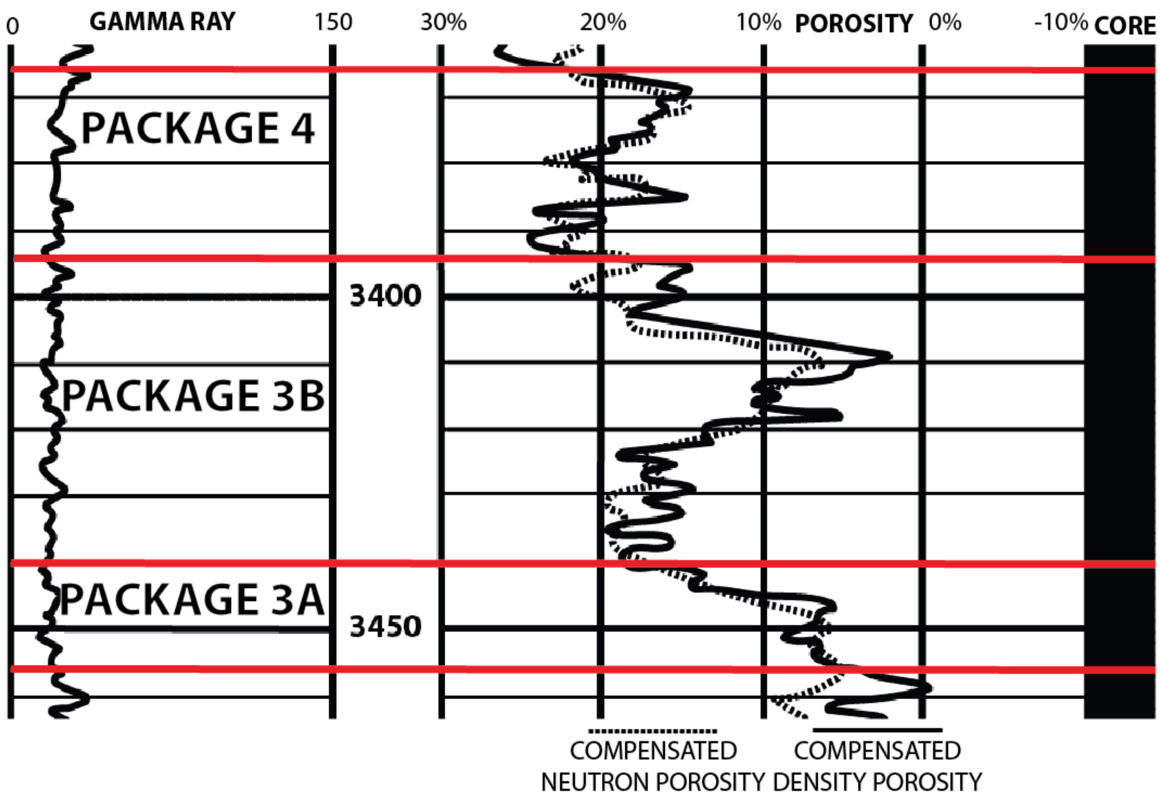


Figure 20: Gamma-ray and density/neutron porosity curves for packages 3A, 3B, and 4 in Blueridge Petroleum Corporation, Bartel #1-16. Package 3A shows a transition from the ~7% porosity of package two to the higher overall porosity signature of package 3B (7-20%). Package 4 has higher porosity (~15-23%) than package 3B. Boundaries of packages are represented by red lines.

Package six is a white to light tan tripolite that extends from 3342-3307.9 feet (Fig. 23). The percentage of tripolite increases from around 30% at the bottom of the package to 100% towards the top. Abundant oil staining occurs in this package and the section glows dull yellow under ultraviolet light. The low density of this tripolitic rock is noticeable in hand sample when similar sized pieces are compared. Average porosity measurements on the density/neutron curve exceed 30% and reaches maximum values greater than 40%. (Fig. 24). High porosity and permeability are evident in hand sample as the rock readily absorbs water.

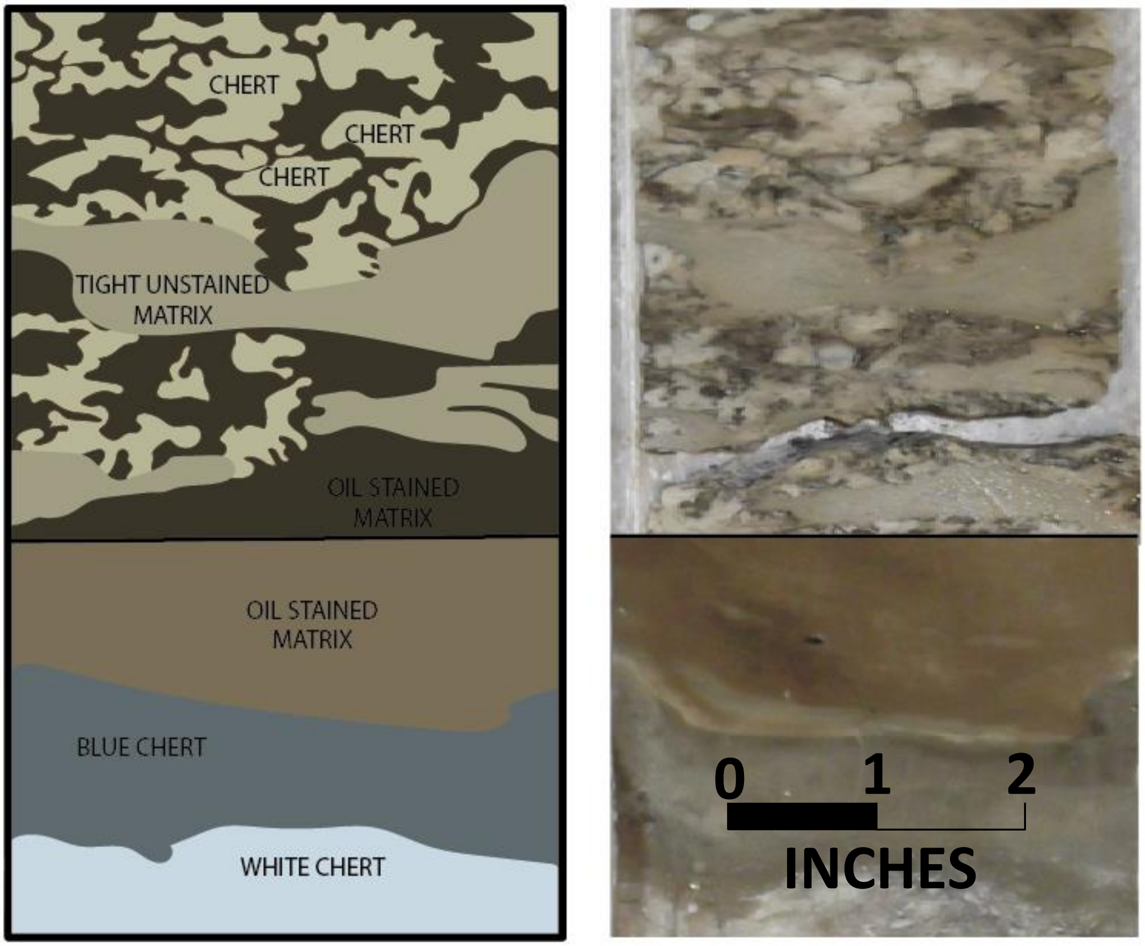


Figure 21: Annotated drawing (left) and two core photographs (right) of a representative section of package five. Note the large amount of oil staining found in this package. This is the first package that contains a significant amount of oil staining. Blueridge Petroleum, Bartel #1-16. Top photo depth 3356 feet, lower photo depth 3358 feet.

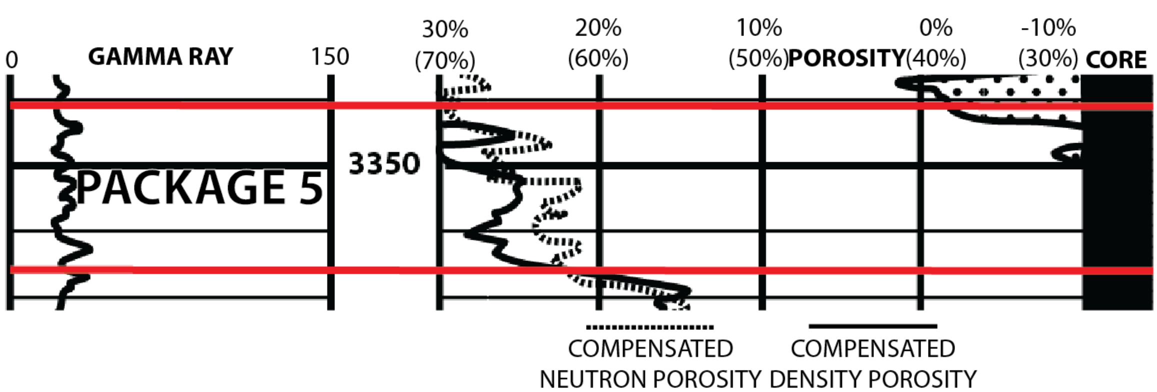


Figure 22: Gamma-ray and density/neutron porosity curves for package five in the Blueridge Petroleum Corporation, Bartel #1-16. Package five marks the highest porosity values of the carbonate (non tripolitic) section with a range of 23-33% porosity. Upper and lower boundaries of package five are represented by red lines.

The section above package six is dominated by karst features and extends from 3307.9-3290 feet. Due to weathering, this section of the core has variable lithology and fabric. Karst features seen include solution pipes, cavity filling breccias, and a light green sandy shale infill (Fig 25). This interval provides the only substantial variation in the gamma-ray curve response observed in the Mississippian carbonate interval as the gamma-ray curve contains two small increases from 3307.9 to 3290 feet (the top of the Mississippian). The increase in gamma-ray signature is attributed to the sediment infill in solution cavities generated during the exposure of the Mississippian during the pre-Pennsylvanian unconformity. This infill of sandy and shaly sediments reduces porosity values and the karst section has 15-20% porosity compared to 30-40% porosity in tripolitic package six (Fig. 26).

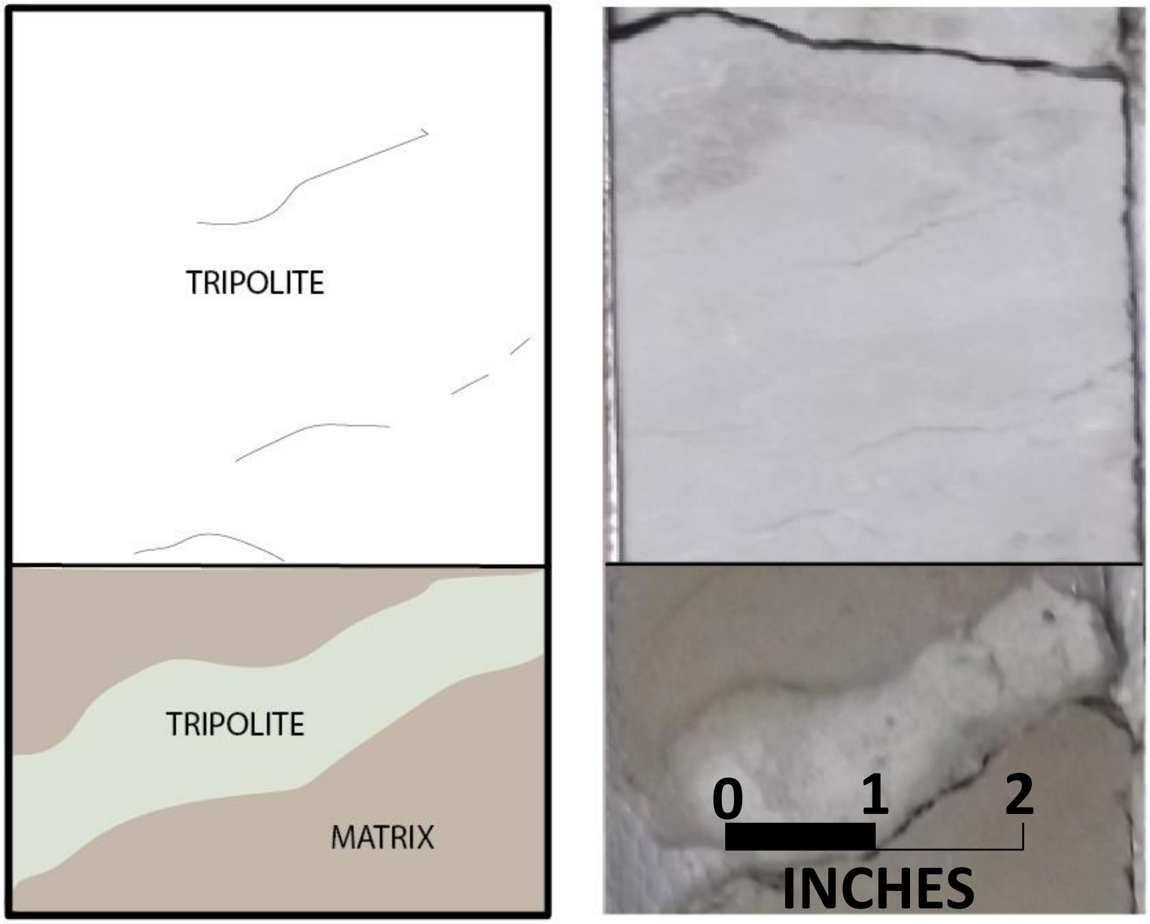


Figure 23: Stylized representation (left) and two core photograph (right) of a representative section of package six. Tripolitic chert in this package contributes to the high 30-40% porosity. The high porosity is also accompanied by a high permeability as evidenced by the inability to keep the rock surface wet due to rapid absorption. Blueridge Petroleum, Bartel #1-16. Top photo depth 3316 feet, lower photo depth 3313 feet.

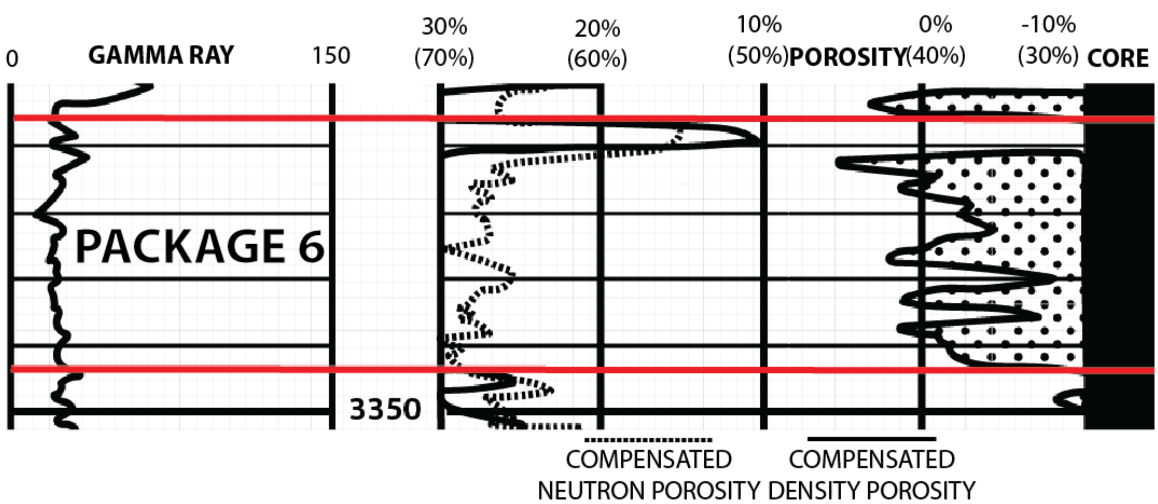


Figure 24: Gamma-ray and density/neutron porosity curves for package six in the Blueridge Petroleum Corporation, Bartel #1-16. Package six has the highest porosity values in the Mississippian carbonate section and is attributed to the tripolitic chert in this package. Upper and lower boundaries of package six are represented by red lines.

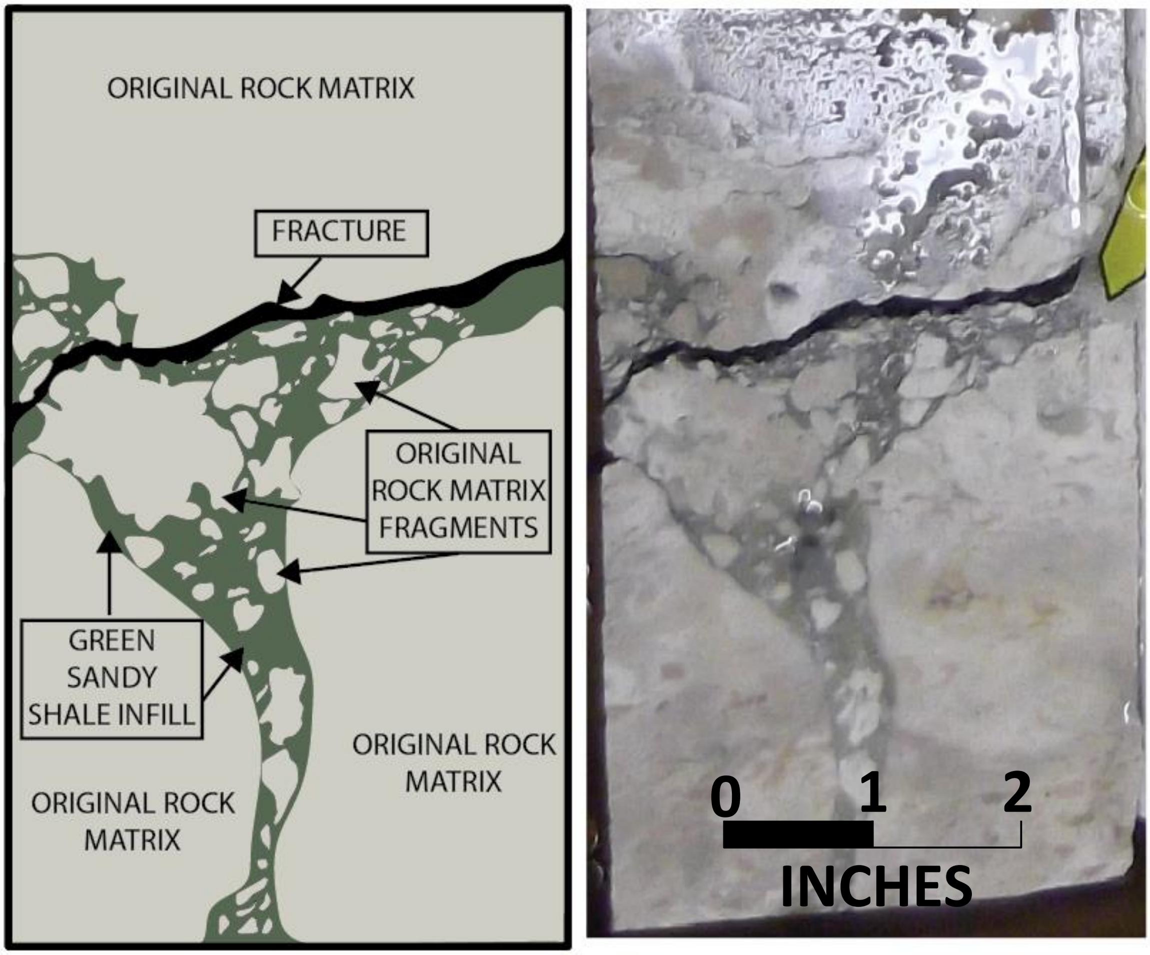


Figure 25: Annotated drawing (left) and core photograph (right) of a representative section of the karsted/weathered package. The extensively weathered rock has sediment infill and lower porosity values than the porous tripolitic chert found in package six. Blueridge Petroleum, Bartel #1-16. Depth 3303 feet.

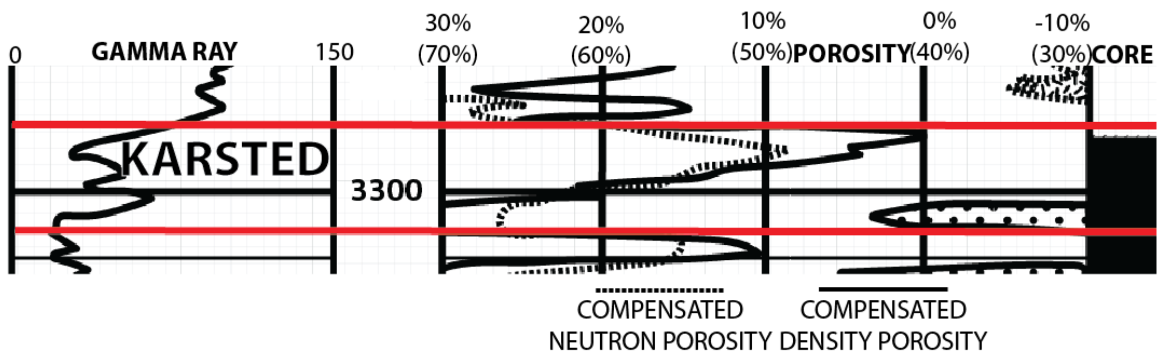


Figure 26: Gamma-ray and density/neutron porosity curves for the karsted/weathered package above package six in Blueridge Petroleum Corporation, Bartel #1-16. Infill of sandy and shaly sediments into the weathered carbonate is the cause of a large range in porosity and the only noticeable variation in gamma-ray signature within the Mississippian carbonate. Upper and lower boundaries of the karsted package are represented by red lines.

INTERPRETATION

The sedimentary packages observed in the Bartel #1-16 core exhibit an upward cleaning or shallowing upward signature. From package one to package five the carbonates exhibit an overall shoaling upwards trend. Package one with its high frequency fining-upward cycles is interpreted to have been deposited in a restricted distal position on the ramp below the storm wave base and received clasts and crinoid fragments from farther up the ramp in pulses associated with storms (Fig. 27 and 29). Package two is interpreted to represent a slightly proximal shift on the ramp to a depth fluctuating from slightly above to slightly below normal wave base corresponding to the increase in grain size and the more evenly distributed crinoid fragments (Fig. 27 and 29). Package 3A is interpreted to be part of a lower shoreface as evidenced by a mixture of mud-rich to grain-rich packstone composed of fine to medium sized carbonate grains (Fig. 27 and 29). Package 3B is interpreted to have been deposited in a shoreface environment similar to 3A but slightly more proximal corresponding to a decrease in mud and a slight increase in grain size (Fig. 27 and 29). Package four is slightly less muddy and has slightly larger grains as compared to 3B and is interpreted have been deposited in a foreshore environment (Fig. 27 and 29). Package five is interpreted to represent deposition in a supratidal zone as evidenced by the fine grains (Fig. 27 and 29). Packages three (A and B) and four are extensively altered with much of the original sediment replaced by chert making depositional features in much of the packages unrecognizable. Without diagnostic features to correlate to depositional process or a particular depositional environment it was very difficult to interpret. Package six was near completely replaced by chert that was subsequently weathered to tripolite, resulting in no diagnostic depositional features. All section above package six is too extensively weathered and brecciated to be of any use in the interpretation of original depositional features.

It is interpreted that the cored Mississippian carbonate section in the Bartel #1-16 represents a proximal position on the distally steepened ramp (Fig. 27). When the location is compared to the current pre-Pennsylvanian subcrop map, it seems logical that the Mississippian section at this location represents early to middle Mississippian sedimentation (Fig. 28) The occurrence of supratidal sedimentation in package five and possibly package six suggests a proximal depositional setting with minimal accommodation. With that in mind, it is possible that during the deposition at this location accommodation controlled Mississippian thickness and may have influenced subsequent deposition as the lack of accommodation forced younger sediments towards the basin axis. As a result, younger sedimentation prograded away from the proximal position of the Bartel #1-16 and into the basin.

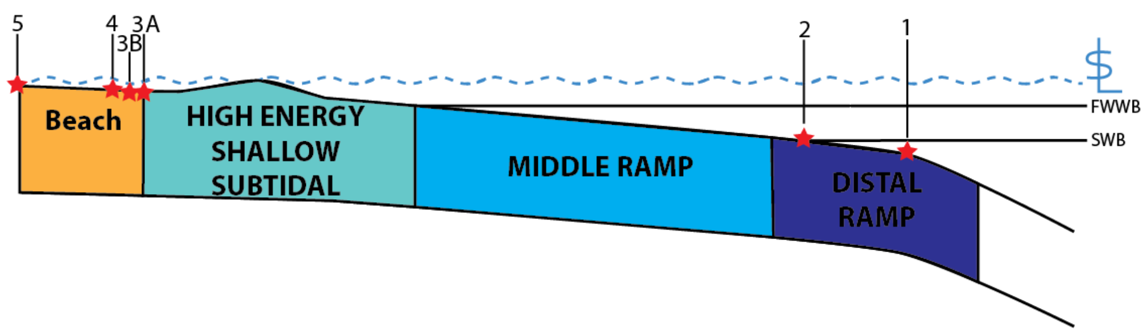


Figure 27: Cross section of a carbonate ramp with stars that indicate interpreted depositional environment for each package. Modified from Kaufman and Jameson (2002).

While the gamma-ray signature did not exhibit enough variation in the Bartel #1-16 or surrounding wells to be used to correlate the surfaces identified in the core, other log tracks, especially the compensated density/neutron porosity log, were useful in identifying the depositional packages and were the basis for log correlations across the area.

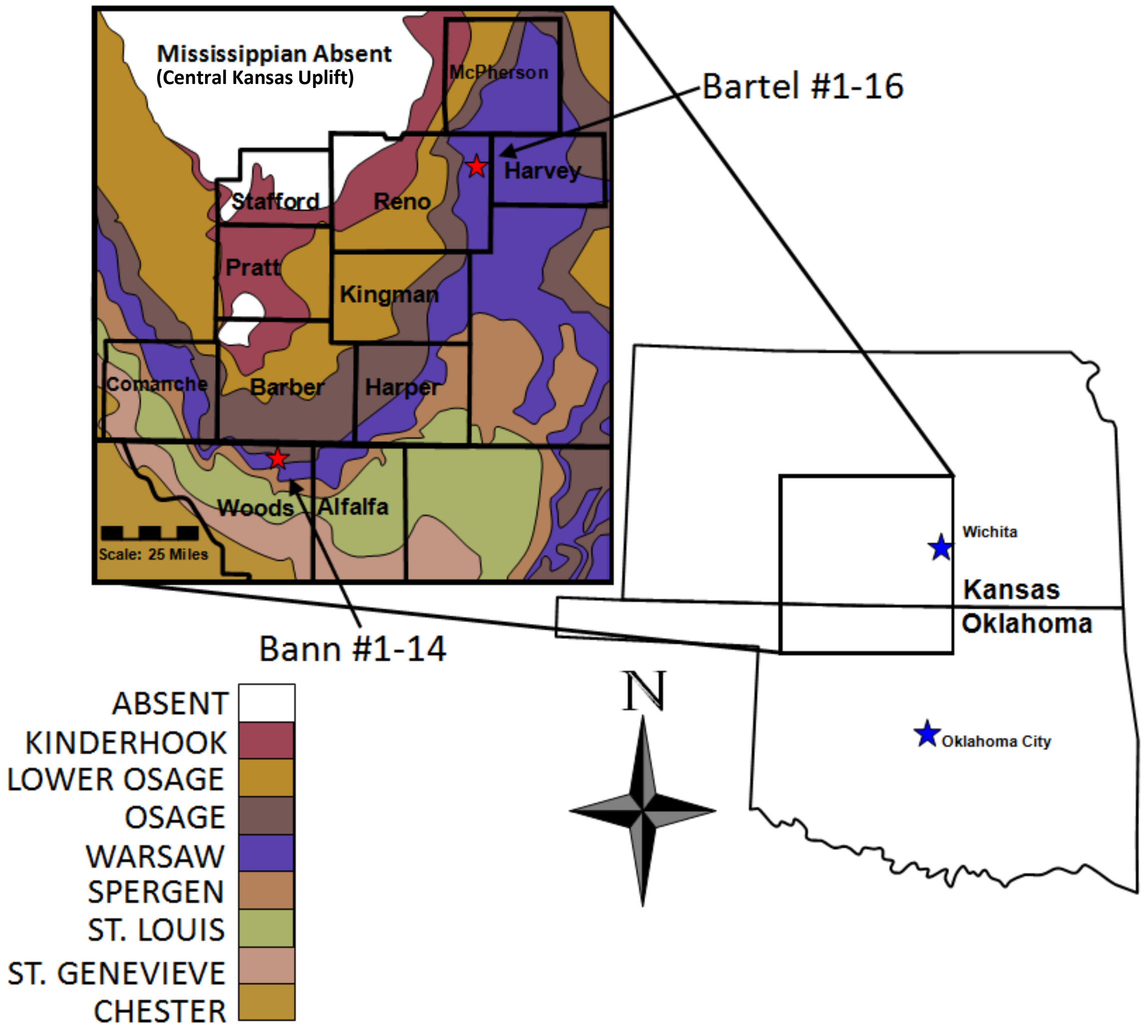


Figure 28: Map showing the location of the Bartel #1-16 in relationship to the current Pre-Pennsylvanian subcrop map. Modified from Sandridge (2013).

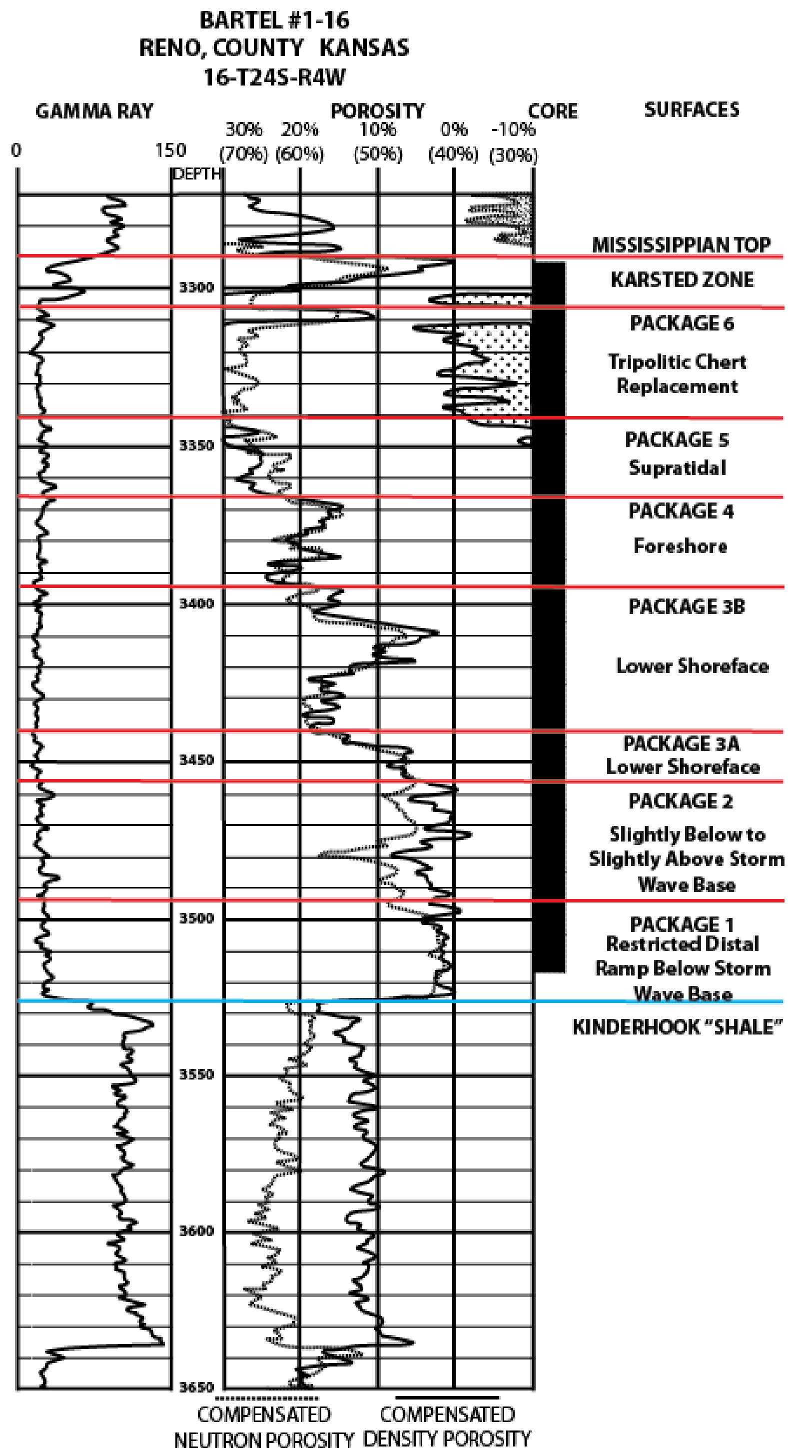


Figure 29: Section of the wireline log for the Blueridge Petroleum Bartel #1-16. The gamma-ray curve is in track one to the left of the depth track. The density/neutron curve is located on the right in track two. The black box right of the log indicates the cored interval. The interpreted depositional environments for the packages are posted to the right of the core.

BANN #1-14

Chesapeake Energy Corporation drilled the Bann #1-14 in September of 2007 in S14-T28N-R14W of Woods County, Oklahoma (Fig. 30). The well was cored from 5205 feet to 5355 feet (150 feet). Of the cored interval, fifteen feet of core was not recovered from 5230 feet to 5243 feet. The core is composed of 147 feet of the Mississippian carbonate and 3 feet of the shale-dominated Pennsylvanian section. Approximately 295 feet of Mississippian carbonate section was not cored. The entire Mississippian section is 442 feet thick in this well and extends from 5208 feet to 5650 feet (Fig. 31). Two open-hole logs were used, compensated density/neutron log and a dual induction log. Both resistivity and porosity suites were run in conjunction with the gamma-ray tool.

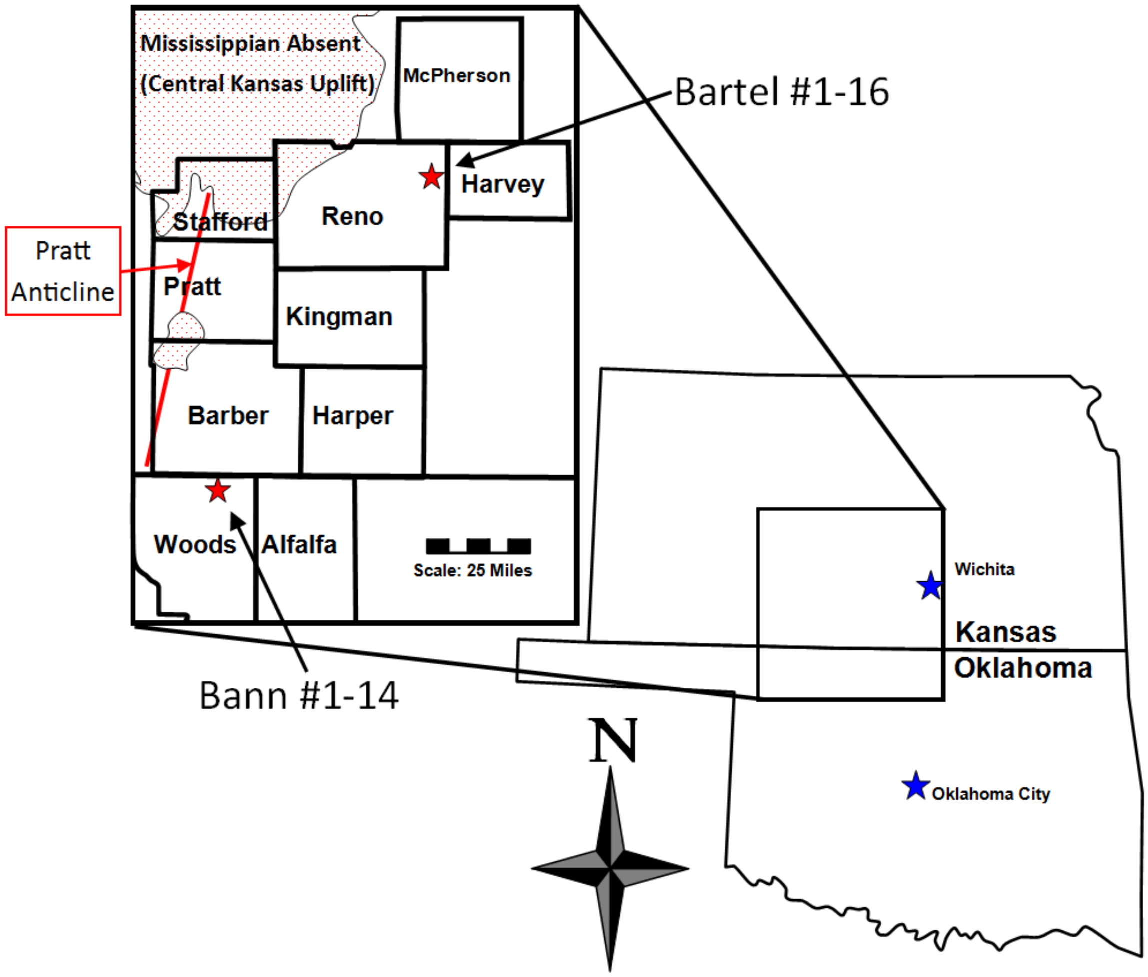


Figure 30: Map showing the location of the Bann #1-14 in relationship to Pratt Anticline and the Central Kansas Uplift.

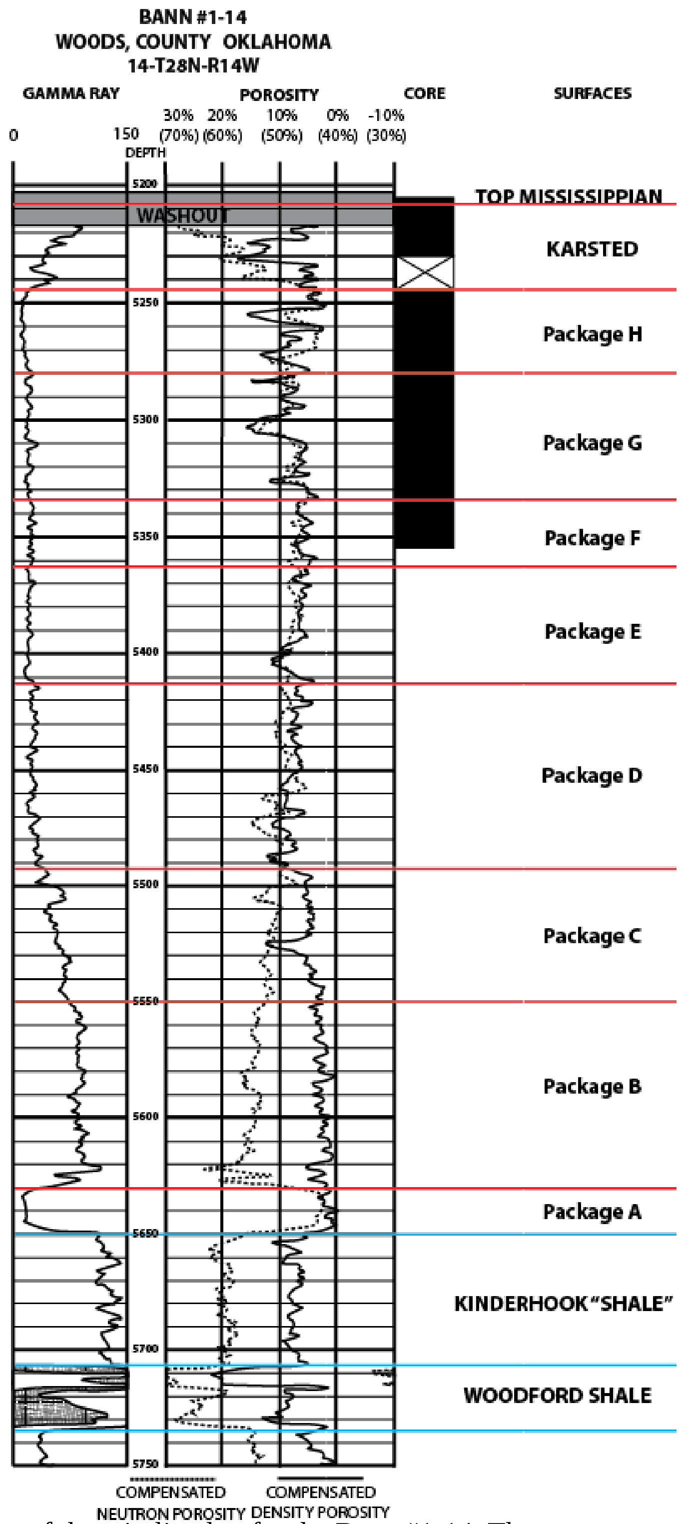


Figure 31: A section of the wireline log for the Bann #1-14. The gamma-ray is to the left of the depth track and the density/neutron are to the right. Right of the density/neutron curves a box indicates the cored interval. The top of the Mississippian carbonate and the surfaces within the carbonate interval are indicated with red lines and labeled to the right. The bottom of the Mississippian carbonate and top of the Kinderhookian "Shale" are indicated with a blue line below package one. The Woodford Shale is present below the Kinderhook "Shale".

DESCRIPTION

The description of the Chesapeake Energy Corporation's, Bann #1-14 was provided by Jaeckel (2015) who is establishing a high-resolution sequence stratigraphic framework for the cored interval. The description included in this study concentrates on the petrophysically significant packages determined by core and wireline logs. The Mississippian section in this well is divided into 9 petrophysically significant packages. In this well correlations from the core to the well log and from well log to well log in cross section were done using the gamma-ray curve (Fig. 32). Due to the large section of Mississippian that was not cored, only packages F, G, H, and the karsted package are represented in the core, whereas packages A-E are divided solely based on gamma-ray and porosity log characteristics. The core description was obtained using the polished library set and thin sections.

Package A is the lowermost package contained in the well and extends from 5650 to 5630 feet. Package A is characterized by a low gamma-ray value (<20 API) and by low 1-4% density/neutron porosity (Fig. 33). Package B in the Bann #1-14 extends from 5630 to 5550 feet and is characterized with the highest gamma-ray signature in the Mississippian carbonate section and 8-10% porosity (Fig. 34). Package C begins at 5550 feet and ends at 5494 feet. It represents the transition from the higher gamma-ray values of package B to the consistently lower gamma-ray values of package D. Package C has density/neutron porosity from 7-12% and gamma-ray values of 75-30 API (Fig. 35). Package D (5494 to 5412 feet) is characterized by slight decrease in gamma-ray across the package and gamma-ray values of <40 API. Density/neutron porosity ranges from 7-12% with higher porosity near the base at 5494 feet and lower values towards the top at 5412 feet (Fig. 36). Package E begins at 5412 feet and ends at 5362 feet. It represents the lowest gamma-ray values observed in the Mississippian section and changes very little from the base of package E to the top of package H (Fig. 37). Package E is characterized by density/neutron porosity values from 5-11% (Fig. 37).

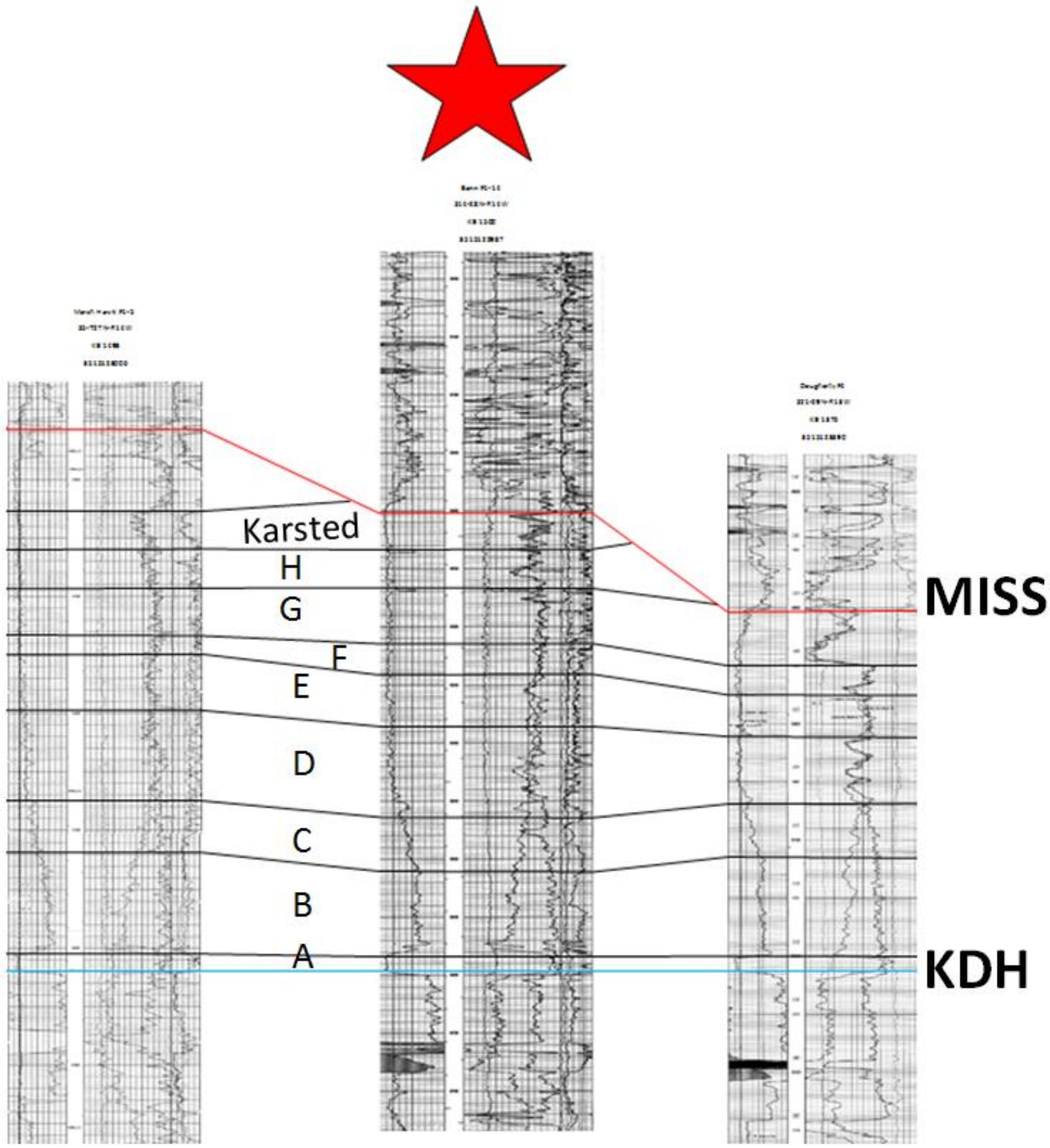


Figure 32: Cross section showing the correlation of packages using gamma-ray curves with the Bann #1-14 located in the center. Packages A-D are the better correlations because of the presence of the similarity in gamma-ray profiles. Packages E-H have lower confidence in correlations because this portion of the section has few distinctive features in the gamma-ray or the density/neutron porosity that are correlatable. This made the correlations for E-H more tenuous.

Package F extends from 5362 to 5334 feet. Only the uppermost portion of package F was cored. It is a light to medium grey, grain-rich packstone to grainstone that contains sub-millimeter scale crinoid fragments, mildly bioturbated and contains centimeter scale clasts in the upper 9 feet (5343-5334) (Fig. 38). Package F is composed of approximately 10% blue grey chert. On logs it is characterized by a clean gamma-ray signature with very little variation and porosity ranging from 5-8% (Fig. 39). The portion of package F captured in the core, 5355 feet to 5334, is heavily oil stained and glows bright yellow under ultraviolet light.

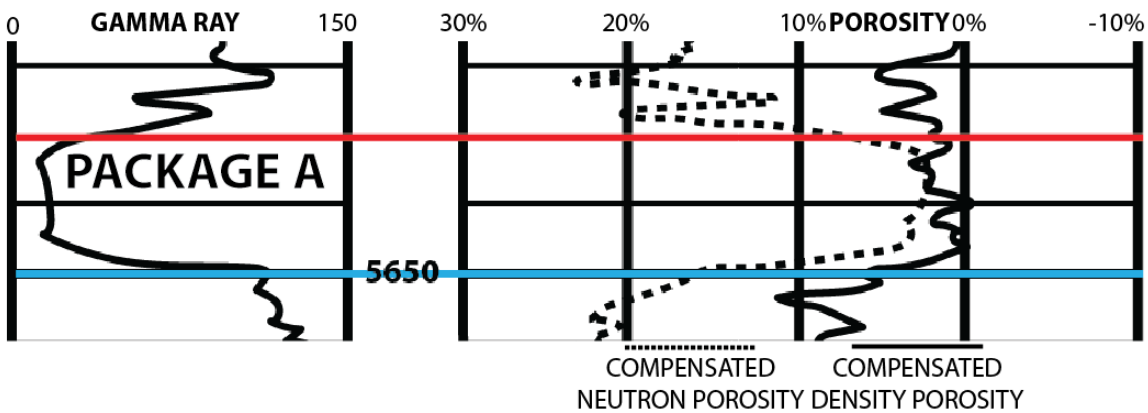


Figure 33: Gamma-ray and density/neutron porosity across package A in the Chesapeake Energy Corporation, Bann #1-14. Contact between package A and the Kinderhookian "Shale" (blue line) below is characterized by a decrease in gamma-ray and porosity values from the Kinderhookian shale to package A.

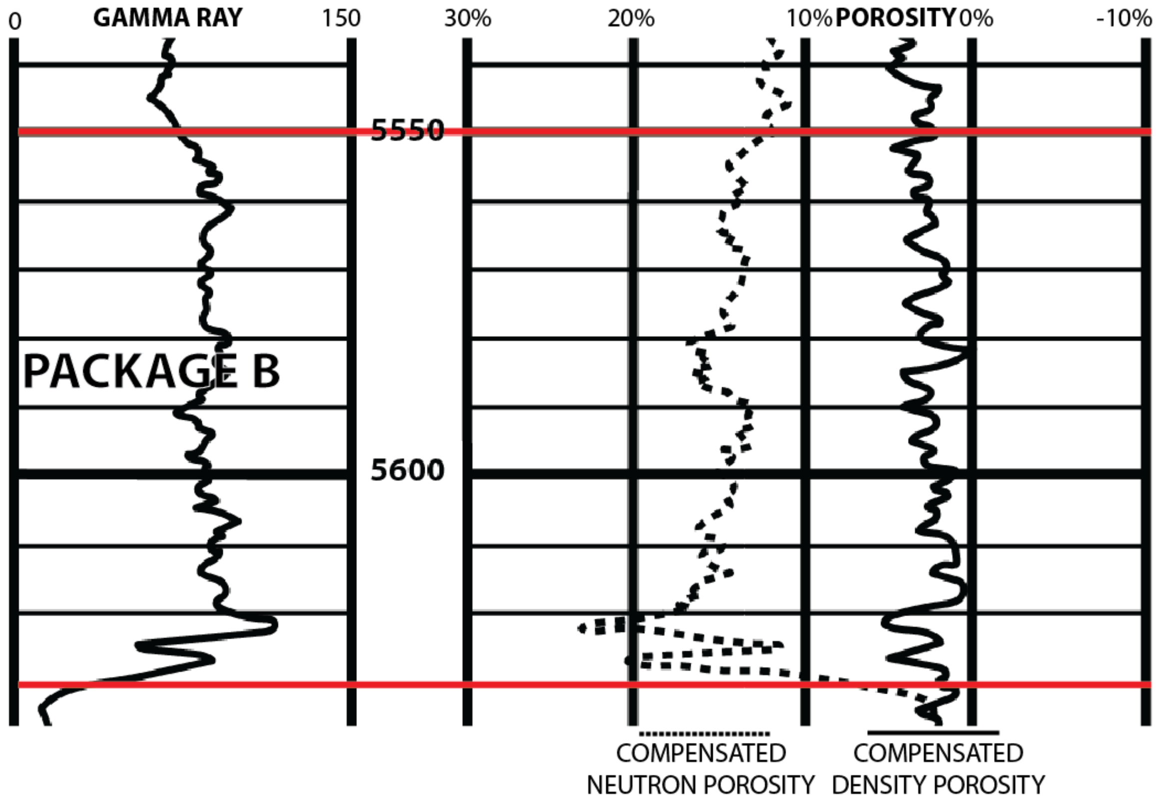


Figure 34: Gamma-ray and density/neutron porosity across package B in the Chesapeake Energy Corporation, Bann #1-14. Contact between package A and B is represented by a sharp increase in gamma-ray values from <15 API to >75 API and an increase in density/neutron porosity to mostly >7%.

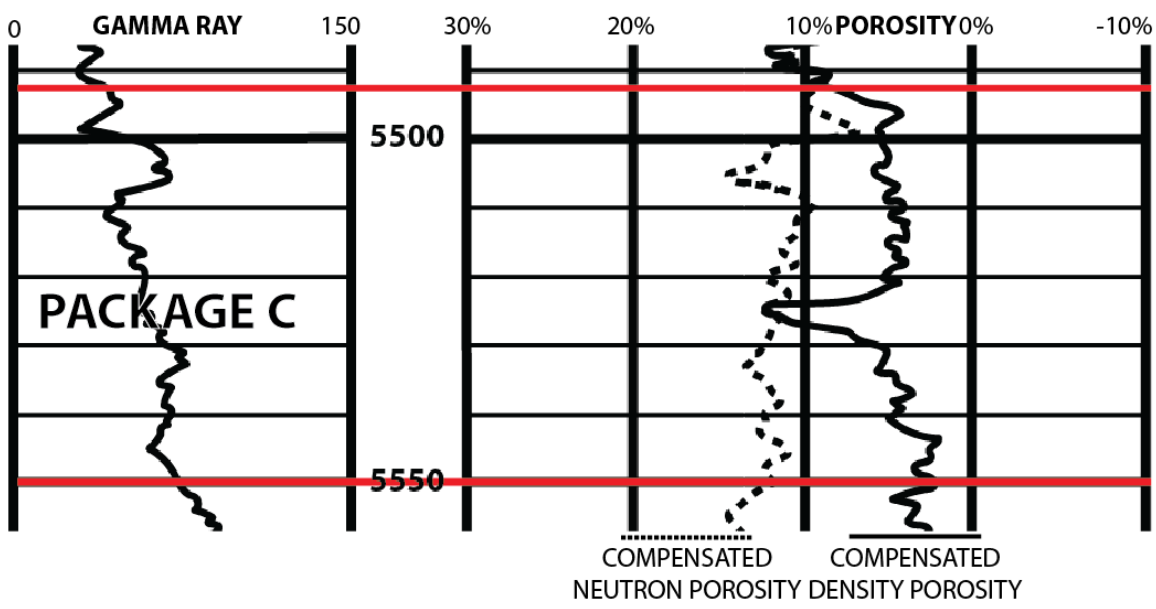


Figure 35: Gamma-ray and density/neutron porosity curves across package C in the Chesapeake Energy Corporation, Bann #1-14. Gamma-ray steadily decreases across package C from ~75 API at the base to ~50 API near the top of the package. Density/neutron porosity increases from slightly <7% near the base to ~9% at the top of the package.

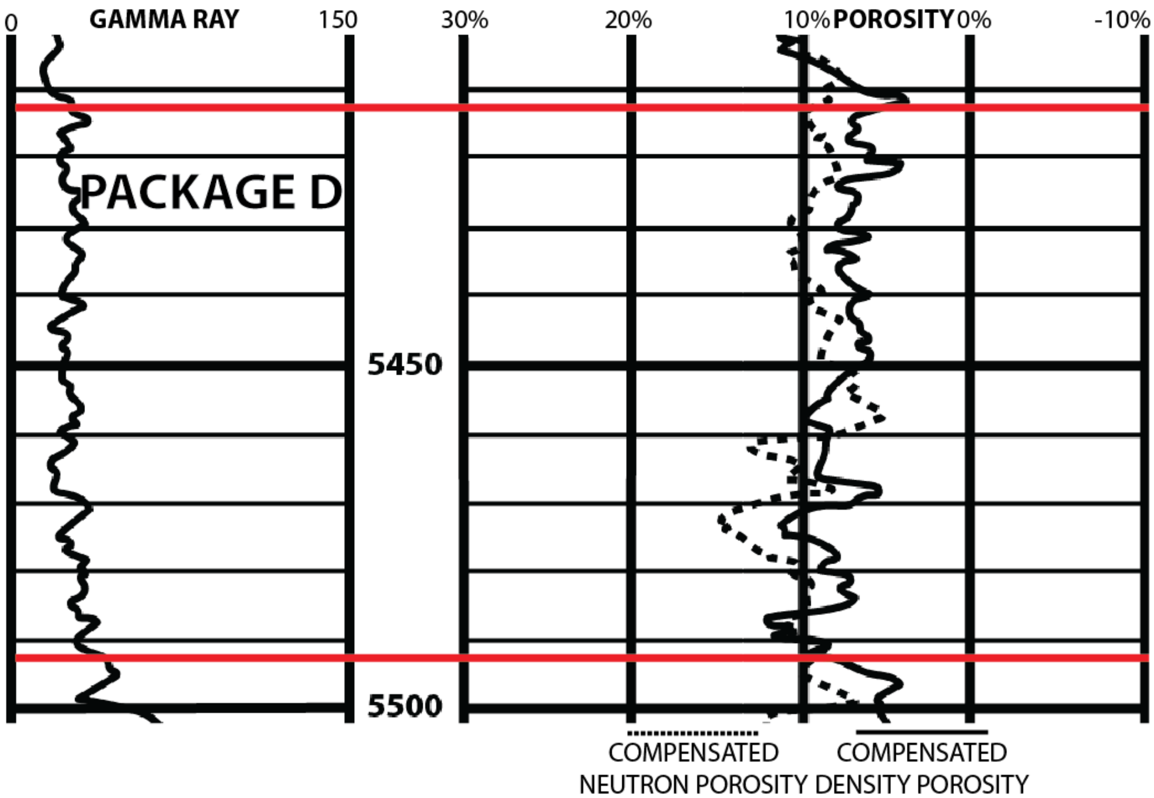


Figure 36: Gamma-ray and density/neutron porosity across package D in the Chesapeake Energy Corporation, Bann #1-14. Gamma-ray decreases slightly across package D from ~50 API to <40 API at the top of the package. Density/neutron porosity values decrease from ~12% to ~7%.

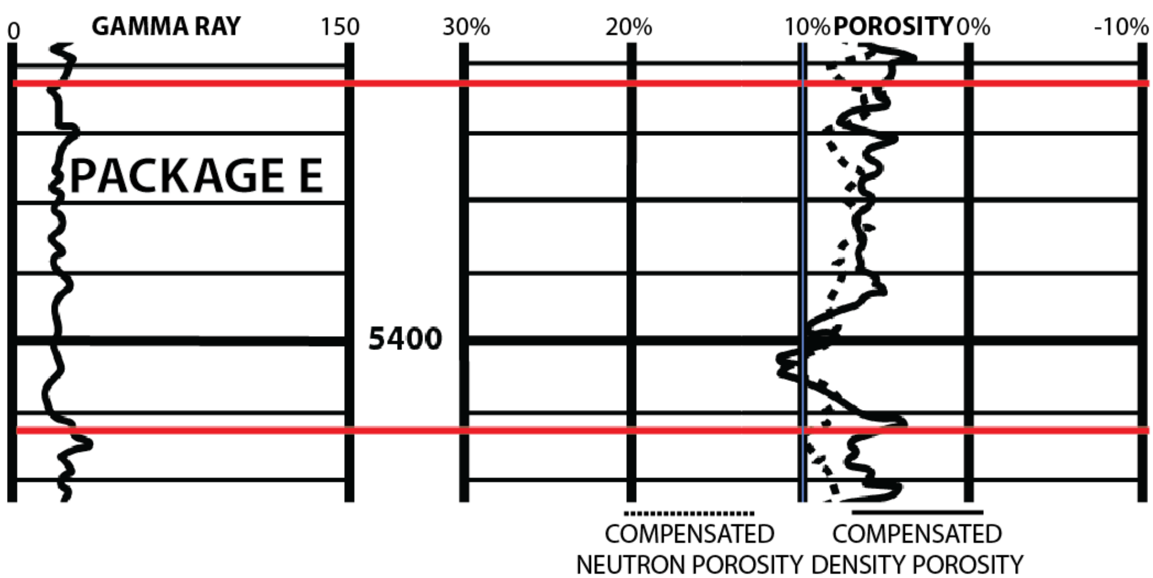


Figure 37: Gamma-ray and density/neutron porosity across package E in the Chesapeake Energy Corporation, Bann #1-14. Gamma-ray has no noticeable variation in package E. Density/neutron porosity values decrease from ~8% to ~6%.

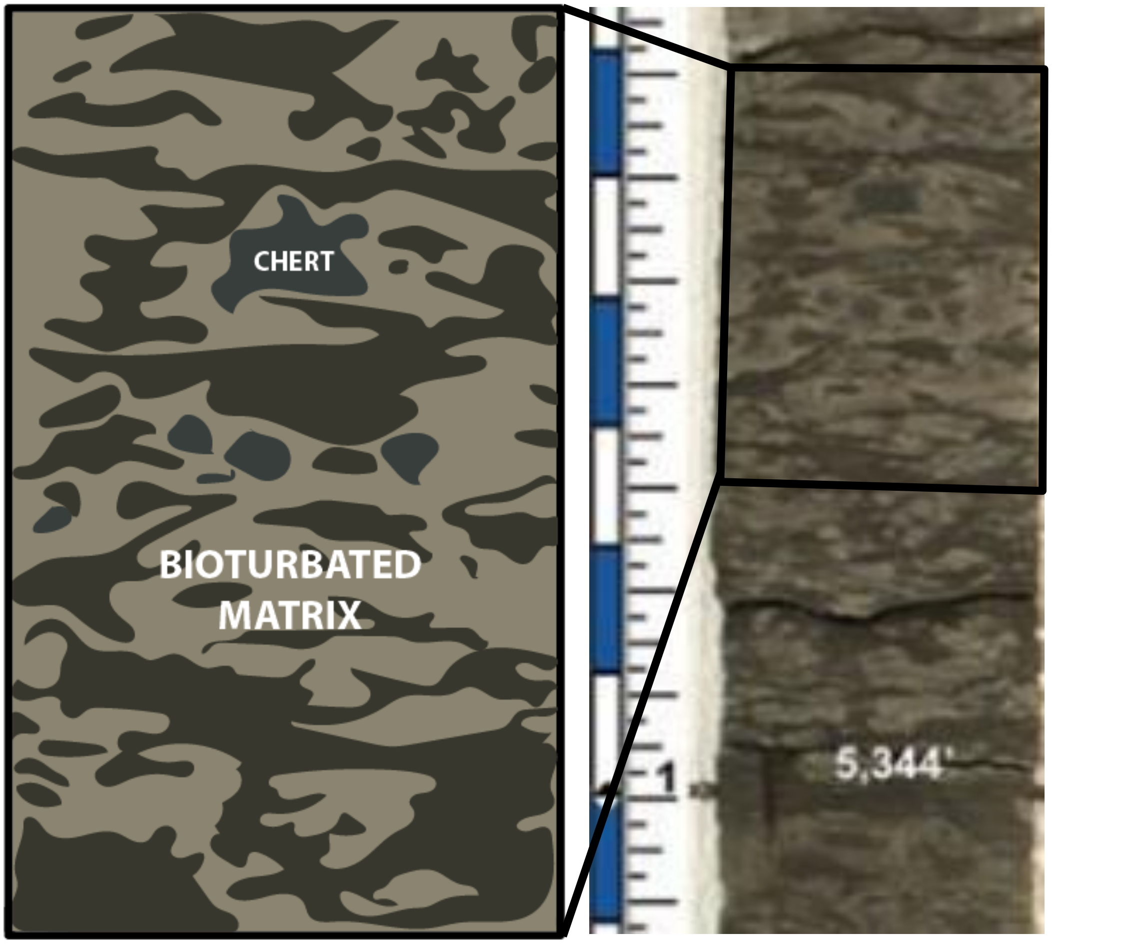


Figure 38: Stylized representation (left) and corresponding core photograph (right) of a representative section of package F. The mildly bioturbated rock has few distinguishable features and is heavily oil stained. Chesapeake Energy Corporation, Bann #1-14. Depth 5343 feet.

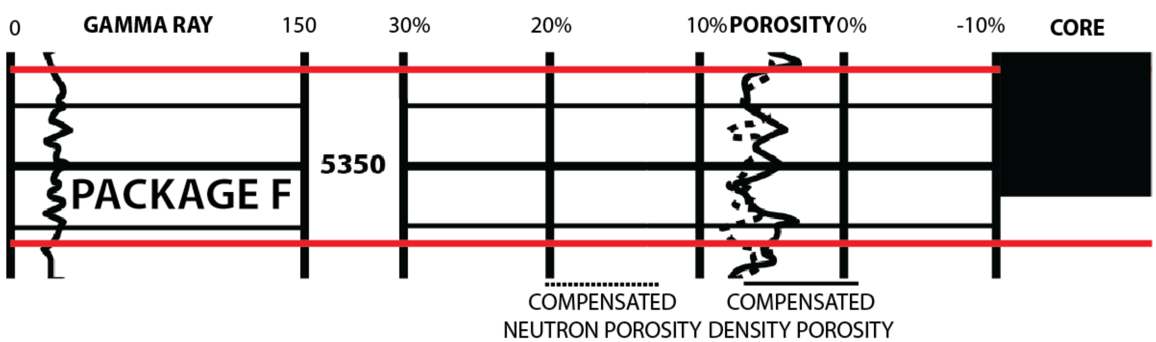


Figure 39: Gamma-ray and density/neutron porosity curves across package F in the Chesapeake Energy Corporation, Bann #1-14. Gamma-ray is relatively constant around 30 API, whereas density/neutron porosity ranges from 5-7%.

Package G is the second in the cored interval and covers 5334 to 5280.3 feet. The entirety of package G is represented in the core and contains a light to dark tan mud-rich packstone that grades upwards into grain-rich packstone with sub millimeter scale crinoid fragments and mild to heavy bioturbation (Fig. 40). Package G contains approximately 20-40% dark-blue grey chert that occurs as bedded and irregular nodular forms. On logs, the well is characterized by a clean gamma-ray signature (~30 API) with little to no fluctuation and porosity ranging from 5-16% (Fig. 41). The uppermost section of package G is heavily oil stained and glows bright yellow under ultraviolet light.

Package H extends from 5280.3 to 5244 feet and is entirely cored. It is an off white to dark tan grain-rich packstone to grainstone with sub-millimeter scale crinoid fragments and is mildly to heavily bioturbated (Fig. 42). It is composed of approximately 30-50% of dark blue grey chert. On logs, this package is characterized as the cleanest gamma-ray signature (<30 API) with no fluctuation and porosity ranging from 4-12% (Fig. 43). Package H is heavily oil stained and glows bright yellow under ultraviolet light.

Above package H is a karsted section from 5244-5208 feet. The lowermost portion of this package (5243-5230 feet) represents the 15 feet of core that was unrecoverable. It is assumed that this unrecoverable portion has similar exposure features that are seen in the section of core above it. The karsted section is highly variable because of weathering features including solution pipes, karst associated breccias, and eroded mobilized blocks (Fig. 44). This portion of the core has an increasing gamma-ray signature and is represented by a range of porosity values from 10-18% (Fig. 45). The caliper curve from 5218-5202 feet shows the bore hole is larger than bit size and due to poor quality tool responses this portion of the log was not used.

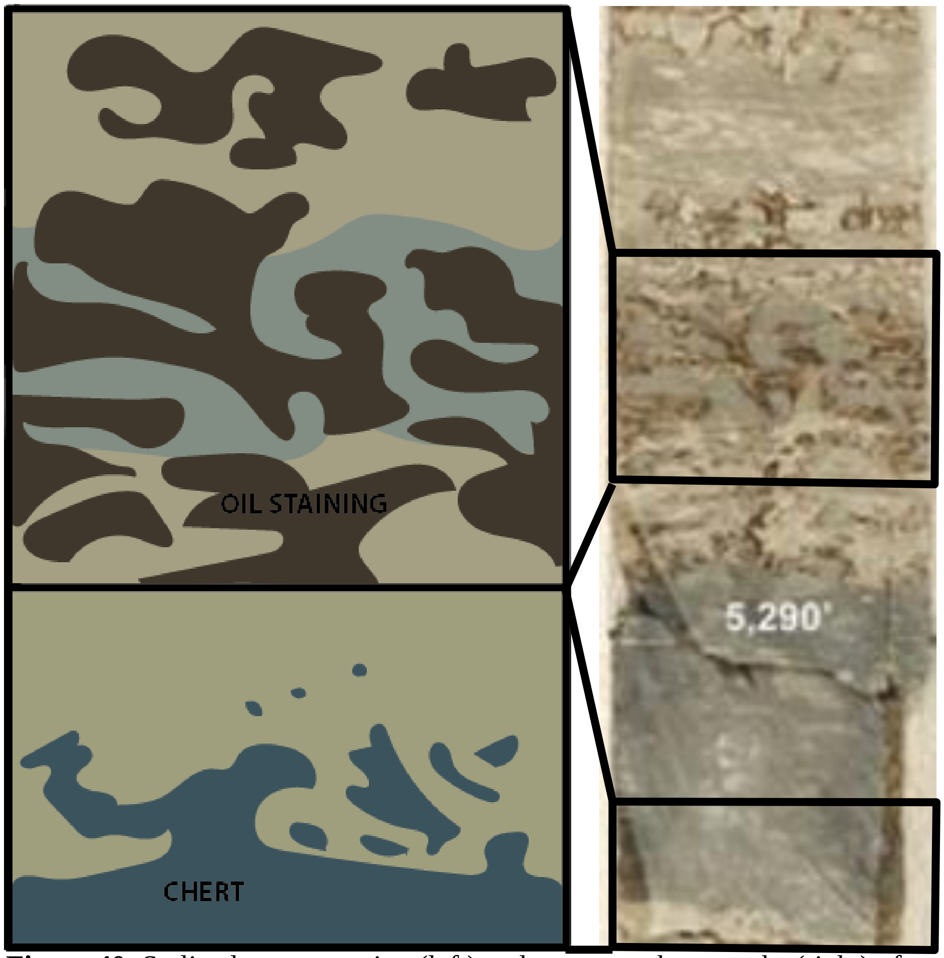


Figure 40: Stylized representation (left) and two core photographs (right) of a representative section of package G. The mildly to heavily bioturbated rock has few distinguishable features and is heavily oil stained. Chesapeake Energy Corporation, Bann #1-14. Top photo depth 5289 feet, lower photo depth 5290 feet.

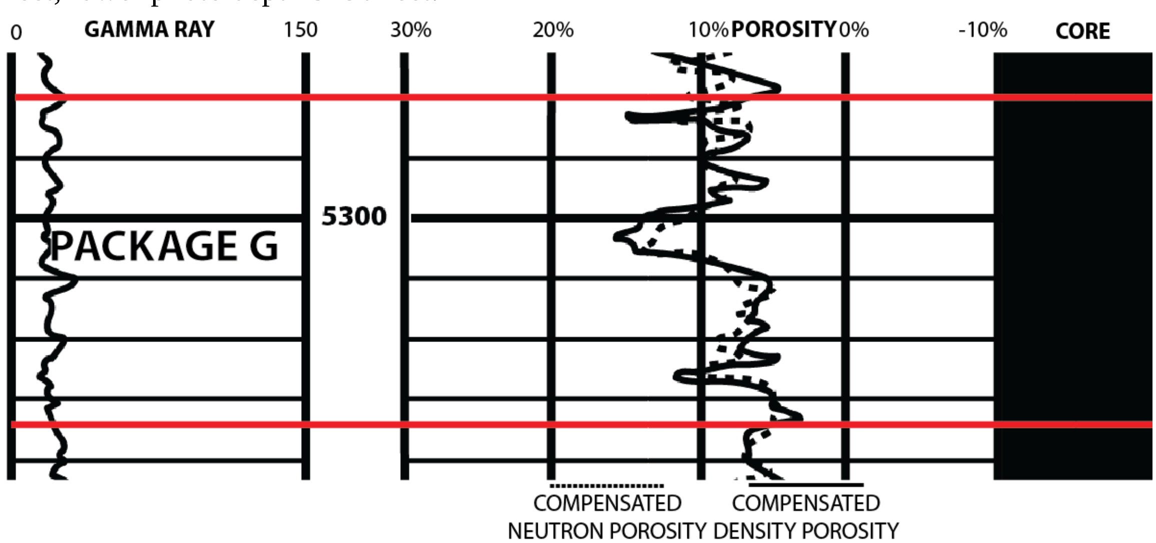


Figure 41: Gamma-ray and density/neutron porosity curves across package G in the Chesapeake Energy Corporation, Bann #1-14. Gamma-ray is relatively constant around 30 API, whereas density/neutron porosity ranges from 5-15%.

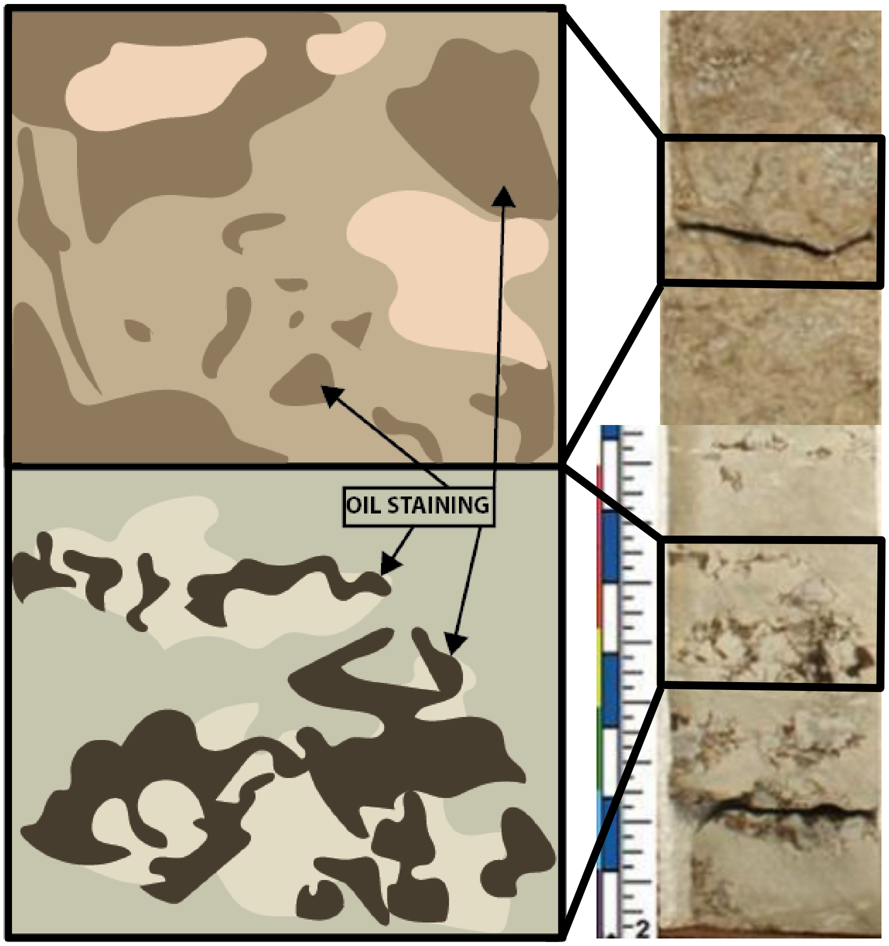


Figure 42: Annotated representation (left) and two core photographs (right) of a representative section of package H. The mildly to heavily bioturbated rock has few distinguishable features and is heavily oil stained. Chesapeake Energy Corporation, Bann #1-14. Top photo depth 5255 feet, lower photo depth 5274 feet.

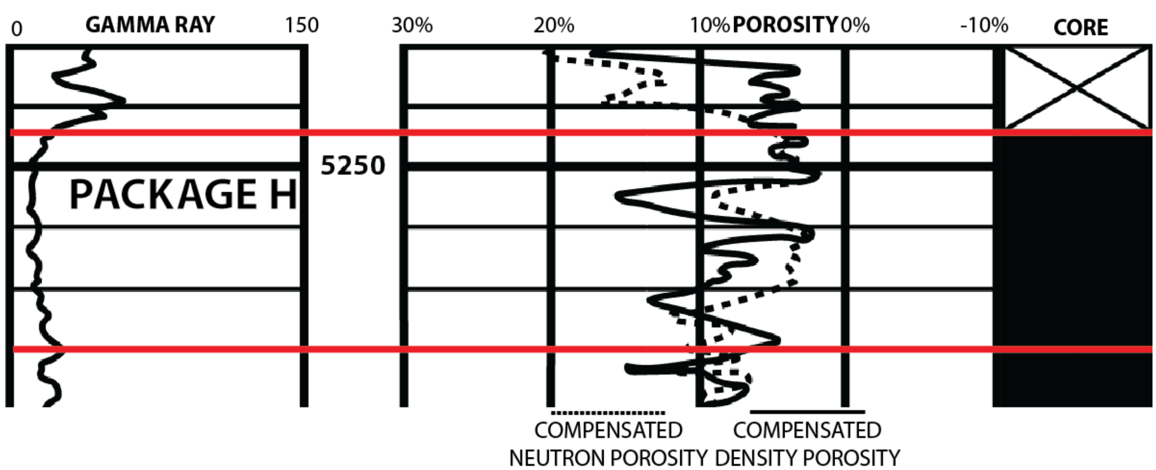


Figure 43: Gamma-ray and density/neutron porosity curves across package H in the Chesapeake Energy Corporation, Bann #1-14. Gamma-ray is slightly less than 30 API. Density/neutron porosity decreases from ~11% to ~4%.

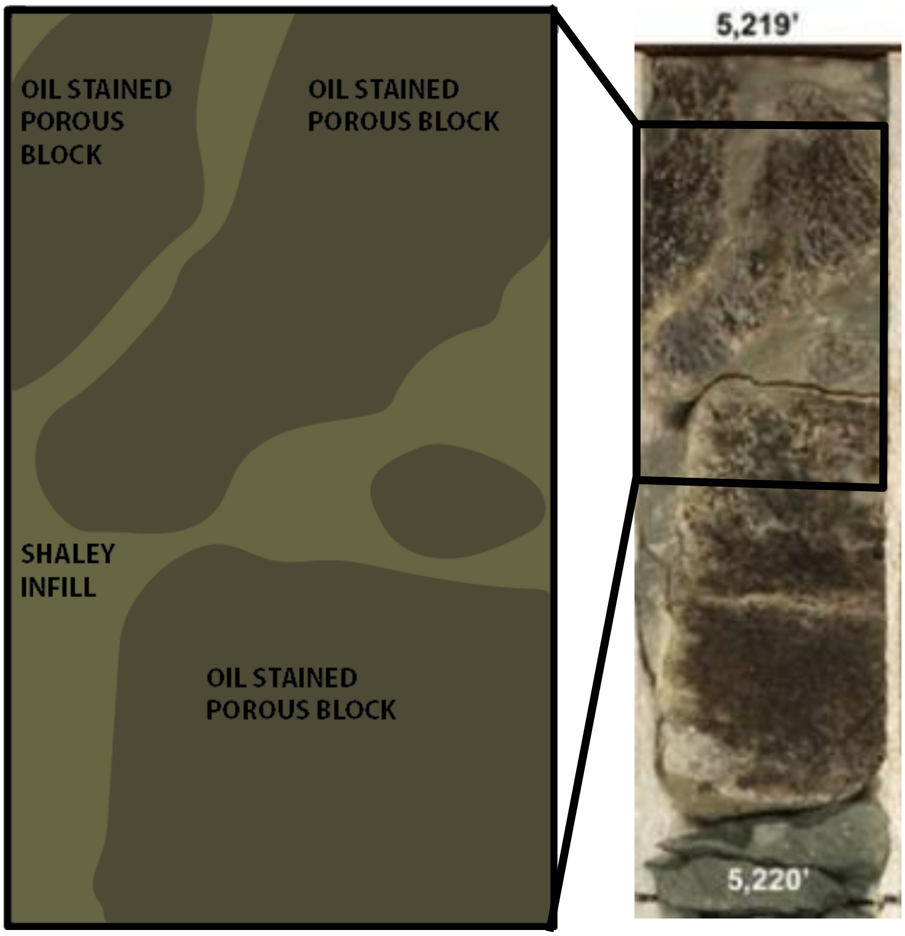


Figure 44: Stylized representation (left) and core photograph (right) of a representative section of the karsted/weathered package above package H. Oil stained porous blocks have eroded green shaly sediment infill between. Chesapeake Energy Corporation, Bann #1-14. Depth 5219 feet.

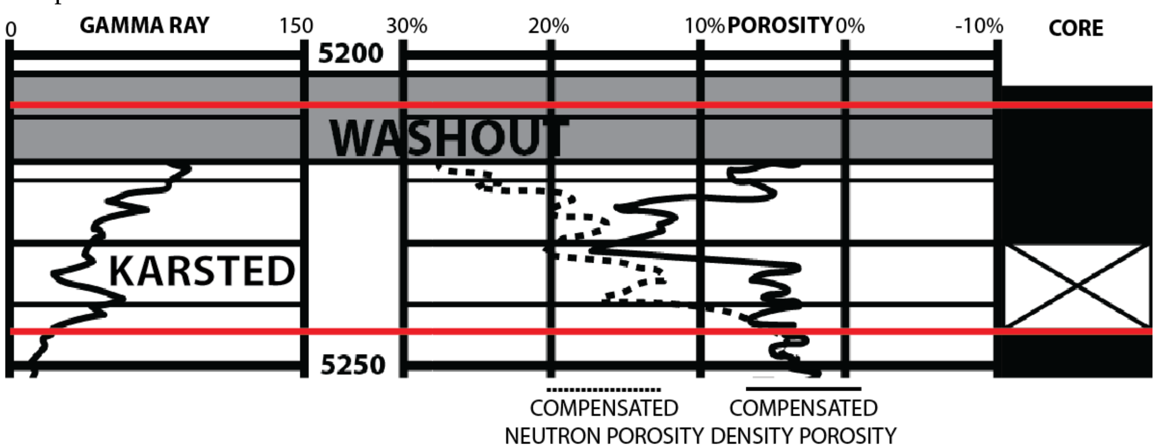


Figure 45: Gamma-ray and density/neutron porosity across the karsted package in Chesapeake Energy Corporation, Bann #1-14. Gamma-ray and porosity increases across this package from >30 API to ~80 API and 6% to 17% porosity respectively. Due to the washout of the wellbore (as indicated by the caliper log not pictured), wireline log responses are not reliable above 5218 feet.

INTERPRETATION

Overall the Mississippian section in this well shows a shoaling upwards trend. The interpretation for the portion of the Mississippian section not represented in core is based on other Mississippian core descriptions (LeBlanc, 2014) (Bertalott, 2014), interpretations of wireline log curves and an understanding of carbonate sedimentation patterns. Package A is interpreted to be the initial transgression over the Kinderhookian "Shale" (Fig. 46 and 47). As the transgression continued, water depth increased and conditions became more restricted. Sediment deposition slowed and the increased presence of clay generates the higher gamma-ray signature of package B. It is interpreted that package B was deposited below storm wave base due to the higher gamma-ray signature indicating sedimentation in a low energy environment (Fig. 46 and 47). Package C represents the depositional environment beginning to shallow and approach storm wave base (Fig. 46 and 47). Package D is interpreted to have been deposited at or slightly above storm weather wave base (Fig. 46 and 47). Package E is interpreted to have deposited between storm weather wave base and fair weather wave base (Fig. 46 and 47). Package F is interpreted to represent sedimentation at or above fair weather wave base (Fig. 46 and 47). The burrows and grainy textures observed in core support this interpretation. Package G is interpreted to have formed in a slightly shallower environment as compared to package F (Fig. 46 and 47). Package H is interpreted to represent another slight shallowing of the depositional environment as compared to package G (Fig. 46 and 47).

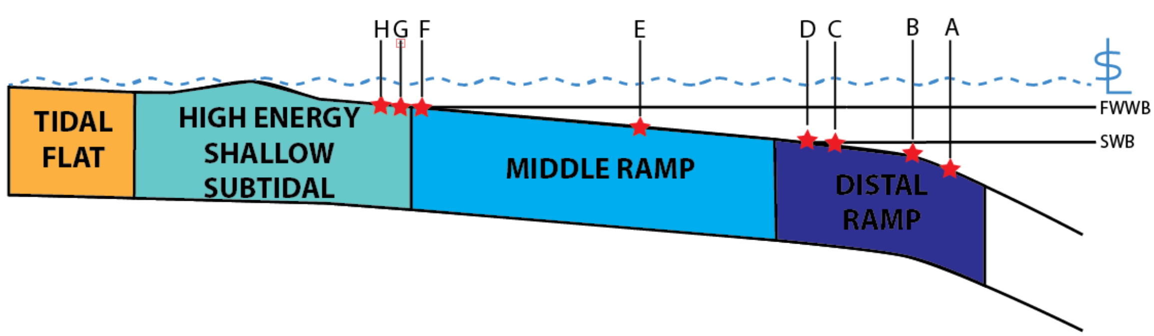


Figure 46: Cross section of a carbonate ramp with stars that indicate the interpreted location and depositional environment for each package. Modified from Kaufman and Jameson (2002).

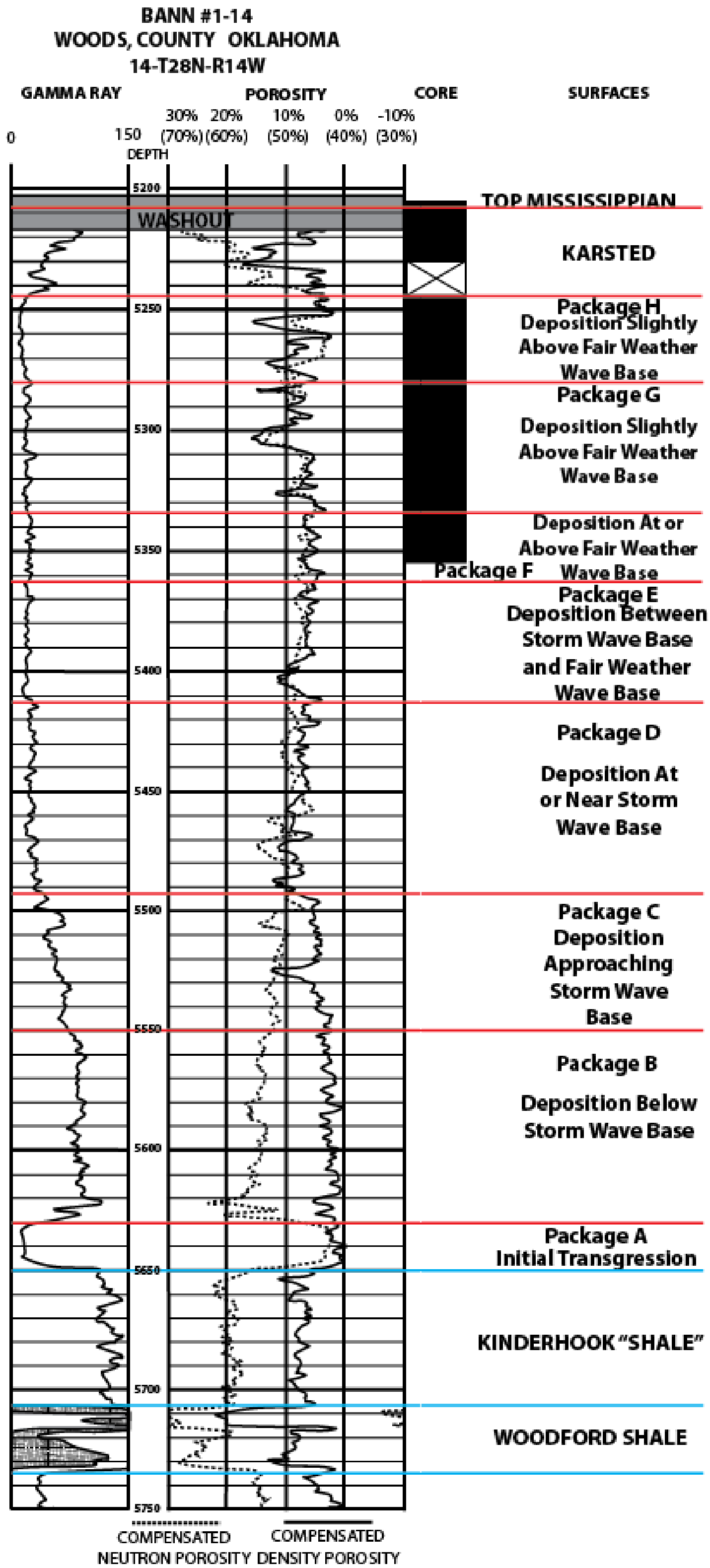


Figure 47: A section of the wireline log for the Bann #1-14. The gamma-ray track is in track one and the density/neutron porosity curves are located in tracks two and three. The black rectangle indicates the cored interval. The interpreted depositional environments for the packages are posted to the right of the core.

There is no indication that the accommodation was fully filled in this location. This interpretation is based on the lack of depositional textures suggesting shallow water high energy environments (i.e. shoreface, beach, or supratidal) deposition. As such, it is interpreted that this location is located on the distally steepened portion of the distally steepened ramp.

CROSS SECTION ANALYSIS

DISCRIPTION

Four cross sections were constructed for this project consisting of 43 wells (Fig. 48). Only representative logs are shown for the four cross sections. Approximately 160 logs were used for correlation purposes. Wireline logs were found in publically available sources from the Kansas Geological Survey and the Oklahoma Corporation Commission. Density/neutron porosity logs were used when available. Correlations were made using a combination of gamma-ray and density/neutron porosity curves. Most logs shown on the cross section are spaced approximately six miles apart. The longest cross section (A-A') was constructed parallel to the Central Kansas Uplift/Pratt Anticline and extends approximately 100 miles from McPherson County in central Kansas southwesterly to Woods County in northwestern Oklahoma. Cross Section A-A' represents an oblique regional dip cross section. Two of the shorter cross sections (B-B' and C-C') are each approximately 30 miles long and intersect A-A' at the position of the two cored wells (Bartel #1-16, and Bann #1-14 respectively). Cross Sections B-B', C-C' and D-D' were constructed perpendicular to the Central Kansas Uplift/Pratt Anticline and run oblique to regional depositional strike. All four cross sections were constructed as structural cross sections and as stratigraphic cross sections flattened either on the base of the Mississippian carbonate datum or the top of the Mississippian. Each cross section includes wireline logs that show the Mississippian-Pennsylvanian unconformity (red line), the Mississippian carbonate section, and the point where gamma-ray abruptly increases indicating the contact between Mississippian carbonate and the underlying Kinderhookian aged “shale” (blue line).

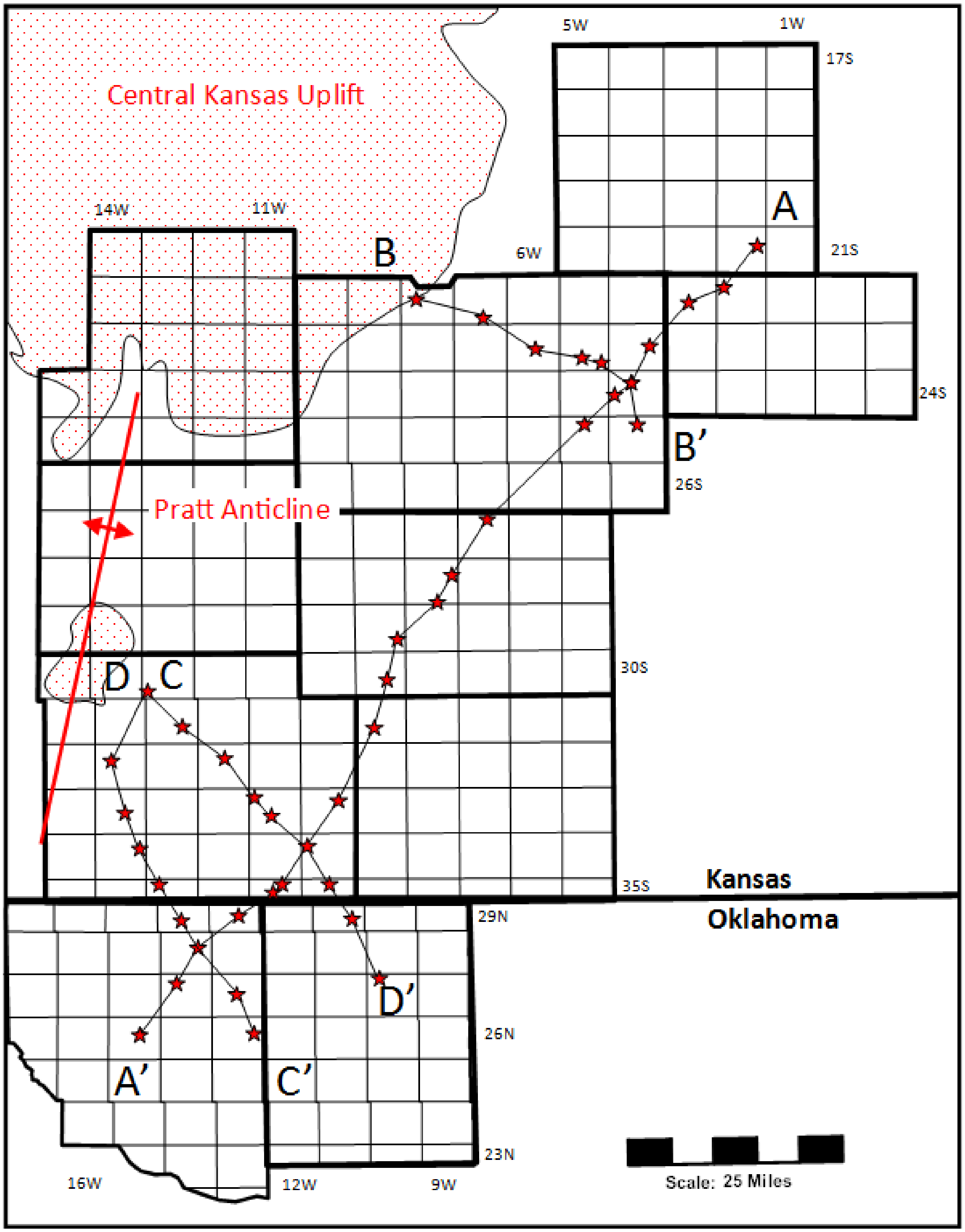


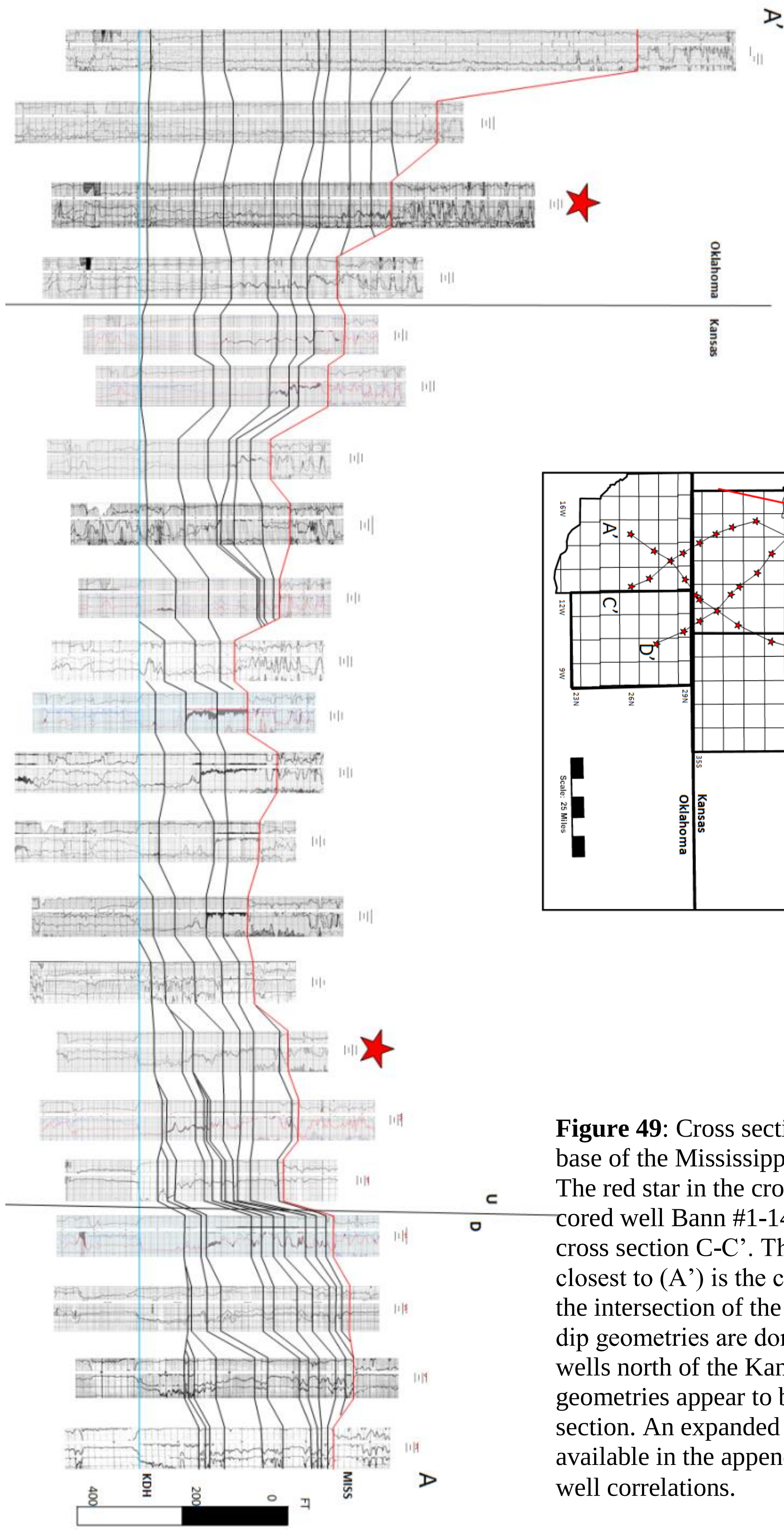
Figure 48: A map showing the locations of the four cross sections used in this project to represent stratigraphic and structural relationships. Each square represents a township. Cross section B-B’ intersects A-A’ at the cored well Bartel #1-16. Cross section C-C’ intersects A-A’ at the cored well Bann #1-14. A total of 43 wells were selected for these cross sections.

CROSS SECTION A-A'

Cross Section A-A' extends from McPherson County in central Kansas southwesterly to Woods County in northwestern Oklahoma. Cross Section A-A' trends north-northeast/south-southwest and is slightly oblique to the regional depositional dip. It is located approximately 25 miles east of the eastern edge the Central Kansas Uplift/Pratt Anticline where the Mississippian section is absent. Correlations of packages between wells in the north were primarily accomplished using density/neutron porosity curves. The high energy environments on the proximal position of the ramp hindered the deposition of clay minerals making correlations with gamma-ray difficult. To the south in Woods County, Oklahoma, gamma-ray curves facilitated correlation as these wells were drilled in Mississippian carbonate deposited in a more distal position on the distally steepened ramp.

A number of depositional wedges are identified on Cross Section A-A' that appear to prograde in a generally southerly direction (Fig. 49 and 50). These progradational packages extend approximately 25 miles. In the northernmost portion of the Cross Section A-A' there is evidence of backstepping of packages, which is interpreted as a transgressional period. The few most southerly wells in Kansas and all of the wells in Oklahoma in A-A' show a change from dip to strike geometries. This important observation is described further in the description of Cross Section C-C'.

The patterns interpreted from Cross Section A-A' supports the concept that depositional wedges were prograding in a mostly southern direction towards the pre-Pennsylvanian Oklahoma Basin. This observation is supported by the geometry of the identified packages and their overall shape. Packages tend to downlap on older surfaces and the wedges become younger as sedimentation progrades in the basinward direction (Fig. 49)



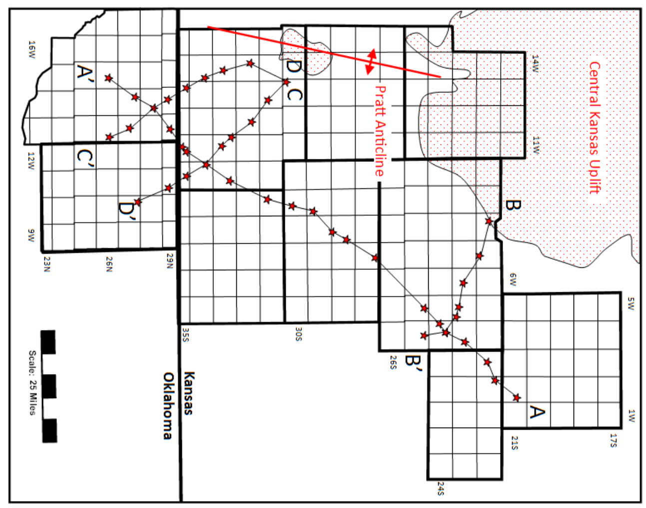


Figure 49: Cross section A-A’ that is flattened at the base of the Mississippian carbonate section (blue line). The red star in the cross section closest to (A) is the cored well Bann #1-14 and marks the intersection of the cross section C-C’. The red star in the cross section closest to (A’) is the cored well Bartel #1-14 and marks the intersection of the cross section B-B’. Progradational dip geometries are dominant from the north (A’) to four wells north of the Kansas/Oklahoma border where the geometries appear to be from a strike oriented cross section. An expanded view of this cross section is available in the appendix that better illustrates well to well correlations.

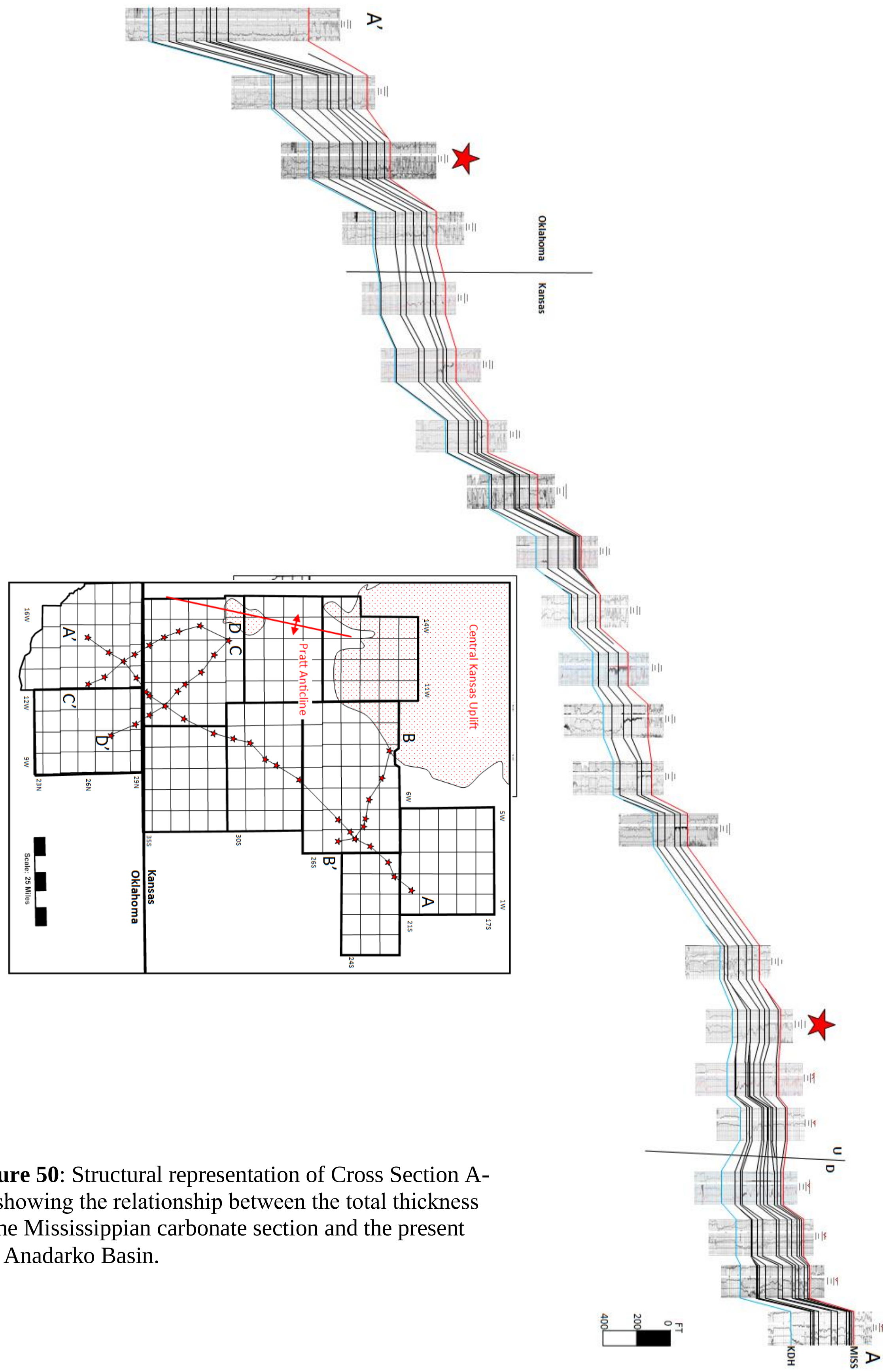
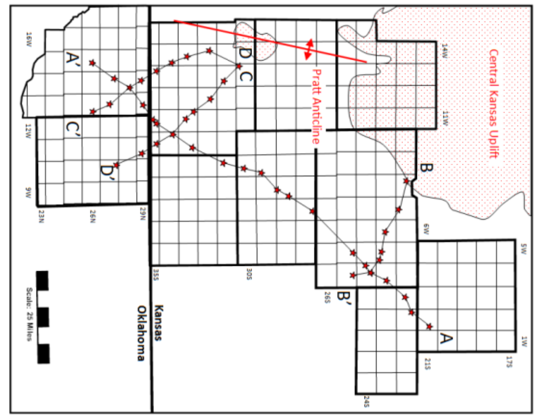


Figure 50: Structural representation of Cross Section A-A' showing the relationship between the total thickness of the Mississippian carbonate section and the present day Anadarko Basin.

CROSS SECTION B-B’

Cross Section B-B’ extends from the eastern edge of the Central Kansas Uplift in northwest Reno County, Kansas southeast to the point it intersects Cross Section A-A’ at the cored well, the Blueridge Petroleum, Bartel #1-16. Cross Section B-B’ is oriented west-northwest/east-southeast approximately parallel to depositional strike and perpendicular to the western limit of the eroded Mississippian section on the Central Kansas Uplift.

All but the uppermost depositional packages appear to thin as wells approach the Central Kansas Uplift (Fig. 51 and 52). Weathering associated with the Mississippian-Pennsylvanian unconformity makes correlation much more difficult at the top of the Mississippian carbonate section as compared to the lower part. Evidence of westward thinning of packages in the lower portion of the Mississippian carbonate section and onlap on the Kinderhookian “Shale” is interpreted to indicate that the Central Kansas Uplift was a positive feature post-Kinderhookian. This also suggests that not all of the Mississippian section was deposited across the Central Kansas Uplift and the missing sediments could be due to non-deposition and not all the result of post-Mississippian erosion of a full Mississippian section. While there is evidence that the uplift influenced deposition as shown on Cross Section B-B’; it is apparent from the Cross Section A-A’ that the Central Kansas Uplift did not change the direction of progradation in the vicinity of the Bartel #1-16.



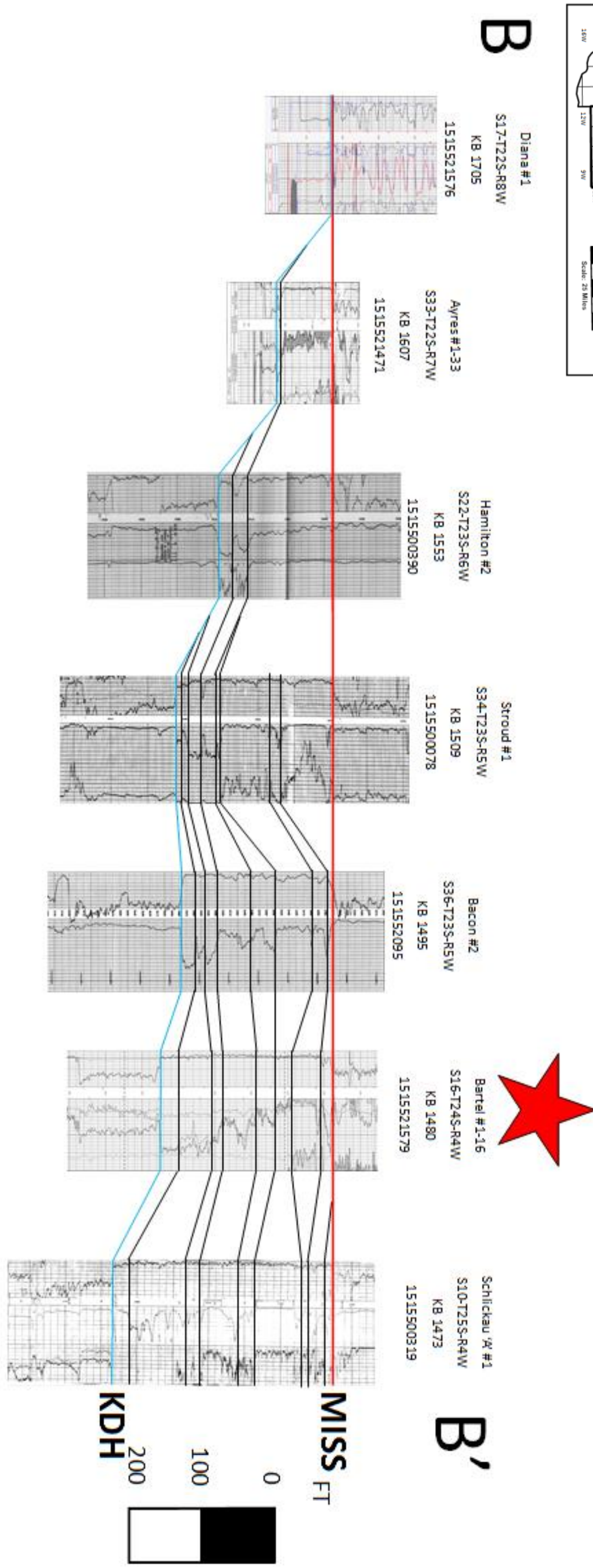


Figure 51: Cross section B-B' flattened at the top of the Mississippian section (red line). The red star in the cross section represents the cored Blueridge Petroleum Bartel #1-16. Thinning of the depositional packages is evident as the representative wells approach the Central Kansas Uplift (B). Correlation of packages beneath the Pennsylvanian unconformity is difficult due to weathering enhanced alteration.

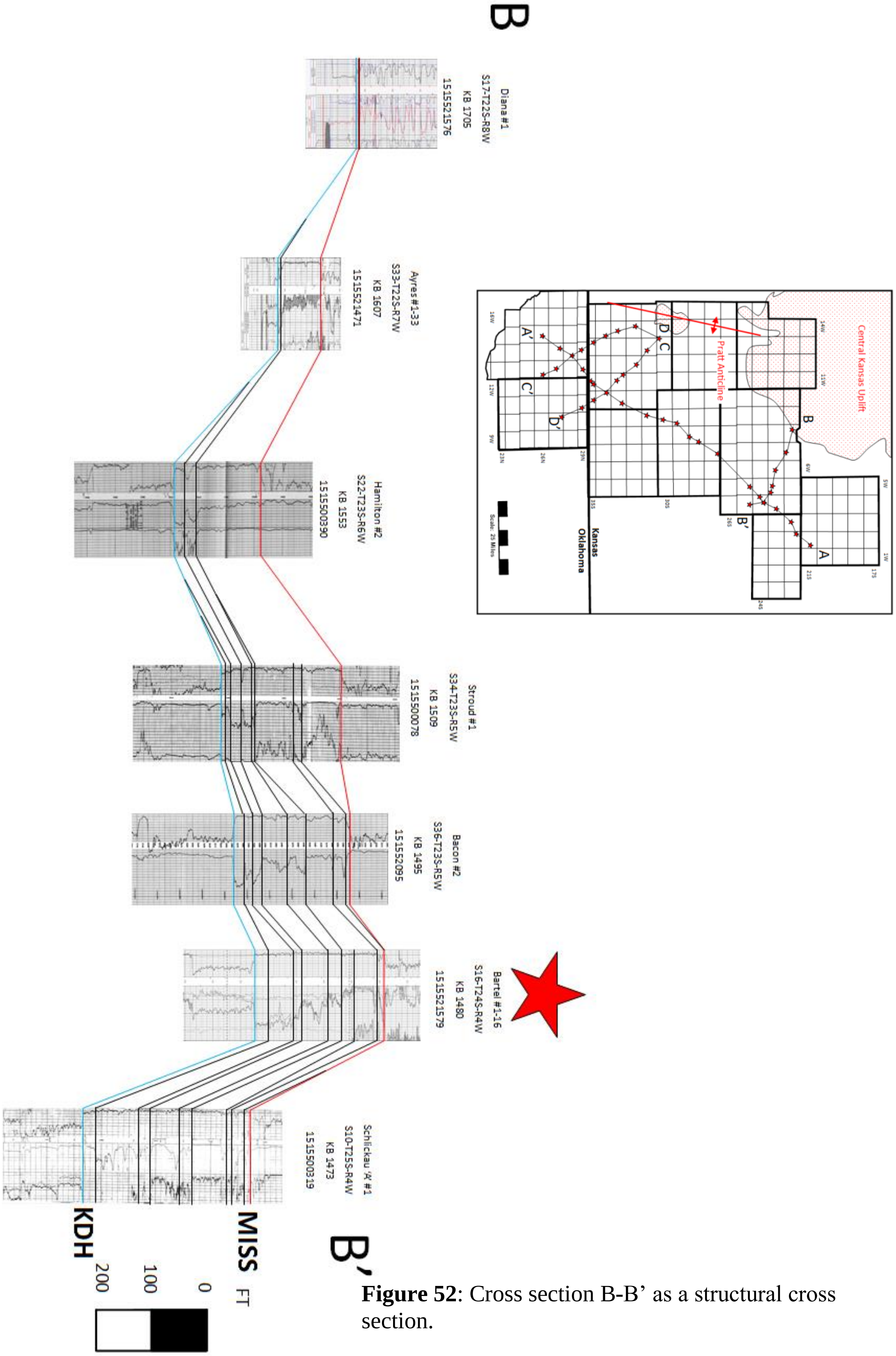


Figure 52: Cross section B-B' as a structural cross section.

CROSS SECTION C-C’

Cross Section C-C’ extends from the southern Central Kansas Uplift/Pratt Anticline in Barber County, Kansas to east-central Woods County, Oklahoma where it intersects Cross Section A-A’ at the location of the Chesapeake Energy Corporation, Bann #1-14. Cross Section C-C’ is oriented north-northwest/south-southeast oblique to depositional strike/dip and perpendicular to the orientation of the Pratt Anticline (NE-SW).

On Cross Section C-C’, the patterns represented shows that in southern Kansas, near the Pratt Anticline, depositional wedges are prograding in a southeasterly direction (Fig. 53 and 54). This direction of progradation is supported by patterns apparent in the southern half of Cross Sections A-A’. In Cross Section A-A’, a shift in the direction of the prograding wedges is evident by a change in the patterns. The geometry of the depositional packages intersected by the cross section shift from dip-oriented progradational geometries to geometries associated with strike-oriented cross sections. This shift from a dip-oriented section to a strike-oriented section occurs at a location between the fourth and fifth well north of the Kansas/Oklahoma border. The shift seen in geometries in Cross Section A-A’ could be interpreted as a poor correlation. However, the perpendicular cross section, C-C’, showing dip-oriented geometries supports what is seen in Cross Section A-A’ (Fig. 41).

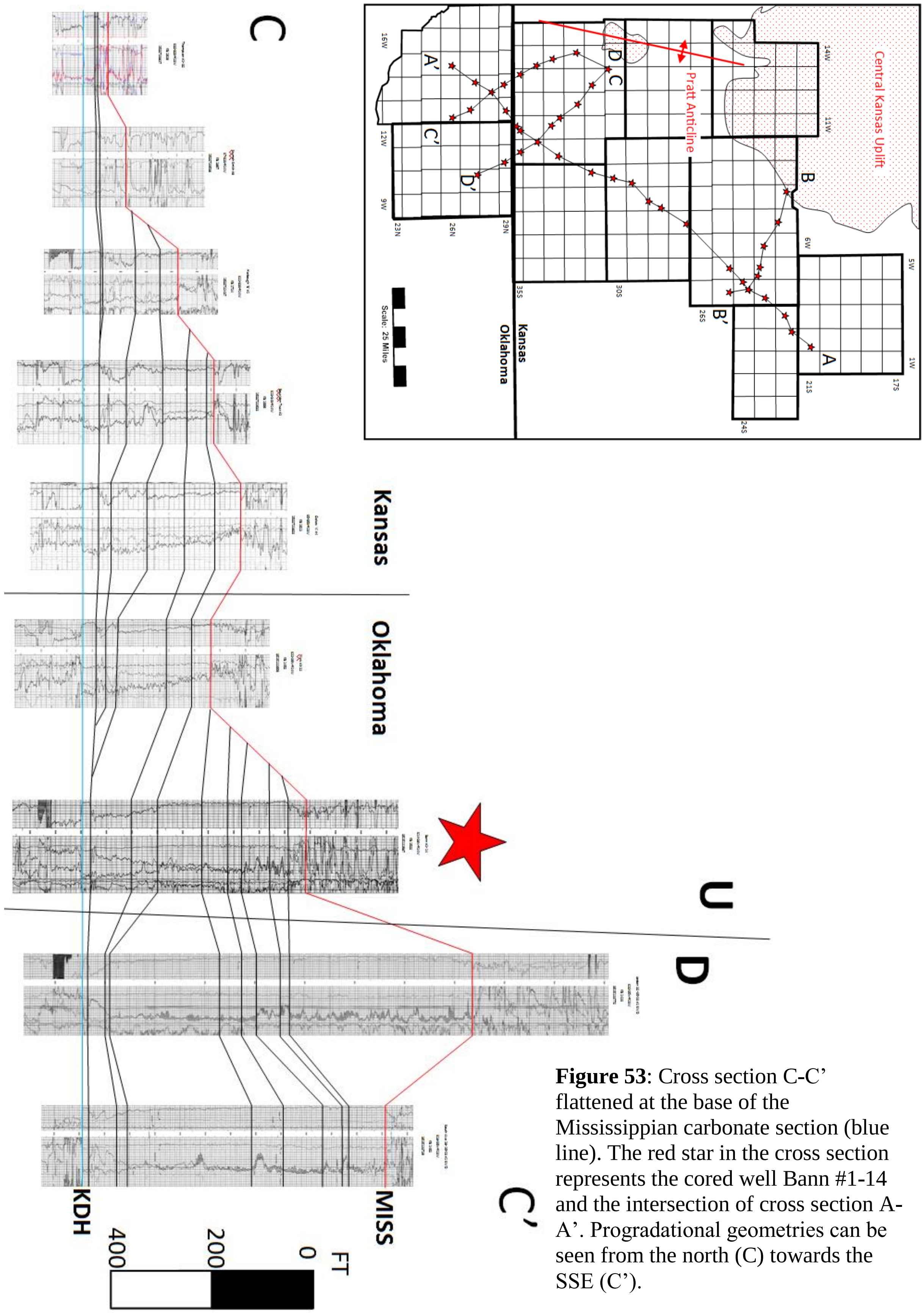


Figure 53: Cross section C-C' flattened at the base of the Mississippian carbonate section (blue line). The red star in the cross section represents the cored well Bann #1-14 and the intersection of cross section A-A'. Progradational geometries can be seen from the north (C) towards the SSE (C').

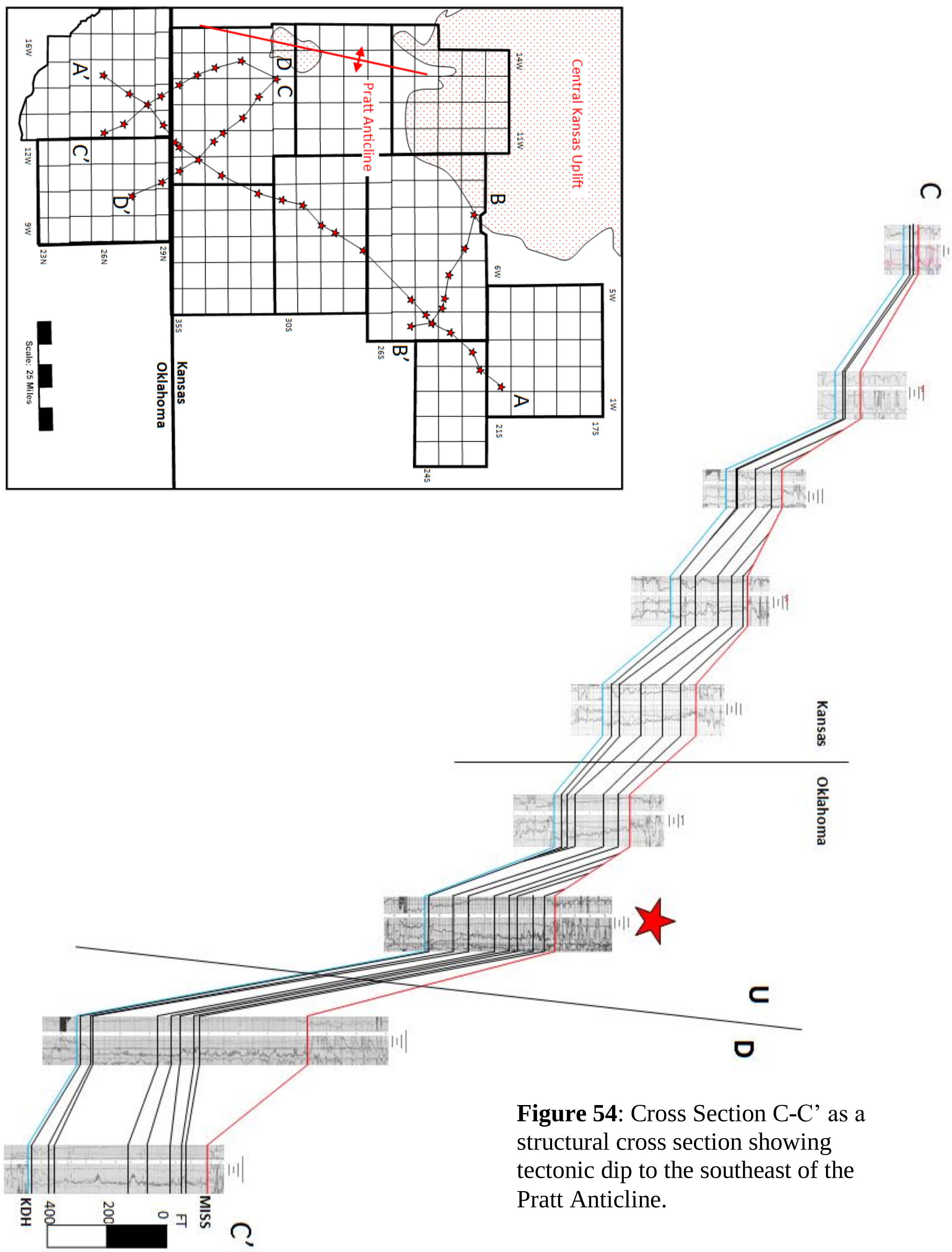
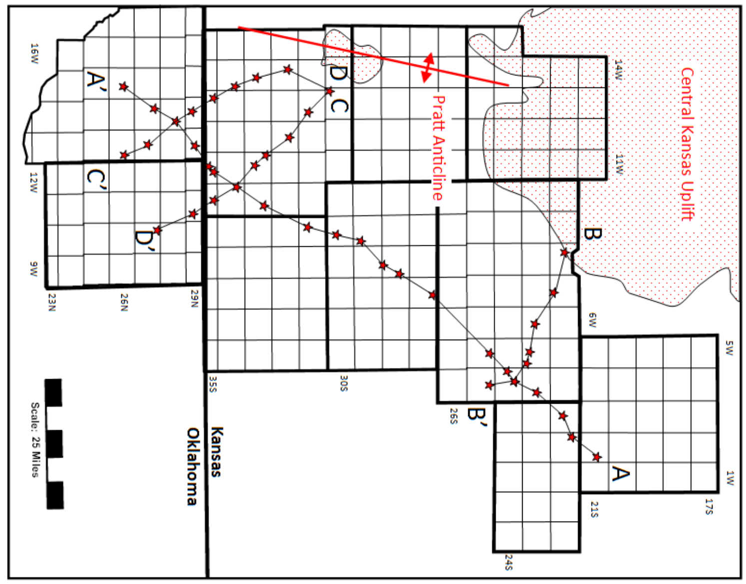


Figure 54: Cross Section C-C' as a structural cross section showing tectonic dip to the southeast of the Pratt Anticline.

CROSS SECTION D-D’

Cross Section D-D’ extends from the northern well in cross section C-C’ on the southern Central Kansas Uplift/Pratt Anticline in Barber County, Kansas to central Alfalfa County, Oklahoma. Cross Section D-D’ is oriented northwest/southeast oblique to the regional depositional strike/dip and roughly perpendicular to the crest of the Pratt Anticline (NNE-SSW).

The patterns on Cross Section D-D’, show that in southern Kansas, around the Pratt Anticline, depositional wedges are prograding in a southeasterly direction (Fig. 55 and 56). This direction of progradation is supported by patterns apparent in the southern half of Cross Sections A-A’ and in the parallel cross section C-C’. In Cross Section A-A’, a shift in the direction of the prograding wedges is evident by a change in the geometries. The geometry of the depositional packages intersected by the cross section shift from dip-oriented progradational geometries to strike-oriented geometries with uniform thickness. This shift from a dip oriented section to a strike oriented section occurs at a location between the fourth and fifth well north of the Kansas/Oklahoma border. The shift seen in geometries in Cross Section A-A’ could be interpreted as a poor correlation. However, the perpendicular cross sections, C-C’, showing dip-oriented geometries supports what is seen in Cross Section A-A’ (Fig. 49). The geometries in cross section D-D’ are oblique to both strike and dip. This cross section intersects cross section A-A’ where the shift from dip to strike oriented geometries and is supported by the geometries seen in D-D’.



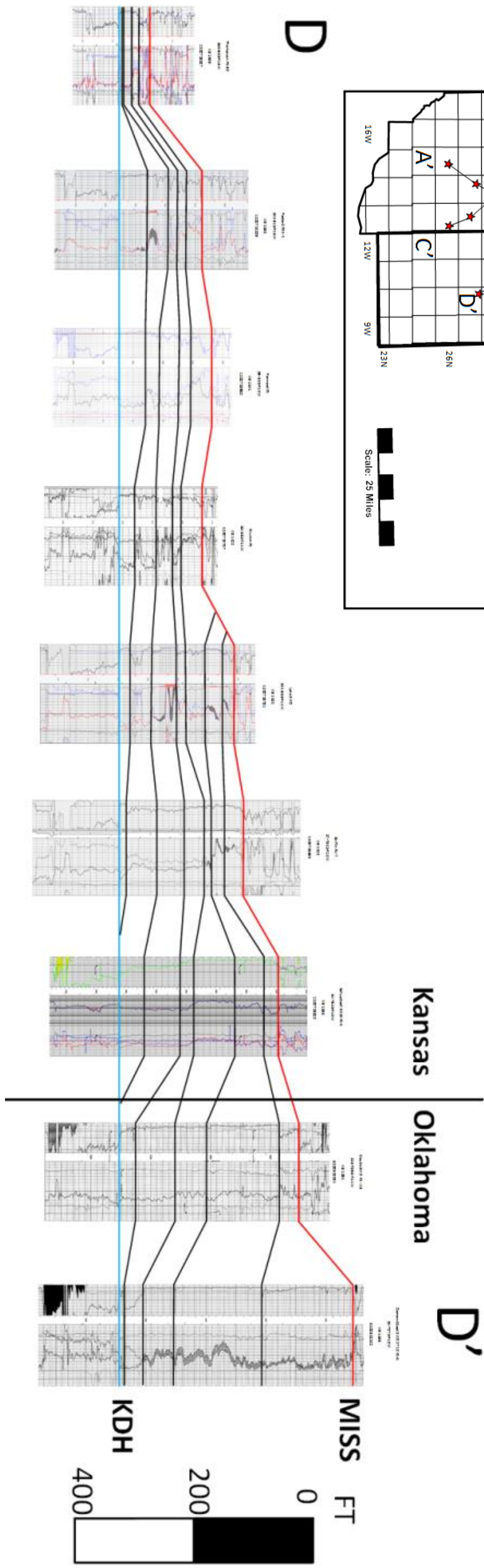


Figure 55: Cross section D-D' flattened at the base of the Mississippian carbonate section (blue line). Oblique progradational geometries can be seen from the north (D) towards the SSE (D'). There are not as pronounced progradational geometries evident in cross section C-C'; supporting the idea that the shift in geometries is more prominent to the south.

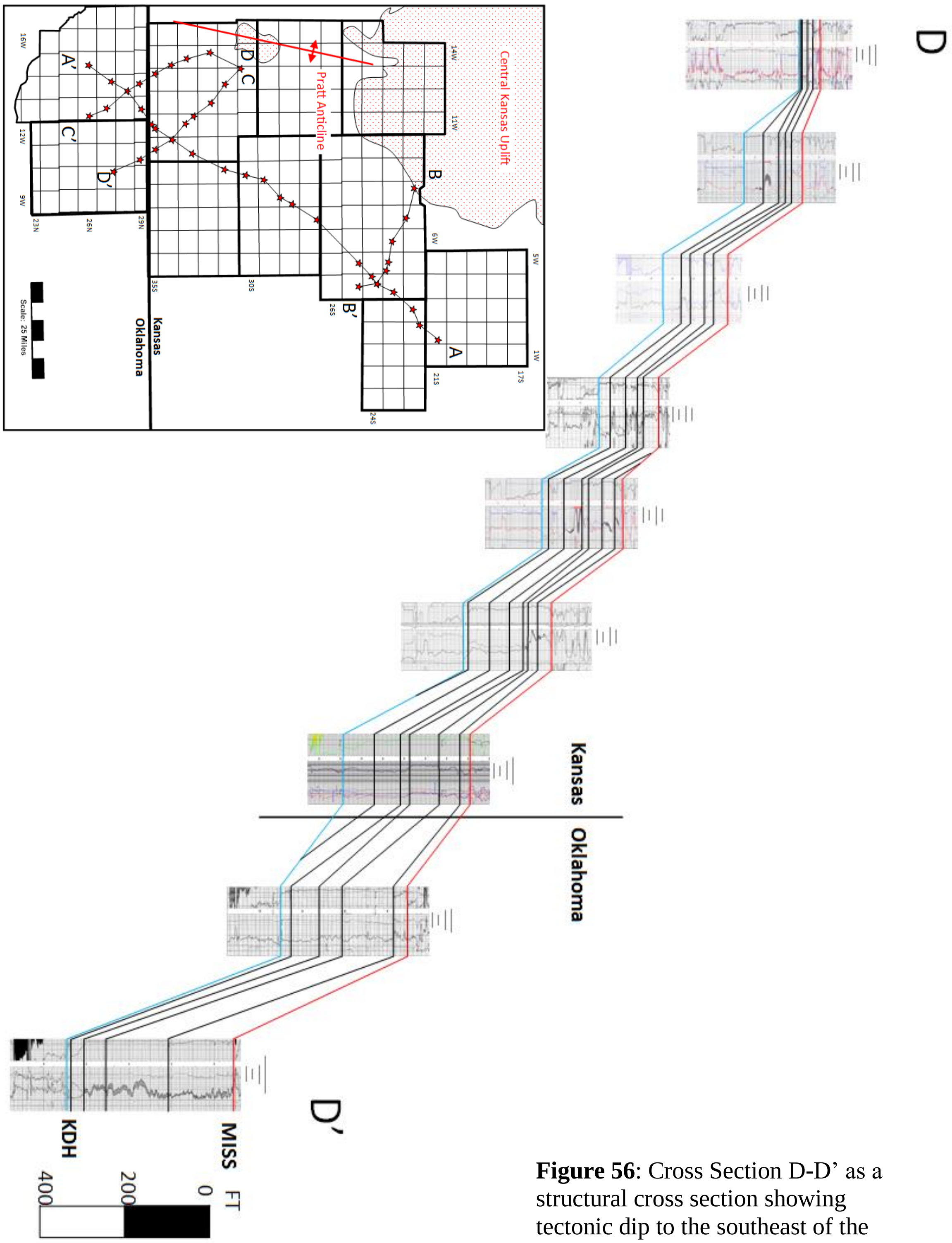


Figure 56: Cross Section D-D' as a structural cross section showing tectonic dip to the southeast of the Pratt Anticline.

CHAPTER III

DISCUSSION

POSITION ON RAMP AND AFFECT ON CORRELATIONS

Position on the distally steepened ramp greatly influenced the effectiveness of specific log curves in correlating surfaces in the Mississippian carbonate section. The gamma-ray signature showed no variation in the Bartel #1-16 that was useful for correlation purposes. This lack of gamma-ray variation is due to the higher energy found in the proximal depositional environments observed in the Bartel #1-16. The higher energy found in proximal locations at and above fair weather wave base moves finer grained muddy material down the ramp leaving behind only larger grains. The increase in gamma-ray signature at flooding surfaces is generally associated with finer grained or muddy material that is removed by the higher energy in proximal settings. This is why the flooding surfaces are not evident in logs from this location. The log curves whose patterns most closely matched rock fabric in core were the density/neutron porosity curves.

The Bann #1-14 was in a more distal position on the ramp and showed little variation in the density/neutron porosity curve that could be used for correlations. Wells in this portion of the project had to be correlated using the gamma-ray signature. While there were no distinctive increases of gamma-ray signature observed in the upper part of the Bann #1-14 the lower half of the Mississippian carbonate section has a bell shaped curve that was able to be correlated to nearby wells in the area. Confidence in correlations became less as the amount of variation evident in the gamma-ray signature decreased progressively upward through the Mississippian carbonate section.

Using the porosity curves for correlations compared to using the gamma-ray curve introduces a few problems that must be considered. Correlating increases in gamma-ray associated with flooding surfaces means that correlations are being made on a surface that signifies an event that should have affected the entire basin. This is why these sharp increases in gamma-ray are favored for regional or basin wide correlations. When correlations are made using porosity it is assumed that these porosity trends tie to depositional environments or facies. Expectations are that as these porosity trends are followed away from the control well with the core calibrated wireline log, correlations would quickly become hard to follow in the matter of just a few miles. This would be expected because moving in a dip direction (landward or basinward) different depositional environments or facies would be crossed. It was observed when porosity trends were correlated that correlations did not become difficult to follow, but rather could be followed to the top of the Mississippian carbonate section in the landward direction and the base of the carbonate section in the basinward direction. This resulted in the construction of an apparent dip-oriented cross-sectional geometry of prograding depositional wedges.

A possible explanation for the ability to correlate porosity logs is that the porosity trends are following specific depositional environments. Depositional environments are generally associated with the amount of energy the location receives from the wind and waves. In a shallow inclination ramp (<5°) a strip of the ramp miles wide in the dip direction would be subjected to similar amounts of energy, generating a similar depositional environment. The shallower the inclination of a ramp the wider the depositional environments would be expressed on the ramp

(Fig. 57). These wide depositional environments would appear even wider on cross sections that are oriented oblique to depositional strike and dip (Fig. 58). These factors may explain the ability to follow the porosity trends much farther than expected and could mean that prograding wedges evident in cross section could represent smaller-scale facies belts in a larger prograding wedge.

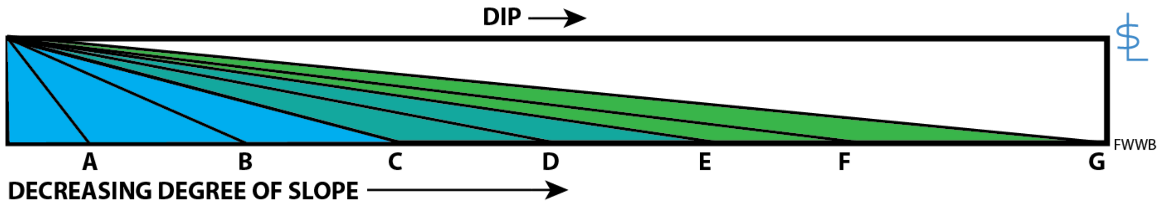


Figure 57: A cross sectional view of several carbonate ramps at different angles (A-G). The top line represents sea level and the bottom line represents fair weather wave base. This column of water would have high environmental energy and create a high energy depositional environment. This depositional environment would be represented in map view as a "belt" parallel to strike (see figure 58). Ramp A is the steepest ramp shown and would have the smallest width of the depositional environment represented on the ramp. Ramp G is the shallowest dipping ramp and would have the largest width of this depositional environment represented on the ramp. If the Mississippian in the study area was deposited on a shallow dipping ramp like G (or shallower) depositional environments/facies would be represented by large "belts". This could explain why porosity trends are able to be traced farther than expected.

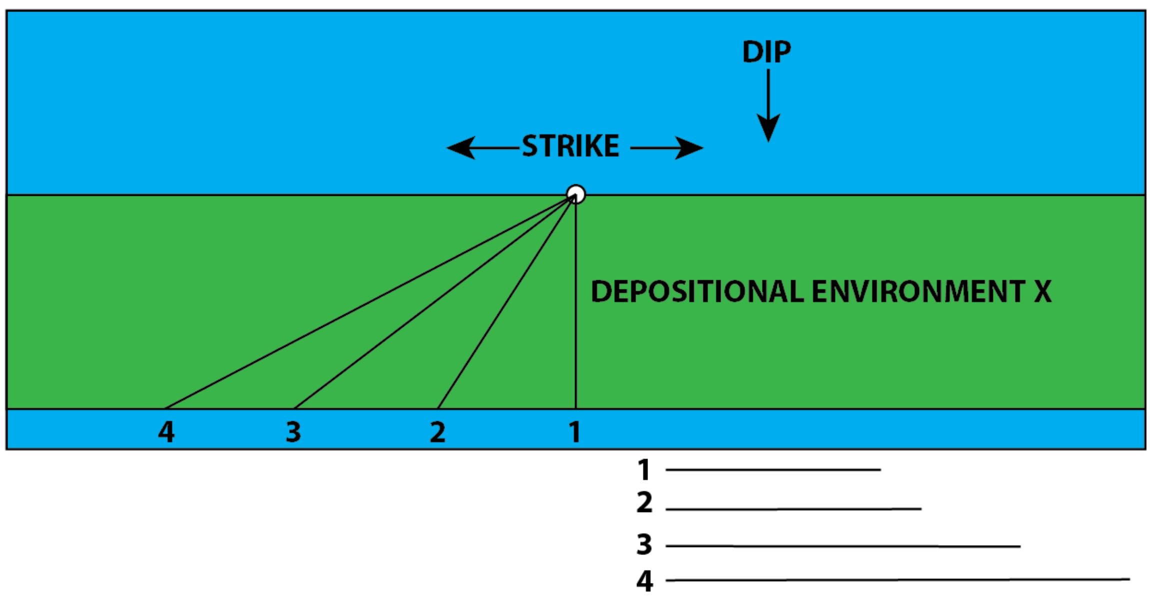


Figure 58: A map view of a carbonate ramp with an arbitrary depositional environment (X) belt (green rectangle). Four cross sections are depicted intersecting depositional environment X at different angles. Cross section 1 intersects the depositional environment perfectly perpendicular to strike creating the shortest representation of the environment. Cross sections 2, 3, and 4 progressively intersect the depositional environment at more oblique angles to dip. The oblique cross sections create the longest representations of the depositional environment and should still show dip oriented geometries. The cross sections have been oriented at the bottom of the figure to show the difference in length depositional environment X could be represented as. It is likely that cross section A-A' is best represented as one of the three oblique cross sections shown here.

STRUCTURAL FEATURES EFFECTS ON DEPOSITIONAL WEDGES

Previous studies have observed progradation of depositional wedges in the Mid-Continent Mississippian. Boardman, et al. (2010) saw prograding wedges in outcrop studies using conodont biostratigraphic zonation and Bertalott (2014) observed prograding wedges in a subsurface study similar to this study. Progradation was also observed in this study. It was observed that the depositional wedges shifted their direction of progradation from a southern direction to a southeast direction. This shift in the direction of progradation could be due to the positive structural features created by the Central Kansas Uplift and the Pratt Anticline. In the northern portion of the study, Cross Section B-B' shows that depositional packages in the lower portion of the Mississippian carbonate section thinned as they approached the Central Kansas Uplift. This thinning is interpreted as indicating that the structure was a positive feature during the Mississippian and influenced sedimentation, but not so much as to shift the direction of prograding wedges. The geometries seen in B-B' are not purely indicative of either strike or dip geometries. This may be explained by the Central Kansas Uplift only having a small impact on deposition this far north. A shift in geometries is evident on Cross Section A-A' near where the cross section crosses the Kansas/Oklahoma border. In wells immediately north of the border, patterns on Cross Section A-A' depict a shift from dip-oriented geometries to strike oriented geometries. This change is supported by the apparent dip-oriented geometries evident on Cross Section C-C' and D-D', which are perpendicular to A-A'. This shift in the direction of progradation is likely due to the positive presence of the Pratt Anticline and the southern portion of the Central Kansas Uplift. The degree of influence these structures exerted on deposition increased as the wedges prograded to a more distal position on the distally steepened ramp.

Similar water depths should have approximately the same rate of sedimentation in a regional carbonate system, as the ocean floor at a depth should be subjected to similar environmental factors (Tucker and Wright, 1990). It can be concluded that bathymetric variations influence the direction depositional wedges prograde. In a carbonate system on a hypothetically perfect ramp (a single plane with no variation set at a slight angle) depositional wedges should be perfectly parallel to strike (Fig. 59). Any interruptions, in the form of a positive structure, to this plane would force the depositional wedges to wrap around the structure in an effort to maintain the same water depth. It is expected the shallowing generated by the structure would shift facies basinward (Fig. 60). A slight positive structural interruption of the plane, similar to what is shown in Cross Section B-B', would force a thinning of the wedges against the structure and most likely create a "hook" at the end of a depositional wedge. A large positive structural interruption of the plane, like the one shown in the southern part of the project, would force the depositional wedges to shift direction to account for the perturbation in the directions of dip and strike caused by the structure. An interpretation of arbitrary depositional wedges applied to the study area helps to explain the changes evident in cross sections (Fig. 61).

Many carbonate reservoirs are related to bathymetry and consequently are associated with depositional environments that are oriented parallel with depositional strike. When a structure such as the Central Kansas Uplift or the Pratt Anticline changes that strike direction locally, it likely forces depositional environments basinward that are regionally found in a more proximal position on the distally steepened ramp. As seen in cross section A-A', C-C' and D-D' the structures altered the direction of progradation, which is turn was reflected in package geometry. Knowing this impacts the way exploration would occur around the structures and also the direction of horizontal well bores in that region.

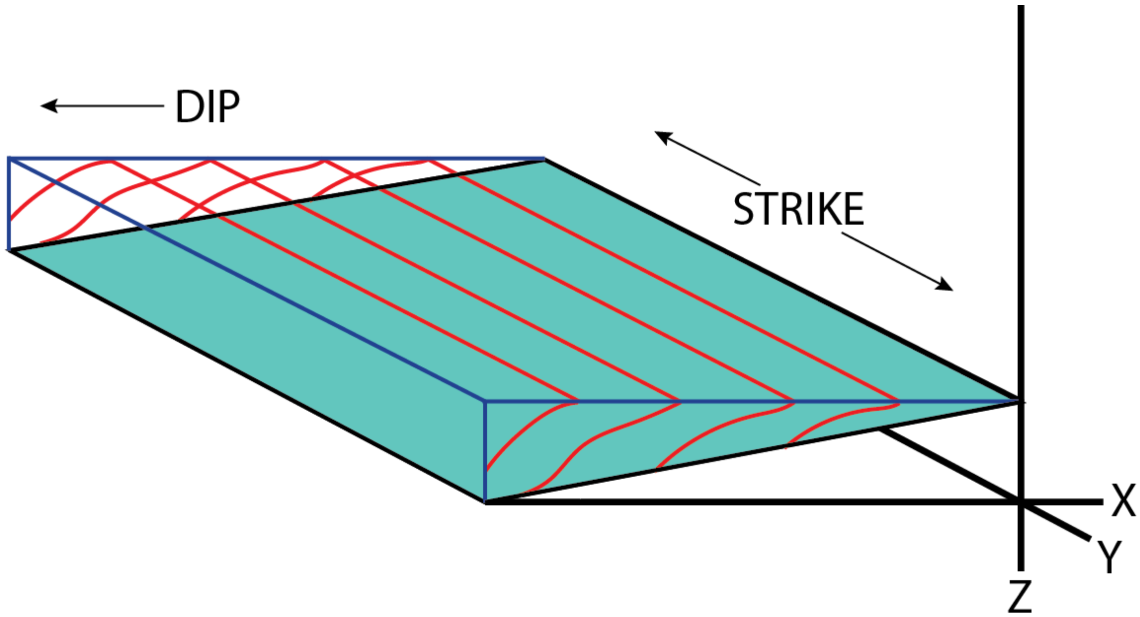


Figure 59: An idealized and simplified block model of a ramp with simple prograding wedges. The ramp represented here is a perfect plane with no variation. The dip angle is exaggerated to show detail. Applying a carbonate depositional system to the plane, with the assumption that the same water depth across the model would have the same sedimentation rate due to receiving the same amounts of different inputs (energy, light, etc.), the direction of progradation would occur parallel to regional dip and would be oriented parallel to strike as depicted above.

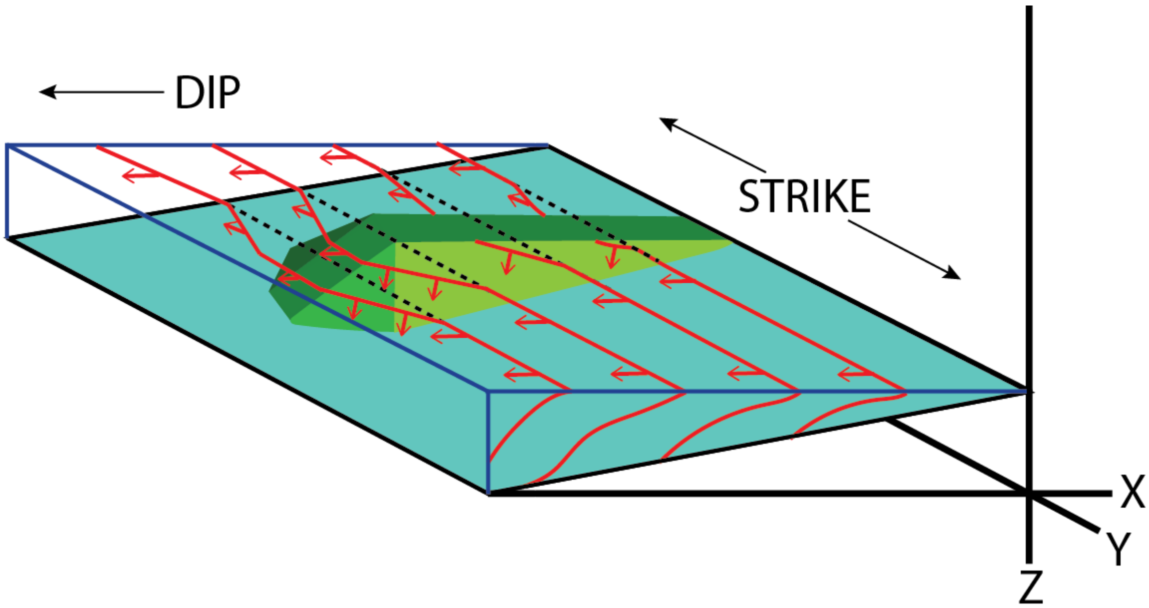


Figure 60: An idealized and simplified block model of a ramp with simple prograding wedges. The dip angle is exaggerated to show detail. The ramp represented here is a perfect plane with the exception of the positive structural feature in the middle of the plane (represented in green). The black dotted lines extending across the top of the structure help to illustrate the deviation by showing where the wedges would be if there was no structure. Red arrows indicate the direction of progradation. Applying a carbonate depositional system to the plane, with the assumption that the same water depth across the model would have the same sedimentation rate due to receiving the same amounts of different inputs (energy, light, etc.), the direction of progradation would occur in the dip direction. In the proximal position of the ramp the structure doesn't affect the wedge except close to the structure. In order for the wedge to stay parallel with the strike of the structure it is forced to deflect basinward. In the distal position, the structure is more dominant and affects the depositional wedge further from the structure. For the wedge to stay parallel to the structure it must start moving basinward farther from the structure. As the wedge goes around the nose it becomes parallel to regional strike again, but in a more basinward position. In the vicinity of the structure carbonate wedges are oriented oblique to regional strike and dip.

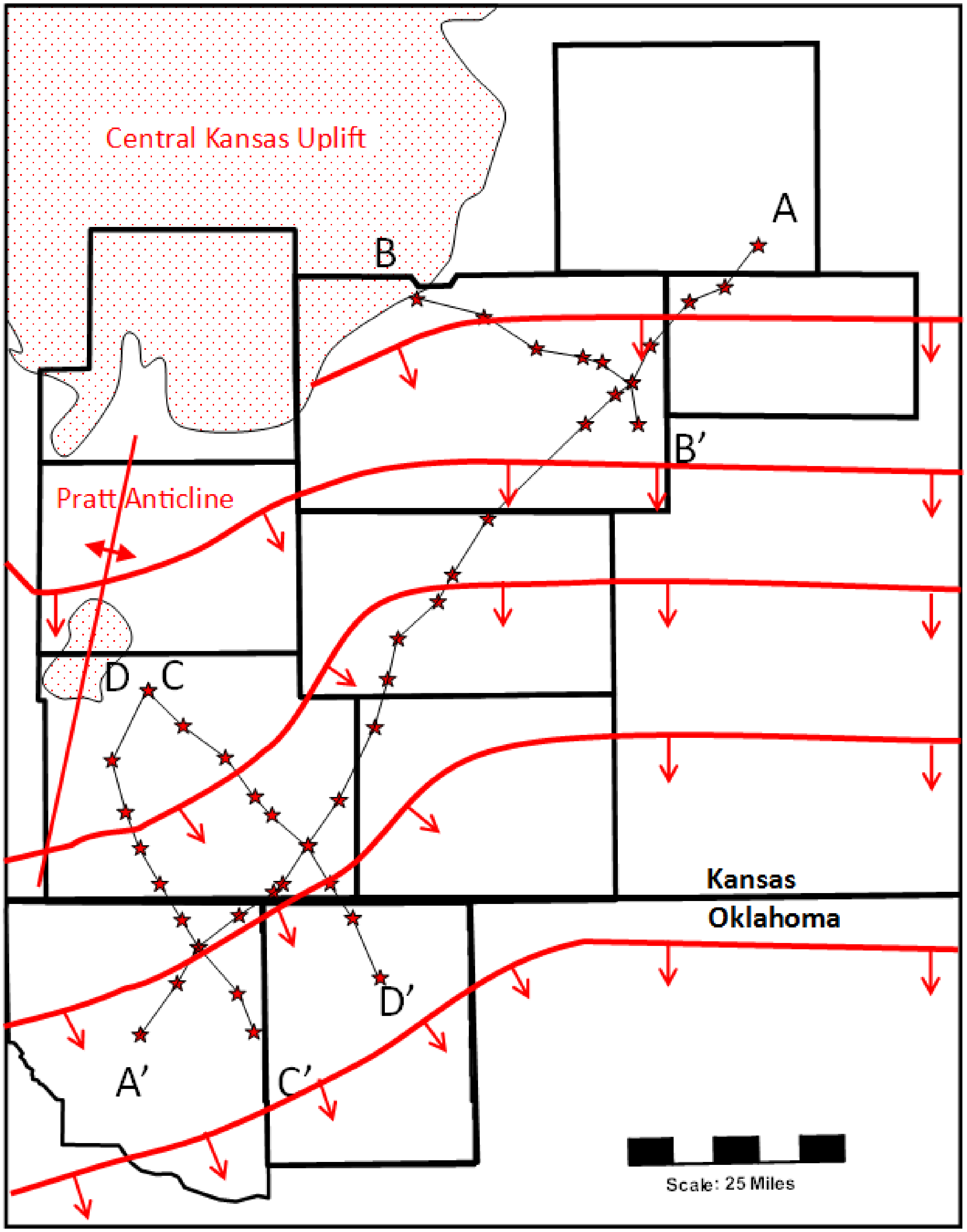


Figure 61: The ramp model from figure 60 applied to the study area using arbitrary progradation lines (red lines) in an attempt to explain why a shift in geometries can be seen in cross section A-A' and supported in cross sections C-C' and D-D'. Red arrows show the direction of progradation.

AGE OF DEPOSITIONAL WEDGES

In cross section A-A’, multiple wedges are evident that prograde from the northeast (proximal ramp) to the southwest (distal ramp) (Fig. 62). When the law of superposition is applied the arrangement of the wedges and the direction of progradation being predominantly towards the south indicates that the Mississippian sediment in Kansas is older than the Mississippian sediment in Oklahoma. Depositional wedges begin to prograde basinward when sediment begins to fill accommodation in the proximal position on the ramp. As the wedges prograde basinward each subsequent wedge is younger than the previous. As a result, the youngest material is deposited towards the basin axis. The current Pre-Pennsylvanian subcrop map of the study area also supports this as the younger aged Mississippian sediments are found in the south and do not appear in the north except in the central part of the present day Sedgwick Basin (partly seen on the right side of the inset map) (Fig. 63).

It should be noted that in cross section A-A’ (Fig 62), the bounding surfaces that appear as black lines on the landward side of the cross section (A) show what could be interpreted as apparent backstepping. This apparent backstepping appears nowhere else in the study area. Unfortunately the Bartel #1-16 core does not capture any of these surfaces and they are picked solely from logs. Confidence in this interpretation is questionable without a core with preserved facies that document a landward shift in facies.

EROSION VS NON-DEPOSITION

The relative ages of the prograding depositional wedges indicates that the Mississippian sediment in the south is younger than the Mississippian sediment in the north. Cross sections also show that the wedges found in the southern part of the project are not represented in the northern part of the project. The younger wedges that do not extend to the northern part of the

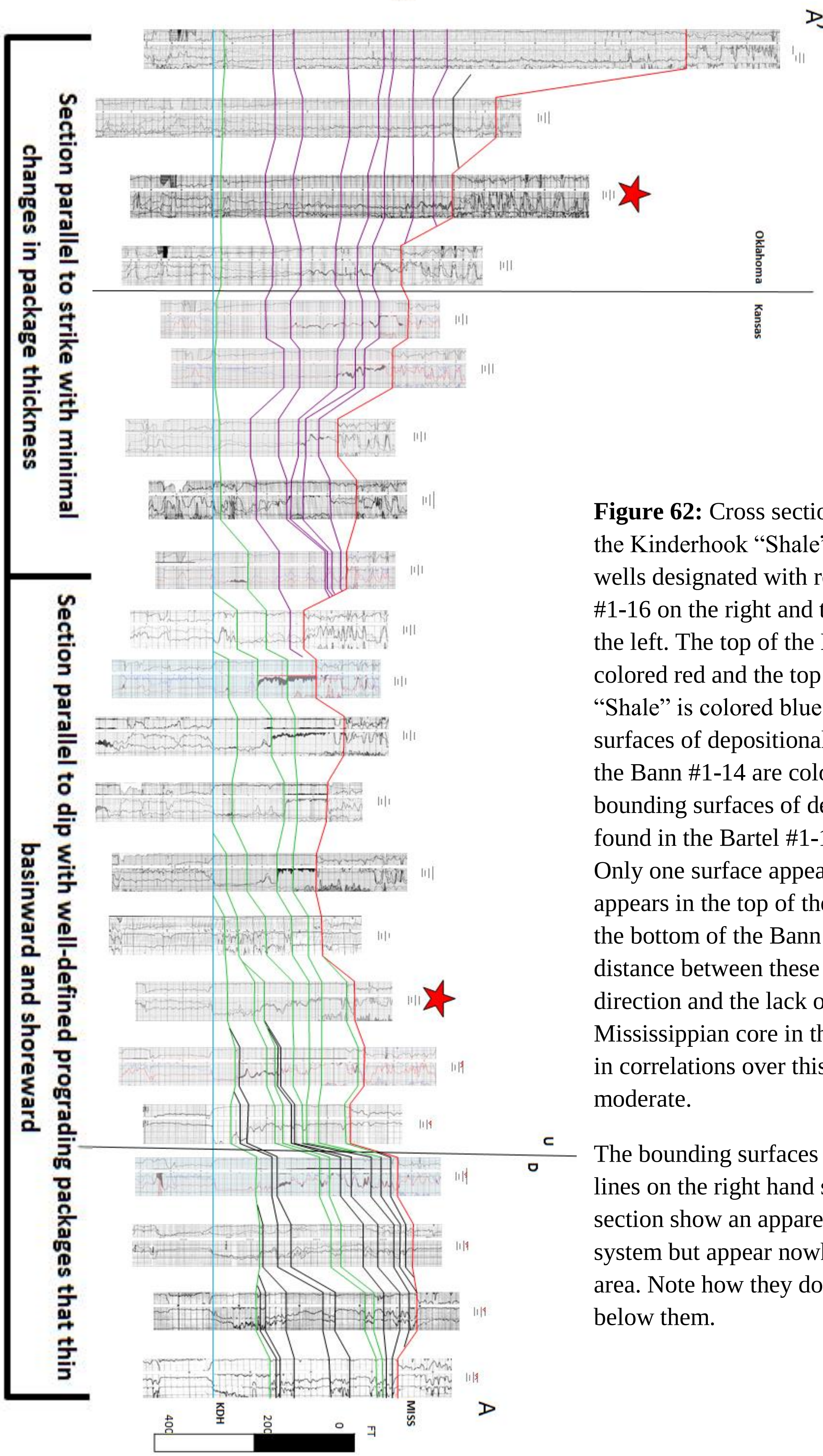


Figure 62: Cross section A-A’ flattened on the Kinderhook “Shale” with the two cored wells designated with red stars; the Bartel #1-16 on the right and the Bann #1-14 on the left. The top of the Mississippian in colored red and the top of the Kinderhook “Shale” is colored blue. The bounding surfaces of depositional wedges found in the Bann #1-14 are colored purple. The bounding surfaces of depositional wedges found in the Bartel #1-16 are colored green. Only one surface appears in both wells. It appears in the top of the Bartel #1-16 and the bottom of the Bann #1-14. Due to the distance between these two wells in the dip direction and the lack of a full Mississippian core in the Bann, confidence in correlations over this distance is moderate.

The bounding surfaces that appear as black lines on the right hand side of the cross section show an apparent backstep in the system but appear nowhere else in the study area. Note how they downlap onto surfaces below them.

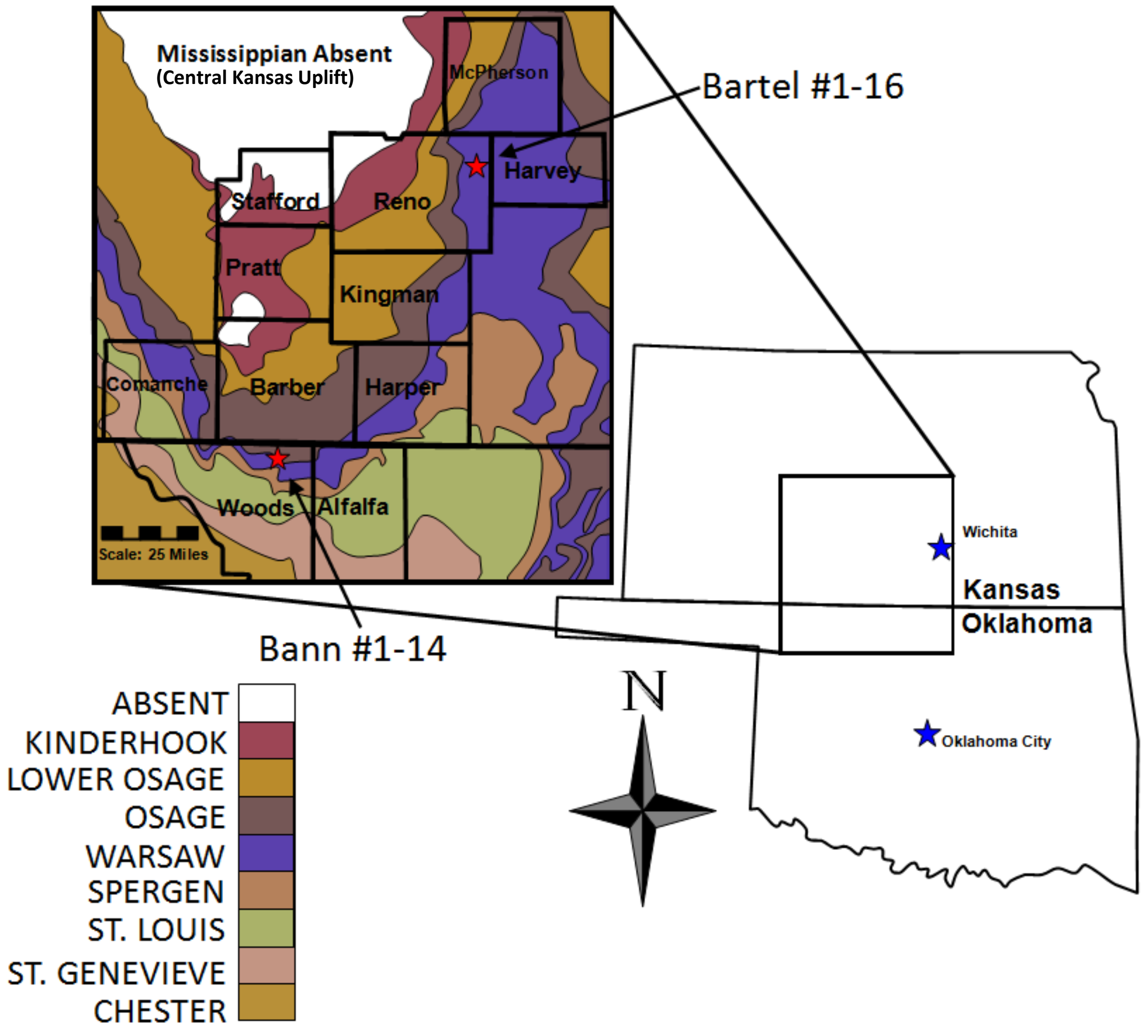


Figure 63: Map showing the location of the two cored wells (Bartel #1-16 and Bann #1-16) in relationship to the current Pre-Pennsylvanian subcrop map. Modified from Sandridge (2013).

project could be absent due to erosion, non-deposition or both. Due to the low accommodation in the proximal position on distally steepened ramps, it is reasonable to assume that accommodation was filled by older sediments around the Bartel #1-16 and younger sedimentation was forced basinward. Younger Mississippian sediments in the northern part of the project, if deposited, were likely thin and subsequently could have been removed by erosion.

A large area over the crest of the Central Kansas Uplift has no Mississippian section (Fig. 63). Absence of Mississippian section could be the result of erosion, non-deposition or a combination of these processes (Fig. 64). In cross section B-B’ the lower half of the packages have strong correlations and show thinning as they approach the uplift. This piece of evidence suggests that the area of the Central Kansas Uplift was a positive feature during Mississippian deposition. As a result is it possible Mississippian sediments were not deposited across the crest of the uplift. How much section is missing due to erosion or non-deposition cannot be determined with the data set from this study. Better well log coverage and additional cores closer to the uplift could help to answer this question. Applying high-resolution sequence stratigraphy to several cores in the area could help determine if the missing Mississippian on the uplift if due to erosion or non-deposition. The high-resolution sequence stratigraphy could help determine if the upper half of the packages seen in cross section B-B’, where correlations in this study were poor, also thin towards the uplift like the lower packages do. In the high resolution work, if the missing section on the uplift was the result of erosion, it would be expected that as you get closer to the uplift parts of the top packages would disappear whereas if the sediment is missing because of non-deposition it would be expected that the top packages would thin dramatically before disappearing.

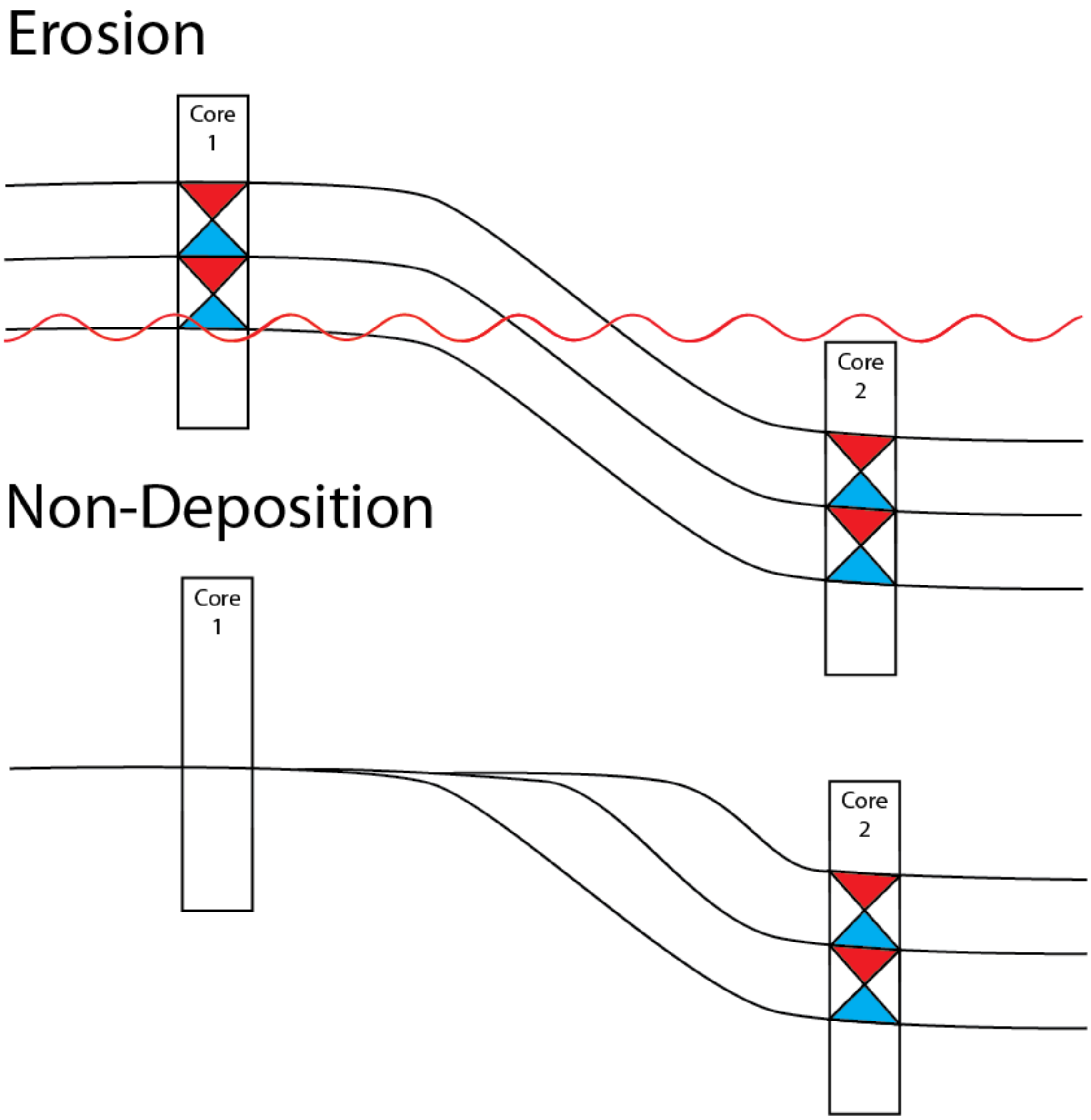


Figure 64: Illustrations of erosion versus non-deposition where the end result is no representation of the two depositional wedges in core 1. Each depositional wedge contains a blue and red triangle in core two representing transgression and regression respectively. If a third core was placed between core 1 and 2 and examined using concepts in high resolution sequence stratigraphy, the absence of wedges in core one could be explained. In the case of erosion it would be expected that little change in the thickness of the transgressive and regressive cycles would be seen because they continued onto the structure during deposition. In the case of non-deposition, it is expected that the transgressive and regressive cycles would thin towards the structure in response to less accommodation.

LIMITATIONS ON STUDY

There are limitations to the procedures used in this study that affect confidence in the correlations. First, with every step in the methodology, the data is farther removed from the original rock data. Starting with the data acquired from the core itself being translated to that wells wireline log. This calibrated log then becomes the starting point for correlations in the cross sections. As the correlations move farther from the cored well, the confidence in the correlations decreases. This limitation is unavoidable because it is unpractical to core every well and to make the correlations there must be correlations to un-cored wells. Including more core calibrated wireline logs to the cross sections is one way to increase the confidence in the correlations.

The width of the prograding wedges in this study (~30 miles) made it where the two cored wells were too far apart to strengthen the correlations between them. Only one surface appeared in both wells. This surface appears at the base of the Bann #1-14 in the southern portion of the project and in the upper portion of the Bartel #1-16. With only one surface appearing in both wells, that surface not cored in the Bann #1-14, and the distance between the two wells being ~85 miles, the confidence in this surface being the same is low. If the wells were 30 miles apart or less (the approximate width of depositional wedges) it would be expected that multiple surfaces would appear in both wells. Having multiple surfaces in both wells would strengthen the correlations between them.

Wireline logs also introduce limitations to the study. Limits in the resolution of logging tools can cause complications. The vertical and horizontal resolution is different for different logging tools, but generally the finest vertical resolution is greater than one foot under the best conditions. The speed the tool is pulled through the well bore during logging and the quality of the well bore itself can also affect quality.

The spacing of the wireline log data also creates limitation to the correlations. Most logs that are available occur in clusters from productive oil and/or gas fields. Between the different oil and gas fields the density of wells drilled is much less. Making correlations between the oil and gas fields can force correlation across several miles. Ideally correlations would be best with spacing between wells of a half mile or less; with less being better. This close spacing greatly reduces the chances of miscorrelations. The best chance for this type of data density would be in a field sized study with cross sections only being a few miles long. In this regional study with the smallest cross sections being 30 miles long and the longest being over 100 miles, correlations across several miles were unavoidable.

CHAPTER IV

CONCLUSIONS

This study identified petrophysically significant rock packages in the Mississippian carbonate section in two cores that represent proximal and distal positions respectively on a distally steepened ramp. Core-calibrated electrofacies package geometries were used to determine if the Central Kansas Uplift and/or the Pratt Anticline were positive features that influenced deposition of Mississippian sediments.

Key findings from this study are:

1) Petrophysically correlatable packages were identified in both the proximal and distal core locations. The top package in both wells consisted of weathered/karsted Mississippian carbonate of variable thickness with infiltration of Pennsylvanian sediments.
2) Multiple wireline log curves were required for correlation as a single type was not sufficient to correlate depositional packages across the distally steepened ramp from the proximal to distal positions. Flooding surfaces, with their characteristic increase in gamma-ray curve signature usually used in regional correlations are not present in the proximal high-energy positions on the distally steepened ramp. The high-energy environments found in the proximal position of the distally steepened ramp hindered the deposition of clays that contribute to the increase in

gamma-ray value and produce stratigraphically important flooding surfaces. Other log tracks (i.e. density/neutron porosity, resistivity, etc.) were used to correlate packages of similar type rock rather than the surfaces that bound them as is done with gamma-ray correlations.

3) Depositional geometry defined package limits and determined how far surfaces or packages could be traced. Most surfaces identified in the cored wells were only able to be traced 20-25 miles before they downlapped and disappeared. The Bartel #1-16 and the Bann #1-14 are approximately 85 miles apart, with the Bann #1-14 in a dip direction from the Bartel #1-16. Only one package appeared in both wells and was found near the top of the Bartel #1-16 and near the base of the Bann #1-14. Due to the distance between the two cored wells and the package not being cored in the Bann #1-14, there is low confidence in the correlation.
4) Based on the prograding carbonate wedge model, the Mississippian section in the Bann #1-14 is younger than the section in the Bartel #1-16.
5) Both thinning of depositional packages and an apparent change in the direction of progradation were observed and attributed to a positive structural influence by the Central Kansas Uplift and the Pratt Anticline.
6) Supratidal facies present near the top of the Bartel #1-16 (the proximally located well) in association with the thinning of these packages as they approach the Central Kansas Uplift strongly suggests that in the proximal area, accommodation was filled or nearly filled and sedimentation moved basinward. If this inference is confirmed, much of the Mississippian section missing on the crest and flanks of the Central Kansas Uplift could be the result of non- or limited deposition and not totally the result of pre-Pennsylvanian erosion.

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APPENDICES

APPENDIX A

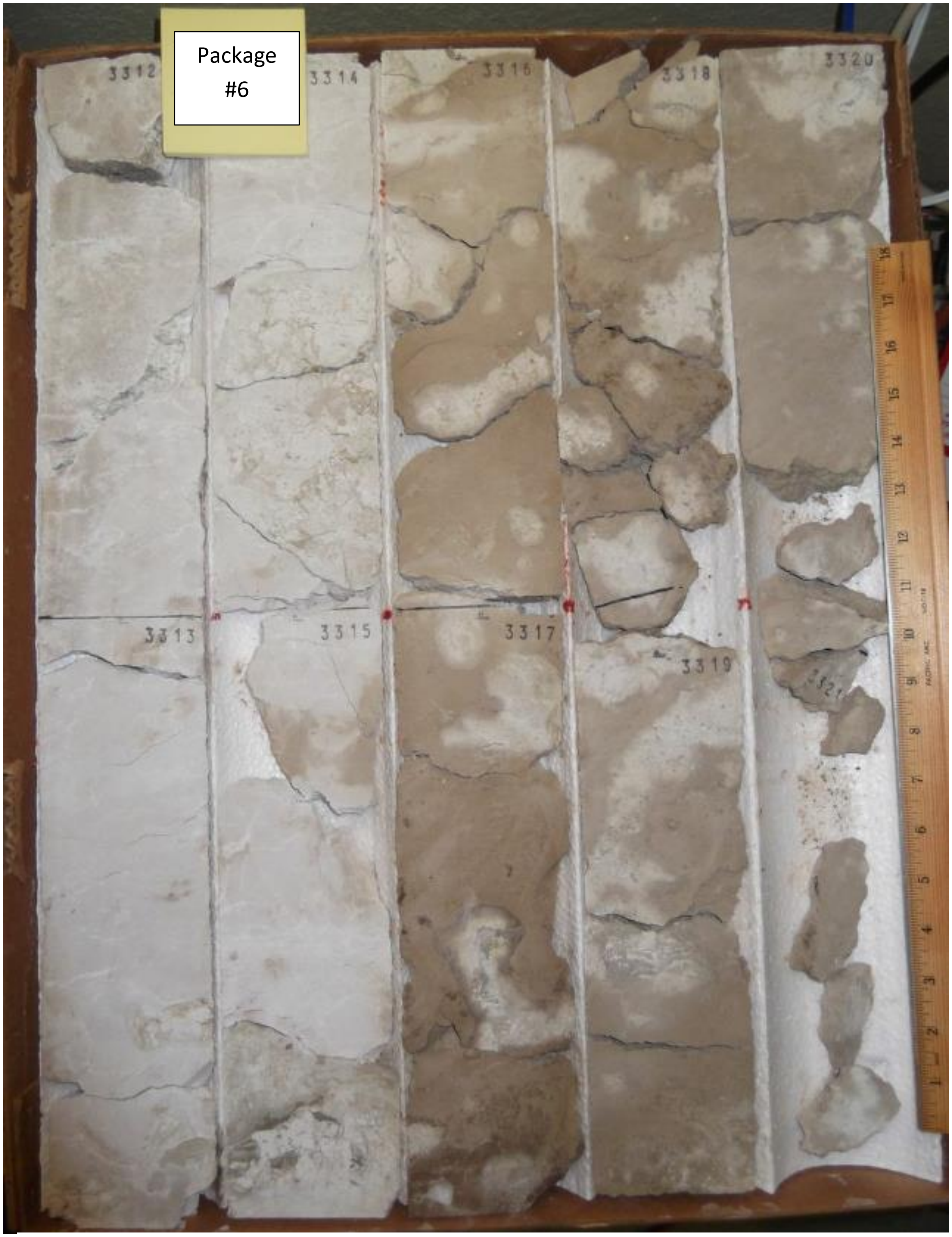
BARTEL #1-16 WHOLE CORE PHOTOGRAPHS

DRY

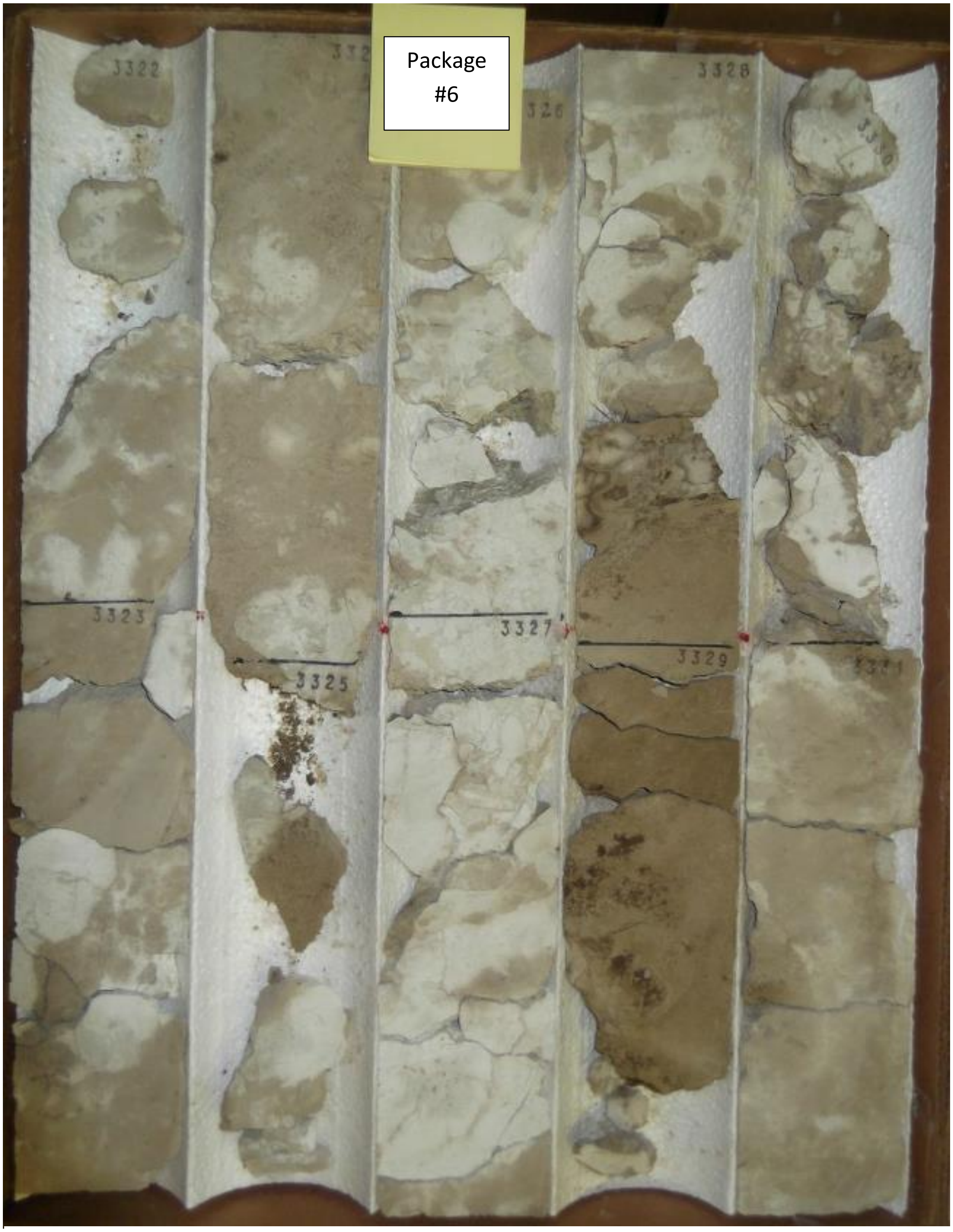
WHITE LIGHT

Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #1 3292 feet to 3302 feet.

Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #2 3302 feet to 3312 feet.

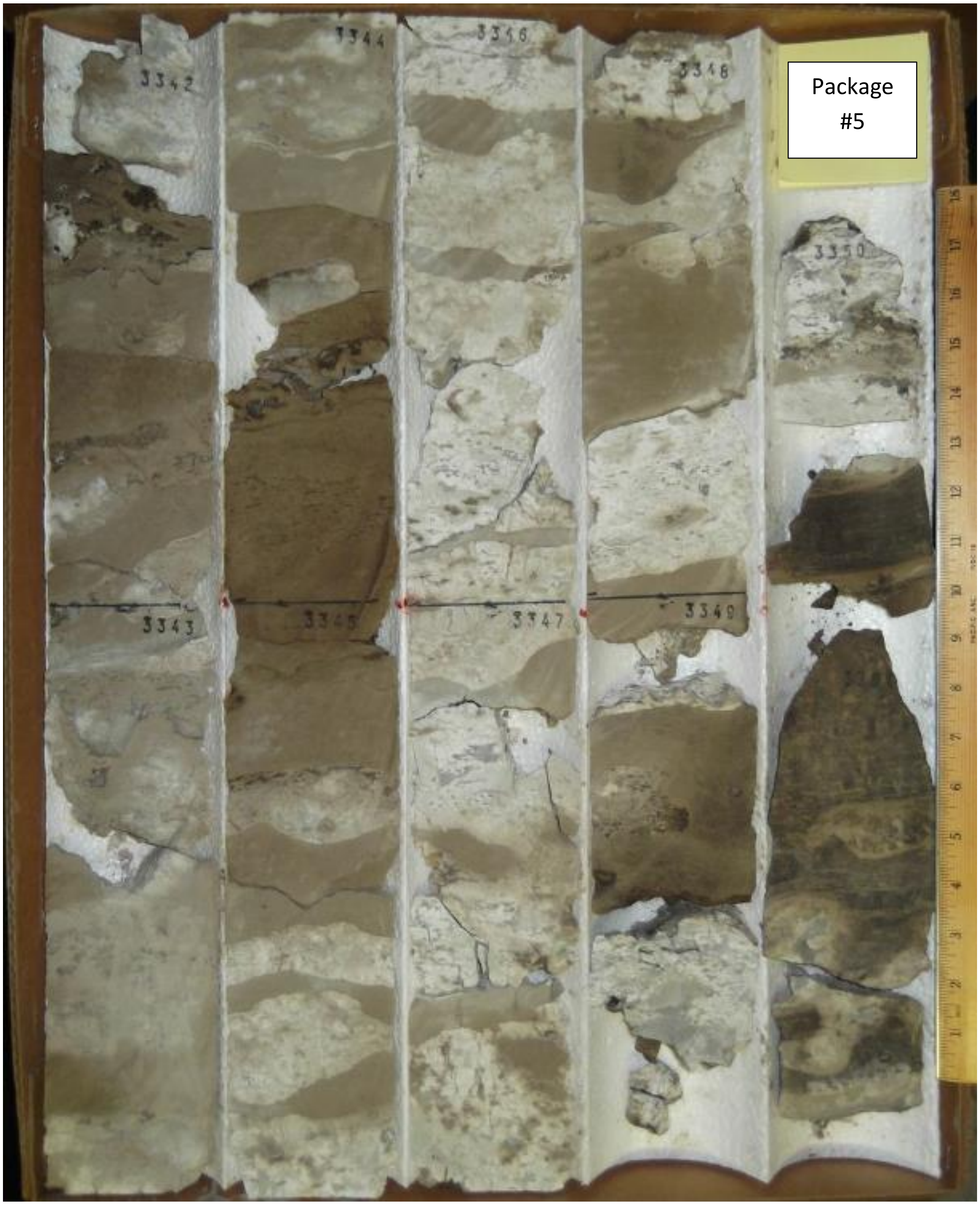


Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #3
3312 feet to 3322 feet.



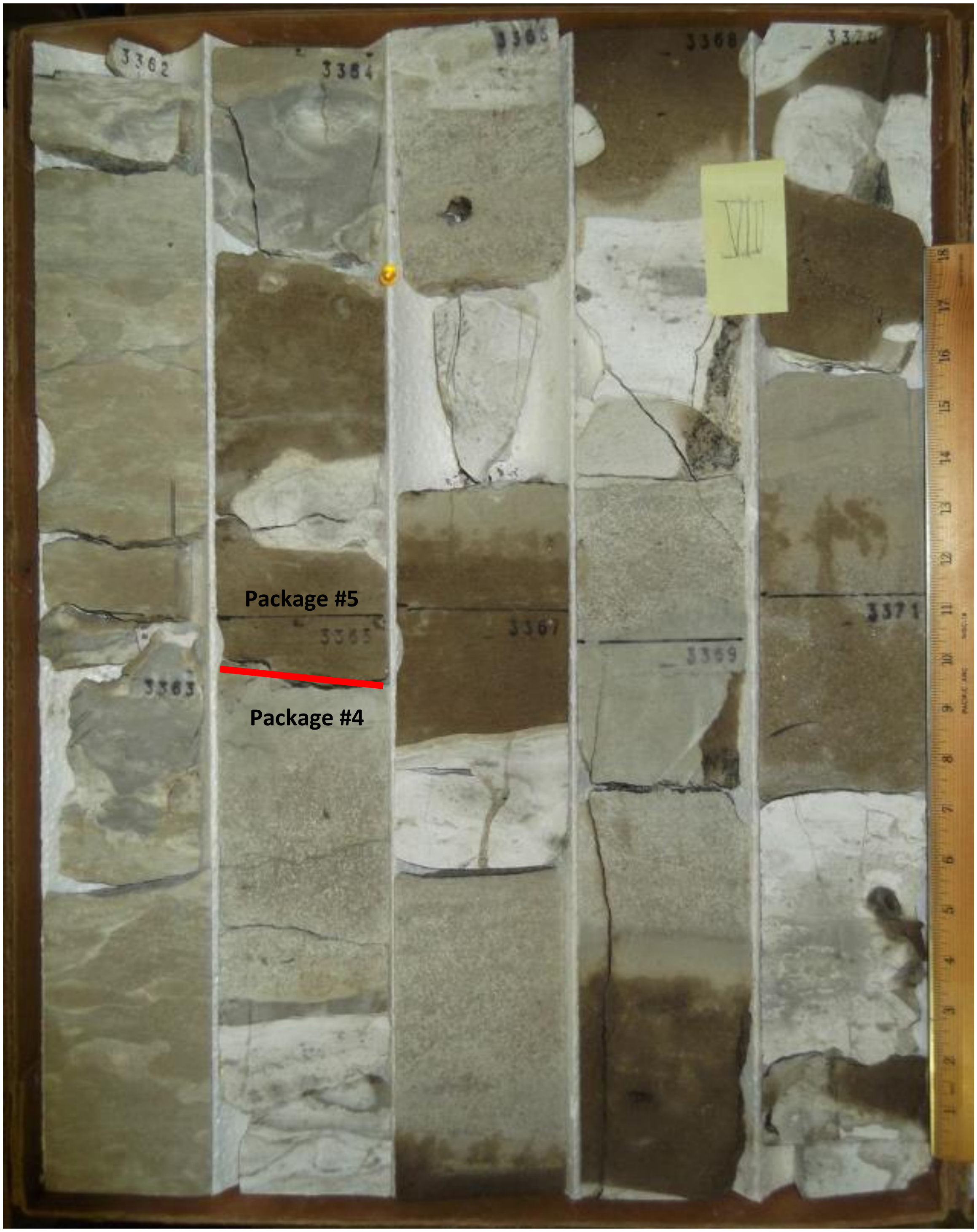
Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #4 3322 feet to 3332 feet.

Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #5 3332 feet to 3342 feet.



Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #6 3342 feet to 3352 feet.

Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #7
3352 feet to 3362 feet.



Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #8 3362 feet to 3372 feet.

Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #9
3372 feet to 3382 feet.

Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #10 3382 feet to 3392 feet.

Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #11 3392 feet to 3402 feet.

Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #12 3402 feet to 3412 feet.

Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #13 3412 feet to 3422 feet.

Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #14 3422 feet to 3432 feet.

Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #15 3432 feet to 3442 feet.

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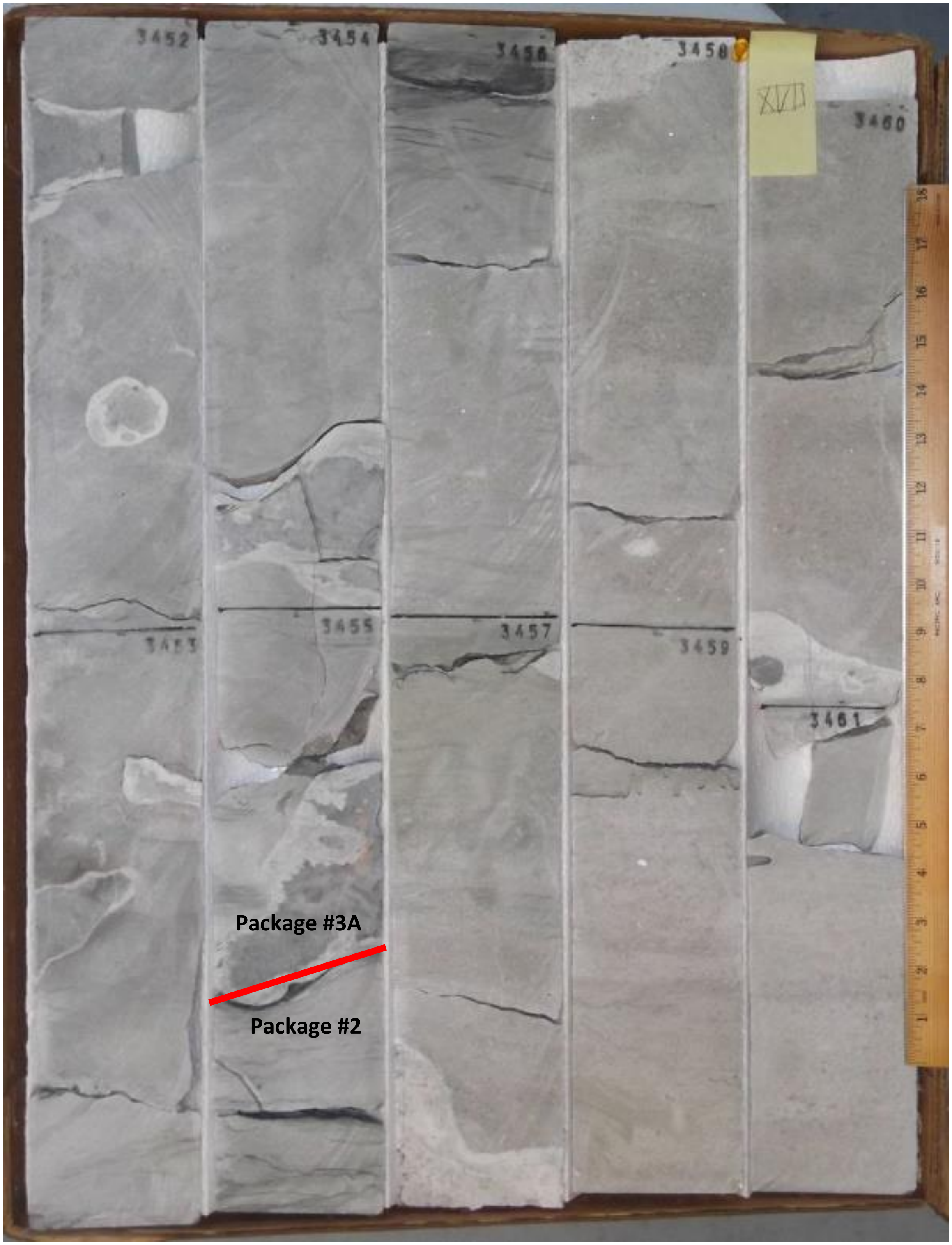
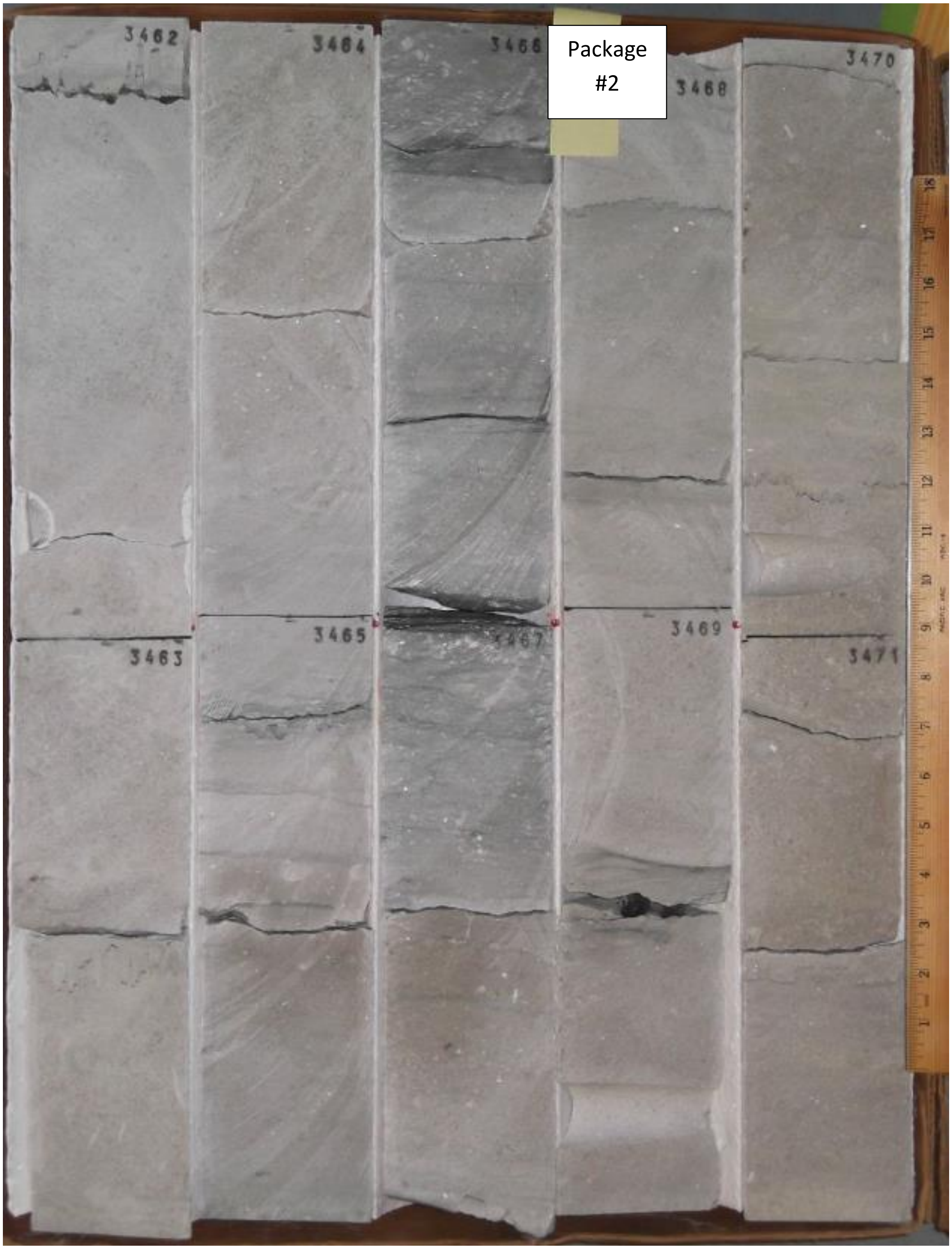
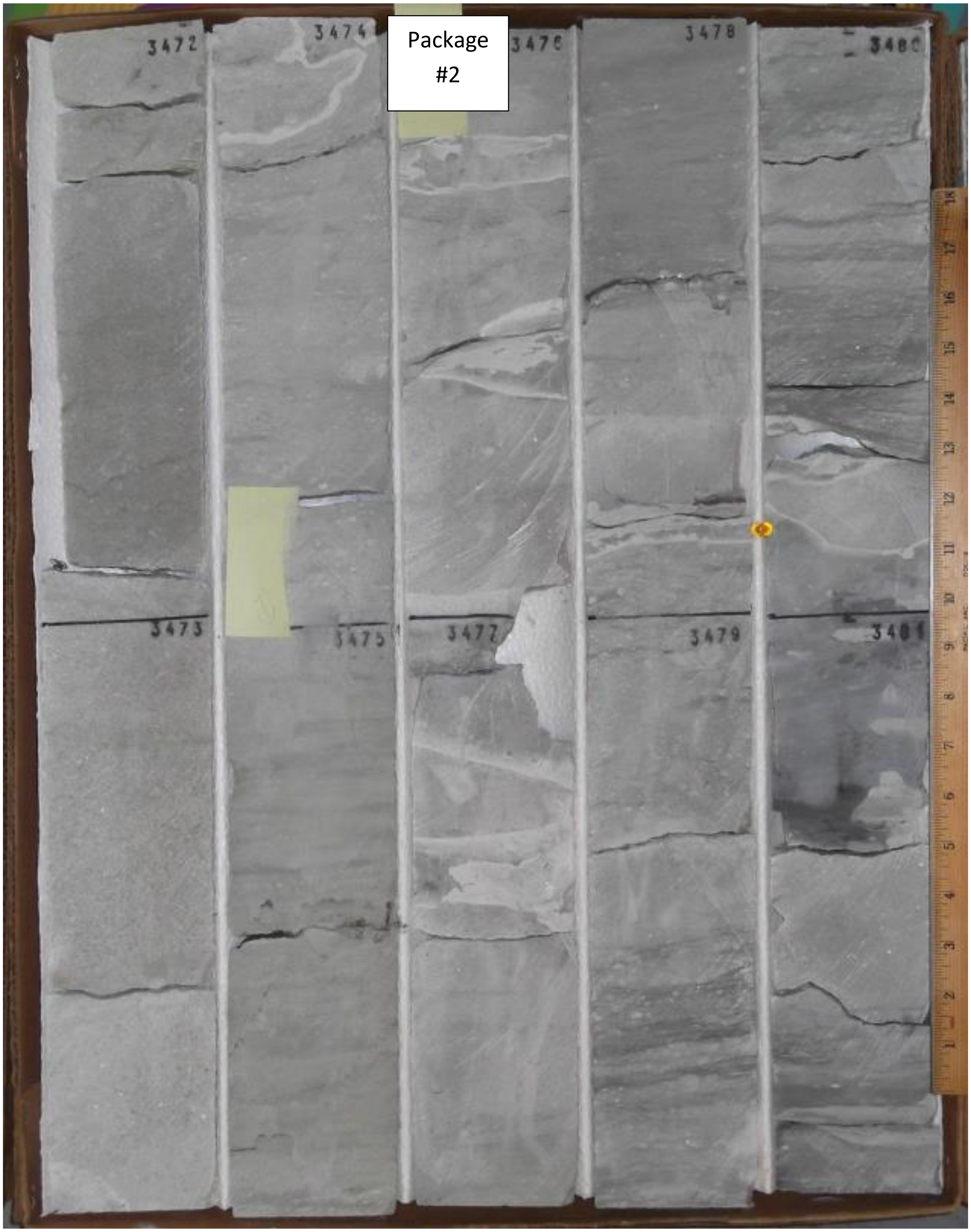


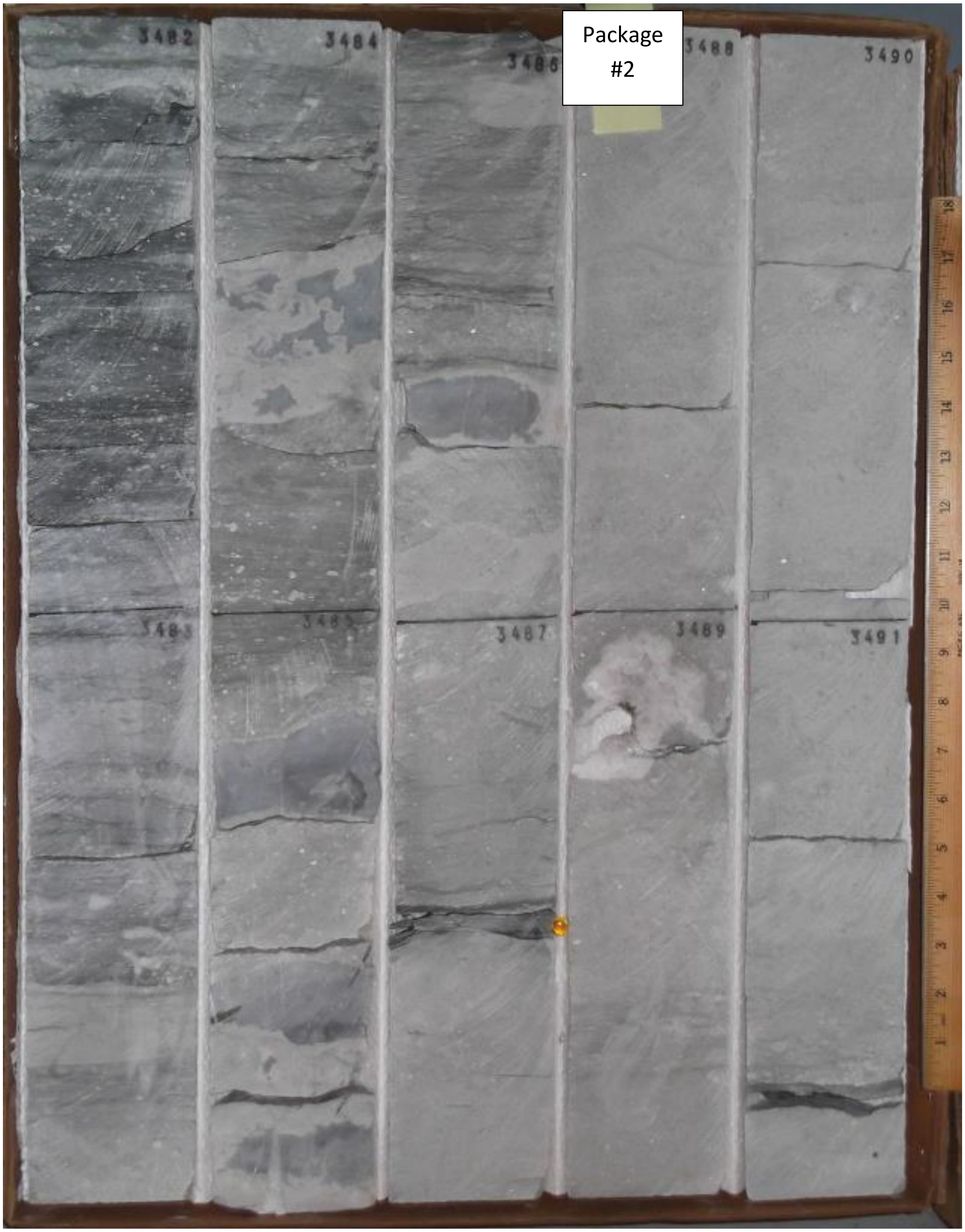
Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #17 3452 feet to 3462 feet.



Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #18 3462 feet to 3472 feet.



Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #19 3472 feet to 3482 feet.



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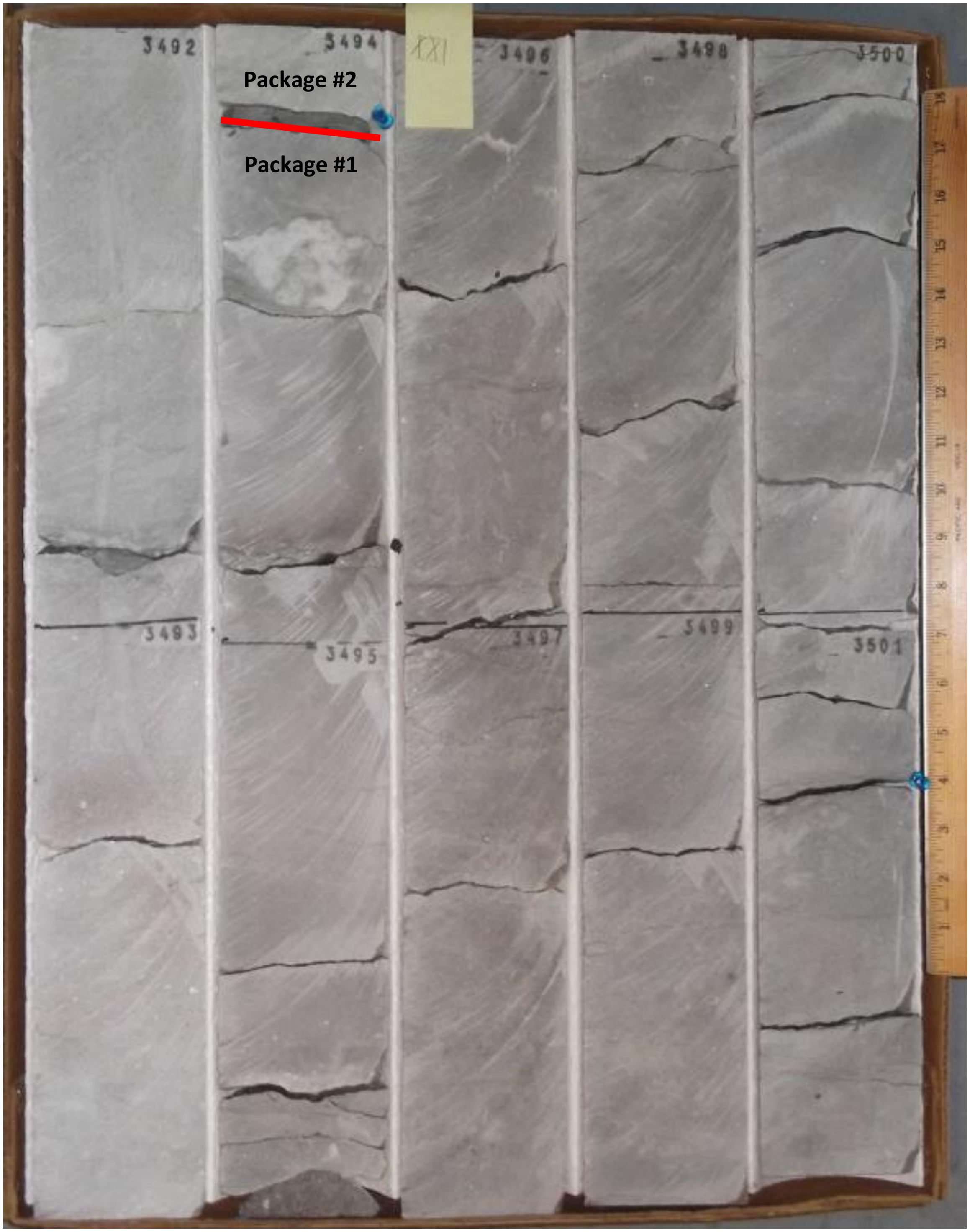
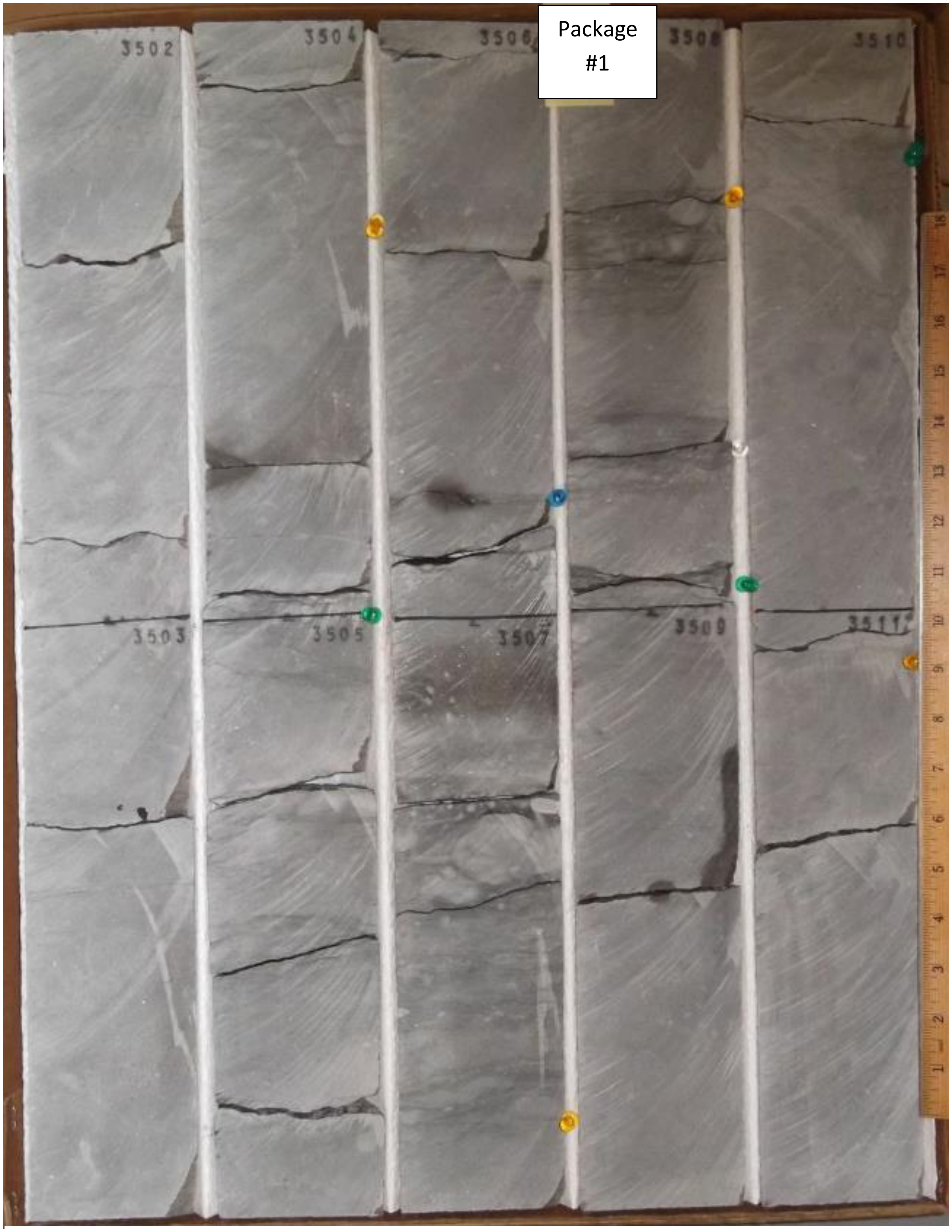
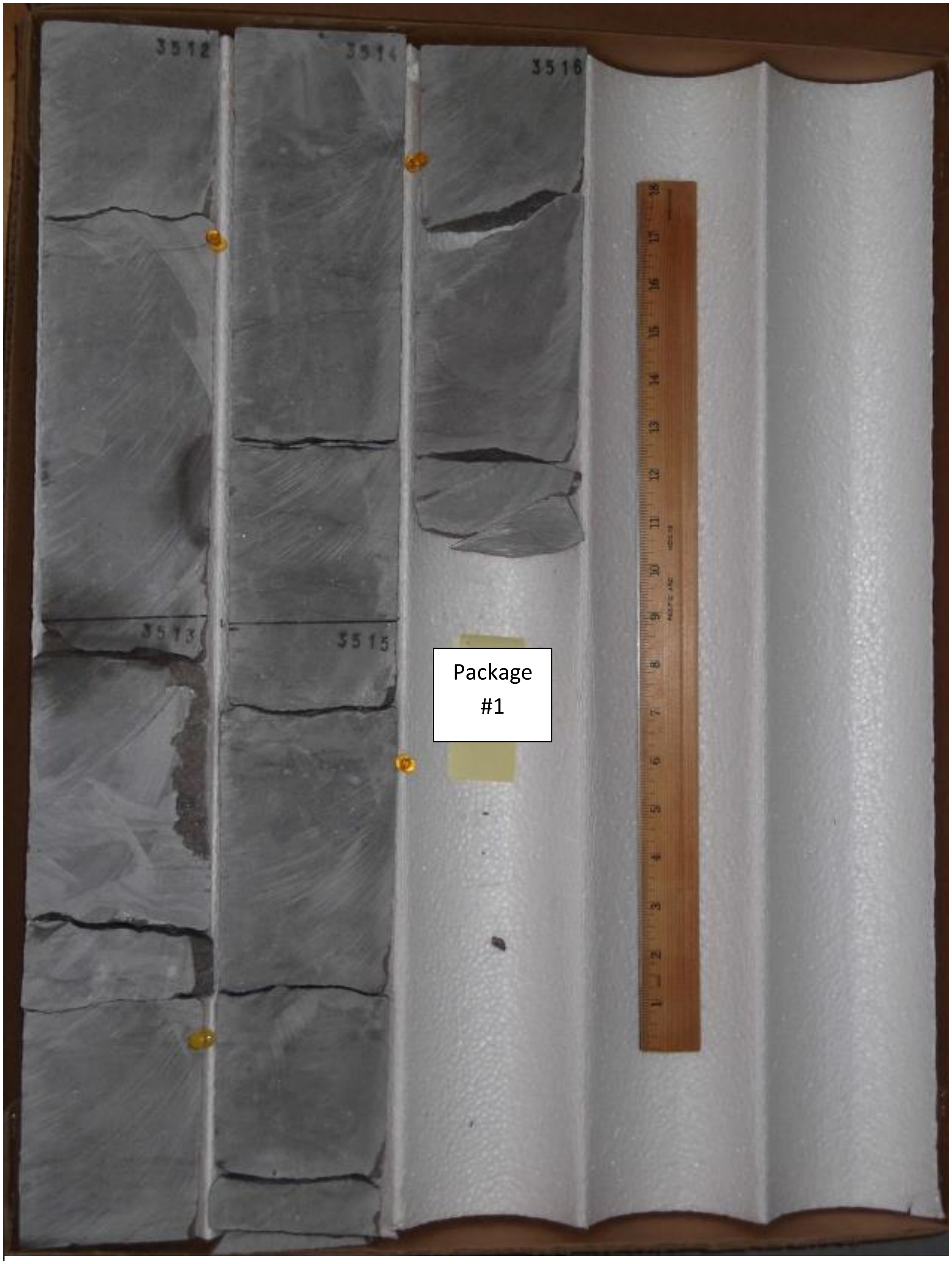


Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #21 3492 feet to 3502 feet.



Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #22 3502 feet to 3512 feet.



Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #23 3512 feet to 3517 feet.

APPENDIX B

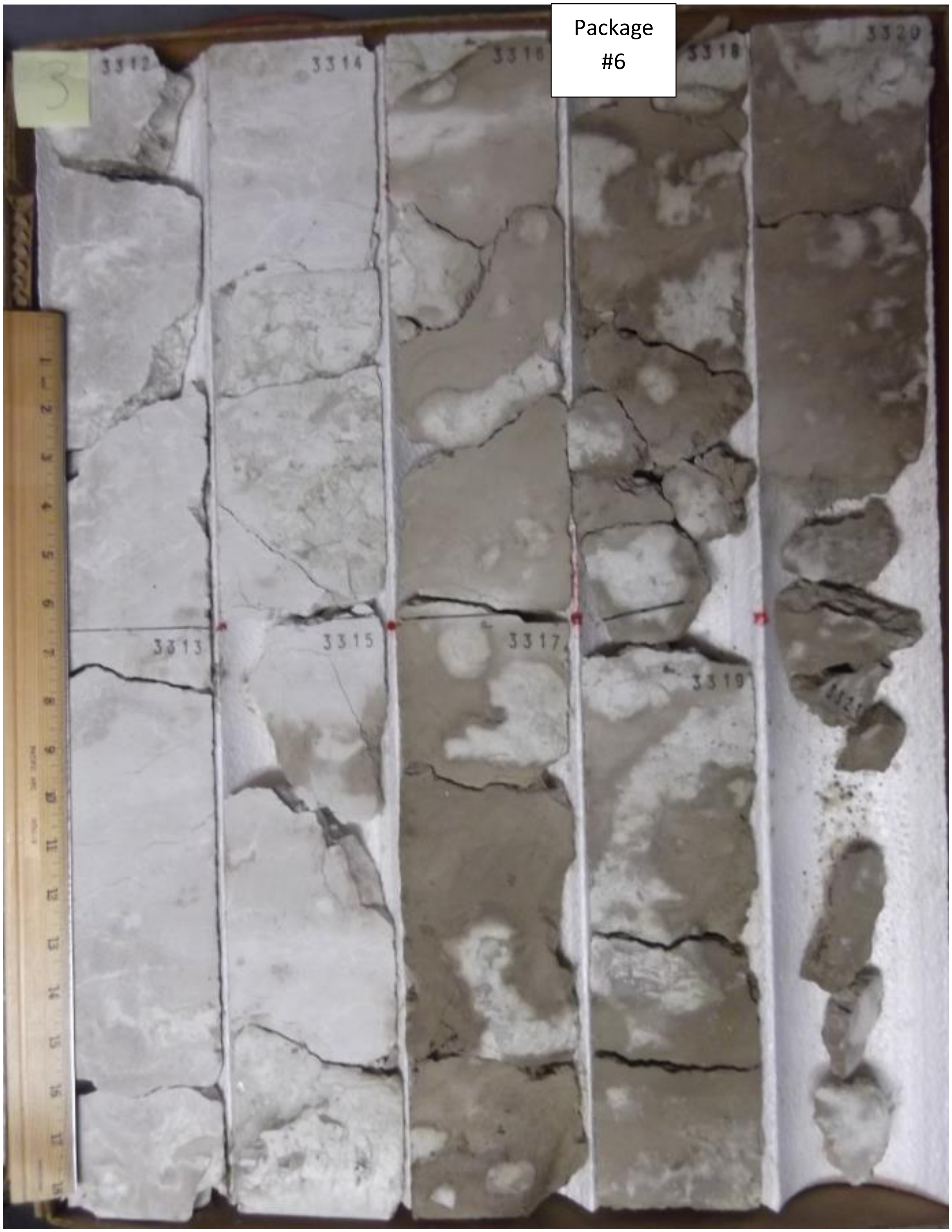
BARTEL #1-16 WHOLE CORE PHOTOGRAPHS

WET

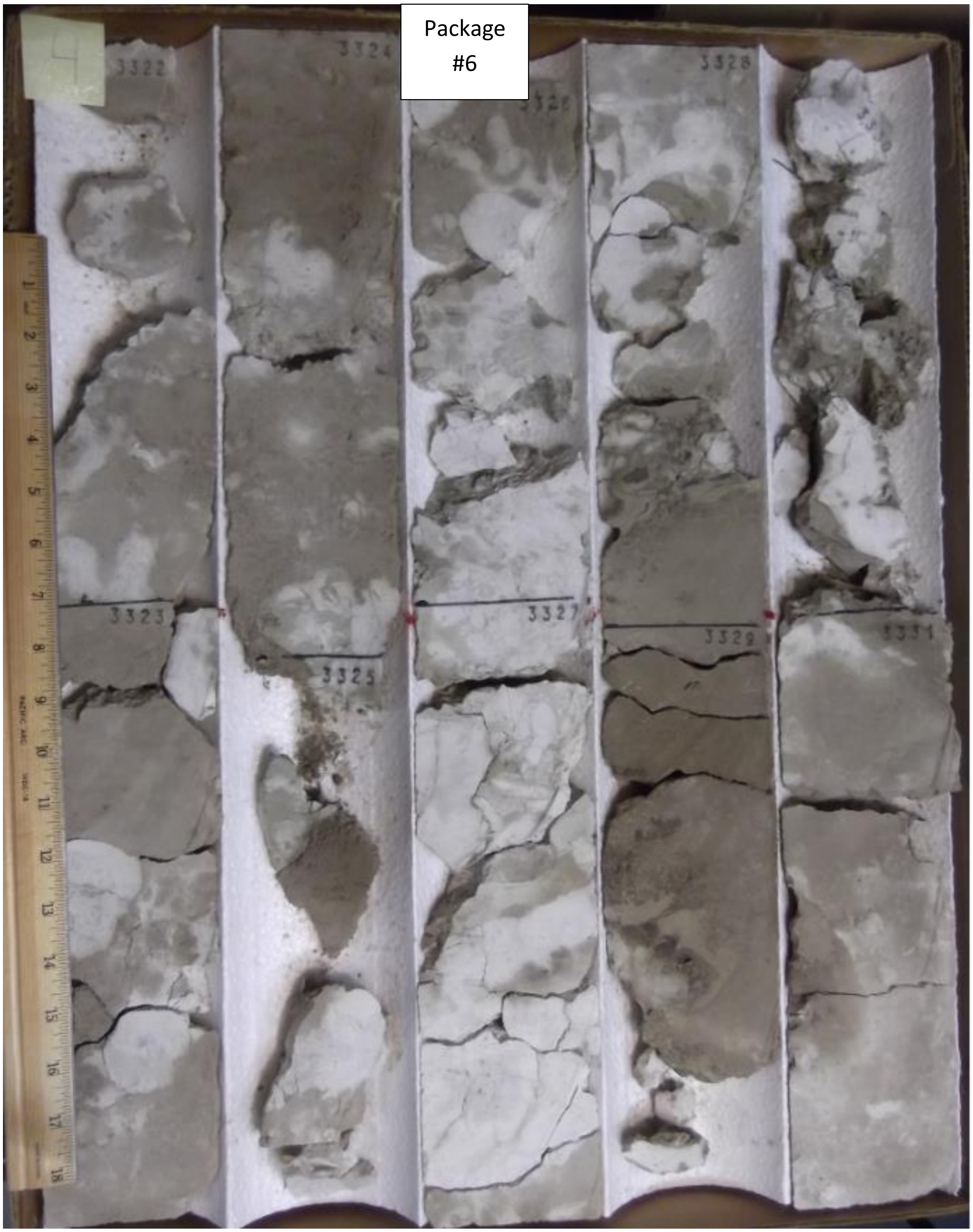
WHITE LIGHT

Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #1 3922 feet to 3302 feet.

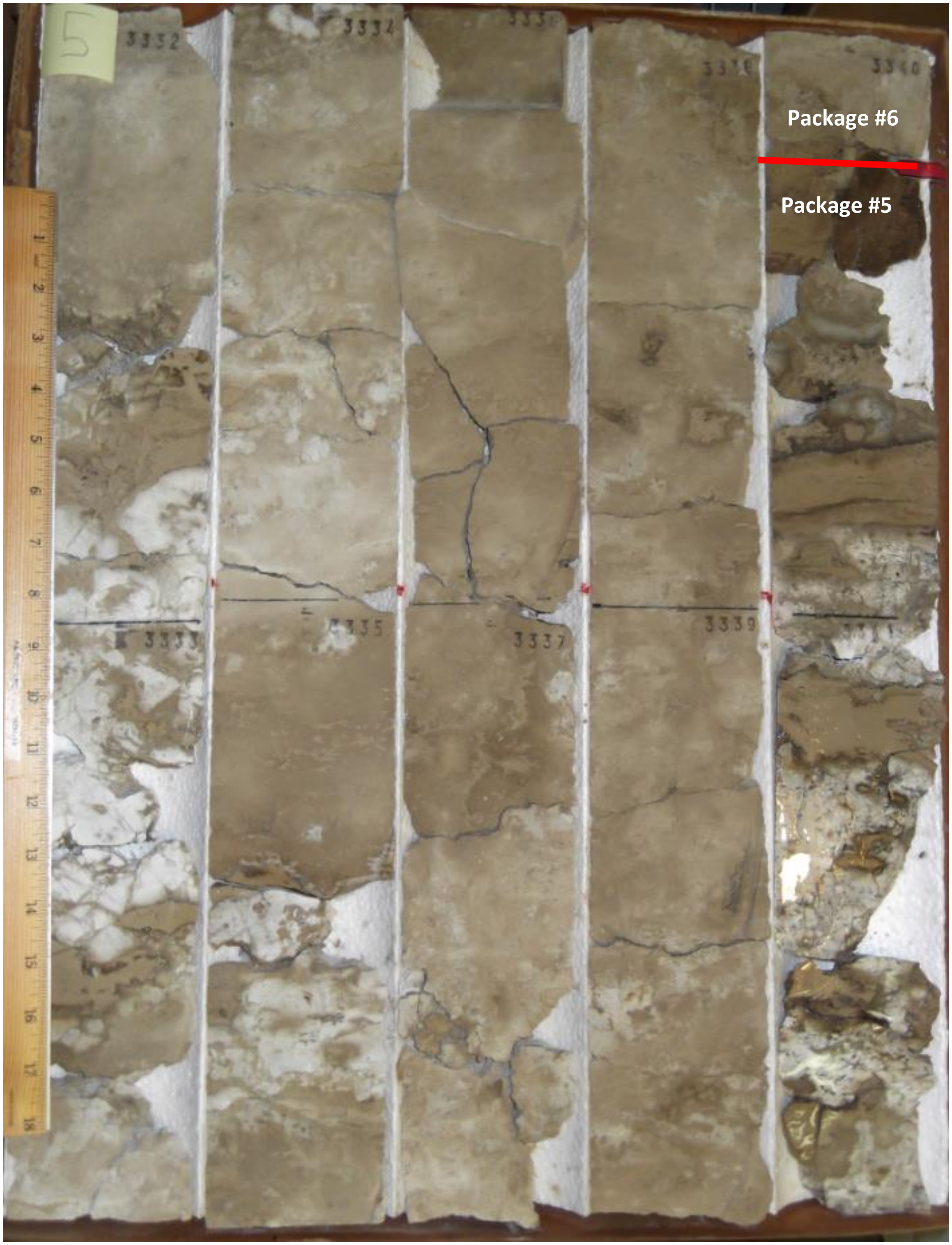
Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #2 3302 feet to 3312 feet.



Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #3
3312 feet to 3322 feet.

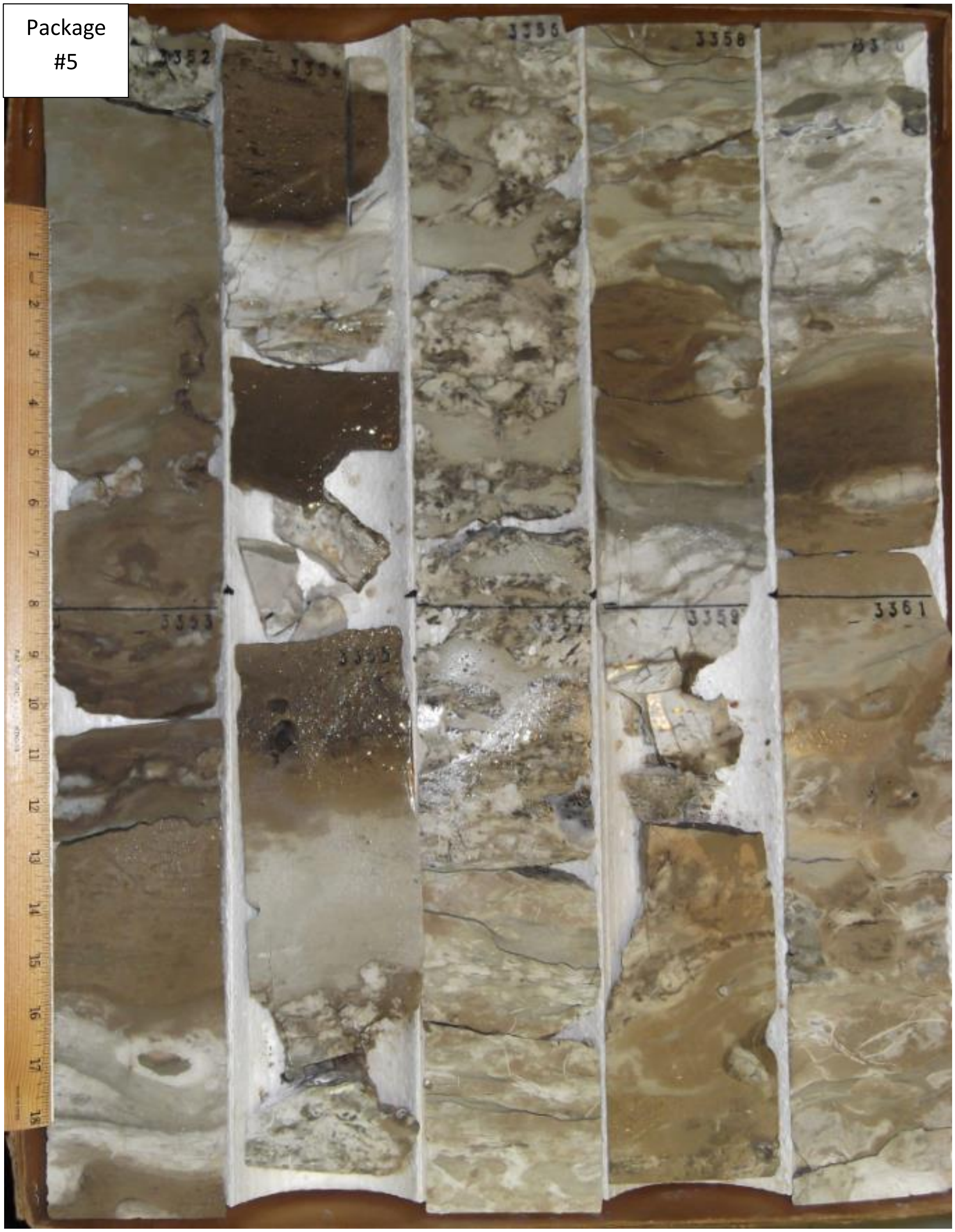


Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #4 3322 feet to 3332 feet.



Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #5 3332 feet to 3342 feet.

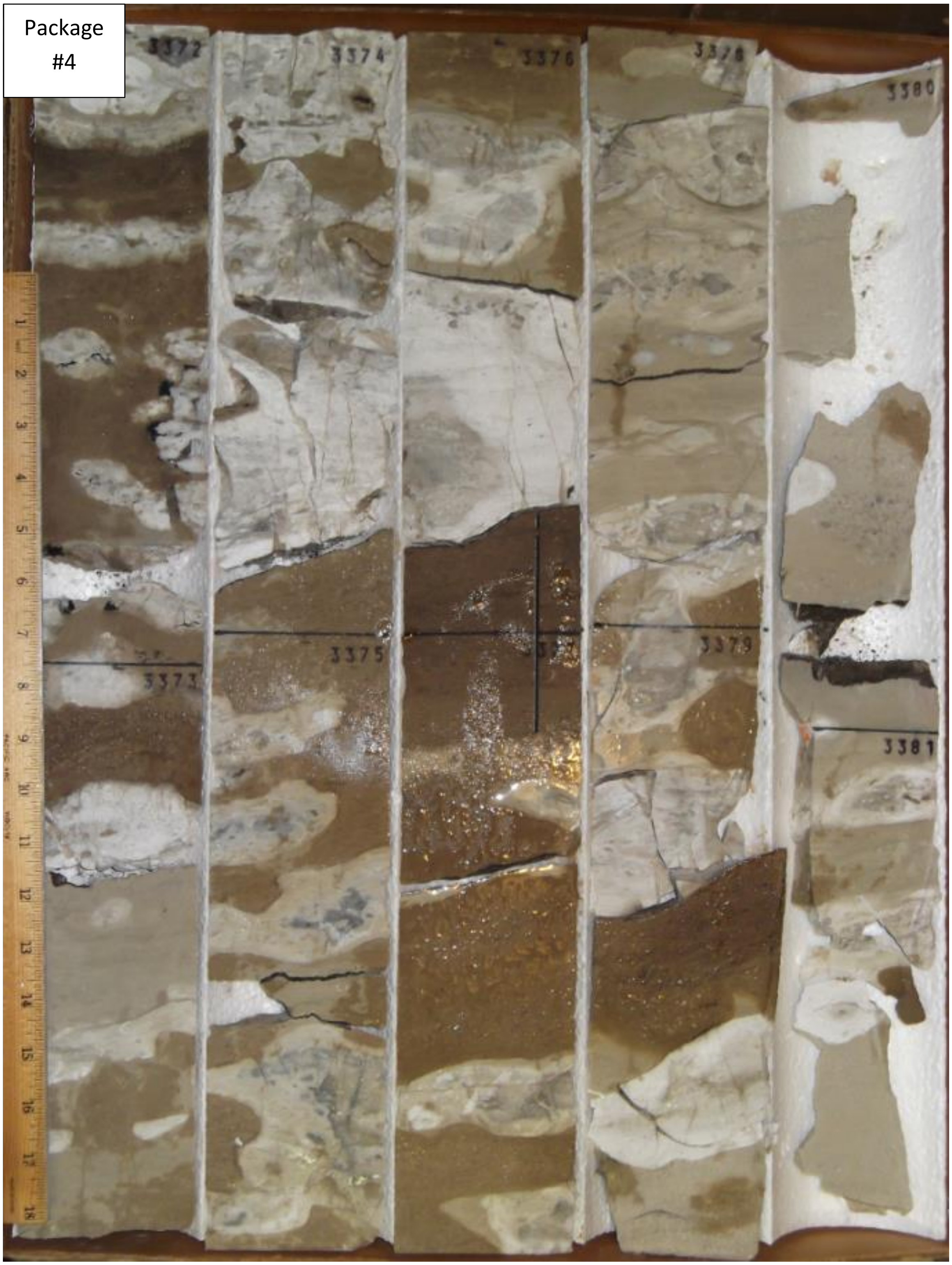
Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #6 3342 feet to 3352 feet.



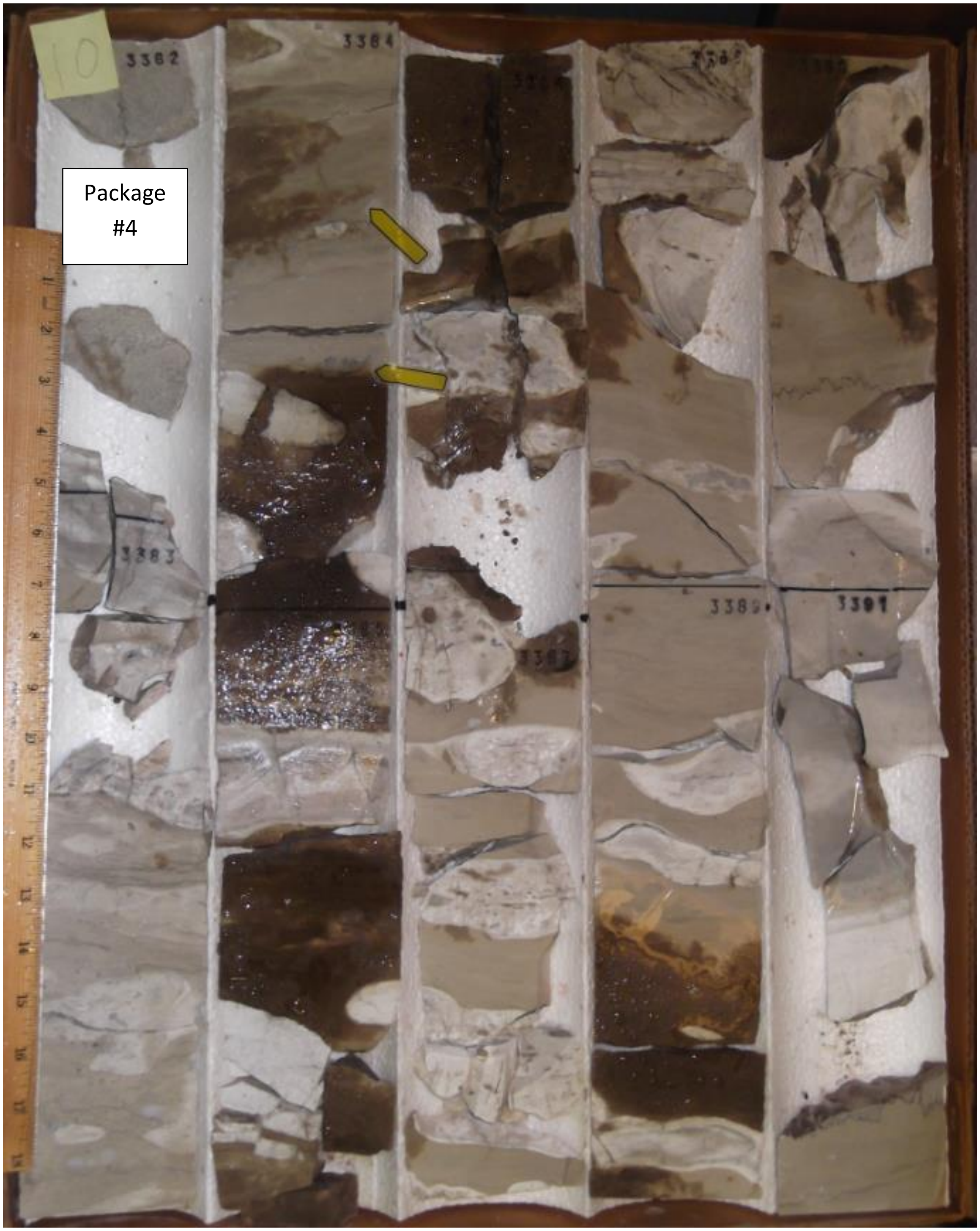
Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #7 3352 feet to 3362 feet.

00

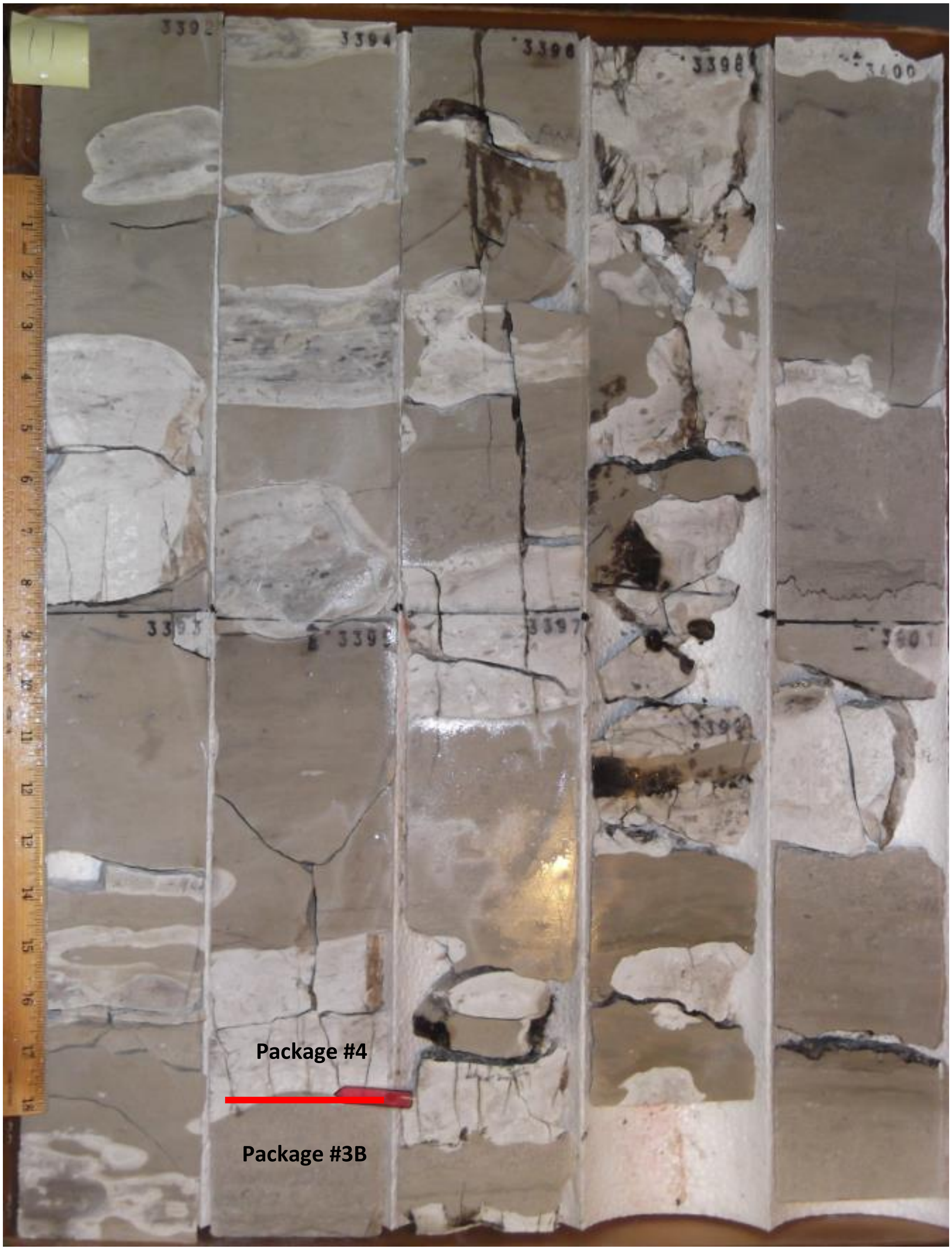
Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #8 3362 feet to 3372 feet.



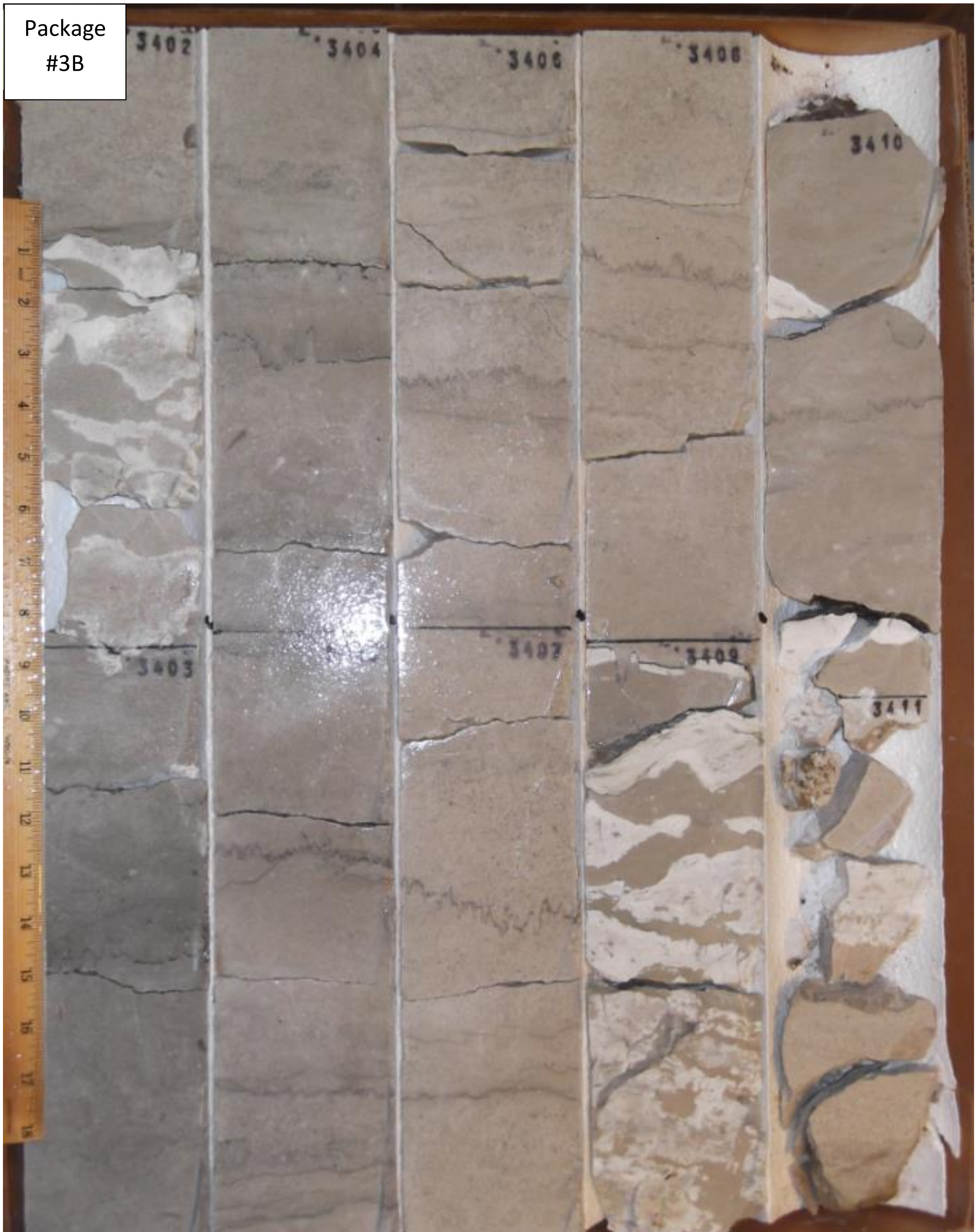
Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #9 3372 feet to 3382 feet.



Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #10 3382 feet to 3392 feet.

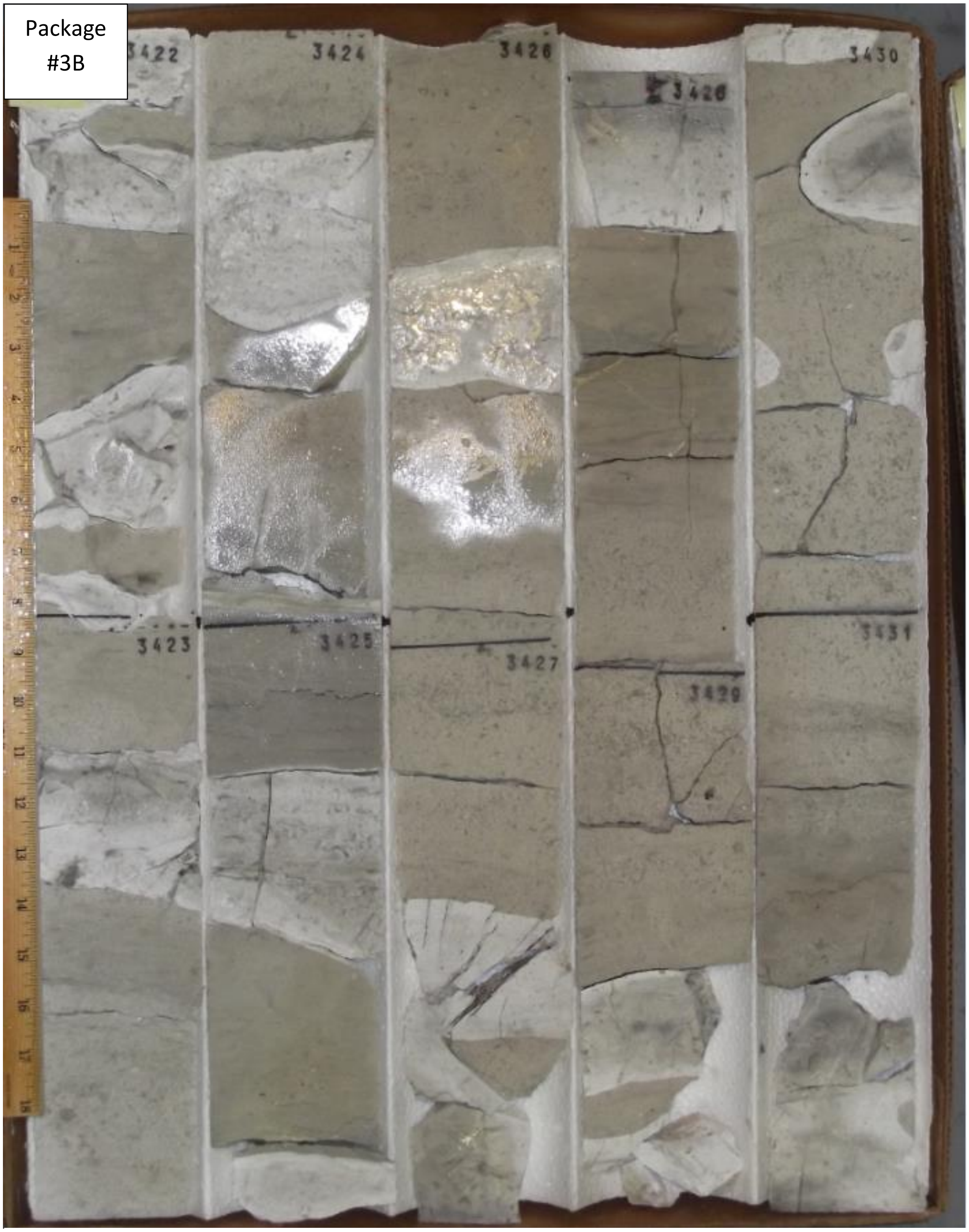


Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #11 3392 feet to 3402 feet.



Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #12 3402 feet to 3412 feet.

Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #13 3412 feet to 3422 feet.

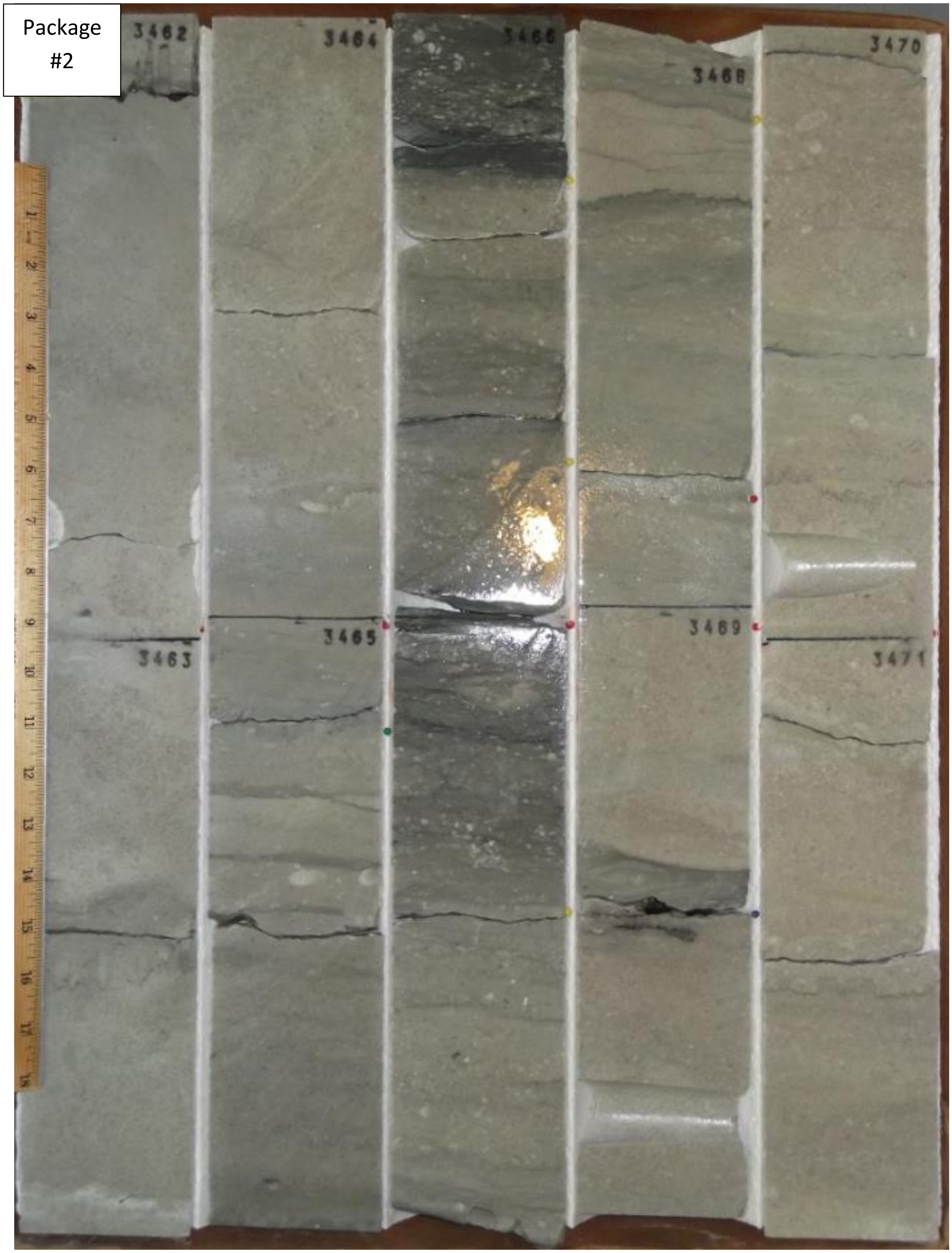


Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #14 3422 feet to 3432 feet.

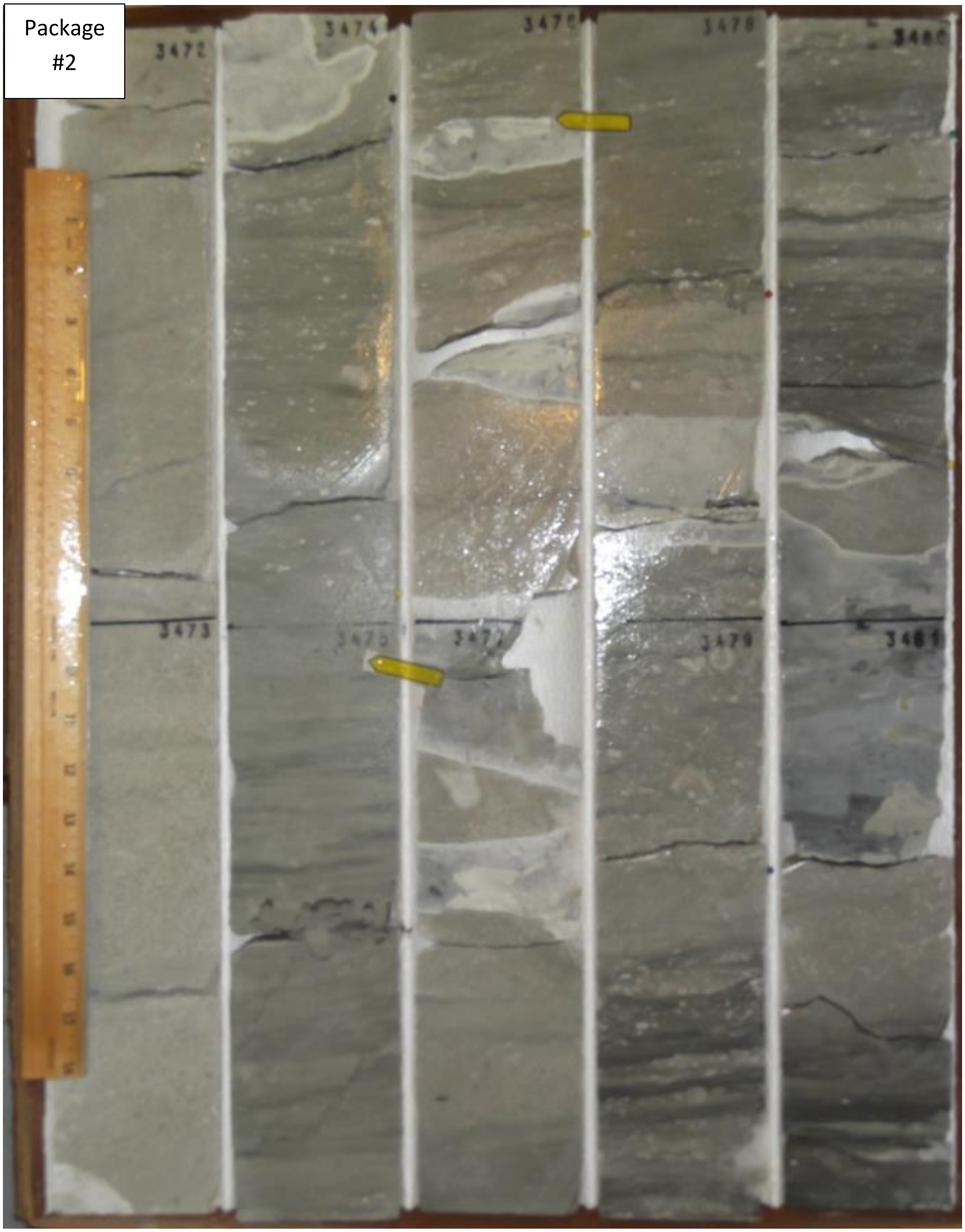
Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #15 3432 feet to 3442 feet.

Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #16 3442 feet to 3452 feet.

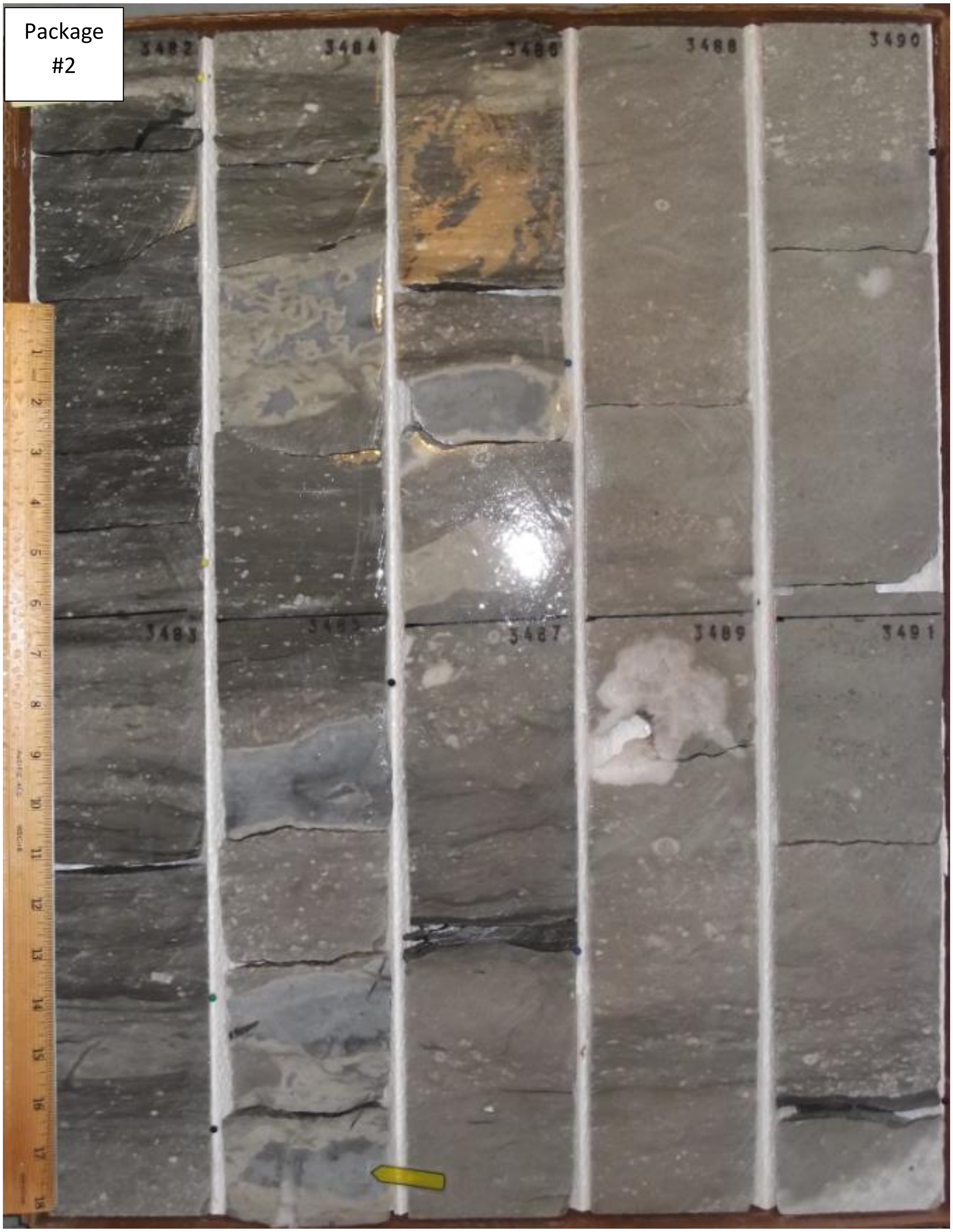
Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #17 3452 feet to 3462 feet.



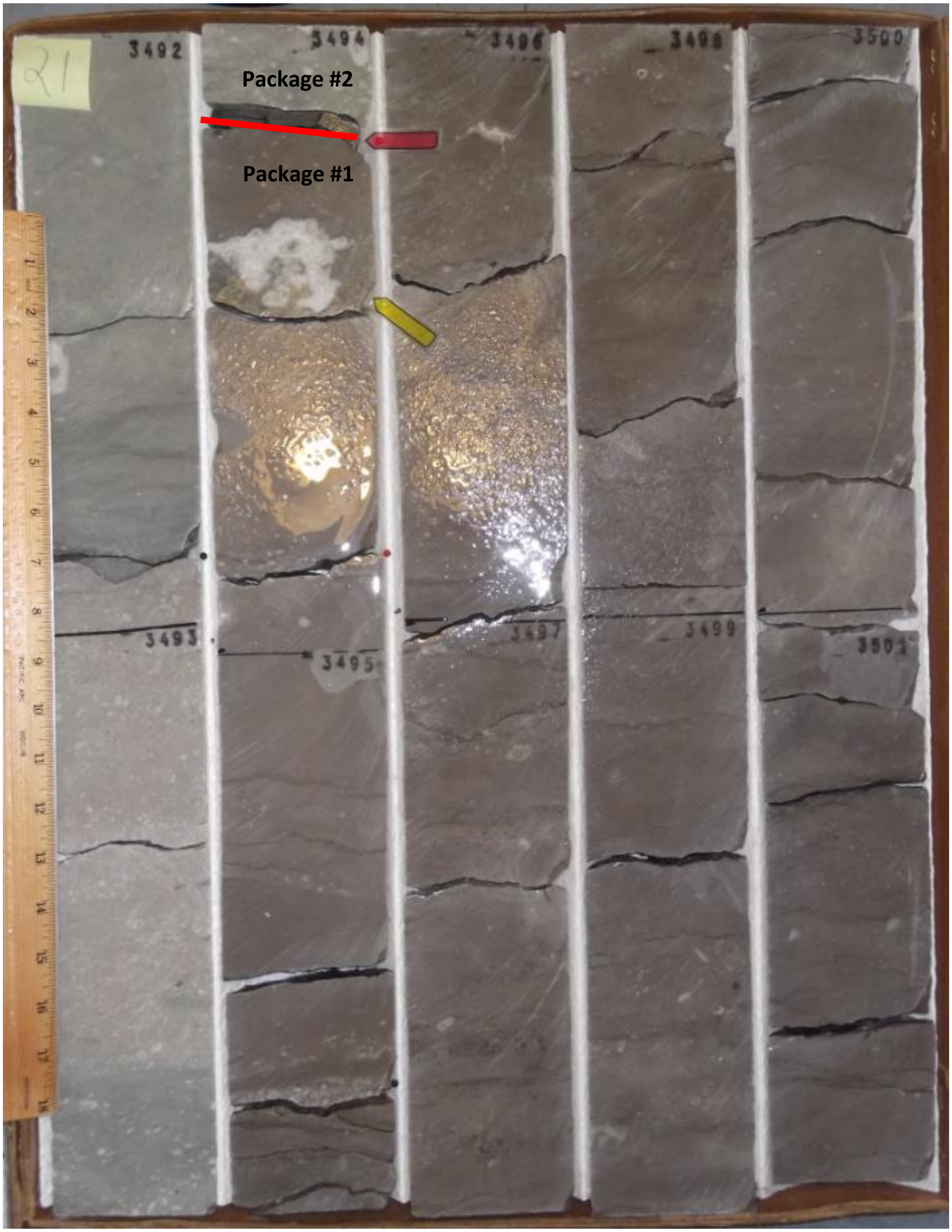
Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #18 3462 feet to 3472 feet.



Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #19 3472 feet to 3482 feet.



Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #20 3482 feet to 3492 feet.



Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #20 3492 feet to 3502 feet.

Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #22 3502 feet to 3512 feet.

Bartel #1-16, Blueridge Petroleum Corporation, S16-T24S-R4W, Reno County, Kansas. Box #23 3512 feet to 3517 feet.

APPENDIX C

BANN #1-14 WHOLE CORE PHOTOGRAPHS

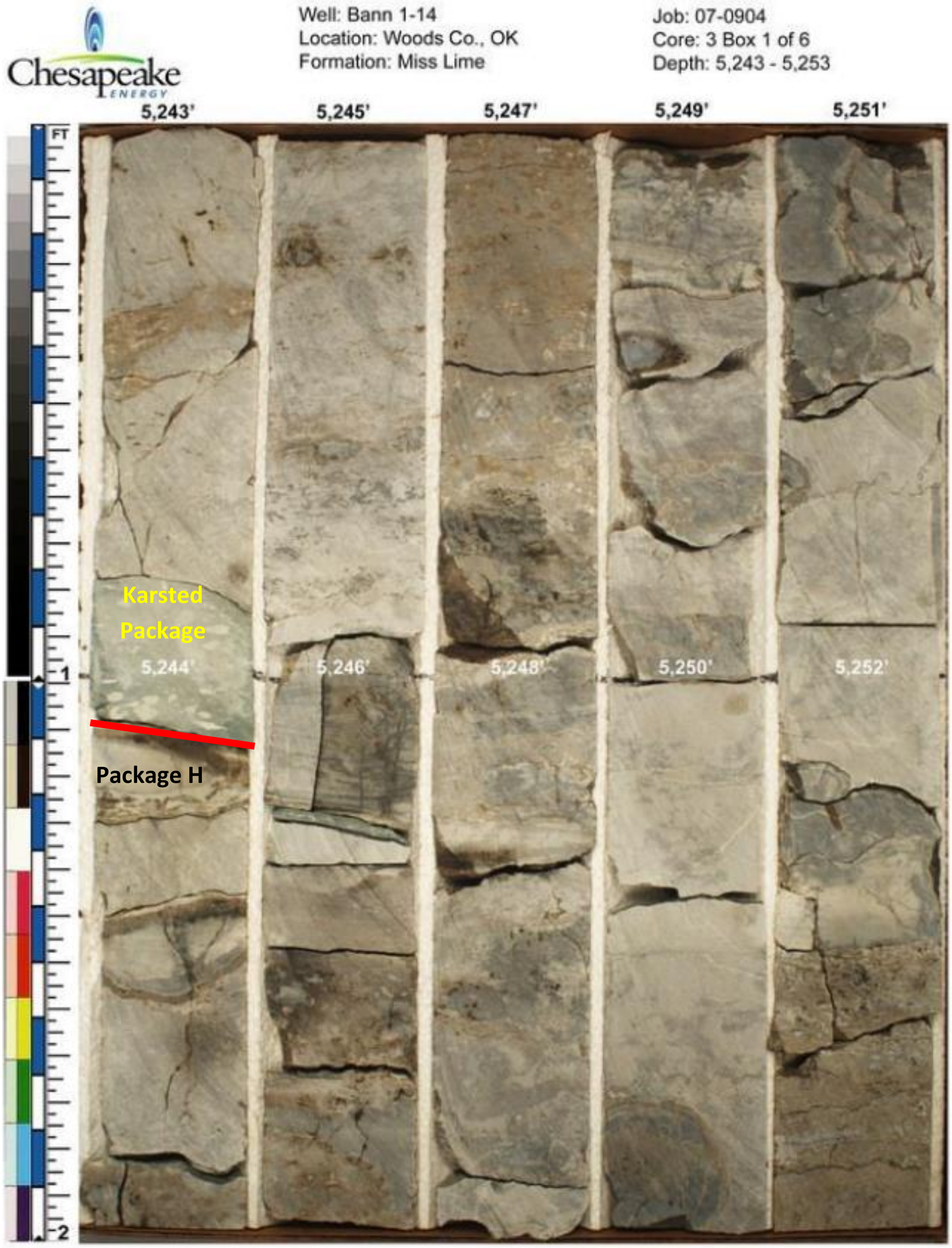
DRY

WHITE LIGHT

Chesapeake ENERGY
Well: Bann 1-14
Location: Woods Co., OK
Formation: Miss Lime
Job: 07-0904
Core: 1 Box 1 of 2
Depth: 5,205 - 5,215
5,205'
5,207'
5,209'
5,211'
5,213'
FT
1
2
5,206'
5,208'
5,210'
5,212'
5,214'
Pennsylvanian
Karsted
Package


Chesapeake ENERGY
Well: Bann 1-14
Location: Woods Co., OK
Formation: Miss Lime
Job: 07-0904
Core: 1 Box 2 of 2
Depth: 5,215 - 5,225
5,215'
5,217'
5,219'
5,221'
5,223'
Karsted Package
FT
1
2
5,216'
5,218'
5,220'
5,222'
5,224'

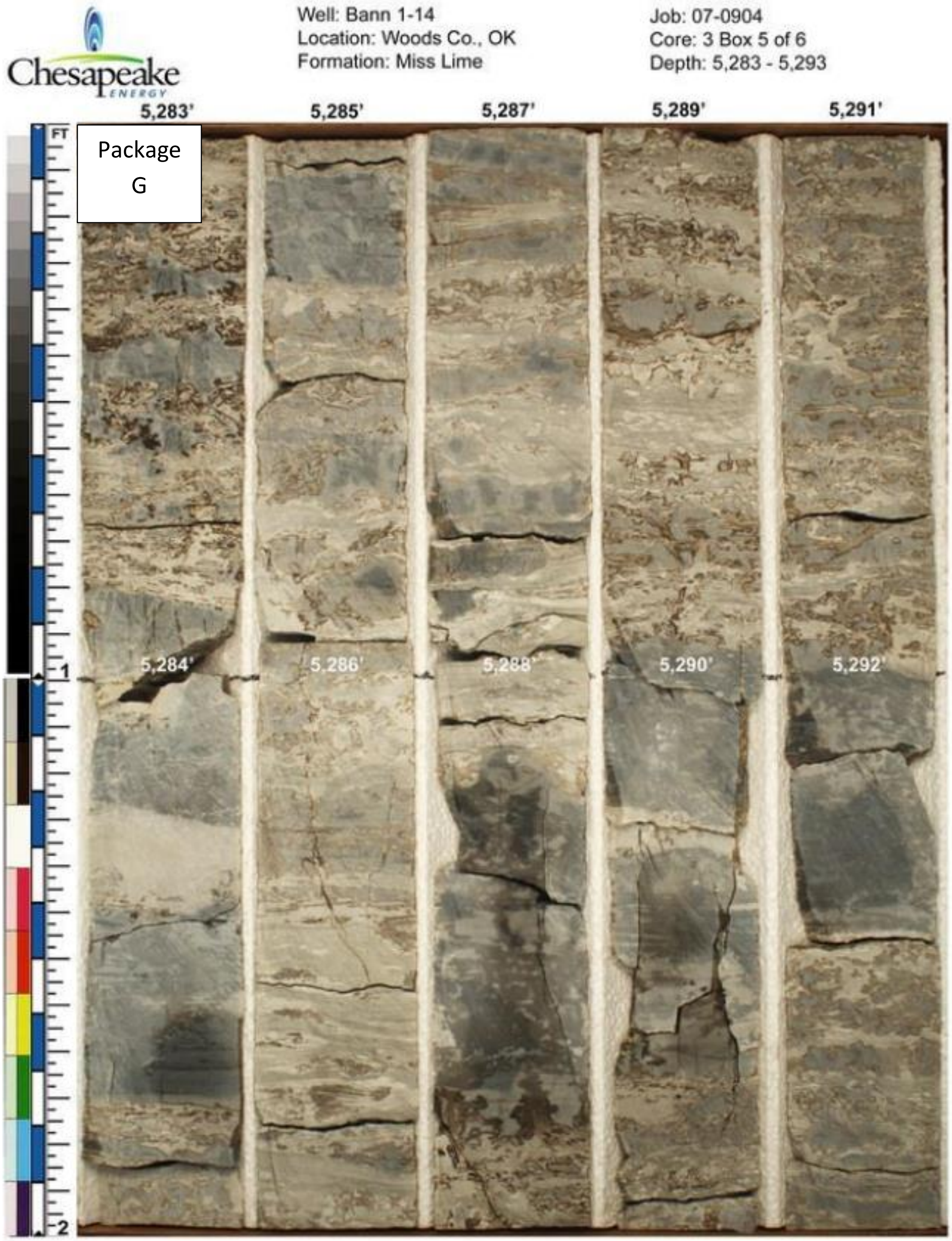

Chesapeake ENERGY
Well: Bann 1-14
Location: Woods Co., OK
Formation: Miss Lime
Job: 07-0904
Core: 2 Box 1 of 1
Depth: 5,225 - 5,230
5,225'
5,227'
5,229'
FT
5,226'
5,228'
5,230'
1
2
Karsted Package


Chesapeake ENERGY
Well: Bann 1-14
Location: Woods Co., OK
Formation: Miss Lime
Job: 07-0904
Core: 3 Box 1 of 6
Depth: 5,243 - 5,253
5,243'
5,245'
5,247'
5,249'
5,251'
FT
Karsted Package
5,244'
5,246'
5,248'
5,250'
5,252'
Package H
1
2


Chesapeake
ENERGY
Well: Bann 1-14
Location: Woods Co., OK
Formation: Miss Lime
Job: 07-0904
Core: 3 Box 2 of 6
Depth: 5,253 - 5,263
5,253'
5,255'
5,257'
5,259'
5,261'
Package H
FT
1
2
5,254'
5,256'
5,258'
5,260'
5,262'

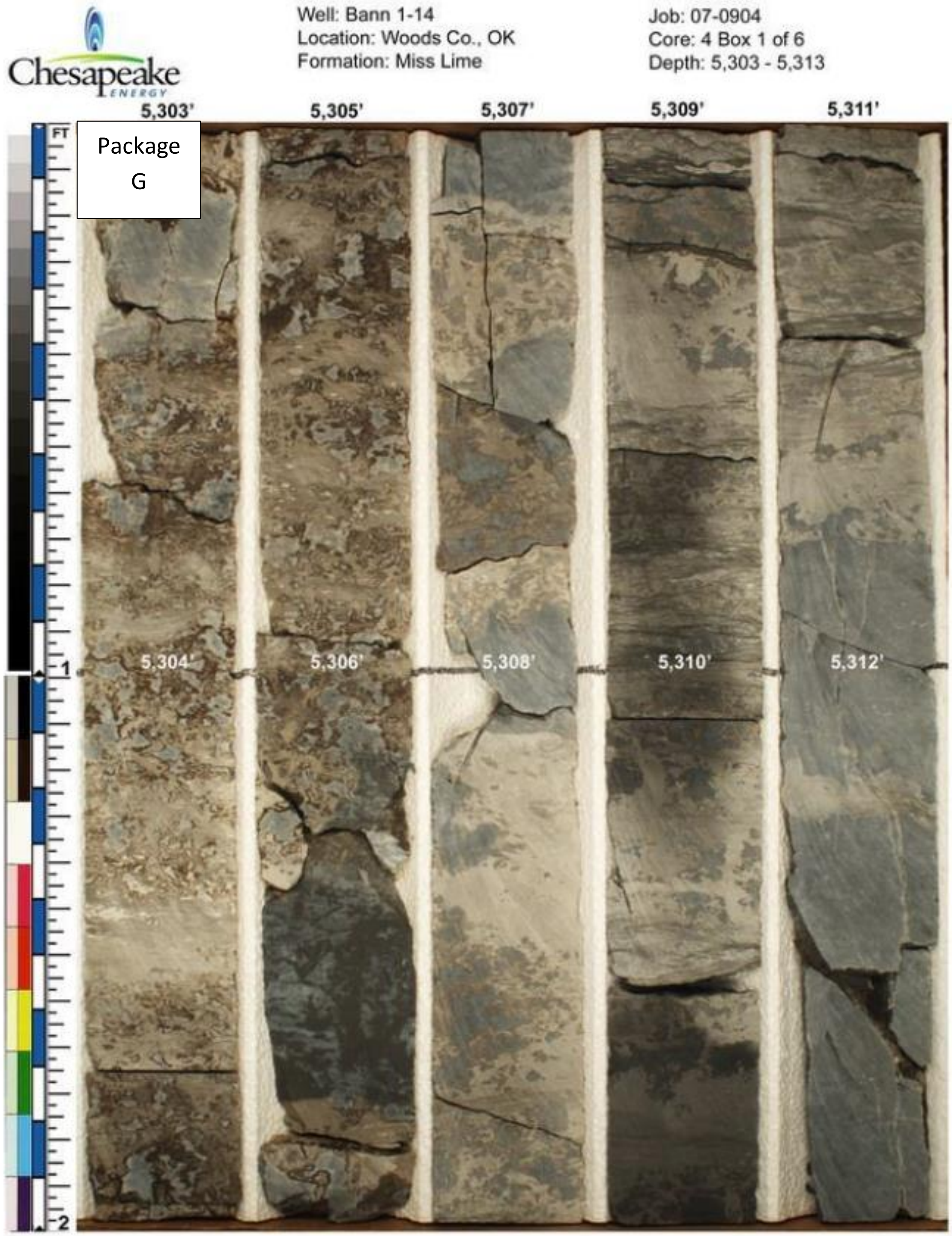

Chesapeake
ENERGY
Well: Bann 1-14
Location: Woods Co., OK
Formation: Miss Lime
Job: 07-0904
Core: 3 Box 3 of 6
Depth: 5,263 - 5,273
5,263'
5,265'
5,267'
5,269'
5,271'
Package
H
FT
5,264'
5,266'
5,268'
5,270'
5,272'
1
2

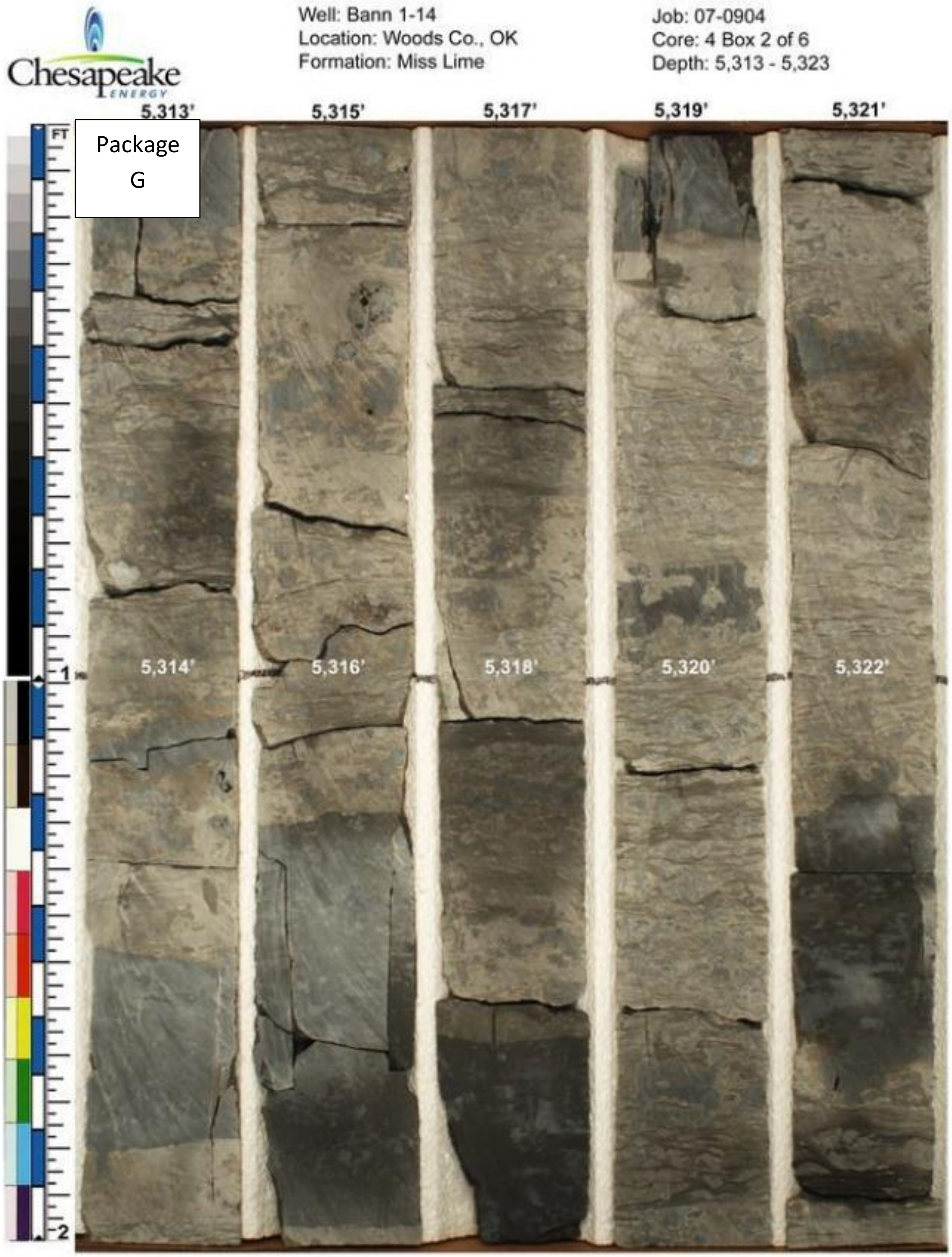

Chesapeake ENERGY
Well: Bann 1-14
Location: Woods Co., OK
Formation: Miss Lime
Job: 07-0904
Core: 3 Box 4 of 6
Depth: 5,273 - 5,283
5,273'
5,275'
5,277'
5,279'
5,281'
FT
1
2
5,274'
5,276'
5,278'
5,280'
5,282'
Package H
Package G


Chesapeake ENERGY
Well: Bann 1-14
Location: Woods Co., OK
Formation: Miss Lime
Job: 07-0904
Core: 3 Box 5 of 6
Depth: 5,283 - 5,293
5,283'
5,285'
5,287'
5,289'
5,291'
Package G
5,284'
5,286'
5,288'
5,290'
5,292'
FT
1
2

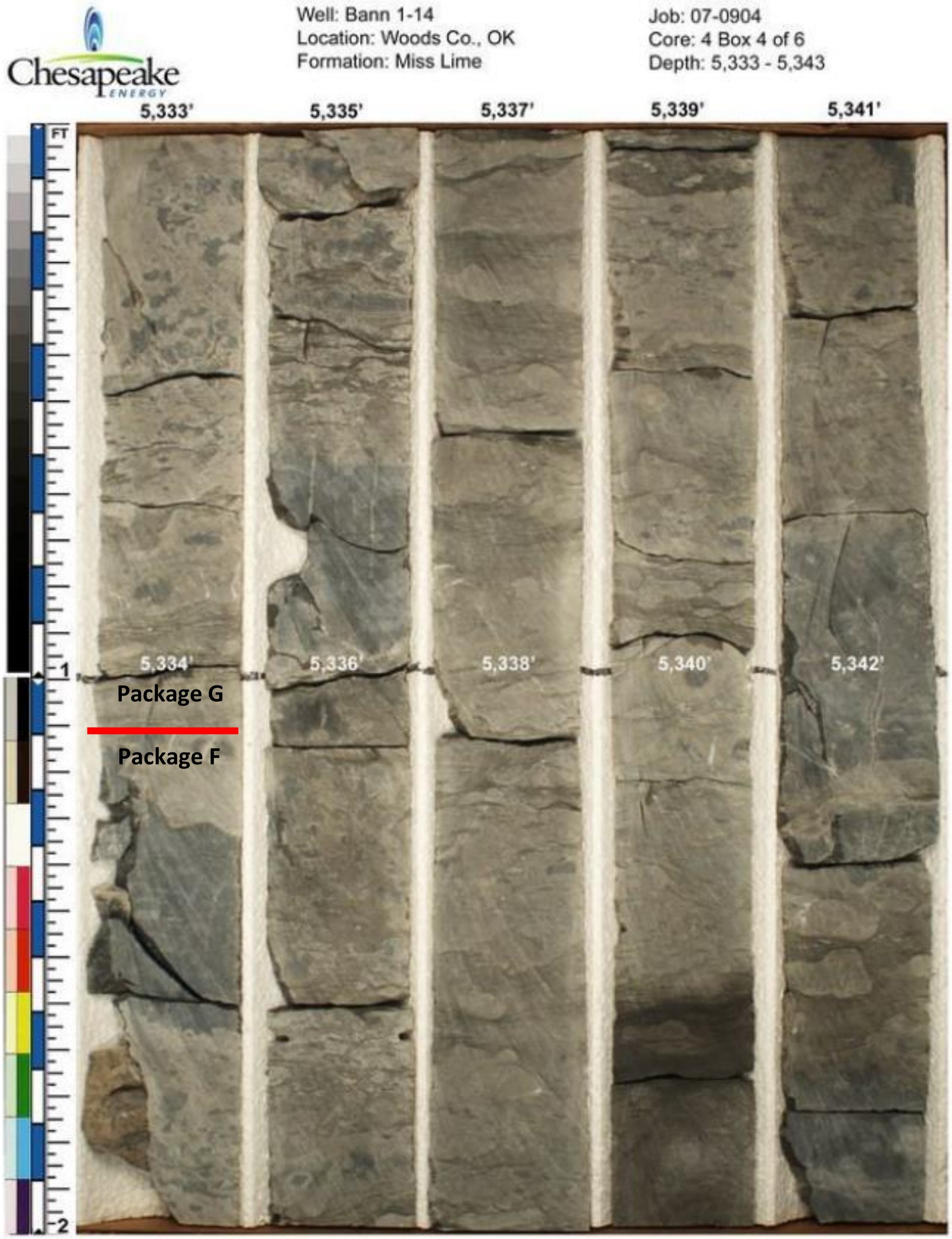
Well: Bann 1-14
Location: Woods Co., OK
Formation: Miss Lime

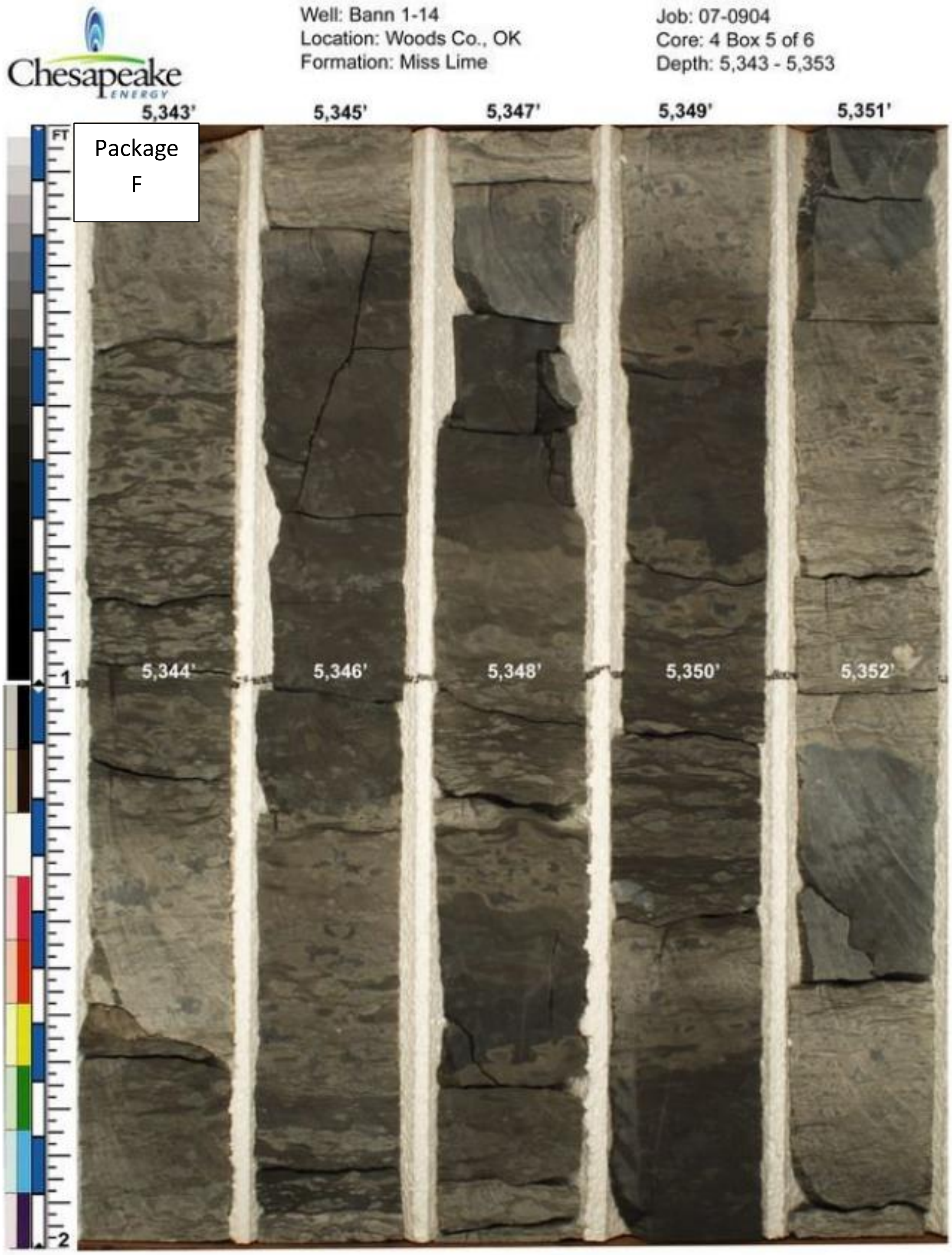
Job: 07-0904
Core: 3 Box 6 of 6
Depth: 5,293 - 5,303


Chesapeake ENERGY
Well: Bann 1-14
Location: Woods Co., OK
Formation: Miss Lime
Job: 07-0904
Core: 4 Box 1 of 6
Depth: 5,303 - 5,313
5,303'
5,305'
5,307'
5,309'
5,311'
Package G
5,304'
5,306'
5,308'
5,310'
5,312'
FT
1
2


Well: Bann 1-14
Location: Woods Co., OK
Formation: Miss Lime
Job: 07-0904
Core: 4 Box 2 of 6
Depth: 5,313 - 5,323
5,313'
5,315'
5,317'
5,319'
5,321'
Package
G
FT
1
2
5,314'
5,316'
5,318'
5,320'
5,322'


Chesapeake ENERGY
Well: Bann 1-14
Location: Woods Co., OK
Formation: Miss Lime
Job: 07-0904
Core: 4 Box 3 of 6
Depth: 5,323 - 5,333
5,323'
5,325'
5,327'
5,329'
5,331'
FT
Package G
5,324'
5,326'
5,328'
5,330'
5,332'
1
2


Chesapeake
ENERGY
Well: Bann 1-14
Location: Woods Co., OK
Formation: Miss Lime
Job: 07-0904
Core: 4 Box 4 of 6
Depth: 5,333 - 5,343
5,333'
5,335'
5,337'
5,339'
5,341'
FT
1
2
5,334'
5,336'
5,338'
5,340'
5,342'
Package G
Package F


Chesapeake ENERGY
Well: Bann 1-14
Location: Woods Co., OK
Formation: Miss Lime
Job: 07-0904
Core: 4 Box 5 of 6
Depth: 5,343 - 5,353
5,343'
5,345'
5,347'
5,349'
5,351'
Package F
FT
5,344'
5,346'
5,348'
5,350'
5,352'
1
2

Well: Bann 1-14
Location: Woods Co., OK
Formation: Miss Lime

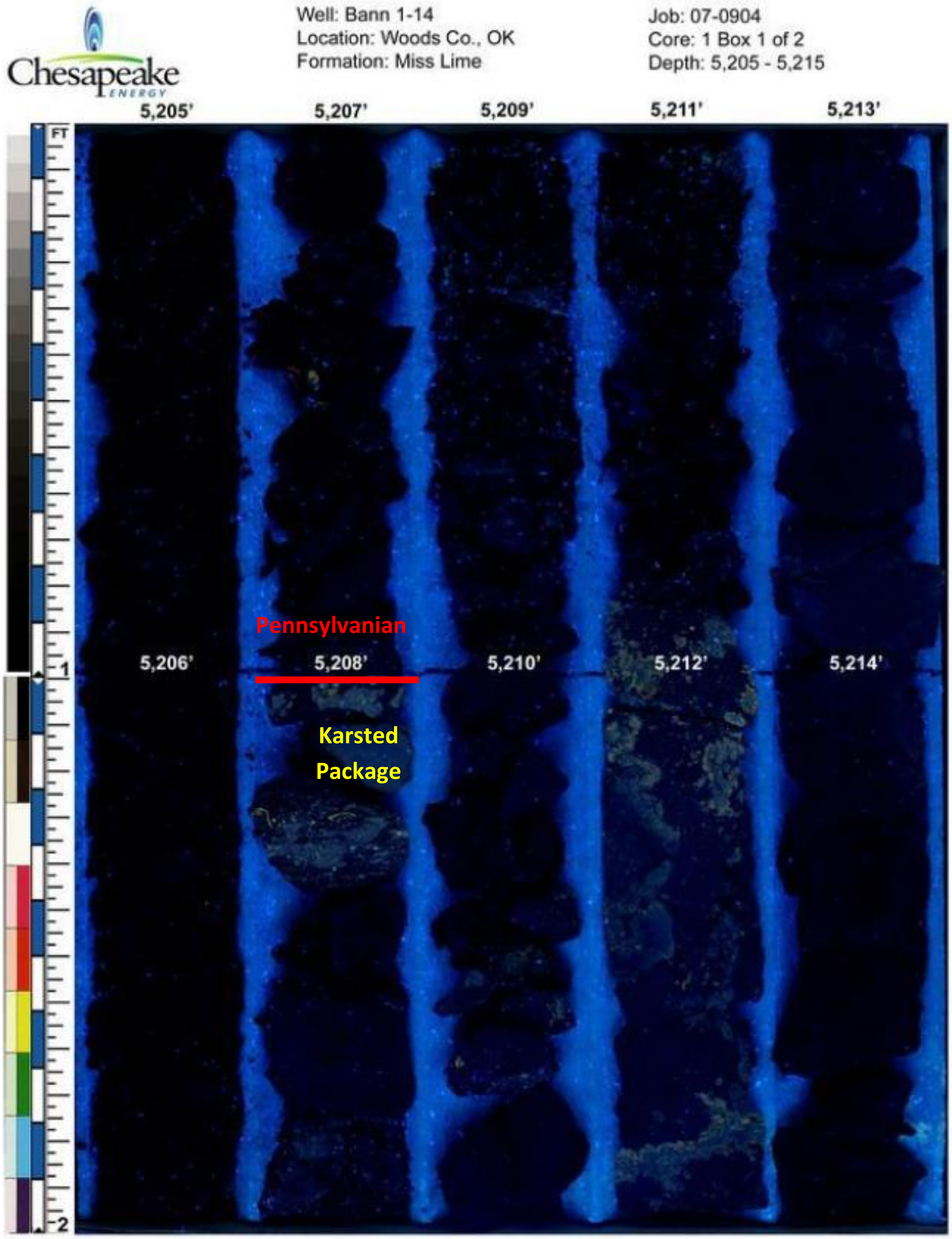
Job: 07-0904
Core: 4 Box 6 of 6
Depth: 5,353 - 5,355

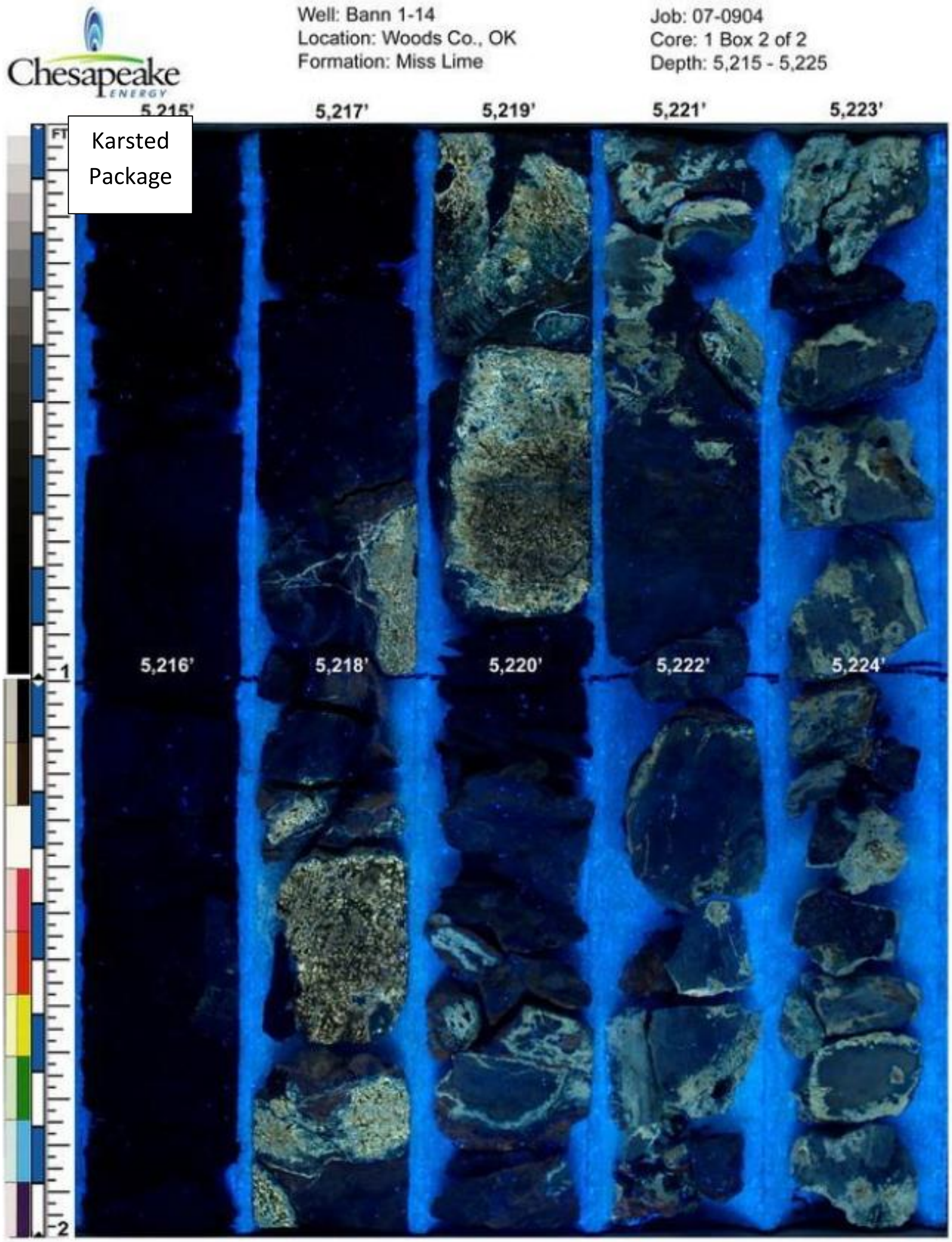
APPENDIX D

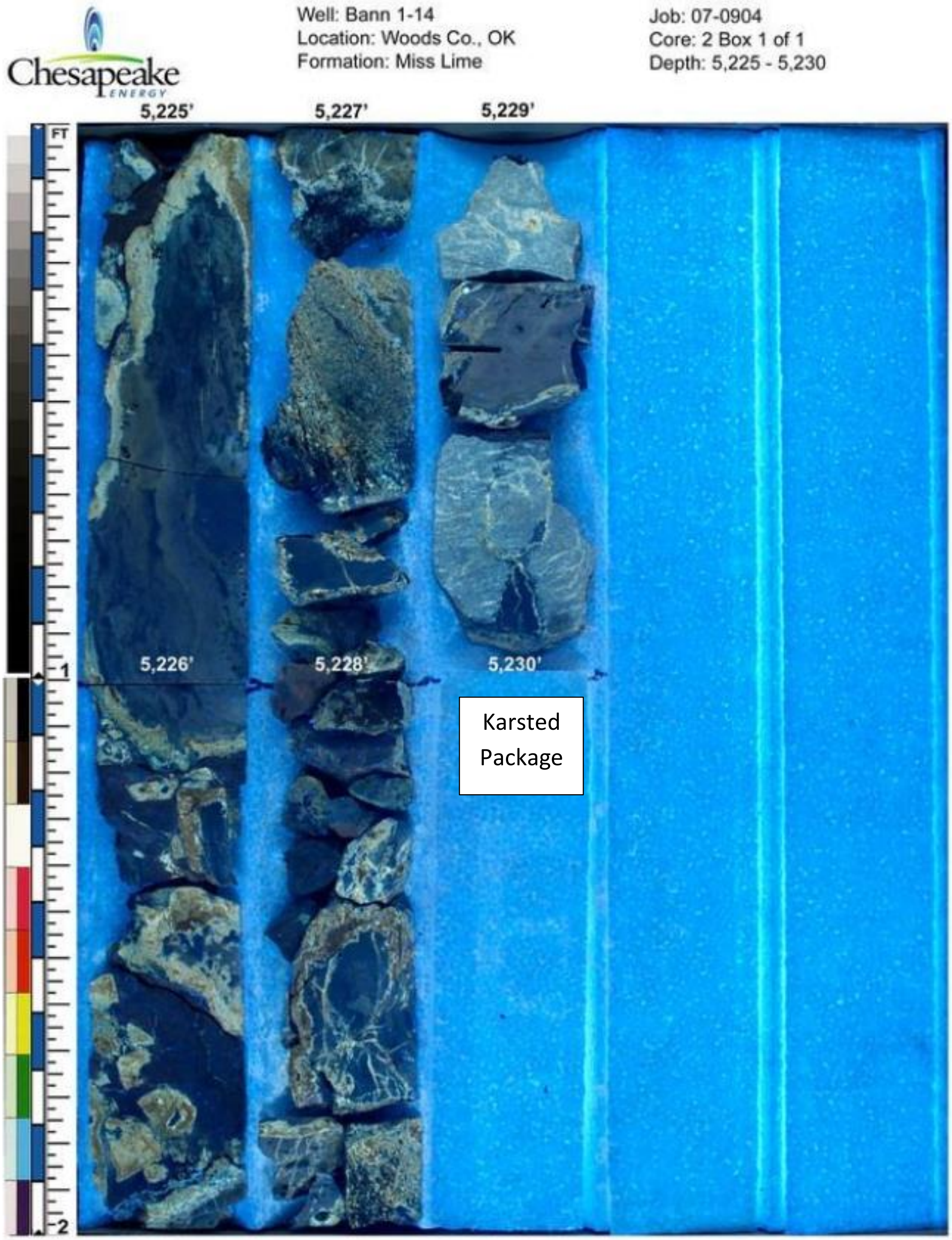
BANN #1-14 WHOLE CORE PHOTOGRAPHS

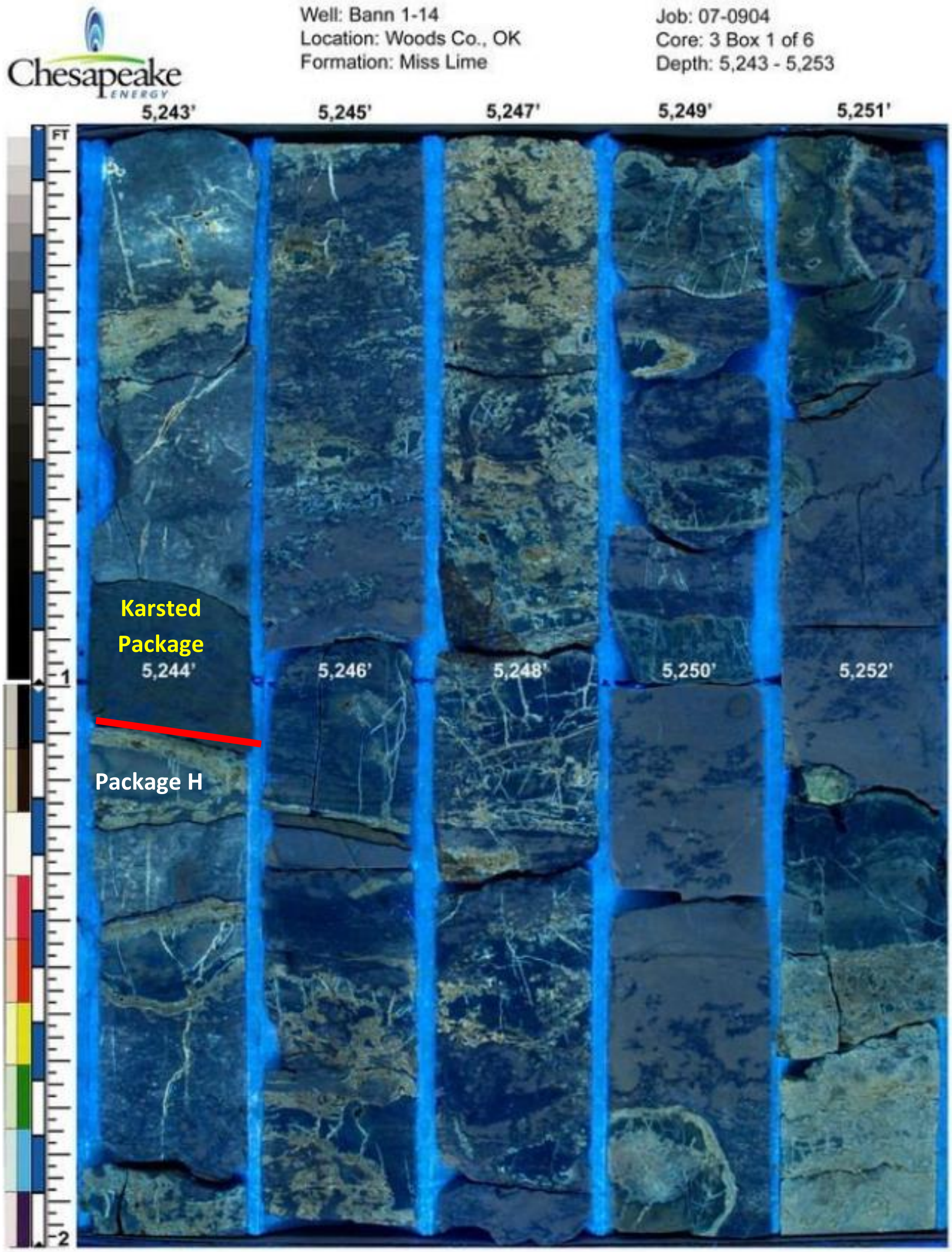
DRY

UV LIGHT

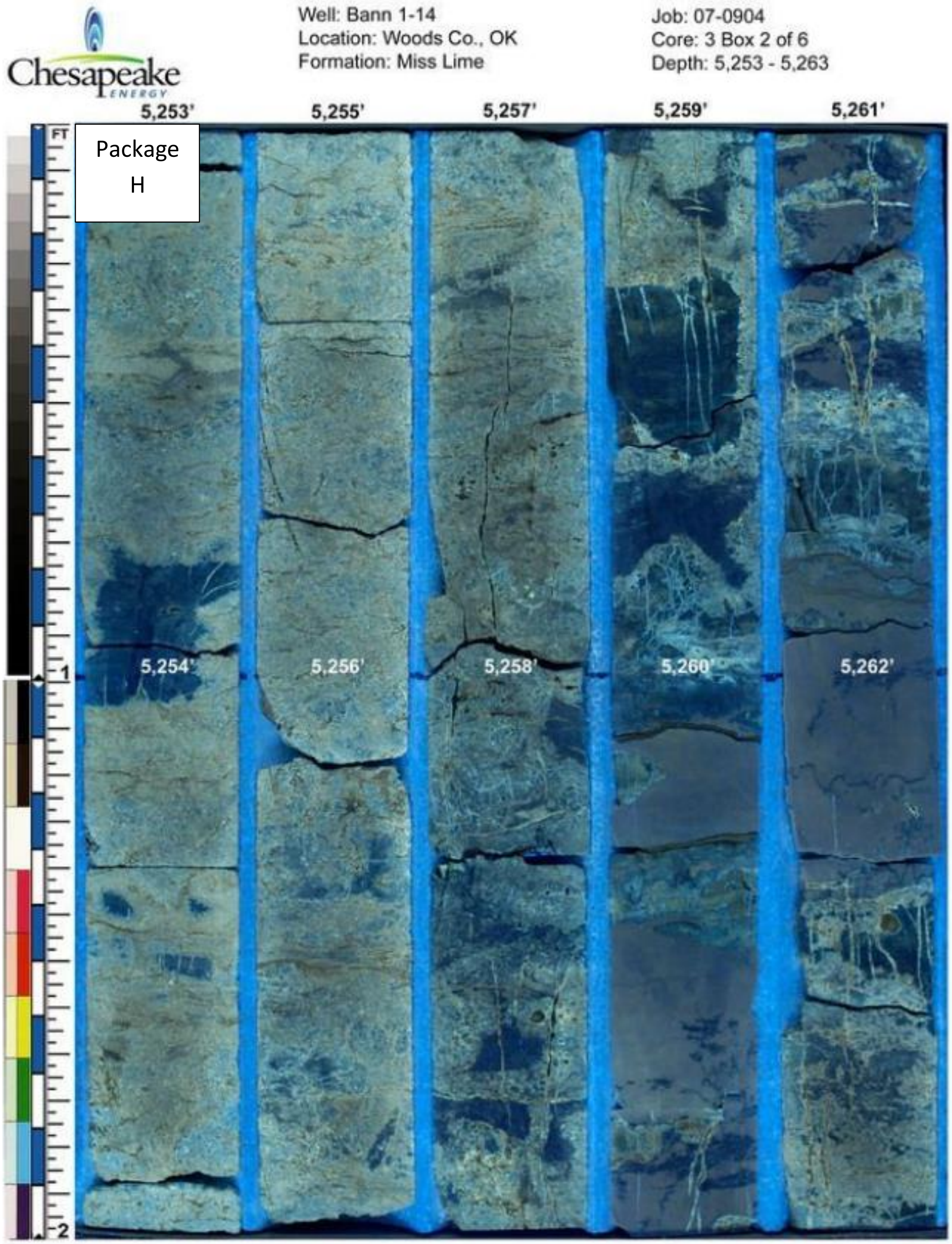

Chesapeake ENERGY
Well: Bann 1-14
Location: Woods Co., OK
Formation: Miss Lime
Job: 07-0904
Core: 1 Box 1 of 2
Depth: 5,205 - 5,215
5,205'
5,207'
5,209'
5,211'
5,213'
FT
1
2
Pennsylvanian
5,206'
5,208'
5,210'
5,212'
5,214'
Karsted
Package

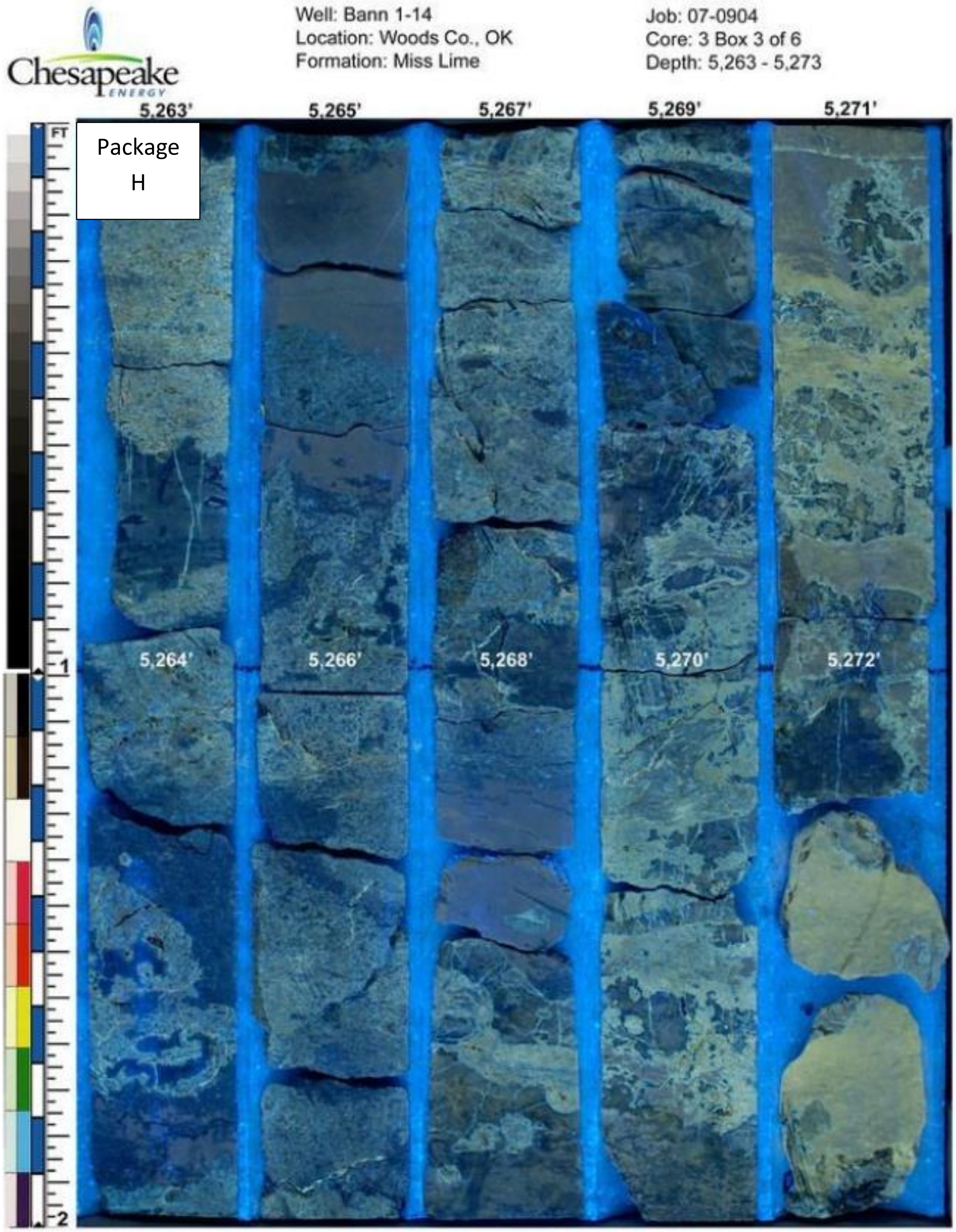

Chesapeake
ENERGY
Well: Bann 1-14
Location: Woods Co., OK
Formation: Miss Lime
Job: 07-0904
Core: 1 Box 2 of 2
Depth: 5,215 - 5,225
5,215'
5,217'
5,219'
5,221'
5,223'
FT
Karsted
Package
5,216'
5,218'
5,220'
5,222'
5,224'
1
2

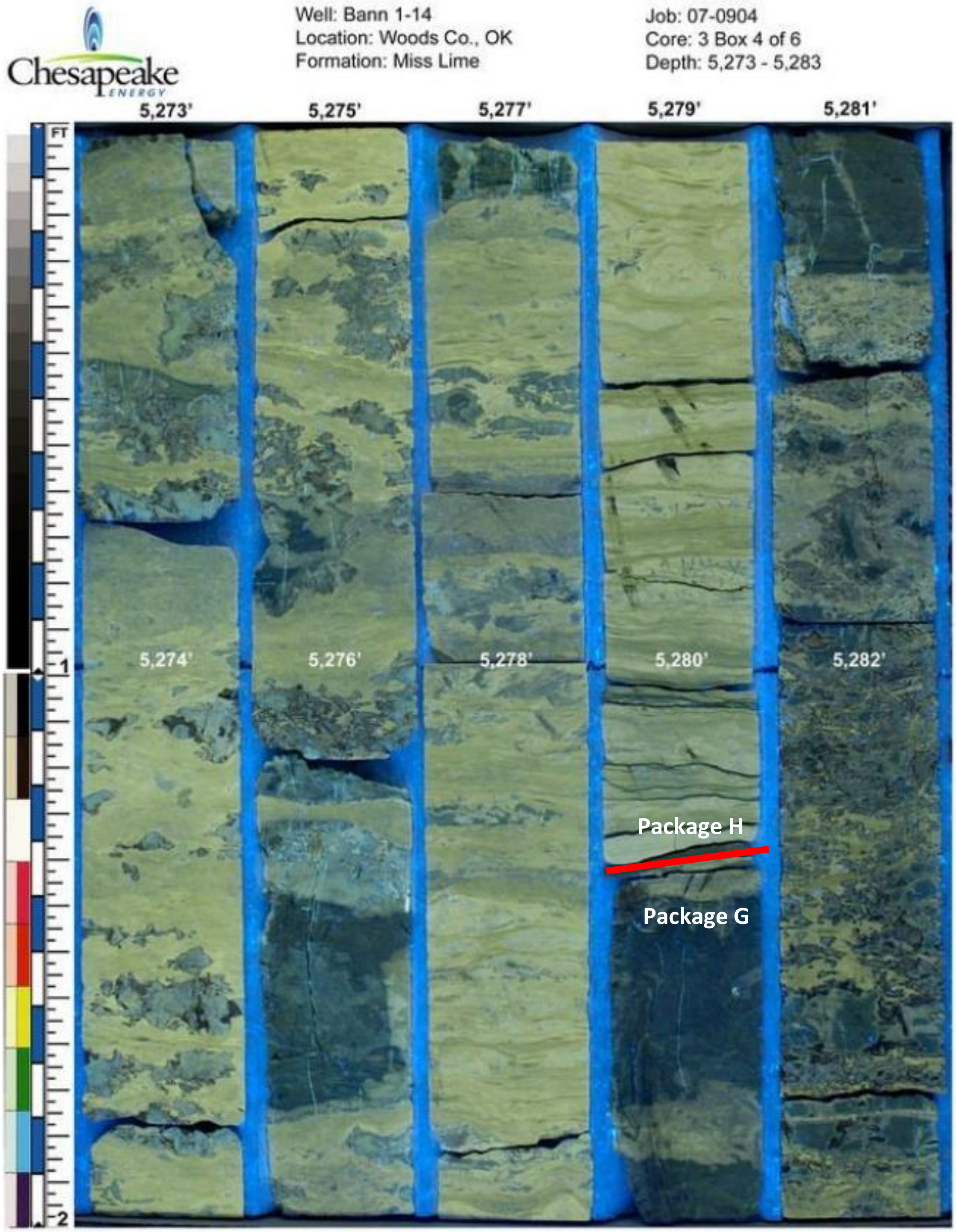

Well: Bann 1-14
Location: Woods Co., OK
Formation: Miss Lime
Job: 07-0904
Core: 2 Box 1 of 1
Depth: 5,225 - 5,230
5,225'
5,227'
5,229'
5,226'
5,228'
5,230'
Karsted Package

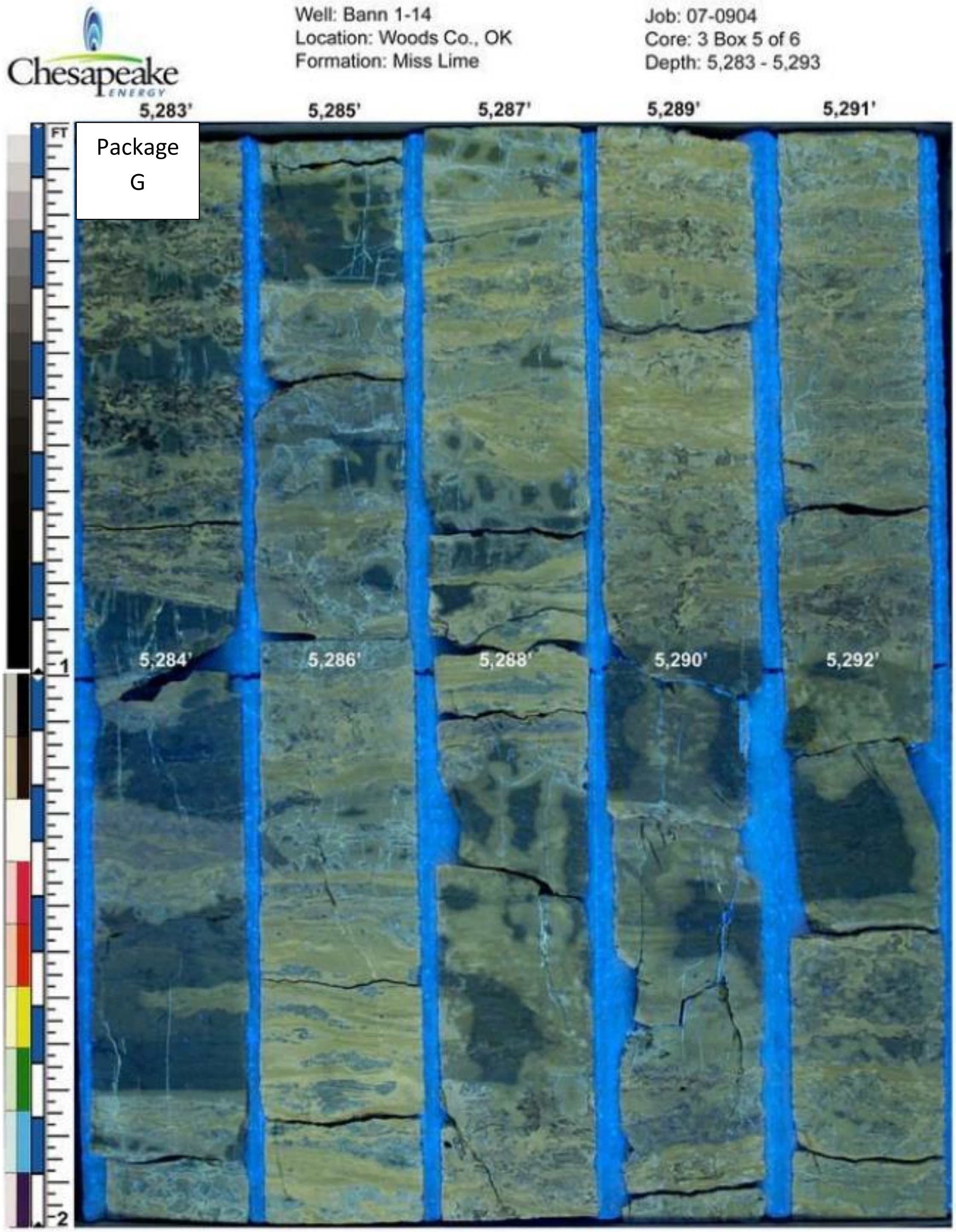


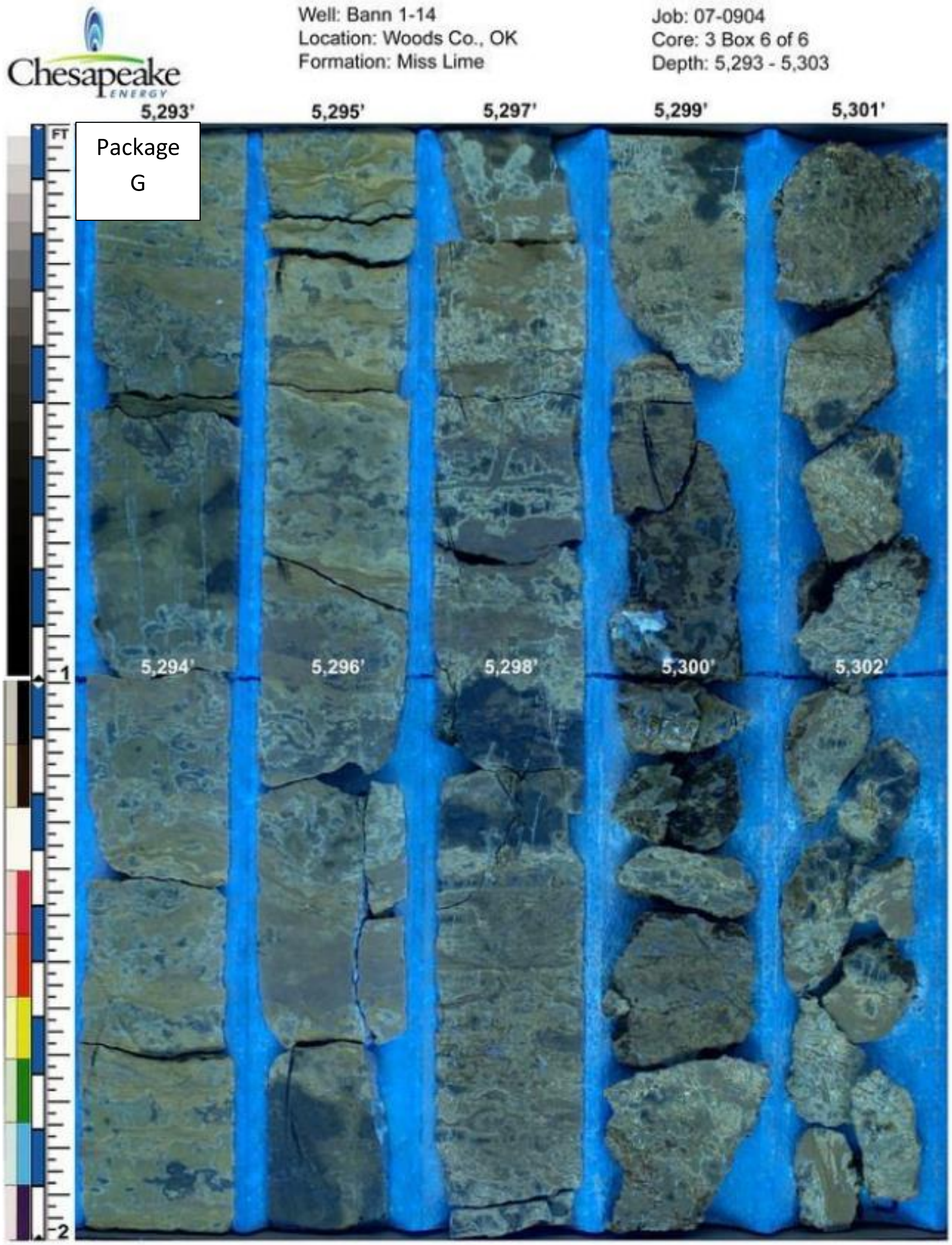
Chesapeake ENERGY
Well: Bann 1-14
Location: Woods Co., OK
Formation: Miss Lime
Job: 07-0904
Core: 3 Box 1 of 6
Depth: 5,243 - 5,253
5,243'
5,245'
5,247'
5,249'
5,251'
FT
Karsted
Package
5,244'
5,246'
5,248'
5,250'
5,252'
Package H
1
2

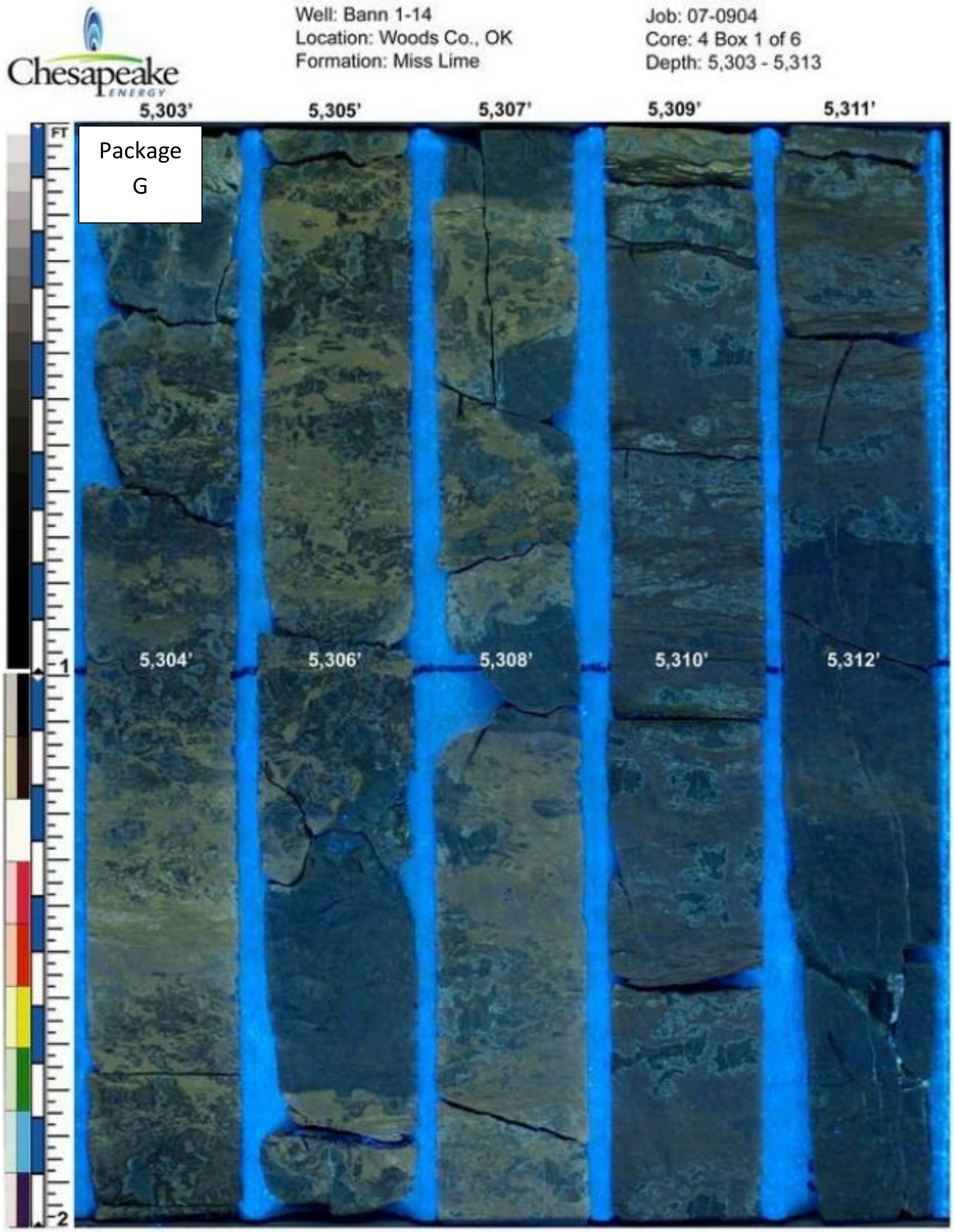

Chesapeake ENERGY
Well: Bann 1-14
Location: Woods Co., OK
Formation: Miss Lime
Job: 07-0904
Core: 3 Box 2 of 6
Depth: 5,253 - 5,263
5,253'
5,255'
5,257'
5,259'
5,261'
Package H
5,254'
5,256'
5,258'
5,260'
5,262'
FT
1
2

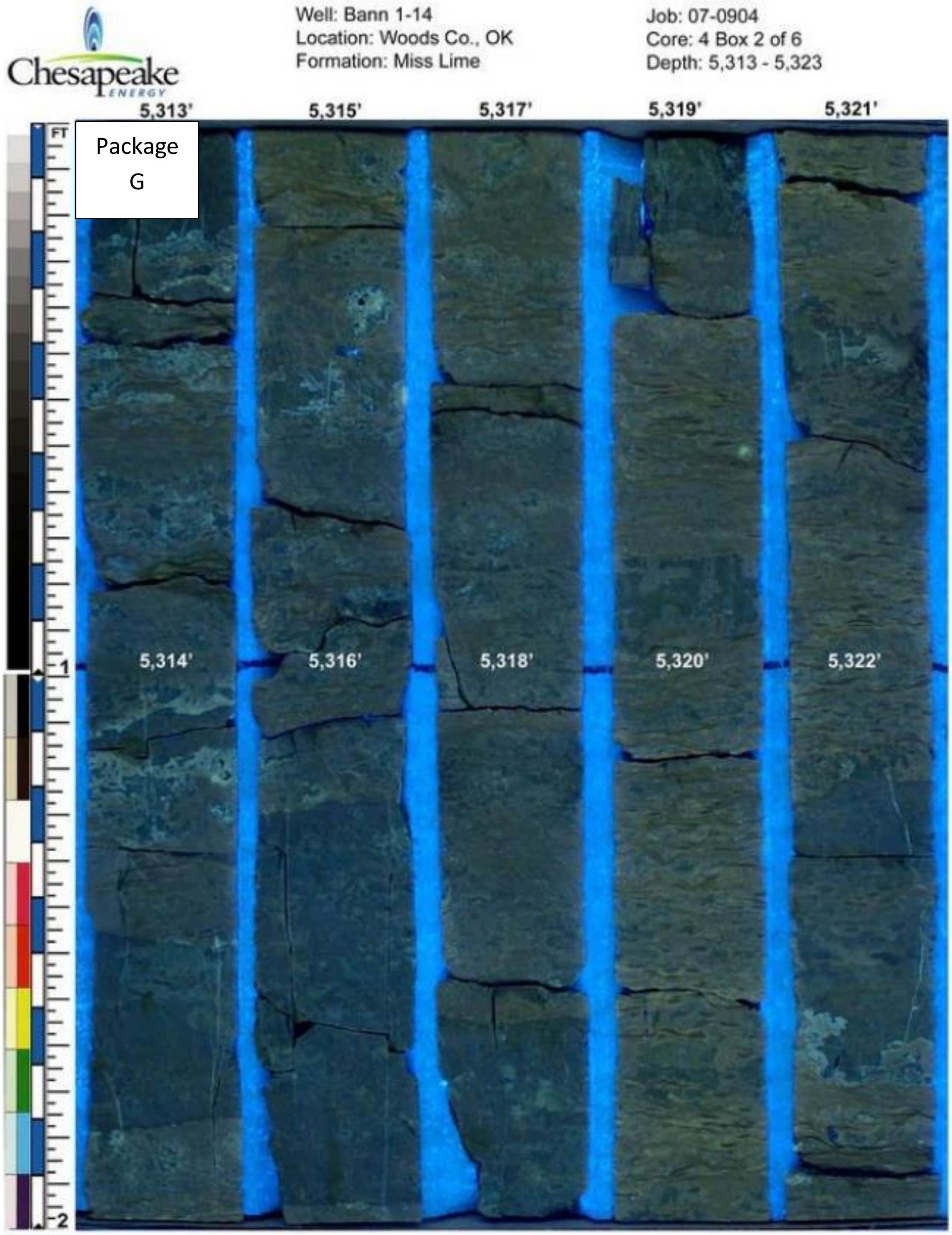

Chesapeake
ENERGY
Well: Bann 1-14
Location: Woods Co., OK
Formation: Miss Lime
Job: 07-0904
Core: 3 Box 3 of 6
Depth: 5,263 - 5,273
5,263'
5,265'
5,267'
5,269'
5,271'
Package
H
FT
1
2
5,264'
5,266'
5,268'
5,270'
5,272'

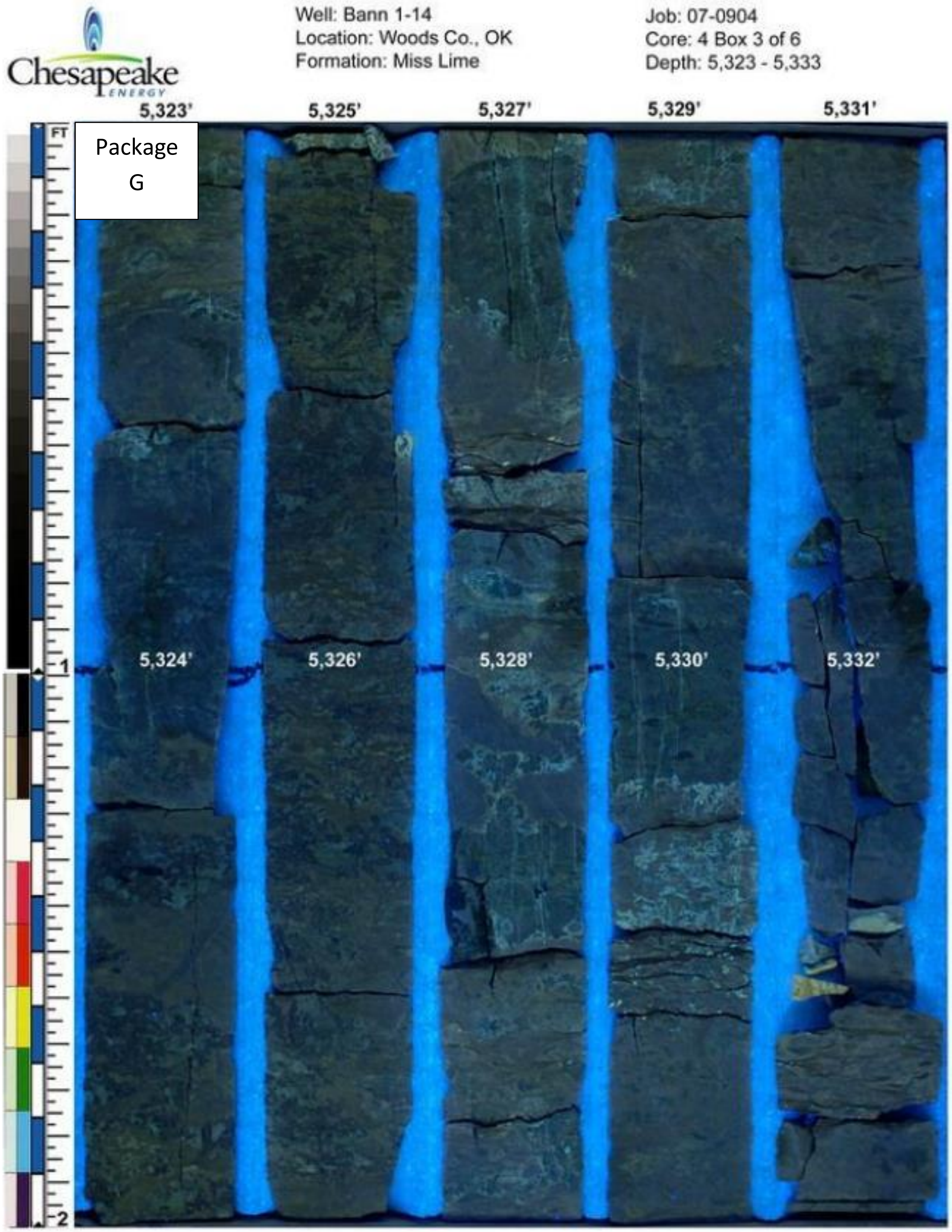

Chesapeake ENERGY
Well: Bann 1-14
Location: Woods Co., OK
Formation: Miss Lime
Job: 07-0904
Core: 3 Box 4 of 6
Depth: 5,273 - 5,283
5,273'
5,275'
5,277'
5,279'
5,281'
FT
1
2
5,274'
5,276'
5,278'
5,280'
5,282'
Package H
Package G

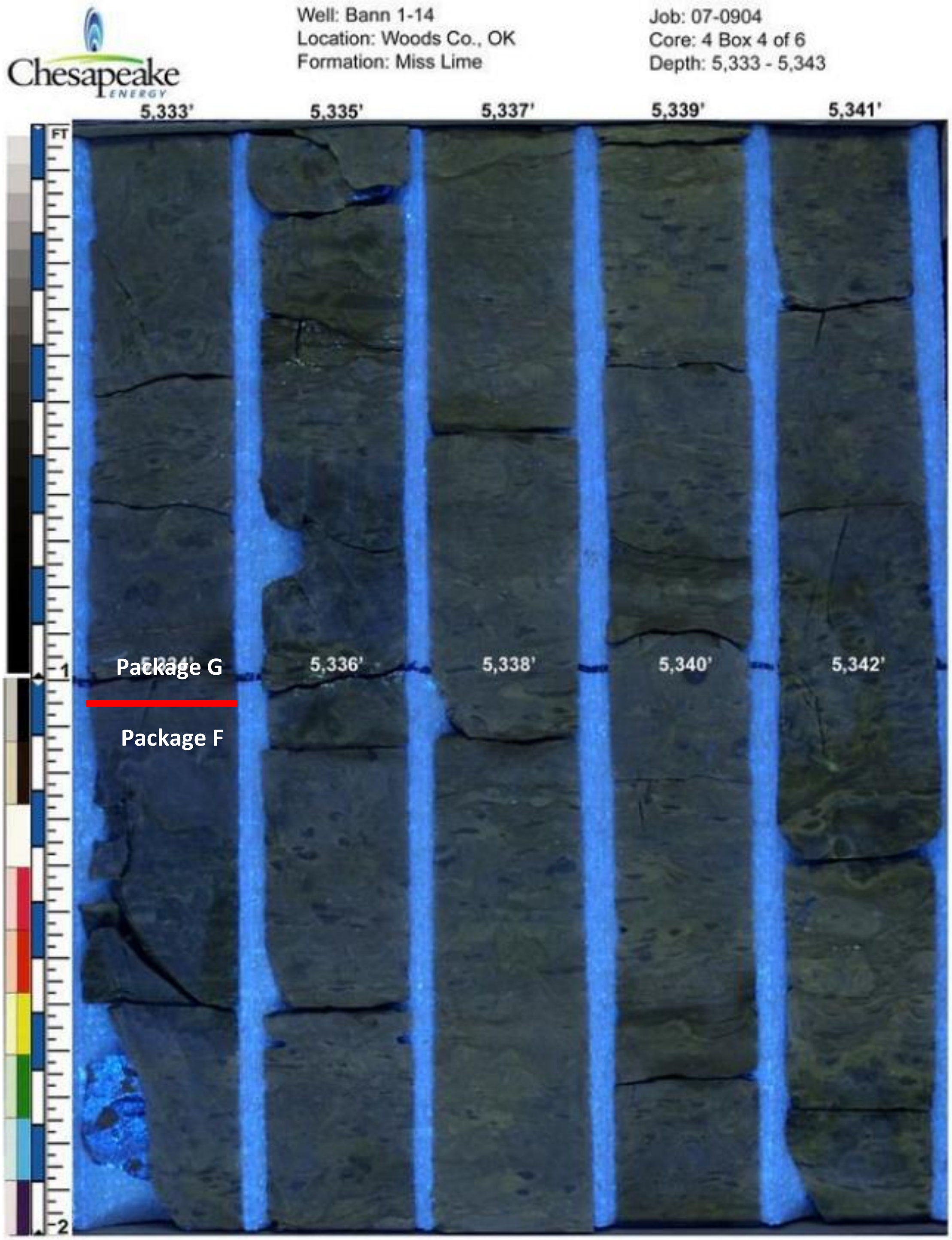

Chesapeake ENERGY
Well: Bann 1-14
Location: Woods Co., OK
Formation: Miss Lime
Job: 07-0904
Core: 3 Box 5 of 6
Depth: 5,283 - 5,293
5,283'
5,285'
5,287'
5,289'
5,291'
Package G
FT
5,284'
5,286'
5,288'
5,290'
5,292'
1
2


Chesapeake ENERGY
Well: Bann 1-14
Location: Woods Co., OK
Formation: Miss Lime
Job: 07-0904
Core: 3 Box 6 of 6
Depth: 5,293 - 5,303
5,293'
5,295'
5,297'
5,299'
5,301'
Package G
FT
5,294'
5,296'
5,298'
5,300'
5,302'
1
2

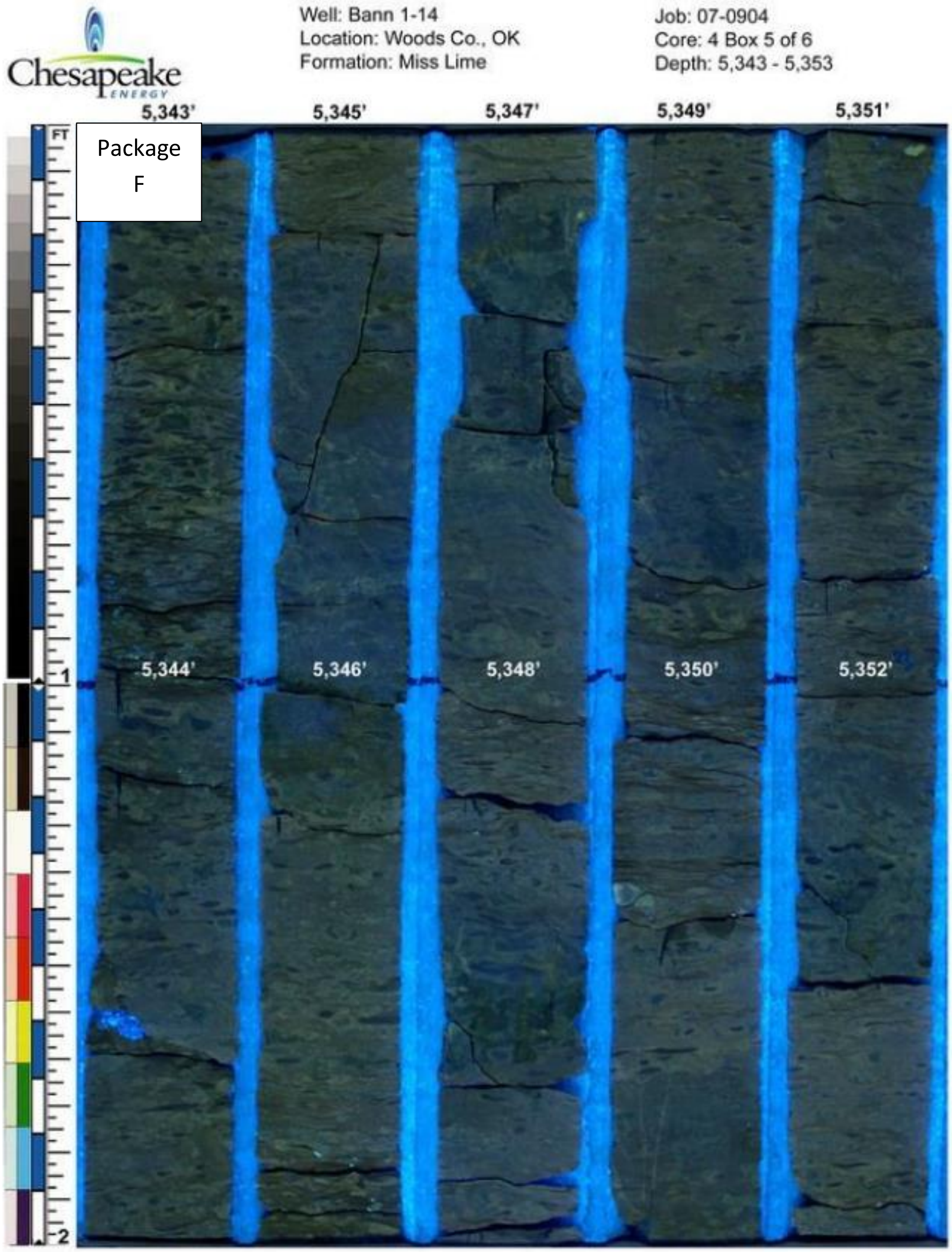

Chesapeake
ENERGY
Well: Bann 1-14
Location: Woods Co., OK
Formation: Miss Lime
Job: 07-0904
Core: 4 Box 1 of 6
Depth: 5,303 - 5,313
5,303'
5,305'
5,307'
5,309'
5,311'
FT
Package
G
5,304'
5,306'
5,308'
5,310'
5,312'
1
2

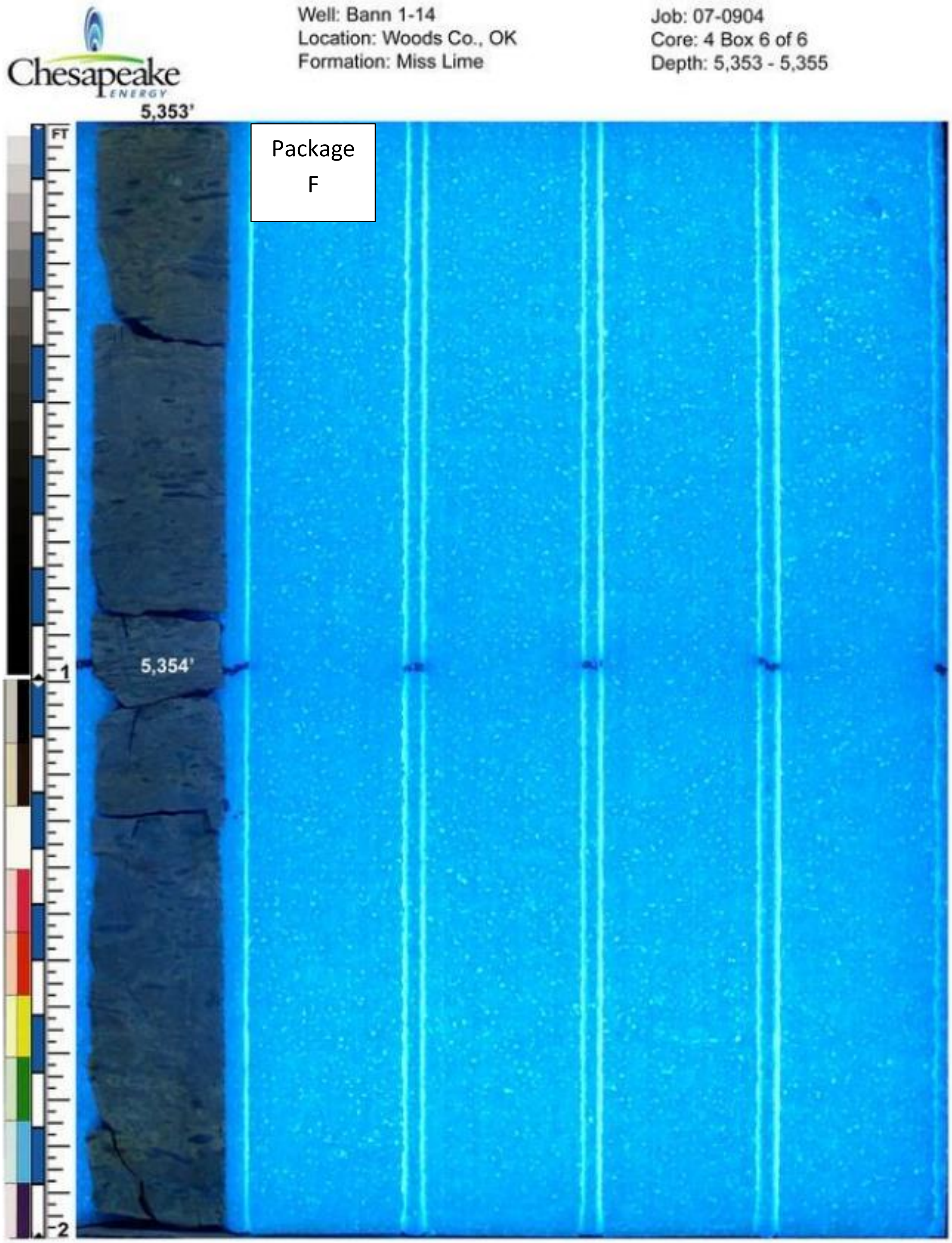

Chesapeake ENERGY
Well: Bann 1-14
Location: Woods Co., OK
Formation: Miss Lime
Job: 07-0904
Core: 4 Box 2 of 6
Depth: 5,313 - 5,323
5,313'
5,315'
5,317'
5,319'
5,321'
Package G
5,314'
5,316'
5,318'
5,320'
5,322'
FT
1
2


Chesapeake
ENERGY
Well: Bann 1-14
Location: Woods Co., OK
Formation: Miss Lime
Job: 07-0904
Core: 4 Box 3 of 6
Depth: 5,323 - 5,333
5,323'
5,325'
5,327'
5,329'
5,331'
FT
Package
G
5,324'
5,326'
5,328'
5,330'
5,332'
1
2



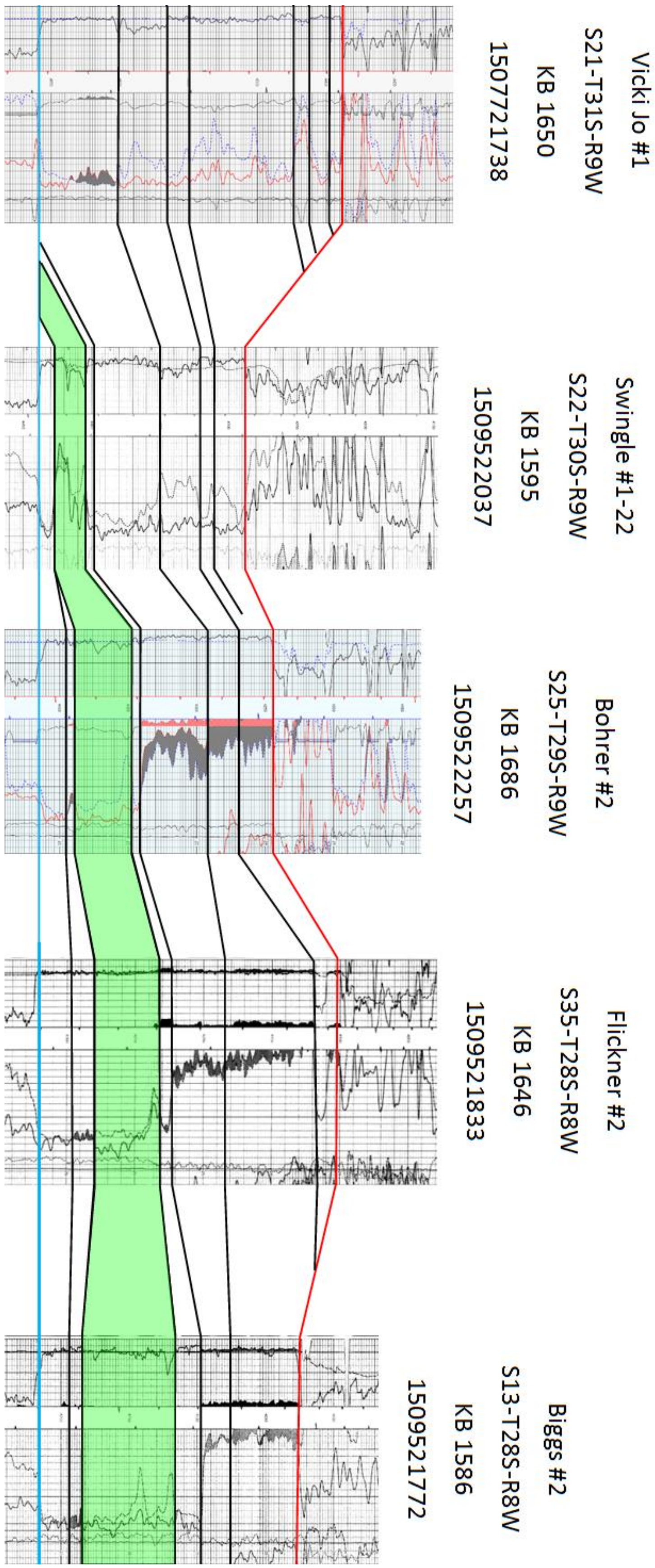
Chesapeake
ENERGY
Well: Bann 1-14
Location: Woods Co., OK
Formation: Miss Lime
Job: 07-0904
Core: 4 Box 4 of 6
Depth: 5,333 - 5,343
5,333'
5,335'
5,337'
5,339'
5,341'
FT
1
2
Package G
Package F
5,336'
5,338'
5,340'
5,342'


Chesapeake ENERGY
Well: Bann 1-14
Location: Woods Co., OK
Formation: Miss Lime
Job: 07-0904
Core: 4 Box 5 of 6
Depth: 5,343 - 5,353
5,343'
5,345'
5,347'
5,349'
5,351'
FT
Package F
5,344'
5,346'
5,348'
5,350'
5,352'
1
2


Chesapeake
ENERGY
Well: Bann 1-14
Location: Woods Co., OK
Formation: Miss Lime
Job: 07-0904
Core: 4 Box 6 of 6
Depth: 5,353 - 5,355
5,353'
Package
F
FT
5,354'
1
2

APPENDIX E

CROSS SECTION A-A’: Example of Downlapping Depositional Wedge


Vicki Jo #1
S21-T31S-R9W
KB 1650
1507721738
Swingle #1-22
S22-T30S-R9W
KB 1595
1509522037
Bohrer #2
S25-T29S-R9W
KB 1686
1509522257
Flickner #2
S35-T28S-R8W
KB 1646
1509521833
Biggs #2
S13-T28S-R8W
KB 1586
1509521772

VITA

Preston Lee Doll

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