SURFACE-TO-SUBSURFACE STRATIGRAPHY OF THE CANEY SHALE IN PORTIONS ON PONTOTOC, COAL, PITTSBURG, AND HUGHES COUNTIES, OKLAHOMA, ARKOMA BASIN

By

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Title of Study: SURFACE-TO-SUBSURFACE STRATIGRAPHY OF THE CANEY SHALE IN PORTIONS OF PONTOTOC, COAL, PITTSBURG, AND HUGHES COUNTIES, OKLAHOMA, ARKOMA BASIN

Major Field: Geology

Abstract: The Caney Shale is an organic-rich, dark fissile shale of late Mississippian age with localized phosphate and limestone concretions. The Caney Shale in the Arkoma basin of Oklahoma is stratigraphically equivalent to the Barnett Shale of the Fort Worth basin, Texas and partially equivalent to the Fayetteville Shale. The Caney Shale is subdivided into three members; Ahloso, Delaware Creek, and Sand Branch. The Ahloso Member is characterized by its silt content, the Delaware Creek Member is characterized by its loss of silt and addition of carbonate concretions, and the Sand Branch Member is organic-rich, phosphatic, and contains minor carbonate concretions. The three members have distinct wireline log signatures that can be correlated from outcrop into the subsurface and used to map the distributions of each member. In general, all members gradually thin to the northeast and southeast. The Ahloso Member is the thinnest, whereas the Delaware Creek Member and Sand Branch Member are relatively close in thickness. Pay, as defined by total gamma-ray, was determined for the Sand Branch Member and appears to mirror its total thickness.

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INTRODUCTION

Unconventional shale-gas plays are an increasing focus of activity in the United States. These unconventional reservoirs hold the potential to renew entire basins with the discoveries of large volumes of reserves. With discovery and development of gas reservoirs in the Woodford Shale in the western part of the Arkoma basin, Oklahoma, and the Barnett Shale in the Fort Worth basin, Texas, many companies have targeted reservoirs like these to expand and grow their assets. These shale-gas plays rapidly increased in importance as the result of several factors including price, hydraulic fracturing, and horizontal drilling technology.

First, what is shale and shale gas? Shale is a typically dark fine-grained clastic sedimentary rock composed of layers of compressed clay, silt, or mud. Shale formed as particles of sediment accumulated in relatively calm waters of shallow inland seas or deeper ocean basins. Shale gas is natural gas that is trapped within shales or other mudrocks. Since the late 1990's, shale-gas plays such as the Barnett have intrigued the petroleum industry because of the vast amount of gas trapped within the nano to micro pores that occur in shale. With new technology such as hydraulic fracturing, exploration companies have discovered ways to increase the permeability of shale using large volumes of water and proppant.

The Caney Shale is an organic-rich, dark gray to gray green fissile shale of late Mississippian age with localized phosphate and limestone concretions. The Caney Shale in the Arkoma basin of Oklahoma is the partial stratigraphic equivalent to the Barnett Shale in Texas and the Fayetteville Shale in the Arkoma basin of Oklahoma and Arkansas. Both the Barnett and Fayetteville shales have successfully produced large volumes of natural gas, which raises the question if the Caney Shale is destined to be a producing formation as well. However, as of this writing, no one has developed a standard completion process for the Caney Shale that will produce consistent production as is found in the Barnett Shale or Fayetteville Shale (Maughan, 2006). The results and techniques tried thus far clearly indicate that what works for one shale gas system does not necessarily work in others, even if they appear to be of similar age.

In this study area, which includes the western Arkoma basin, Lawrence Uplift, and Tishomingo Uplift, the Caney Shale rests disconformably on the Welden Limestone or the Woodford Shale and is overlain by the Rhoda Creek Formation. The Caney Shale contains three members in ascending order: Ahloso, Delaware Creek, and Sand Branch. The Ahloso Member is characterized by its higher silt content, the Delaware Creek Member is characterized by its decreased silt content and the presence of carbonate concretions, whereas the Sand Branch Member is characterized by its darker color, increased organic content and abundance of phosphate and minor carbonate concretions.

The goals of this study are to clarify the terminology applied to the Caney Shale, describe core with the intent of identifying the members, and to show that it is possible to correlate these members in the subsurface. The Caney Shale has the potential to produce natural gas, but the stratigraphy must be established so that reservoir properties can be linked to facies.

REVIEW OF LITERATURE

The term “Caney” was first used by J.A. Taff in 1901 for Carboniferous aged shales found in the Coalgate quadrangle (Taff, 1901). Taff originally described the Caney Shale as being found in both the Arbuckle Mountains and Ouachita Mountains. Taff’s description, which was very short and generalized, says, “In each locality of the Caney shale in this quadrangle about 800 feet of rock is exposed, approximately the upper half of the formation. This part of the formation is composed of blue clay shale, with thin beds of clay, ironstone, lenticular concretions, and a few blue limestone septaria. In the lower part of the formation, in the adjoining Atoka quadrangle, the blue shale grades into black, friable, bituminous shale with dark-blue limestone segregations. They Caney shale throughout is laminated, fissile, and friable, and in consequence is rarely exposed” (Taff, 1901). One year later in 1902, Taff refers to the Caney Shale as Lower Carboniferous in age. He states, “Shales of lower Carboniferous age, known as the Caney shale, succeed the Woodford chert in the northwestern part of the Atoka quadrangle and elsewhere throughout the Arbuckle Mountains region” (Taff, 1902). He then says, “The Caney shale in its lower parts consists of black, bituminous, fissile shale with spherical calcareous segregations and irregular, dense, blue limestone bodies. This bituminous shale is succeeded by clay shales which include small ironstone concretions and occasional calcareous septaria” (Taff, 1902). Nowhere in any of Taff’s publications did he describe the type section of the Caney Shale or the type locality.

Girty (1909) was the first geologist to report on the paleontology of the Caney Shale in an article titled, “The Fauna of the Caney Shale of Oklahoma,” in which the Caney was both Mississippian and Pennsylvanian based on fossils collected by both Girty and Taff. This is the only reference located that specifically references a type locality for the Caney Shale. Girty (1909) described the fossil localities as being in sections 3-4, T.1S, R.16E.

To further confuse the situation, Gould (1923) wrote, “I had gotten into my mind that they type locality of this shale had been described.” He then goes on to describe how Taff in 1901 had picked the type locality of the Caney Shale as, “the locality is the valley of the Cane Creek…” This was contradictory because Taff’s maps called this same valley the “Caney” Creek. Ulrich (1927) proposed to change the names to help clear up some of this confusion. He proposed the name “John’s Valley shale for the Pennsylvanian age black shales exposed” in this area. This John’s Valley shale would replace the name Ouachita Caney.

The next published work describing the Caney Shale was Elias (1956). This work clarified terminology along the Arbuckle Uplift by examining upper Mississippian and lower Pennsylvanian formations. Elias (1956) states, “The Caney shale of southern Oklahoma has been differentiated into the lower or “Mississippian” Caney, and the upper or “Pennsylvanian” Caney, usually called the “Springer shale” or the “Goddard shale.” Elias noted that the Mississippian Caney lies between the Welden Limestone (below) and the Rhoda Creek sandstone (above) on the northeastern flank of the Arbuckle Mountains, and lies between the Sycamore limestone (below) and Goddard Formation (above) on the southwestern flank. Elias (1956) differentiated the Mississippian Caney Shale and subdivided it into three new members: the Ahlosa (later corrected to Ahloso), the Delaware Creek, and the Sand Branch, in ascending order.

Elias (1956) also proposed the name “Rhoda Creek Formation” to describe the dark shale sequence that is above the Sand Branch Member on the northeastern flank of the Arbuckle Mountains. This shale sequence includes part of what had originally and informally been designated as the “Pennsylvanian Caney” by previous authors.

The first attempt to clarify the type locality of the Caney Shale came in 1959. Elias and Branson (1959) published a paper that would, “designate a type section in an area of good exposures and where the unit has characteristics considered those of the Caney by geologists.” They defined a new type locality along the eastern flank of the Arbuckle Mountains and stated the term “Caney Shale” could only be used with certainty in this area. This change in type section moved the type locality to Johnson County, along Delaware Creek. The type section is now in section 14 T.2S, R.7E. Elias and Branson (1959) designated, “five measured sections in the adjacent ravines west of Viola townsite…” Their goal was to provide the most complete measurable sections of the Caney Shale and to describe the Ahloso, Delaware Creek, and Sand Branch Members from the new type locality.

Though the term “Caney” was first established in 1901, nearly a century later, uncertainty concerning Caney stratigraphy prevailed. Figure 1 shows the stratigraphic uncertainty of the Caney Shale in the Arkoma basin. Sutherland (1988) noted that the original type locality of the Caney Shale was, “of the erratic boulders in the Johns Valley and other formations in the Ouachita facies,” and the term cannot be properly defined. Sutherland (1988) also noted that, “the Caney is subdivided into the Mississippian Caney and Pennsylvanian Caney. The Mississippian part of this interval is termed “Caney” in the frontal Ouachita Mountains in Oklahoma.” Sutherland then states, “In the central and southern part of the Arkoma basin, the typical Morrowan sequence begins with the Pennsylvanian Caney, which cannot be subdivided in most places from the underlying Mississippian Caney. Most subsurface workers therefore use the base of the overlying Cromwell sandstone as a marker for the base of the Pennsylvanian.”

Kleehammer (1991) examined Mississippian shale outcrops on the southwestern and northeastern flanks of the Arbuckle Mountains. Kleehammer argued that the lithologic subdivisions of Elias (1956) were not viable and that, “further subdivisions of the Caney into members (i.e., Ahloso, Delaware Creek, and Sand Branch) is unwarranted as this has been based largely on paleontologic criteria rather than substantive lithologic differences.” Since according to Kleehammer neither lithological nor paleontological evidence can be agreed upon, he suggests that the mappable units of the Caney Shale should not be subdivided at all.

Maughan (2006) published an article addressing the discrepancy of names. Maughan (2006) stated, “A term, Pennsylvanian Caney, was applied to a section above the Caney that would later be renamed the Goddard Shale. Another term, called the False Caney, appeared in a study by Richard Andrews (2003) when describing a Goddard section.” Maughan (2006) divided the Caney into a relatively simple format.

A primary purpose of this thesis is to show that the members of the Caney Shale as established by Elias (1956) and Maughan (2006) can be identified and correlated over distances of tens of kilometers, using core data, outcrop samples, and well logs.

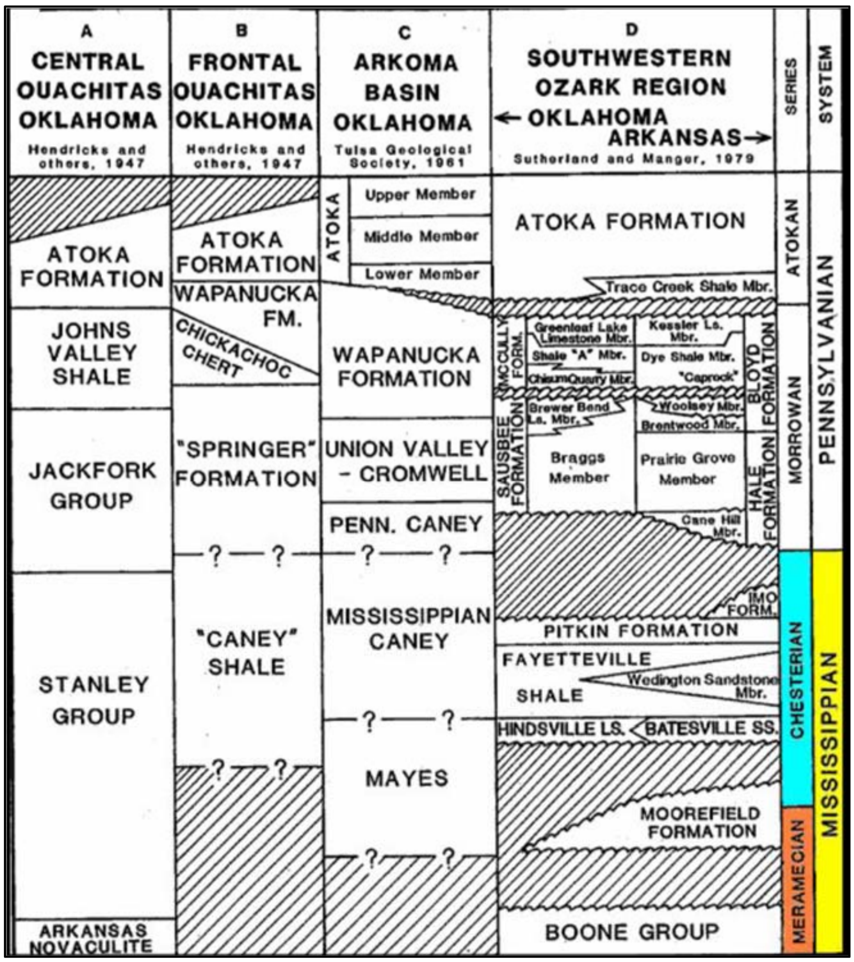

Figure 1 – Mississippian nomenclature from Sutherland (1988) that shows the uncertainty surrounding upper Mississippian strata (Mayes and Caney) in parts of southern Oklahoma.

GEOLOGIC SETTING

The Arkoma basin includes portions of both Arkansas and Oklahoma and includes an area of approximately 33,800 square miles. It is an arcuate foreland basin of the Ouachita fold-thrust belt containing about 5,000 feet of Middle Cambrian to Late Mississippian rocks and overlain by about 22,000 feet of Pennsylvanian rocks (Cemen, et al, 2009). On the Oklahoma side of the Arkoma basin, it is bounded to the north by the Cherokee Platform and to the south by the Ouachita Orogenic Belt (Figure 2).

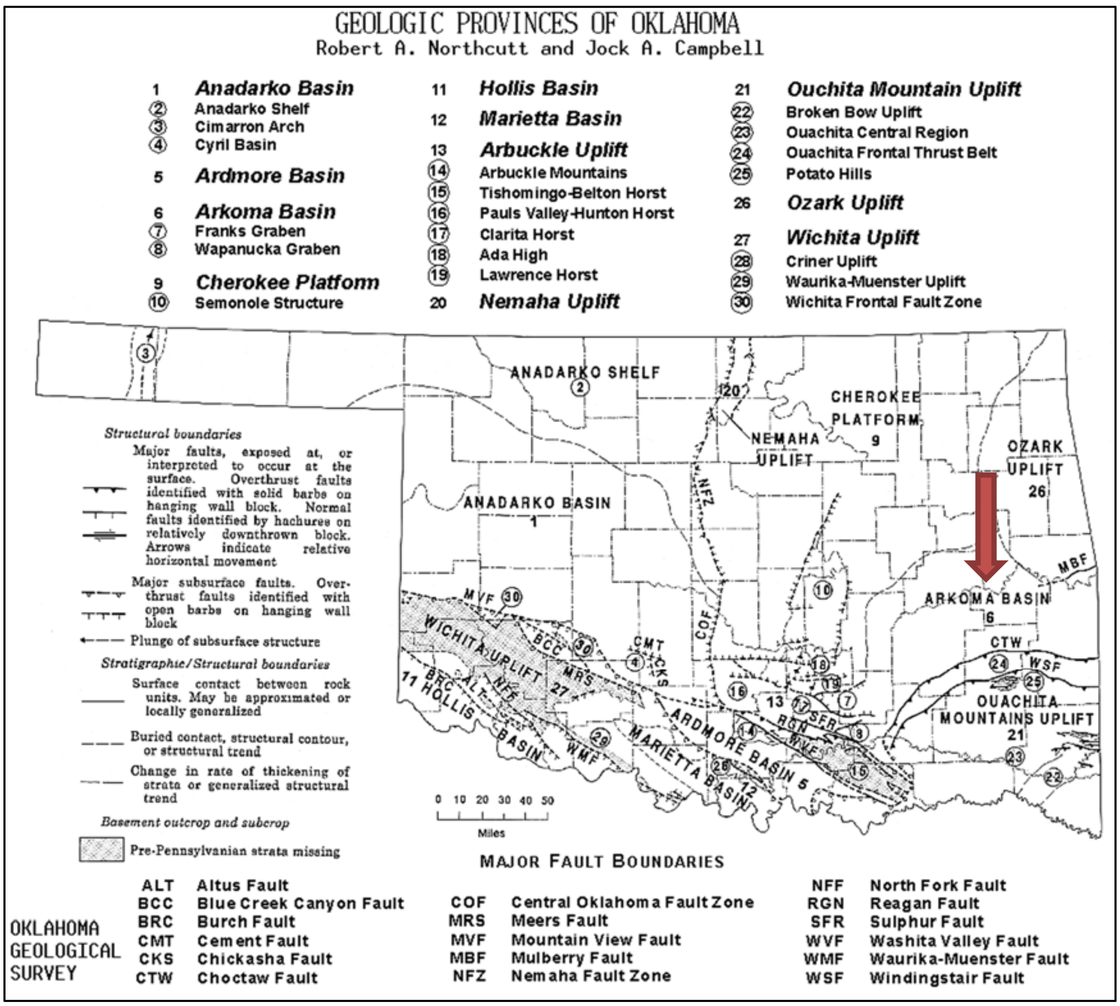

Figure 2 – Major geologic provinces of Oklahoma (Northcutt and Campbell, 1995).

The Mississippian spans from approximately 359 to 318 million years ago (Maughan, 2006). During this time (Figure 3), the global carbon dioxide levels were relatively low and temperatures hovered around 20-22º Clesius (68-71.6º Fahrenheit). The climate was warm and tropical with luxuriant plant growth and coal bed formation. The explosion of flourishing plant growth during this time is the reason for the name, "Carboniferous Period."

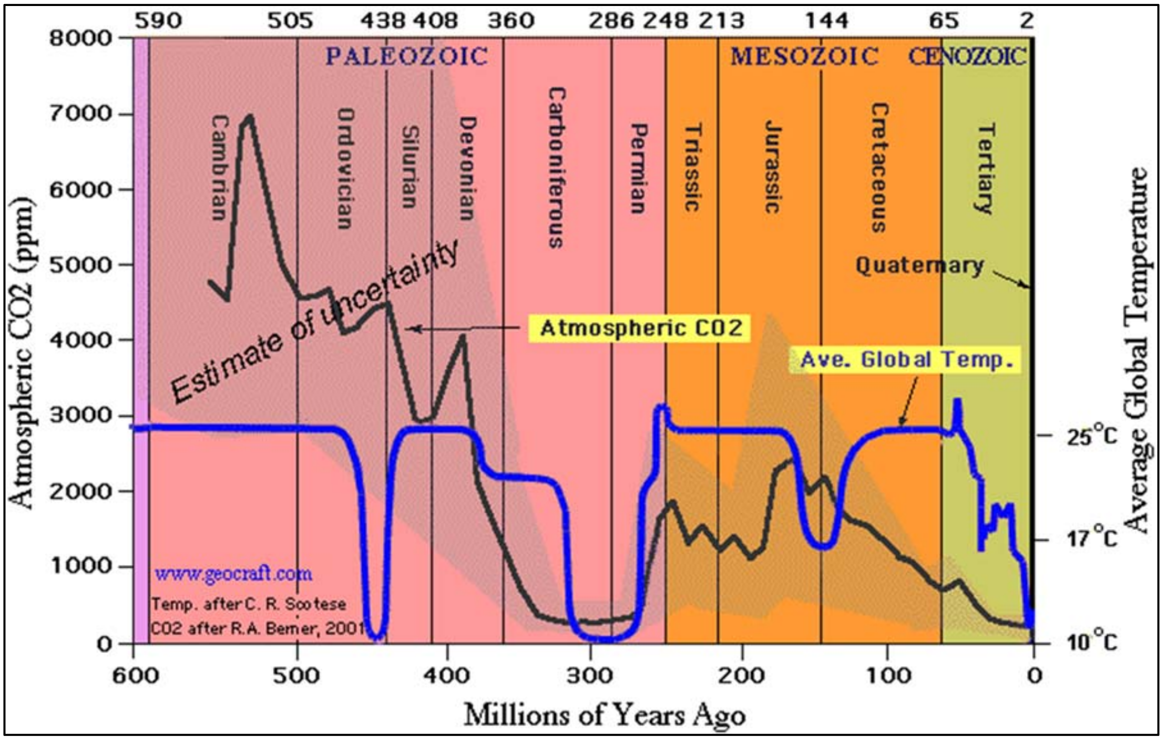

Figure 3 - Global temperature and atmospheric CO2 over geologic time. Temperature after C.R. Scotese (PALEOMAP Project) http://www.scotese.com/climate.htm and *CO2 after R.A. Berner, 2001 (GEOCARB III).*

Interpretations of regional and global paleogeography during the Mississippian are from Blakey (2004). During the Carboniferous, southern Gondwana moved over the South Pole, resulting in extensive continental glaciation (Figure 4). The advance and retreat of these glaciers produced changes in sea level which affected the sedimentation patterns on the cratons. As Gondwana continued to move northward, it was only a matter of time until it was going to collide with Laurussia. At this time, Oklahoma is still drifting northward, closer to the equator and taking a more low-latitude position that it previously occupied.

The southern edge of the craton bordered the Rheic Ocean (located between Gondwana and Laurussia) and for the next 40 million years during the Mississippian, the Rheic Ocean narrowed and the environment became restricted as the two continental plates converged (Blakey, 2004 and Craig and Connor, 1979). After a deep, anoxic water phase caused by the large land masses that blocked open ocean circulation and led to the deposition of black shales, the Lower Mississippian became a time of carbonate deposition (Blakey, 2004 and Craig and Connor, 1979). Directly south of where Oklahoma is located, a volcanic arc formed at the western end of the convergent zone (Blakey, 2004 and Craig and Connor, 1979).

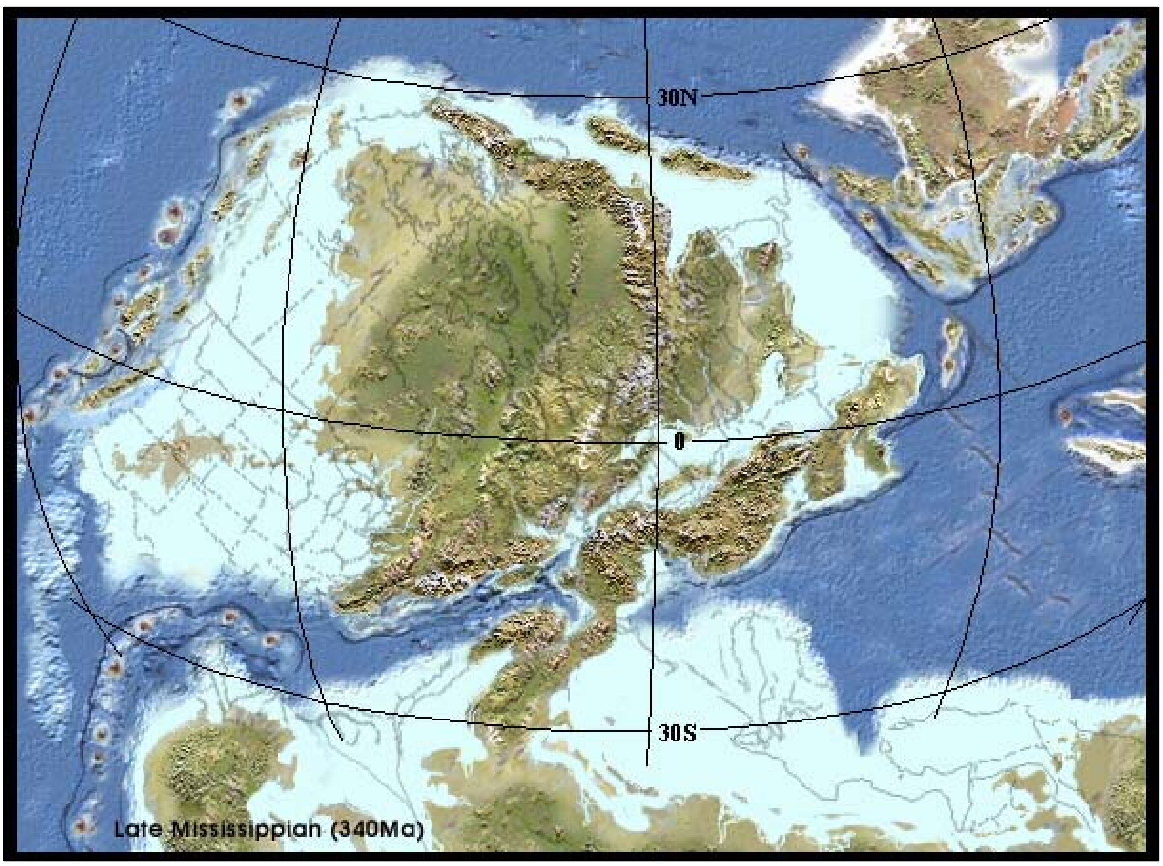

Figure 4 – Late Mississippian paleogeography from Blakey (2006).

Gondwana first collided with Laurussia during the Early Carboniferous and continued colliding with it during the rest of the Carboniferous. Because Gondwana rotated clockwise relative to Laurussia, deformation of the two continents progressed in a northeast-to-southwest direction (Blakey, 2004 and Craig and Connor, 1979). In the paleoreconstruction shown in Figure 4, Oklahoma lies close to the margin of Laurussia and just to the north of a volcanic island arc. With the presence of Mississippian age volcanic tuff deposits in the Ouachita Mountains of southeastern Oklahoma, there is evidence of an island arc producing convergent plate boundary with a south-dipping subduction zone (Houseknecht, 1986). Prior to Mississippian deposition in Oklahoma, a Devonian-age erosional event sculpted the paleolandscape of ancestral Oklahoma (known by industry in Oklahoma as the post-Hunton unconformity). The late Devonian sea transgressed and the sediments were deposited that became the Woodford Shale. The Woodford Shale thickens and thins in response to underlying paleotopography and this infilling provided a low relief surface for the onset of post-Woodford Mississippian deposition.

During the 1960's and 1970's, the United States Geological Survey directed a widespread review of the Mississippian System with emphasis on paleotectonic investigations. The Mississippian Series in the Midcontinent was subdivided into four provincial units (from youngest to oldest): Kinderhookian, Osagean, Meramecian, and Chesterian that Craig and Connor (1979) used to show the evolution of the Mississippian depositional settings over time (Figures 5-8).

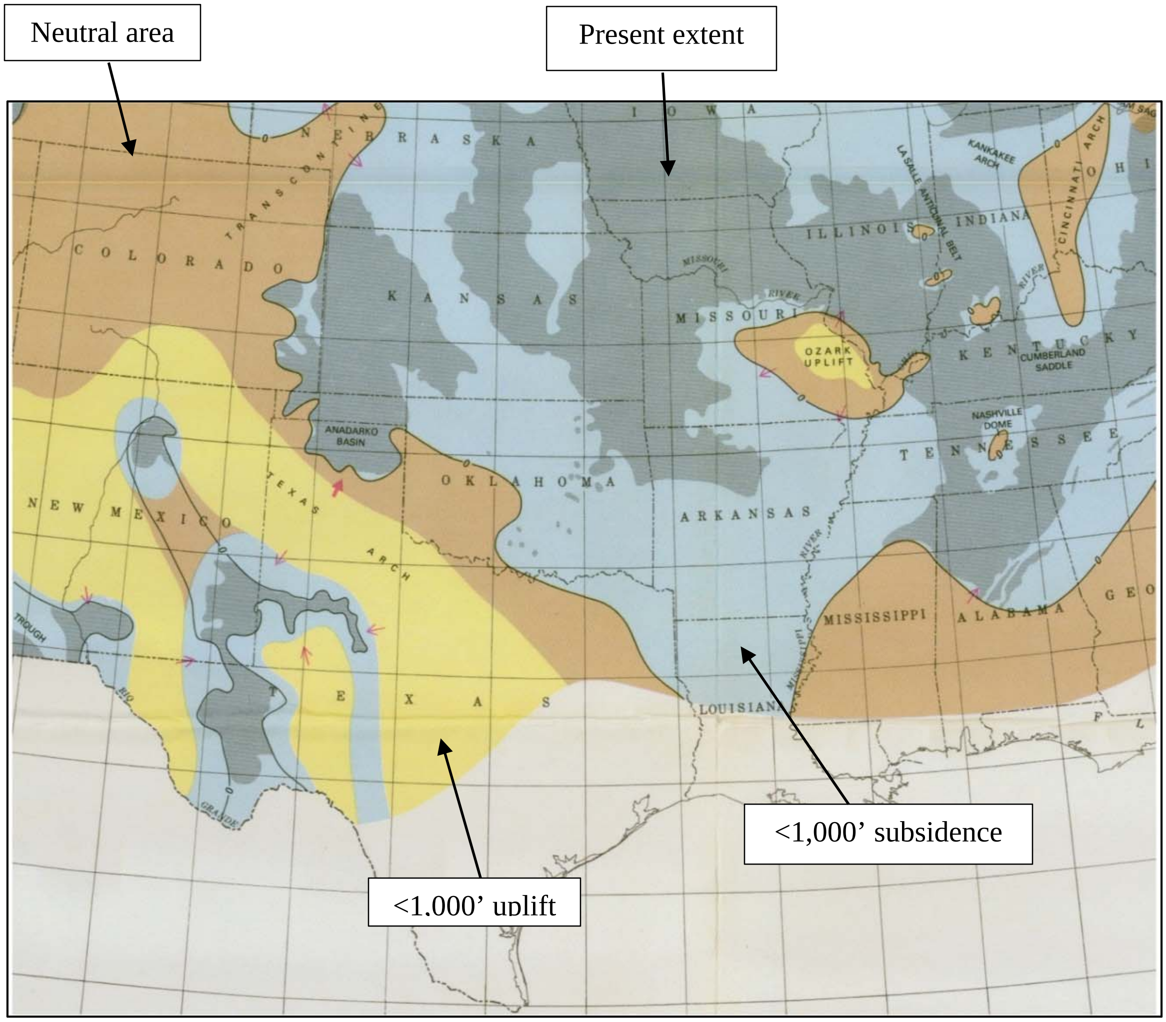

Figure 5 – Kinderhookian geographic features (Craig and Connor, 1979).

At the start of the Kinderhookian (Figure 5), the Midcontinent was a low-lying platform undergoing erosion. Throughout the Kinderhookian, the Midcontinent region was undergoing epeirogenic subsidence causing Oklahoma and Arkansas to be mostly covered by shallow seas. At the end of the Kinderhookian and beginning of the Osagean, sediments being deposited were mainly calcium carbonate with the water depth remaining relatively shallow and well oxygenated to contain marine fauna (Craig and Connor, 1979).

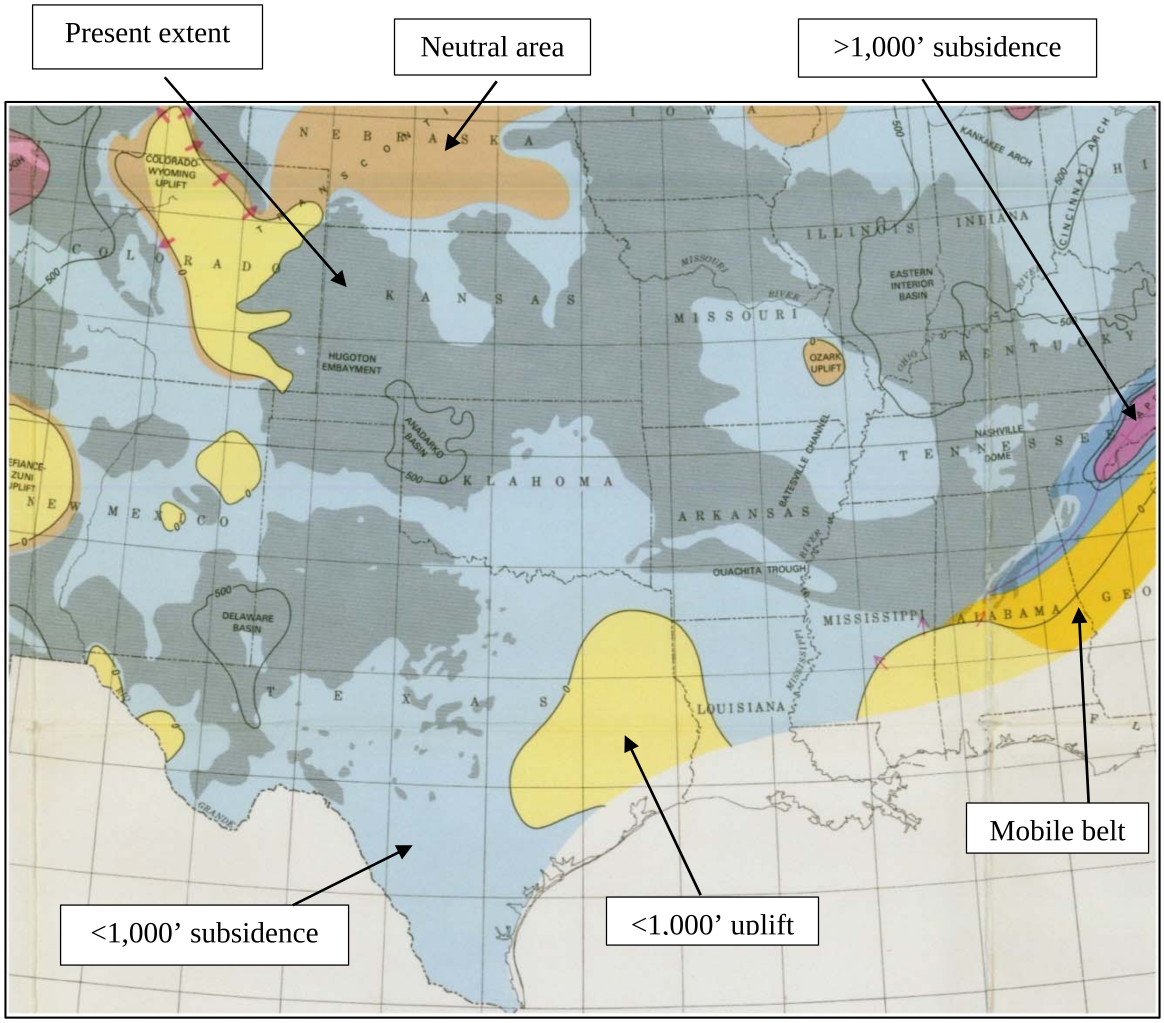

Figure 6 - Osagean geographic features (Craig and Connor, 1979).

At the beginning of the Osagean, the Midcontinent was undergoing relatively gentle subsidence (Figure 6). During the Osagean, sediments being deposited were mainly deeper-water muds and shallow, well oxygenated, low energy carbonates (Craig and Connor, 1979). These sediments were mainly being deposited in the eastern proto-Arkoma basin. The western (Oklahoma side) proto-Arkoma basin did receive the same sediments as the Arkansas side. The Oklahoma side lacks both Osagean and Kinderhookian age section while the Arkansas side contains Osagean section (Craig and Connor, 1979).

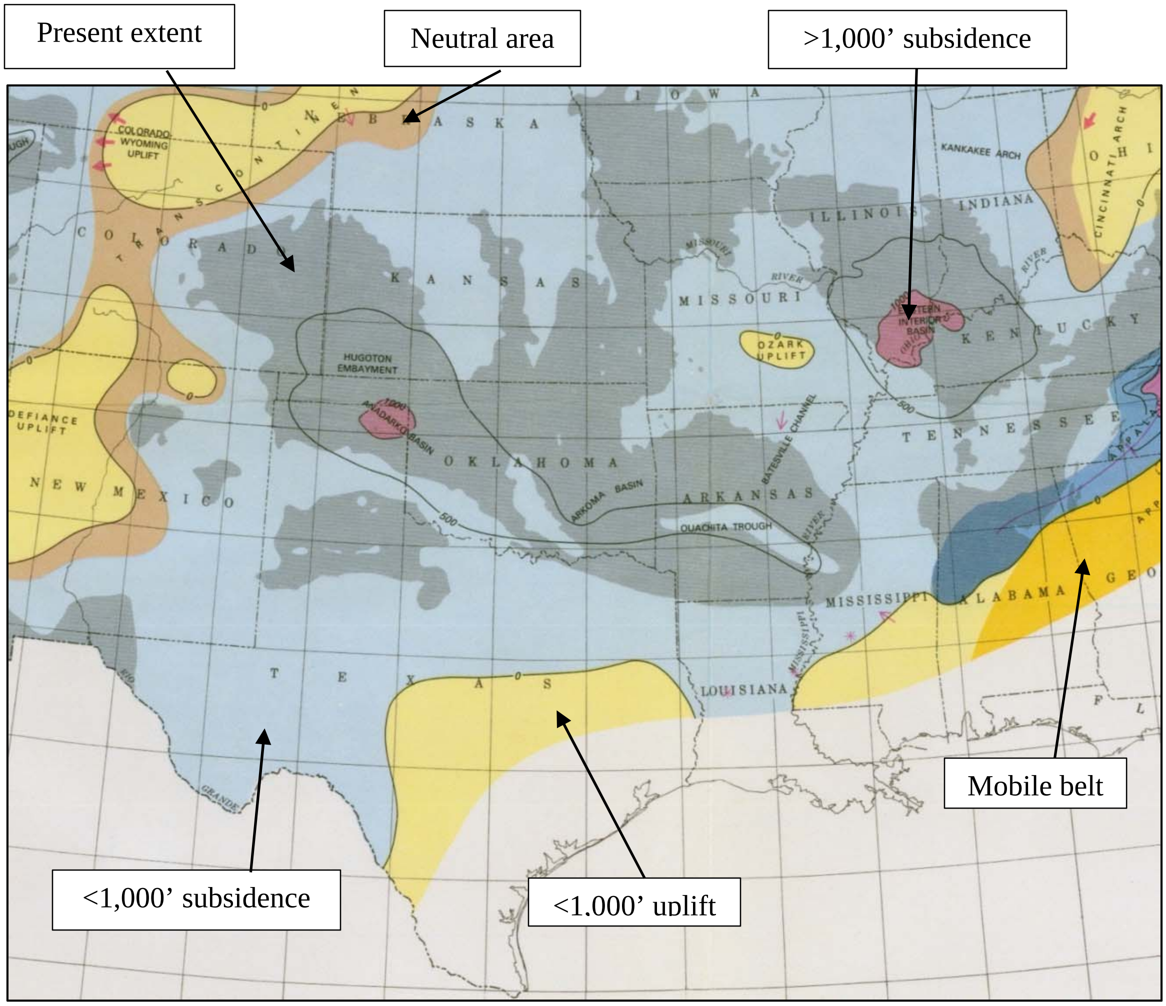

Figure 7 - Meramecian geographic features (Craig and Connor, 1979).

Meramecian (Figure 7) geographic features are quite different from the previous Kinderhookian and Osagean features. Tectonic activity was much more intense at this time. During the Meramecian, both the Ouachita trough in Arkansas and Oklahoma basin in western Oklahoma, were undergoing subsidence. The Ouachita trough began to extend westward into Oklahoma and started to connect with the Oklahoma basin. While the two troughs were subsiding, each received different sediment types. The Ouachita trough deposited detrital sediments (organic-rich muds) while carbonate sediments accumulated in the Oklahoma basin (Craig and Connor, 1979).

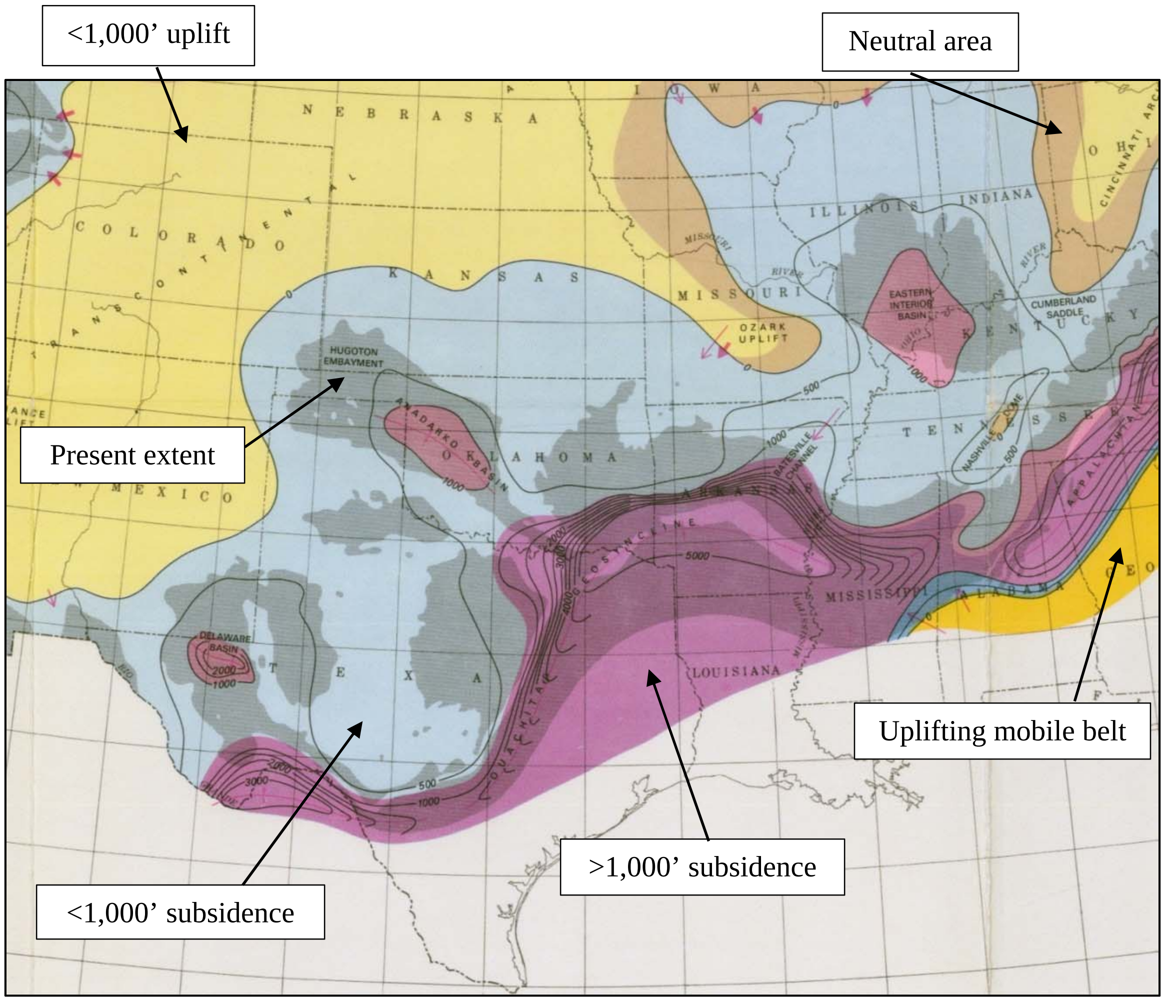

Figure 8 - Chesterian geographic features (Craig and Connor, 1979).

Chesterian geographic features (Figure 8) are similar to Meramecian geographic features except that the rate of subsidence during the Chesterian is greater. The increased rate of subsidence was mainly in the proto-Arkoma basin. The most significant tectonic event occurring during this time was the re-alignment of the proto-Arkoma basin from a west-trending feature to a southwest-trending feature (Craig and Connor, 1979). Sediments being deposited during the late Meramecian and Chesterian was mainly organic muds and carbonates.

By the end of the Mississippian, Gondwana had collided with Laurussia along the eastern seaboard of North America and the collision was slowly moving south. Sediments generated in the orogenic belt were transported to the west toward the deep, relic ocean basin.

STUDY AREA

This study includes portions of four counties: Pontotoc, Coal, Pittsburg, and Hughes (Figure 9). A total of 90 wells were used to correlate tops, make structure maps, isopach maps, and generate cross-sections. Logs were obtained from IHS, Inc., and imported into Petra® to create these maps. One well, the Current #1 in Pontotoc County, Oklahoma, has LAS files courtesy of the Oklahoma Geological Survey/Kansas Geological Survey.

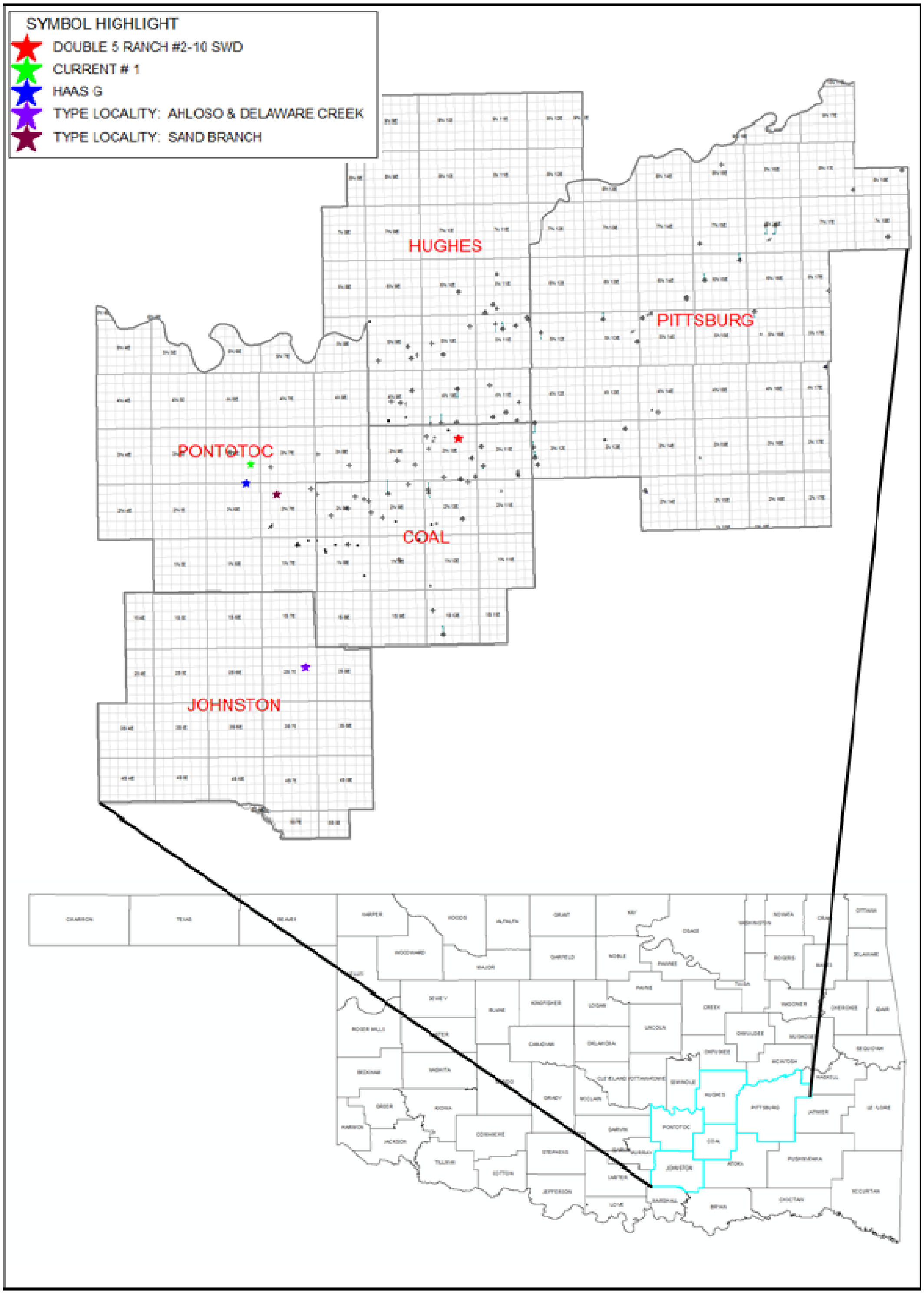

Figure 9 – Location of study area (outlined in blue) and shown by inset. Stars indicate the positions of cores as well as the type locations of the members of the Caney Shale, and the important Haas G outcrop on the Lawrence Uplift.

CHAPTER II

STRATIGRAPHY

Since the Caney Shale was first described in 1901 by Taff as Carboniferous aged shales in southeastern Oklahoma, considerable field and core work has been completed by numerous geologists to improve the understanding of the Caney Shale and its associated members. This thesis is designed to test the hypothesis that the members of the Caney Shale have distinct properties that allow them to be correlated from outcrop to the subsurface. It is hoped that these correlations and the subsequent mapping will help clarify correlations of the internal stratigraphy of the Caney Shale. A stratigraphic column is shown in Figure 10.

For this study, the accepted Caney Shale stratigraphy is utilized and the three members identified using detailed core descriptions and well logs. In ascending order these are the Ahloso, Delaware Creek, and Sand Branch members (Figure 10). A detailed description of slabbed core from the Devon Energy Corporation, Double 5 Ranch #2-10 in 10-3N-10E, Coal County, Oklahoma helped identify these three zones. The Double 5 Ranch core was supplemented with the OGS-KGS Current #1 core in 26-3N-6E, Pontotoc County, Oklahoma and outcrop descriptions.

Elias (1956) differentiated the Caney Shale and established the Ahloso, Delaware Creek, and Sand Branch members. The type locality for both the Ahloso and Delaware Creek members is in the NE/4 of 14-2S-7E in Johnston County, Oklahoma (Figure 9). The Ahloso was named for a village at the junction of Highway 99 and 3 which is about three miles to the southeast of Ada, Oklahoma. Elias (1956) described the Ahloso as being, “light gray, medium hard, more or less calcareous shale, with a very few small concretions, and generally with irregular cleavage along bedding planes.”

The Delaware Creek Member was named for outcrops along Delaware Creek, which flows eastward in the Bromide and Wapanucka area in Johnston, Oklahoma. Elias (1956) described the Delaware Creek as being, “gray, softer, and only slightly calcareous to non-calcareous shale, and commonly bears very large up to 12-foot diameter calcareous concretions, most of which are distinctly septaria in structure.”

The type locality for the Sand Branch Member is the NW/4 of 8-2N-7E, in Pontotoc County, Oklahoma (Figure 9). This member was named after Sand Branch, which is an eastern tributary of Clear Boggy Creek whose confluence is located approximately one mile to the northwest of the village of Frisco. Elias (1956) described the Sand Branch Member as follows, “The Sand Branch generally carries more or less the same kind of concretions (as the Delaware Creek), but its shale is dark gray to black, and much impregnated with pyrite, the oxidation of which at or near the surface, results in ‘rotten’ (shattered or broken) appearance of the shale.”

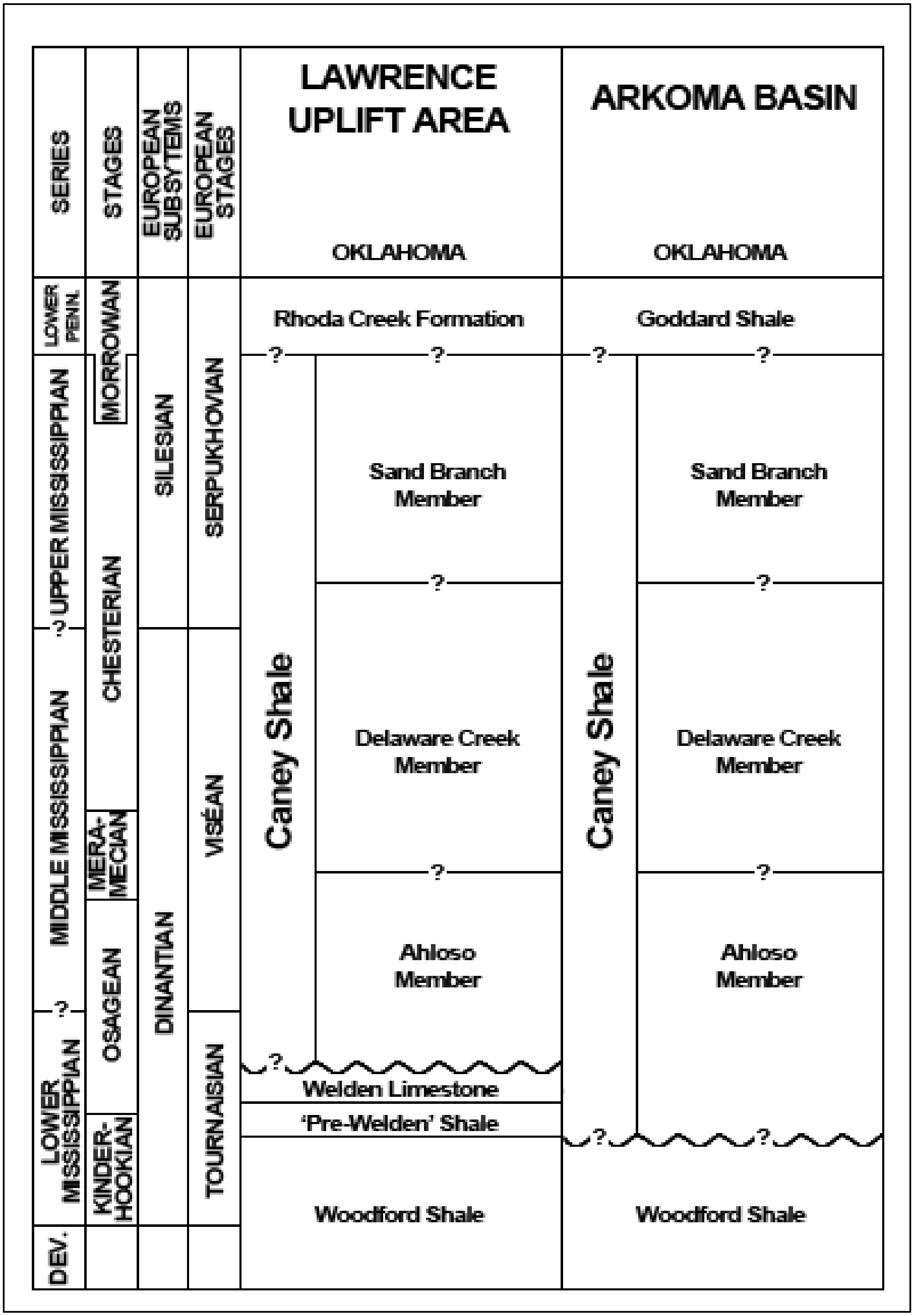

Figure 10 – Generalized stratigraphic nomenclature for the Mississippian strata in the study area (Oklahoma Geological Survey, 2007).

Defining Caney Shale Members

Type Log - Double 5 Ranch #2-10 SWD

The Caney Shale and its members were correlated using wireline log signatures on openhole logs. This correlation was based on outcrop stratigraphy captured in the wireline log suite for the OGS/KGS Current #1 in section 26-T3N-R6E, Pontotoc County, Oklahoma. The most useful logs for correlation were the induction, gamma-ray, density porosity, and neutron porosity logs. Figure 11 shows the boundaries of the members of the Caney Shale in the Double 5 Ranch #2-10 SWD well, located 2452FSL, 217FEL, in section 10-T3N-R10E, Coal County, Oklahoma. These same boundaries were identified in the OGS-KGS Current # 1 (Figure 12). The Current #1 well was cored from the Rhoda Creek Formation to the Hunton Group (Figure 12). The Double 5 Ranch #2-10 SWD was cored from the Rhoda Creek Formation to the Viola Limestone.

To facilitate wireline log correlation, the regional markers with consistent log signatures were identified. In ascending order these were the Viola Group, Sylvan Shale, Hunton Group, Woodford Shale, and Caney Shale. Once the regional markers were correlated, a set of useful correlations within the Caney Shale were established and applied to well logs throughout the study area.

The Woodford Shale is consistently radiogenic shale that is easily correlated using the gamma-ray curve. The Ahloso Member of the Caney Shale rests disconformably on the Welden Limestone or the Woodford Shale and was by far the most difficult to correlate. On the type log, the top of the Ahloso Member was picked at the first major radiogenic shale marker that appears on the gamma-ray curve above the underlying Woodford Shale. However, relying on the gamma-ray curve only is not recommended when correlating this one using wireline logs. Resistivity curves are equally important when trying to correlate the Ahloso Member in the Arkoma basin

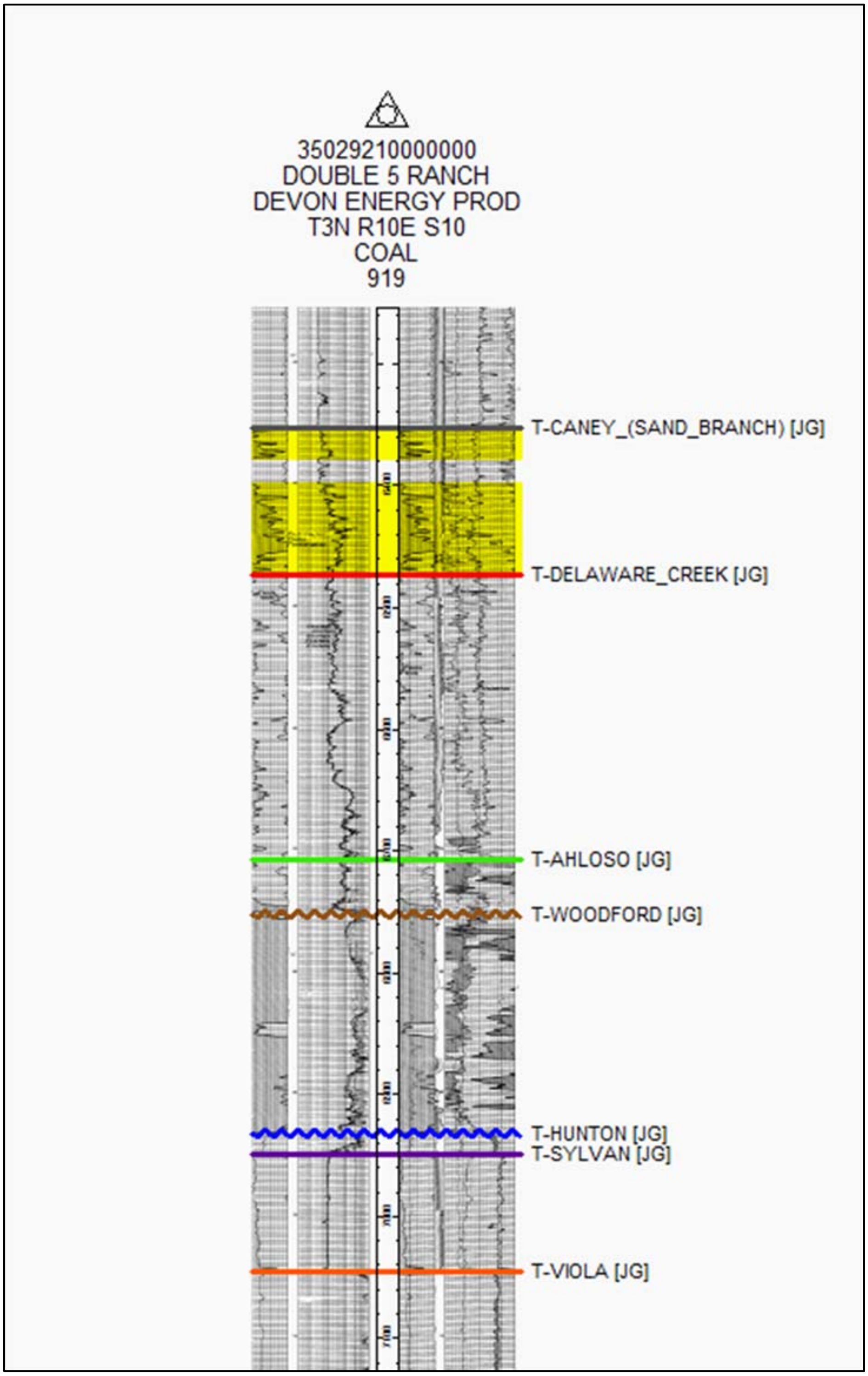

Figure 11 – Type log: Double 5 Ranch #2-10 SWD, 2452FSL, 217FEL, 10-3N-10E in Coal County, Oklahoma. A portion of the "type" wireline log showing gamma-ray, density porosity, and neutron porosity curves covering the Viola to Pennsylvanian section in the Devon Energy Double 5 Ranch #2-10 SWD in 10-3N-10E, Coal County, Oklahoma. Interpreted boundaries of the members of the Caney Shale as well as the Woodford Shale, Hunton Group, Sylvan Shale, and Viola Group were correlated.

because it typically exhibits a lower resistivity that the overlying Delaware Creek Member (Figure 13).

The Delaware Creek Member consists of an easily correlatable group of carbonaceous/radiogenic shales that mark the base of the Sand Branch Member and separate it from the Delaware Creek Member. The Sand Branch Member is the most radiogenic member of the Caney Shale (Kamann, 2006) and this more radioactive gamma-ray signature can be correlated throughout the study area. A corresponding increase in resistivity of an average of 500 ohm-m marks the contact between the Delaware Creek Member and the overlying Sand Branch Member.

The top of the Caney Shale coincides with a decrease in radioactivity and increase in resistivity associated with the Rhoda Creek.

OGS-KGS Current #1

The OGS-KGS Current #1 in section 26-T3N-R6E, Pontotoc County, Oklahoma was logged by the Kansas Geological Survey. Figure 12 shows gamma-ray and density porosity signatures for the Caney Shale and a few feet of the Hunton Group and the contacts between the three members of the Caney Shale. Figure 14 shows correlation of outcrop stratigraphy as shown by the Current #1 to subsurface stratigraphy of the Double 5 Ranch #2-10 SWD.

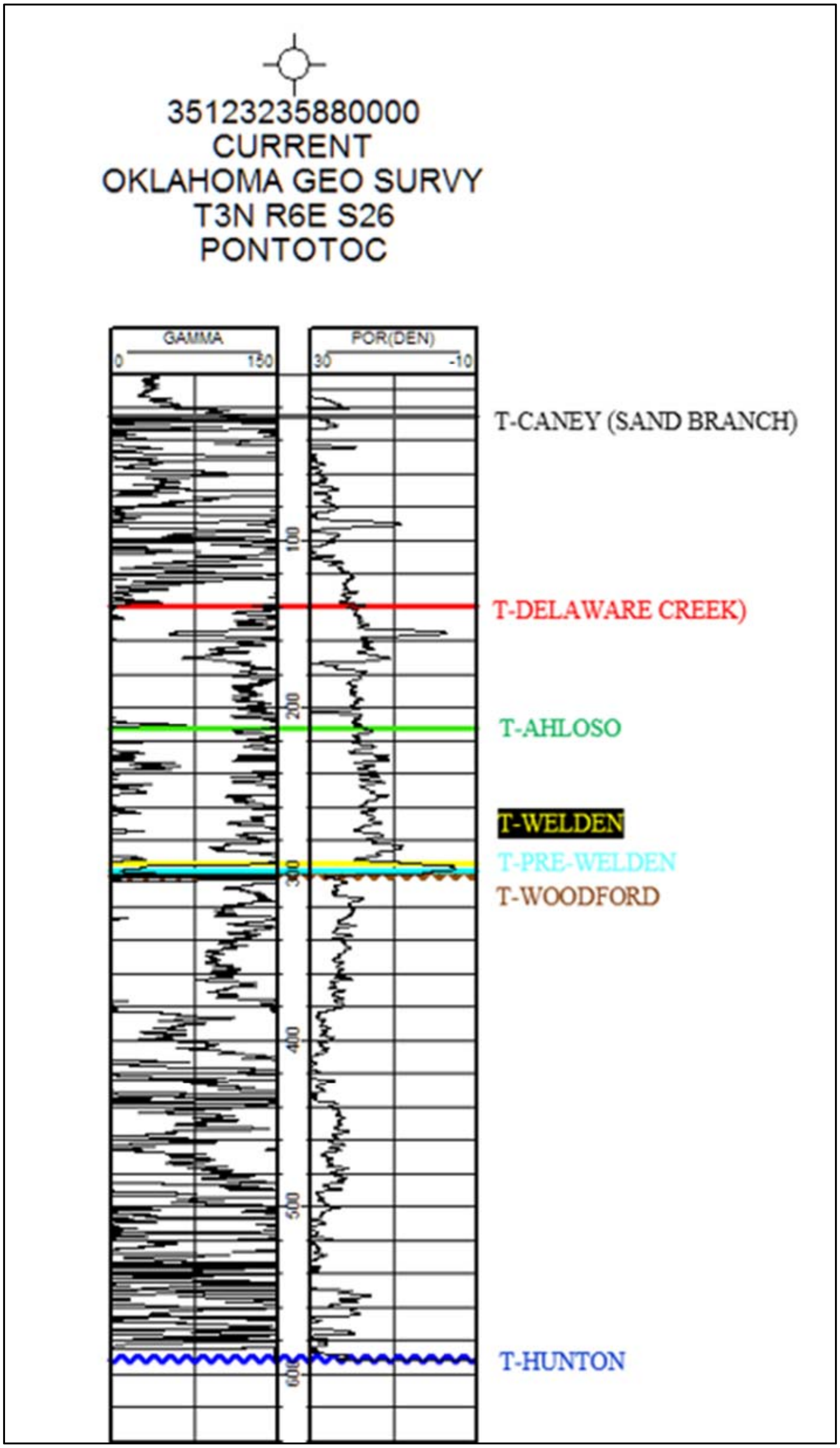

Figure 12 – Gamma-ray and density porosity curves for the OGS-KGS Current #1 in section 26-T3N-R6E, Pontotoc County, Oklahoma.

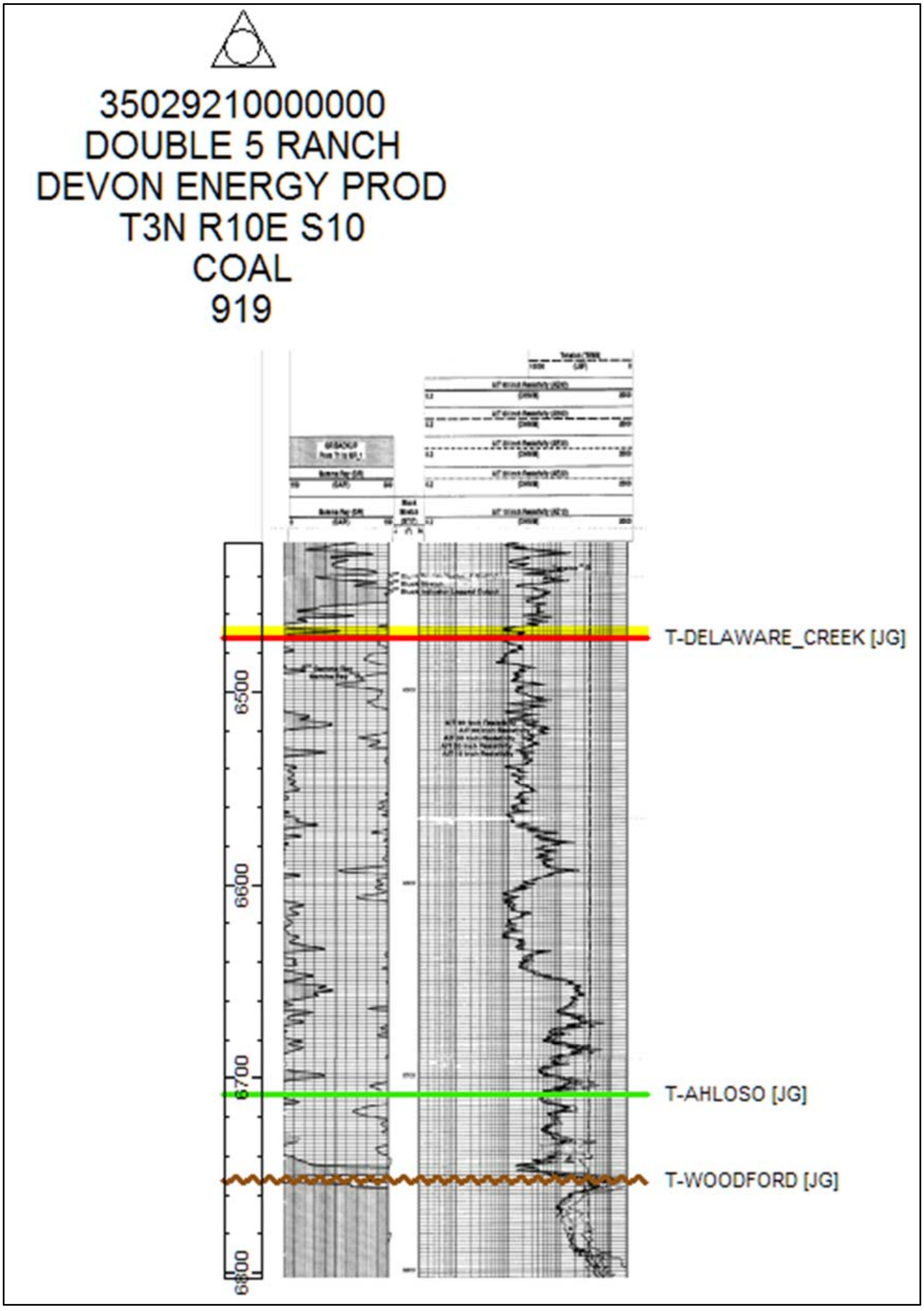

Figure 13 – Resistivity curves for Devon Energy Corporation Double 5 Ranch #2-10 SWD, 2452FSL, 217FEL, 10-3N-10E in Coal County, Oklahoma.

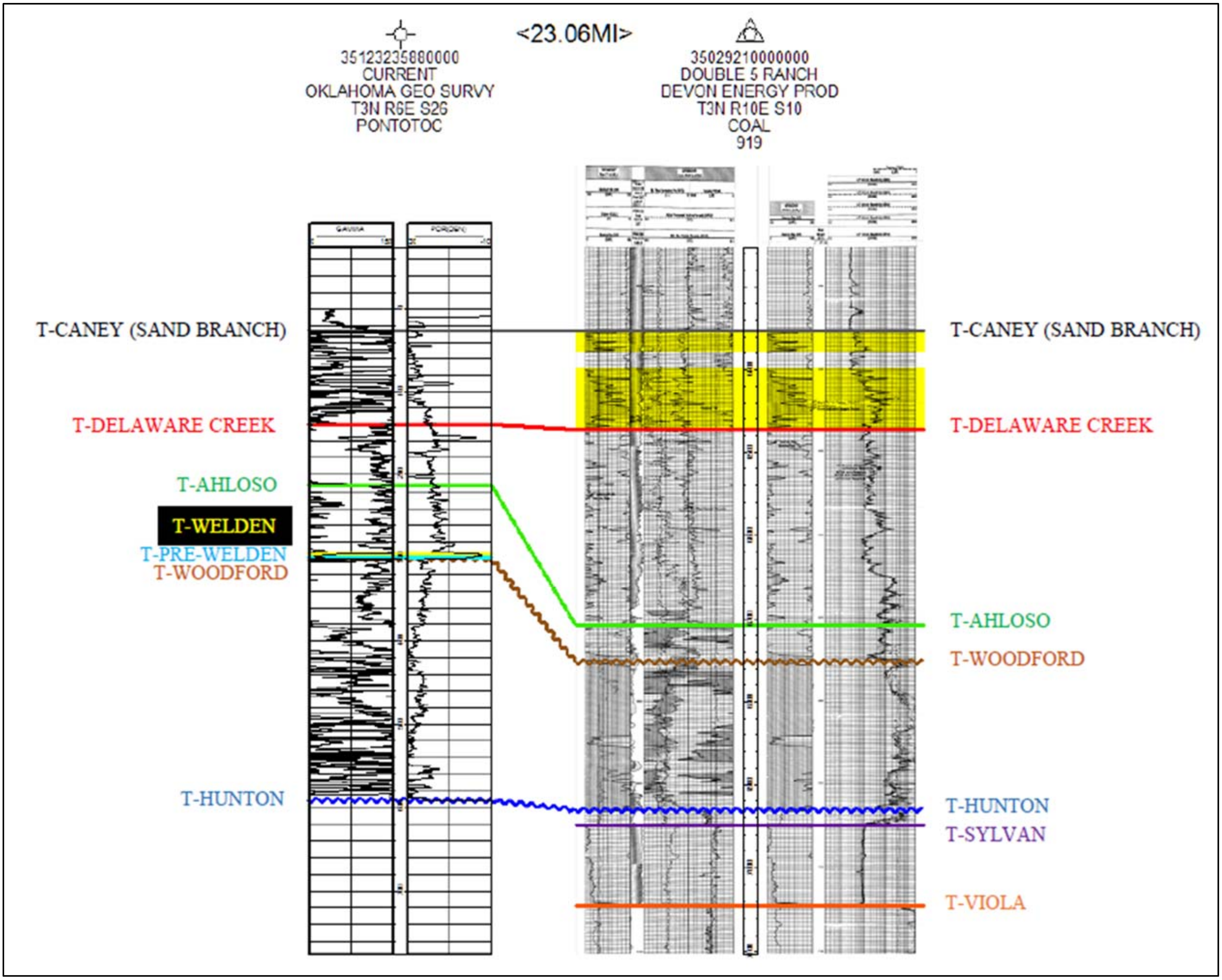

Figure 14 – Correlation of outcrop stratigraphy from OGS-KGS Current #1 in section 26-T3N-R6E, Pontotoc County, Oklahoma to subsurface stratigraphy in Devon Energy Corporation Double 5 Ranch #2-10 SWD, 2452FSL, 217FEL, 10-3N-10E in Coal County, Oklahoma.

Core Descriptions

Devon Energy Corporation Double 5 Ranch #2-10 SWD core

The Caney Shale in the Devon Energy Corporation Double 5 Ranch #2-10 SWD well is a laminated, organic-rich black shale with occasional diamictite beds (beds containing sedimentary rock fragments) and intervals containing carbonate concretions or bullion. The shale is fossiliferous and contains conodonts, gastropods and brachiopods. It also frequently contains *Phycosiphon*, which is a horizontally oriented burrow that can have U-shaped loops that are interpreted as feeding burrows of a small worm-like animal. It also possible contains *Helminthopsis*, which is a worm-like animal that can create both horizontal and vertical burrows. Phosphate and silica nodules also occur in the Sand Branch Member of the Caney Shale. The detailed core description is in Appendix 1 (images A1.1 – A1.12).

Lithology of Members from the Double 5 Ranch #2-10 SWD core

Each member of the Caney Shale has distinct lithologic characteristics. Distinguishing the Woodford Shale or Welden Limestone from the overlying Ahloso Member of the Caney Shale is not difficult as the Woodford Shale is a highly contorted and brecciated, dark gray to black and bluish black carbonaceous shale (A2.1), and the Welden Limestone is a light tan to brown limestone. In contrast, the Ahloso Member is silt-rich mudstone/siltstone.

The Ahloso Member contains glauconitic sandstone that disconformably overlies the Woodford Shale in much of the study area. The Ahloso Member is characterized by its silt content (A2.1). It is a gray to dark gray to bluish black, more or less calcareous muddy siltstone containing a few limestone beds. The Ahloso Member also contains sedimentary rock fragments as well as dark gray to black interbedded shale/mudstone and arenaceous siltstone (A2.1). Conodonts occur in the glauconitic sandstone in the lower most section just above the contact with the Woodford Shale (A2.1). The interval immediately above the Woodford Shale contact is heavily bioturbated by *Phycosiphon* trace fossils (A2.1). Some intervals contain brachiopods and bivalves as well as gastropod fragments. Near the top of the Ahloso Member are alternating dark and light gray, massive, calcareous muddy siltstones that are heavily bioturbated by *Phycosiphon* trace fossils (A2.2).

The contact between the top of the Ahloso Member and the overlying Delaware Creek Member is transitional, rather than sharp. The Delaware Creek Member is characterized by its loss of silt and addition of carbonate concretions (A2.3). It is a gray to dark gray, non-calcareous to slightly calcareous silty mudstone that contains both limestone concretions and diamictite beds (A2.4-5). The upper part of the Delaware Creek Member contains intervals that are weathered and have high clay content. Trace fossils occur within the Delaware Creek Member and gastropods, cephalopod, brachiopods, and bivalve fragments were also identified (A2.6).

The Sand Branch Member is the most organic-rich member and is characterized by an abundance of phosphate and minor carbonate concretions (A2.7). The top of the Sand Branch Member (top of the Caney Shale) is at 6,354' (A2.8). The Sand Branch Member is dark gray to black, pyritic, finely laminated carbonaceous shale that contains carbonate concretions and diamictite beds similar to these in the Delaware Creek Member (A2.9). The carbonate concretions are commonly septarian and similar to those in the Delaware Creek Member. Phosphate and silica nodules occur in this section as well as recrystallized ammonoids and nautiloids (A2.10). Diamictite beds exhibiting fining-upward textures (A2.11) are interbedded with laminated sandy beds that transition into mudstone that is slightly calcareous and contain small numbers of shell fragments (A2.11). Conodonts, bivalves, brachiopods, and *Phycosiphon* trace fossils occur in the Sand Branch Member.

The top of the Caney Shale is superceded by the Rhoda Creek Formation. The Rhoda Creek Formation is distinguished by its decreased gamma-ray signature that is in sharp contrast to the more radiogenic shale and higher gamma-ray values of the Caney Shale. The cored section of the Rhoda Creek Formation is mostly dark gray to black fissile shale that contains siderite nodules.

Haas G Locality

The Haas G outcrop is located along the bank of the South Fork of Jackfork Creek in section 33-T3N-R6E, Pontotoc County, Oklahoma (longitude -96.6460100, latitude 34.6799050). This locality is on the Lawrence Uplift and contains the upper portion of the Woodford Shale, Pre-Welden Shale, Welden Limestone, and basal Caney Shale (Ahloso Member). Figure 15 is the stratigraphic column made from this locality.

The upper part of the Woodford Shale is a finely laminated black clay shale with thin phosphate laminae. The Pre-Welden Shale that overlies the Woodford Shale is a greenish gray to bluish green clay shale that is glauconitic. A sharp contact separates the Welden Limestone from the Pre-Welden Shale. The Welden Limestone is a wackestone to grainstone, and calcareous silty shale. The basal Caney Shale (Ahloso Member) is dark yellowish orange to dark yellowish brown, less oxidized blocky mudstone overlain by a more oxidized clayey shale. A prominent glauconite-rich interval is overlain by tan shale and zone with abundant inarticulate brachiopods, *Lingula* and *Orbiculoidea.* The inarticulate brachiopod bed is succeeded by argillaceous limestone that contains abundant thin shelled articulate brachiopods of the genera *Leiorhynchus* (Godwin, 2015, personal communication). A grayish orange, slightly calcareous, shaly siltstone overlies the dark colored brachiopod-rich limestone.

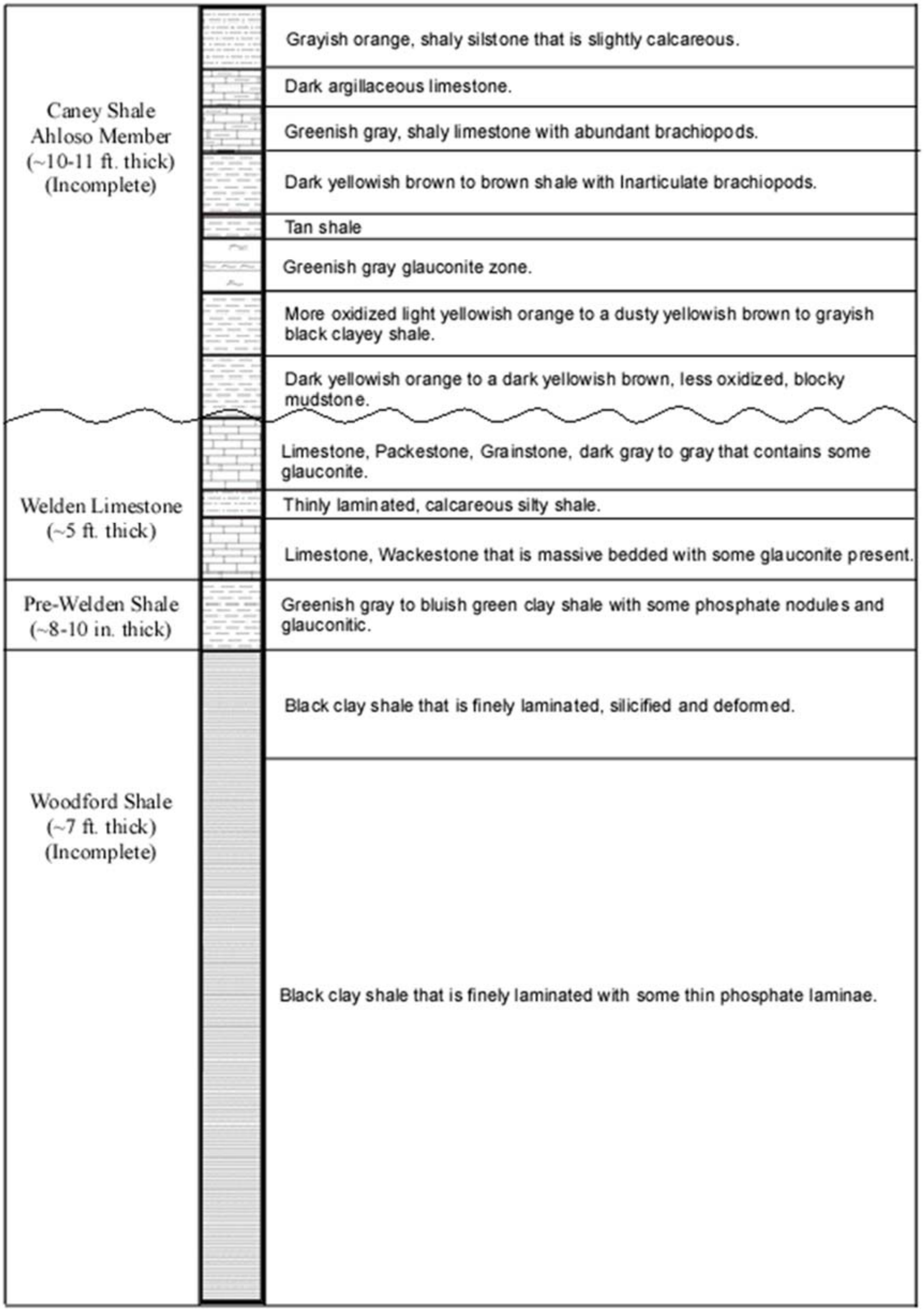

Figure 15 – Outcrop description for Haas G section in section 33-T3N, R6E, Pontotoc County, Oklahoma.

OGS-KGS Current #1

The OGS-KGS Current # 1 core in section 26-T3N-R6E, Pontotoc County contains 230 feet of Woodford Shale, 20 feet of Welden Limestone and Pre-Welden Shale, and 290 feet of Caney Shale (Figure 16). The core was described by Boardman and Watney (2006) and summarized as follows.

The Woodford Shale is a light gray to black clay shale containing silt, phosphate laminae, phosphate nodules, lenticular bedded phosphate, burrows, and inarticulate brachiopods (Boardman and Watney, 2006). The Pre-Welden Shale is a greenish gray to grayish yellow green containing large lenticular phosphate, phosphate nodules, and possibly dolomitic (Boardman and Watney, 2006). The Welden Limestone is a fossiliferous, slightly glauconitic wackestone (Boardman and Watney, 2006). The basal Caney Shale (Ahloso Member) is a light bluish gray to dark gray shale with intervals of calcareous light brown to pale yellowish brown shale with glauconite-rich intervals containing articulate brachiopods, laminar phosphate, ammonoids and brachiopods (Boardman and Watney, 2006). The middle Caney Shale (Delaware Creek Member) is a medium dark gray to dark gray shale containing faint phosphate laminae, ammonoids, and intervals of carbonate mudstone with bivalves and bullion. The top of the Caney Shale (Sand Branch Member) is a medium dark gray to dark gray crumbly shale with phosphate laminae, phosphate nodules, bivalves, ammonoids, and bactritoid cephalopods (Boardman and Watney, 2006).

In this core the Caney Shale is a laminated, organic-rich shale with intervals containing phosphate laminae and bullion. The shale is fossiliferous and contains burrows, bivalves, cephalopods and ammonoids.

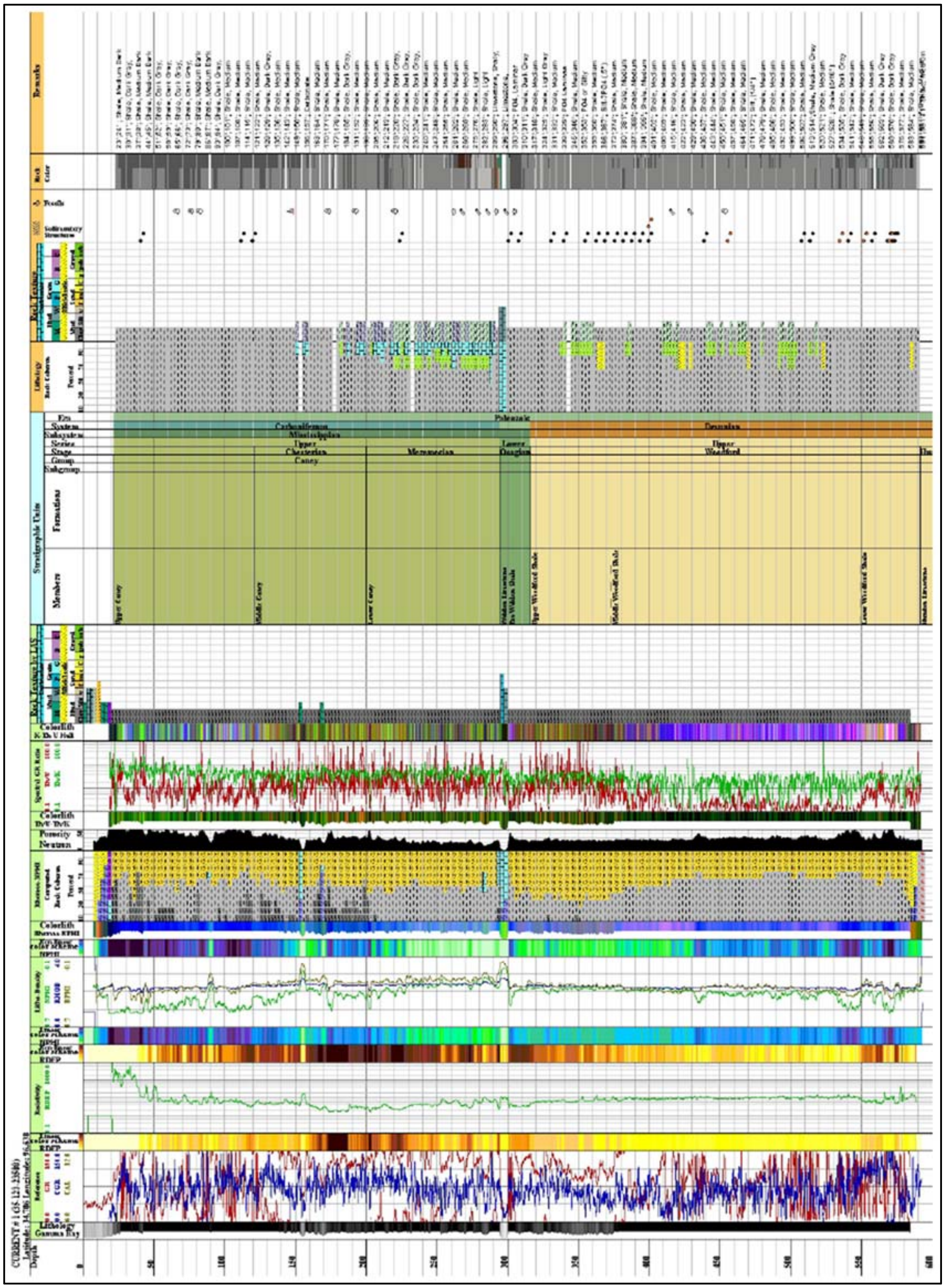

Figure 16 – Core description (rock textures, stratigraphic units, lithology, and colors), and wireline logs (resistivity, neutron-density porosity, spectral gamma-ray, and gamma-ray) from Watney et al (2013), OGS-KGS Current #1 in section 26-T3N-R6E, Pontotoc County, Oklahoma.

Regional Cross-sections

Once the outcrop to subsurface correlations were established, regional correlations were made through Pontotoc, Coal, Pittsburg, and Hughes Counties, Oklahoma (Appendix 3 – Cross-sections A-A' to J-J' - Figures A3.1-A3.10). To help with correlations, the newest logs were used that penetrated the top of the Caney Shale. A subset of 90 wireline logs from wells that penetrated the Caney Shale were used to construct cross-sections. Wireline logs without distinct markers above the Caney Shale were correlated using the Woodford Shale as datum as it is easily recognized on logs because of its high gamma-ray readings. Figure 17 shows the locations of the cross-sections within the study area.

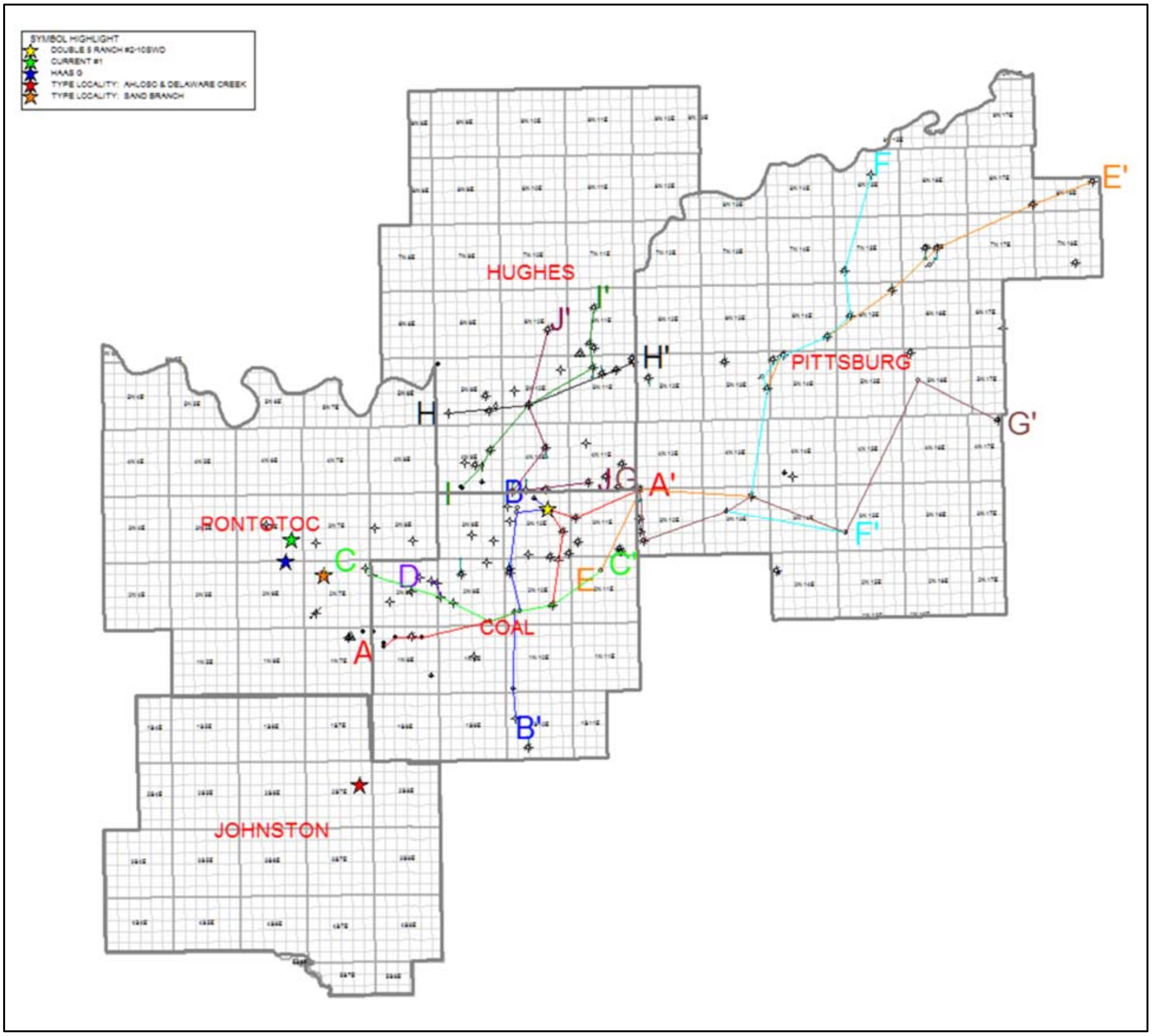

Figure 17 – Location map of cross-sections within Pontotoc, Coal, Hughes, and Pittsburg Counties, Oklahoma. All cross-sections are in Appendix C (A-A' to J-J').

The members of the Caney Shale generally maintain their gamma-ray and resistivity log signatures throughout the study area. All members gradually thin to the northeast and southeast. The Ahloso Member is the thinnest, whereas the Delaware Creek Member and Sand Branch Member are thicker.

In section 13-T2N-R8E, Coal County, Oklahoma, one well has all section below the top twenty five (25) feet of the Delaware Creek Member faulted out and as a result the Delaware Creek Member is juxtaposed on limestone of the Hunton Group. This fault is likely to be Pennsylvanian due to the fact that the entire Sand Branch Member section still exists in this well (A3.4 – D-D'). The faults interpreted were taken from a paper by Harlton (1969) were hand drawn into Petra® and intersect wells with missing section.

Regional Structure Maps

Structure maps were constructed for the top of the Woodford Shale and top of the Caney Shale. The Woodford Shale structure map is shown in Figure 18. The Woodford Shale dips approximately 250 feet per mile to the southeast and ranges in depths from several hundred feet above sea level in Pontotoc County, Oklahoma to over 13,000 feet below sea level in Pittsburg County, Oklahoma.

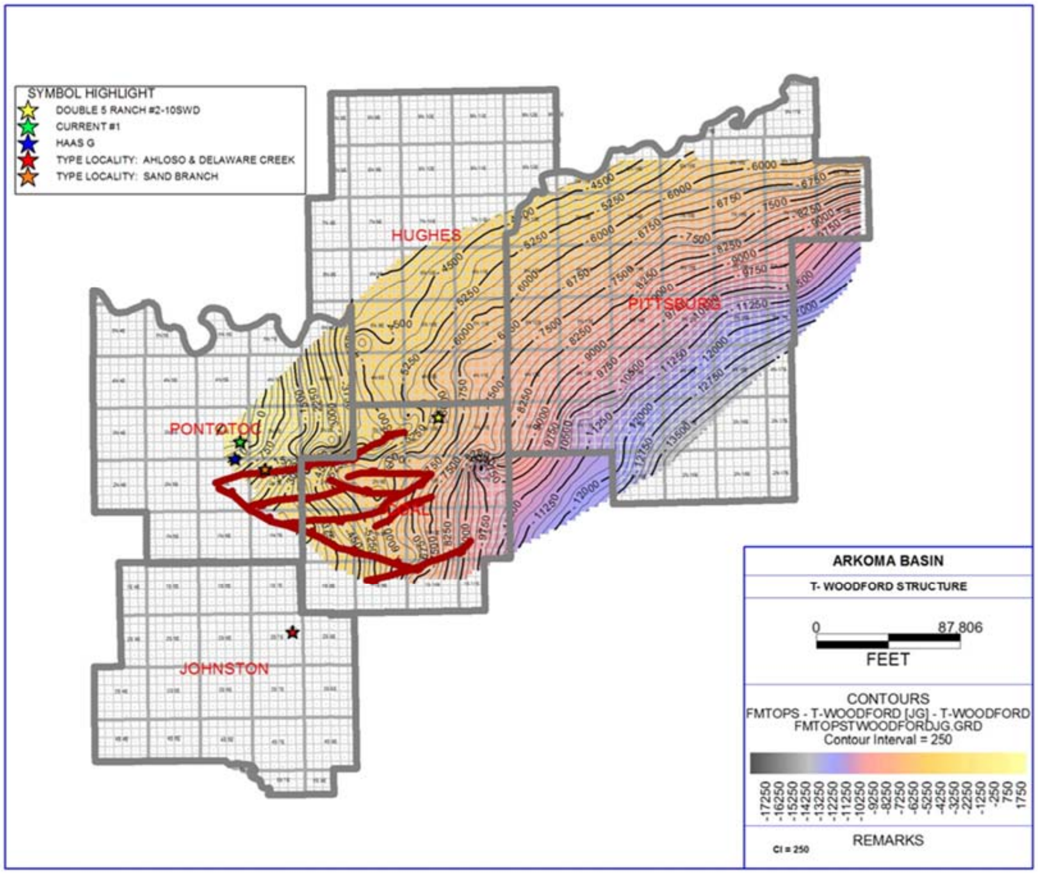

Figure 18 – Structural contour map constructed on the top of the Woodford Shale as identified on gamma-ray and resistivity wireline logs. Contour interval is 250 feet. Faults shown are from Harlton (1969).

The structure map constructed for the top of the Caney Shale is shown in Figure 19. The structural attitude of the Caney Shale is very similar to that of the Woodford Shale as the Caney Shale dips approximately 250 feet per mile to the southeast. However, faults that are recognized by offset of the top of the Caney Shale are not mappable in the sparsely populated wireline log set. Similar to the Woodford Shale, the Caney Shale is above sea level in Pontotoc County, Oklahoma and 13,000 feet below sea level in Pittsburg County, Oklahoma. It is important to note that these are regional structure maps based on sparse well control. As a result, additional faults could be present that are not reflected on the contour maps.

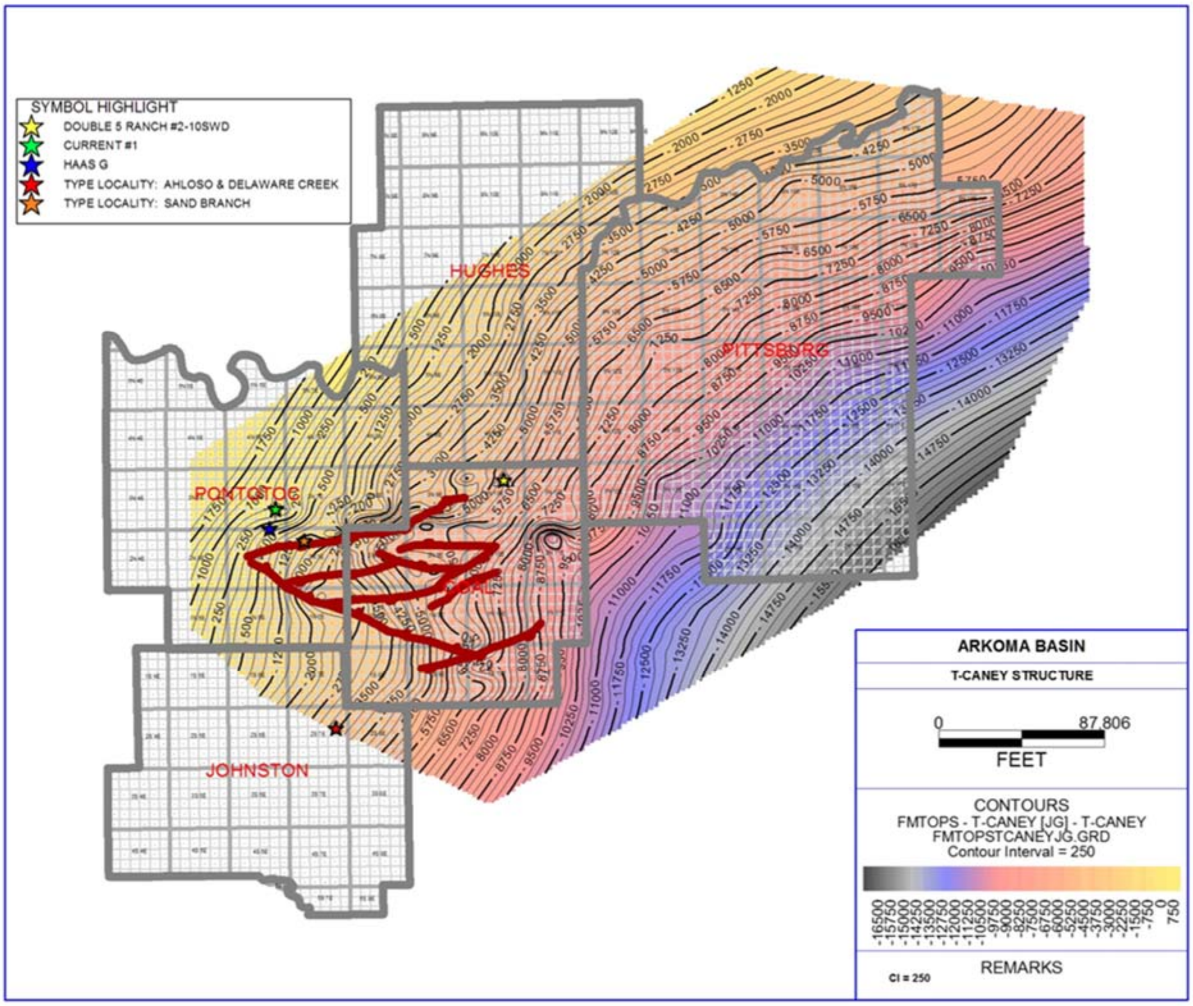

Figure 19 – Structural contour map constructed on the top of the Caney Shale as identified on gamma-ray and resistivity wireline logs. Contour interval is 250 feet. Faults shown are from Harlton (1969).

Regional Isopach Maps

Isopach maps were constructed to illustrate changes in depositional patterns during the Late Devonian to Mississippian. Drilled and logged thicknesses are expressed to be true vertical thicknesses as deviated and horizontal wells were not included in the data set. The Woodford Shale map (Figure 20) shows that the thickest section of the Woodford Shale occurs in northeastern Coal County, Oklahoma (~170-200'), southern Hughes County, Oklahoma (~160-

200'), and central Pontotoc County, Oklahoma (250'+). The trends of the thick Woodford Shale are NW-SE and similar to trends mapped by Blackford (2007) in portions of the study area.

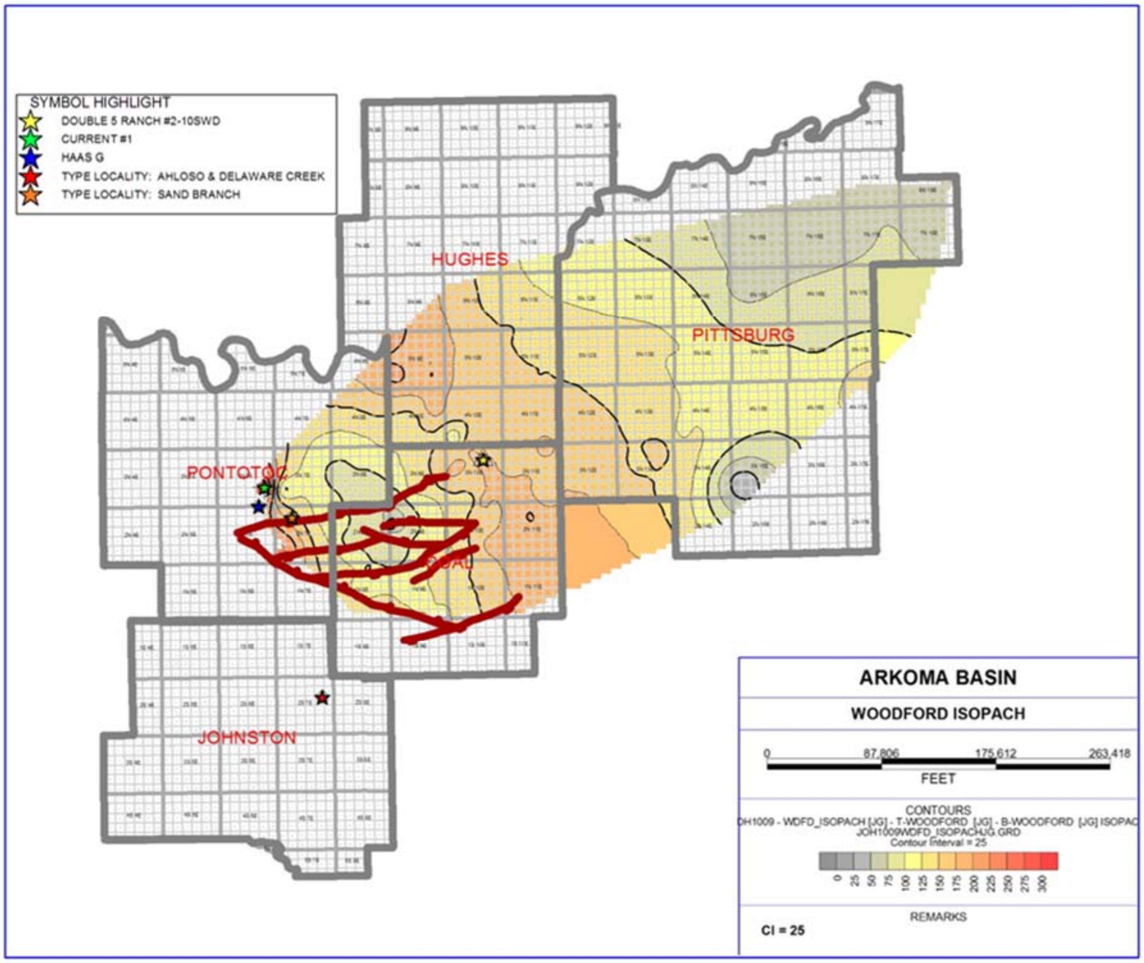

Figure 20 – Isopach map of the Woodford Shale in portions of Pontotoc, Coal, Pittsburg, and Hughes Counties, Oklahoma. Fault locations are from Harlton (1969).

The thickness of the total Caney Shale is shown in Figure 21. The trends in Caney Shale thickness are NW-SE and similar to those for the Woodford Shale.

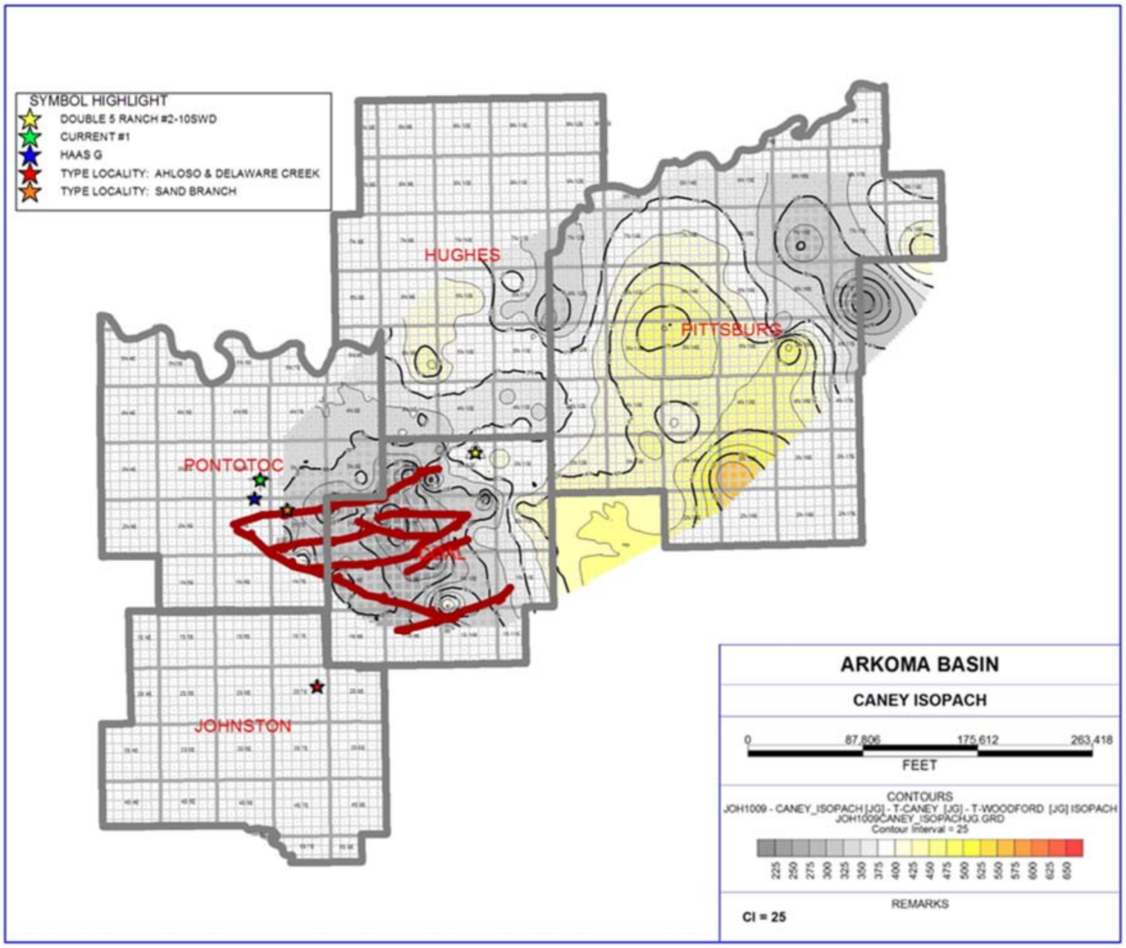

Figure 21– Isopach map of the Caney Shale in portions of Pontotoc, Coal, Pittsburg, and Hughes Counties, Oklahoma. Fault locations are from Harlton (1969).

The isopach map of the Ahloso Member is shown in Figure 22. Due to difficulties with correlations, this map may be the most prone to error. However, it appears that the Ahloso Member is relatively the same thickness through the mapped study area. The thickness of the Ahloso Member may have been influenced by topography below the pre Caney-post Welden unconformity. Pennsylvanian tectonism also impacted the thickness of the Ahloso Member as the entire section is faulted out in a well in section 13-T2N-R8E, Coal County, Oklahoma (A3.4 – D-D').

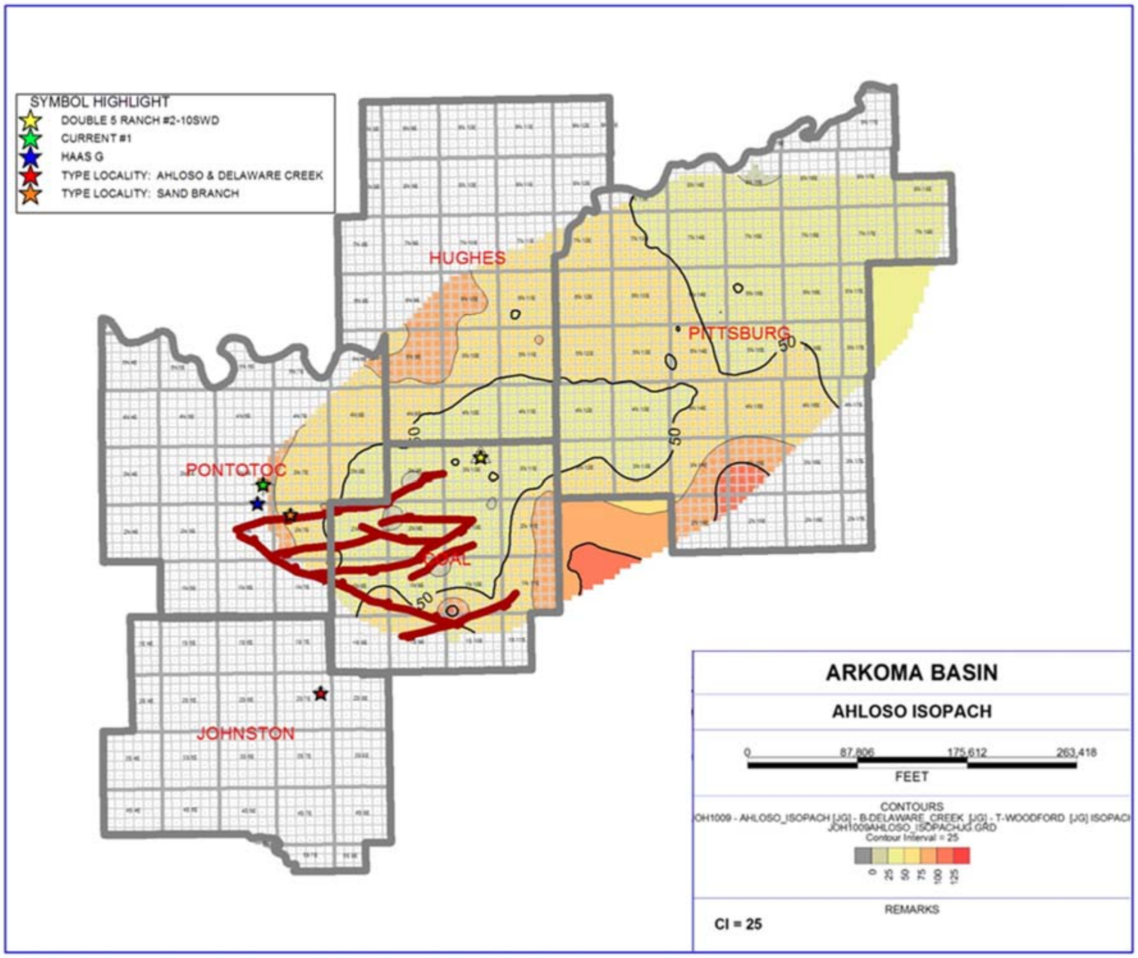

Figure 22 – Isopach map of the Ahloso Member in portions of Pontotoc, Coal, Pittsburg, and Hughes Counties, Oklahoma. Fault locations are from Harlton (1969).

The Delaware Creek Member isopach map (Figure 23) is similar to the isopach map of the total Caney Shale. The depocenter for the depositional basin (Oklahoma Basin) during Delaware Creek time appears to be in the center of the study area and trending NW-SE. From the depositional axis, the Delaware Creek Member thins to the northeast and southwest. Most of the Delaware Creek Member is faulted out in the previously mentioned well in section 13-T2N-R8E, Coal County, Oklahoma.

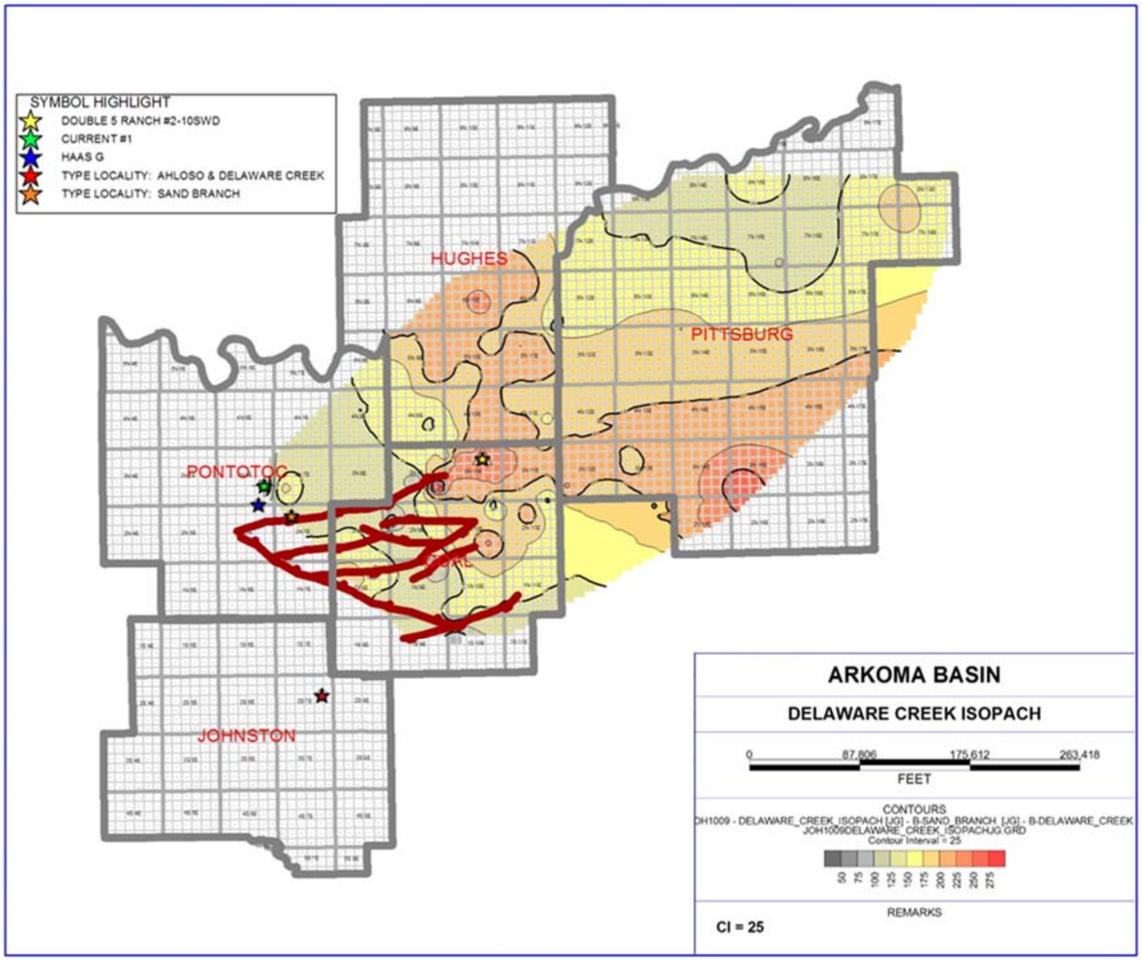

Figure 23 – Isopach map of the Delaware Creek Member in portions of Pontotoc, Coal, Pittsburg, and Hughes Counties, Oklahoma. Fault locations are from Harlton (1969).

The isopach map for the Sand Branch Member is different than previous maps in that mappable faults are not known (Figure 24). The regional isopach map shows that the basin depocenter shifted more to the northeast part of the study area during Sand Branch time and that this localized depocenter trends NW-SE. It is important to note that due to a lack of well control, the isopach of the Sand Branch Member is subject to error outside the study area in Pontotoc, Coal, Pittsburg, and Hughes Counties, Oklahoma.

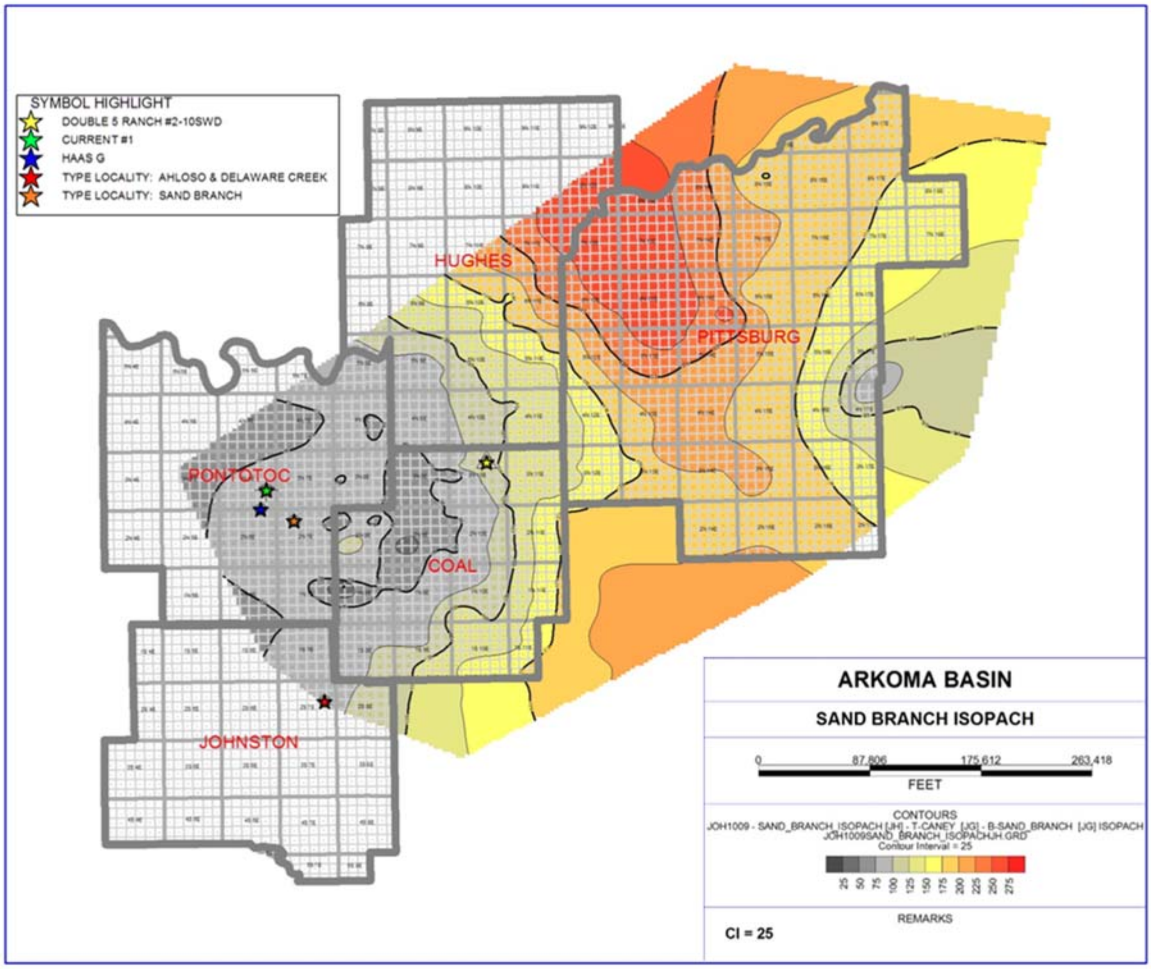

Figure 24 – Isopach map of the Sand Branch Member in portions of Pontotoc, Coal, Pittsburg, and Hughes Counties, Oklahoma.

Potential Hydrocarbon Production

Gas production from the Caney Shale in the Arkoma basin is minimal. With this in mind, the potential for gas production from the Caney Shale was explored by companies because of its characteristics that are similar to those of other shale plays, in particular, the Barnett Shale. The Sand Branch Member is equivalent to parts of the Fayetteville Shale, another important gas-producing shale in the southern United States. Potential natural gas pay in the Sand Branch Member was defined as more radioactive shales that exceed 150 API units on the gamma-ray curve. Figure 25 shows the calculated net gas-producing pay within the Sand Branch Member based on a gamma-ray signature that is greater than 150 API units.

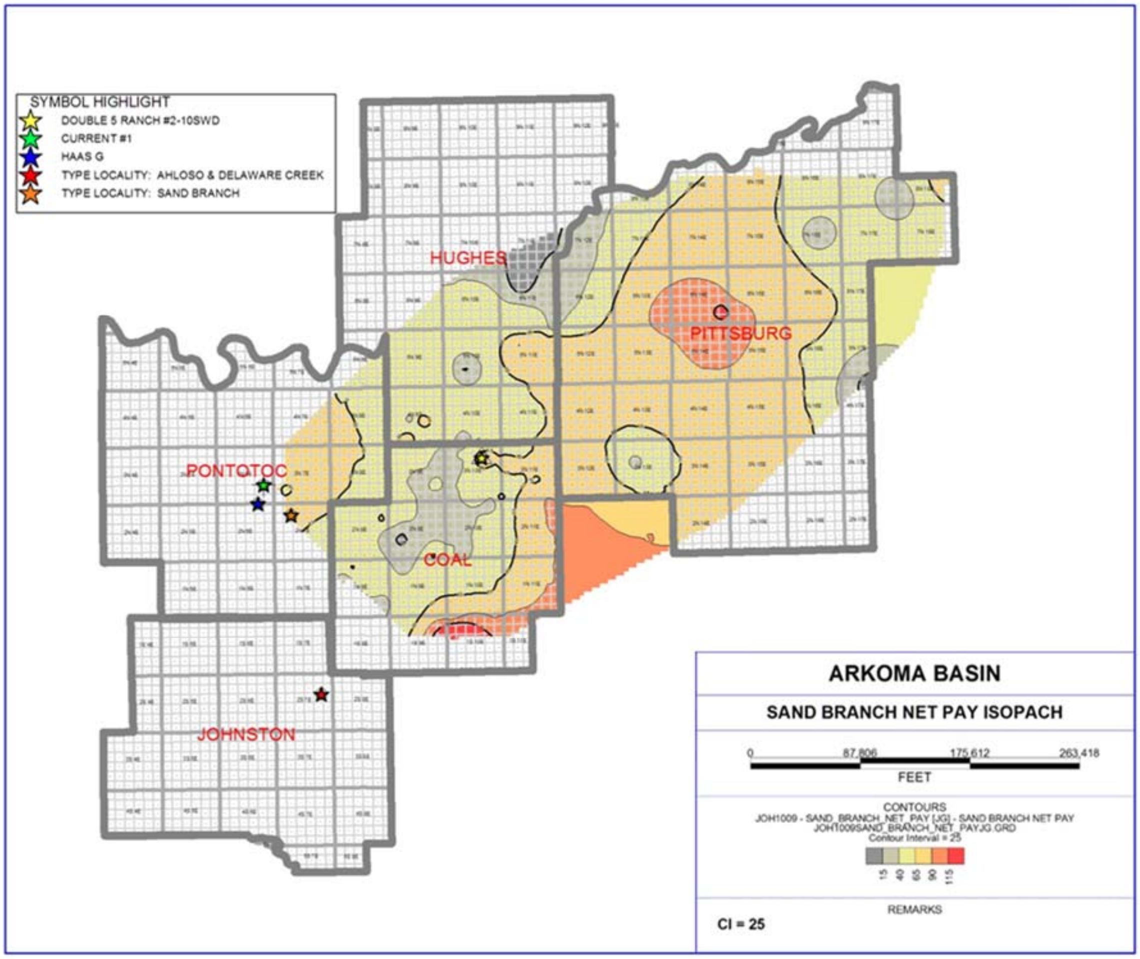

Figure 25 – Isopach map of the Sand Branch Member net gas-producing pay (150+ API units on the gamma-ray curve) in portions of Pontotoc, Coal, Pittsburg, and Hughes Counties, Oklahoma.

CHAPTER III

DISCUSSION AND CONCLUSIONS

Unconventional reservoirs such as the Caney Shale are the most important sources of domestic natural gas in the United States. Like most natural gas plays in the United States, the oil and gas industry identified these natural gas reservoirs years ago, but lacked the science and technology to effectively exploit them. The Caney Shale is the stratigraphic equivalent to the Barnett Shale and stands poised to become a rich and much needed gas resource. Thousands of wells have been drilled through the Caney Shale in Oklahoma. If the Caney Shale is similar to the Barnett Shale, or Fayetteville Shale, the Arkoma Basin provides thick sections available for testing completion techniques.

Shale-gas plays such as the Fayetteville, Barnett, and Woodford Shale are successful because of carbonate and silica cements that generate brittle rock. The Woodford Shale is more silica-rich, whereas the Caney Shale is more clay-rich. As a result, the silica-rich Woodford is brittle and generates fractures in addition to containing natural fractures. Since the Caney Shale is predominantly a clay-rich lithology, it absorbs fracture energy and permeability is not significantly increased by hydraulic stimulation.

The Caney Shale of the Arkoma Basin in Oklahoma is an organic-rich, gas-bearing, dark fissile shale of late Mississippian age. In this study, the Caney Shale was evaluated in both surface outcrops and in the subsurface using core and wireline logs. The Caney Shale is subdivided into three members; in ascending order, the Ahloso, Delaware Creek, and Sand Branch, that can be correlated from outcrop into the subsurface.

These members have distinct wireline log signature and lithologic characteristics that allow them to be correlated across the Lawrence Uplift and into the Arkoma Basin.

The goals of this study were to clarify the terminology applied to the Caney Shale, describe core with the intent of identifying the members, and to show that it is possible to correlate these members in the subsurface. The Caney Shale has the potential to produce natural gas, but establishing the stratigraphy was critical so that reservoir properties can be linked to facies. Future studies should build on this work and expand the Caney Shale study with additional surface and subsurface data. Now that a correlation of the Ahloso, Delaware Creek, and Sand Branch members has been established, future studies can focus on a more petrophysical and geomechanical evaluation to help unlock the future potential of the Caney Shale.

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APPENDICES

APPENDIX 1

Core description of the Devon Energy Corporations Double 5 Ranch #2-10 SWD

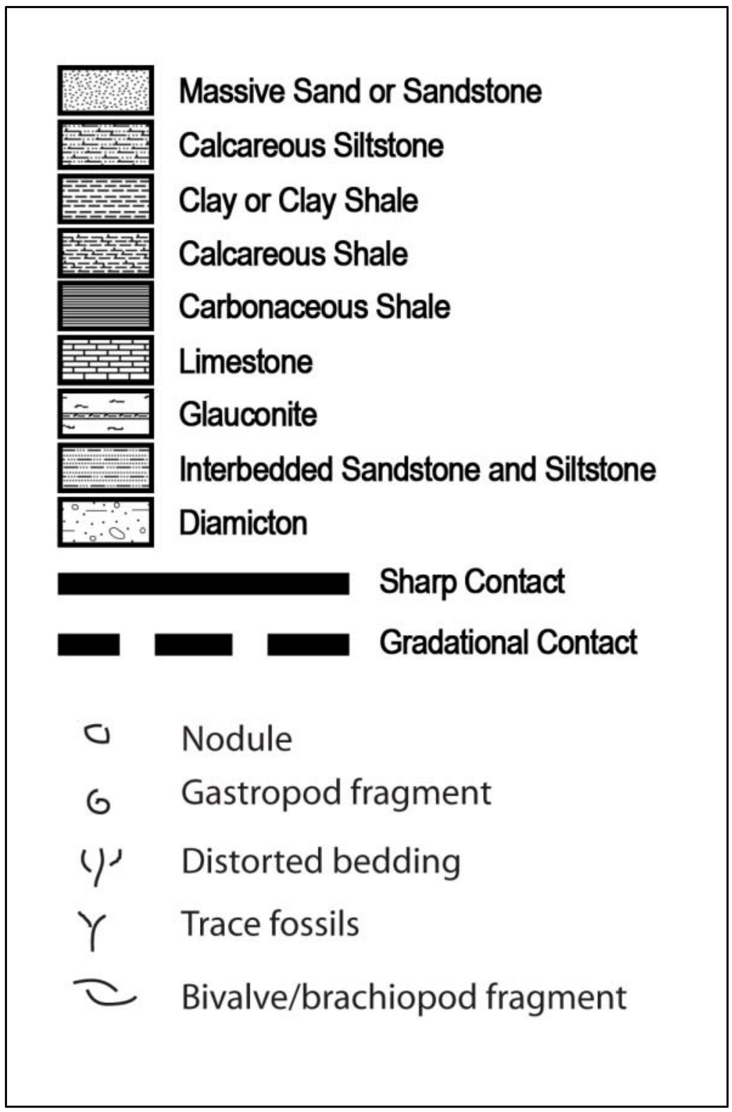


Figure A1.1 - Legend for core descriptions

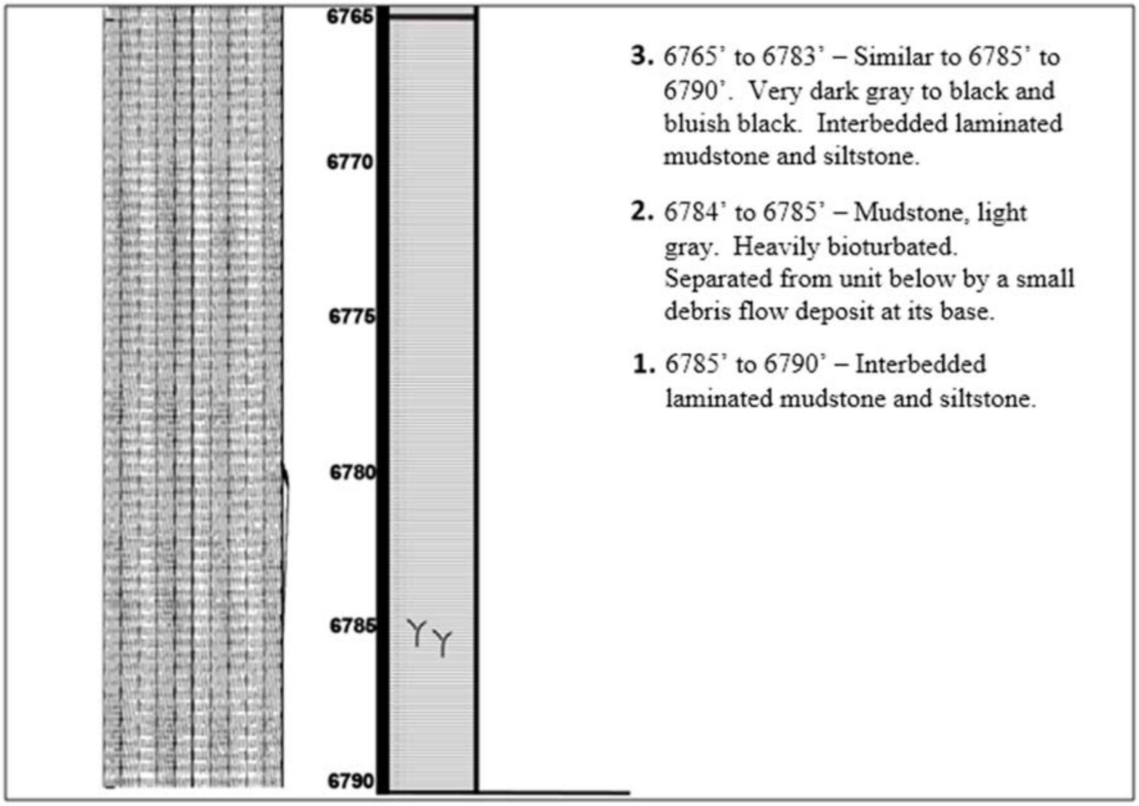


Figure A1.2 – Core descriptions of the Devon Energy Corporations Double 5 Ranch #2-10 SWD. Woodford Shale depth 6790 to 6765 feet.

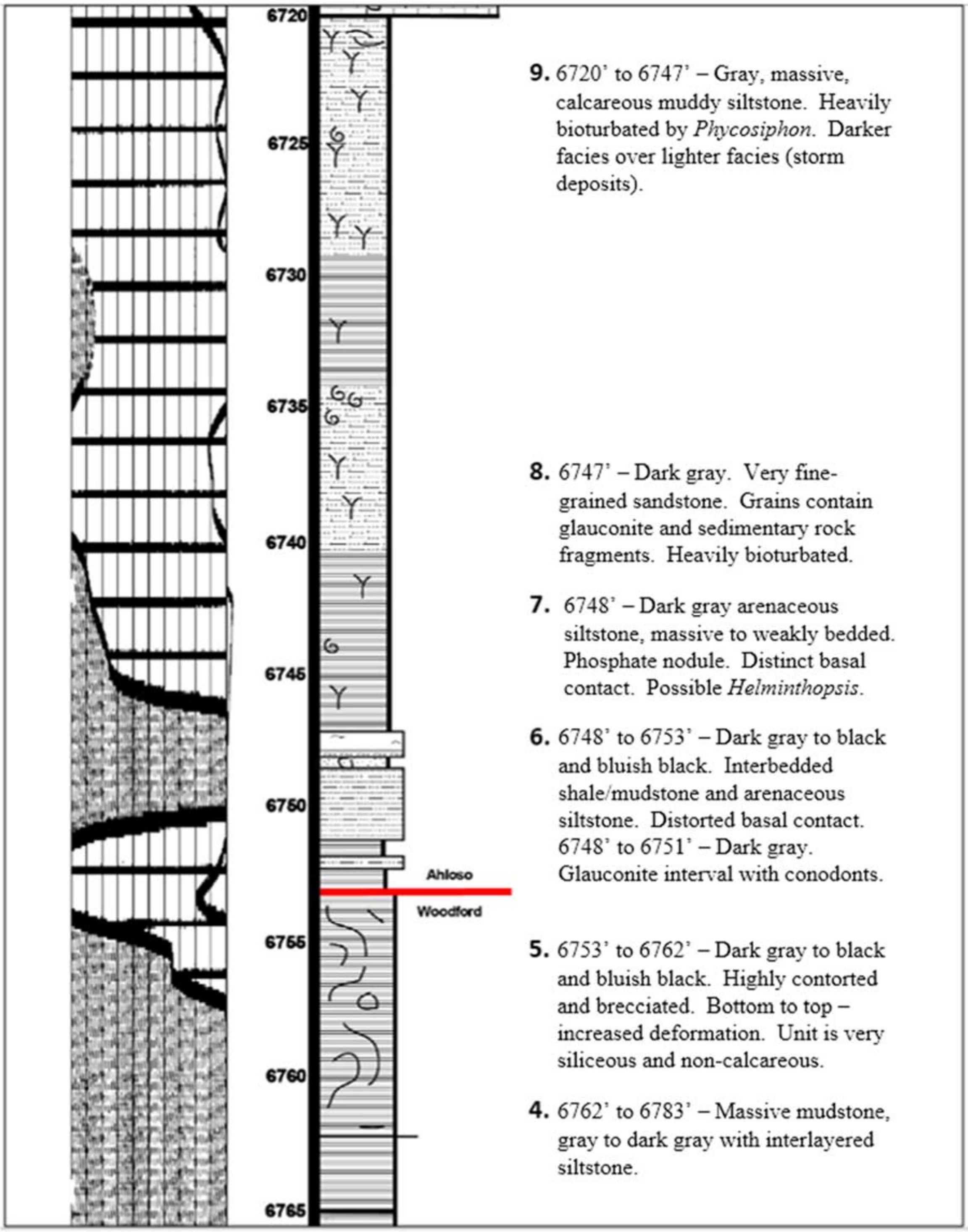


Figure A1.3 – Core descriptions of the Devon Energy Corporations Double 5 Ranch #2-10 SWD. Woodford Shale depth 6765 to 6753 feet. Caney Shale (Ahloso Member) 6753 to 6720 feet.

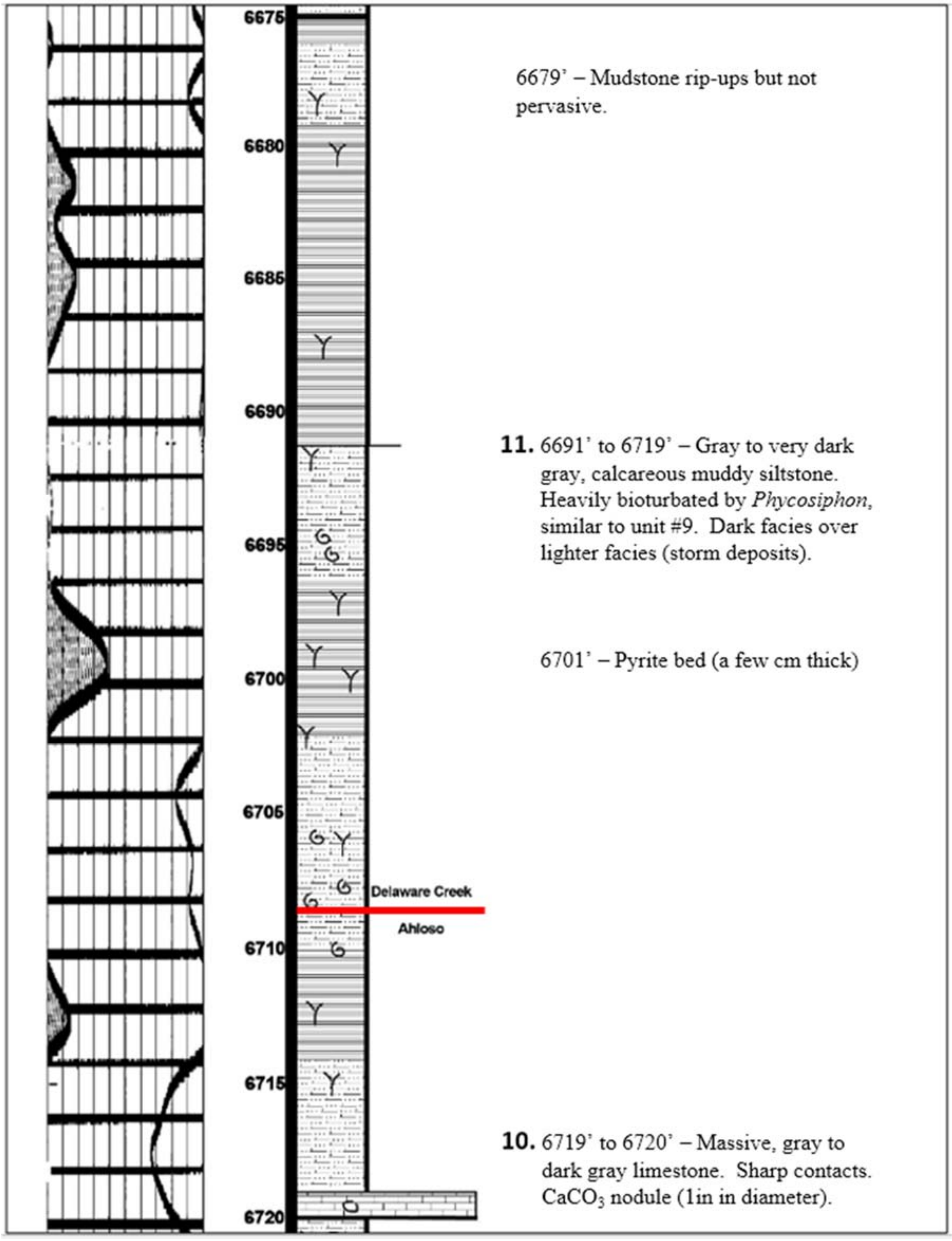


Figure A1.4 – Core descriptions of the Devon Energy Corporations Double 5 Ranch #2-10 SWD. Ahloso Member 6720 to 6709 feet. Delaware Creek Member, 6709 to 6675 feet.

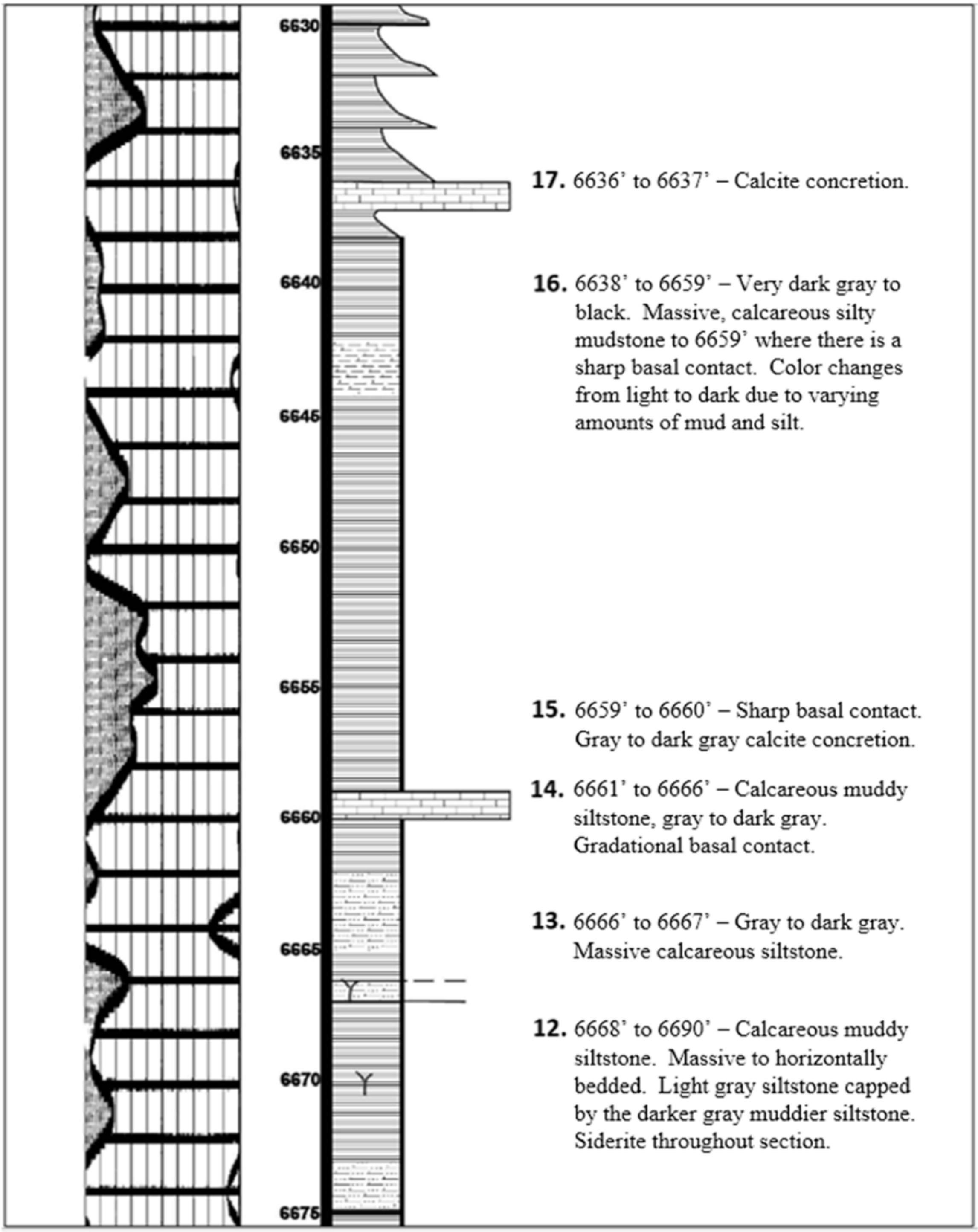


Figure A1.5 – Core descriptions of the Devon Energy Corporations Double 5 Ranch #2-10 SWD. Delaware Creek Member, 6675 to 6630 feet.

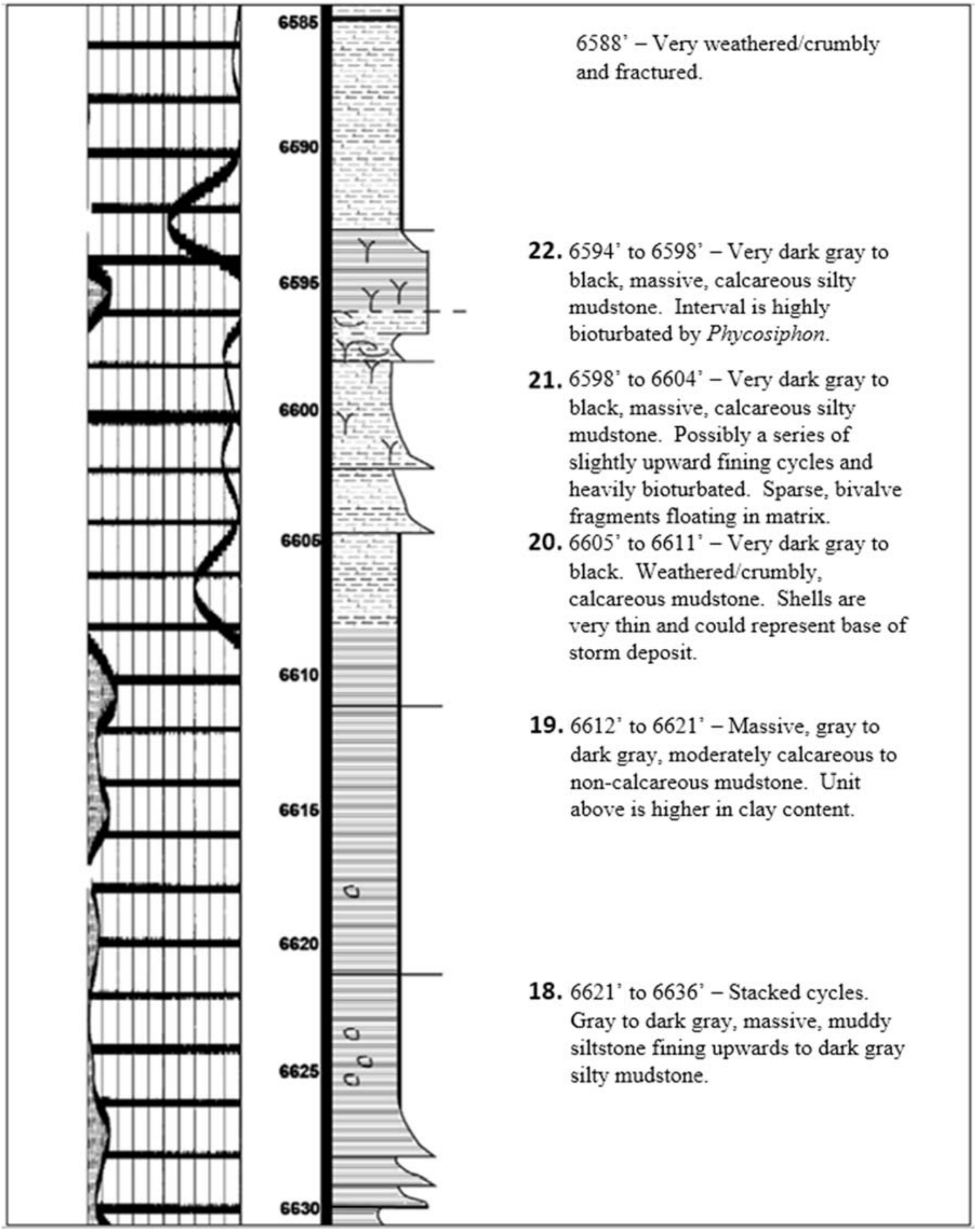


Figure A1.6 – Core descriptions of the Devon Energy Corporations Double 5 Ranch #2-10 SWD. Delaware Creek Member, 6630 to 6585 feet.

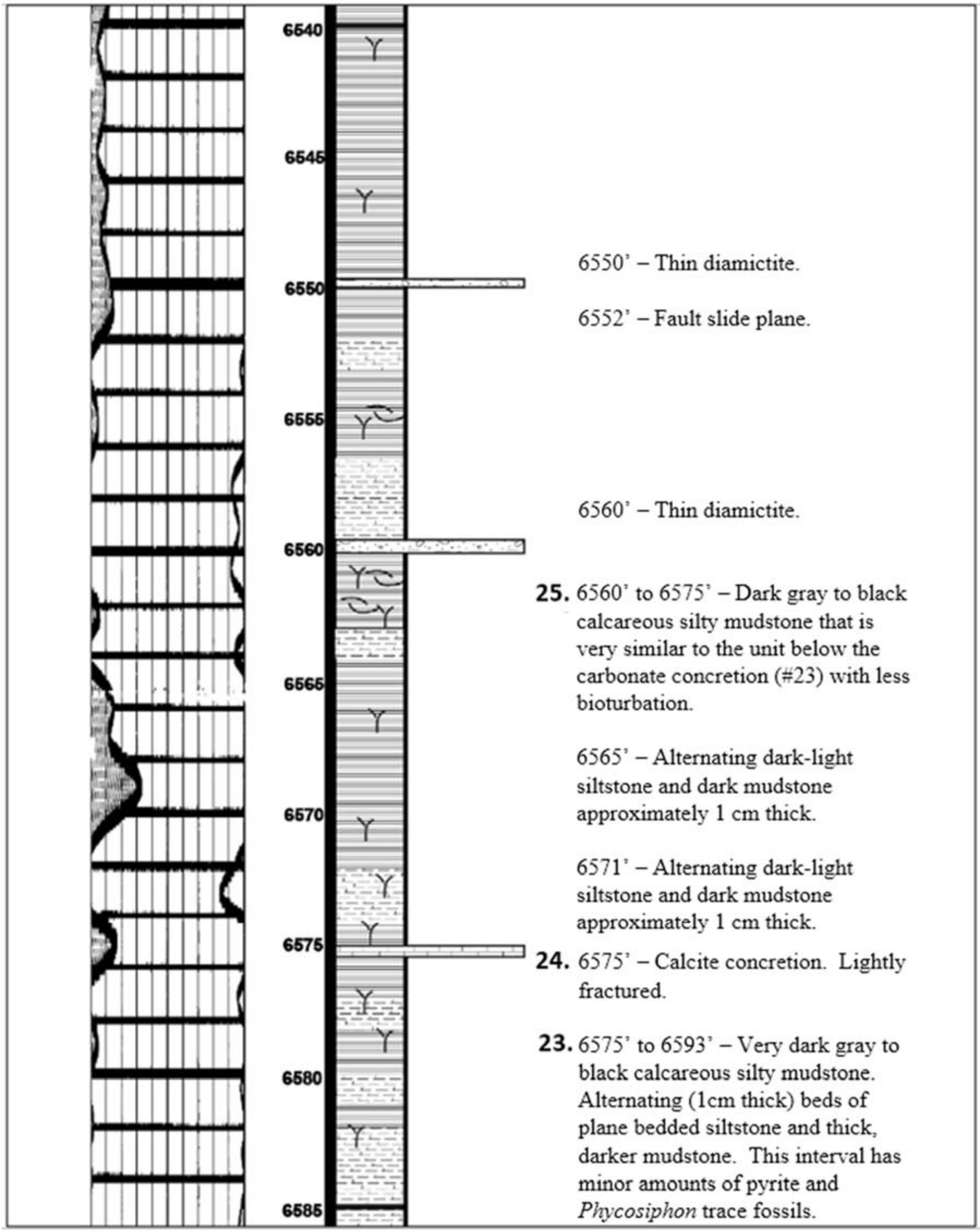


Figure A1.7 – Core descriptions of the Devon Energy Corporations Double 5 Ranch #2-10 SWD. Delaware Creek Member, 6585 to 6540 feet.

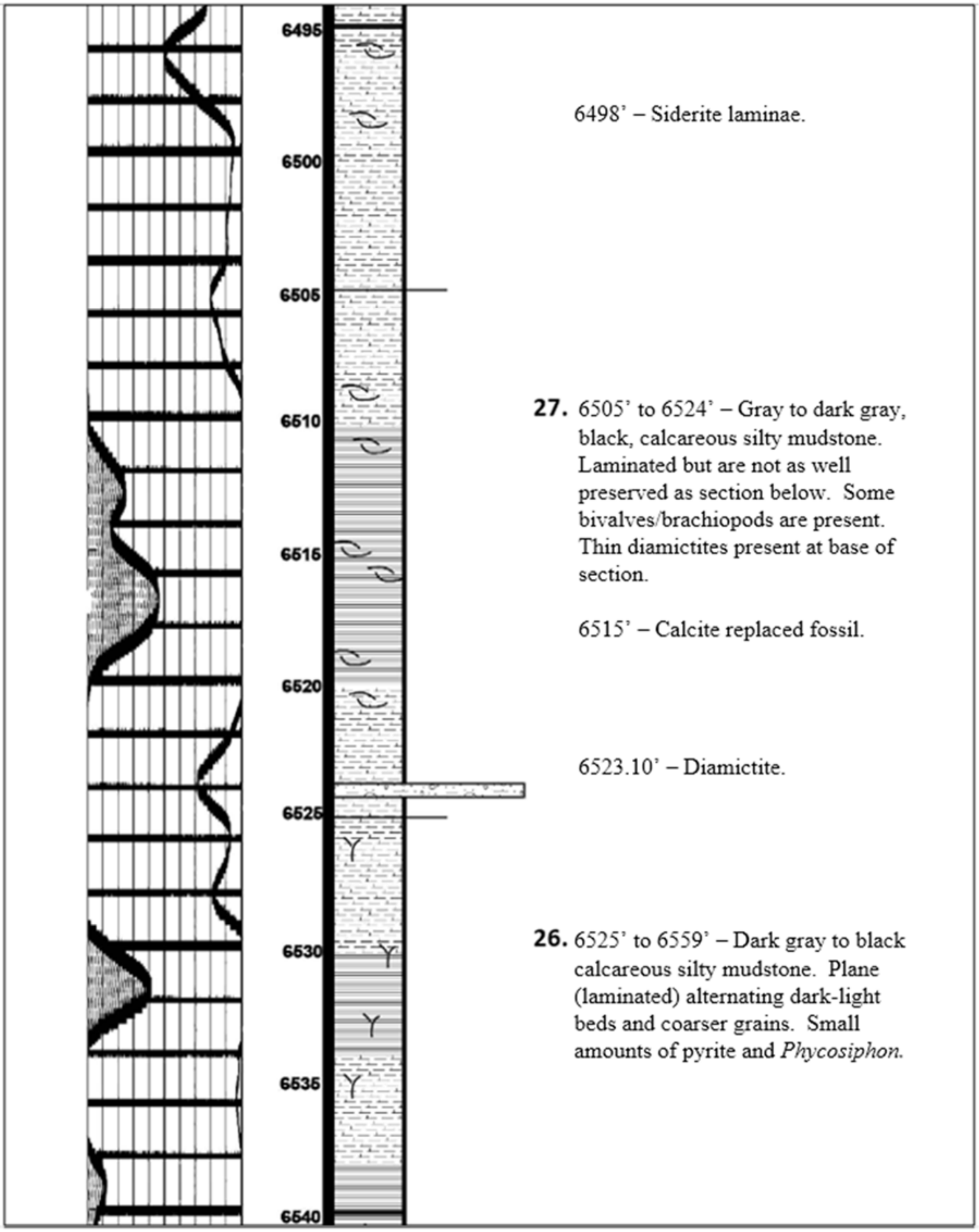


Figure A1.8 – Core descriptions of the Devon Energy Corporations Double 5 Ranch #2-10 SWD. Delaware Creek Member, 6540 to 6495 feet.

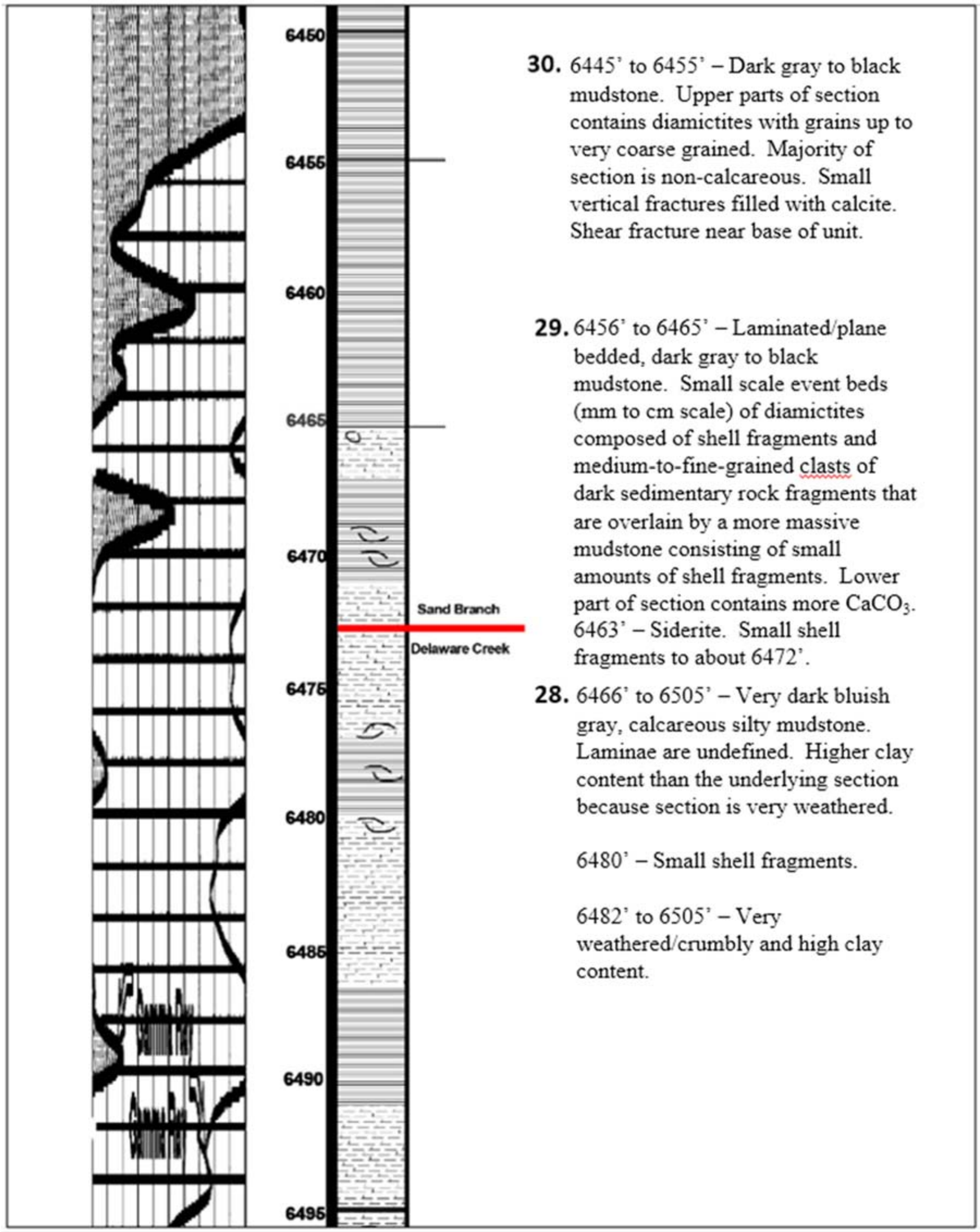


Figure A1.9 – Core descriptions of the Devon Energy Corporations Double 5 Ranch #2-10 SWD. Delaware Creek Member, 6495 to 6473 feet. Sand Branch Member, 6473 to 6540 feet.

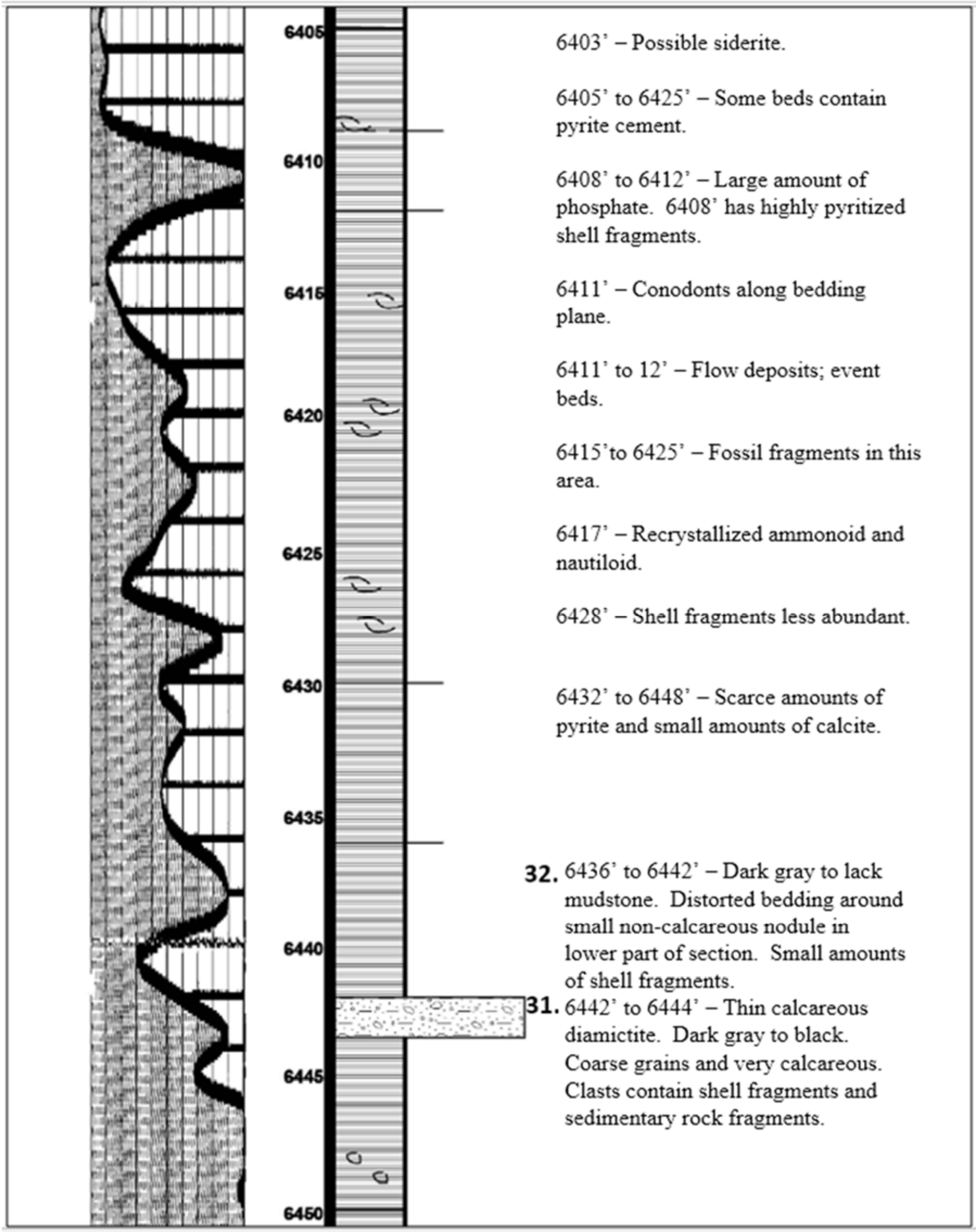


Figure A1.10 – Core descriptions of the Devon Energy Corporations Double 5 Ranch #2-10 SWD. Sand Branch Member, 6540 to 6405 feet.

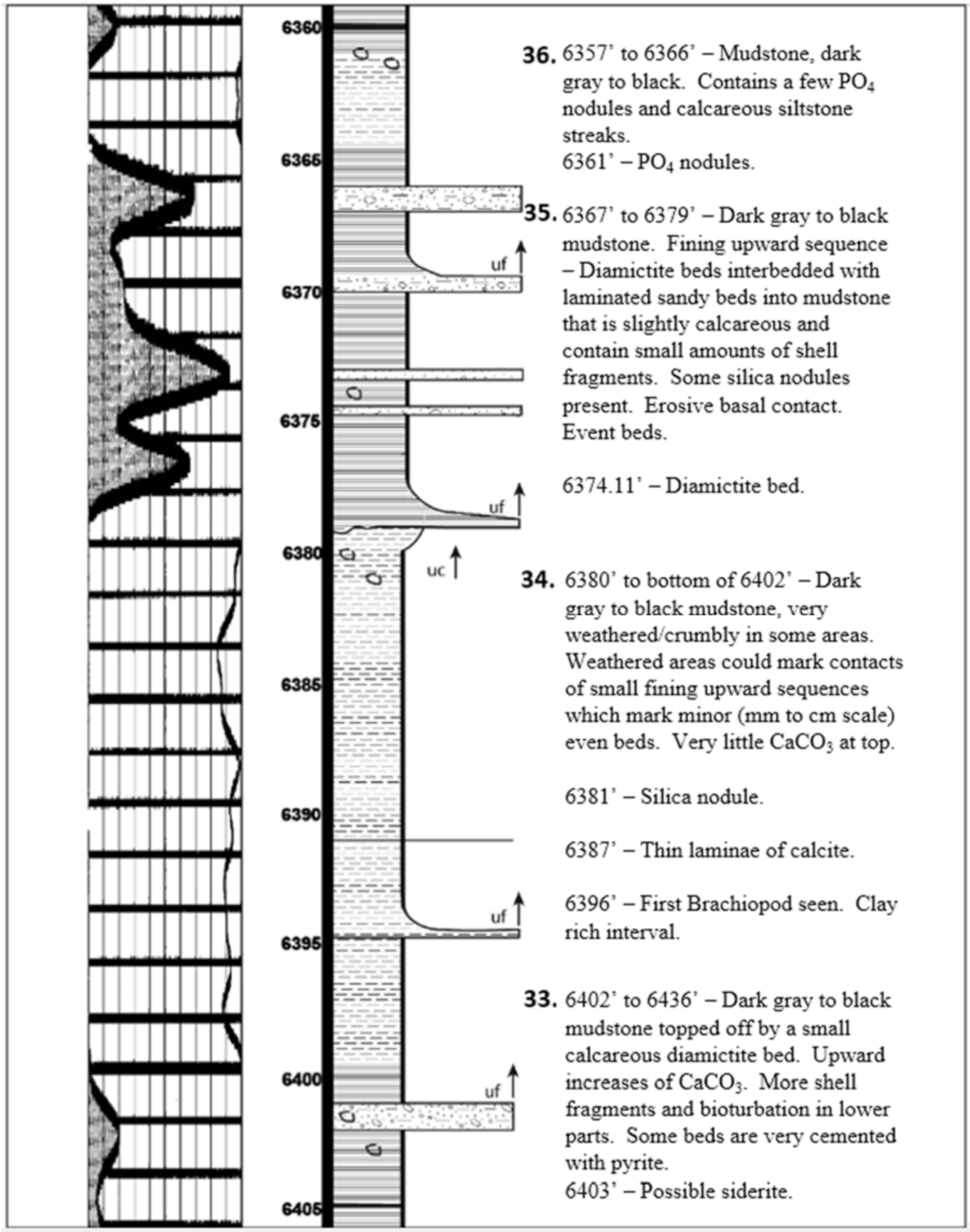


Figure A1.11 – Core descriptions of the Devon Energy Corporations Double 5 Ranch #2-10 SWD. Sand Branch Member, 6405 to 6360 feet.

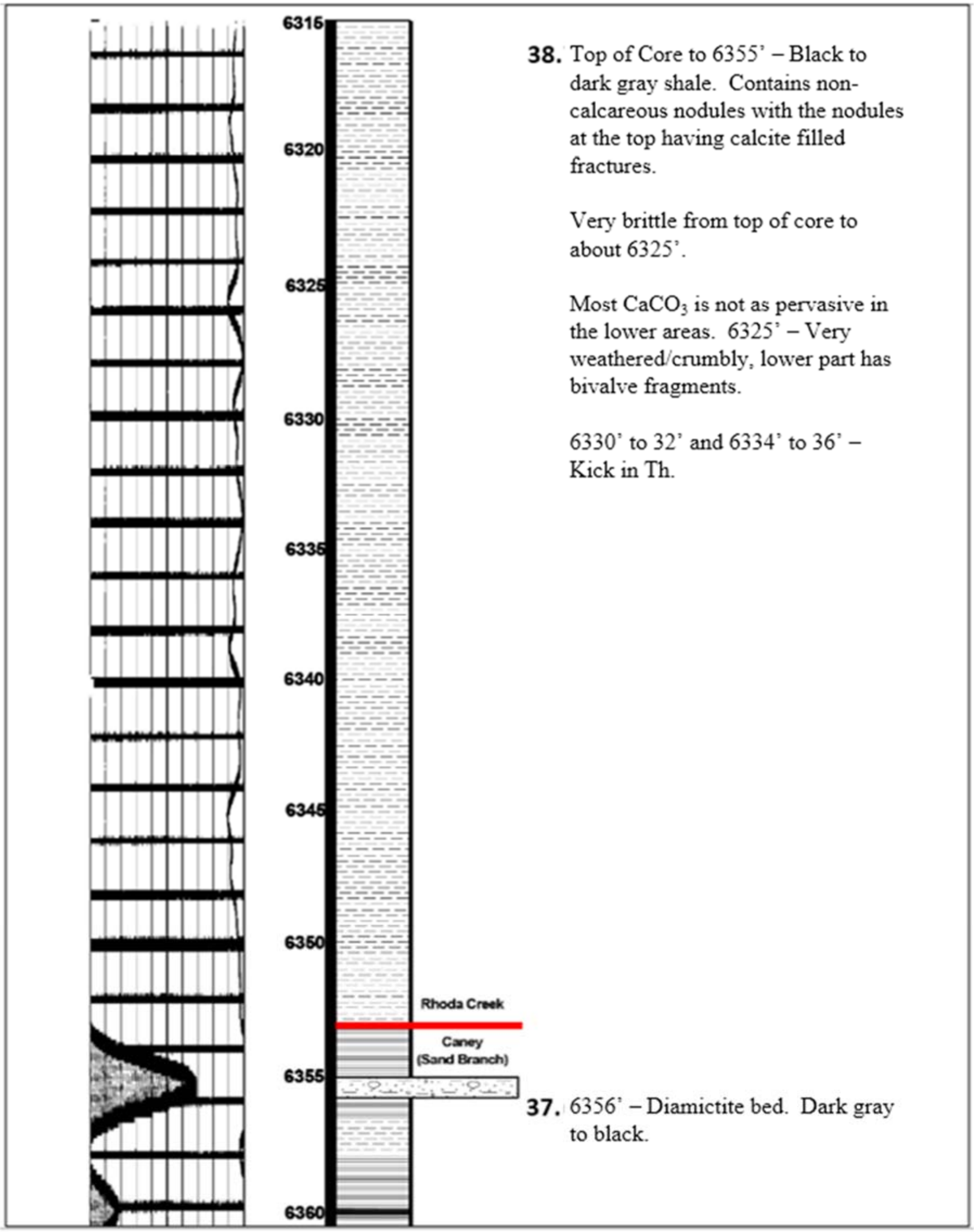
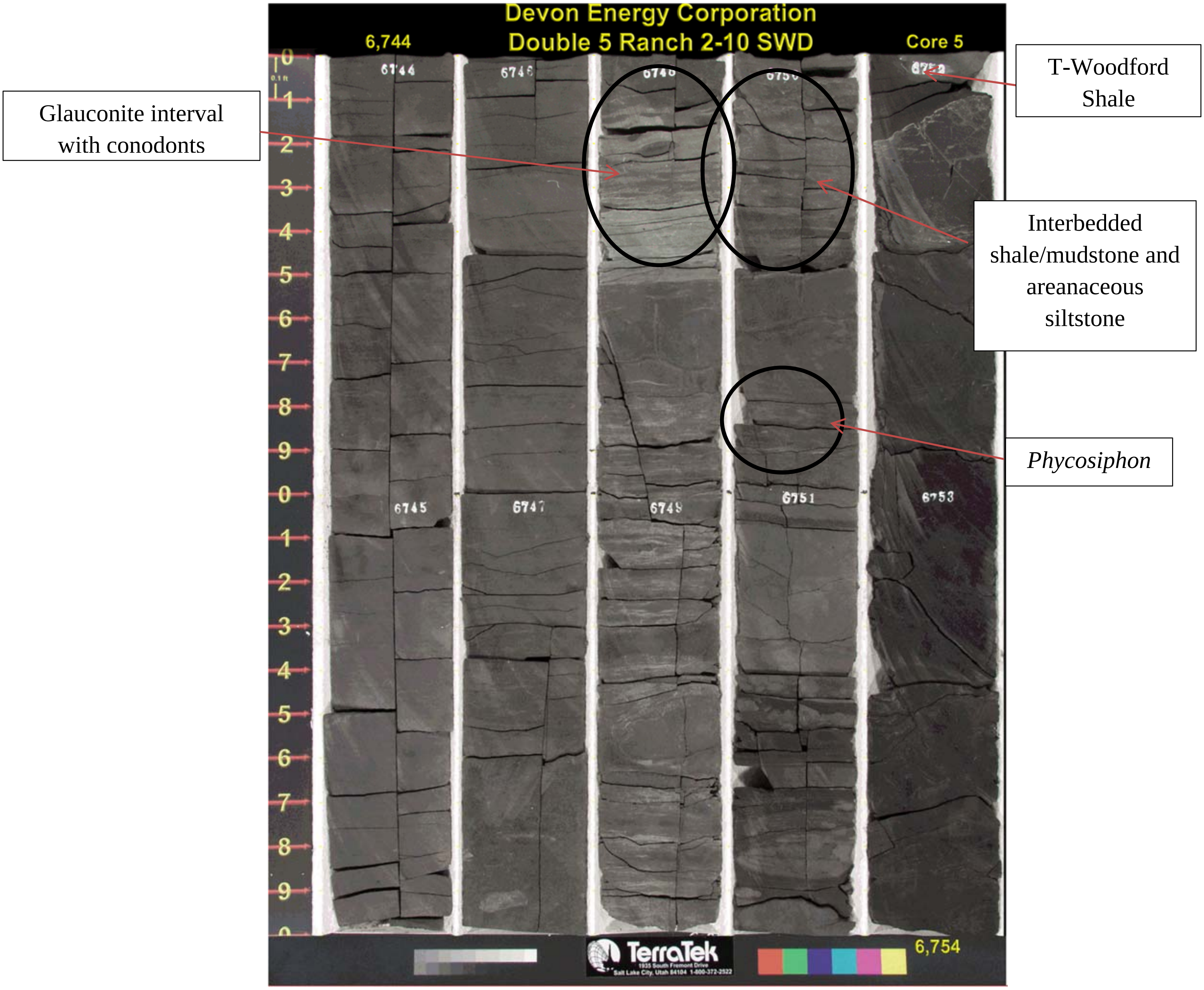


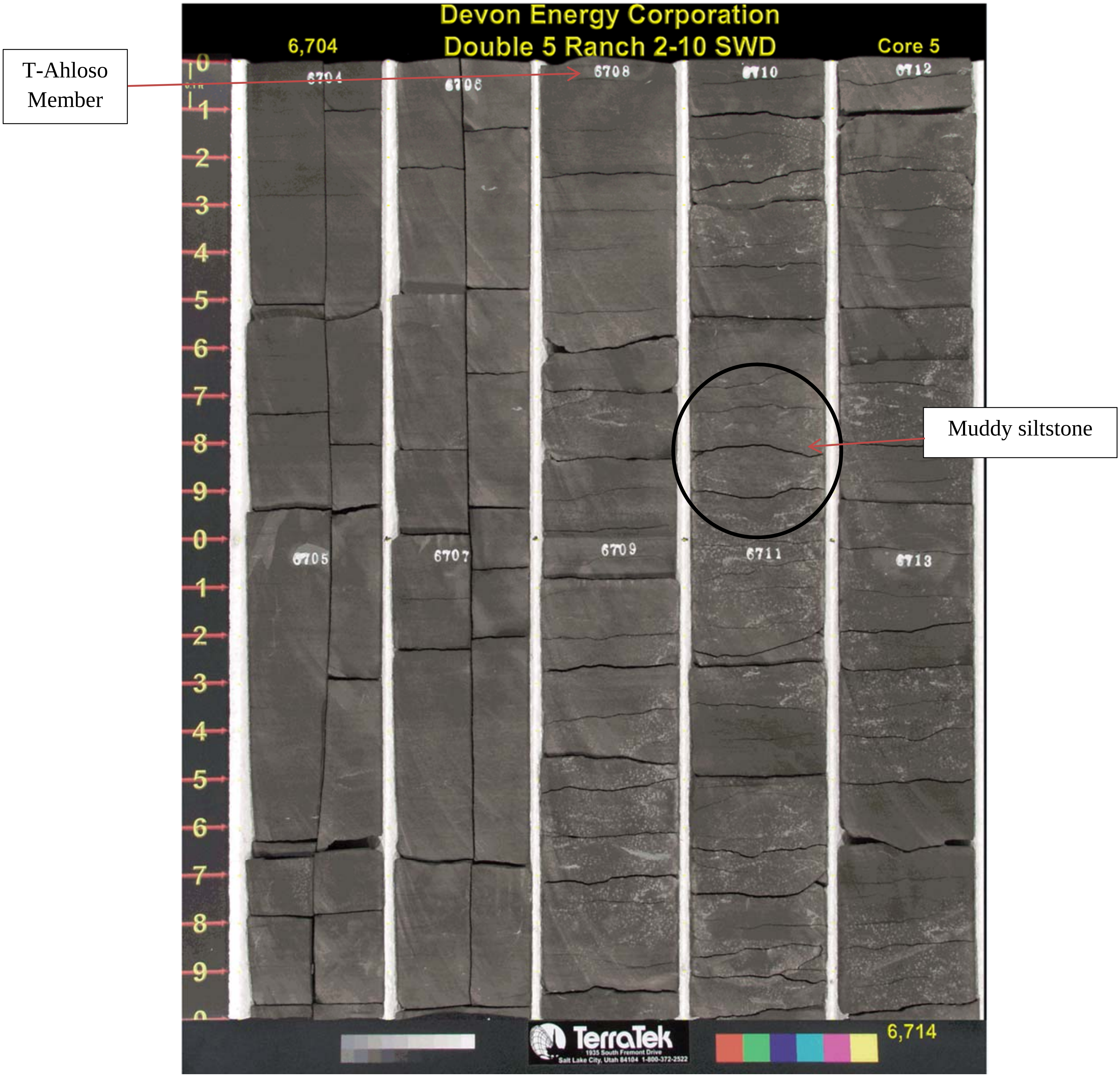
Figure A1.12 – Core descriptions of the Devon Energy Corporations Double 5 Ranch #2-10 SWD. Sand Branch Member, 6360 to 6353 feet. Rhoda Creek, 6353 to 6315 feet.

APPENDIX 2

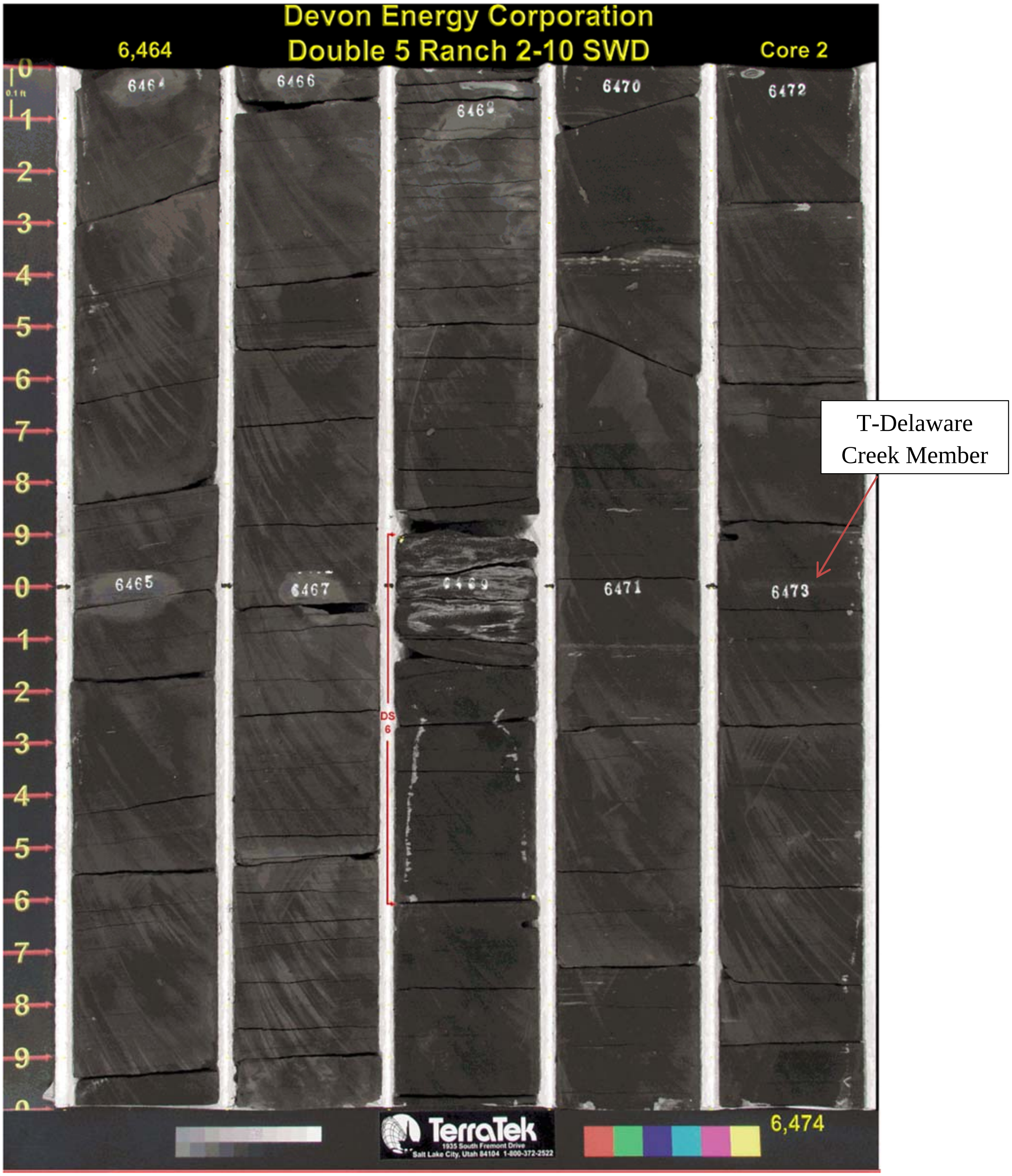
Core photos of the Devon Energy Corporations Double 5 Ranch #2-10 SWD



Core photo A2.1 – Core photo of the Devon Energy Corporations Double 5 Ranch #2-10 SWD. Woodford Shale, 6752 to 6753 feet. Caney Shale (Ahloso Member), 6744 to 6752 feet.

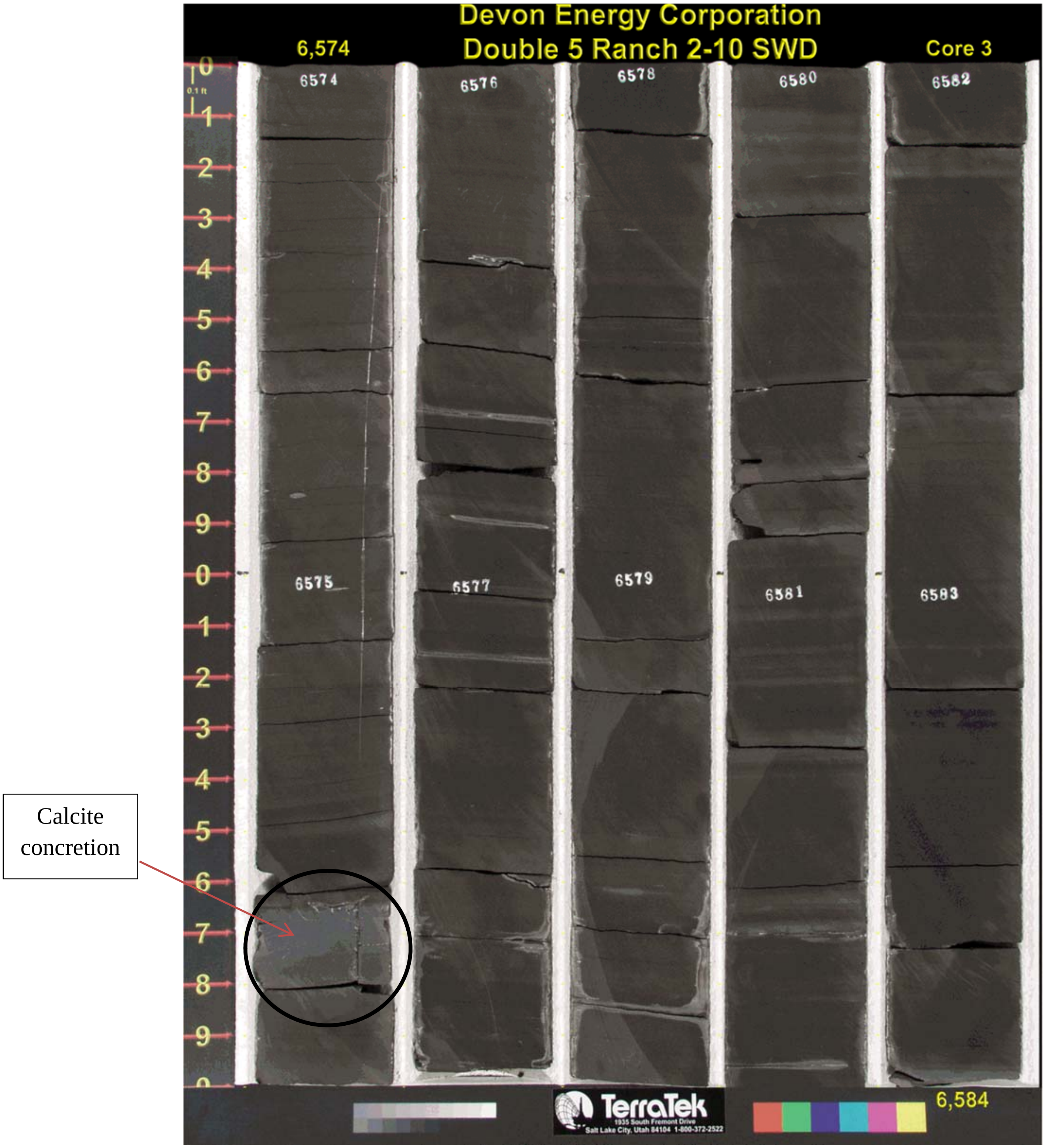


Core photo A2.2 – Core photo of the Devon Energy Corporations Double 5 Ranch #2-10 SWD. Ahloso Member, 6708 to 6713 feet. Delaware Creek Member, 6704 to 6708 feet.

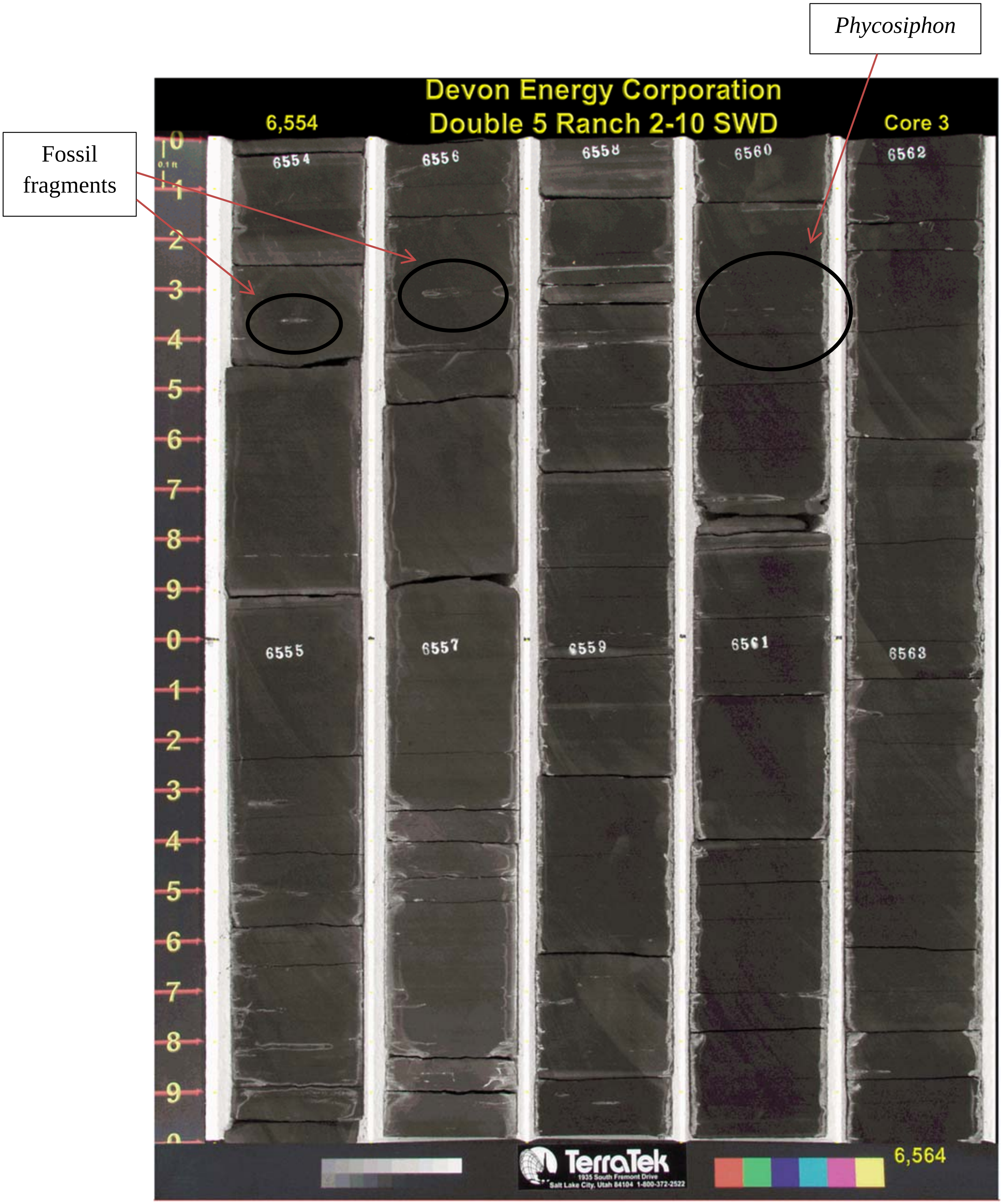


Core photo A2.3 – Core photo of the Devon Energy Corporations Double 5 Ranch #2-10 SWD. Delaware Creek Member, 6743 to 6744 feet. Sand Branch Member, 6464 to 6473 feet.

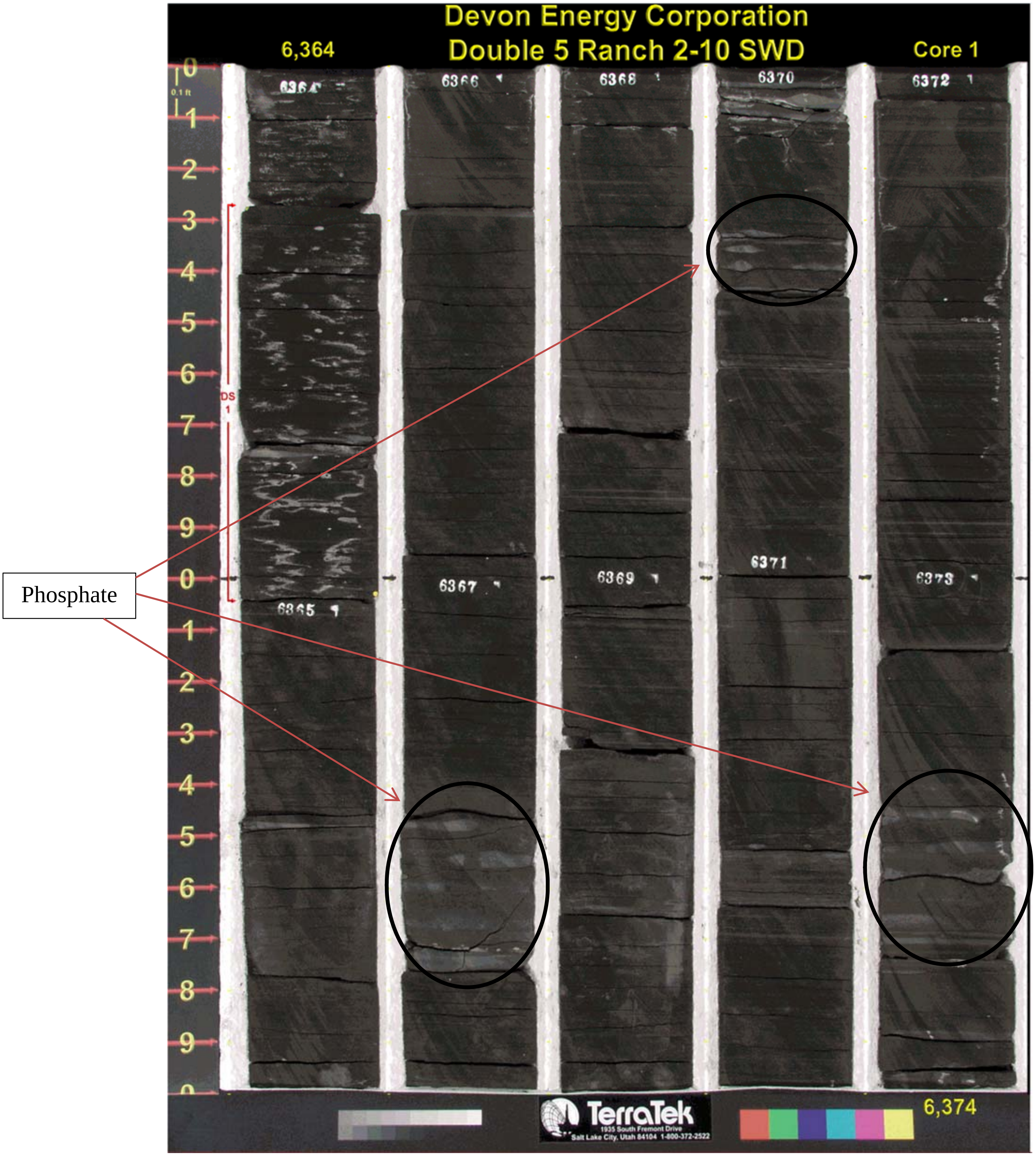
Core photo A2.4 – Core photo of the Devon Energy Corporations Double 5 Ranch #2-10 SWD. Delaware Creek Member, 6514 to 6524 feet.



Core photo A2.5 – Core photo of the Devon Energy Corporations Double 5 Ranch #2-10 SWD. Delaware Creek Member, 6574 to 6584 feet.



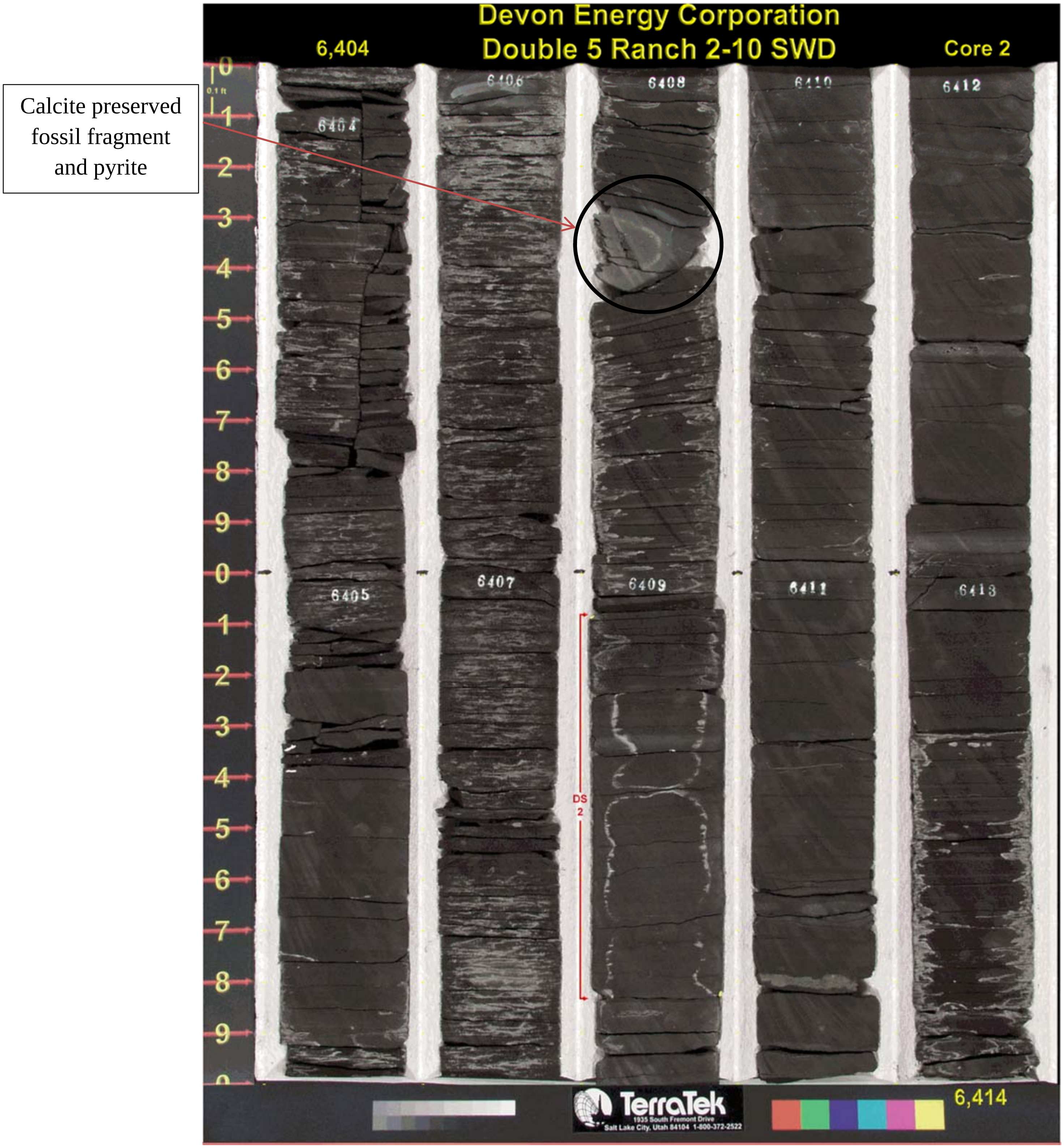
Core photo A2.6 – Core photo of the Devon Energy Corporations Double 5 Ranch #2-10 SWD. Delaware Creek Member, 6554 to 6564 feet.



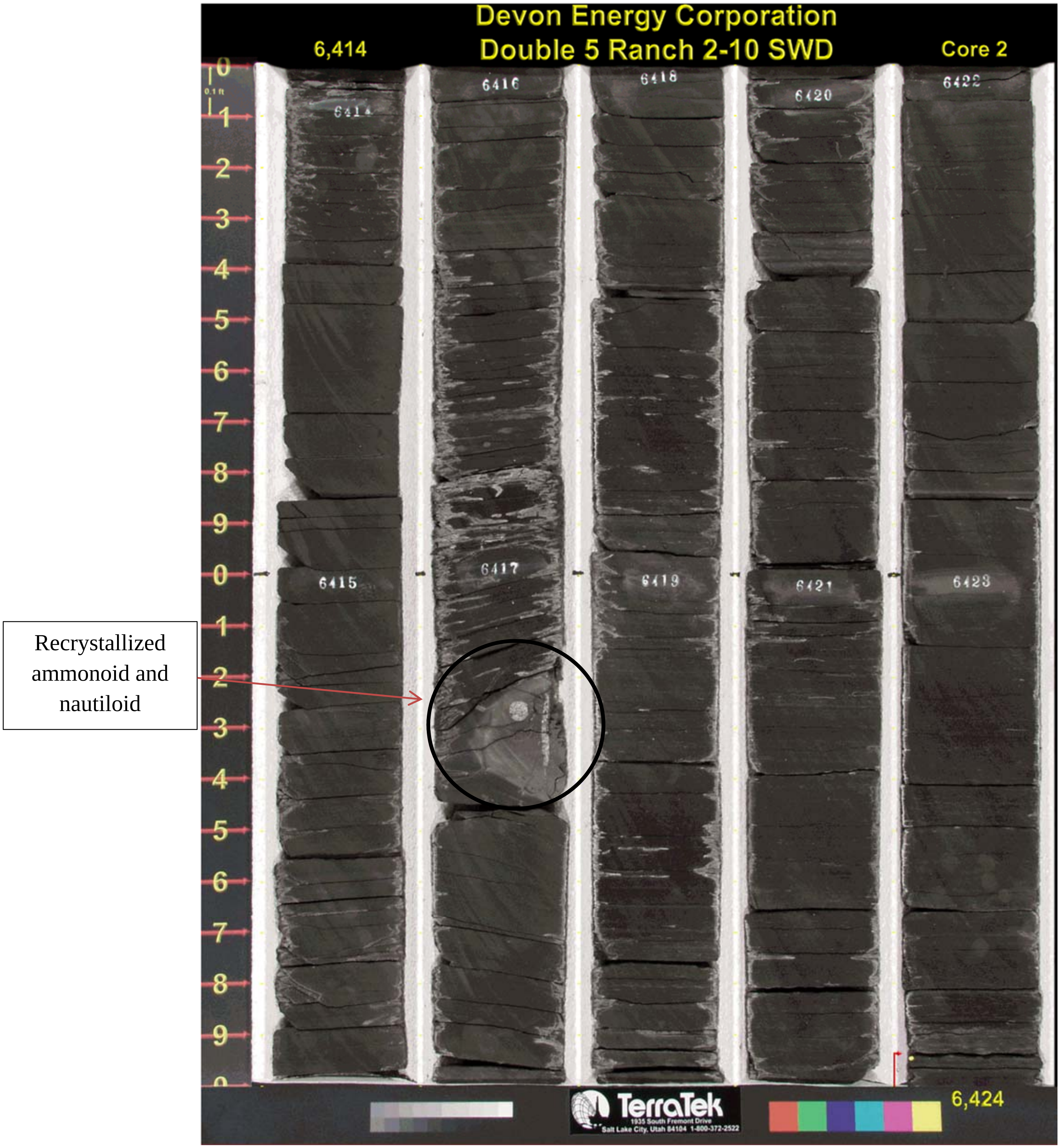
Core photo A2.7 – Core photo of the Devon Energy Corporations Double 5 Ranch #2-10 SWD. Sand Branch Member, 6364 to 6374 feet.

T-Caney Shale (Sand Branch Member)

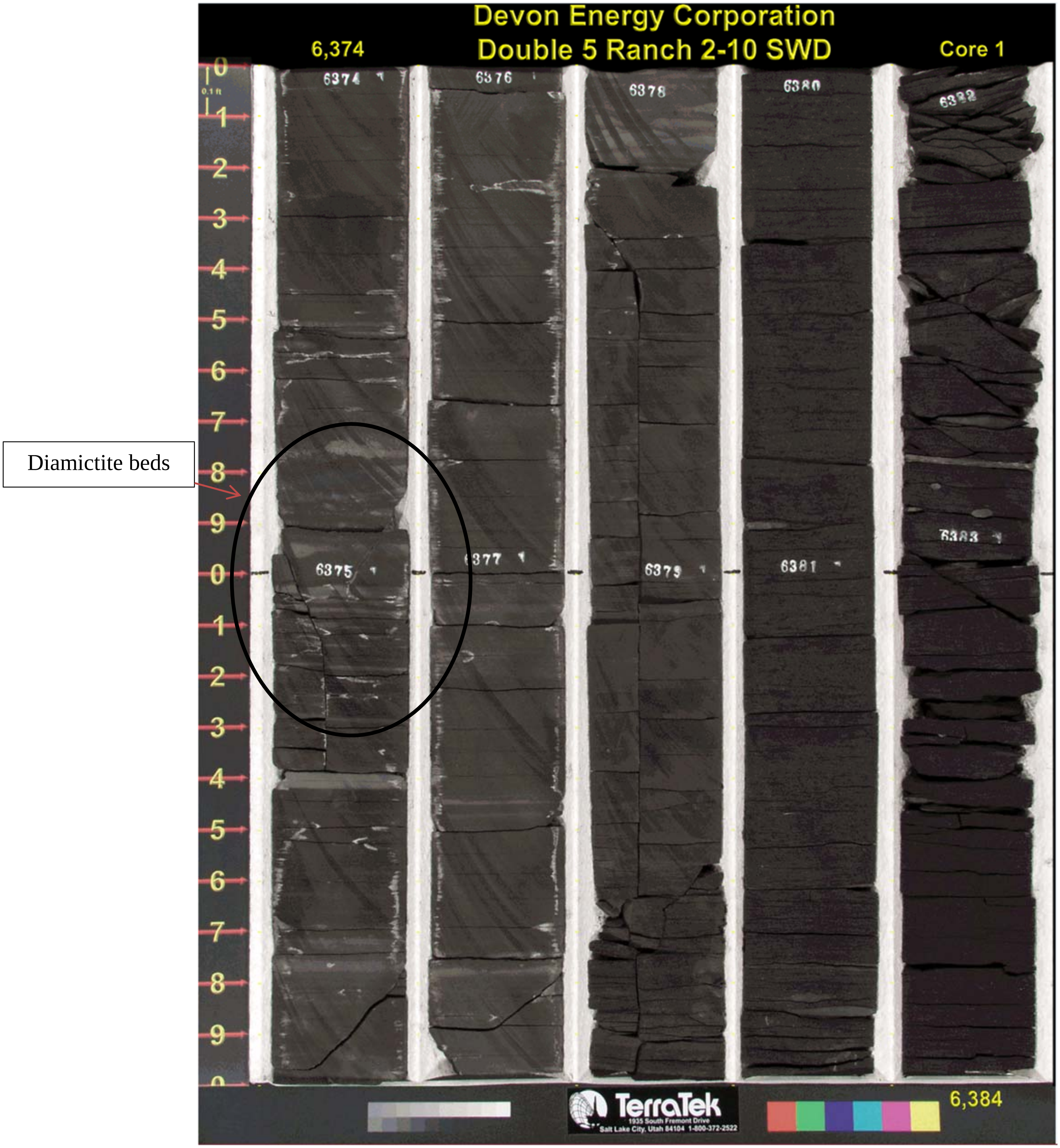
Core photo A2.8 – Core photo of the Devon Energy Corporations Double 5 Ranch #2-10 SWD. Top of Caney Shale (Sand Branch Member), 6354 to 6364 feet.



Core photo A2.9 – Core photo of the Devon Energy Corporations Double 5 Ranch #2-10 SWD. Sand Branch Member, 6404 to 6414 feet.

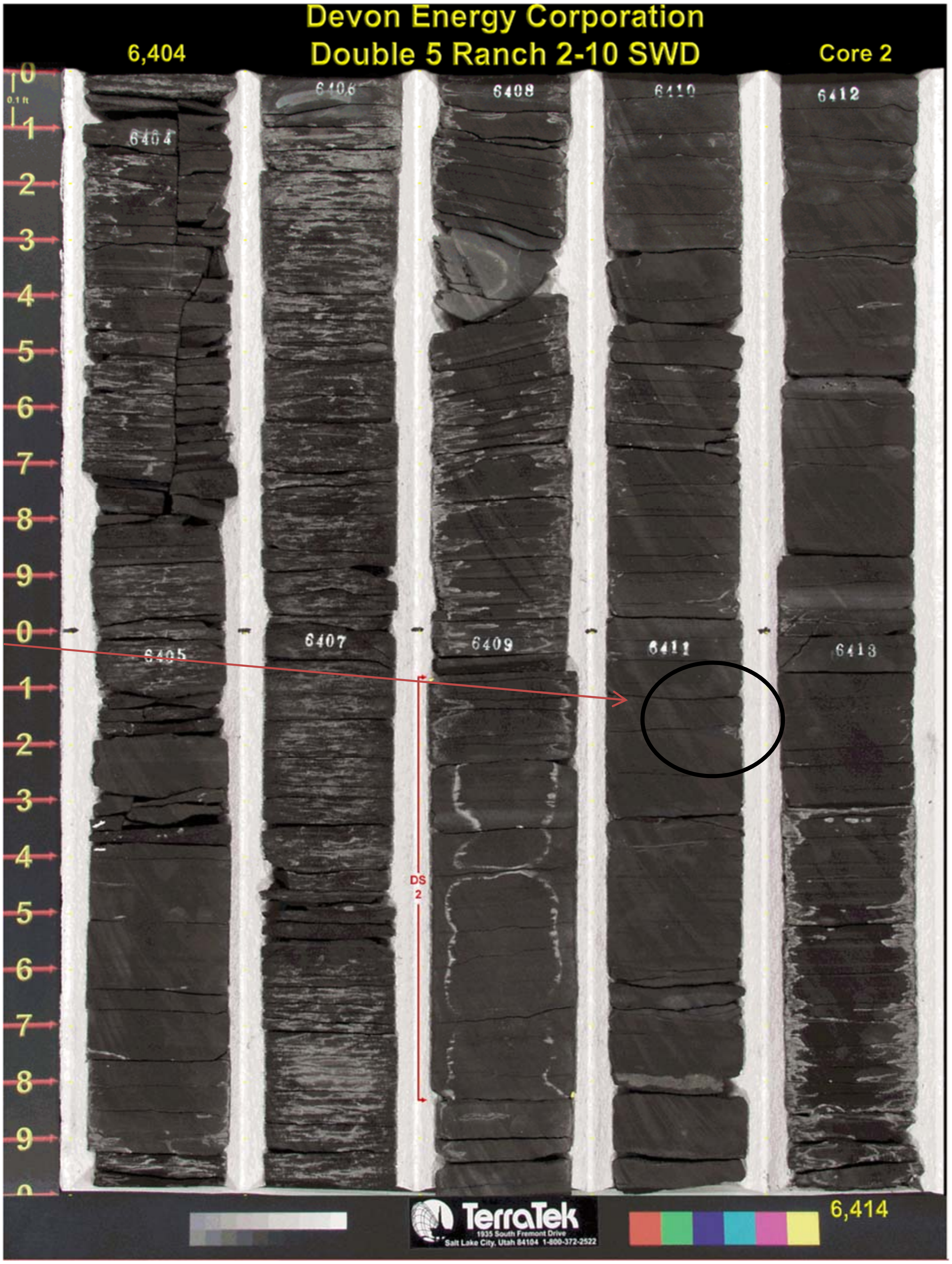


Core photo A2.10 – Core photo of the Devon Energy Corporations Double 5 Ranch #2-10 SWD. Sand Branch Member, 6414 to 6424 feet.



Core photo A2.11 – Core photo of the Devon Energy Corporations Double 5 Ranch #2-10 SWD. Sand Branch Member, 6374 to 6384 feet.

Conodonts along bedding plane



Core photo A2.11 – Core photo of the Devon Energy Corporations Double 5 Ranch #2-10 SWD. Sand Branch Member, 6404 to 6414 feet.

APPENDIX 3

Regional cross-sections A-A' to J-J'

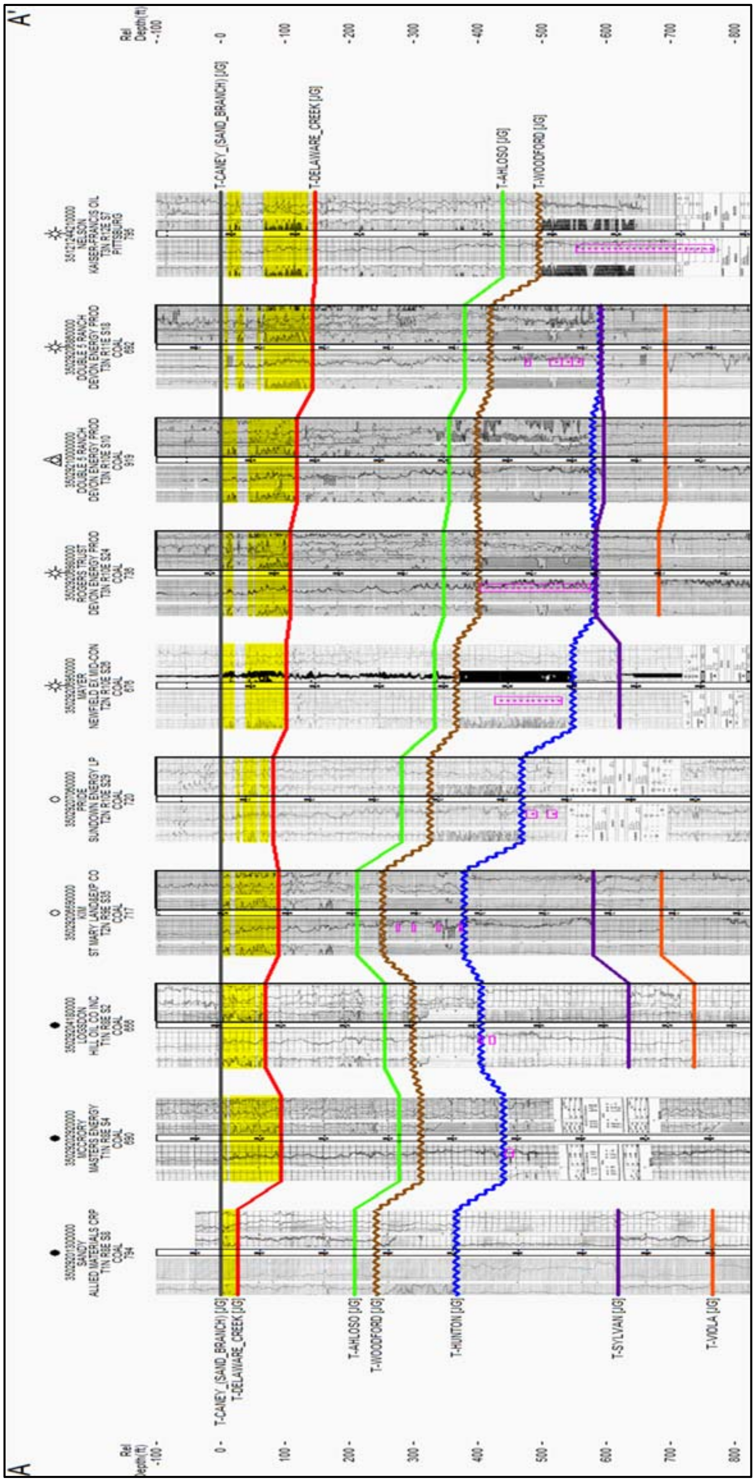


Figure A3.1 - Regional cross-section A-A'. Location is shown in Figure 17.

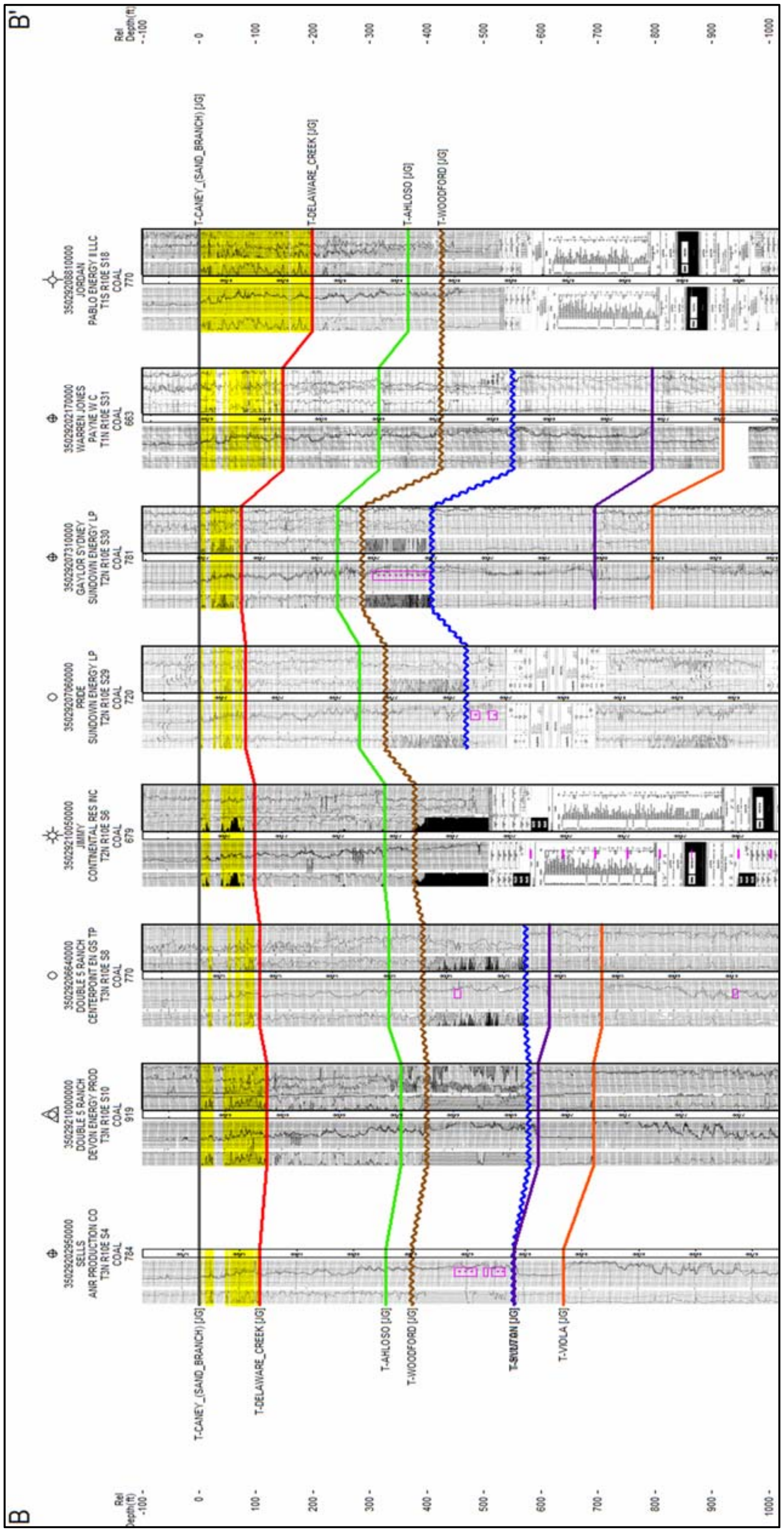


Figure A3.2 - Regional cross-section B-B'. Location is shown in Figure 17.

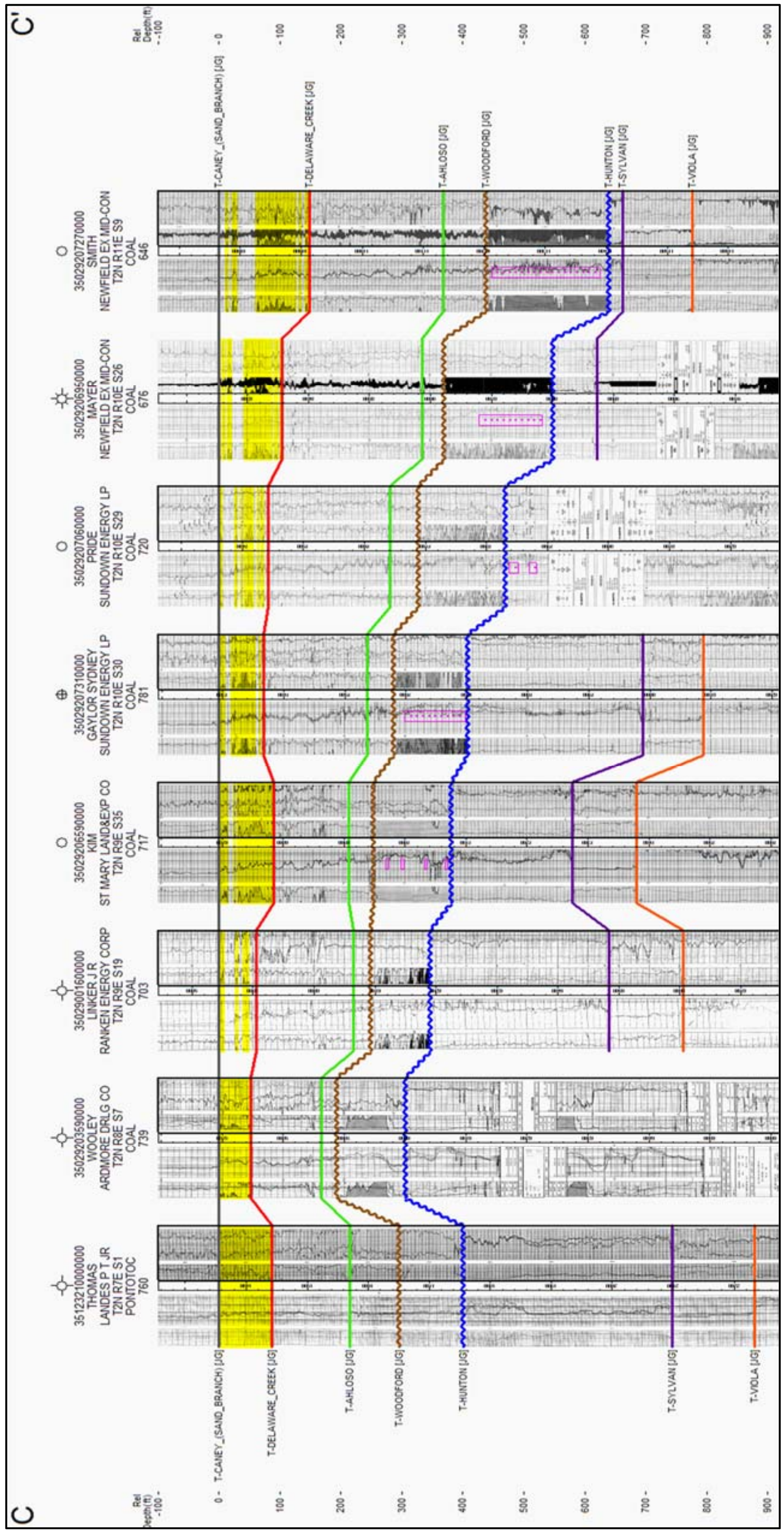


Figure A3.3 - Regional cross-section C-C'. Location is shown in Figure 17.

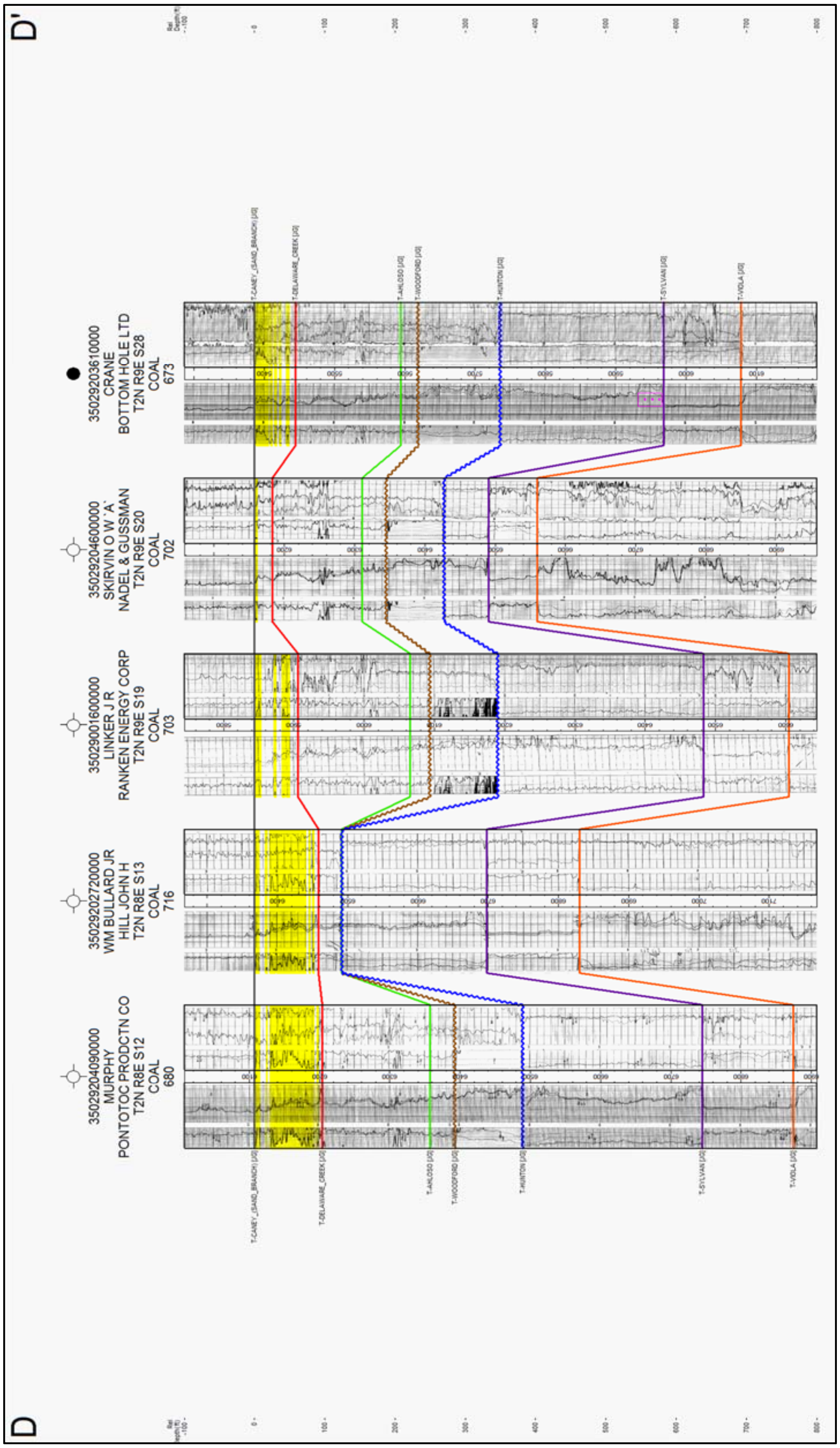


Figure A3.4 - Regional cross-section D-D'. Location is shown in Figure 17.

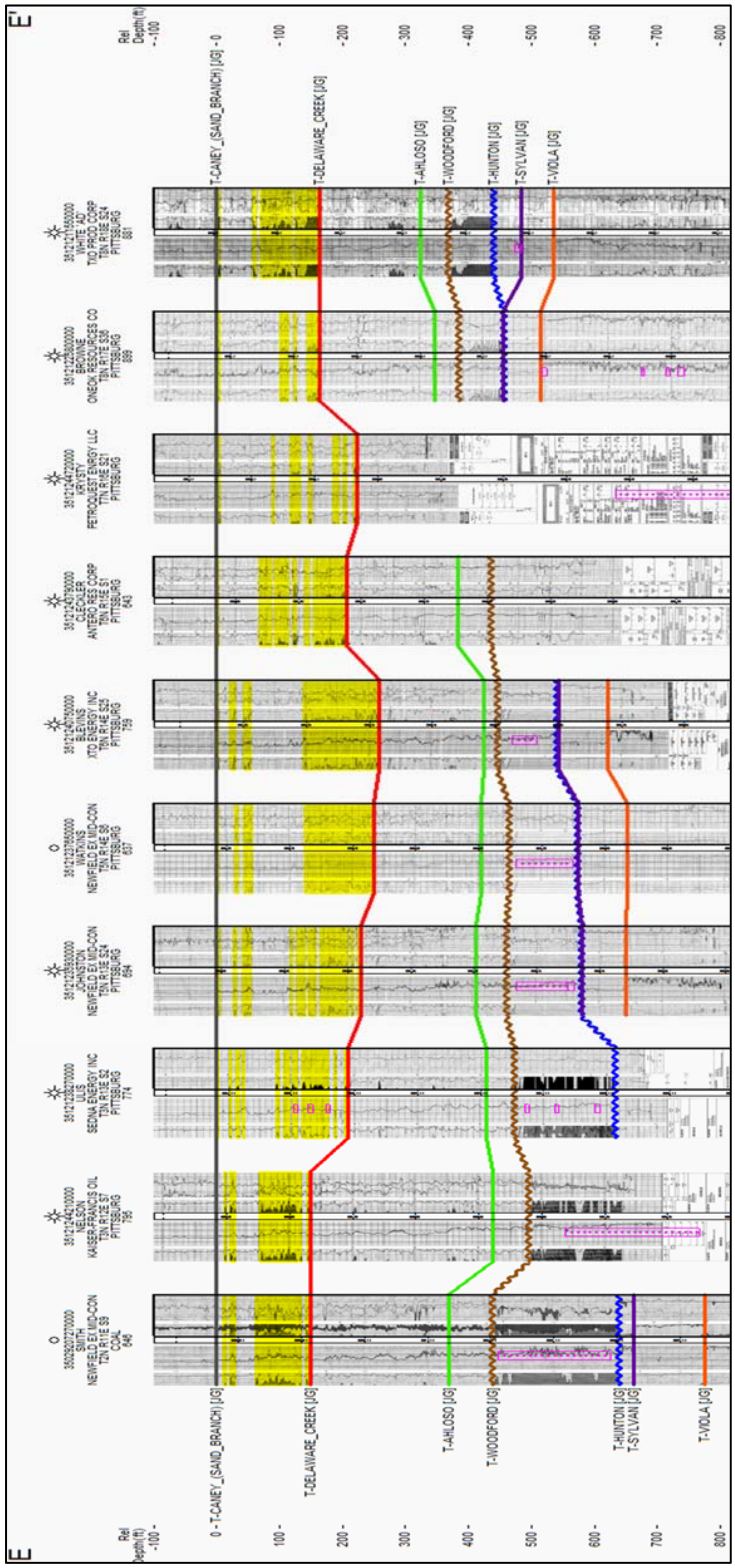


Figure A3.5 - Regional cross-section E-E'. Location is shown in Figure 17.

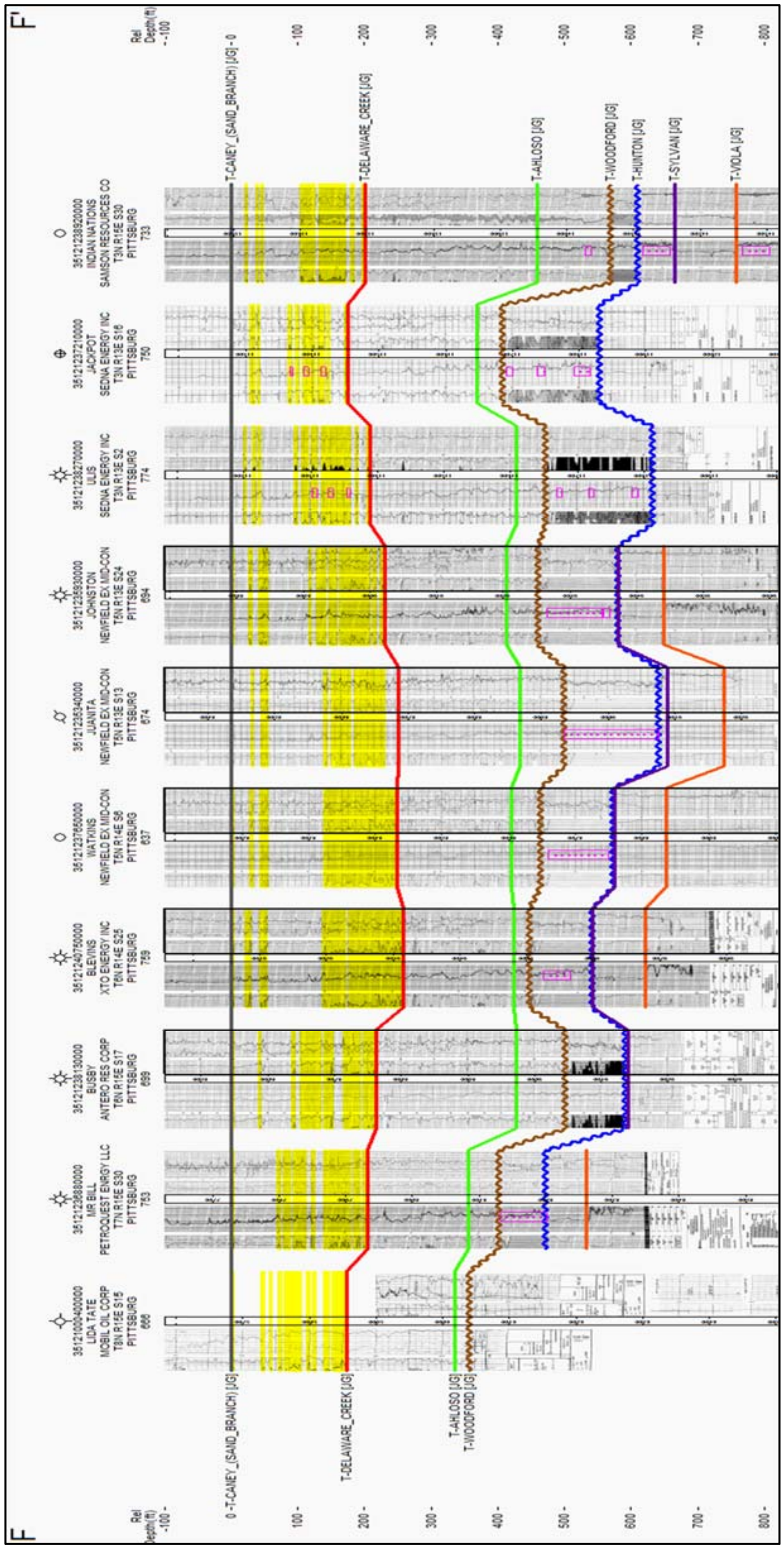


Figure A3.6 - Regional cross-section F-F'. Location is shown in Figure 17.

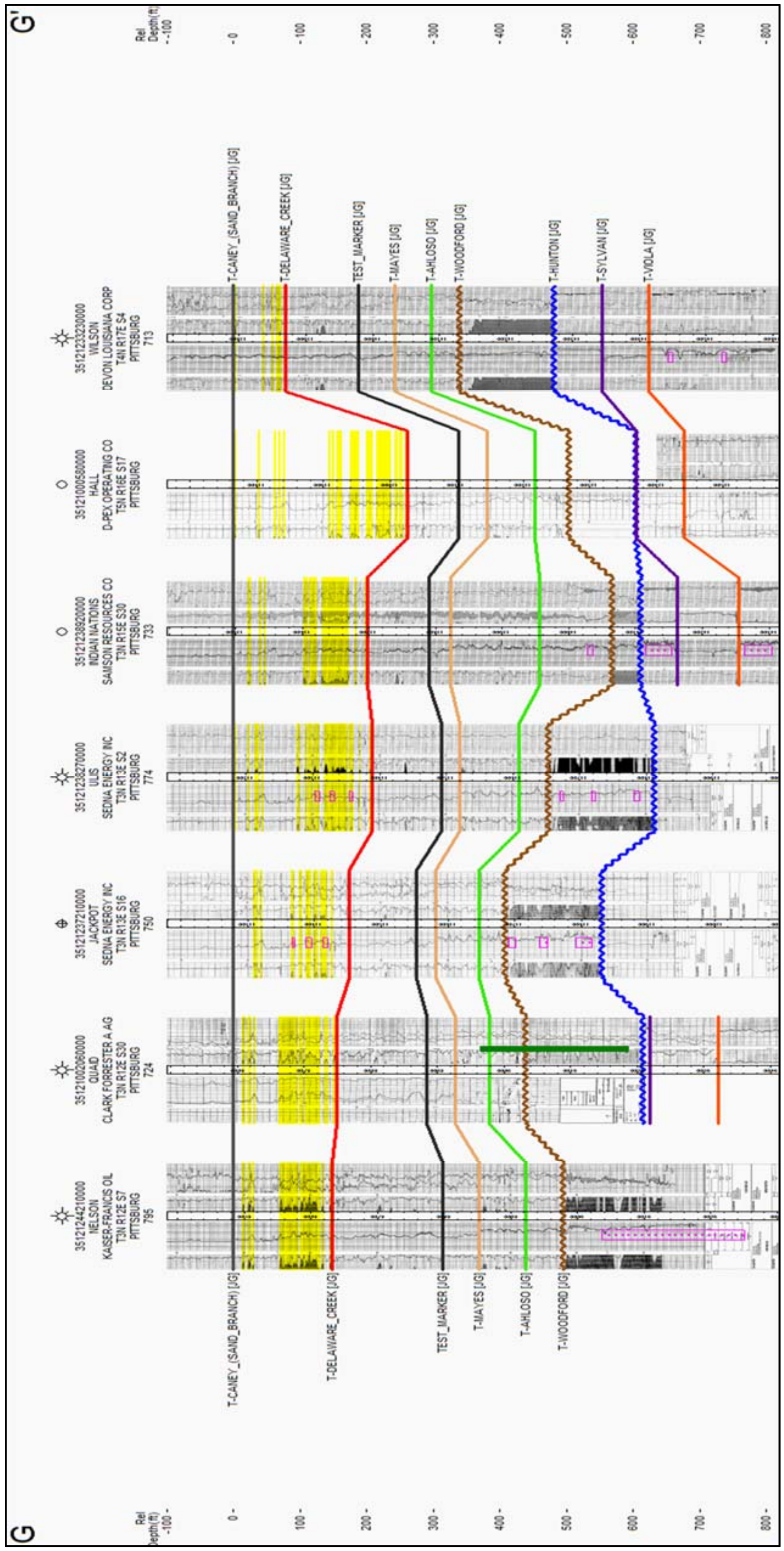


Figure A3.7 - Regional cross-section G-G'. Location is shown in Figure 17.

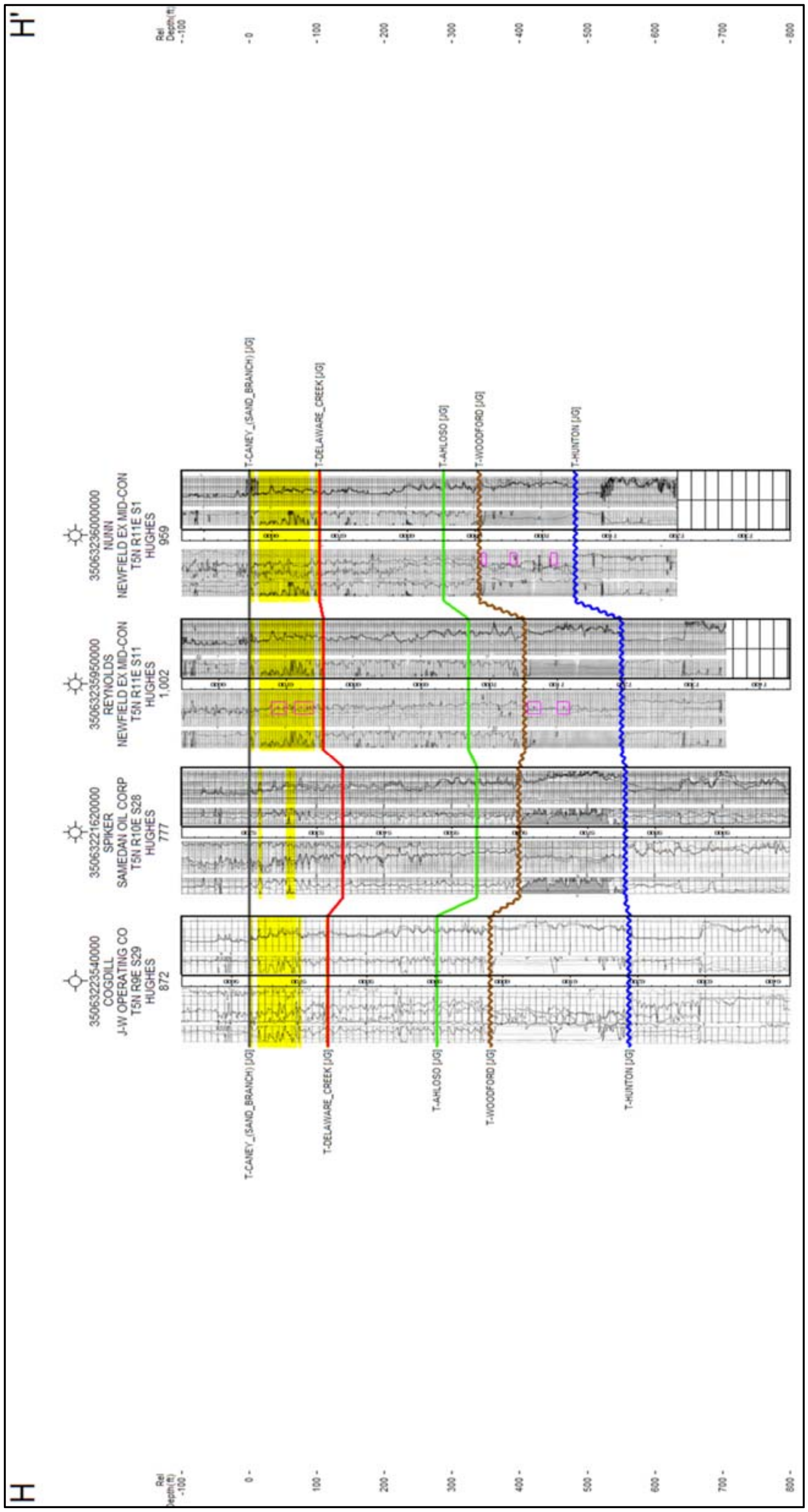


Figure A3.8 - Regional cross-section H-H'. Location is shown in Figure 17.

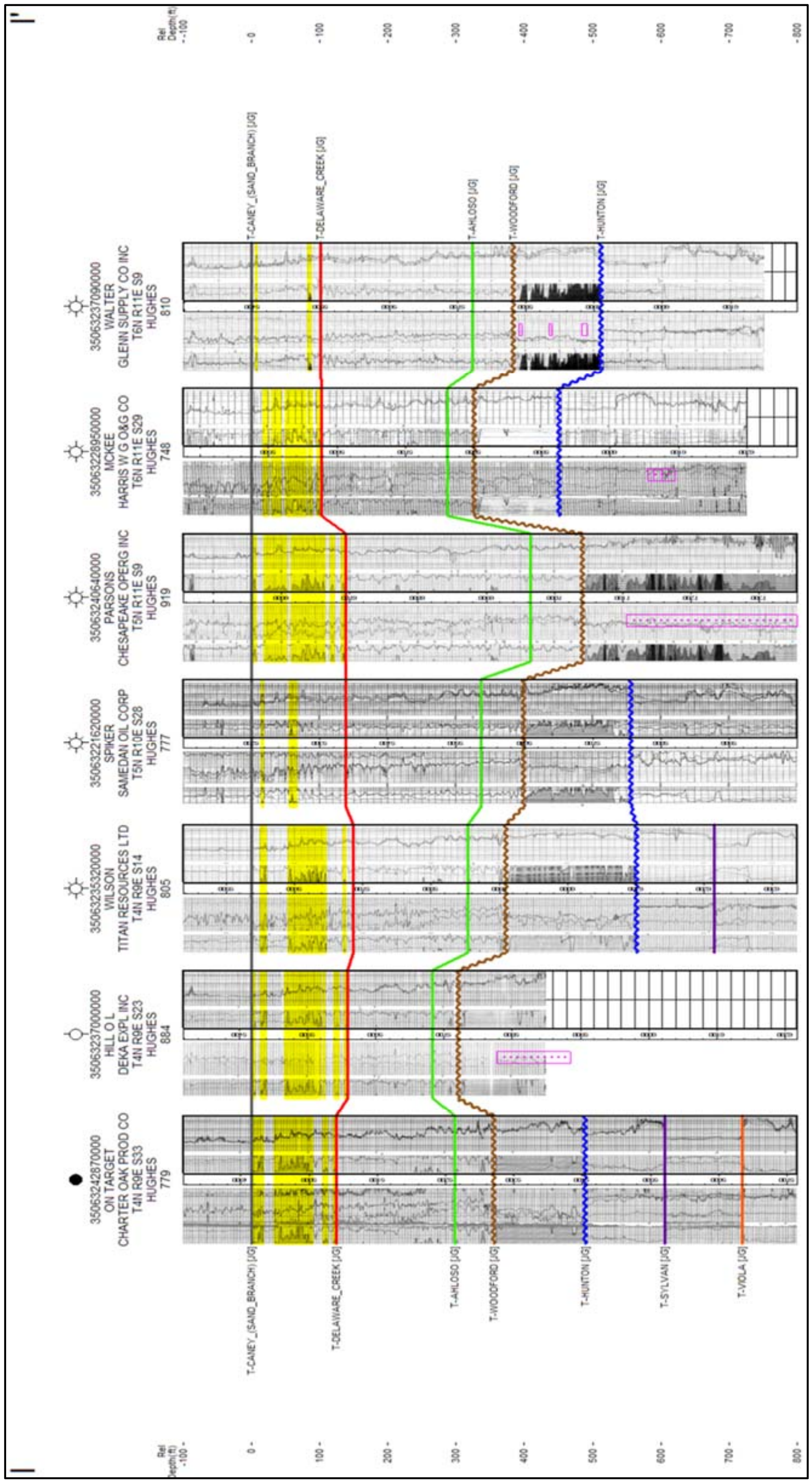


Figure A3.9 - Regional cross-section I-I'. Location is shown in Figure 17.

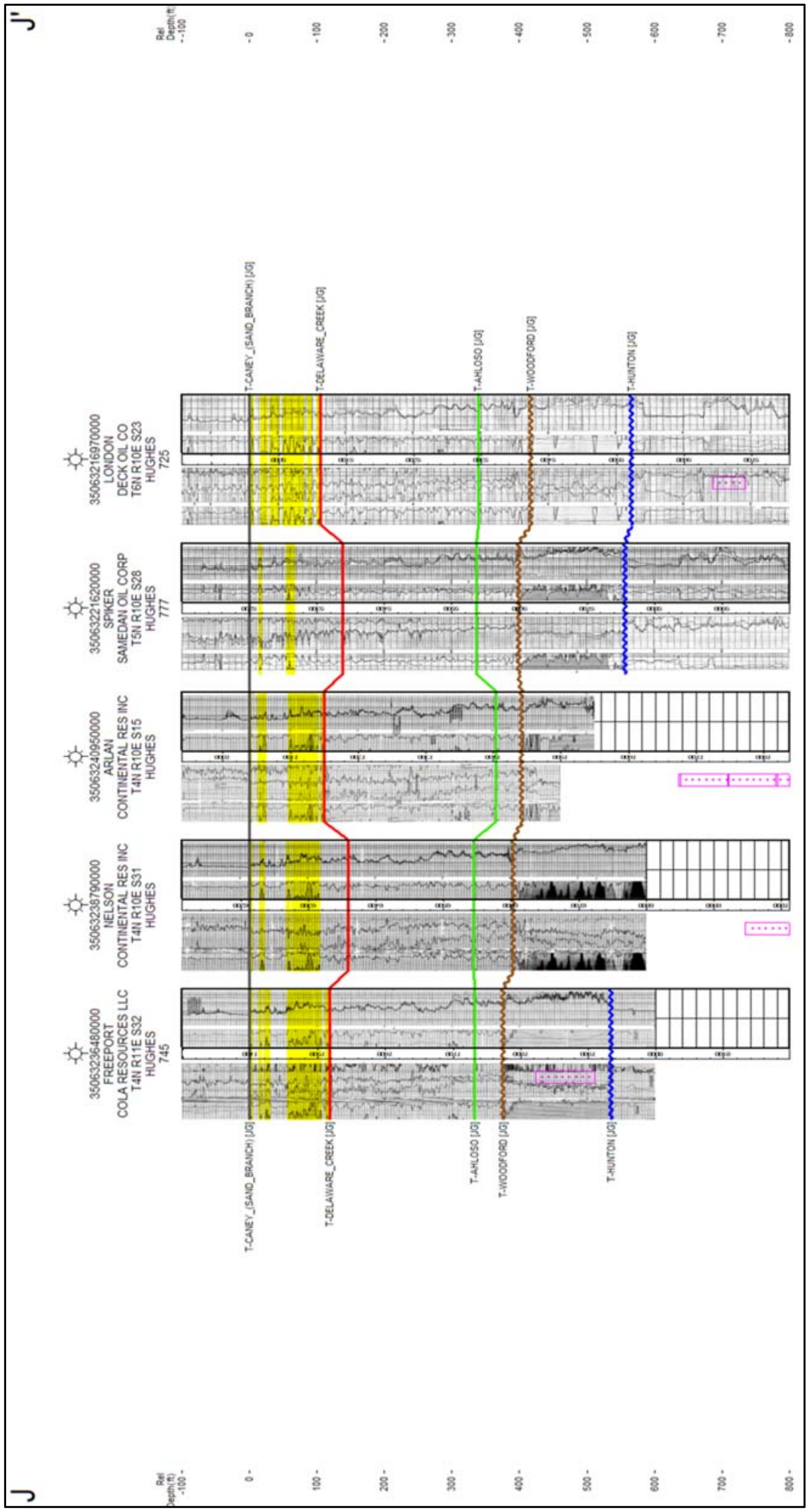


Figure A3.10 - Regional cross-section J-J'. Location is shown in Figure 17.

Table 1

Wells used in study

UWI/API	WELL NAME	WEL LNO	OPERATOR	LEASE	FIELD	COUNTY	STATE	SECTION	TOWNSHIP	RANGE
35121000110000	MULLINS	1	CARTER GRAGG OIL CO	MULLINS	BREWER SOUTH	PITTSBURG	OK	29	4N	14E
35121000230000	FRED MANSCHRICK	1	MAGNOLIA PET CO	FRED MANSCHRICK	UNNAMED	PITTSBURG	OK	28	6N	17E
35121000270000	BROWNE	28-Jan	DAVIS OPERATING CO	BROWNE	UNNAMED	PITTSBURG	OK	28	7N	16E
35121000400000	LIDA TATE	1	MOBIL OIL CORP	LIDA TATE	WILDCAT	PITTSBURG	OK	15	8N	15E
35121000580000	HALL	1	D-PEX OPERATING CO	HALL	WILBURTON	PITTSBURG	OK	17	5N	16E
35121002060000	QUAID	1	CLARK FORRESTER A AG	QUAID	ASHLAND SOUTH	PITTSBURG	OK	30	3N	12E
35121002980000	JEFFREY-CHRISMAN UN	1	SINCLAIR	JEFFREY-CHRISMAN UN	BREWER SOUTH	PITTSBURG	OK	33	4N	14E
35121225800000	BROWNE	May-36	ONEOK RESOURCES CO	BROWNE	BROOKEN	PITTSBURG	OK	36	8N	17E
35121211550000	WHITE `AD`	1	TXO PROD CORP	WHITE `AD`	KINTA	PITTSBURG	OK	24	8N	18E
35121233230000	WILSON	4-Jan	DEVON LOUISIANA CORP	WILSON	WILBURTON	PITTSBURG	OK	4	4N	17E
35121234100000	WATKINS	6-Feb	NEWFIELD EX MID-CON	WATKINS	MCALESTER	PITTSBURG	OK	6	5N	14E
35121235340000	JUANITA	13-Feb	NEWFIELD EX MID-CON	JUANITA	PINE HOLLOW SOUTH	PITTSBURG	OK	13	5N	13E
35121235850000	MILLS	5-Jan	NEWFIELD EX MID-CON	MILLS	MCALESTER	PITTSBURG	OK	5	5N	14E
35121235930000	JOHNSTON	24-Mar	NEWFIELD EX MID-CON	JOHNSTON	PINE HOLLOW SOUTH	PITTSBURG	OK	24	5N	13E
35121236880000	MR BILL	30-Jan	PETROQUEST ENRGY LLC	MR BILL	PITTSBURG CTY CBM	PITTSBURG	OK	30	7N	15E
35121237210000	JACKPOT	16-Jan	SEDNA ENERGY INC	JACKPOT	KIOWA NORTHWEST	PITTSBURG	OK	16	3N	13E
35121237650000	WATKINS	6-May	NEWFIELD EX MID-CON	WATKINS	MCALESTER	PITTSBURG	OK	6	5N	14E
35121238130000	BUSBY	17-1H	ANTERO RES CORP	BUSBY	MEKKO	PITTSBURG	OK	17	6N	15E
35121238210000	DILLARD	10-19H	XTO ENERGY INC	DILLARD	ASHLAND	PITTSBURG	OK	19	3N	12E
35121238270000	ULIS	2-Jan	SEDNA ENERGY INC	ULIS	BREWER SOUTH	PITTSBURG	OK	2	3N	13E
35121238430000	BLUE CREEK	7-Mar	SAMSON RESOURCES CO	BLUE CREEK	PITTSBURG	PITTSBURG	OK	7	2N	14E
35121238920000	INDIAN NATIONS	Feb-30	SAMSON RESOURCES CO	INDIAN NATIONS	BLANCO SOUTH	PITTSBURG	OK	30	3N	15E
35121239460000	MARY	1-6H	CONTINENTAL RES INC	MARY	MCALESTER EAST	PITTSBURG	OK	6	5N	16E
35121239510000	BOWEN	18-1H	ANTERO RES CORP	BOWEN	ASHLAND SOUTH	PITTSBURG	OK	18	3N	12E
35121240310000	BLACK	3-17H	XTO ENERGY INC	BLACK	PINE HOLLOW SOUTH	PITTSBURG	OK	17	5N	12E
35121240750000	BLEVINS	25-Jan	XTO ENERGY INC	BLEVINS	MOUSER	PITTSBURG	OK	25	6N	14E
35121241960000	ROSA	1H-5	NEWFIELD EX MID-CON	ROSA	PINE HOLLOW SOUTH	PITTSBURG	OK	5	5N	13E
35121243790000	CLECKLER	1-1H	ANTERO RES CORP	CLECKLER	REAMS SOUTHEAST	PITTSBURG	OK	1	6N	15E
35121244210000	NELSON	2-6H	KAISER-FRANCIS OIL	NELSON	ASHLAND	PITTSBURG	OK	7	3N	12E
35121244280000	RUYANA	1-21H	PETROQUEST ENRGY LLC	RUYANA	QUINTON DISTRICT	PITTSBURG	OK	21	7N	16E
35121244720000	KRYSTY	1-27/22H	PETROQUEST ENRGY LLC	KRYSTY	QUINTON DISTRICT	PITTSBURG	OK	21	7N	16E
35121300430000	MURDAUGH	1	SKELLY OIL COMPANY	MURDAUGH	QUINTON SOUTH	PITTSBURG	OK	27	7N	18E
35123023140000	MID FITTS UNIT	2-Sep	KERR-MCGEE CORP	MID FITTS UNIT	FITTS	PONTOTOC	OK	29	2N	7E
35123210000000	THOMAS	1-Jan	LANDES P T JR	THOMAS	STONEWALL NE	PONTOTOC	OK	1	2N	7E
35123210490000	ROLLOW	1	MOREY JOHN B	ROLLOW	WILDCAT	PONTOTOC	OK	29	3N	7E
35123212870000	MACK-BROOKS	27-5	UNLIMITED LTD	MACK-BROOKS	WILDCAT	PONTOTOC	OK	27	3N	8E
35123073720000	MID FITTS UNIT TR 9	2-A	SUN OIL COMPANY	MID FITTS UNIT TR 9	FITTS	PONTOTOC	OK	29	2N	7E
35123075930000	THOMPSON	1	SINCLAIR PRAIRIE OIL	THOMPSON	FITTS	PONTOTOC	OK	1	1N	7E
35123076260000	SMITH	1	CONTINENTAL OIL CO	SMITH	FITTS	PONTOTOC	OK	2	1N	7E
35123076360000	SWIFT	1	MAGNOLIA OIL CO ETAL	SWIFT	FITTS	PONTOTOC	OK	3	1N	7E
35123226970000	COULSON	16-Jan	EASON OIL CO	COULSON	WILDCAT	PONTOTOC	OK	16	3N	6E
35123230970000	SAINT	1	KLABZUBA JOE J	SAINT	WILDCAT	PONTOTOC	OK	19	3N	8E
35123235880000	CURRENT	1	OKLAHOMA GEO SURVY	CURRANT	UNNAMED	PONTOTOC	OK	26	3N	6E
35029600130000	NIX	1	BOYLE PHILLIP INC	NIX	FITTS	COAL	OK	8	1N	8E
35029600490000	BENTON	1	HUBER J M-NATL COOP	BENTON	UNNAMED	COAL	OK	15	1N	9E
35029001600000	LINKER J R	19-Jan	RANKEN ENERGY CORP	LINKER J R	TUPELO NORTHEAST	COAL	OK	19	2N	9E

Table 1 – Wells used in study.

35029200390000	JOE W THOMPSON	1	GETTY OIL COMPANY	JOE W THOMPSON	CHILES DOME	COAL	OK	18	3N	10E
35029201300000	SANDY	1A	ALLIED MATERIALS CRP	SANDY	FITTS	COAL	OK	8	1N	8E
35029201500000	SIDMORE	Jan-35	ARKLA EXPL CO	SIDMORE	ASHLAND SOUTH	COAL	OK	35	3N	11E
35029202170000	WARREN JONES	31-Jan	PAYNE W C	WARREN JONES	OLNEY NORTHEAST	COAL	OK	31	1N	10E
35029202230000	SCOTT	1-Nov	HESTON OIL CO	SCOTT	WILDCAT	COAL	OK	11	2N	8E
35029202720000	WM BULLARD JR	1	HILL JOHN H	WM BULLARD JR	CENTRAHOMA NW	COAL	OK	13	2N	8E
35029202820000	GREGORY ROGERS /B/	1	BOYLE PHILLIP INC	GREGORY ROGERS /B/	FITTS	COAL	OK	6	1N	8E
35029202920000	MCCRORY	2	MASTERS ENERGY	MCCRORY	JESSE EAST	COAL	OK	4	1N	8E
35029202950000	SELLS	1	ANR PRODUCTION CO	SELLS	NON SOUTHWEST	COAL	OK	4	3N	10E
35029203030000	HOKETT	3-Jan	TENNECO OIL CO	HOKETT	JESSE EAST	COAL	OK	3	1N	8E
35029203080000	HUNT	1	SHIPLEY ENERGY	HUNT	WILDCAT	COAL	OK	7	3N	10E
35029203180000	CODY	25-Jan	MAPCO PRODUCTION CO	CODY	CHILES DOME	COAL	OK	25	3N	9E
35029203190000	MORGAN T	2-Jan	MAPCO PRODUCTION CO	MORGAN T	CHILES DOME SW	COAL	OK	2	2N	9E
35029203210000	MORGAN T	22-Jan	MAPCO PRODUCTION CO	MORGAN T	LULA NORTHEAST	COAL	OK	22	3N	9E
35029203220000	STALLCUP	15-Jan	MAPCO PRODUCTION CO	STALLCUP	TUPELO NORTHWEST	COAL	OK	15	2N	8E
35029203340000	BRYANT	20-1	HOLDEN ENERGY CO INC	BRYANT	WILDCAT	COAL	OK	20	2N	8E
35029203590000	WOOLEY	1-Jul	ARDMORE DRLG CO	WOOLEY	STONEWALL NE	COAL	OK	7	2N	8E
35029203660000	EDDINGS	Jan-35	HADSON PET USA INC	EDDINGS	CHILES DOME	COAL	OK	35	3N	10E
35029203820000	BARNES	2-Jan	HADSON PET USA INC	BARNES	CHILES DOME SE	COAL	OK	2	2N	10E
35029204090000	MURPHY	1	PONTOTOC PRODCTN CO	MURPHY	WILDCAT	COAL	OK	12	2N	8E
35029204180000	LOGSDON	2	HILL OIL CO INC	LOGSDON	TUPELO SOUTH	COAL	OK	2	1N	8E
35029204520000	CLARITA	1	TIERRA PETROLEUM INC	CLARITA	CLARITA	COAL	OK	25	1N	8E
35029204600000	SKIRVIN O W `A`	1	NADEL & GUSSMAN	SKIRVIN O W `A`	TUPELO NORTHEAST	COAL	OK	20	2N	9E
35029205570000	REARDEN	33C-2	OEXCO INCORPORATED	REARDEN	LEGAL SOUTHWEST	COAL	OK	33	3N	10E
35029206590000	KIM	Jan-35	ST MARY LAND&EXP CO	KIM	CENTRAHOMA	COAL	OK	35	2N	9E
35029206640000	DOUBLE 5 RANCH	8-Jan	CENTERPOINT EN GS TP	DOUBLE 5 RANCH	UNNAMED	COAL	OK	8	3N	10E
35029206670000	SIDMORE	Oct-35	XTO ENERGY INC	SIDMORE	ASHLAND SOUTH	COAL	OK	35	3N	11E
35029206860000	DOUBLE 5 RANCH	18-Jan	DEVON ENERGY PROD	DOUBLE 5 RANCH	COAL CTY COAL BED	COAL	OK	18	3N	11E
35029206950000	MAYER	1D-26	NEWFIELD EX MID-CON	MAYER	WILDCAT	COAL	OK	26	2N	10E
35029206980000	ROGERS TRUST	24-Jan	DEVON ENERGY PROD	ROGERS TRUST	CHILES DOME	COAL	OK	24	3N	10E
35029207060000	PRIDE	29-Jan	SUNDOWN ENERGY LP	PRIDE	CENTRAHOMA	COAL	OK	29	2N	10E
35029207080000	PASQUALI	Jan-36	NEWFIELD EX MID-CON	PASQUALI	CHILES DOME	COAL	OK	36	3N	10E
35029207130000	DOUBLE 5 RANCH	8-Mar	DEKA EXPL INC	DOUBLE 5 RANCH	MIDWELL	COAL	OK	8	3N	10E
35029207270000	SMITH	9-Jan	NEWFIELD EX MID-CON	SMITH	ASHLAND SW	COAL	OK	9	2N	11E
35029207310000	GAYLOR SYDNEY	30-Jan	SUNDOWN ENERGY LP	GAYLOR SYDNEY	CENTRAHOMA	COAL	OK	30	2N	10E
35029208810000	JORDAN	1H-18	PABLO ENERGY II LLC	JORDAN	CENTRAHOMA	COAL	OK	18	1S	10E
35029209030000	RUSHING	1-7H	CONTINENTAL RES INC	RUSHING	CENTRAHOMA NE	COAL	OK	7	2N	10E
35029209150000	GLASS	29-1H	ANTERO RES CORP	GLASS	LEHIGH SOUTHWEST	COAL	OK	29	1S	10E
35029210000000	DOUBLE 5 RANCH	2-10SWD	DEVON ENERGY PROD	DOUBLE 5 RANCH	UNNAMED	COAL	OK	10	3N	10E
35029210050000	JIMMY	1-6H	CONTINENTAL RES INC	JIMMY	CENTRAHOMA	COAL	OK	6	2N	10E
35029210270000	PASQUALI	4-30H	CONTINENTAL RES INC	PASQUALI	UNNAMED	COAL	OK	30	3N	11E
35029210280000	NORFLEET	1H-4W	NEWFIELD EX MID-CON	NORFLEET	LULA EAST	COAL	OK	33	3N	9E
35063005990000	HAMILTON	1	CARTER PHILLIPS & R	HAMILTON	CITRA	HUGHES	OK	33	4N	9E
35063203100000	JENSON	1	MUSTANG PROD CO	JENSON	WILDCAT	HUGHES	OK	20	5N	10E
35063203490000	MARTIN	1	WESTERN DVRSFD MGMT	MARTIN	LEGAL NORTH	HUGHES	OK	23	4N	11E
35063210860000	CHAPMAN	1	GODSEY-EARLOUGHR INC	CHAPMAN	CALVIN SOUTHEAST	HUGHES	OK	12	5N	10E
35063214530000	LAWSON	2	HILL OIL CO INC	LAWSON	CITRA	HUGHES	OK	35	4N	9E
35063214590000	TATUM	1	AVANTI ENERGY CORP	TATUM	CITRA	HUGHES	OK	21	4N	9E
35063216970000	LONDON	1	DECK OIL CO	LONDON	CALVIN EAST	HUGHES	OK	23	6N	10E
35063221620000	SPIKER	1	SAMEDAN OIL CORP	SPIKER	CALVIN SOUTHEAST	HUGHES	OK	28	5N	10E
35063222970000	GRAY J D	1	EXPORT PET CORP	GRAY J D	GERTY NORTHWEST	HUGHES	OK	23	5N	9E
35063223000000	CONNER	2	EXPORT PET CORP	CONNER	GERTY NORTHWEST	HUGHES	OK	26	5N	9E
35063223540000	COGDILL	29-Jan	J-W OPERATING CO	COGDILL	ALLEN DISTRICT	HUGHES	OK	29	5N	9E
35063225250000	PHILPOT ENTERPRISES	1	PHILPOT G O	PHILPOT ENTERPRISES	ALLEN DISTRICT	HUGHES	OK	6	5N	9E
35063226960000	BADGER MELINGA	25-1	THERMAL EXPL INC	BADGER MELINGA	GERTY NORTHWEST	HUGHES	OK	25	5N	9E
35063228950000	MCKEE	1A-29	HARRIS W G O&G CO	MCKEE	HILL TOP NORTH	HUGHES	OK	29	6N	11E
35063235320000	WILSON	1	TITAN RESOURCES LTD	WILSON	CITRA NORTHEAST	HUGHES	OK	14	4N	9E
35063235950000	REYNOLDS	11-Jan	NEWFIELD EX MID-CON	REYNOLDS	HILL TOP	HUGHES	OK	11	5N	11E
35063236000000	NUNN	1-Jan	NEWFIELD EX MID-CON	NUNN	PINE HOLLOW SOUTH	HUGHES	OK	1	5N	11E
35063236320000	SUMMERS	1D-27	NEWFIELD EX MID-CON	SUMMERS	ASHLAND NORTH	HUGHES	OK	27	4N	11E
35063236370000	NUNN	1-Feb	NEWFIELD EX MID-CON	NUNN	PINE HOLLOW SOUTH	HUGHES	OK	1	5N	11E
35063236480000	FREEPORT	Feb-32	COLA RESOURCES LLC	FREEPORT	GREASY CREEK	HUGHES	OK	32	4N	11E
35063236500000	RICHARDSON	Feb-33	SOUTHERN RESRCS INCO	RICHARDSON	HILL TOP NORTH	HUGHES	OK	33	6N	11E
35063236520000	RUSSELL LEON	Feb-34	NEWFIELD EX MID-CON	RUSSELL LEON	WILDCAT	HUGHES	OK	34	4N	10E
35063236560000	SELLERS	Mar-35	CHESAPEAKE OPERG INC	SELLERS	ASHLAND NORTH	HUGHES	OK	35	4N	11E
35063237000000	HILL O L	A 23-12	DEKA EXPL INC	HILL O L	CITRA	HUGHES	OK	23	4N	9E
35063237090000	WALTER	9-Jan	GLENN SUPPLY CO INC	WALTER	SHADY GROVE SW	HUGHES	OK	9	6N	11E
35063237120000	PRICE	A 22-7-10	CONTINENTAL RES INC	PRICE	CITRA	HUGHES	OK	22	4N	9E
35063238790000	NELSON	1-31H	CONTINENTAL RES INC	NELSON	CITRA	HUGHES	OK	31	4N	10E
35063239120000	CATTLE	8-May	NEWFIELD EX MID-CON	CATTLE	ASHLAND NORTH	HUGHES	OK	8	4N	11E
35063240110000	CLAYTON	3H-33	NEWFIELD EX MID-CON	CLAYTON	WILDCAT	HUGHES	OK	28	4N	10E
35063240320000	CHAPMAN UNIT	1H	NEWFIELD EX MID-CON	CHAPMAN UNIT	HILL TOP	HUGHES	OK	4	5N	11E
35063240640000	PARSONS	1-9H	CHESAPEAKE OPERG INC	PARSONS	HILL TOP	HUGHES	OK	9	5N	11E
35063240950000	ARLAN	4-15H	CONTINENTAL RES INC	ARLAN	GERTY EAST	HUGHES	OK	15	4N	10E
35063242870000	ON TARGET	Jan-33	CHARTER OAK PROD CO	ON TARGET	CITRA	HUGHES	OK	33	4N	9E
35063243150000	PALE MOON SWD	31-Jan	XTO ENERGY INC	PALE MOON SWD	HILL TOP NORTH	HUGHES	OK	31	6N	11E

Table 1 continued – Wells used in study.

VITA

John Edward Gage

Candidate for the Degree of

Master of Science

Thesis: SURFACE-TO-SUBSURFACE STRATIGRAPHY OF THE CANEY SHALE IN PORTIONS OF PONTOTOC, COAL, PITTSBURG, AND HUGHES COUNTIES, OKLAHOMA, ARKOMA BASIN

Major Field: Petroleum Geology

Biographical:

Education:

Completed the requirements for the Master of Science in Petroleum Geology at Oklahoma State University, Stillwater, Oklahoma in May, 2015.

Completed the requirements for the Bachelor of Science in your Geology at Oklahoma State University, Stillwater, Oklahoma in May, 2008.

Experience: HighMount Exploration and Production LLC, 2011-2014,
Browning Oil Company, Inc., 2014-present.

Professional Memberships: AAPG, WTGS, OCGS, DGS, YPE