

HIGH RESOLUTION CORRELATION OF PENNSYLVANIAN
MARINE CONDENSED SECTIONS FROM
OUTCROP TO SUBSURFACE

By

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Abstract: The stratigraphic complexity and repetition in Pennsylvanian deposition in the Midcontinent region of North America is manifested by numerous stacked cyclothems. Condensed sections in each cyclothem examined in this study were from the Cherokee, Marmaton, Pleasanton, Kansas City, Lansing, Douglas, and Shawnee Groups of the Middle to Upper Pennsylvanian. Correlation was based upon conodont distributions at outcrops in northeast Oklahoma, eastern Kansas, northwest Missouri, and southern Iowa and cores from southwestern Anadarko Basin. Conodonts recovered from outcrop were compiled for future work. Conodonts were recovered from six cores were correlated to outcrop. The correlated condensed sections are the Nuyaka Creek Shale, Stark Shale, Block Limestone, Quivira Shale, and Muncie Creek Shale. The Nuyaka Creek Shale (Top Marmaton in subsurface) is easily correlatable through the presence of *Swadelina nodocarinata*, *Idiognathodus expansus*, and the last appearance of *Neognathodus*. *Idiognathodus* is abundant and diverse in the Stark Shale (Hogshooter) with *I. magnificus*, *I. confragus*, *I. cancellosus*, and *I. cherryvalensis*. The Block Limestone (Hogshooter) contains the first introduction of *Streptognathodus* with *S. gracilis*, *S. elegantulus*, and *S. excelsus* as well as *Idiognathodus magnificus* and *Idiognathodus cherryvalensis*. The Quivira Shale (Upper Hogshooter) is distinguished by an abundance of *Gondolella*, *S. gracilis*, *S. elegantulus*, *S. excelsus*, and *I. mafnificus*. The Muncie Creek Shale (Lower Avant) contains a distinct form of *Idiognathodus magnificus* and *S. gracilis*, *S. elegantulus*, and *S. excelsus*. Wireline log cross sections were created to show the distribution of condensed section electrofacies.

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CHAPTER I

INTRODUCTION

Problem and Purpose

The stratigraphic complexity of the Pennsylvanian (Upper Carboniferous) in the U.S. Midcontinent has garnered interest since Udden (1912) first documented its cyclical deposits. Later, Moore (1930) studied Pennsylvanian deposits more extensively, and Wanless and Weller (1932) coined the term cyclothem (which is effectively equivalent to a modern unconformity-bounded depositional sequence) to describe the sedimentary cycles. More recently, Phil Heckel (1977, 1980, 1984, 1986) began to refine the cyclothem model and time boundaries through biostratigraphic research (Heckel and Baesmann, 1975). The significance of conodonts for biostratigraphic research was first mentioned by Ulrich and Bassler (1926). T. S. Loutit et al. (1988) paper details the importance of condensed sections and biostratigraphy in globally and locally age dating and correlating. In the Midcontinent, Boardman and Heckel (1989) used biostratigraphy to correlate cycles from Texas to Iowa. On a global scale, Heckel et al. (2007) correlated the Midcontinent section to that in the Moscow Basin in Russia and the Donets Basin in Ukraine using conodonts. A correlation to the subsurface in Kansas was done by Watney et al. (1999). Through regional study of outcrops, cores, and wireline logs they were able to correlate the Pennsylvanian sequences using marine shale units (maximum flooding surfaces

and condensed sections) in the subsurface in Kansas. Much is known about these depositional sequences at the surface, but correlation to the subsurface has been limited. This is evident in a quote from Rascoe and Adler (1983), "Correlation of the cyclothem of the shelf with equivalent units in the clastic facies of the Anadarko Basin is exceedingly difficult."

Within the Desmoinesian, Missourian, and Virgilian of the Middle and Upper Pennsylvanian in the Midcontinent, there are nine stratigraphic groups. In this study, seven groups were studied; they are in descending order the Shawnee, Douglas, Lansing, Kansas City, Pleasanton, Marmaton, and Cherokee. In all, twenty two condensed sections were examined at outcrops (Figure 1) while eight marine shales were studied in the subsurface (Figure 2).

The purpose of this study is to: (1) develop a high-resolution biostratigraphic correlation of Pennsylvanian depositional sequences from outcrop to subsurface in the Anadarko Basin and (2) gather conodont biostratigraphic data to lay the groundwork for future work in the Pennsylvanian. Photomicrographs of conodont elements were used to correlate the sequences. A schematic cross-section from the outcrop study area to subsurface study area was created along with plates exhibiting the biostratigraphic data used. Secondly, a stratigraphic framework was completed using wireline log cross-sections in the subsurface.

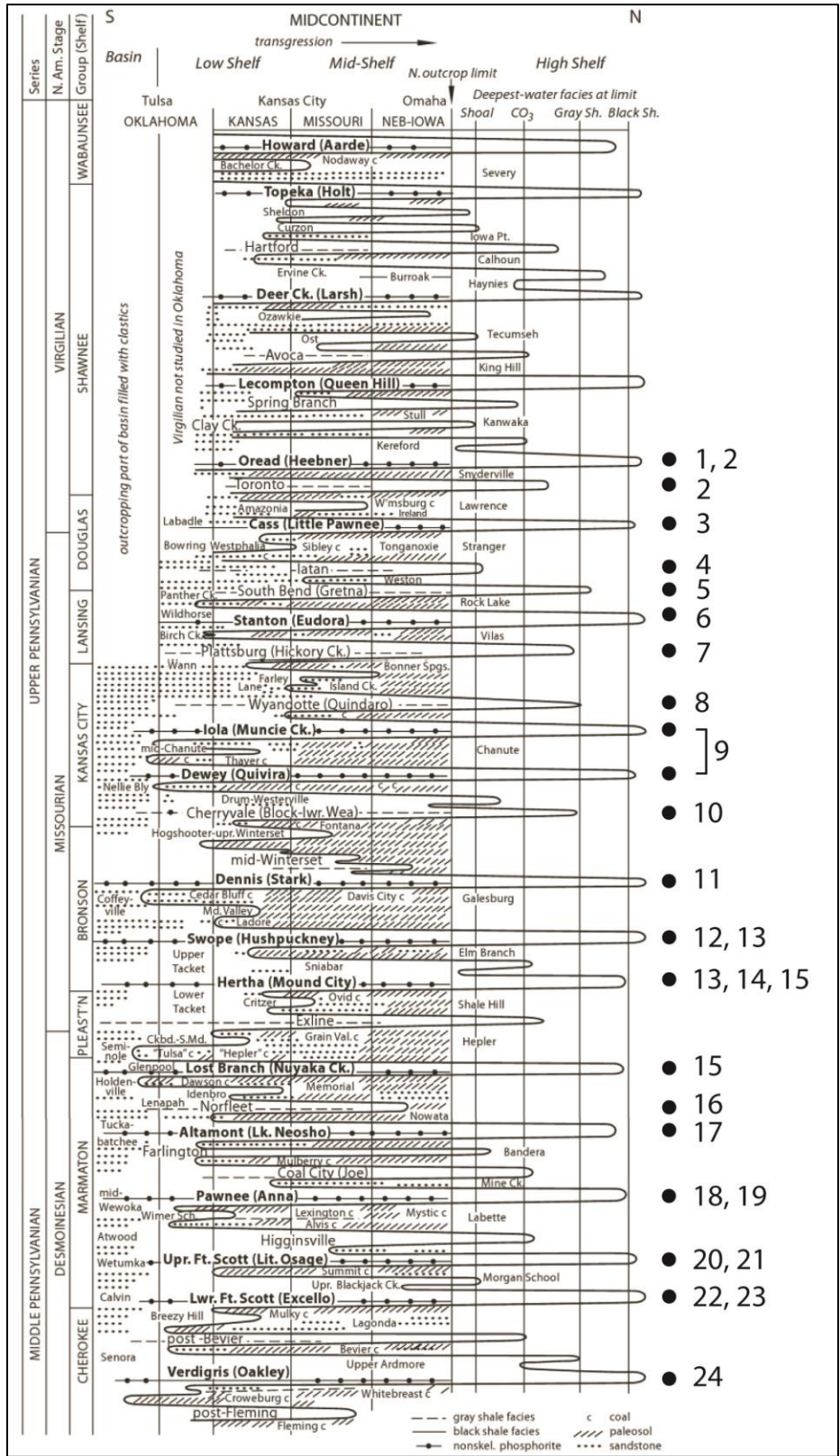


Figure 1. Middle and Upper Pennsylvanian stratigraphic column and sea-level curve showing sampled formations at outcrop. Modified from Heckel et al. (1999).

Location of Study Area

There are two broad study areas for the subsurface and surface Pennsylvanian condensed sections described in the study. The subsurface study area is in the Anadarko Basin in southwestern Oklahoma (Figure 3). Cores are in two groups in the northwestern and southeastern corners of the Anadarko Basin. Five cores are located in Roger Mills, Ellis, and Dewey Counties in the northwestern area of the basin. In the southeastern region of the basin, ten cores are located within Caddo and Grady Counties. Appendix B contains core photos, core gamma scans, and geophysical well logs. The surface study comprises outcrops located in the northeast trending Pennsylvanian outcrop belt from northeast Oklahoma to south central Iowa (Figure 4). These outcrops were located through the use of previous works done by Heckel and Pope (1992), Heckel et al. (1999), Heckel and Watney (2002), Rosscoe (2008), and Pope and Anderson (2009). The outcrops occur in clusters beginning in northeast Oklahoma and southeast Kansas. A couple of localities are south of Fort Scott on US 69. Another bulk of the localities is around the Kansas City area in both Missouri and Kansas. The northern most localities are located in south central Iowa in Madison County. Appendix A contains photographs showing sample locations at outcrop and topographic maps of the localities.

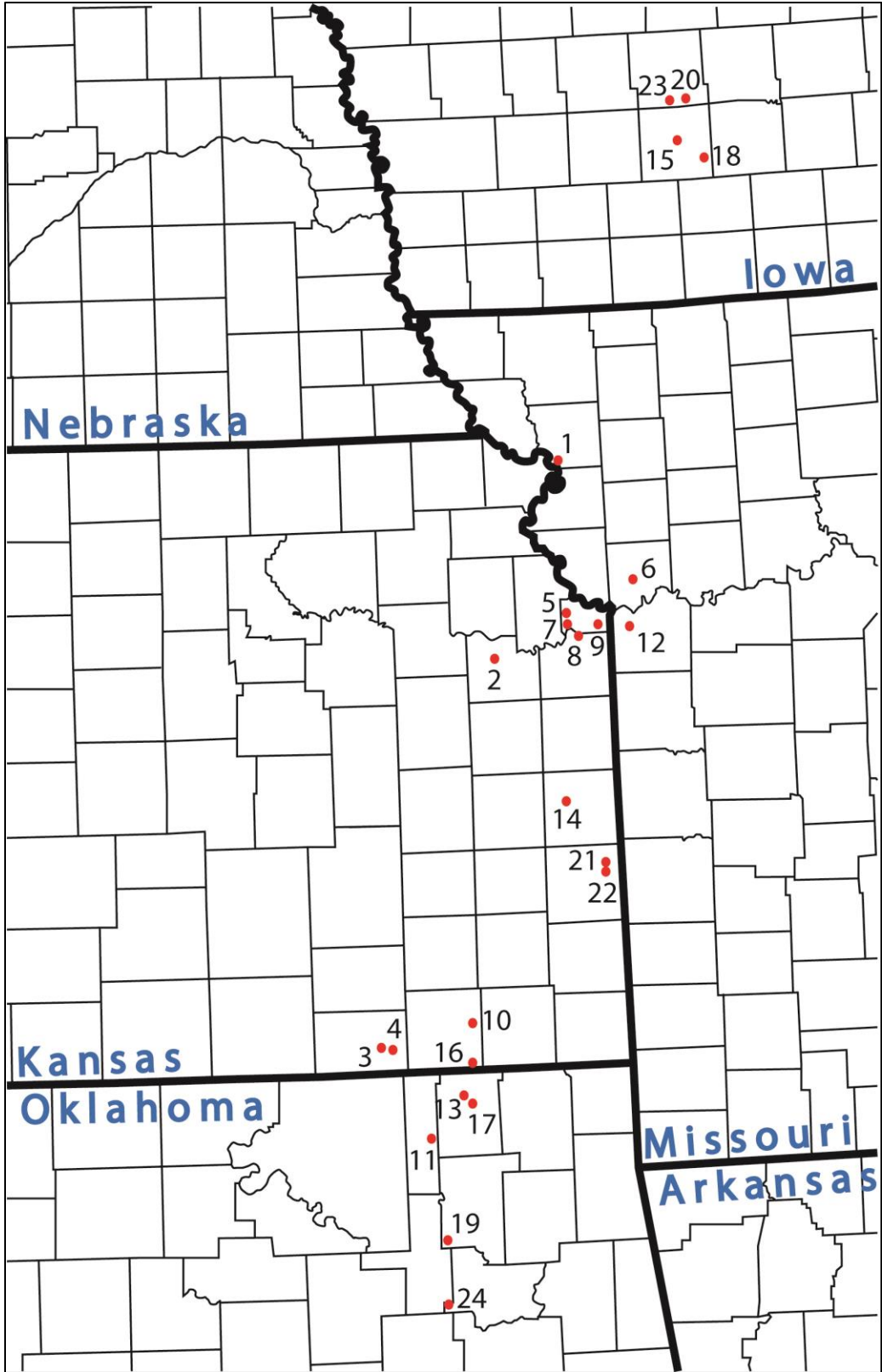
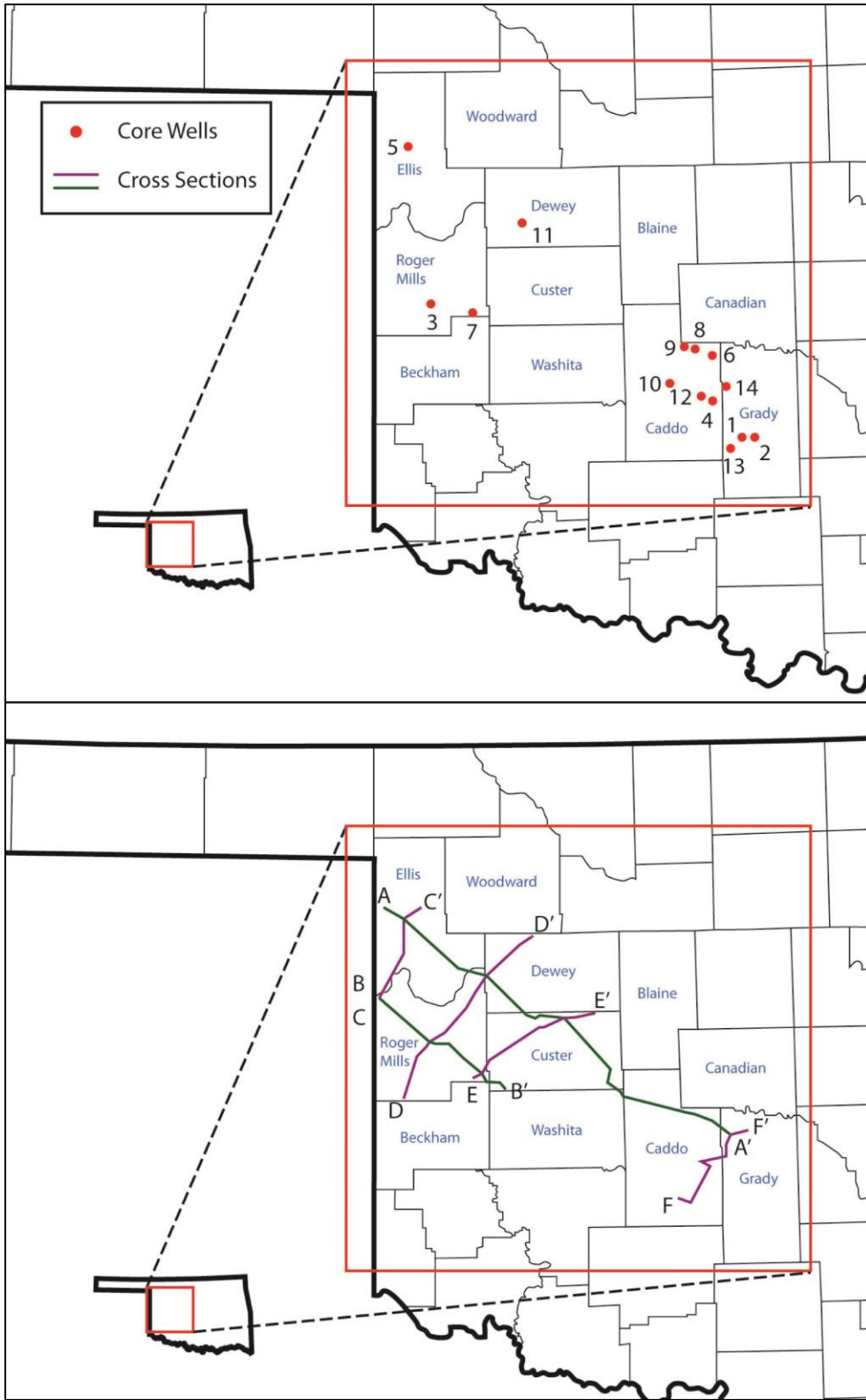


Figure 2. Location of surface study area showing outcrop localities.



Figures 3a and 3b. Location of subsurface study area in Oklahoma, Kansas, Missouri, and Iowa. Each numbered red dot represents a locality. Cross-section paths are represented by the green (strike to Anadarko Basin) and purple lines (dip direction to the Anadarko Basin).

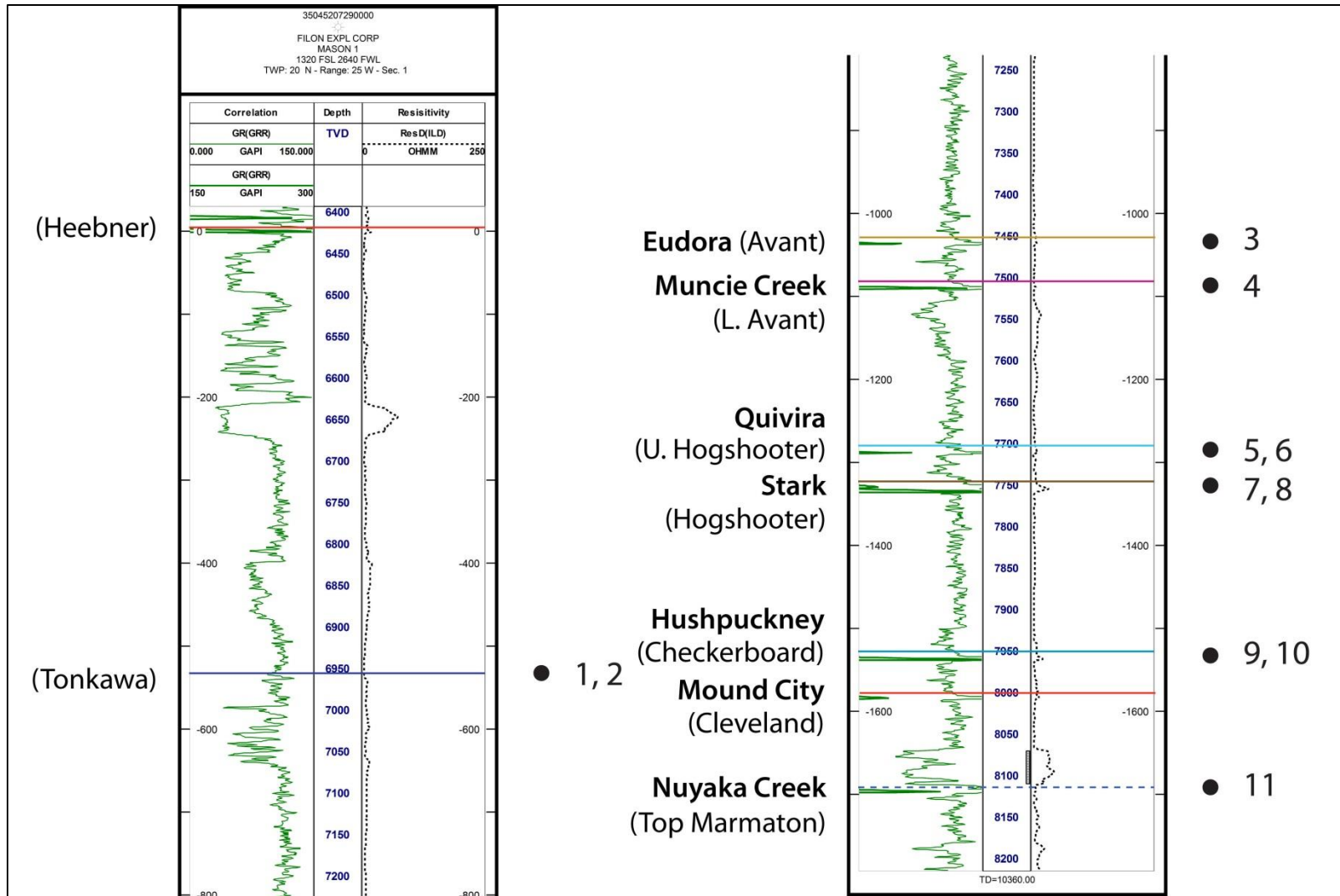


Figure 4. Type log showing “hot shale markers” and core sampled intervals.

Methodology

Surface Study

Surface exposures of condensed sections were examined in ascending order in the Cherokee, Marmaton, Pleasanton, Kansas City, Lansing, Douglas, and Shawnee. The complete Shawnee and Cherokee Groups were not examined, only the lower Shawnee Group and upper Cherokee Group. Twenty six localities representing all condensed sections (Figure 1) were selected based upon the section being complete and recoverable conodonts with a few being duplicated.

At each locality, the section was photographed and sampled. Samples of 1-2 kilograms were taken in 1-foot increments spanning the section. Where appropriate, samples were taken at or near notable facies and bed changes. Condensed sections which are typically black shale were of primary focus, but if possible, the overlying and underlying limestone were sampled.

The collected samples were processed by chemical solution depending upon rock type to extract the conodonts. Limestone and calcareous shale were placed in a 10% formic acid solution, whereas non-calcareous shale was placed in a 32% hydrogen peroxide. Samples in formic acid were left in solution for 24-36 hours. Shale sample processing time varies greatly based on the amount of organic material present, as this is what reacts with the peroxide. Depending on the clay content, samples could also be broken down using kerosene. Each sample was sieved in a 35- and 120-mesh sieve and dried in an oven. These steps were repeated on all 35-mesh samples until enough 120-mesh sample was recovered.

Subsurface Study

The subsurface phase of the study consists of two parts: constructing a cross-section grid and sampling and processing cores. The first step in sampling cores was identifying cores with radioactive shale units that are the maximum flooding intervals and thought to be condensed sections. To do this, formation tops were picked and correlated throughout the Anadarko basin. A grid pattern was used in each county of the study area for uniformity. The depths of all cores in the basin were then examined to determine if they contained condensed sections. Gamma scans were run on cores to match the cored interval to the measured depth in geophysical well logs (See Appendix A). Cores containing condensed sections were cut into slab sections for sampling. Same as the surface samples, a 1 kilogram sample was taken, but due to the amount of core left from slab cutting, samples were taken in 1.5 foot increments. The same process of extracting conodonts as the surface samples is applied. Due to subsurface samples being partially metamorphosed, processing steps must be repeated many times.

The maximum flooding intervals examined through well-logs in the subsurface are commonly called "hot shales" due to their high gamma ray readings over 150 API units. These hot shales are black, fissile shales with high concentrations of uranium. They make great marker beds and aid in correlating in the subsurface. Cross sections were constructed to show the lateral extent of these hot shales. A grid of stratigraphic cross-sections but oriented structurally strike and dip to the Anadarko Basin was made. Six total stratigraphic cross sections were constructed.

Lab Analysis

All samples were examined under a 10x magnification microscope to separate conodonts from sediment residue. The identification of the conodonts was done by utilizing Rosscoe's (2008) catalog of conodont species in the Pennsylvanian. Figure 5 shows the morphology of conodonts as illustrated by Rosscoe (2008). Rosscoe provided the methodology used in identifying conodonts, a detailed description of each conodont species, and photomicrographs of each species. Figures 5 and 6 provide examples of the terminology used in Rosscoe's paper. Once identified, the conodonts representing the conodont diversity from each interval are placed on plates. These conodonts are taken to the SEM lab to be photomicrographed. The conodonts in these pictures were then used to correlate condensed sections in the subsurface to surface.

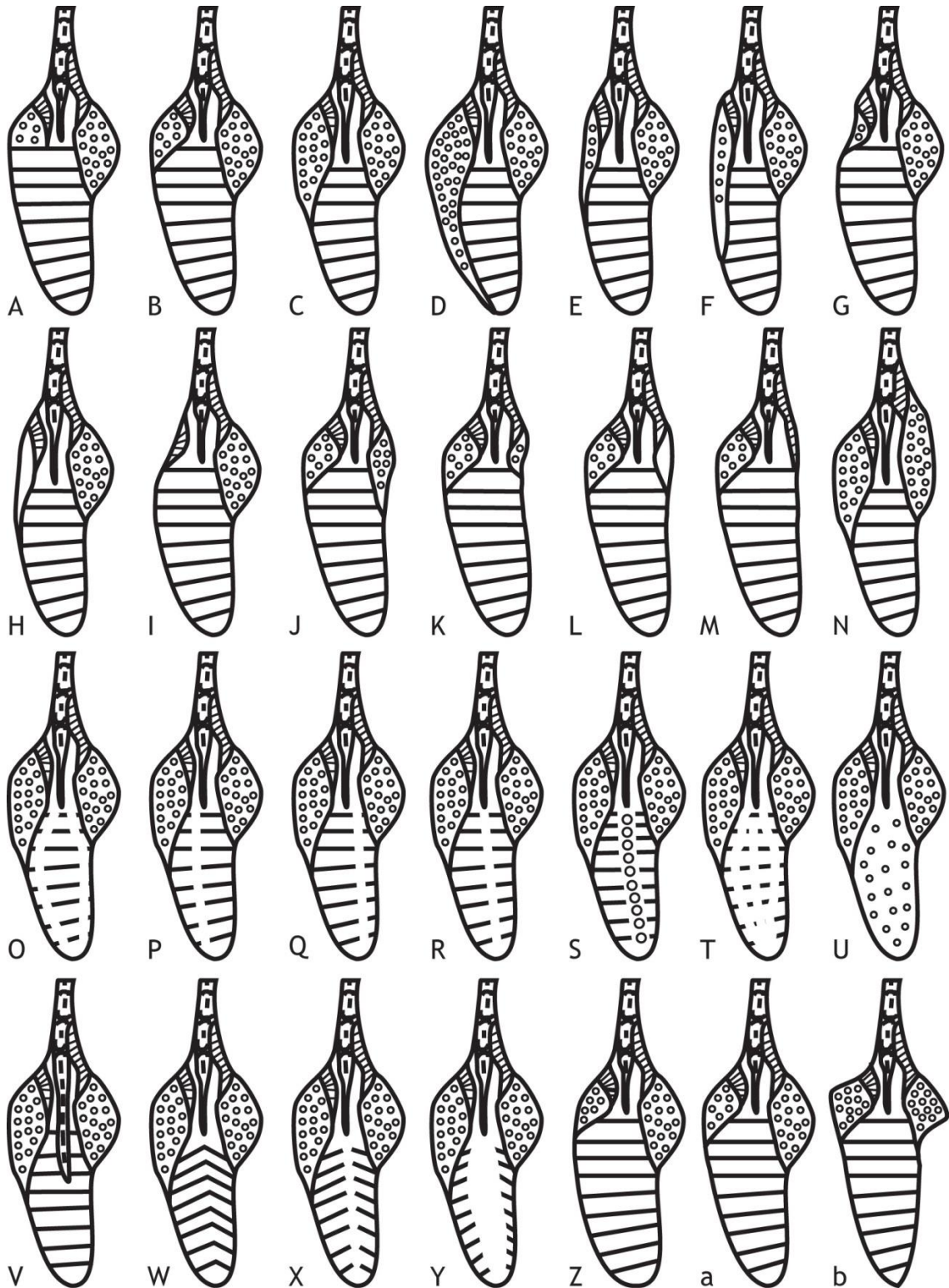


Figure 5. *Idiognathodus* and *Streptognathodus* conodont diagrams representing the variations observed by Rosscoe (2008). A-I = Rostral Lobe Variation, J-M = Caudal Lobe Variation, N-V = Platform Ornamentation Variation, W-Y = Platform Troughing, and Z-b = Platform Shape Variation.

Table 1. Morphological feature names and descriptions for Figure 5. Modified from Rosscoe (2008).

	Morphological Feature	Description
A	Restricted Rostral Lobe	A small rostral lobe restricted to the ventral quarter of the platform by the ventral-most transverse ridge.
B	Moderately Restricted Rostral Lobe	A moderately sized rostral lobe that has a small dorsal extension beyond the first one, maximum two, transverse ridges.
C	Expanded Rostral Lobe	A rostral lobe that is expanded in the dorsal direction up to one-half the length of the platform.
D	Elongate Rostral Lobe	The most elongate rostral lobe in the dorsal direction, extending between one-half and the entire length of the platform. The lobe also expands in the rostral direction with at least two rows of nodes on the ventral portion of the lobe. Usually only a single row of nodes ornaments the dorsal portion of the lobe.
E	Reduced Rostral Lobe	A narrow rostral lobe containing a single row of ornamenting nodes that extends up to one-third the length of the platform in the dorsal direction.
F	Reduced Elongate Rostral Lobe	A narrow lobe containing a single row of ornamenting nodes extending beyond one-third the length of the platform in the dorsal direction.
G	Inset Rostral Lobe	A small rostral lobe with room for only one or two nodes that forms at the inflexion point where the rostral margin of the element joins the rostral adcarinal ridge.
H	Ghost Rostral Lobe	A rostral unornamented lobe-like extension that is distinctively separate from the main body of the platform.
I	Missing Rostral Lobe	A rostral margin lacking any rostral or ghost rostral lobe.
J	Reduced Caudal Lobe	A caudal lobe that is elongate in the dorso-ventral direction with room for a maximum of two nodes in the rostro-caudal direction.
K	Inset Caudal Lobe	A small caudal lobe with room for only one or two nodes that forms at an inflection point between the caudal margin of the element and the caudal adcarinal ridge.
L	Ghost Caudal Lobe	A caudal unornamented lobe-like extension that is distinctively separate from the main body of the platform.
M	Missing Caudal Lobe	A caudal margin lacking any caudal or ghost caudal lobe.
N	Ventrally Shifted Lobe	A P_1 element where the caudal lobe is shifted in the ventral direction, up to one-half the length of the caudal lobe is ventral of the ventral termination of the rostral lobe.
O	Marginal Grooves	A disruption of all transverse ridges along the rostral or caudal margin of the platform in the form of a groove.

Table 2. Continuation of morphological features and descriptions for Figure 5. Modified from Rosscoe (2008).

	Morphological Feature	Description
P	Rostral Eccentric Groove	A disruption of all transverse ridges on the rostral portion of the platform from the rostral side of the medial carina to the dorsal margin of the platform. Only found when there is a caudal eccentric groove.
Q	Caudal Eccentric Groove	A disruption of all transverse ridges on the caudal portion of the platform from the caudal side of the medial carina to the dorsal margin of the platform.
R	Medial Groove	A disruption of transverse ridges from the dorsal tip of the medial carina to the dorsal tip of the platform. Will form as complete medial groove or partial medial groove.
S	Medial Nodosity	A row of nodes disrupting all transverse ridges from the dorsal tip of the medial carina to the dorsal tip of the platform.
T	Chaotic Disruption	A platform exhibiting incomplete transverse ridges throughout the entirety of the platform. Raised features form along the trends of the transverse ridges but are expressed as individual short ridges or nodes.
U	Nodose Platform	A platform that is completely ornamented with discrete nodes.
V	Elongate Medial Carina	The normal extension of medial carina is less than one-quarter the length of the platform. Extension beyond this is considered elongate.
W	Weak Trough	A platform that has elevated margins and decreases in elevation to the center of the element.
X	Ridged Trough with Groove	A platform with elevated margins that decreases in elevation to the center of the element. The central axis of the platform is marked by a deep, well-defined groove.
Y	Wide, Smooth Trough	A platform with elevated margins that decreases in elevation to the center of the element. The central axis is dominated by a wide and smooth trough.
Z	Rounded Dorsal	A dorsal margin that is rounded.
A	Subrounded Dorsal	A dorsal margin that is subrounded
b	Pointed Dorsal	A dorsal margin that is pointed.
A-I	Normal Caudal Lobe	A caudal lobe that expands in the caudal direction so that it can hold more than two nodes along its rostro-caudal axis. The lobe is nearly as rostro-caudally expanded as it is in the dorso-ventral direction.
A-N	Complete Transverse Ridges	A platform that bears complete transverse ridges from the rostral to caudal margins. These ridges may be oriented along with the rostro-caudal axis, at an angle to the rostro-caudal axis, or show a deflection in the ventral direction on the caudal portion of the platform.

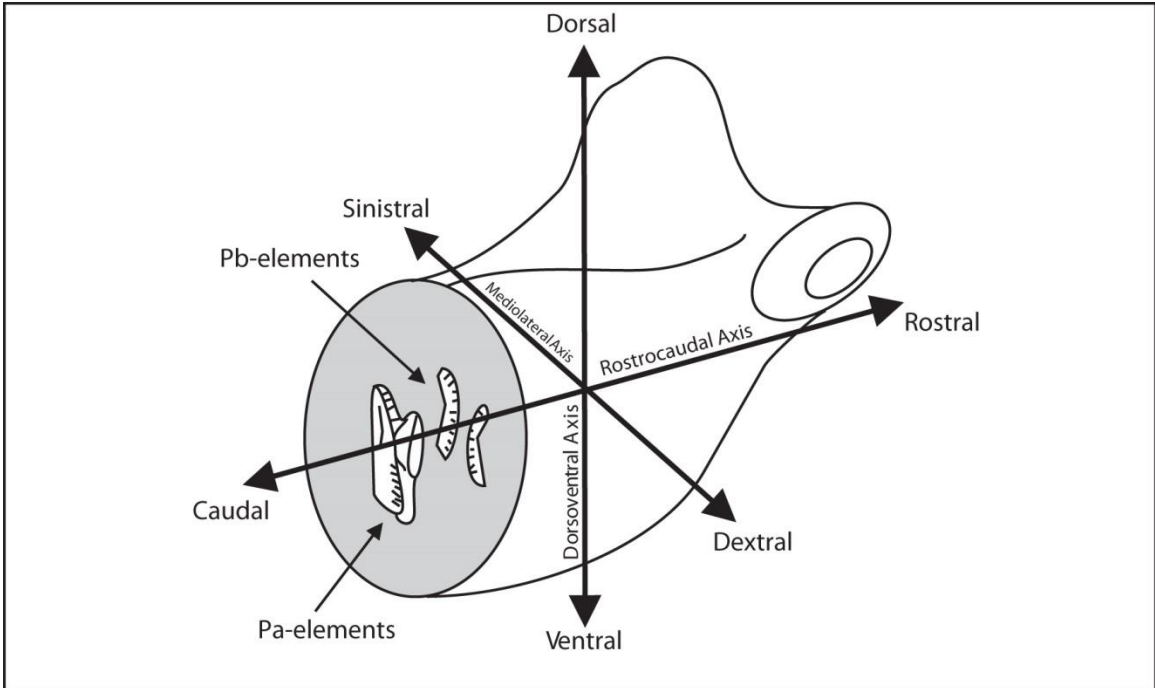


Figure 6. Illustration exhibiting the anatomical orientation and terminology for conodont elements (after Purnell et al., 2000; Rosscoe, 2005).

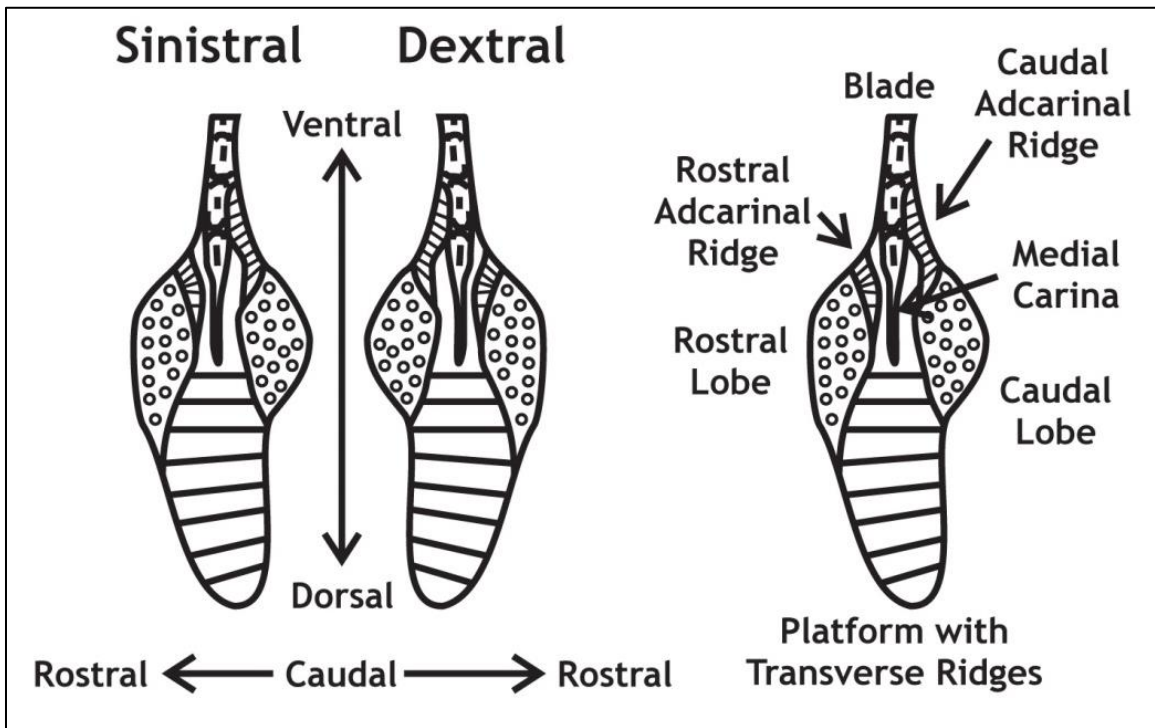


Figure 7. Illustration of the terminology used in describing conodont elements after Rosscoe (2008).

Geological Setting

The sedimentation of the Middle to Upper Pennsylvanian was affected by several structural features in the Midcontinent (Rascoe and Adler, 1983). They are the Nemaha Uplift, Cherokee Platform, Bourbon Arch, Ozark Uplift, and Forest City Basin in the Northern Midcontinent Shelf subdivision of the Midcontinent Basin. The Northern Midcontinent Shelf extends from Oklahoma to Iowa. South of the Northern Midcontinent Shelf are the Anadarko Basin and Arkoma Basin in Oklahoma and Arkansas. Structural features affecting the sedimentation of the Anadarko Basin and Arkoma Basin included the Wichita-Amarillo Uplift, Arbuckle Uplift, and Ouachita Mountains to the south. All structural features mentioned formed during the Carboniferous-Permian orogenesis associated with the assembly of Pangea (Rascoe and Adler, 1983). Figure 6 shows the structural features in relation to the study areas.

The Anadarko and Arkoma Basins are deep foreland basins with sediment thickness in excess of 30,000 ft (Watney, 1999). The thickness of the Pennsylvanian section in these basins exceeds 15,000 ft (Johnson et al, 1989). In the Anadarko Basin, sediment was deposited by prograding cratonic deltas in the northeast and in alluvial-turbidite complexes adjacent to the Wichita-Amarillo Mountains to the southwest (Rascoe and Adler, 1983). These sediments consisted of marine shales, sandstones and limestones with limestones becoming more prominent up section (Johnson et al, 1989). The Arkoma Basin clastic sediments were probably derived from the Ouachita Mountains to the south (Rascoe and Adler, 1983) and possibly the Ozark Uplift to the north. On the Northern Midcontinent shelf, sediments are sequences of limestones, shales, and clastic sediments being deposited from the Nemaha Uplift and Bourbon Arch (Moore and Jewett, 1942). The Forest City Basin, bounded by the Nemaha Uplift and Bourbon Arch, includes over 2,000 ft of Pennsylvanian shelf deposits (Anderson and Wells, 1986). While the Anadarko Basin and Arkoma Basin subsided rapidly under major tectonic and

sediment loads, the Cherokee Platform was relatively stable during the Pennsylvanian (Moore, 1979). Shales with some limestones and sandstones were deposited on the Cherokee Platform.

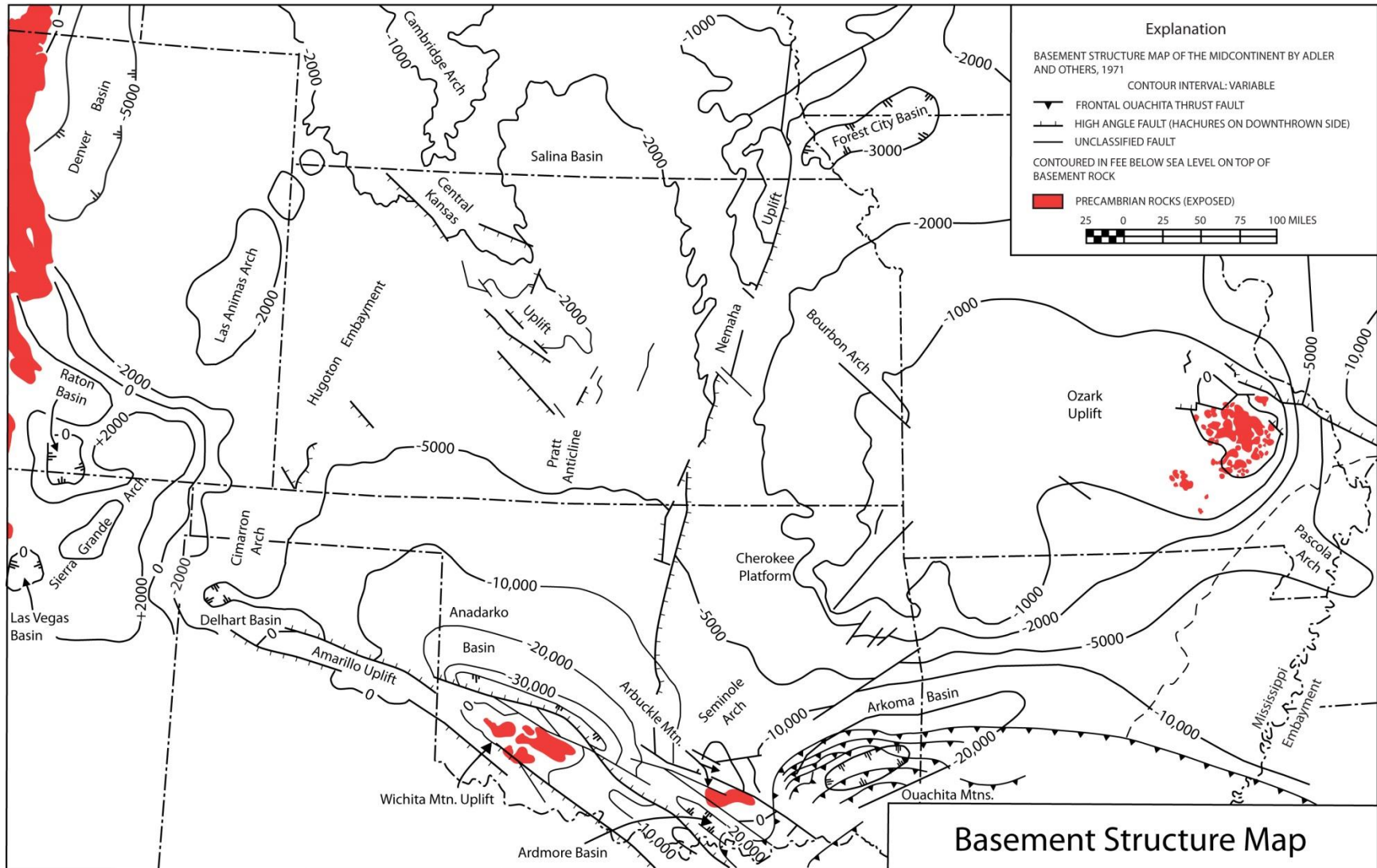


Figure 8. Structural contour map of the southern Midcontinent. Modified from Adler et al. (1987).

Previous works

Cyclothems

Numerous studies have been conducted on the stratigraphy of the Pennsylvanian System in the Midcontinent beginning with J. A. Udden (1912). Recognizing the cyclical nature of the sedimentary succession, Udden was one of the first to establish a grouping of cycle deposits. The four cycles were broken down into ascending stages of coal, shale, limestone, sandstone, and underclay.

Little research was done on Pennsylvanian cyclic deposits until a couple decades later when Weller (1930) introduced orogenesis as the origin of the cycles. Weller also thought the boundary of the cycle was best placed at the base of the sandstone, whereas Udden placed the base of the cycle at the top at the coal. Another change to Udden's paper was the deposition of the black shale which will become a focal point in later studies. Differing from Udden's ideal succession that the shales were reworked peat beds, Weller believed the marine plants disrupted wave movement and were the basis of the black color (Heckel, 1984).

R. C. Moore (1929) examined Pennsylvanian cycles in Kansas and Nebraska. The first major difference in cycles in Kansas and Nebraska to Illinois cycles were the addition of one or two more limestones (Moore, 1931). Moore also studied the black fissile shales further. While Moore did not place an exact depositional environment to the black shales, he did believe the shales to be deposited in calm, shallow, possibly anoxic seas abundant with plant life (Heckel, 1984).

The first use of the term cyclothem came from Wanless and Weller (1932), combining the Greek words *cylcos* and *thema* meaning cycle deposits. Wanless and Weller's research involved the correlation of these cyclothems across the Midcontinent in Illinois, Iowa, Missouri,

Kansas, and Oklahoma. They found that the cyclothems are widespread and proposed that regional correlation is possible.

The first paper to conclude a realistic limitation on the deposition of cyclothems was by Wanless and Shepard (1936). They proposed that the deposition of cyclothems was affected by eustatic sea-level changes driven by the waxing and waning of Gondwanan glacial ice sheets. They recognized that repetition of glacial cycles drives sea-level changes and the deposition of the Pennsylvanian cycles as far away as the tropics. Wanless and Shepard (1936) also simplified cycle classification and created a grouping for differing cyclothems in parts of the Midcontinent. They proposed three facies groups: 1. "piedmont facies" with mostly non-marine sediments with few marine deposits, 2. "delta facies" containing more marine sediments and still non-marine, and 3. "neritic facies" composed of mostly marine sediments with little non-marine sediments.

Building upon his previous work, Moore (1936) developed the term megacyclothem to define a cycle of cyclothems. In this model, Moore created more distinctive units and was able to compare the complex Shawnee cyclothems to the simpler Wabaunsee cyclothems. Still, Moore was unable to address the origins of the black, fissile shale units, as he reversed his original theory that they were derived from marine deposits.

In the 1950s until today, much of the research on cyclothems has shifted from the cyclothems themselves to the black fissile shales within the cycles. Moore (1950) reexamined the black shales and concluded they were deposited in a shallow sea with thick seaweed growth. Moore did not address the widespread nature of the shales nor did he believe they were similar to the deep anoxic deposits of the Black Sea. He did, however, note that they were the only clastic member to not thicken towards the source. Weller (1956, 1957) continued to express the theory that black shales were deposited in shallow seas with abundant marine plant

growth to prohibit wave action. He also recognized that the predominance of nektic, planktonic, and epiplanktonic fossils could be due to anoxic conditions at the sea bottom (Weller, 1957).

The black shale intervals were identified as transgressive by Zangerl and Richardson (1963). They thought the black shales were deposited in stratified waters with an anoxic bottom, and they applied a sargasso sea interpretation to the shale on the basis of abundant allochthonous plant debris in the shale. In 1967, two separate papers were written by J.K. Evans and P.E. Schenk with new ideas that the black shales were offshore facies deposited at maximum transgression. Schenk (1967) explained the phosphate nodules in black shales were due to upwelling. Following these new findings, many more papers were written backing their claims with new evidence that black shales were offshore facies deposited during a transgressive event (James, 1970 and Johnson, 1971).

Finally, in the 1970s, biostratigraphy was introduced to examine the black shales. Seddon and Sweet (1971) found conodonts to be nektic and were able to determine water depth zones. This supported the theory that black shales were offshore facies. Later, Heckel and Baesmann (1975) identified deep water conodonts, *Idioproniodus* and *Gondollela*, in the black, fissile shale. This led them to induce that the limestone, black shale, limestone series were deposited during a transgressive, highstand, regressive event (Heckel, 1984).

The Kansas Cyclothem model was introduced by Heckel in 1977. His model (Figure 9) includes four parts: an outside (nearshore) shale, middle (transgressive) limestone, core (offshore) shale, and upper (regressive) limestone. The core shale is the black fissile shale with phosphate nodules and on overlying gray shale deposited as regression begins. Also, Heckel (1977) introduced a model detailing the deposition of the black shales (Figure 10). He believed

the black shales were deposited in water depths up to 200 meters. This depth allowed for the stratification of the water from winds circulation the water and creating a thermocline. With the cooler waters, came phosphate and an abundance of life, but also depleting the oxygen, thus creating anoxic conditions (Heckel, 1984).

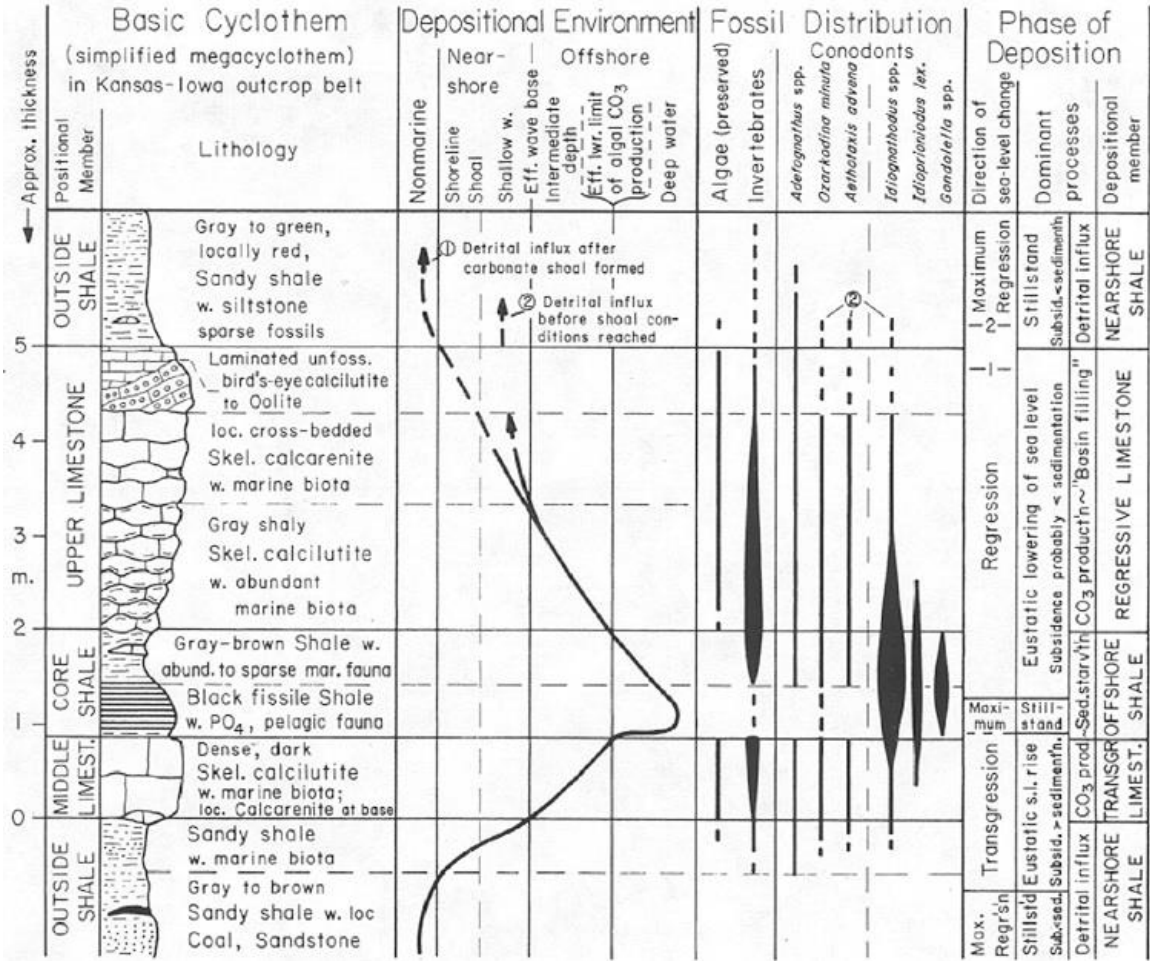


Figure 9. The Pennsylvanian Cyclothem model created by Heckel in 1977.

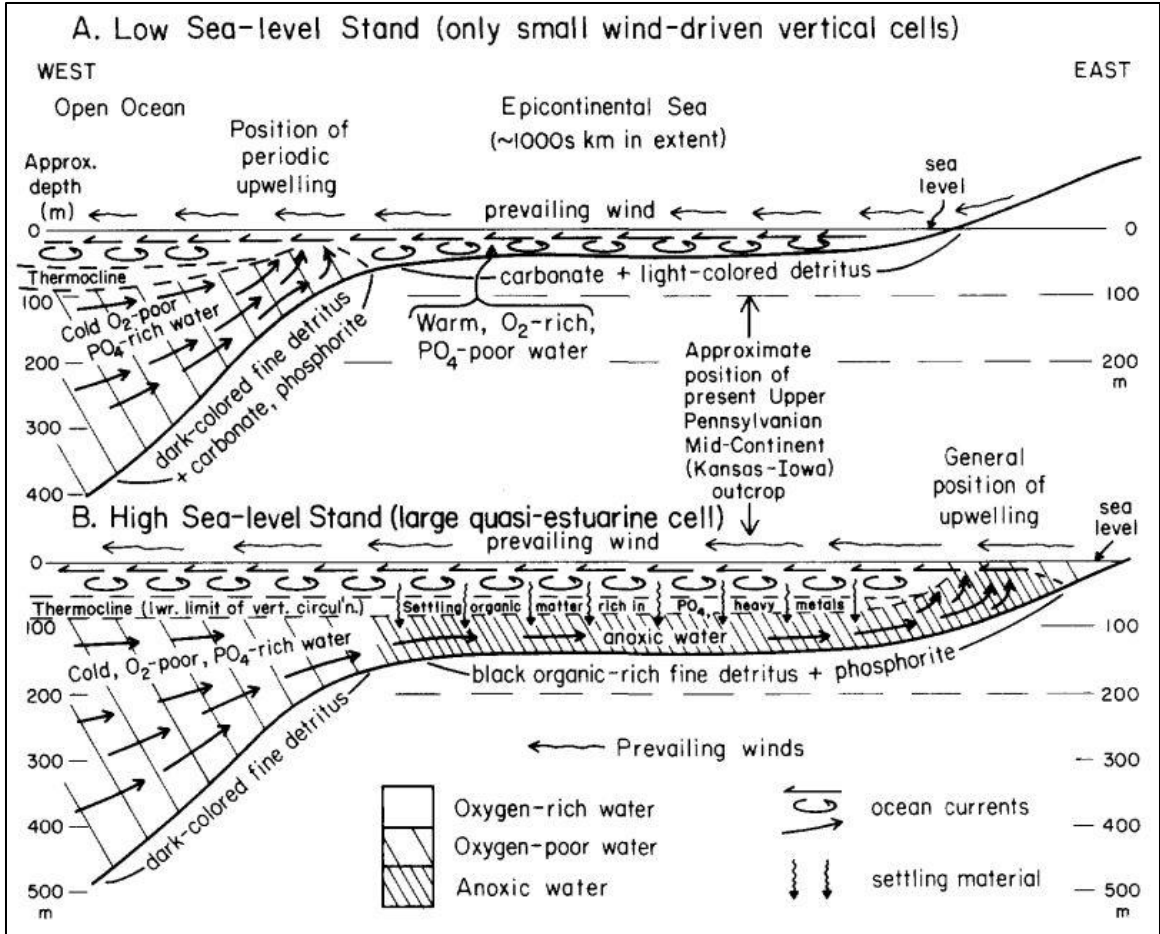


Figure 10. Heckel's model for the deposition of black shales through upwelling, stratification of the water, and ultimately the creation of anoxic conditions (Heckel, 1977).

Conodonts

Inhabiting Paleozoic and Triassic seas, conodonts were first identified and named in 1856 by C. H. Pander (Sweet and Donoghue, 2001). Little research followed until 1926 when E. O. Ulrich and R. S. Bassler provided a summary and classification model. In the 1930s, E. B. Bronson and M. G. Mehl conducted conodont research providing increased taxonomy and knowledge on conodonts (Sweet and Donoghue, 2001). Schmidt (1934) and Scott (1934) found groups of Carboniferous conodonts in black shales.

Initially, all conodonts studied were from loose sandstones and shales, but in the 1950s, the method of extracting conodonts from chemically processed rocks was discovered. Frank Rhodes (1952) laid the foundation of conodont assemblages through his work in the Pennsylvanian of Illinois. Between 1958 and 1966, several papers were written (Huckriede, 1958; Walliser, 1964; Webers, 1966; Bergström and Sweet, 1966) on the classification of large collections which lead to the multi-elemental species. Previously, all conodont analysis was based on individual components (Sweet and Donoghue, 2001). Lindström (1970) created a suprageneric classification of conodonts. During the 1980s, a major discovery for conodont research was made when Briggs, Clarkson, and Aldridge (1983) described a complete conodont fossil.

Recent research (1970–) has dealt with developing ecological models and the environmental interpretation of conodonts. Suddon and Sweet (1971) created a model showing the conodonts and their marine depositional environment. P. H. von Bitter (1972) analyzed the environmental control of Pennsylvanian conodont collections in Kansas. Later, Heckel and Baesmann (1975) built upon the Suddon and Sweet model by combining Baesmann's conodont data with Heckel's lithological observations of Pennsylvanian cyclothems. They created a model of living-depth zones and sedimentary consequences. Boardman et al. (1995) built upon these

models and incorporated other marine microfossils. His onshore-offshore model incorporates depth and oxygen relationships to biofacies.

With the aid of SEM photomicrographs, the morphology and microwear of conodonts has allowed for advances in the taxonomy of conodonts (Rosscoe, 2005). "Microwear is defined as the loss of original element texture" (Rosscoe, 2005). Rosscoe compared the original element texture to the microwear through photomicrographs to determine the functionality of the conodont elements. In his descriptions, Rosscoe utilized the terminology set forth by Purnell et al. (2000). Examining the conodont elements at such a high magnification enabled Rosscoe to notice trends (Figure 9) in the blade and platform morphology of the conodonts and ultimately identify new species. Rosscoe's work could aid in developing a global correlateable boundary between the Middle and Upper Pennsylvanian (Moscovian and Kasimovian). This is evident in the new species of *Idiognathodus* discussed in Rosscoe's paper that matches more commonly with the conodonts used in the boundary (Rosscoe, 2005). Rosscoe also beautifully displays all conodonts found in the Lost Branch Formation (Nuyaka Creek) at the Middle and Upper Pennsylvanian boundary of Oklahoma.

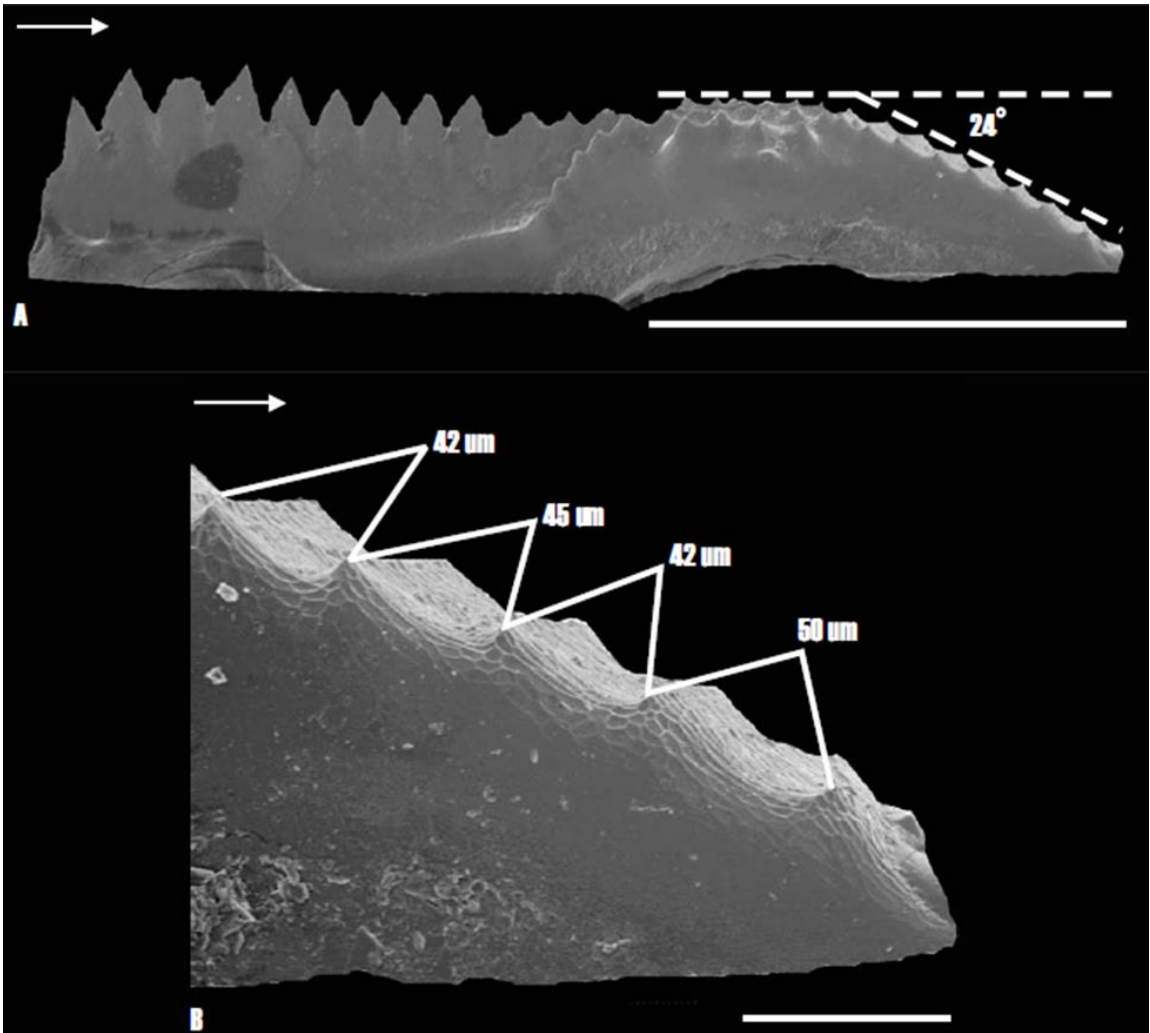


Figure 11. Photomicrograph of Rosscoe's microwear and morphology examinations (Rosscoe, 2005).

Correlation of Cycles

Most of the correlation of Pennsylvanian cycles has been done through outcrop studies. In the Midcontinent, few studies have correlated Pennsylvanian strata to the subsurface like Watney et al. (1999) did in Kansas. Their study utilized outcrop, well-log, and core data to create a stratigraphic framework of Pennsylvanian marine shales (maximum flooding surfaces and condensed sections) in the subsurface. However, the inclusion of biostratigraphic data from the condensed sections is needed for a more accurate and resolute correlation.

Loutit, Hardenbol, and Vail (1988) explain a stratigraphic framework study should include data from three parts: seismic, outcrop, and subsurface data including well-logs and cores. The key to regional and large-scale correlation is through the use of depositional-sequence boundaries and biostratigraphic data in condensed sections. Condensed sections, as defined by Loutit, Hardenbol, and Vail (1999), “are thin marine stratigraphic units consisting of pelagic to hemipelagic sediments characterized by low-sedimentation rates.” They represent deposition at the time of maximum sea-level, and are characterized by diverse and abundant microfossil fauna. The correlation of condensed sections and associated biostratigraphic data allows for the link between shallow and deep water units (Loutit, Hardenbol, and Vail, 1988).

Conodont-based correlations, derived from condensed sections in Pennsylvanian cycles, are common practice now in regional and global studies. Boardman and Heckel (1989) were able to correlate 17 Pennsylvanian sequences from Texas to the Iowa, some 370 miles (600 km), through biostratigraphic data. The condensed sections correlated were the maximum sea-level deposits of dark gray to black phosphatic shales that contained the conodont genera *Idiognathodus*, *Idioprioniodus*, and *Gondolella*. Heckel, Barrick, and Rosscoe (2011) applied this same conodont-based correlation method in the Appalachian Basin where many stratigraphic units were miscorrelated.

The work done by Heckel et al. (2007) has refined correlated the global stage boundaries in the Pennsylvanian in the Midcontinent of North America and eastern Europe. Heckel et al. (2007) correlated sequences in the Midcontinent to sequences in the Moscow Basin and Donets Basin through conodont data. In 2012, M. D. Schmitz and V. I. Davydov added radiometric age data to the biostratigraphic and cyclostratigraphic correlations to establish a pan-Euramerican chronostratigraphic framework. U-Pb zircon ages were taken from ash beds and applied to the existing biostratigraphic framework. The work of Schmitz and Davydov reinforced the previous conodont-based correlations.

CHAPTER II

Stratigraphy

The Middle and Upper Pennsylvanian System examined in this study is divided into three stages: the Desmoinesian, Missourian, and Virgilian. These three stages are divided into seven lithostratigraphic groups (Figure 10) that will be summarized within this chapter. They are in ascending order: the Cherokee, Marmaton, Pleasanton, Kansas City, Lansing, Douglas, and Shawnee Groups. Between these seven groups, they contain 21 condensed sections that were examined within this study.

SYSTEM	SERIES	RUSSIAN STAGE	STAGE	GROUP
CARBONIFEROUS	UPPER PENNSYLVANIAN	GZHELIAN	VIRGILIAN	WABAUNSEE
				SHAWNEE
		DOUGLAS		
		LANSING		
		KANSAS CITY		
	MIDDLE PENN.	KASIMOVIAN	MISSOURIAN	PLEASANTON
				MARMATON
		MOSCOVIAN		CHEROKEE
				DESMOINESIAN

Figure 12. Stratigraphic column of the Middle and Upper Pennsylvanian showing the groups studied highlighted in gray.

Stages

The Desmoinesian Stage was first studied at outcrops along the Des Moines River in Iowa where it got its name from C. R. Keyes (1893). Within the Anadarko Basin, Desmoinesian deposits overly Early Pennsylvanian rocks, however in the Northern Midcontinent Shelf, Desmoinesian rocks rest on pre-Pennsylvanian and Precambrian rocks with an angular unconformity (Moore, 1948; Rascoe, 1962). This overlapping is due to a transgressive event during Desmoinesian time with minor regressive events (Rascoe and Adler, 1983). The Desmoinesian is thickest in the Anadarko Basin, thins on the Northern Midcontinent Shelf with thicknesses ranging from 600 to 750 ft, and thickens again in the Forest City Basin (Heckel, 1999). The thickening rate of Desmoinesian deposits is 10 feet per mile on the shelf and roughly 50 feet per mile within the Anadarko Basin (Rascoe, 1962). Rock types vary between the Anadarko Basin and on the Northern Midcontinent Shelf. The Northern Midcontinent Shelf consists of sequences of shales, limestones, coal beds, and sandstones (Heckel, 1999). While in the Anadarko Basin, the Desmoinesian is dominated by shales and sandstones derived from the Ouachita Mountains (Roscoe and Adler, 1983). The Upper Desmoinesian contains the lithostratigraphic groups the Cherokee, Marmaton, and Pleasanton.

The Missourian Stage was also named by Keyes (1893) for its outcrops on the Missouri River in Iowa and Missouri. Like the Desmoinesian, the Missourian was also deposited during a transgressive time period and oversteps Middle Pennsylvanian rocks to rest on lower Paleozoic and Precambrian rocks in the Northern Midcontinent Shelf with an unconformity (Rascoe and Adler, 1983). On the Northern Midcontinent Shelf, the Missourian has a thickness of roughly 650 ft (Heckel, 1983) and thickens towards the Anadarko Basin at a rate of 4 feet per mile and 18 feet per mile in the Anadarko Basin (Roscoe, 1962). The Missourian thins as northward into Iowa with a thickness of 500 ft (Heckel, 1999). Deposits of the Missourian Stage consist of

clastic facies in the Anadarko Basin with “granite-wash” and “carbonate-wash” clastics being deposited along the Amarillo-Wichita Uplift (Rascoe and Adler, 1983). Along the shelf, the Missourian is comprised of limestone and shale with some sandstone (Heckel, 1999). The Missourian is the unit Heckel (1977) studied to develop his “Kansas Cyclothem” model as the Missourian is dominated by limestone cyclothem with black shale facies in the Northern Midcontinent Shelf (Heckel, 1999). Groups of the Missourian Stage are the Pleasanton, Kansas City, Lansing, and Douglas.

Originally part of the Missourian Stage, the Virgilian Stage was established by Moore (1933) due to a major disconformity. The Virgilian is the thickest of the Middle and Upper Pennsylvanian stages with a thickness of 1400 ft on the Northern Midcontinent Shelf (Heckel, 1999). The thickness of the Virgilian thickens toward the Anadarko Basin at a rate of 6 feet per mile and within the Anadarko Basin thickens at a rate of 22 feet per mile (Rascoe, 1962). The Virgilian deposits are much like the Missourian with mostly shale and limestone with some sandstone. Also within the Virgilian are limestone cyclothem like those found within the Missourian (Heckel, 1999). Lithostratigraphic groups of the Virgilian are the Douglas and Shawnee.

Groups

The Cherokee Group is the basal unit of the Pennsylvanian on the Northern Midcontinent Shelf. The beds of the Cherokee Group are largely shale dominated, alternating with thin limestones, coal-bearing cyclothem, and local sandstones (Rascoe, 1962; Heckel, 1999). These beds encompass the lower Desmoinesian rocks, occupying the interval between the Marmaton Group above and the Atoka Group below. The Cherokee Group is thickest in the Anadarko Basin and thins moving northward. In northeastern Oklahoma the Cherokee reaches

thicknesses of 2,500 ft, thins to about 400 ft in Kansas, and thickens to about 800 ft in the Forest City Basin (Heckel, 1999). The Cherokee Group contains the Oakley Shale condensed section.

Overlying the Cherokee Group is the Marmaton Group and includes nearly all of the upper Desmoinesian Stage. The rocks of the Marmaton consist mostly of limestone and shale with some sandstone and coals (Heckel, 1999). The limestones thicken toward the Anadarko Basin with the addition of shale formations (Rascoe, 1962). On the Northern Midcontinent Shelf, the Marmaton has a maximum thickness of 350 ft (Rascoe, 1962), but the group thins moving northward to 250 ft in Kansas and 140 ft in Iowa due to a decrease in significant subsidence in the Forest City Basin (Heckel, 1999). Southward before entering the Anadarko Basin, the Marmaton Group has thicknesses of 500 ft (Heckel, 1999). The Excello, Little Osage, Anna, Lake Neosho, and Nuyaka Creek Shales were condensed sections examined in the Marmaton.

The Pleasanton Group overlies the Marmaton Group and contains both Desmoinesian and Missourian strata. Due to an increased rate of subsidence in the Northern Midcontinent Shelf, the Pleasanton consists of mostly of shales, sandstones, and only two thin limestones (Rascoe, 1962; Heckel, 1999). The thickness of the Pleasanton is much lower than other groups with 100-150 ft in Kansas (Heckel, 1999). This thickness varies moving north and south depending upon the upper and lower sand intervals.

Lying above the Pleasanton Group is the Kansas City Group containing a large portion of the Missourian Stage. The Kansas City Group consists of limestone-dominated cyclothems and shale formations (Heckel, 1999). The limestone formations are thick, massive, and merge together moving towards the Anadarko Basin (Rascoe, 1962). In the Anadarko Basin, the limestones change to shale sequences with sandstones and thin limestones (Rascoe, 1962). The Kansas City Group is about 150 ft thick in Iowa, 300 ft thick in Kansas, and thickens in the

Anadarko Basin (Heckel, 1999). The Kansas City Group contains the Mound City, Hushpuckney, Stark, Block/Wea, Quivira, Muncie Creek, and Quindaro shale condensed sections that were sampled in the study.

The Lansing Group overlies the Kansas City Group in the Missourian Stage. The contact between the Lansing and Kansas City is conformable south of Kansas City and disconformable northward (Heckel, 1999). Much like the previous groups, the Lansing contains limestone-dominated cyclothems (Heckel, 1999). Thickness ranges from 50 ft in Iowa, 80 ft in Kansas, and increase to 200 ft in southern Kansas (Heckel, 1999). Condensed sections examined within the Lansing Group are the Hickory Creek Shale, Eudora Shale, and Gretna Shale.

Overlying the Lansing Group is the Douglas Group with strata from the Missourian and Virgilian Stage. Rocks of the Lansing are red and gray sandy shales separated by a thin limestone cyclothem (Rascoe, 1962; Heckel, 1999). Local, thick sandstones occur throughout the Douglas (Rascoe, 1962). The Douglas Group is thinnest in Iowa at about 60 ft, thickens to about 240 ft in Kansas, and thickens to 500 ft in southern Kansas (Heckel, 1999).

The Shawnee Group of the Virgilian overlies the Douglas Group disconformably. This is not the last group of the Pennsylvanian, but is the last group included within the study. The Shawnee is comparable to the Pleasanton Group in that the limestone formations thicken, merge, and become massive towards the Anadarko Basin (Rascoe, 1962). The limestone formations make up four thick cyclothems in the Shawnee (Heckel, 1999). The Shawnee is 200 ft thick in Nebraska, thickens to about 330 ft thick in northeastern Kansas, and thickens more moving south and into the Anadarko Basin (Heckel, 1999).

CHAPTER III

RESULTS

Conodont Distribution

In the Cherokee Group, only one condensed section was examined for conodonts. The Oakley Shale Member (Plate 1) yielded species of *Idiognathodus*. In the Marmaton Group, conodonts were identified in five condensed sections: the Excello Shale Member, Little Osage Shale Member, Anna Shale Member, Lake Neosho Shale Member, and Nuyaka Creek Shale Member. The Excello Shale Member (Plates 2 and 3) is dominated by *Idiognathodus* and contains *Gondolella* and *Neognathodus*. In the Little Osage Shale Member (Plates 4 and 5), abundant *Idiognathodus* is present along with *Neognathodus* and *Idiopriodontus*. The Anna Shale Member (Plates 6 and 7) is much like the Little Osage Shale Member containing *Idiognathodus*, *Neognathodus*, and *Idiopriodontus*. The Lake Neosho Shale Member (Plate 8) marks the first appearance of *Swadelina*. Many *Neognathodus*, are present as well as *Idiognathodus* and *Idiopriodontus*. The last condensed section in the Marmaton is the Nuyaka Creek Shale Member (Plate 9). Within the Nuyaka Creek Shale Member is the identifier *Swadelina nodocarinata*. Also observed are *Gondolella magna*, *Neognathodus roundyi*, *Neognathodus expansus*, *Idiognathodus expansus*, and *Idiopriodontus*.

The next examined group containing examined condensed sections is the Kansas City Group. The Mound City Shale Member (Plate 10) is dominated by *Idiognathodus* and contains

some *Gondolella*. Overlying the Mound City Shale Member is the Hushpuckney Shale Member (Plates 11 and 12). *Idiognathodus* were plentiful in the Hushpuckney Shale Member with some *Gondolella*. In the Stark Shale Member (Plate 13), species of *Idiognathodus* is dominate including *I. cancellosus*, *I. magnificus*, *I. fusiformis*, *I. folium*, *I. corrugatus*, *I. confragus*, *I. biluratus* and *I. cherryvalensis*. *Gondolella* was also present in the Stark Shale Member. The next overlying condensed section is the Block Limestone Member (Plates 14 and 15) which marks the first appearance of *Streptognathodus*. In the Block Limestone Member, *Idiognathodus* and *Streptognathodus* are abundant including, *I. cherryvalensis*, *I. symmetricus*, *I. corrugatus*, *I. magnificus*, and *I. species 4* (Rosscoe, 2008). *Streptognathodus* observed are *S. gracilis*, *S. elegantulus*, and *S. excelsus*. The Quivira Shale Member (Plates 16 and 17) of the Kansas City Group contained abundant *Streptognathodus*, *Idiognathodus*, and *Gondolella* as well as *Idiopriodontus*. *Idiognathodus* observed were *I. magnificus*, *I. cancellosus*, *I. turbatus*, and *I. corrugatus*. *Streptognathodus* observed were *S. gracilis*, *S. excelsus*, and *S. elegantulus*. The Muncie Creek Shale Member (Plates 18 and 19) is dominated by *Idiognathodus magnificus* and *Streptognathodus*. *Gondolella* are also present in the Muncie Creek Shale Member. *Streptognathodus* observed include *S. gracilis*, *S. excelsus*, and *S. elegantulus*. The Quindaro Shale Member (Plate 19) is the last condensed section of the Kansas City Group and contains *Streptognathodus*.

The Lansing Group contains three condensed sections: the Hickory Creek Shale Member, Eudora Shale Member, and the Gretna Shale Member. The Hickory Creek Shale Member (Plate 19) and Gretna Shale Member (Plate 21) contain abundant *Streptognathodus*. In the Eudora Shale Member (Plate 20), *Streptognathodus*, *Idiognathodus*, and *Gondolella* are observed.

In the Douglas Group, the Iatan Limestone Member (Plate 22) and Little Pawnee Shale Member (Plate 22) are dominated by *Streptognathodus*. The last group examined in the study is

the Shawnee Group which contains the Toronto Limestone Member (Plate 23) and the Heebner Shale Member (Plate 23). These two condensed sections contain *Idiognathodus*, *Streptognathodus*, and *Idiopriionodus*.

Correlated Condensed Sections

Out of the 11 cores in the Anadarko Basin that were processed, 6 contained conodonts. The five cores that did not yield conodonts is due to a couple of reasons 1) the cored interval contained a hot shale marker that was not a condensed section or 2) the core depth differed from the logging depth meaning the core did not contain a condensed section as the well-log suggests. Problem one was an issue in Cores #1 and #2 while problem two was an issue in Cores #3, #9, and #10. Conodonts recovered from Cores #4, #5, #6, #7, #8, and #11 were correlated to outcrop condensed sections (Figure 13). Some condensed sections were correlated based upon cyclostratigraphy.

Core #11 (Plate 25) contains the Nuyaka Creek Shale Member due to the presence of *Swadelina nodocarinata*. This condensed section also contained *Neognathodus* and *Gondolella*. The Stark Shale Member was correlated to Core #7 (Plate 26). *Idiognathodus* is dominate in this interval, including *I. cancellosus*, *I. magnificus*, *I. corrugatus*, *I. fusiformis*, and *I. cherryvalensis*. Core #8 (Plate 27) was originally believed to contain the Stark Shale Member, but with the appearance of *Streptognathodus* it correlates with the Block Limestone Member. This condensed section contains *S. gracilis*, *S. elegantulus*, and *S. exculsus*. *Idiognathodus* observed are *I. species 4*, *I. fusiformis*, and *I. corrugatus*. The condensed sections in Core #6 and Core #5 correlate to the Quivira Shale Member. In Core #6 (Plate 29), *Idiognathodus magnificus* and abundant *Streptognathodus* were observed including *S. gracilis*, *S. excelsus*, and *S. elegantulus*. In Core #5 (Plate 28), abundant *Idiognathodus magnificus* and *Gondolella* are present. Core #4

(Plates 30 and 31) contains *Idiognathodus magnificus*, *Gondolella*, and *Streptognathodus* including *S. gracilis* and *S. excelsus*. Core #4 correlates to the Muncie Creek Shale Member.

Some of the hot shale markers observed in the subsurface that could not be sampled or conodonts were not recovered from were correlated based upon stratigraphic relationship to the correlated units. The hot shale marker overlying the Muncie Creek Shale Member in the subsurface is believed to be the Eudora Shale Member. This is due to the Eudora being the next major cycle above the Muncie Creek Shale. Two hot shale markers lie between the Nuyaka Creek Shale Member and Stark Shale Member. These are thought to be the Mound City Shale Member and the Hushpuckney Shale Member as these are the only major cycles in that interval.

Cross-sections show these condensed sections are laterally extensive and can be easily correlated throughout the Anadarko basin in an area five counties wide. Six cross-sections can be seen in Appendix B.

Plate 1

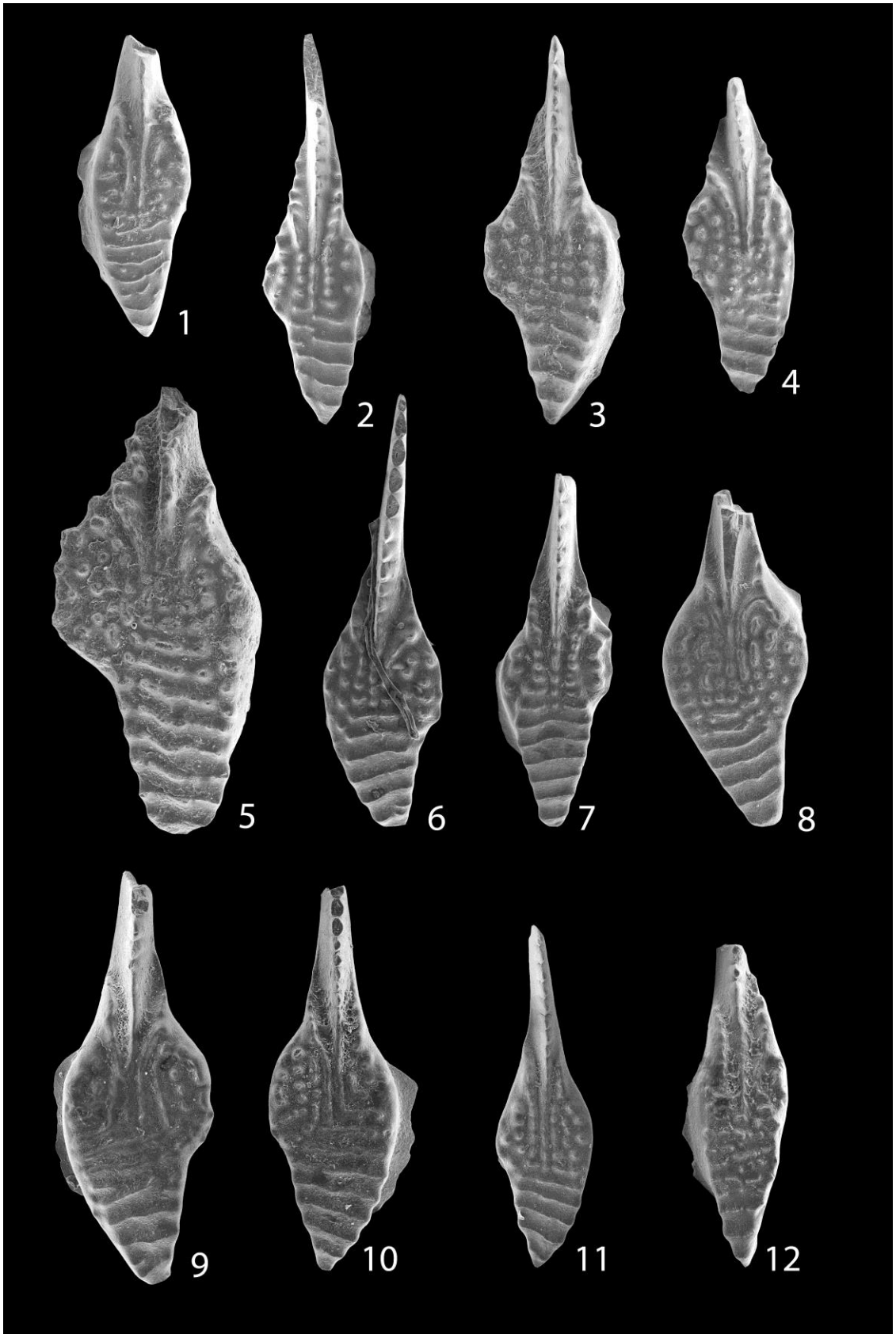


Plate 1. Photomicrographs of *Idiognathodus* from the Oakley Shale Member. All specimens are shown at a magnification of 60X. Specimens were recovered from Locality #24 in Wagoner County, Oklahoma. Figures 1-12. *Idiognathodus*.

Plate 2

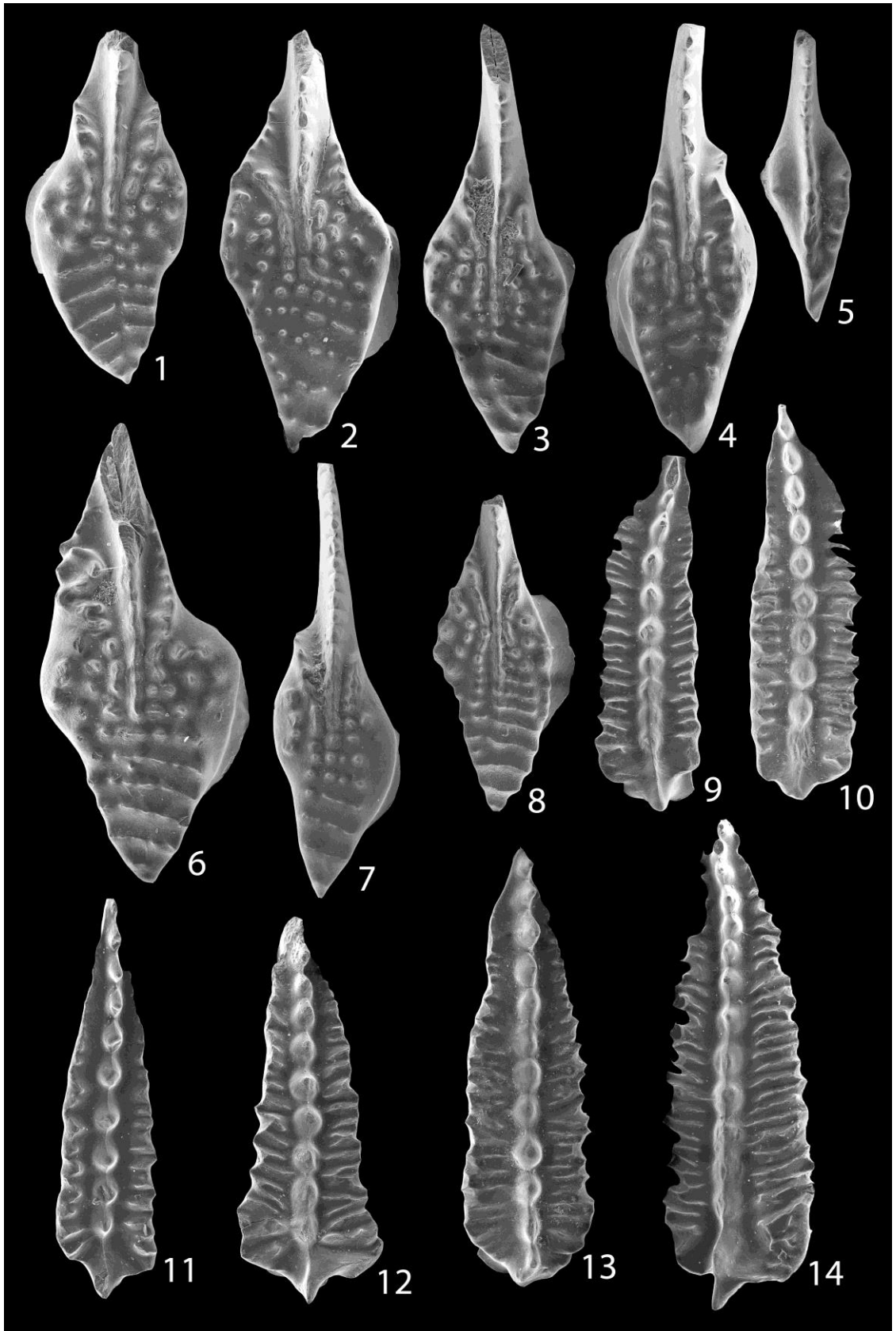


Plate 2. Photomicrographs of *Idiognathodus*, *Gondolella*, and *Neognathodus* from the Exello Shale Member. All specimens are shown at a magnification of 60X. Specimens were recovered from Locality #23 in Dallas County, Iowa. Figures 1-4, 6-8. *Idiognathodus*. Figure 5. *Neognathodus*. Figures 9-14. *Gondolella*.

Plate 3

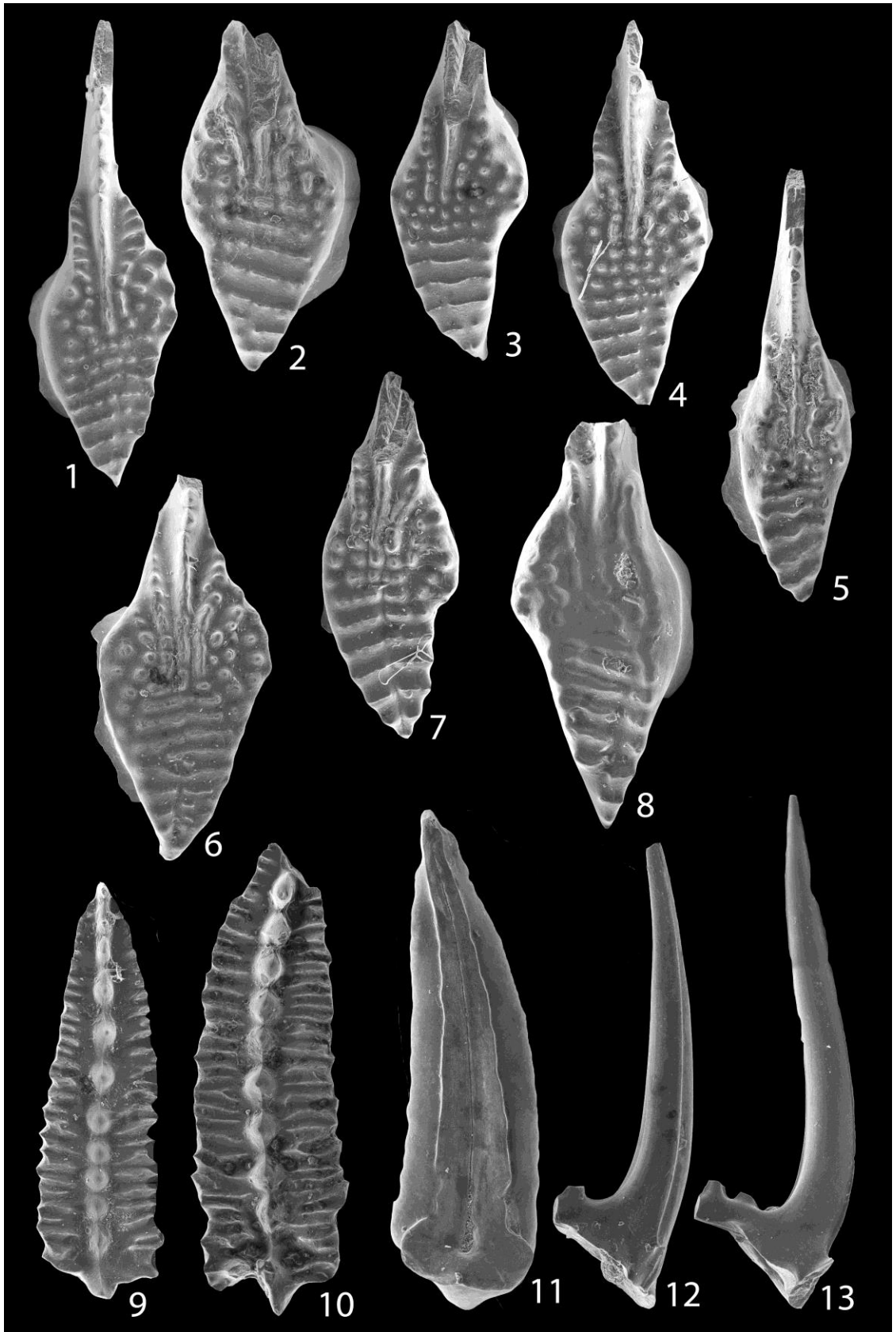


Plate 3. Photomicrographs of *Idiognathodus*, *Gondolella*, and *Idiopriionodus* from the Excello Shale Member. All specimens are shown at a magnification of 60X. Specimens were recovered from Locality #23 in Dallas County, Iowa. Figures 1-8. *Idiognathodus*. Figures 9-11. *Gondolella*. Figures 12, 13. *Idiopriionodus*.

Plate 4

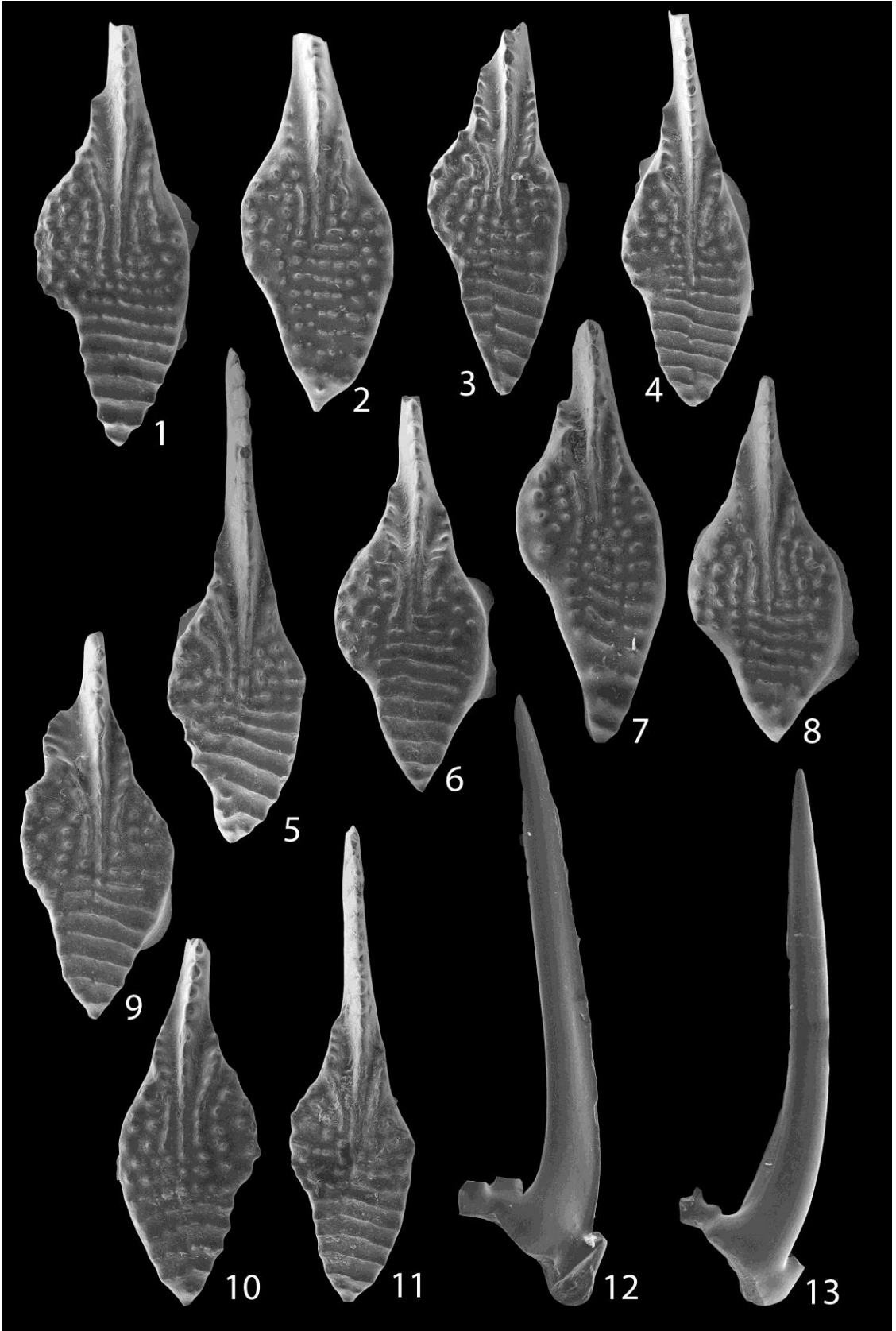


Plate 4. Photomicrographs of *Idiognathodus* and *Idiopriionodus* from the Little Osage Shale Member. All specimens are shown at a magnification of 60X. Specimens were recovered from Locality #20 in Dallas County, Iowa. Figures 1-11. *Idiognathodus*. Figures 12, 13. *Idiopriionodus*.

Plate 5

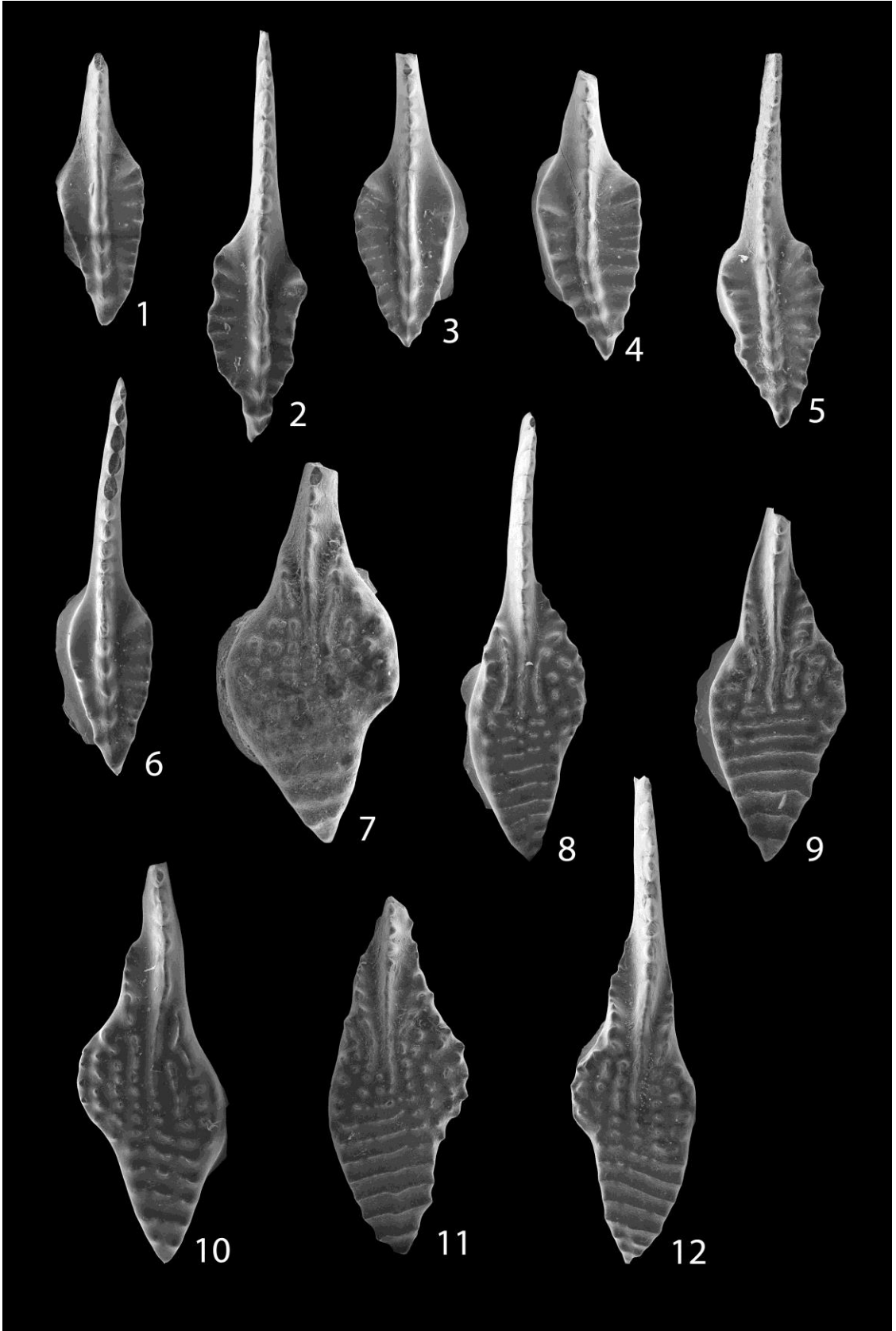


Plate 5. Photomicrographs of *Idiognathodus* and *Neognathodus* from the Little Osage Shale Member. All specimens are shown at a magnification of 60X. Specimens were recovered from Locality #20 in Dallas County, Iowa. Figures 1- 6. *Neognathodus*. Figures 7-12. *Idiopriionodus*.

Plate 6

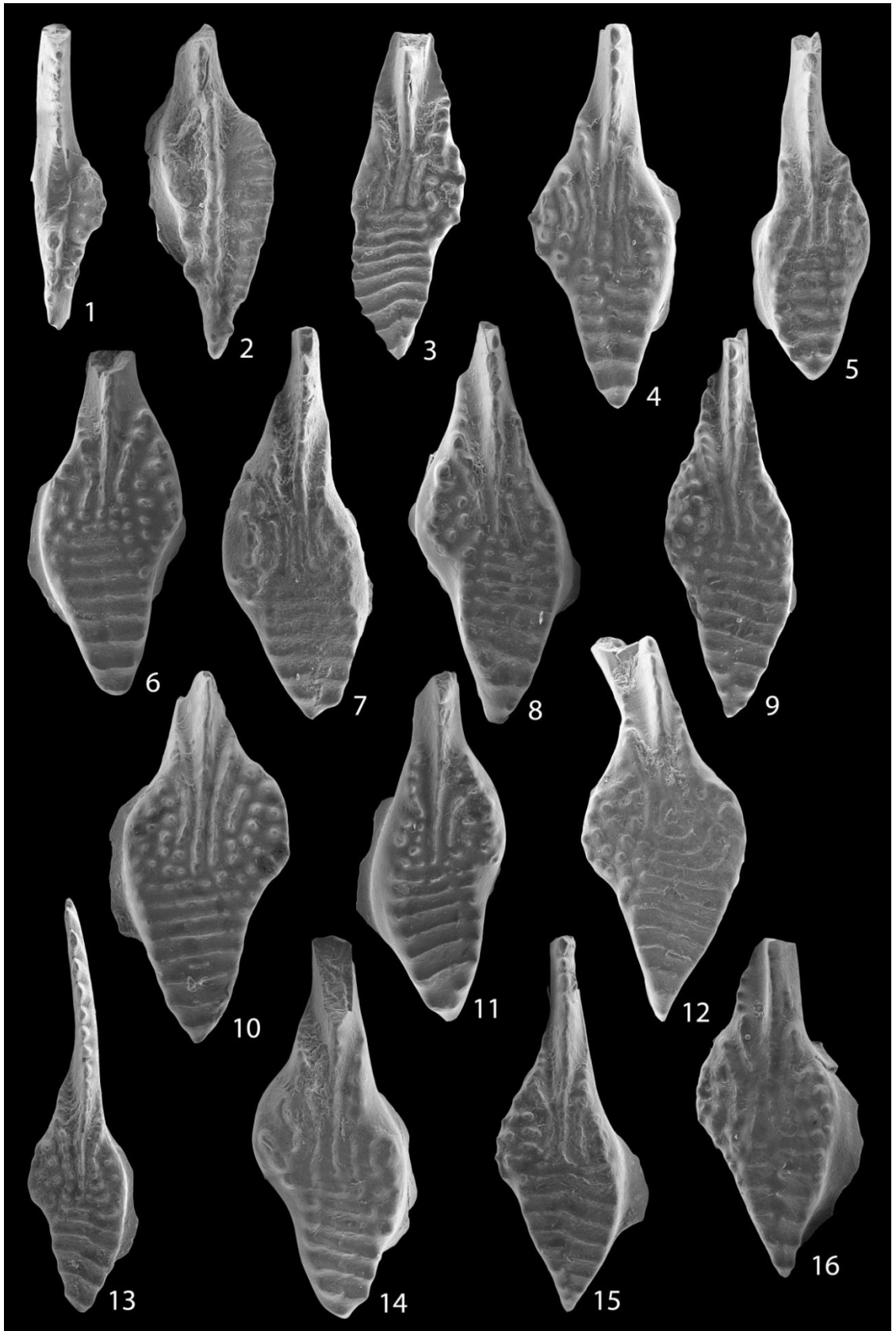


Plate 6. Photomicrographs of *Idiognathodus* and *Neognathodus* from the Anna Shale Member. All specimens are shown at a magnification of 60X. Specimens were recovered from Locality #19 in Rogers County, Oklahoma. Figures 1, 2. *Neognathodus*. Figures 3-16. *Idioprionodus*.

Plate 7

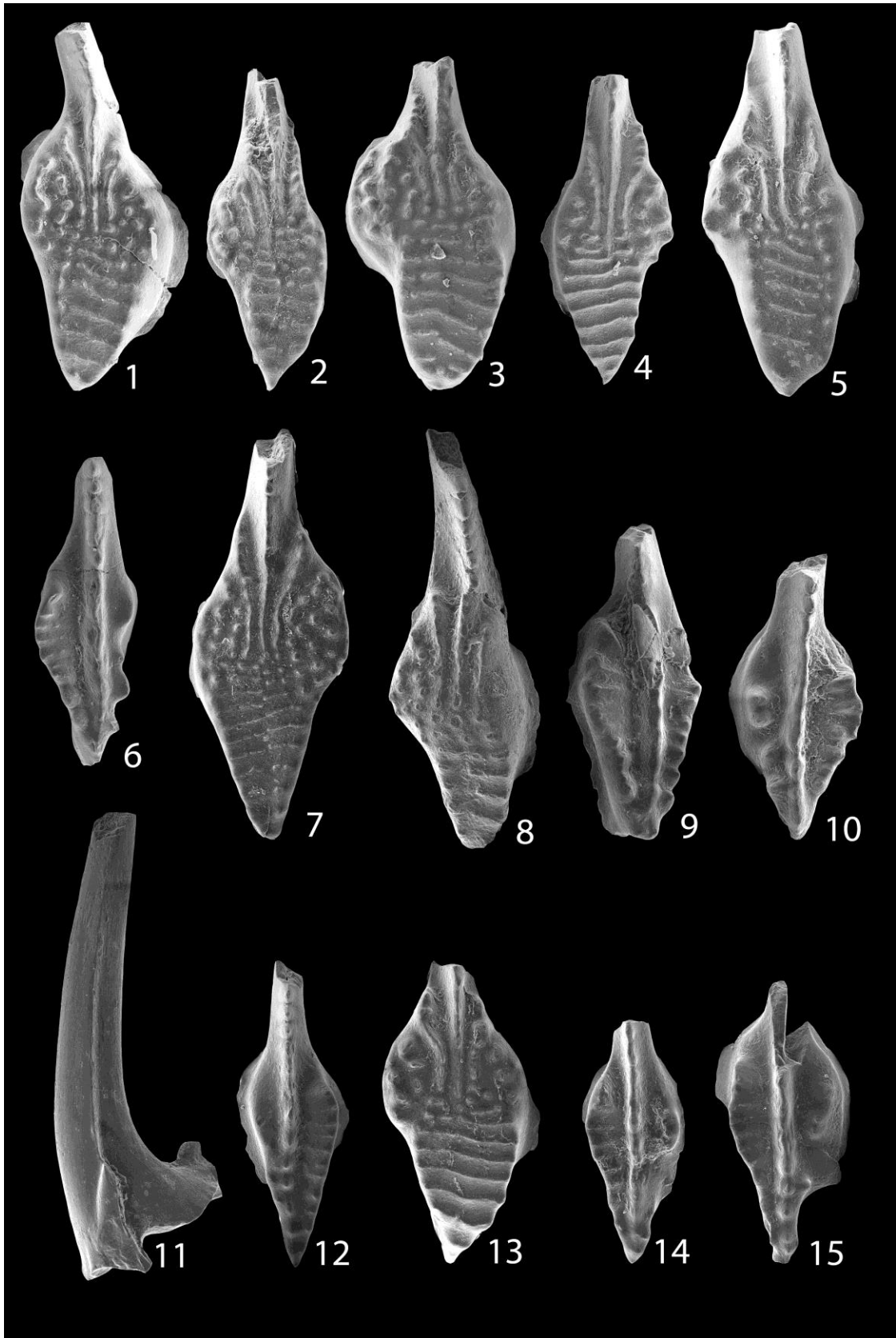


Plate 7. Photomicrographs of *Idiognathodus*, *Neognathodus* and *Idiopriionodus* from the Anna Shale Member. All specimens are shown at a magnification of 60X. Specimens were recovered from Locality #19 in Rogers County, Oklahoma. Figures 1-5, 7, 8, 13. *Idiognathodus*. Figures 6, 9, 10, 12, 14, 15. *Neognathodus*. Figure 11. *Idiopriionodus*.

Plate 8

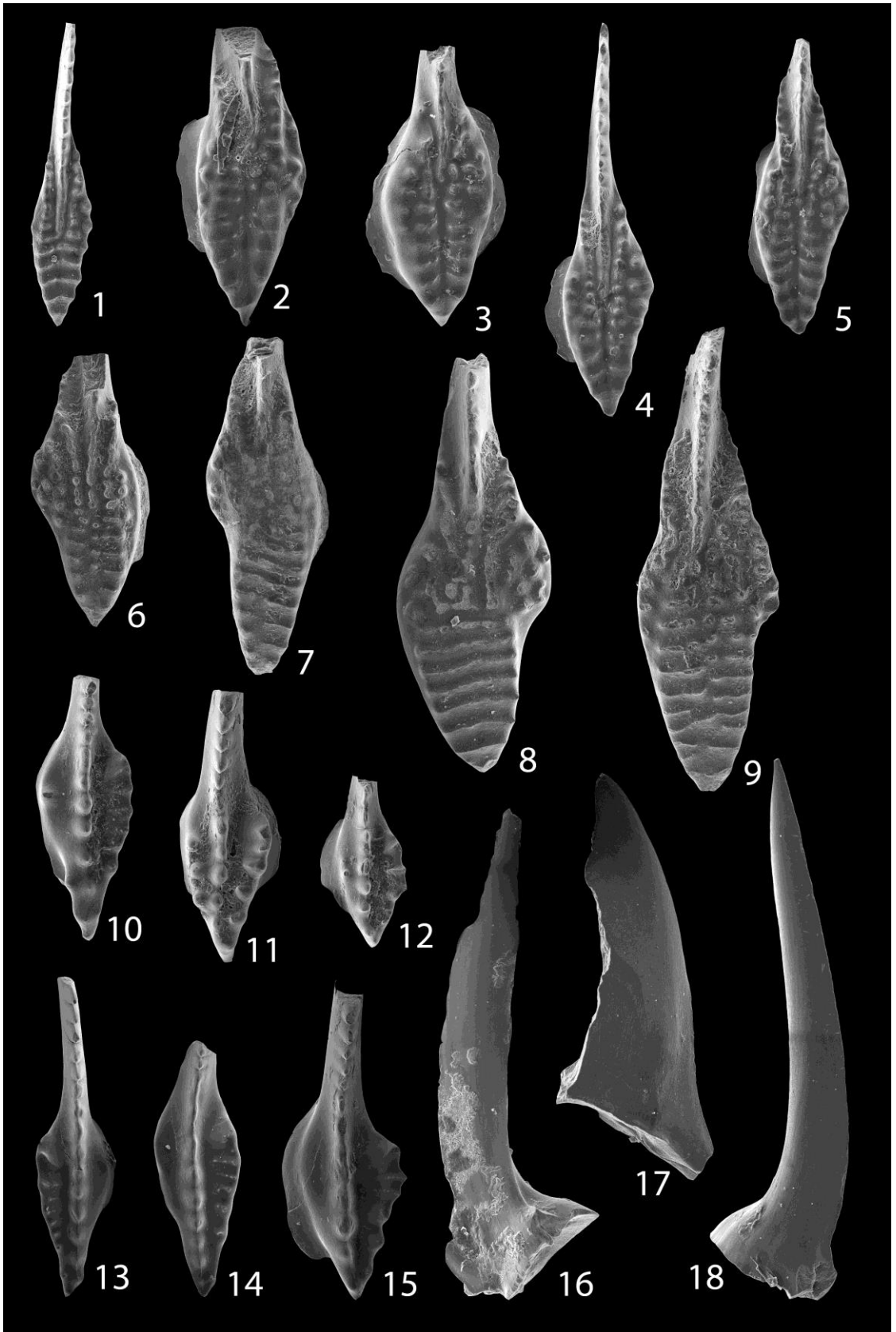


Plate 8. Photomicrographs of *Idiognathodus*, *Swadelina*, *Neognathodus* and *Idiopriionodus* from the Lake Neosho Shale Member. All specimens are shown at a magnification of 60X. Specimens were recovered from Locality #17 in Nowata County, Oklahoma. Figures 1, 7-9. *Idiognathodus*. 2-6. *Swadelina neoshoensis*. Figures 10-15. *Neognathodus*. Figures 16-18. *Idiopriionodus*.

Plate 9

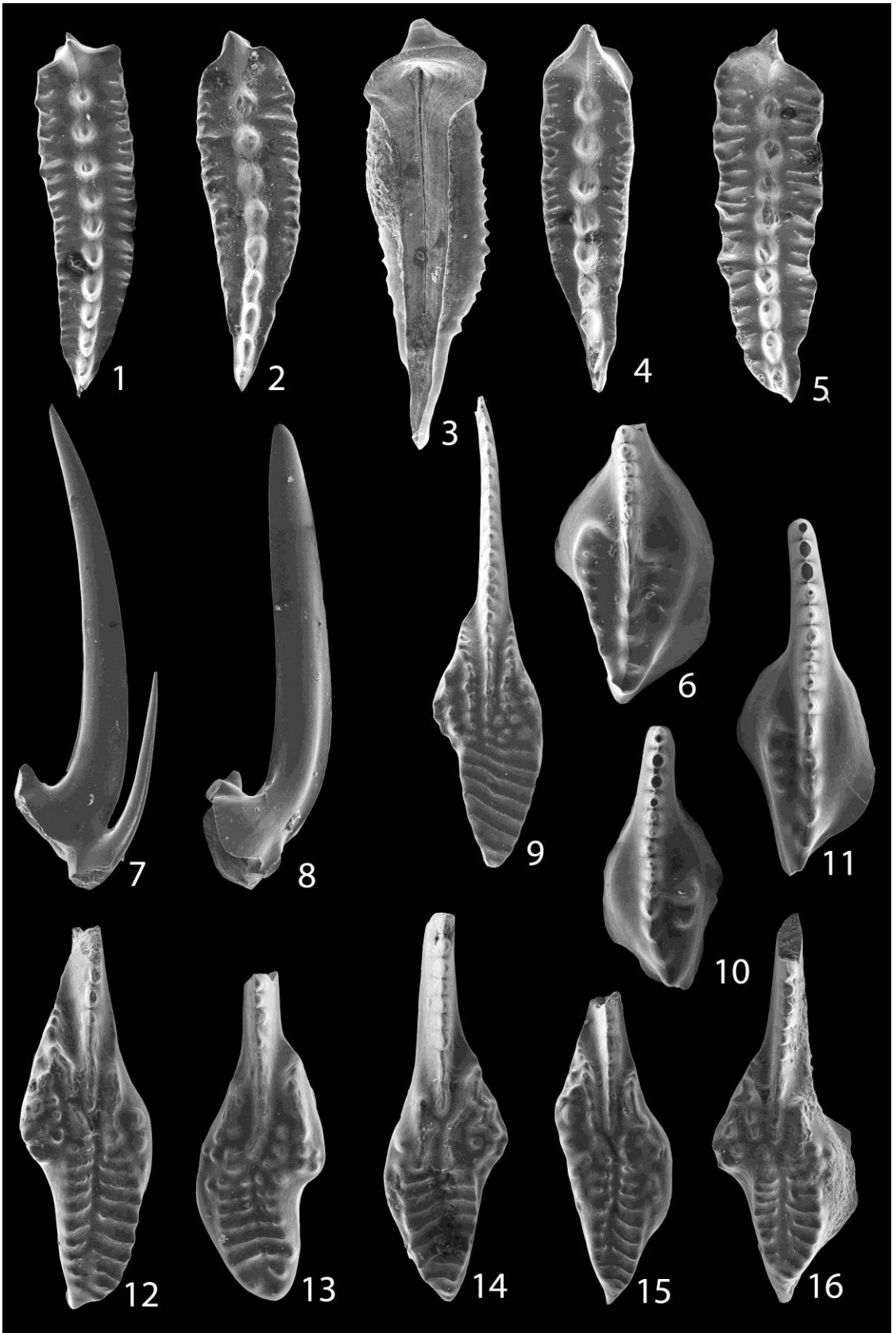


Plate 9. Photomicrographs of *Gondolella*, *Idiognathodus*, *Swadelina*, *Neognathodus* and *Idioprionodus* from the Nuyaka Creek Shale Member. All specimens are shown at a magnification of 60X. Specimens were recovered from Locality #15 in Madison County, Iowa. Figures 1-5. *Gondolella*. Figure 6. *Neognathodus expansus expansus*. Figures 7, 8. *Idioprionodus*. Figure 9. *Idiognathodus expansus*. Figures 10, 11. *Neognathodus roundyi*. Figures 12-16. *Swadelina nodocarinata*.

Plate 10

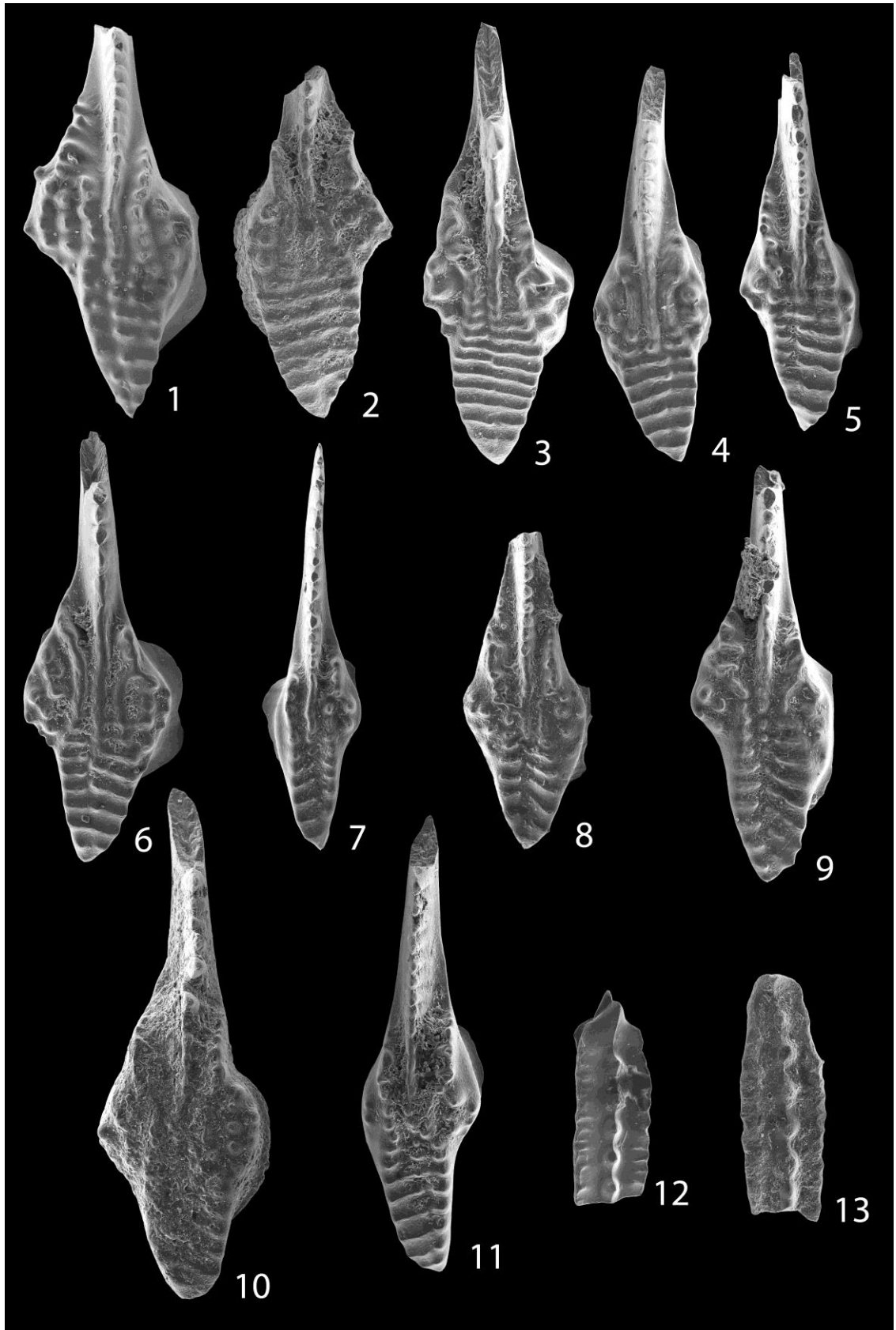


Plate 10. Photomicrographs of *Idiognathodus* and *Gondolella* from the Mound City Shale Member. All specimens are shown at a magnification of 60X. Specimens were recovered from Locality #13 in Nowata County, Oklahoma and Locality #14 in Bourbon County, Kansas. Figures 1-11. *Idiognathodus*. Figures 12, 13. *Gondolella*.

Plate 11

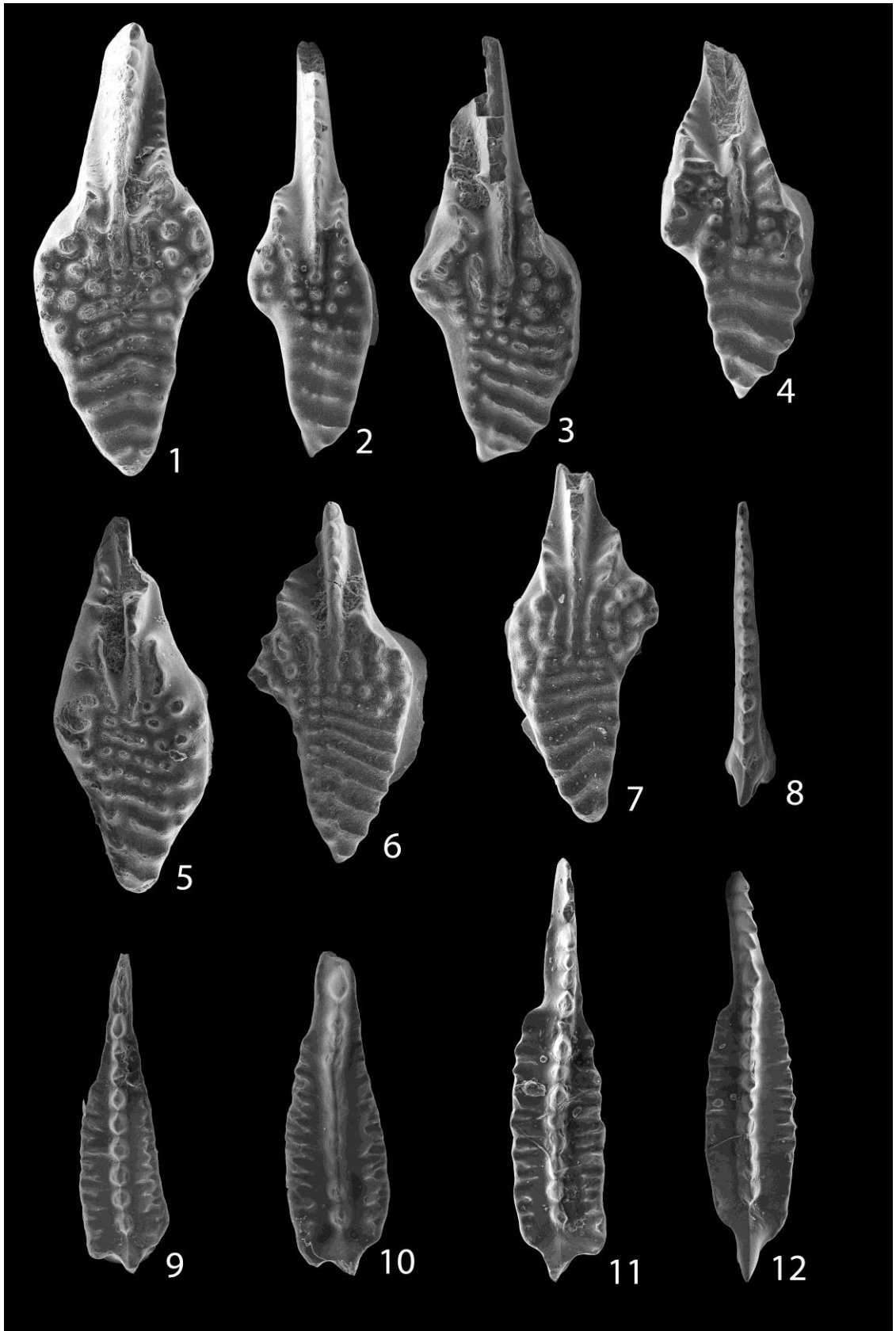


Plate 11. Photomicrographs of *Idiognathodus* and *Gondolella* from the Hushpuckney Shale Member. All specimens are shown at a magnification of 60X. Specimens were recovered from Locality #12 in Jackson County, Missouri. Figures 1-7. *Idiognathodus*. Figures 8-12. *Gondolella*.

Plate 12

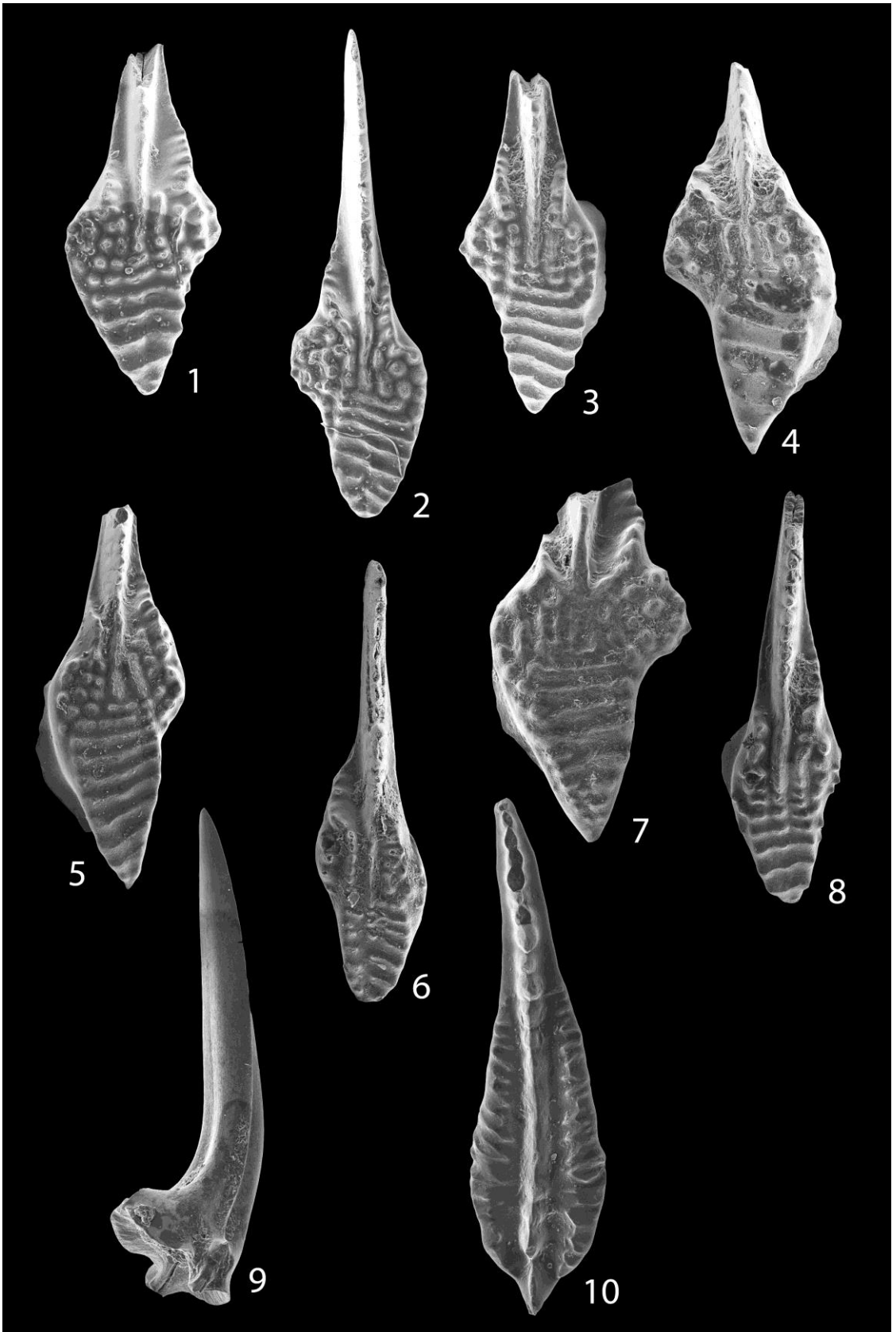


Plate 12. Photomicrographs of *Idiognathodus*, *Gondolella*, and *Idiopriionodus* from the Hushpuckney Shale Member. All specimens are shown at a magnification of 60X. Specimens were recovered from Locality #12 in Jackson County, Missouri. Figures 1-8. *Idiognathodus*. Figure 9. *Idiopriionodus*. Figure 10. *Gondolella*.

Plate 13

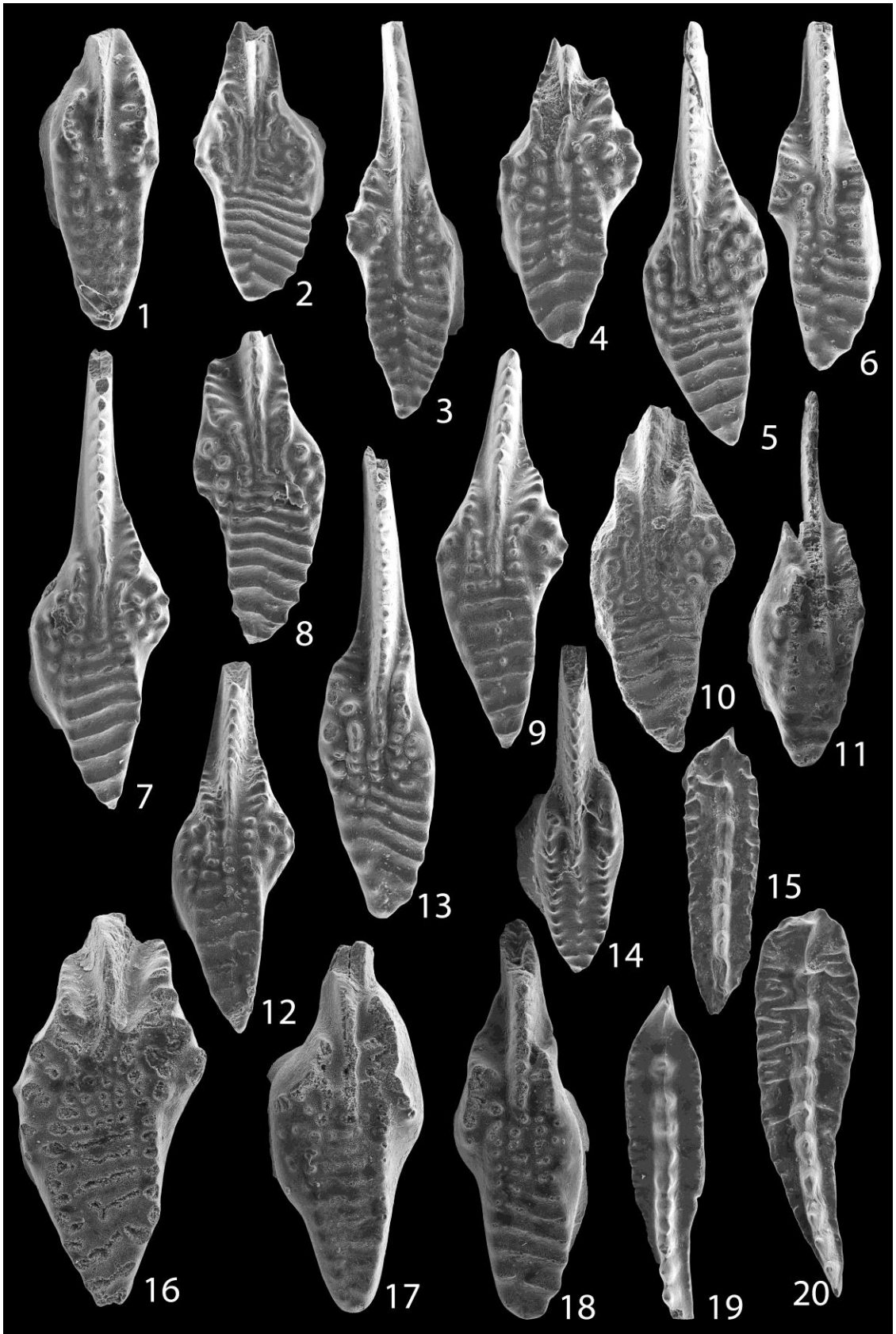


Plate 13. Photomicrographs of *Idiognathodus* and *Gondolella* from the Stark Shale Member. All specimens are shown at a magnification of 60X. Specimens were recovered from Locality #11 in Washington County, Oklahoma. Figures 1, 3, 4, 11, 16. *Idiognathodus cancellosus*. Figure 2. *Idiognathodus magnificus*. Figures 5, 10, 13. *Idiognathodus folium*. Figure 6. *Idiognathodus corrugatus*. Figures 7, 9. *Idiognathodus fusiformis*. Figures 8, 17, 18. *Idiognathodus confragus*. Figure 14. *Idiognathodus biliratus*. Figures 15, 19, 20. *Gondolella*.

Plate 14

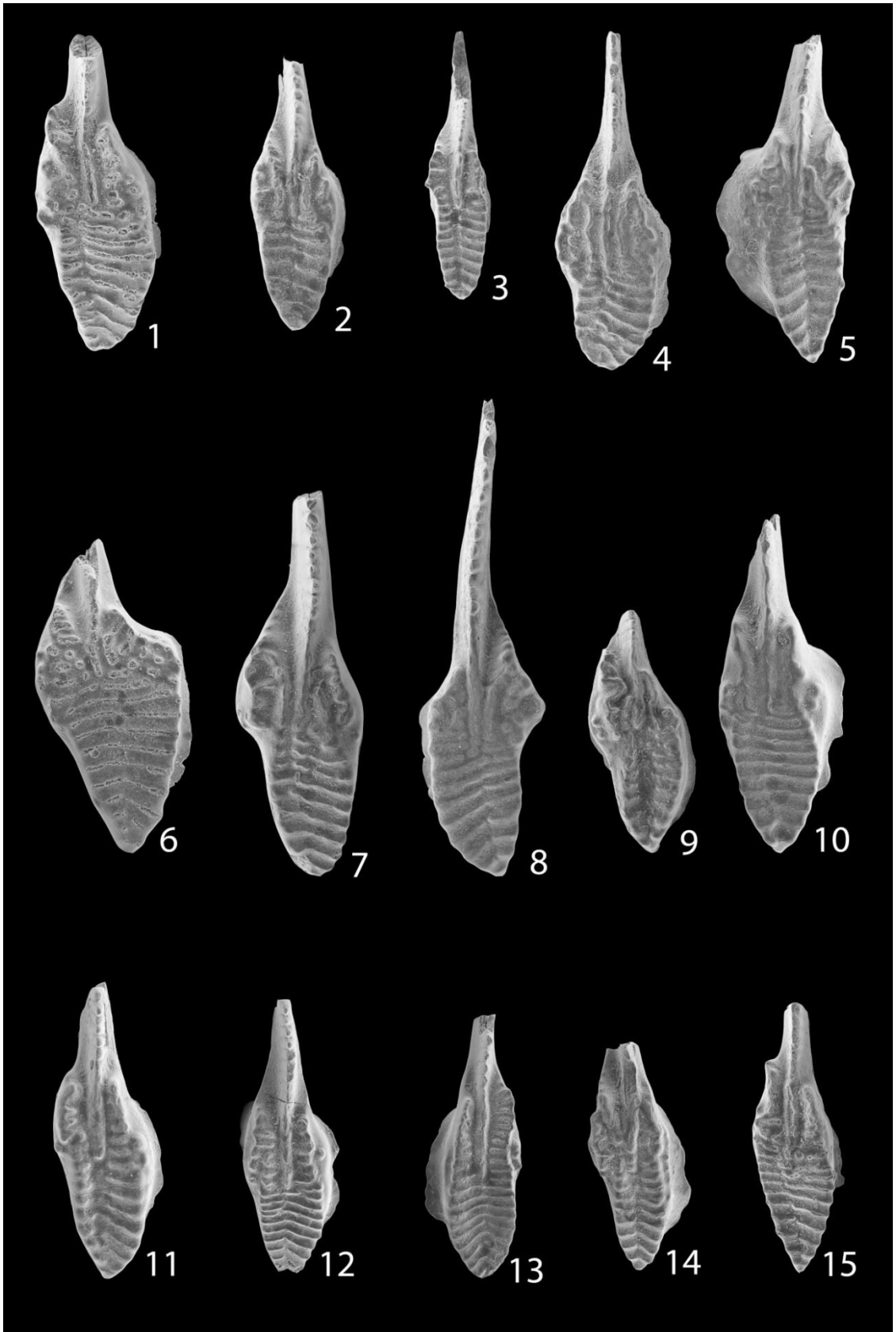


Plate 14. Photomicrographs of *Idiognathodus* and *Streptognathodus* from the Block Limestone Member. All specimens are shown at a magnification of 60X. Specimens were recovered from Locality #10 in Montgomery County, Kansas. Figures 1, 5, 6, 8, 10. *Idiognathodus magnificus*. Figure 2. *Idiognathodus symmetricus*. Figure 3. *Streptognathodus elegantulus*. Figures 4, 7. *Idiognathodus corrugatus*. Figures 9, 11. *Streptognathodus excelsus*. Figures 12, 14, 15. *Idiognathodus cherryvalensis*. Figure 13. *Idiognathodus multinodosus*.

Plate 15

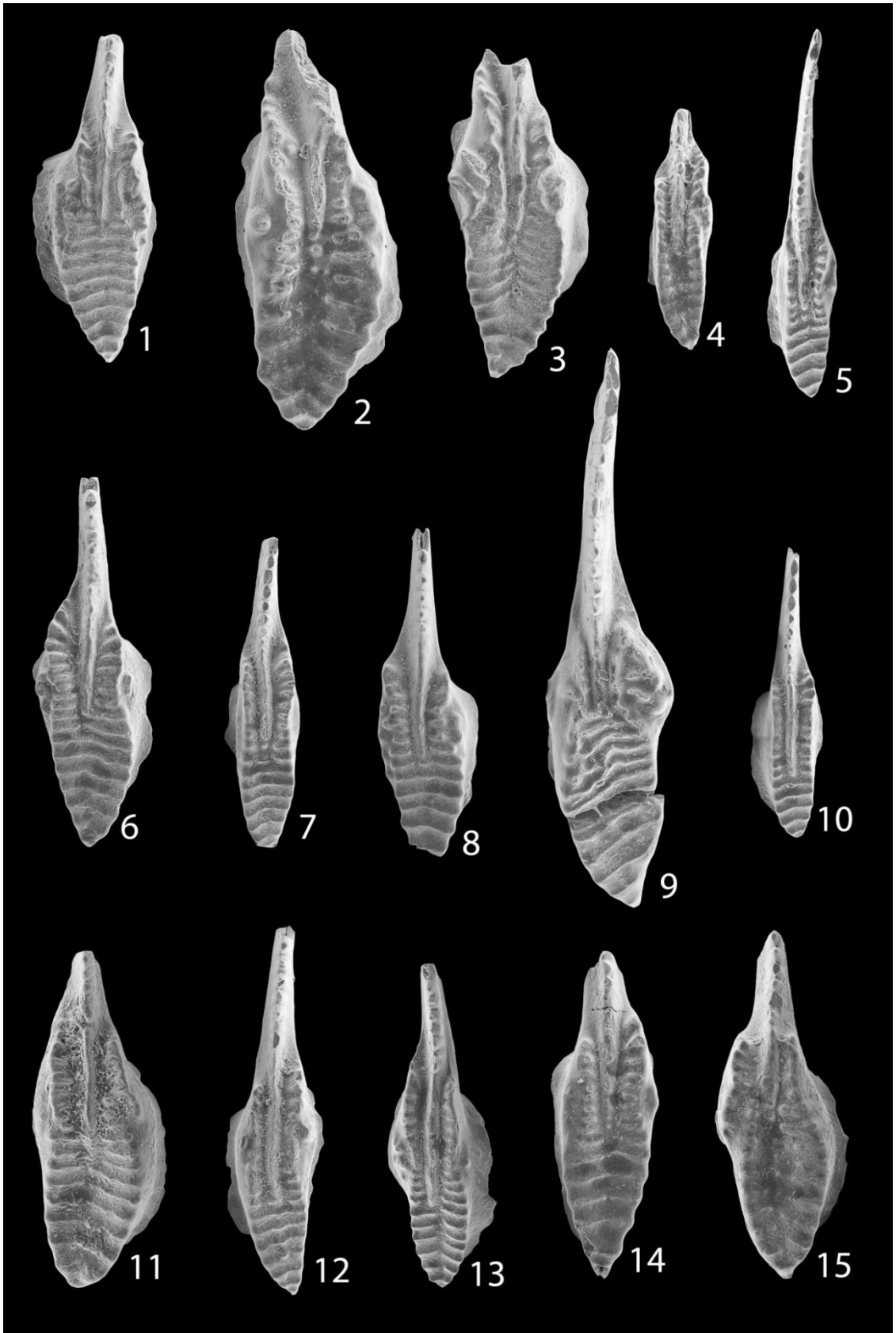


Plate 15. Photomicrographs of *Idiognathodus* and *Streptognathodus* from the Block Limestone Member. All specimens are shown at a magnification of 60X. Specimens were recovered from Locality #10 in Montgomery County, Kansas. Figures 1, 8, 14. *Idiognathodus symmetricus*. Figure 2. *Streptognathodus sulcatus*. Figures 3, 5-7, 10-13. *Idiognathodus cherryvalensis*. Figures 4, 15. *Streptognathodus gracilis*. Figure 9. *Idiognathodus magnificus*.

Plate 16

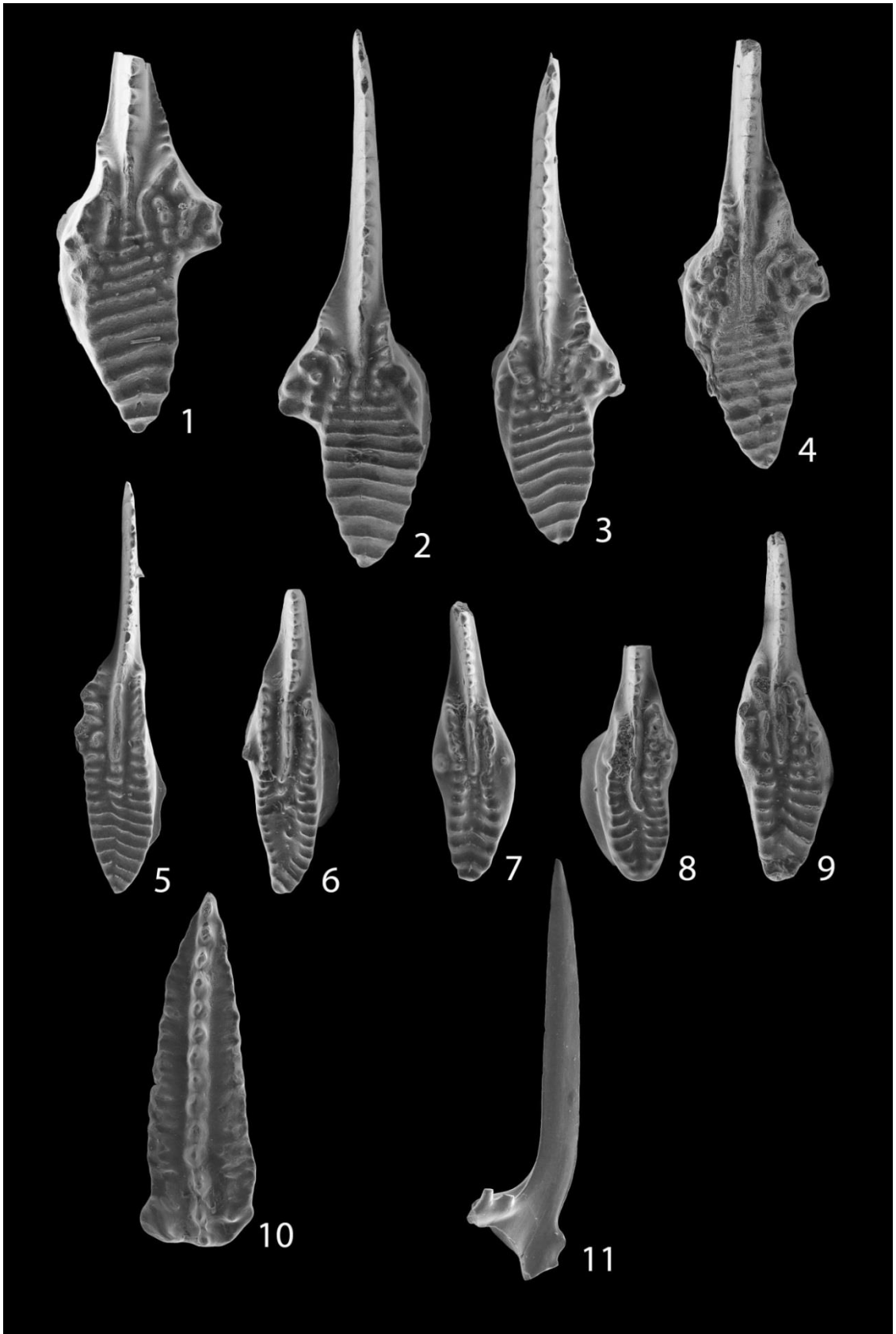


Plate 16. Photomicrographs of *Idiognathodus*, *Streptognathodus*, *Gondolella*, and *Idiopriionodus* from the Quivira Shale Member. All specimens are shown at a magnification of 60X. Specimens were recovered from Locality #9b in Wyandotte County, Kansas. Figures 1-4. *Idiognathodus magnificus*. Figures 5, 6. *Streptognathodus elegantulus*. Figure 7. *Streptognathodus gracilis*. Figure 8. *Streptognathodus increbescens*. Figure 9. *Streptognathodus excelsus*. Figure 10. *Gondolella*. Figure 11. *Idiopriionodus*.

Plate 17

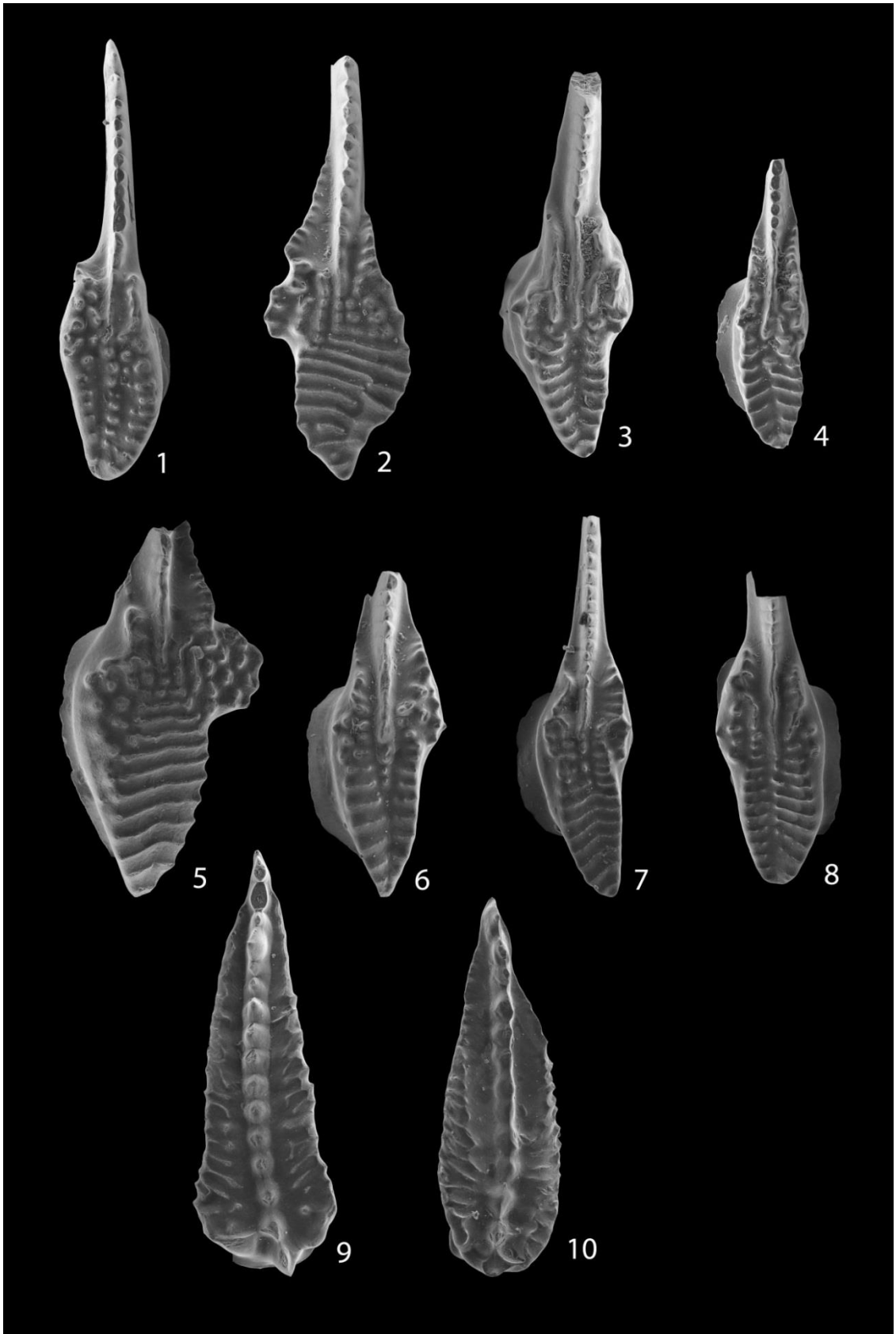


Plate 17. Photomicrographs of *Idiognathodus*, *Streptognathodus*, and *Gondolella* from the Quivira Shale Member. All specimens are shown at a magnification of 60X. Specimens were recovered from Locality #9b in Wyandotte County, Kansas. Figure 1. *Idiognathodus cancellosus*. Figure 2. *Idiognathodus turbatus*. Figures 3, 8. *Streptognathodus excelsus*. Figure 4. *Streptognathodus gracilis*. Figure 5. *Idiognathodus magnificus*. Figure 6. *Streptognathodus increbescens*. Figure 7. *Streptognathodus excelsus*. Figure 9, 10. *Gondolella*.

Plate 18

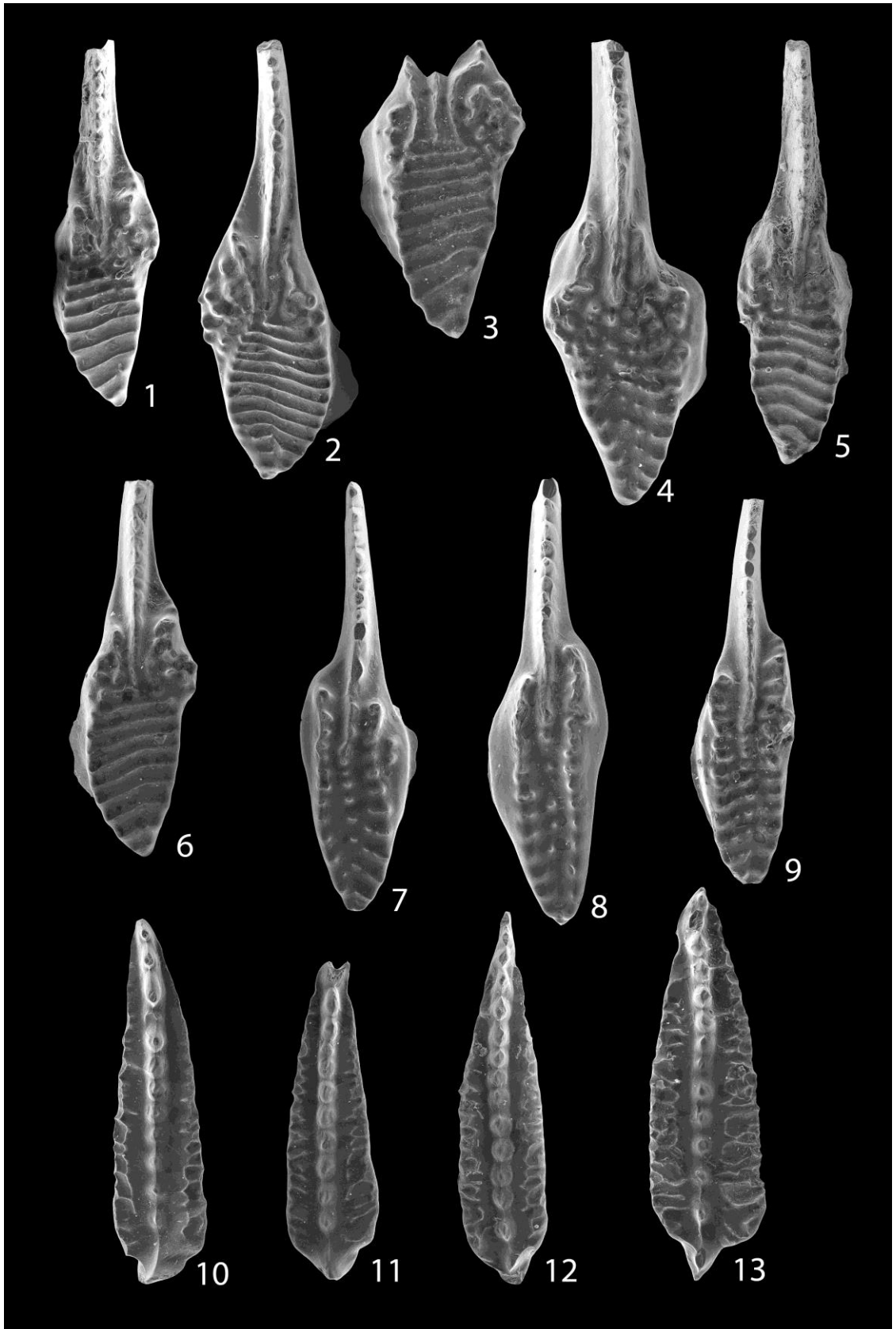


Plate 18. Photomicrographs of *Idiognathodus*, *Streptognathodus*, and *Gondolella* from the Muncie Creek Shale Member. All specimens are shown at a magnification of 60X. Specimens were recovered from Locality #9a in Wyandotte County, Kansas. Figures 1-3, 5, 6. *Idiognathodus magnificus*. Figure 4. *Streptognathodus excelsus*. Figures 7-9. *Streptognathodus gracilis*. Figures 10-13. *Gondolella*.

Plate 19

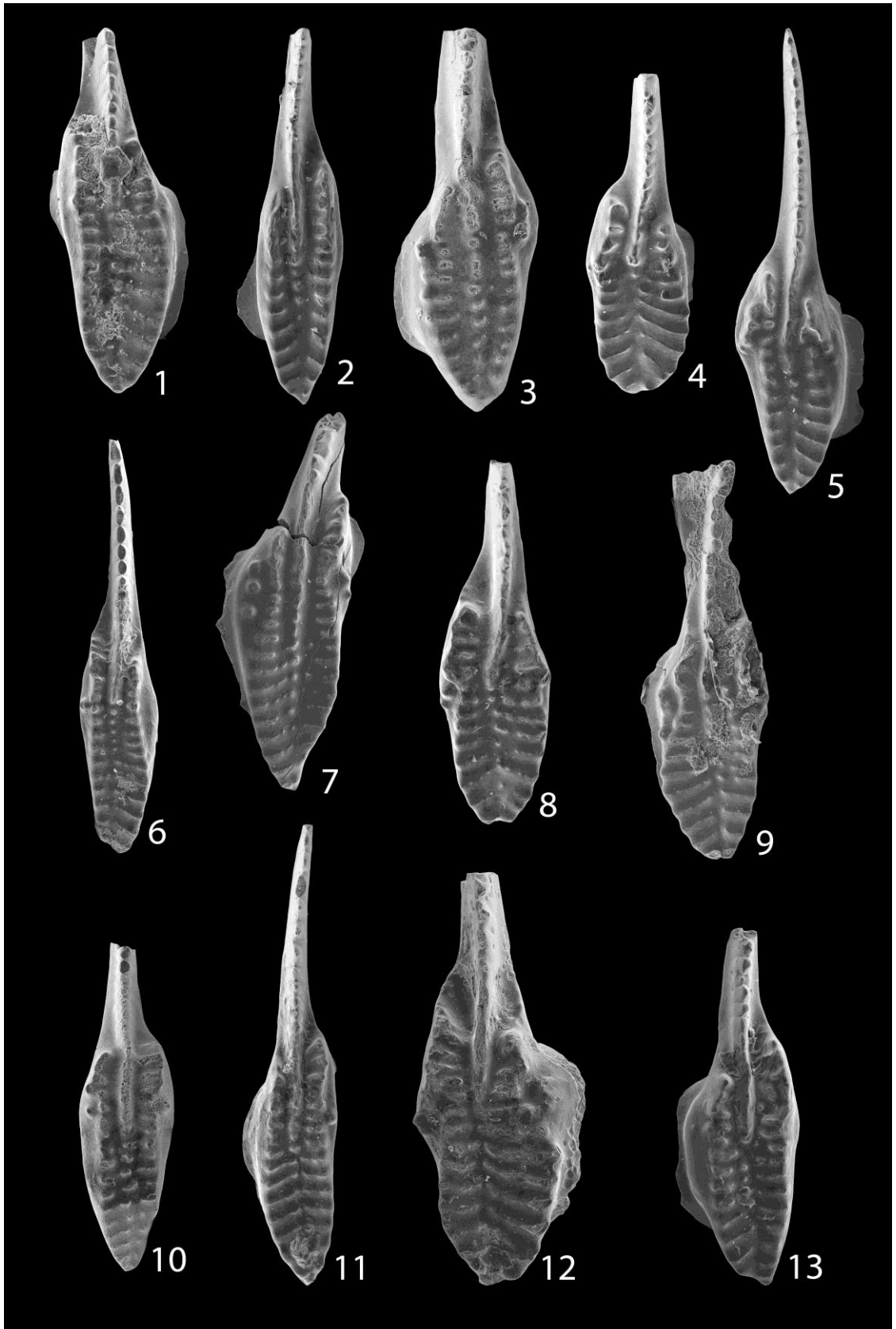


Plate 19. Photomicrographs of *Streptognathodus* from the Muncie Creek Shale Member. All specimens are shown at a magnification of 60X. Specimens were recovered from Locality #9a in Wyandotte County, Kansas. 1, 2, 6, 8, 9, 11. *Streptognathodus elegantulus*. 3, 5, 10. *Streptognathodus gracilis*. 4, 12, 13. *Streptognathodus excelsus*. 7. *Streptognathodus increbescens*.

Plate 20

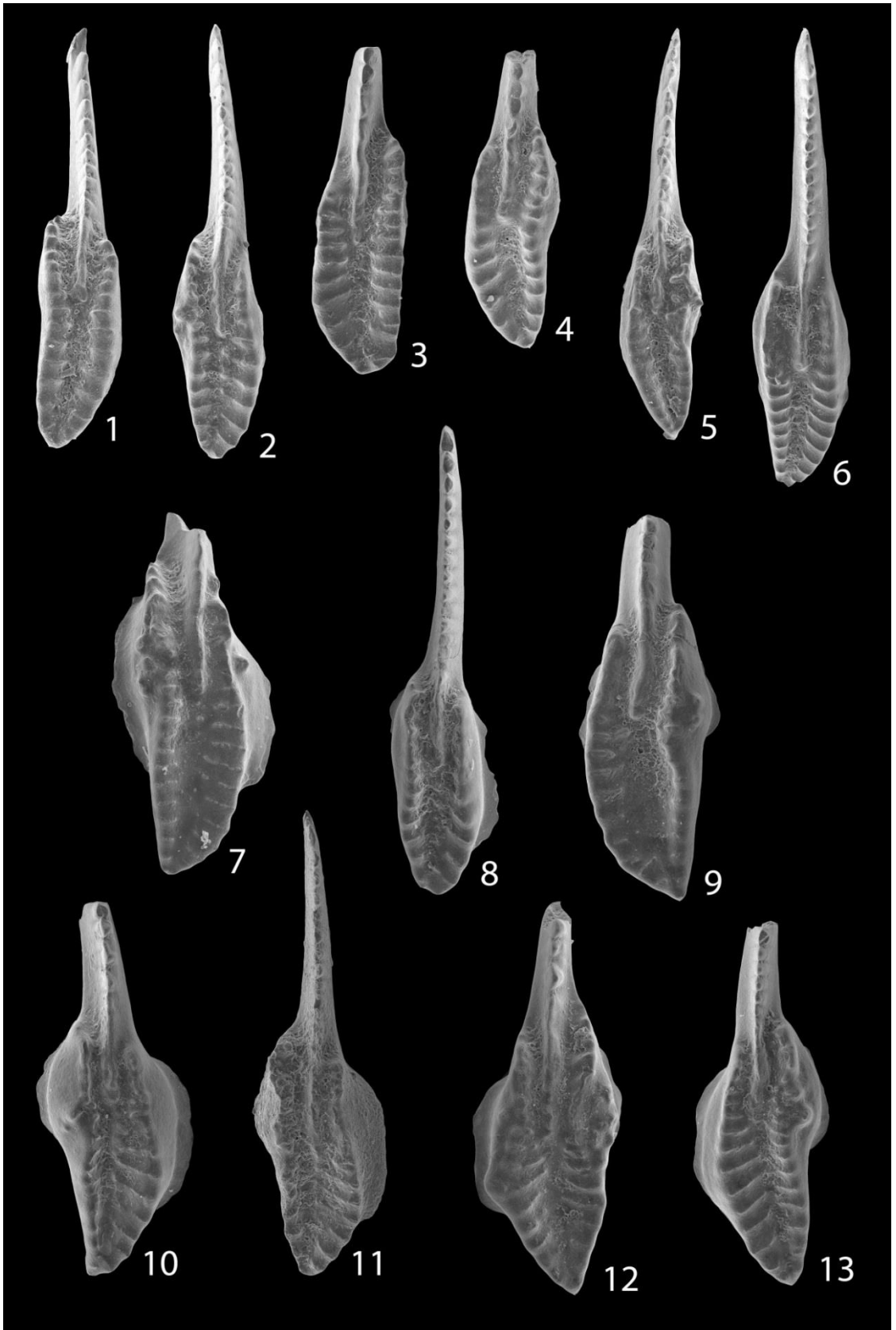


Plate 20. Photomicrographs of *Streptognathodus* from the Hickory Creek Shale Member (HC) and Quindaro Shale Member (Q). All specimens are shown at a magnification of 60X. Specimens were recovered from Locality #7 and Locality #8 in Wyandotte County, Kansas. Figures 1-6 (HC). *Streptognathodus*. Figures 7-13 (Q). *Streptognathodus*.

Plate 21

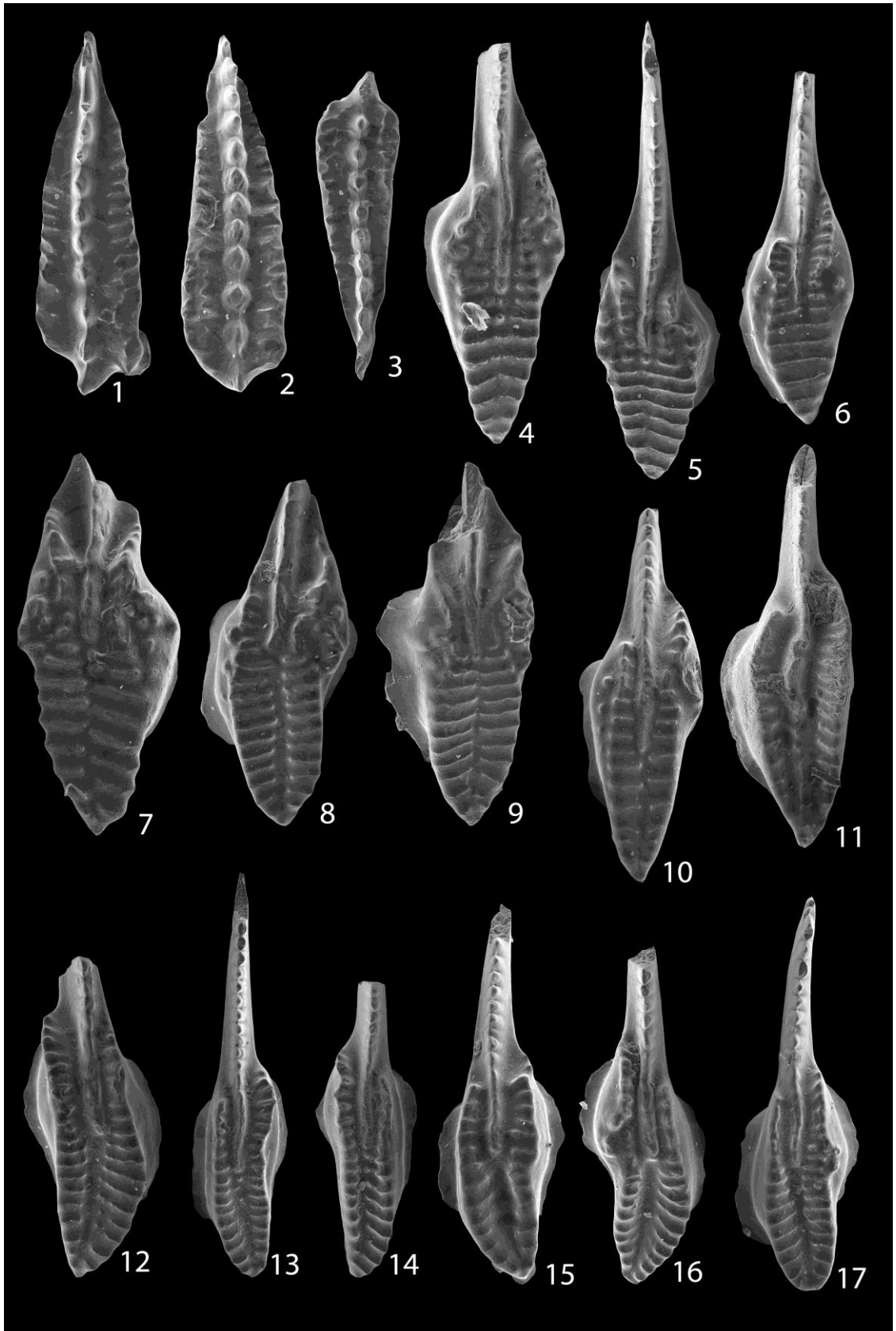


Plate 1. Photomicrographs of *Gondolella*, *Idiognathodus*, and *Streptognathodus* from the Eudora Shale Member. All specimens are shown at a magnification of 60X. Specimens were recovered from Locality #6 in Clay County, Missouri. Figures 1-3. *Gondolella*. Figures 4-10. *Idiognathodus*. Figures 11-17. *Streptognathodus*.

Plate 22

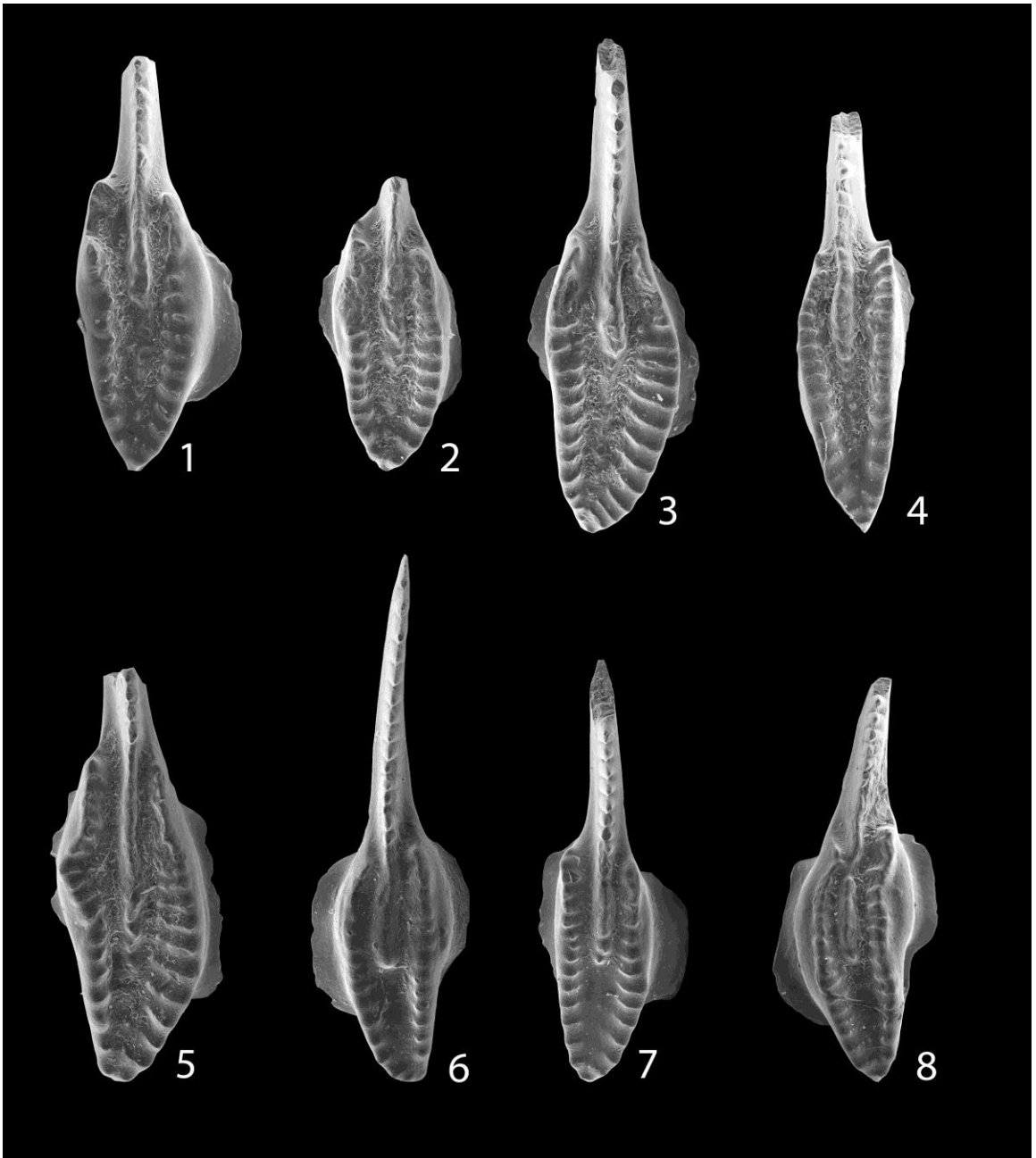


Plate 22. Photomicrographs of *Streptognathodus* from the Gretna Shale Member. All specimens are shown at a magnification of 60X. Specimens were recovered from Locality #5 in Wyandotte County, Kansas. Figures 1-8. *Streptognathodus*.

Plate 23

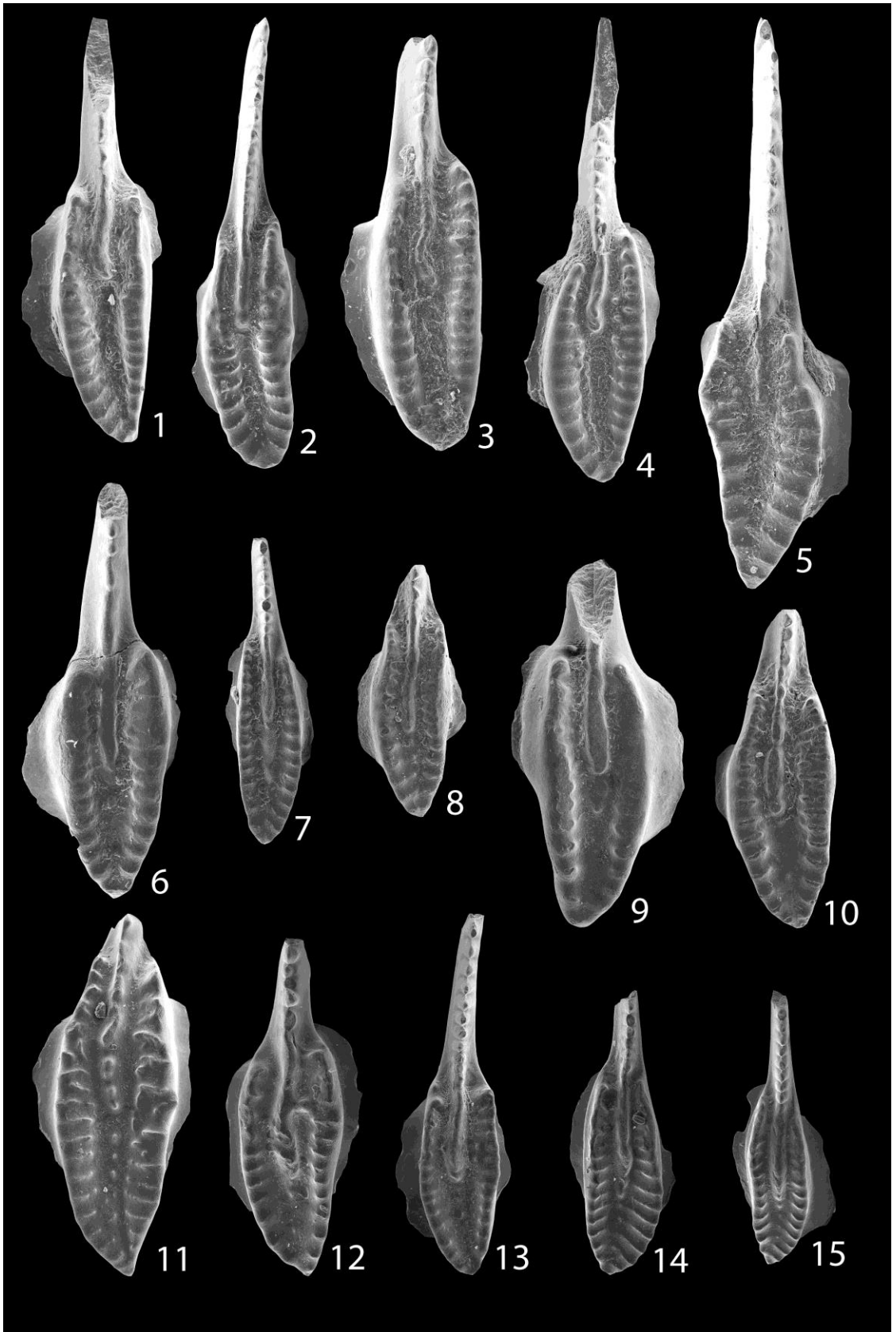


Plate 23. Photomicrographs of *Streptognathodus* from the Little Pawnee Shale Member (LP) and the Iatan Limestone Member (I). All specimens are shown at a magnification of 60X. Specimens were recovered from Locality #3 and Locality #4 in Chautauqua County, Kansas. Figures 1-5 (LP). *Streptognathodus*. Figures 6-15 (I). *Streptognathodus*.

Plate 24

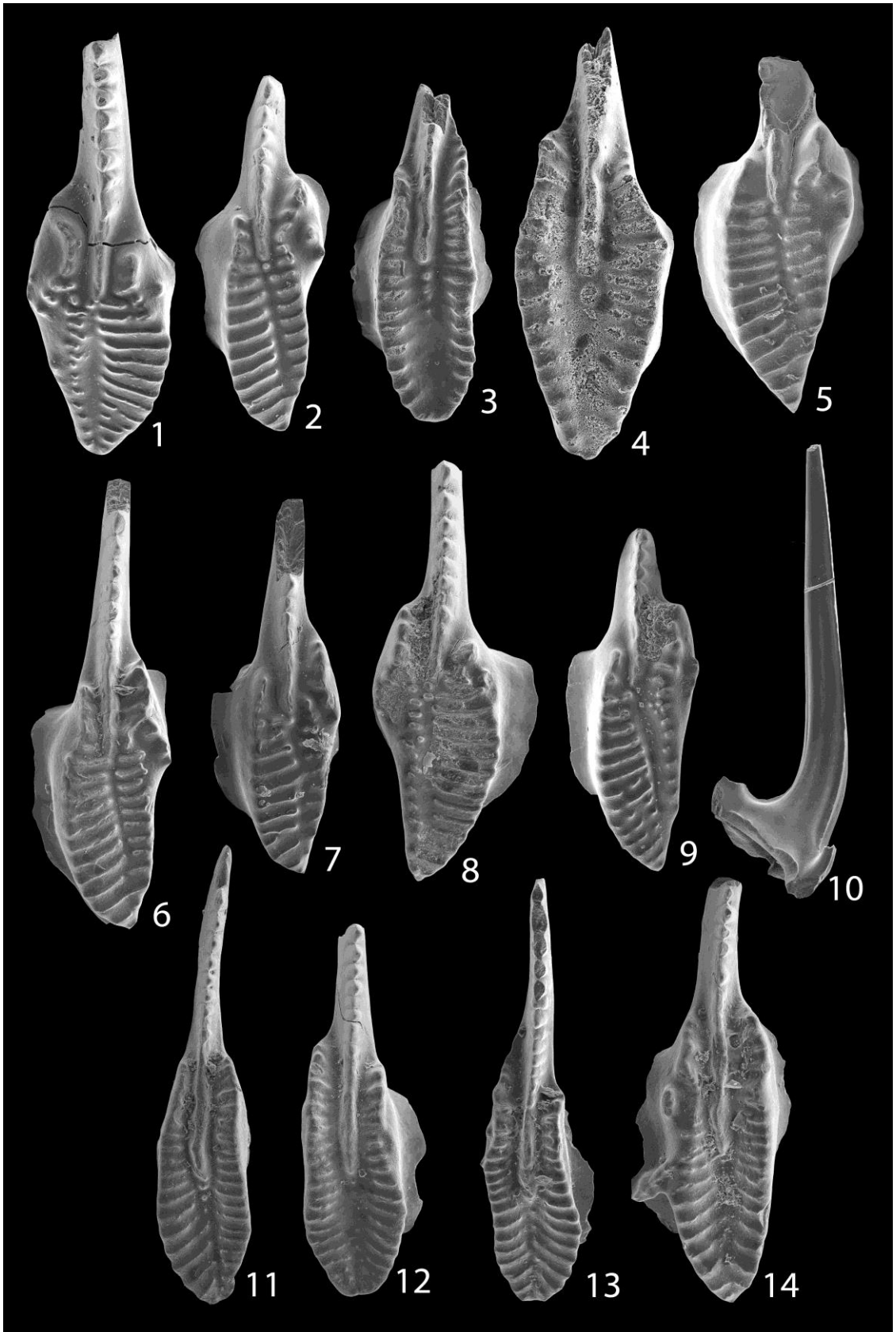


Plate 24. Photomicrographs of *Idiognathodus*, *Streptognathodus*, and *Idiopriionodus* from the Heebner Shale Member (H) and Toronto Limestone Member (T). All specimens are shown at a magnification of 60X. Specimens were recovered from Locality #2 in Douglas County, Kansas. Figures 1, 2, 5-9 (H). *Idiognathodus*. Figures 3, 4 (H). *Streptognathodus*. Figure 10 (H). *Idiopriionodus*. Figures 11-14 (T). *Streptognathodus*.

Plate 25

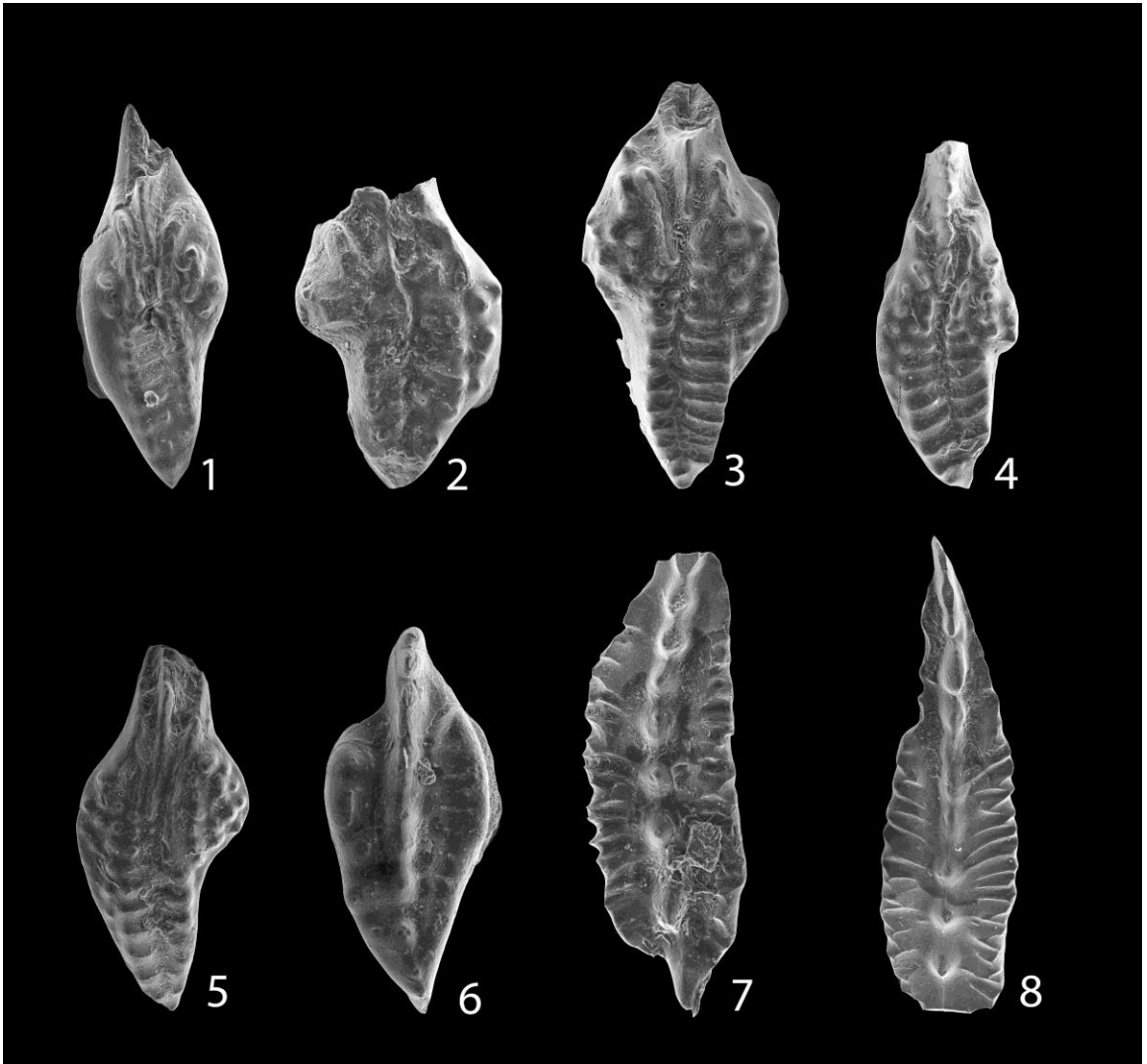


Plate 25. Photomicrographs of *Swadelina*, *Neognathodus*, and *Gondolella* from the Nuyaka Creek Shale Member (Top Marmaton in subsurface). All specimens are shown at a magnification of 60X. Specimens were recovered from Core #11 in Dewey County, Oklahoma. Figures 1-5. *Swadelina nodocarinata*. Figure 6. *Neognathodus expansus*. Figure 7, 8. *Gondolella*.

Plate 26

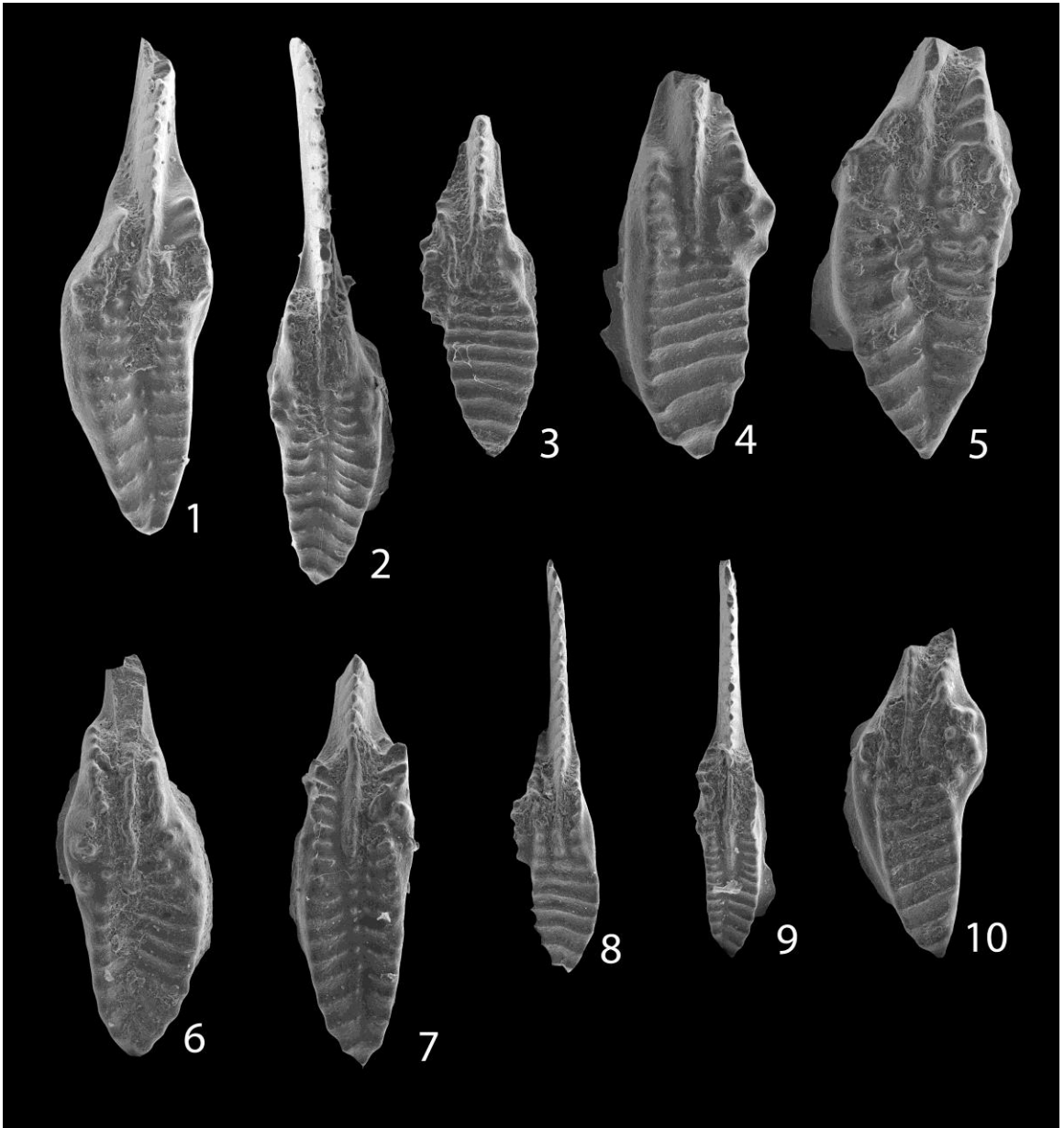


Plate 26. Photomicrographs of *Idiognathodus* from the Stark Shale Member (Hogshooter in the subsurface). All specimens are shown at a magnification of 60X. Specimens were recovered from Core #7 in Caddo County, Oklahoma. Figures 1, 2, 5-7. *Idiognathodus cancellosus*. Figure 3. *Idiognathodus magnificus*. Figures 4, 8. *Idiognathodus corrugatus*. Figure 9. *Idiognathodus cherryvalensis*. Figure 10. *Idiognathodus fusiformis*.

Plate 27

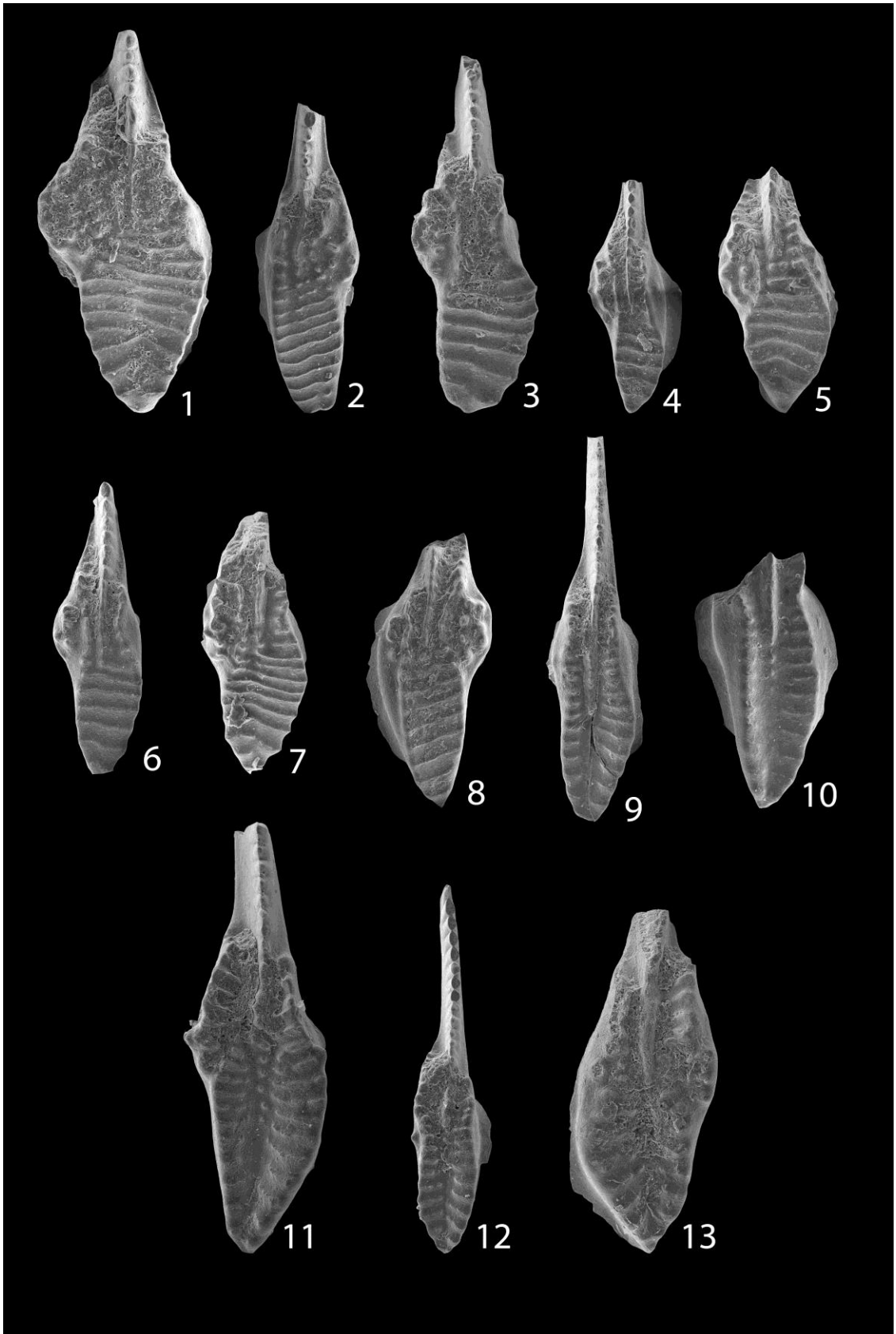


Plate 27. Photomicrographs of *Idiognathodus* and *Streptognathodus* from the Block Limestone Member (Hogshooter in the subsurface). All specimens are shown at a magnification of 60X. Specimens were recovered from Core #8 in Caddo County, Oklahoma. Figures 1, 3, 7. *Idiognathodus species 4* (Rosscoe, 2008). Figure 2. *Idiognathodus fusiformis*. Figures 4-6, 8. *Idiognathodus corrugatus*. Figures 9, 11, 13. *Streptognathodus gracilis*. Figure 10, 12. *Streptognathodus elegantulus*.

Plate 28

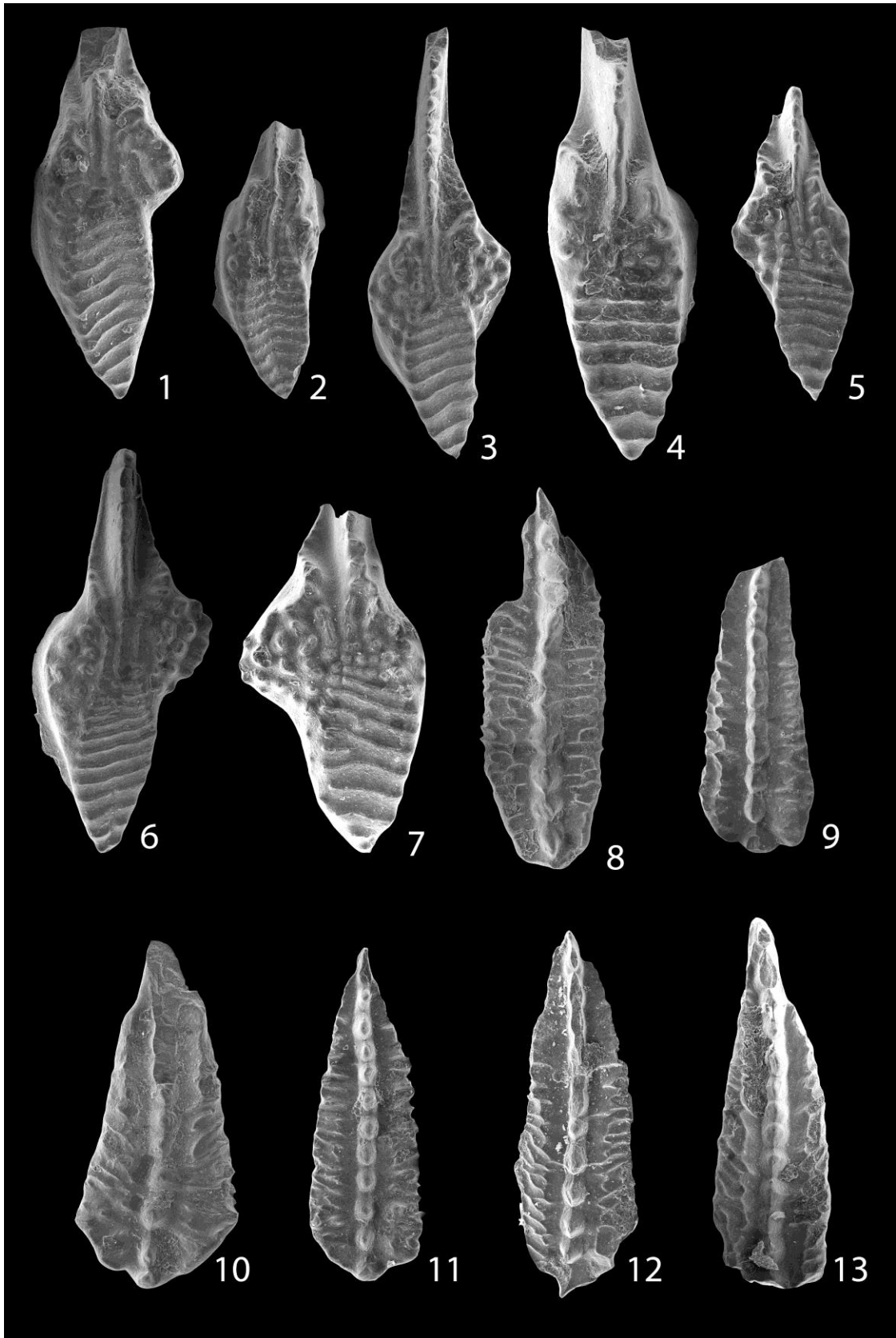


Plate 28. Photomicrographs of *Idiognathodus* and *Gondolella* from the Quivira Shale Member (Upper Hogshooter in the subsurface). All specimens are shown at a magnification of 60X. Specimens were recovered from Core #5 in Caddo County, Oklahoma. Figures 1-7. *Idiognathodus magnificus*. Figures 8-13. *Gondolella*.

Plate 29

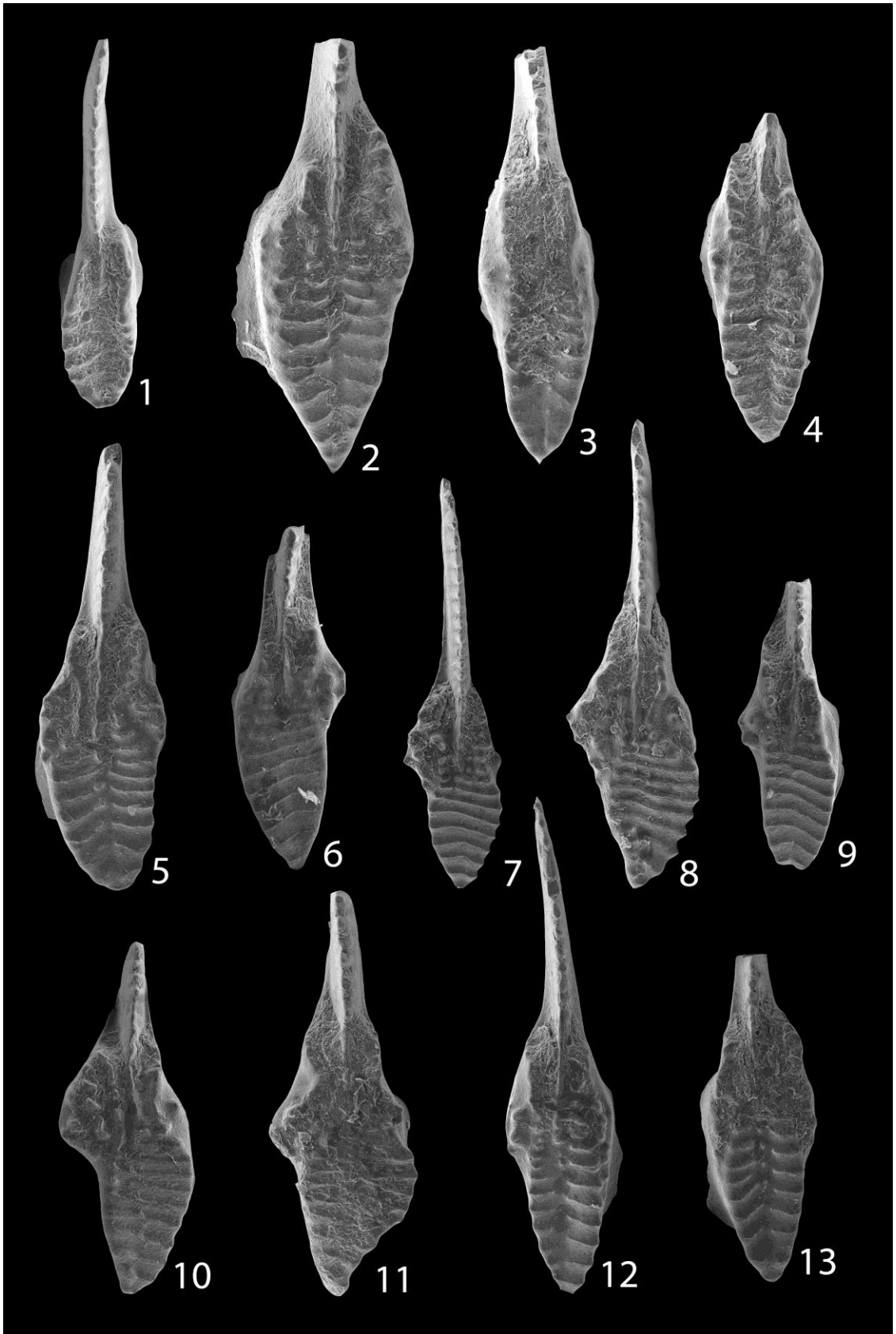


Plate 29. Photomicrographs of *Idiognathodus* and *Streptognathodus* from the Quivira Shale Member (Upper Hogshooter in the subsurface). All specimens are shown at a magnification of 60X. Specimens were recovered from Core #6 in Roger Mills County, Oklahoma. Figures 1, 4, 12, 13. *Streptognathodus gracilis*. Figures 2, 5. *Streptognathodus excelus*. Figure 3. *Streptognathodus elegantulus*. Figures 6-11. *Idiognathodus magnificus*.

Plate 30

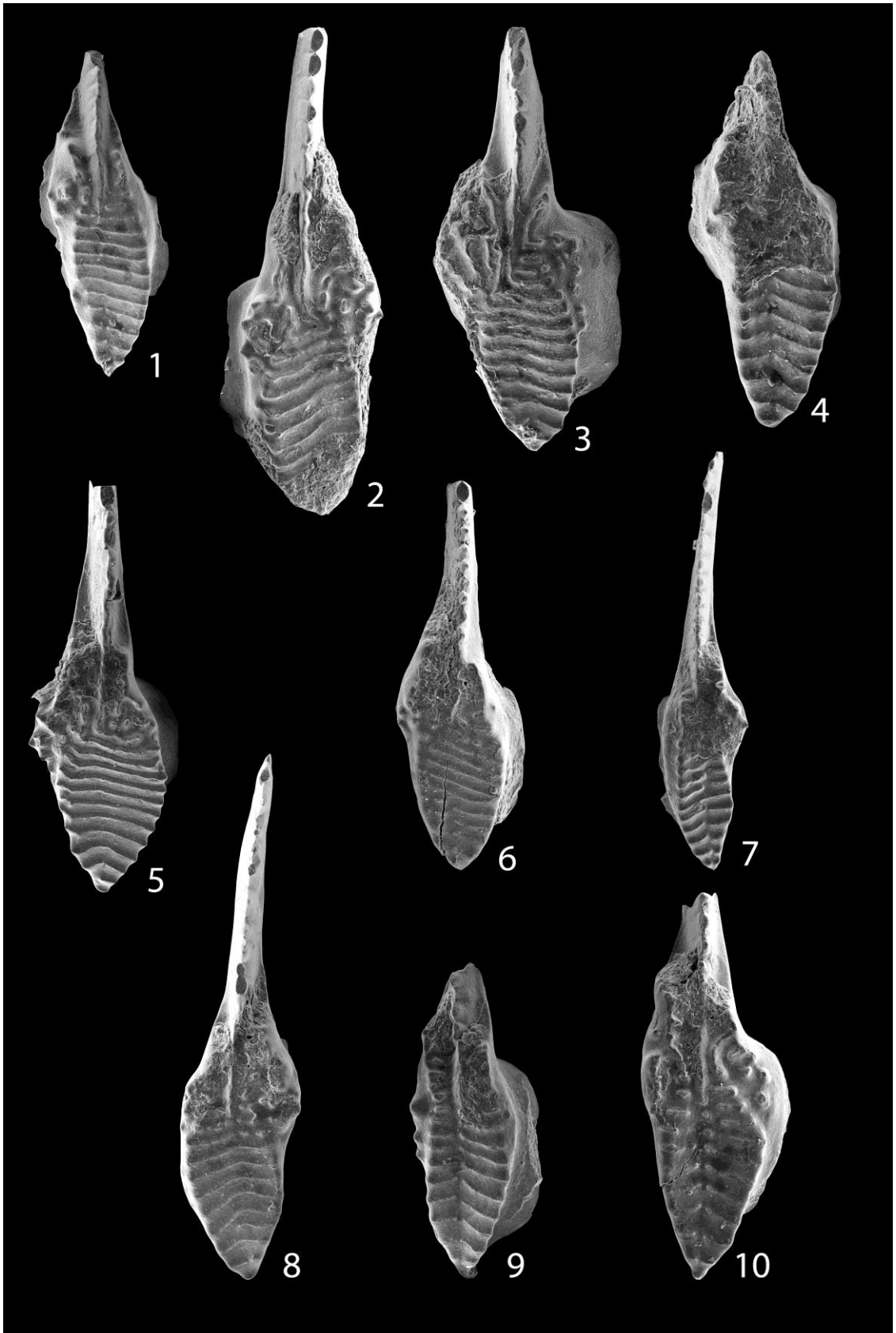


Plate 30. Photomicrographs of *Idiognathodus* and *Streptognathodus* from the Muncie Creek Shale Member (Lower Avant in the Subsurface). All specimens are shown at a magnification of 60X. Specimens were recovered from Core #4 in Caddo County, Oklahoma. Figures 1-3, 5, 6, 8. *Idiognathodus magnificus*. Figures 4, 7, 9. *Streptognathodus gracilis*. Figure 10. *Streptognathodus excelsus*.

Plate 31

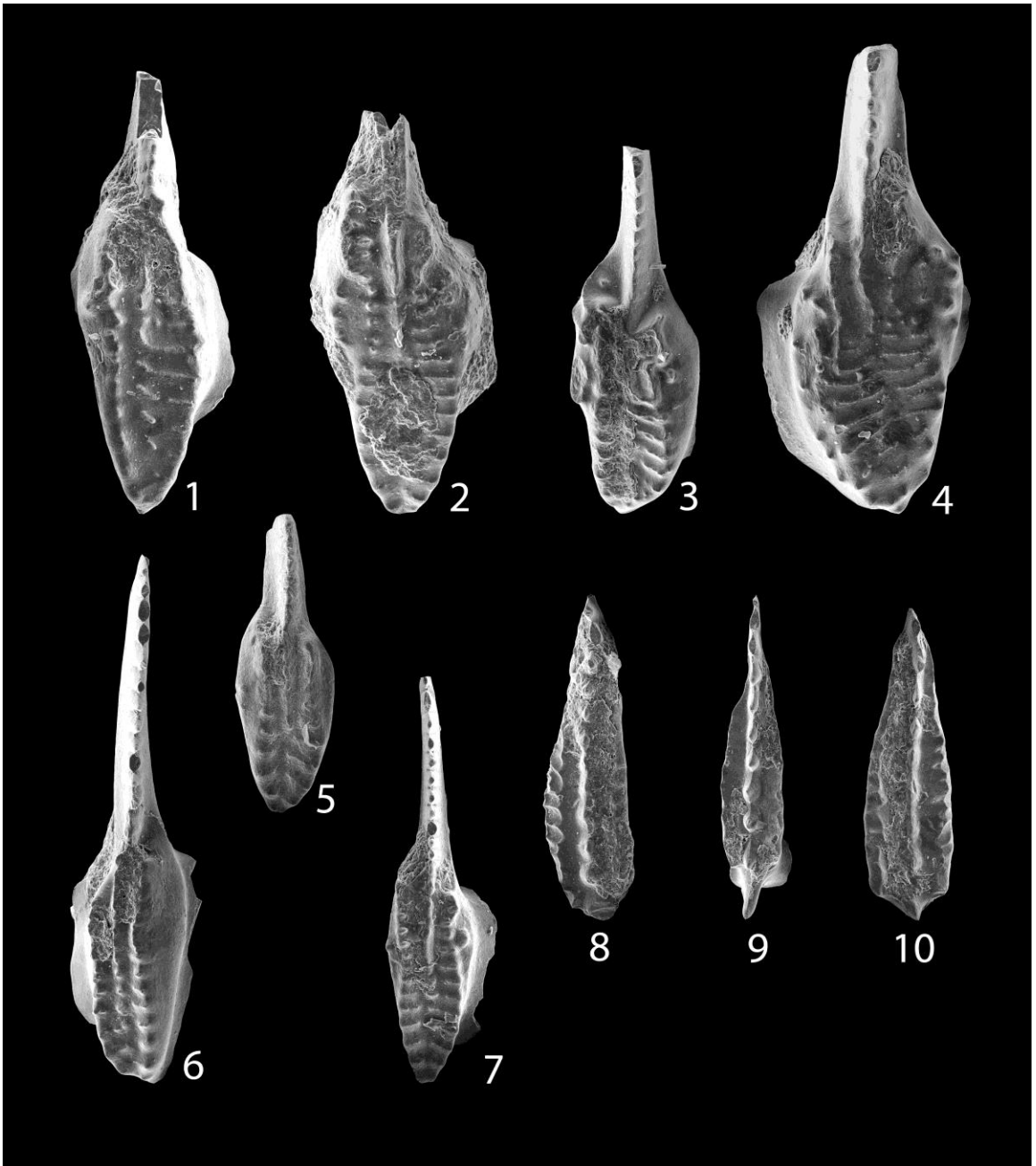


Plate 31. Photomicrographs of *Idiognathodus*, *Streptognathodus*, and *Gondolella* from the Muncie Creek Shale Member (Lower Avant in the Subsurface). All specimens are shown at a magnification of 60X. Specimens were recovered from Core #4 in Caddo County, Oklahoma. Figures 1, 3, 5-7. *Streptognathodus gracilis*. Figure 2. *Streptognathodus excelsus*. Figure 4. *Idiognathodus magnificus*. Figures 8-10. *Gondolella*.

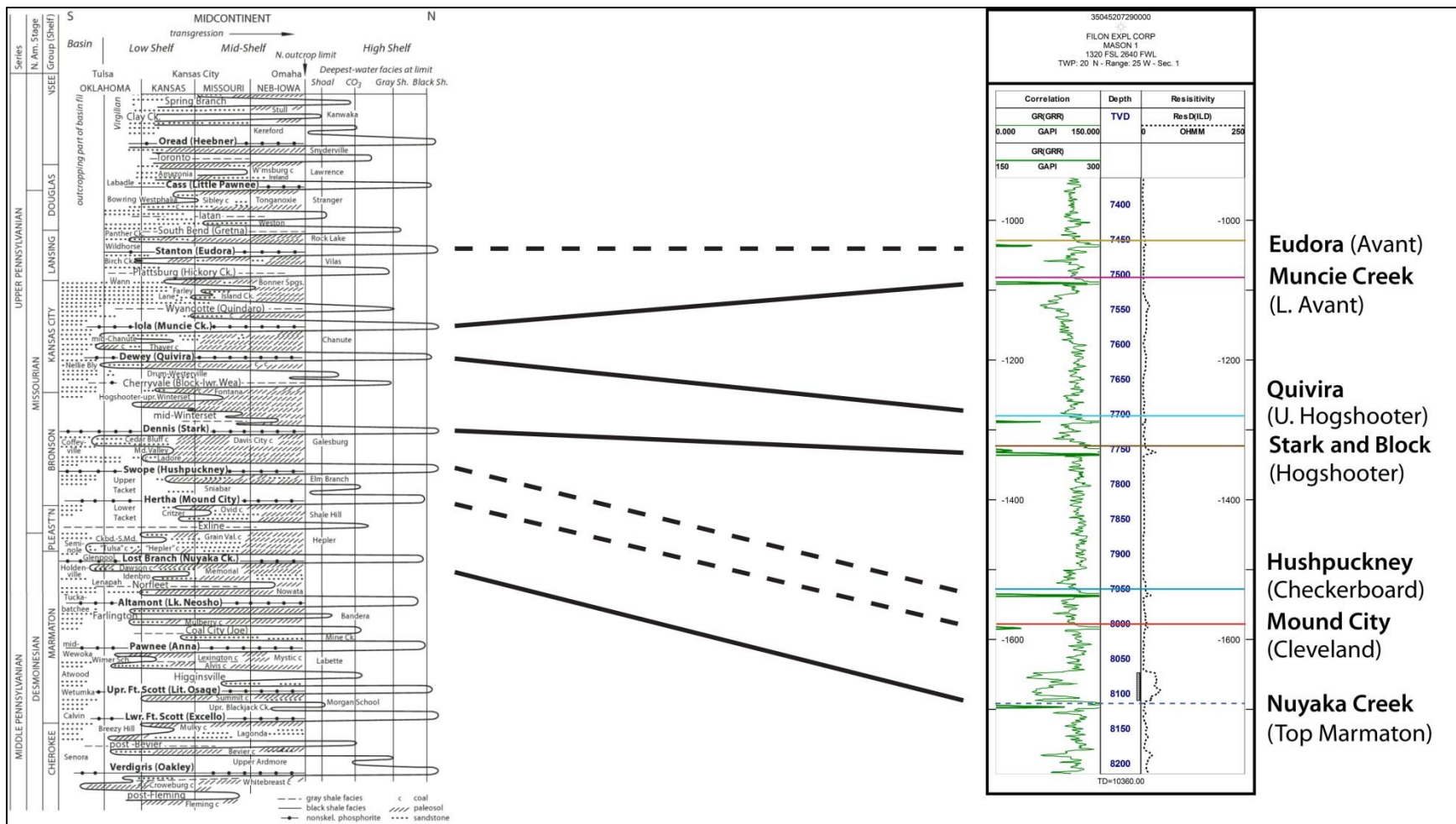


Figure 13. Schematic correlation denoting hot shale markers observed in the subsurface and their equivalent on the surface. Solid lines are correlations backed by biostratigraphy while dashed are not back by biostratigraphic data. The sea-level curve is modified from Heckel et. al. (1999).

Cyclothem and Sequence Stratigraphy Relationship

The cyclothem models first created by Udden (1912) and later modified by Heckel (1977) generalized the succession of Pennsylvanian rocks in very well. However, the variability in the cyclothem is easily noticeable throughout the Midcontinent, as well as outcrops and cores examined in this study. It is understood that these models were constructed for outcrops on the shelf of Midcontinent basins and not the more basinal setting of the cored intervals from wells located in the Anadarko Basin. However, the model, if modified can be applied to depositional patterns observed in the subsurface. Another issue in the cyclothem model is the outside shale member and its associated lithologies. When applying sequence stratigraphy to the cyclothem model, one can see the need to divide the outside shale member into separate sub units. This section aims to discuss the differences of the cyclothem model observed in the study and its relationship to sequence stratigraphy.

Many of the outcrops examined in this study fit the cyclothem model perfectly. It was easy to identify the middle limestone, core shale, and regressive limestone. Many times rock units were either very thin or entirely missing from the ideal succession. In Iowa, limestone above and below the core shale was nonexistent to only a few feet thick. In some instances the middle limestone was not present so the black shale of the core shale was directly overlying the coal bed of the outside shale. In Udden's (1912) original observations of cyclothem in Illinois, the black shale was overlying the coal. This also occurred in the cores from the Anadarko Basin. The deeper water conditions and turbid water did not support large scale limestone deposition. Many times the black shale of the core shale rests directly on top of the deltaic shale. Variations of the cyclothem model should be constructed to accommodate for the water depths and water turbidite rocks from Iowa and the Anadarko Basin.

Another issue with existing cyclothem models concerns the lithologies grouped into the outside shale member. In the outside shale member, we observe sandstone, sandy shale, paleosols, coal, and marine fossils. The presence of marine fossils is evidence that the outside shale should be divided into separate units. When applying sequence stratigraphy to the cyclothem model, this becomes more evident. The sequence boundary would be placed at the base of the coal bed. If modifying the cyclothem model to include a new member, the coal and gray shale with marine fossils would be within this new member and underlying the middle limestone. An alternative is adding these two lithologic units to the middle limestone and changing the name to the transgressive member. This would strengthen the tie between the cyclothem model and sequence stratigraphic models together very well.

The ease of applying sequence stratigraphy to the cyclothem model is evidence to how well the model was constructed. The only difference between the two, which was addressed in the previous paragraph, is the placement of the boundary between the lowstand systems tract and transgressive systems tract. This boundary should be at the base of the coal in the outside shale. Figure 14 shows the cyclothem model and sea-level curve with its relationship two sequence stratigraphy models, Exxon (Vail et. al., 1977) and Hunt and Tucker (1992). As noted by Hunt and Tucker (1992), the Exxon model does not take into consideration a drop in sea-level. The successions seen in the Midcontinent are an example of foreshortened sections meaning the thicknesses of the sections are significantly less than the water depth differences at deposition. This implies forced regression occurred in the cyclothem of the Midcontinent. Figure 14 shows Hunt and Tucker's model as it relates to the cyclothem model. The forced regression systems tract boundary is placed at the change of black shale facies to gray shale facies.

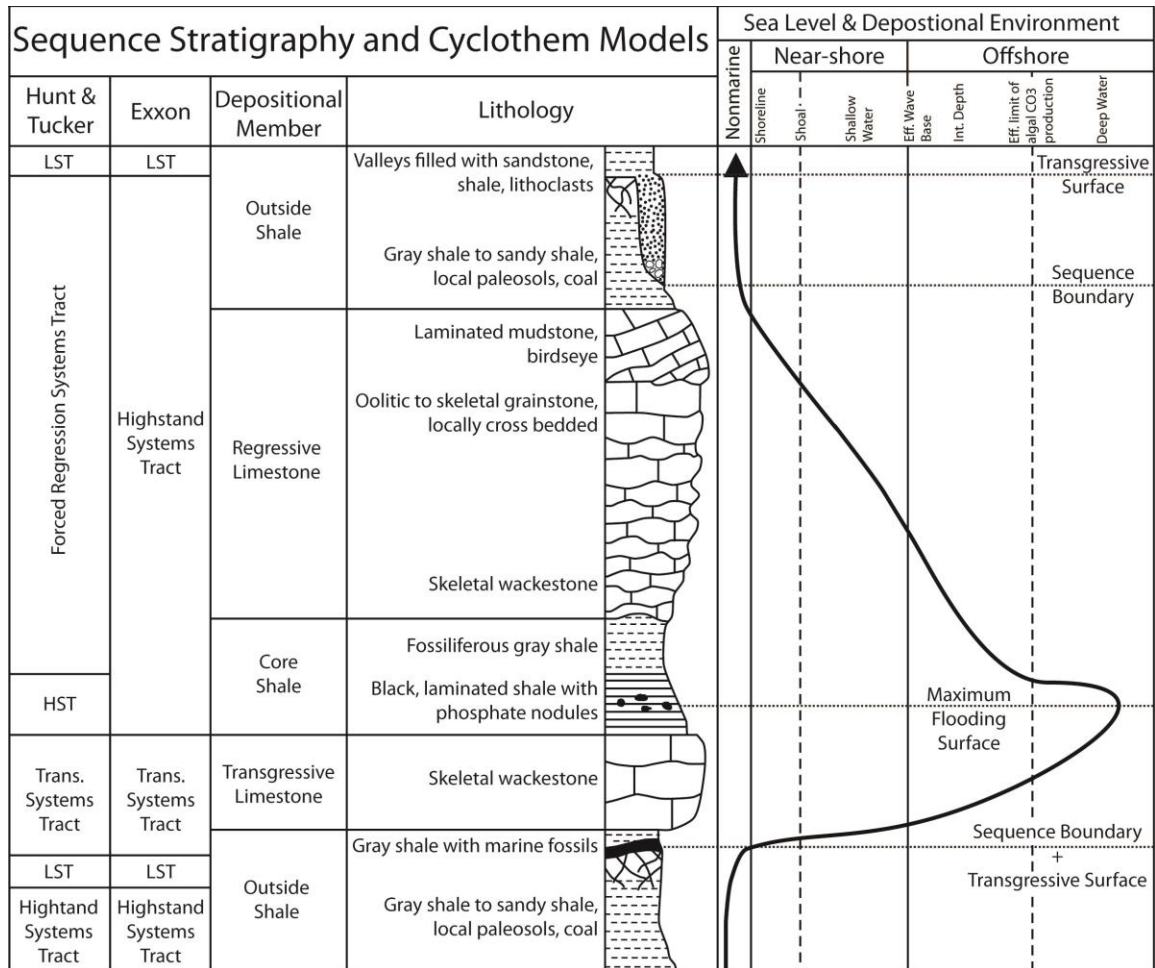


Figure 14. Cyclothem model with sea-level curve and comparison to sequence stratigraphy. (Modified from Feldman, Franseen, Joeckel, and Heckel, 2005)

CHAPTER IV

FUTURE WORK

As previously stated, the purpose of this study was to correlate Pennsylvanian condensed sections from outcrop to subsurface and develop a stratigraphic framework. Also, another goal was to establish a conodont biostratigraphic database for the entire Middle and Upper Pennsylvanian. While the foundation has been laid, there are still several areas of need until full completion. The first and most important objective is to locate more cores containing condensed sections both of condensed sections found in this study and others not previously studied. I suggest looking in Texas and Beaver Counties of the Oklahoma Panhandle. Also, cores located in the Texas portion of the Anadarko Basin would be beneficial. Secondly, cores should undergo in-depth lithological descriptions to couple with the biostratigraphic data. Many cores of condensed sections in this study were not sampled in a short time frame due to their large size. Examining these large cores for lithostratigraphic and biostratigraphic correlation is needed. In this study, well-logs were used to correlate only in the Anadarko Basin. I suggest utilizing well-logs to correlate from the subsurface to outcrop as closely as possible. While it is feasible, it would require obtaining a large amount of well-logs. Lastly, the development of the conodont biostratigraphic data in many intervals is needed. All intervals have been sampled, some require conodonts to be sorted, while some just need the conodonts to be identified.

CHAPTER V

CONCLUSIONS

From the Middle Desmoinesian to Early Virgilian, 21 condensed sections were studied, while 7 condensed sections in the subsurface were sampled. Of the 21 outcrop condensed sections examined in this study, 14 were maximum flooding surfaces represented by black shale and black, phosphatic shale. Seven of these condensed sections were minor flooding surfaces represented by gray to dark gray shale partings in limestone. High concentrations of conodonts were found in all the condensed sections. The abundance of conodonts in the minor flooding surfaces decreases, but is still plentiful.

In the subsurface, all of the condensed sections were represented by dark gray or black shales. Four of the condensed sections in the subsurface yielded conodonts and were correlated to the surface. These were the Nuyaka Creek Shale of the Marmaton Group (Desmoinesian), the Stark Shale, the Quivira Shale, and the Muncie Creek Shale of the Kansas City Group (Missourian). Three condensed sections that conodont data was not available were correlated through cyclic stratigraphy. These are the Mound City Shale and Hushpuckney Shale of the Kansas City Group (Missourian), and the Eudora Shale of the Lansing Group (Missourian).

A stratigraphic framework of these condensed sections was completed in the Anadarko Basin by utilizing well-log data in seven counties in southwestern Oklahoma. Six cross-sections were created to show the lateral extent and distribution of the condensed sections. These condensed sections are basinally extensive and easily correlatable over long distances.

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APPENDIX A

Surface Data

1. Heebner Shale Member, Oread Limestone, Shawnee Group – Andrew County, MO ()

Location: SW, NE, SE, Sec. 19, T58N, R23E, Saint Joseph North Quadrangle

GPS Coordinates: 39°49'0"N 94°51'0"W

- Samples:
1. wackstone, Plattsmouth Limestone Member
 2. gray shale, Heebner Shale Member
 3. black shale, Heebner Shale Member
 4. black fissile shale, Heebner Shale Member
 5. black fissile shale, Heebner Shale Member
 6. black shale, Heebner Shale Member

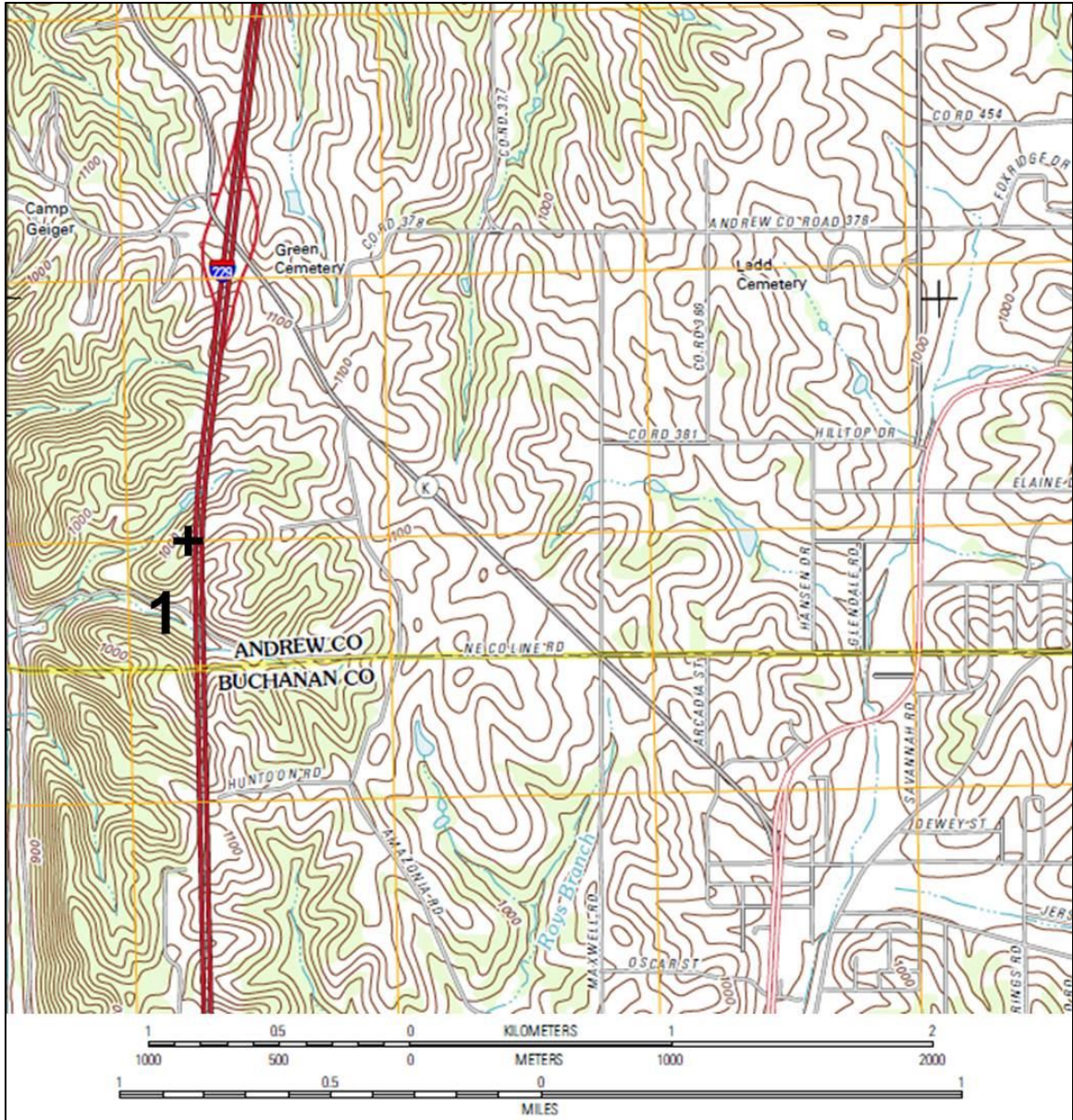


Figure 15. Topographic map of Locality #1, Andrew County, Missouri.

2. Heebner Shale Member and Toronto Limestone Member, Oread Limestone, Shawnee Group –
Douglas County, KS (Watney et. al., 1991, Stop #6)

Location: N/2, NE, NW, Sec. 8, T13S, R19E, Lawrence West Quadrangle

GPS Coordinates: 38°56'31.6"N 95°19'18.2"W

- Samples:
1. gray shale, Heebner Shale Member
 2. dark gray shale, Heebner Shale Member
 3. dark shale, Heebner Shale Member
 4. dark gray shale, Heebner Shale Member
 5. gray wackestone, Leavenworth Limestone Member
 6. gray wackestone, Toronto Limestone Member
 7. gray wackestone, Toronto Limestone Member
 8. gray wackestone, Toronto Limestone Member

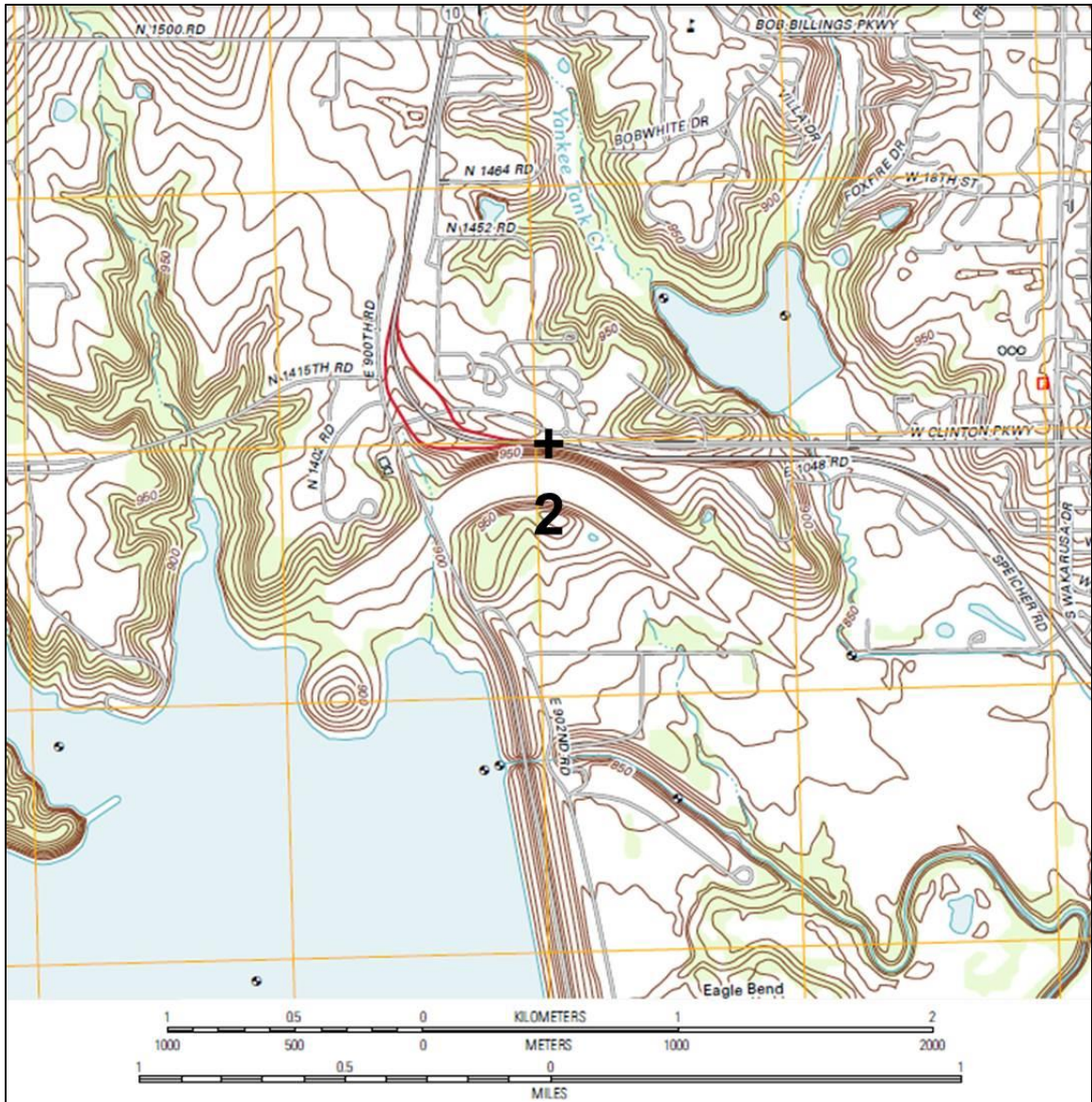


Figure 16. Topographic map of Locality #2, Douglas County, Kansas.

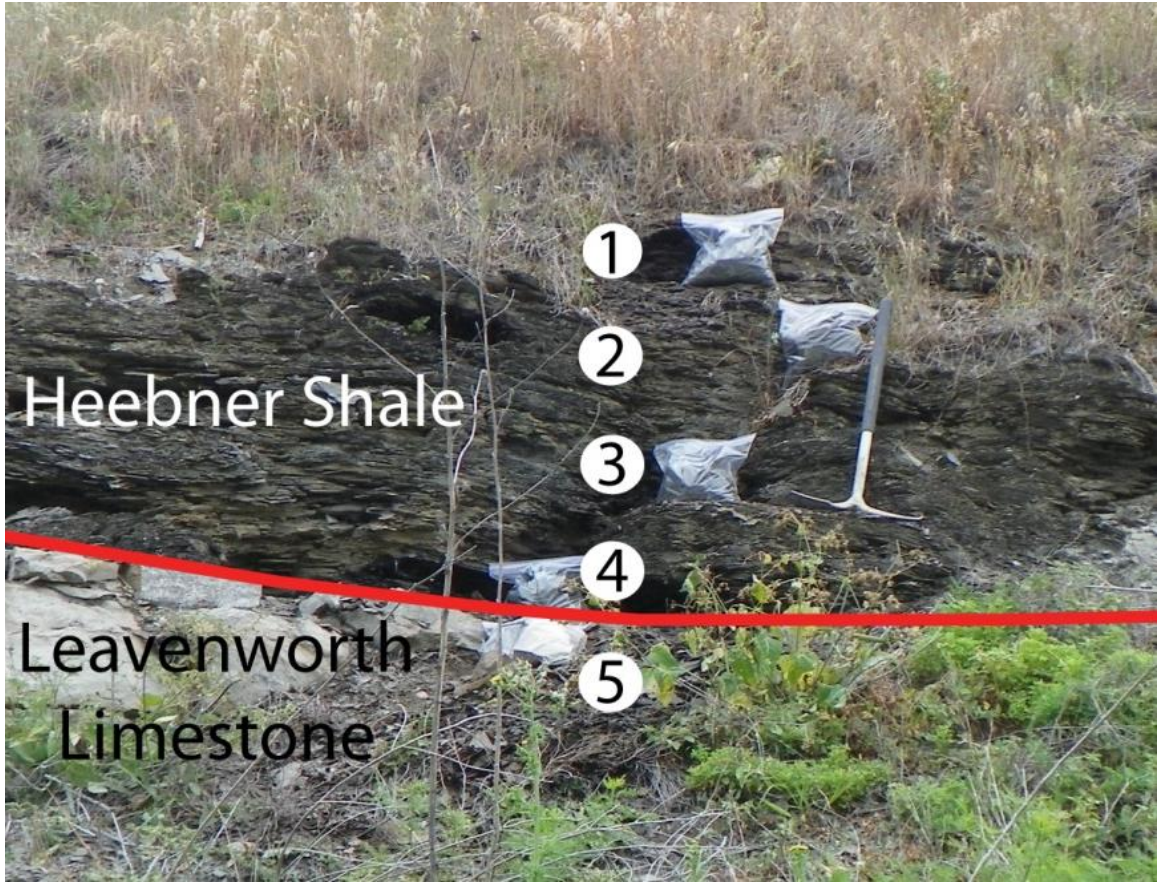


Figure 17. Outcrop photo of the Heeber Shale Member with sample locations.

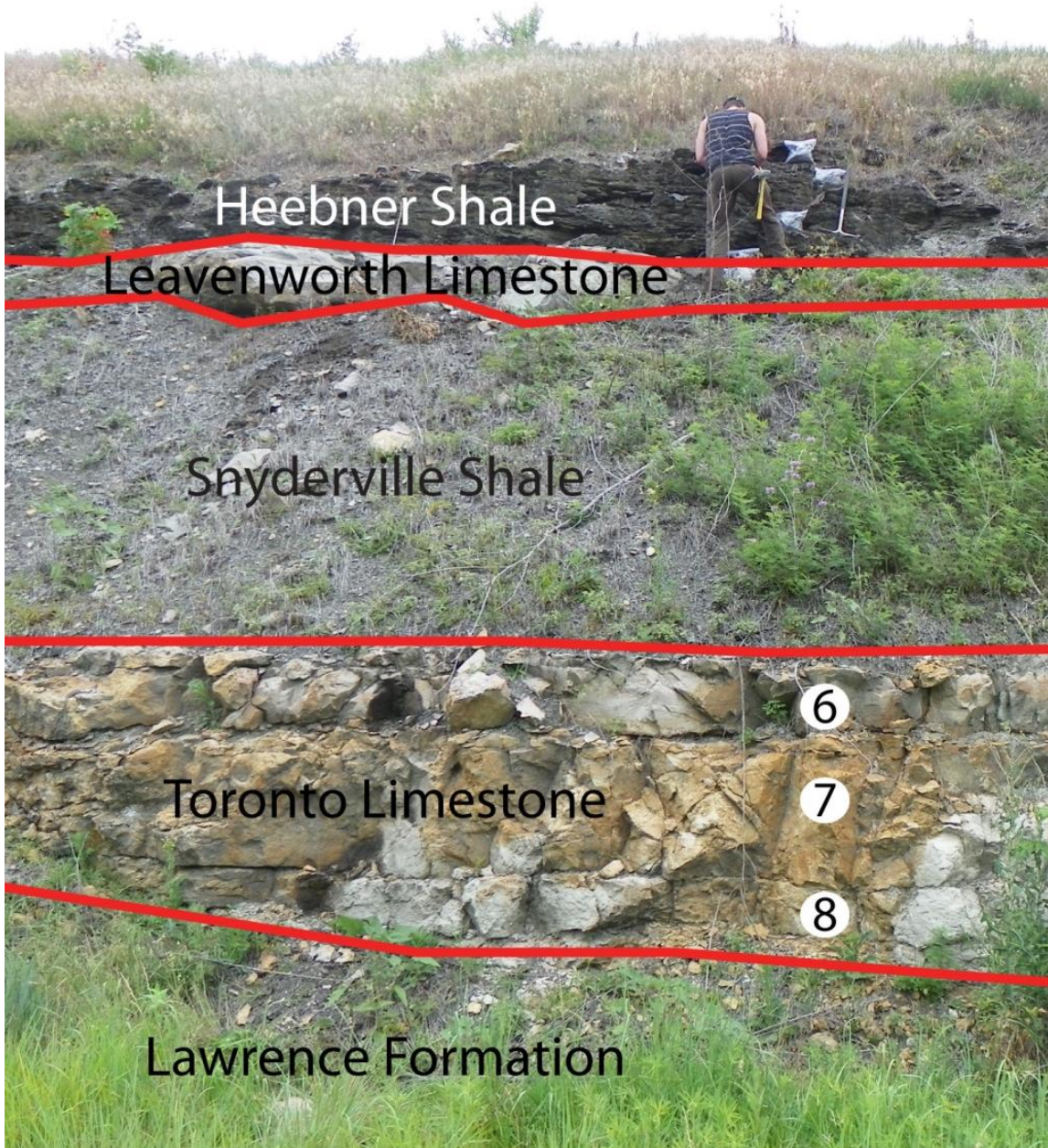


Figure 18. Outcrop photo of the Heebner Shale Member and Toronto Limestone Member with sample locations.

3. Little Pawnee Shale Member, Cass Limestone, Douglas Group – Chautauqua County, KS
(Heckel et. al., 1999, p. 50, outcrop C3)

Location: NE, NE, Sec. 20, T34S, R12E, Peru Quadrangle

GPS Coordinates: 37°04'54.4"N 96°06'42.4"W

- Samples:
1. gray shale, Little Pawnee Shale Member
 2. gray shale, Little Pawnee Shale Member
 3. dark gray shale, Little Pawnee Shale Member
 4. dark gray shale, Little Pawnee Shale Member
 5. black fissile shale, Little Pawnee Shale Member
 6. black fissile shale, Little Pawnee Shale Member
 7. black fissile phosphatic shale, Little Pawnee Shale Member
 8. black fissile phosphatic shale, Little Pawnee Shale Member

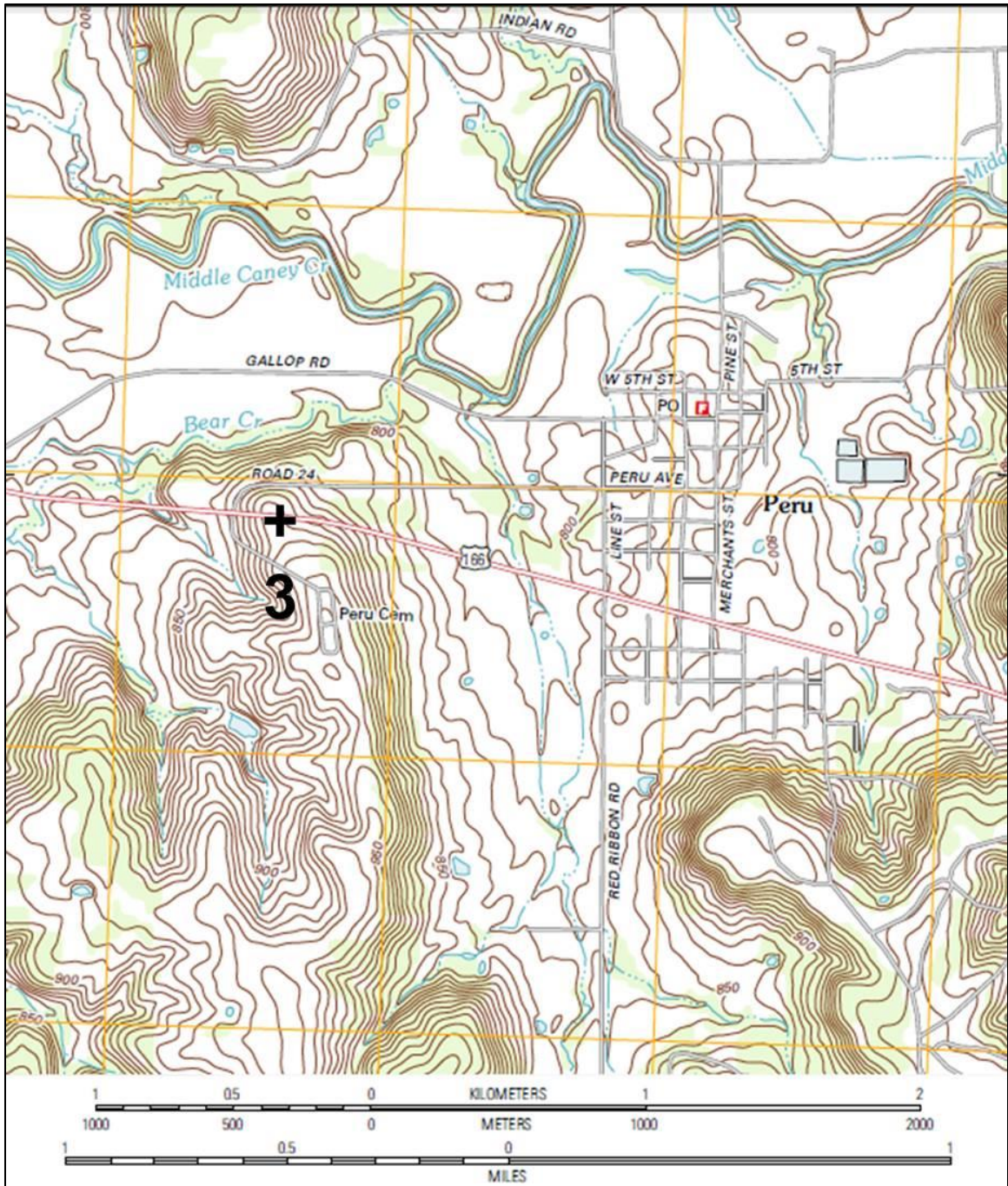


Figure 19. Topographic map of Locality #3, Chautauqua County, Kansas.

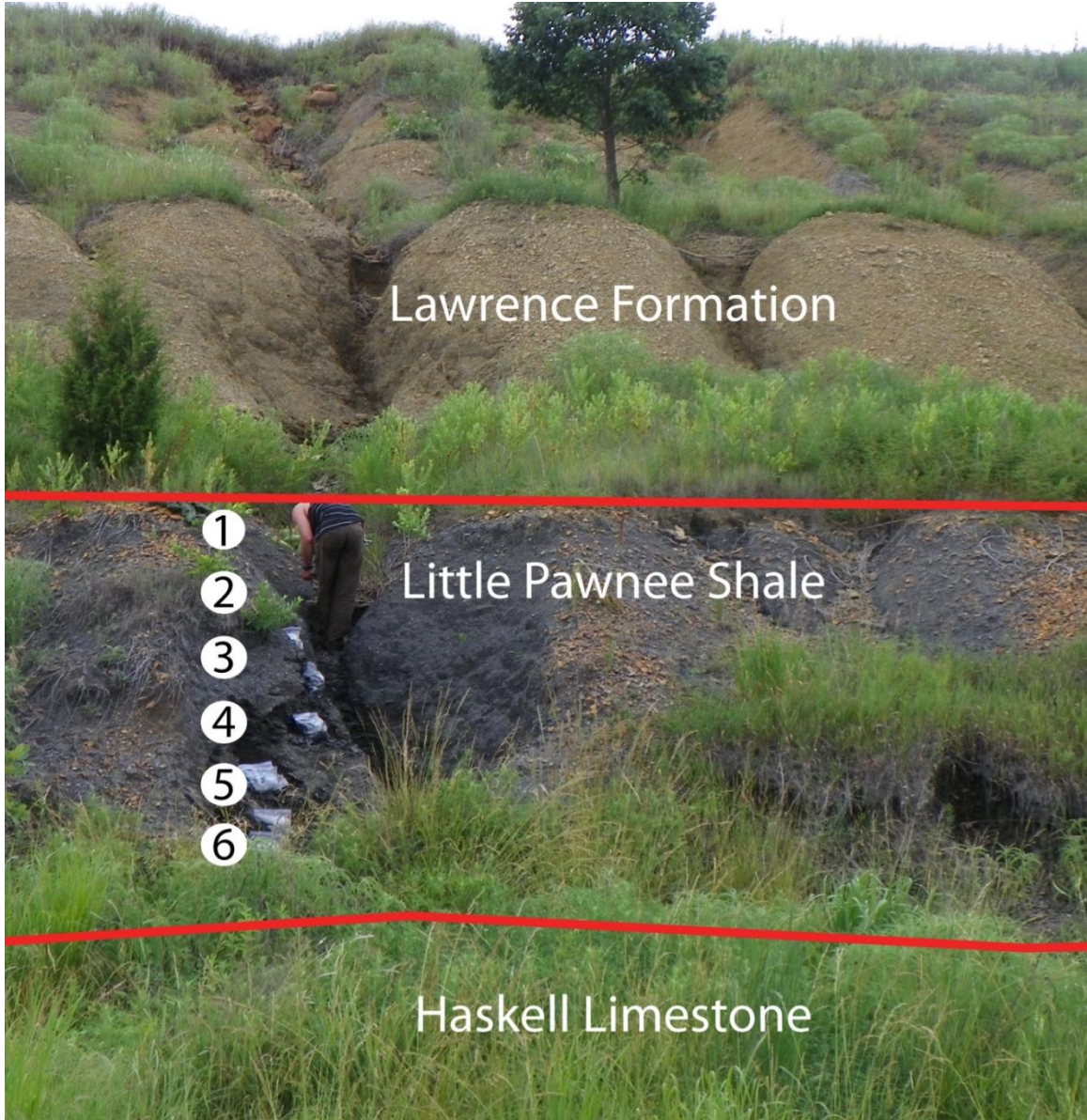


Figure 20. Outcrop photo of the Little Pawnee Shale Member with sample locations.

4. Iatan Limestone Member, Stranger Formation, Douglas Group – Chautauqua County, KS
(Heckel et. al., 1999, p. 49, outcrop C1)

Location: NE, SE, SW, Sec. 23, T34S, R12E, Peru Quadrangle

GPS Coordinates: 37°04'14.1"N 96°03'51.2"W

- Samples:
1. gray wackestone, Iatan Limestone Member
 2. gray fossiliferous clay shale, Iatan Limestone Member
 3. gray shale, Iatan Limestone Member

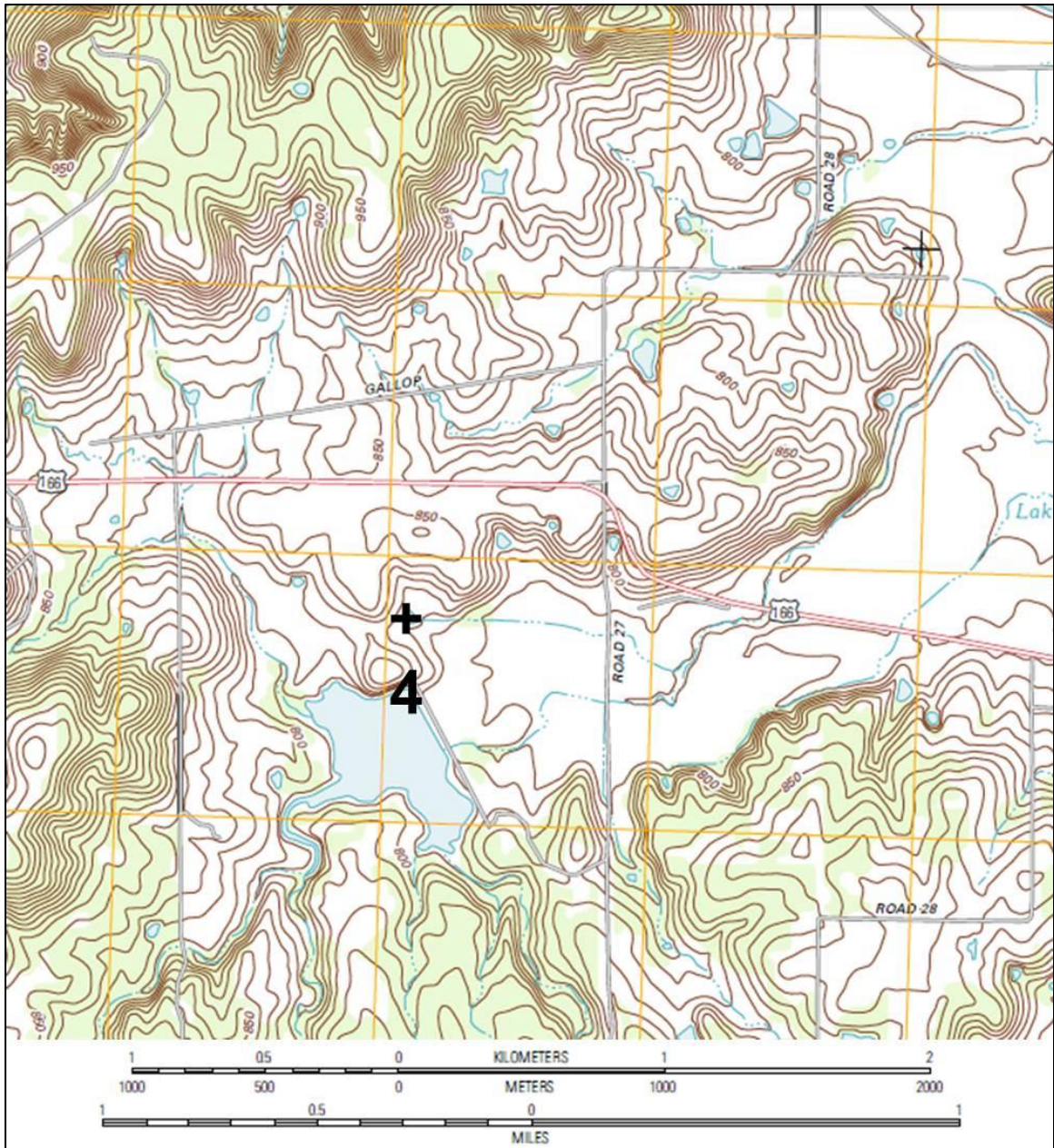


Figure 21. Topographic map of Locality #4, Chautauqua County, Kansas.

5. Gretna Shale Member, South Bend Limestone, Lansing Group – Wyandotte County, KS (Heckel et. al., 1999, p. 28, outcrop A7)

Location: NW, SW, NW, Sec. 8, T11S, R23E, Bonner Springs Quadrangle

GPS Coordinates: 39°06'40"N 94°53'23.7"W

- Samples:
1. gray shale, Gretna Shale Member
 2. gray shale, Gretna Shale Member
 3. yellow wackestone, Little Kaw Limestone Member
 4. yellow shale, Little Kaw Limestone Member
 5. yellow shale, Little Kaw Limestone Member

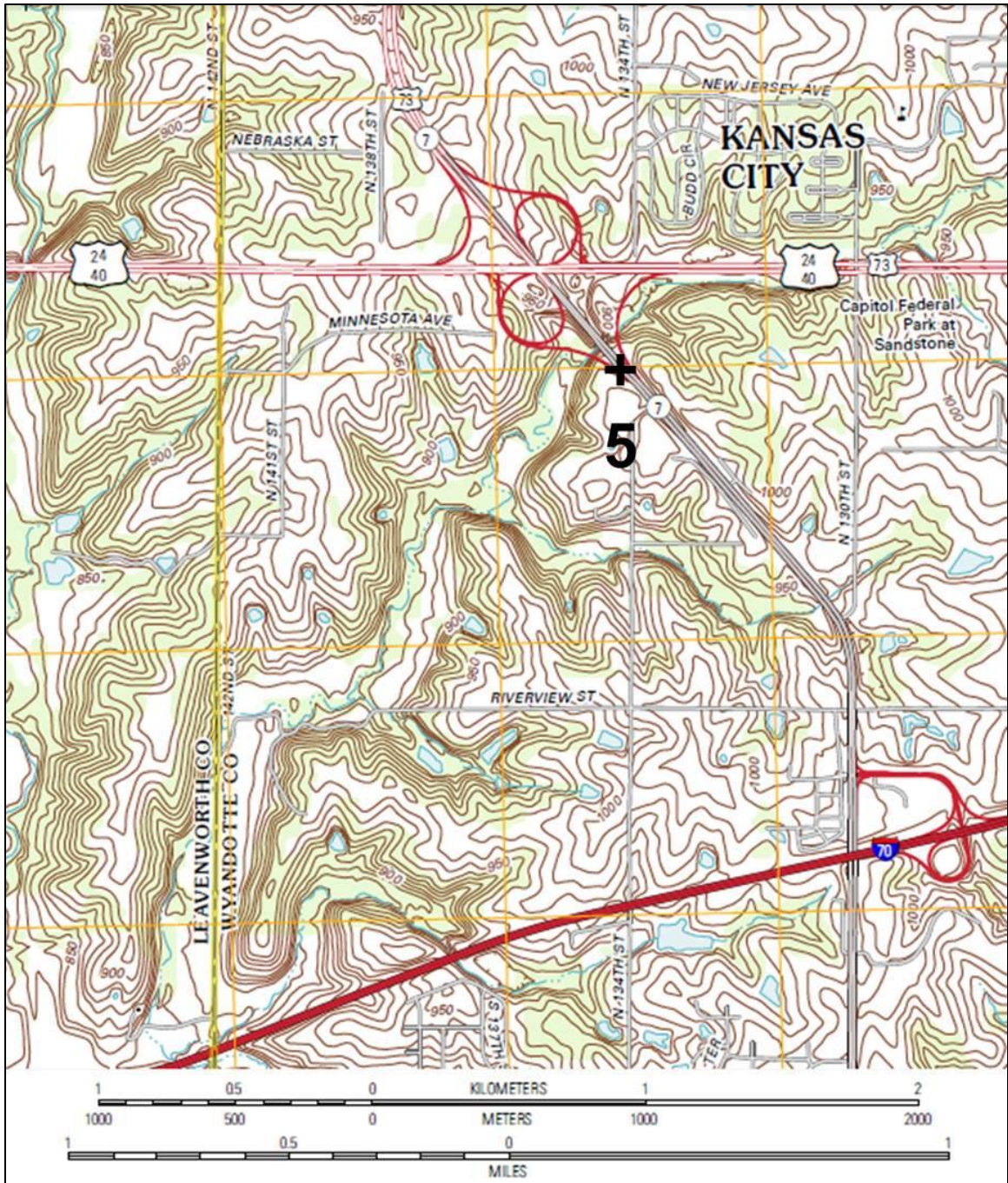


Figure 22. Topographic map of Locality #5, Wyandotte County, Kansas.

6. Eudora Shale Member, Stanton Limestone, Lansing Group – Clay County, MO

Location: SW, SE, NE, Sec. 9, T51N, R32W, Liberty Quadrangle

GPS Coordinates: 39°14'0"N 94°29'0"W

- Samples:
1. gray clay shale, Eudora Shale Member
 2. dark gray clay shale, Eudora Shale Member
 3. black shale, Eudora Shale Member
 4. black fissile shale, Eudora Shale Member
 5. black shale, Eudora Shale Member
 6. gray clay shale, Eudora Shale Member

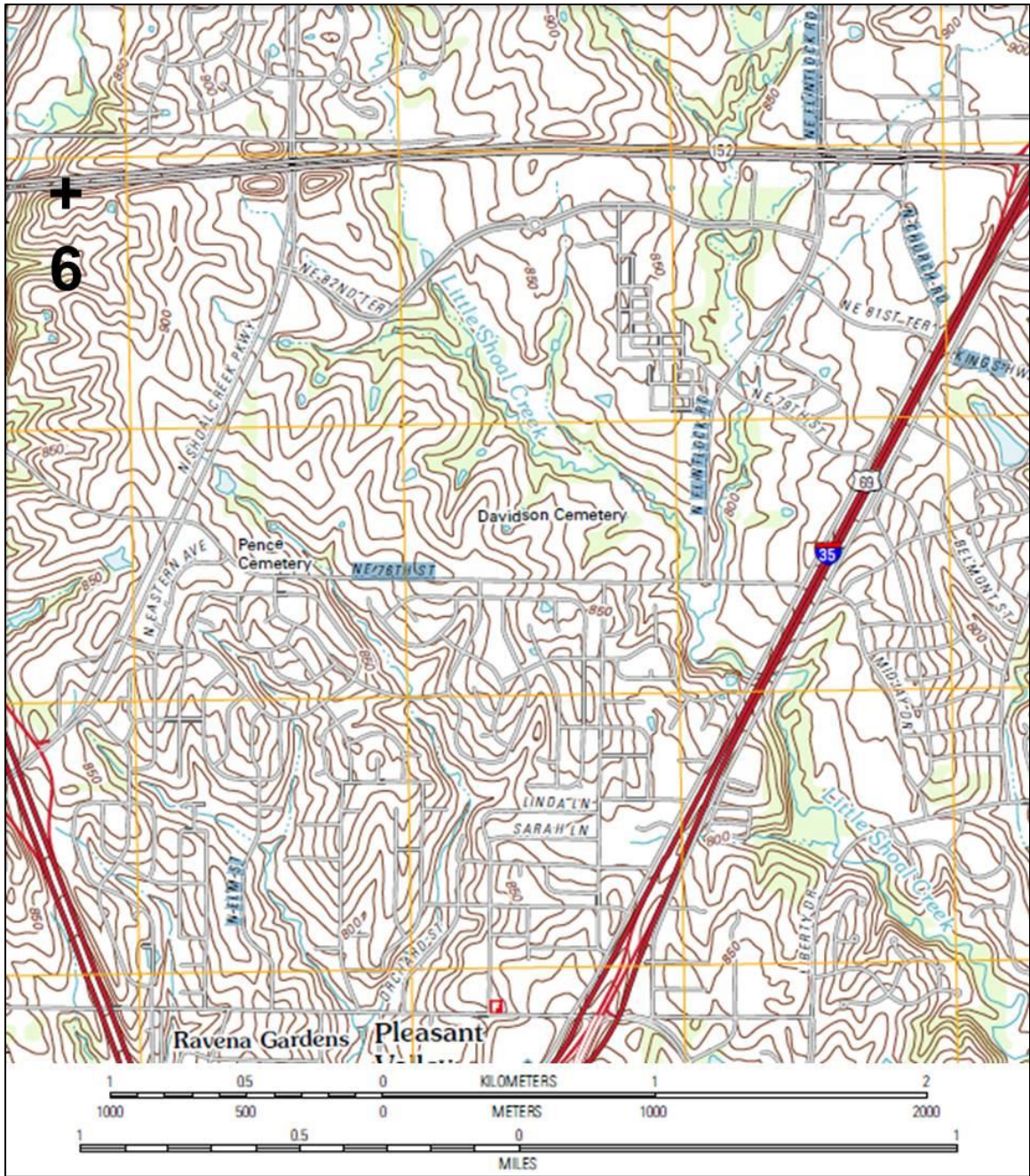


Figure 23. Topographic map of Locality #6, Clay County, Kansas.

7. Hickory Creek Shale Member, Plattsburg Limestone, Lansing Group – Wyandotte County, KS
(Heckel et. al., 1999, p. 26, outcrop A6)

Location: C, S/2, NE, Sec. 29, T11S, R23E, Bonner Springs Quadrangle

GPS Coordinates: 39°03'58"N 94°52'36.6"W

- Samples:
1. tan wackestone, Spring Hill Limestone Member
 2. tan wackestone, Spring Hill Limestone Member
 3. tan shale, Hickory Creek Shale Member

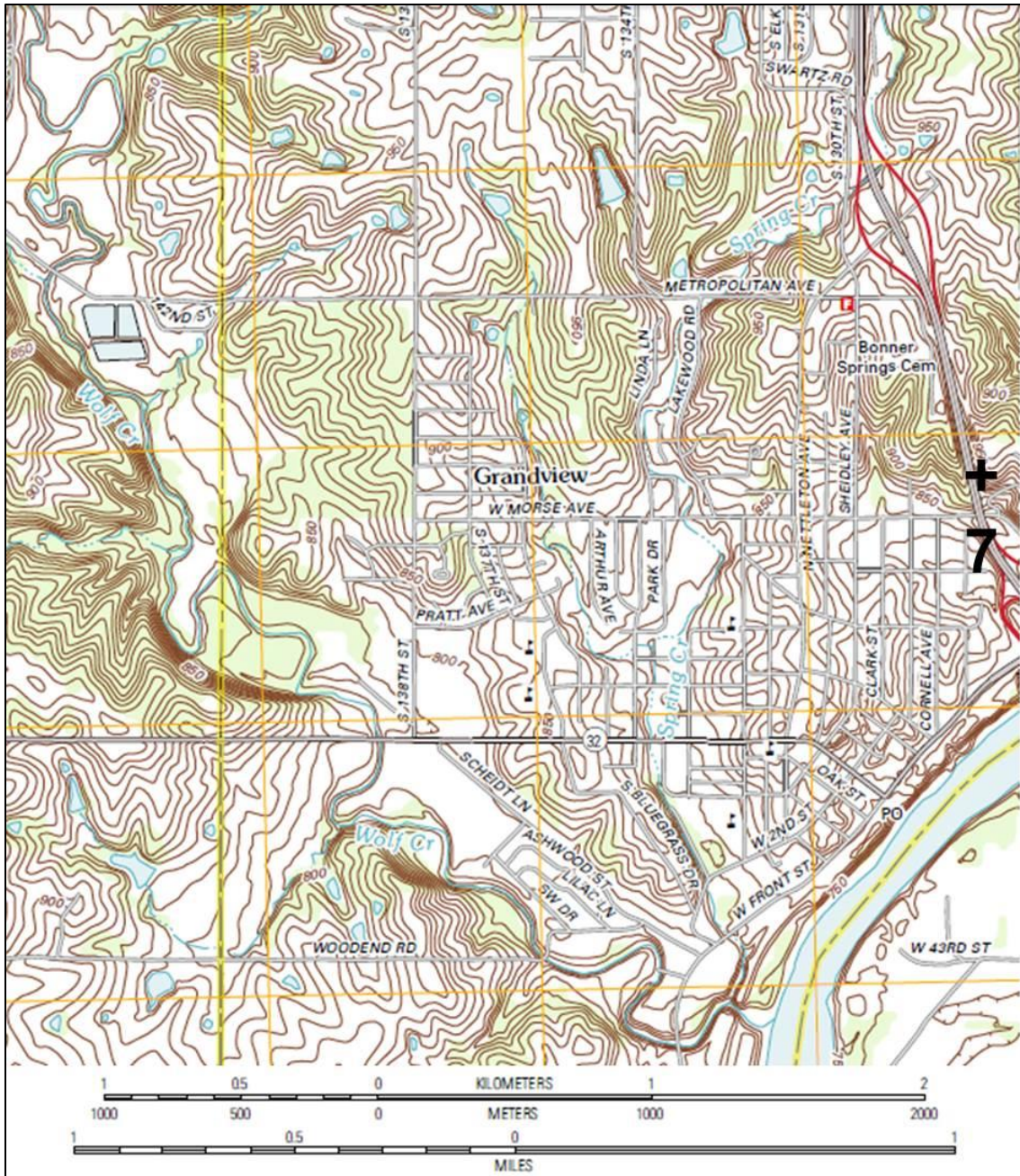


Figure 24. Topographic map of Locality #7, Wyandotte County, Kansas.

8. Quindaro Shale Member, Wyandotte Limestone, Kansas City Group – Wyandotte County, KS
(Heckel et. al., 1999, p. 26, outcrop A5)

Location: S/2, NE, NW, Sec. 6, T12S, R24E, Edwardsville Quadrangle

GPS Coordinates: 39°02'28"N 94°47'29.1"W

Samples: 1. light gray shale, Quindaro Shale Member

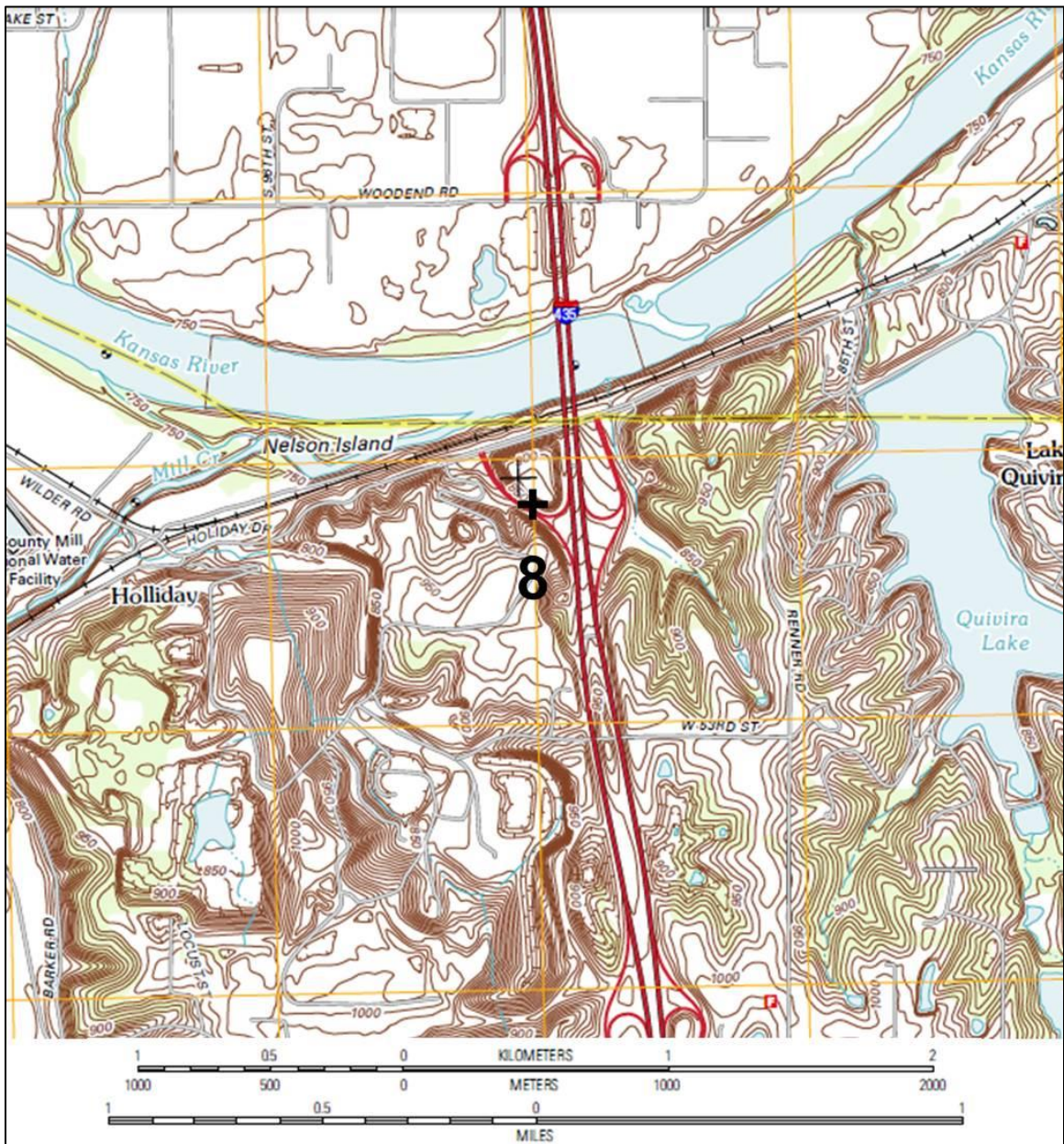


Figure 25. Topographic map of Locality #8, Wyandotte County, Kansas.

9a. Muncie Creek Shale Member, Iola Limestone, Kansas City Group – Wyandotte County, KS
(Heckel et. al., 1999, p. 24, outcrop A4)

Location: C, S/2, SE, Sec. 12, T11S, R24E, Shawnee Quadrangle

GPS Coordinates: 39°06'19.5"N 94°42'01.8"W

- Samples:
1. gray wackestone, Raytown Limestone Member
 2. gray packstone, Raytown Limestone Member
 3. black fissile shale, Muncie Creek Shale Member
 4. black fissile shale, Muncie Creek Shale Member
 5. dark gray wackestone, Paola Limestone Member

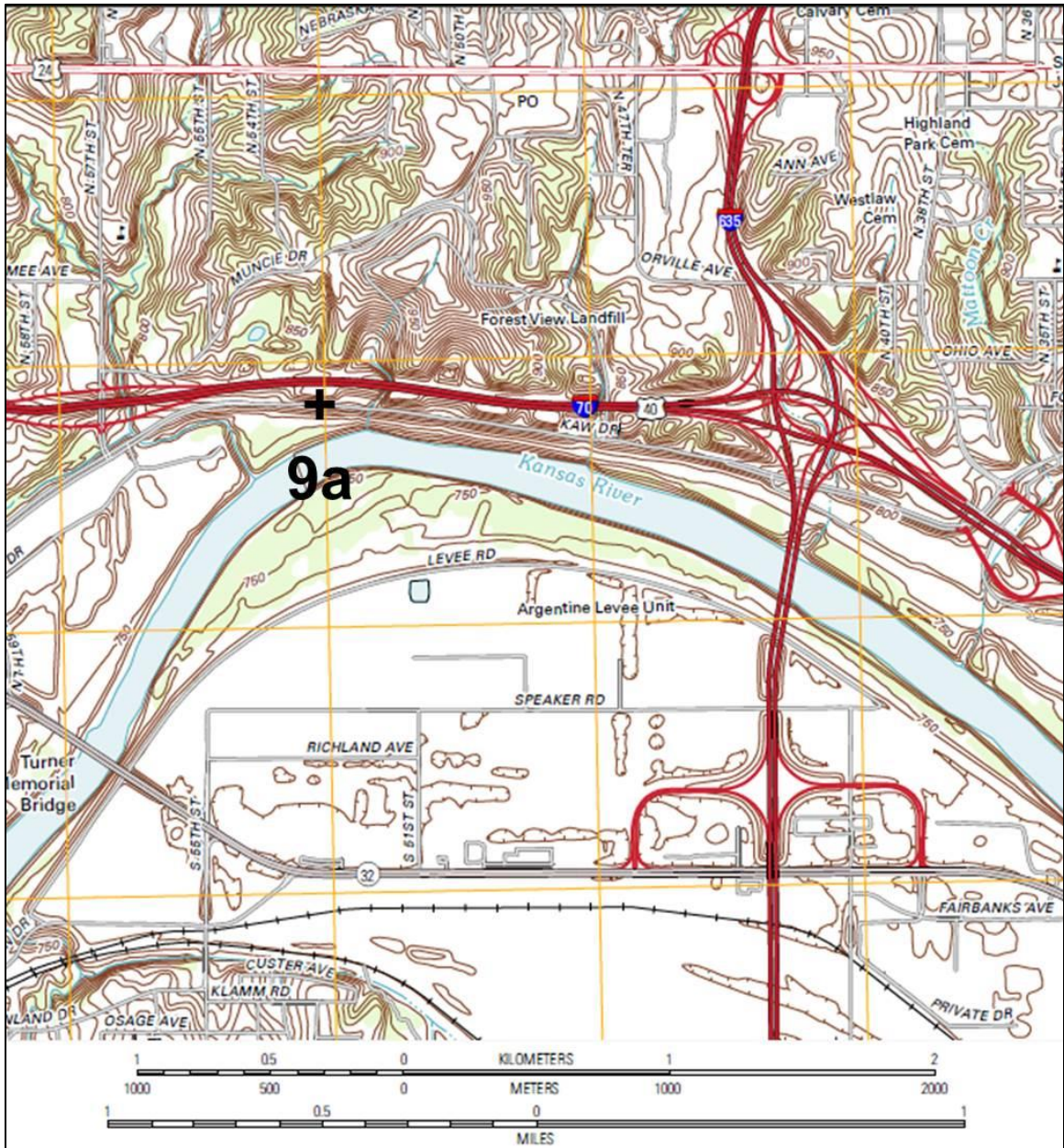


Figure 26. Topographic map of Locality #9a, Wyandotte County, Kansas.

9b. Quivira Shale Member, Iola Limestone, Kansas City Group – Wyandotte County, KS (Heckel et. al., 1999, p. 24, outcrop A4)

Location: C, W/2, SE, SE, Sec. 12, T11S, R24E, Shawnee Quadrangle

GPS Coordinates: 39°06'14.7"N 94°41'15.5"W

- Samples:
1. gray shale, Quivira Shale Member
 2. black shale, Quivira Shale Member
 3. gray shale, Quivira Shale Member



Figure 27. Outcrop photo of the Quivira Shale Member with sample locations.

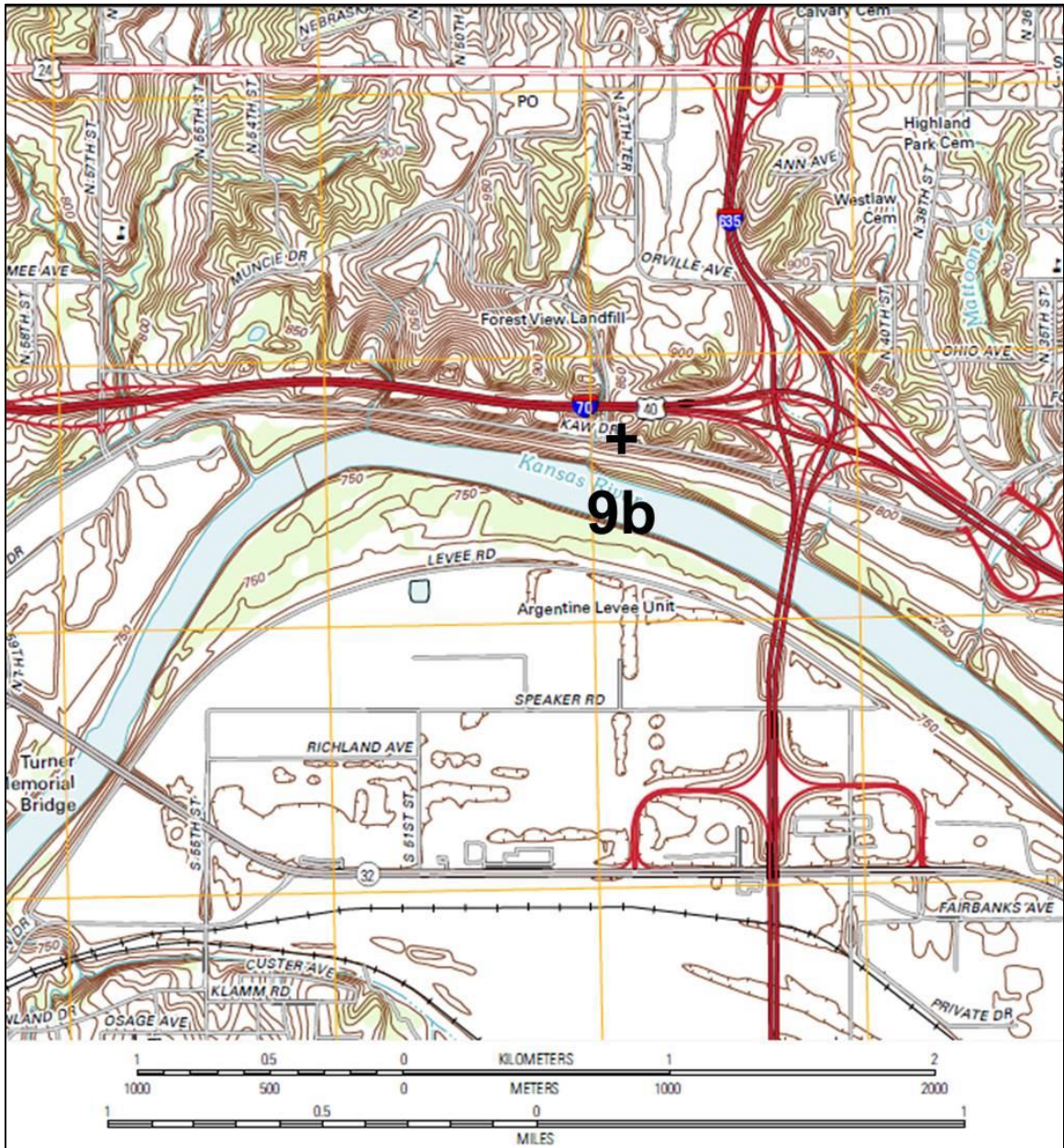


Figure 28. Topographic map of Locality #9b, Wyandotte County, Kansas.

10. Drum Limestone Member and Block Limestone Member, Cherryvale Formation, Kansas City Group – Montgomery County, KS (Roscoe, 2008, p. 81, outcrop Drum Reference)

Location: North Line of NE Sec. 31, T32S, R17E, Liberty Quadrangle

GPS Coordinates: 37°13'25"N 95°34'56"W

- Samples:
1. dark gray massive oolitic limestone, Drum Limestone Member
 2. dark gray massive oolitic limestone, Drum Limestone Member
 3. gray oolitic limestone, Drum Limestone Member
 4. wavy algal limestone, Drum Limestone Member
 5. gray/brown skeletal packstone lense, Block Limestone Member
 6. gray/brown skeletal packstone lense, Block Limestone Member
 7. gray skeletal packstone lense, Block Limestone Member
 8. gray/brown skeletal packstone lense, Block Limestone Member

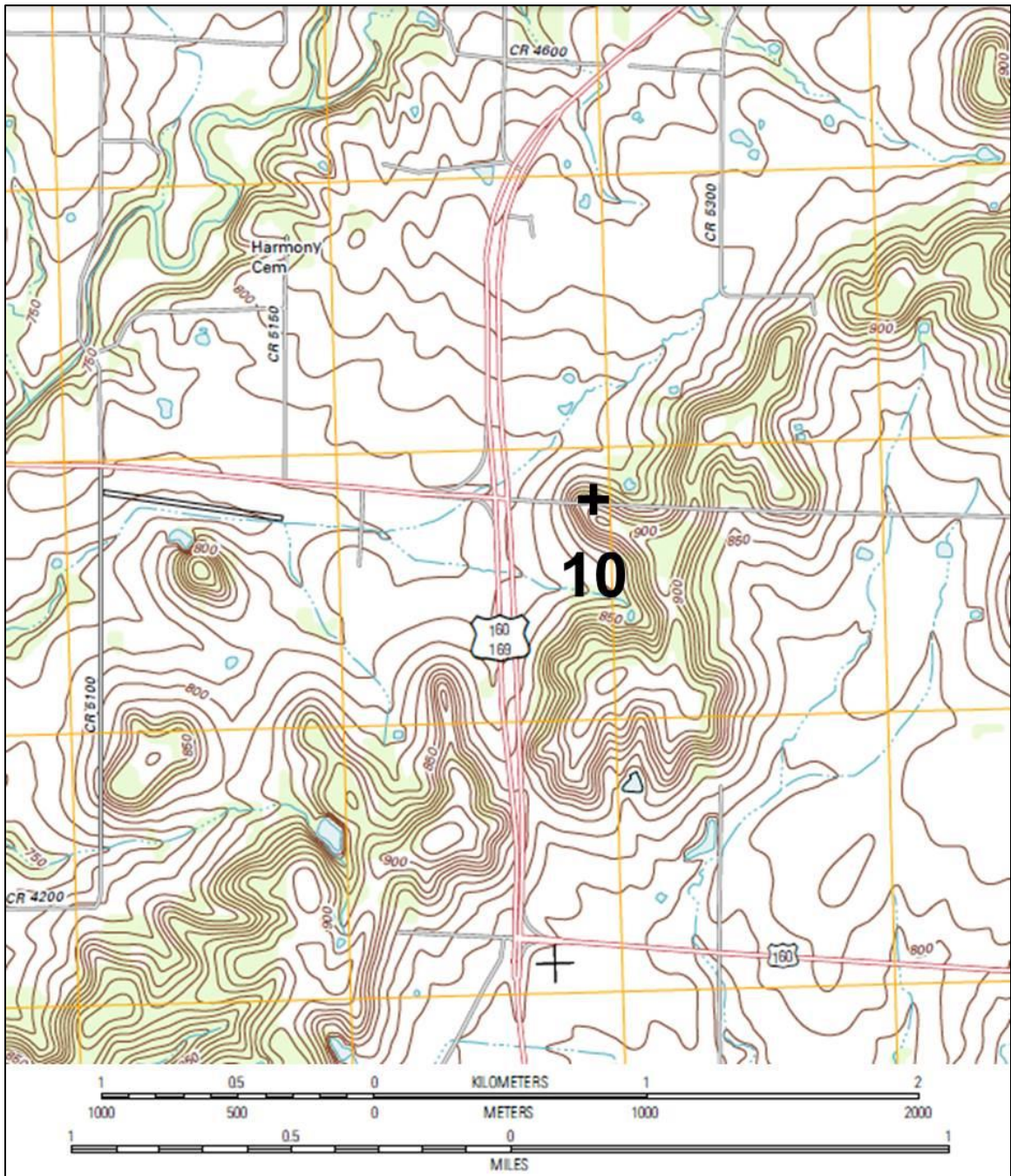


Figure 29. Topographic map of Locality #10, Montgomery County, Kansas.

11. Stark Shale Member, Dennis Limestone, Kansas City Group – Washington County, OK
(Roscoe, 2008, p. 80, outcrop Hogshooter South)

Location: N/2, NW, NE, Sec. 6, T25N, R14E, Oglesby Quadrangle

GPS Coordinates: 36°41.069'N 95°51.172'W

- Samples:
1. gray wackestone, Winterset Limestone Member
 2. gray interbedded packstone, Winterset Limestone Member
 3. gray clay shale, Stark Shale Member
 4. concretion, Stark Shale Member
 5. black fissile shale, Stark Shale Member
 6. black fissile shale, Stark Shale Member
 7. gray shale, Stark Shale Member
 8. gray wackestone, Canville Limestone Member
 9. gray wackestone, Canville Limestone Member
 10. gray clay shale, Canville Limestone Member

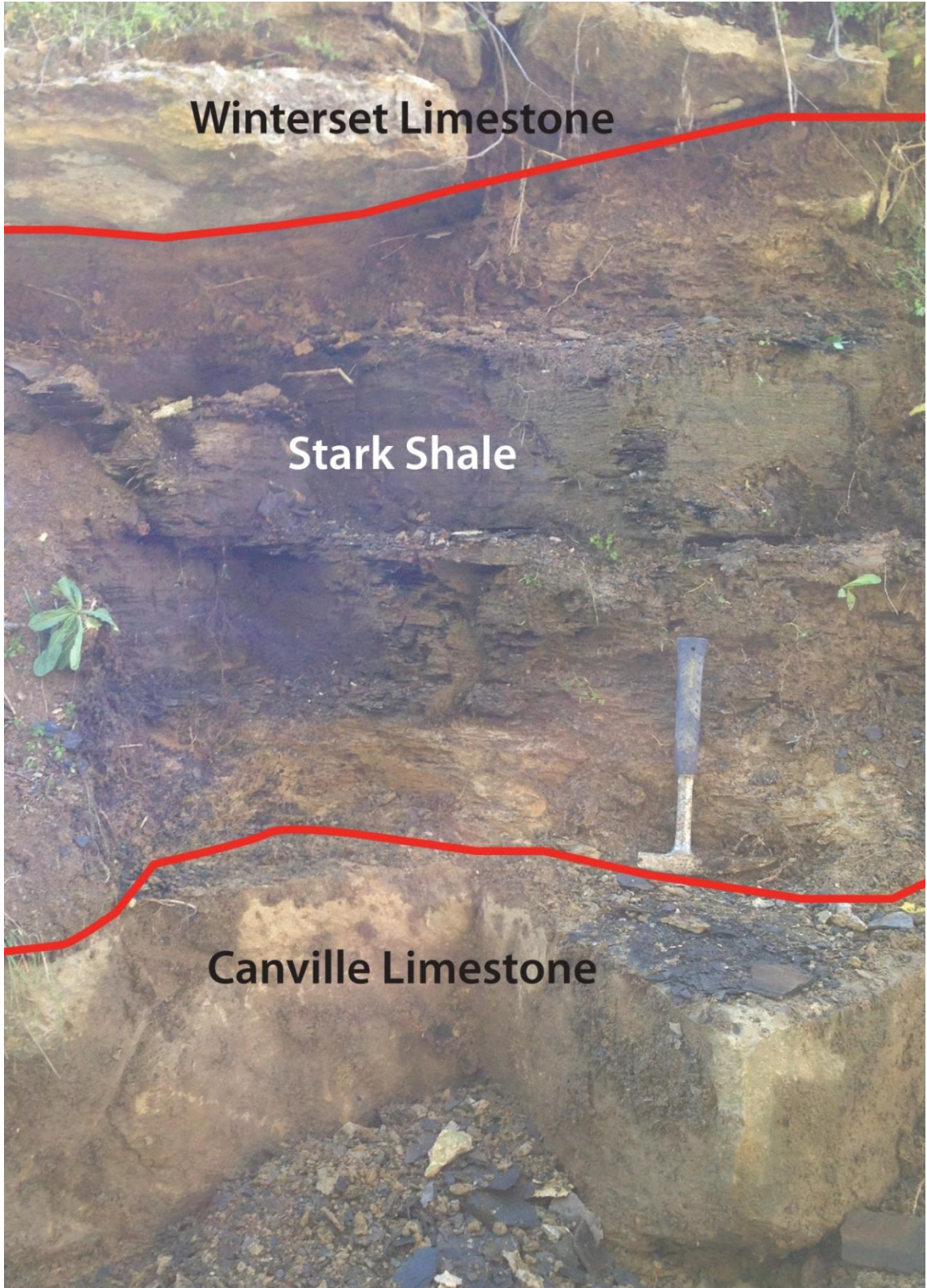


Figure 30. Outcrop photo of the Stark Shale Member.

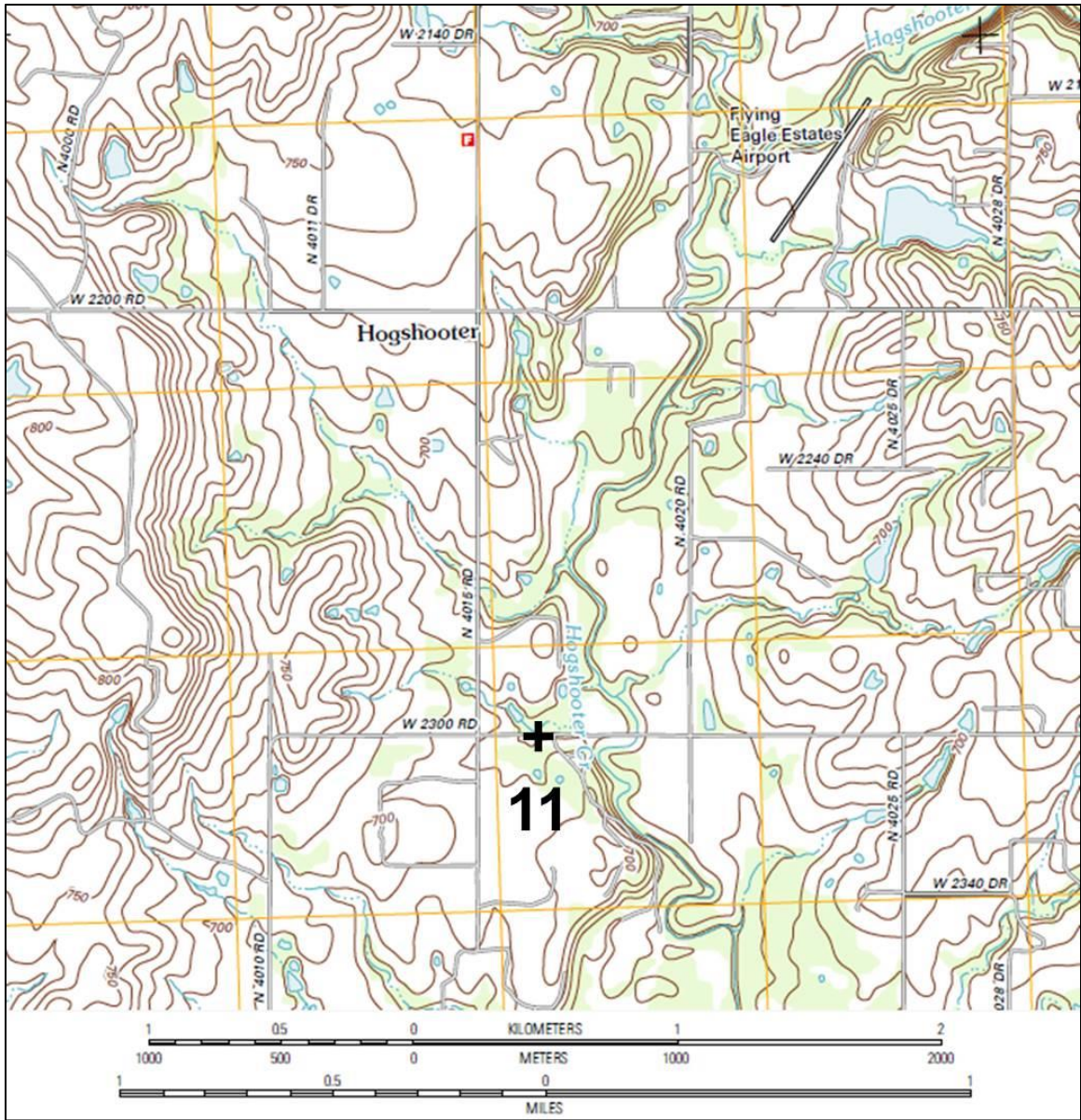


Figure 31. Topographic map of Locality #11, Washington County, Oklahoma.

12. Hushpuckney Shale Member, Swope Limestone, Kansas City Group – Jackson County, MO
(Heckel et. al., 1999, p. 18, outcrop A2)

Location: SW, NW, Sec. 6, T 38N, R32W, Independence Quadrangle

GPS Coordinates: 39°00'44.7"N 94°29'57.9"W

- Samples:
1. gray wackestone, Middle Creek Limestone Member
 2. gray mudstone, Hushpuckney Shale Member
 3. gray shale, Hushpuckney Shale Member
 4. gray shale, Hushpuckney Shale Member
 5. black fissile shale, Hushpuckney Shale Member
 6. black fissile shale, Hushpuckney Shale Member
 7. gray wackestone, Bethany Falls Limestone Member

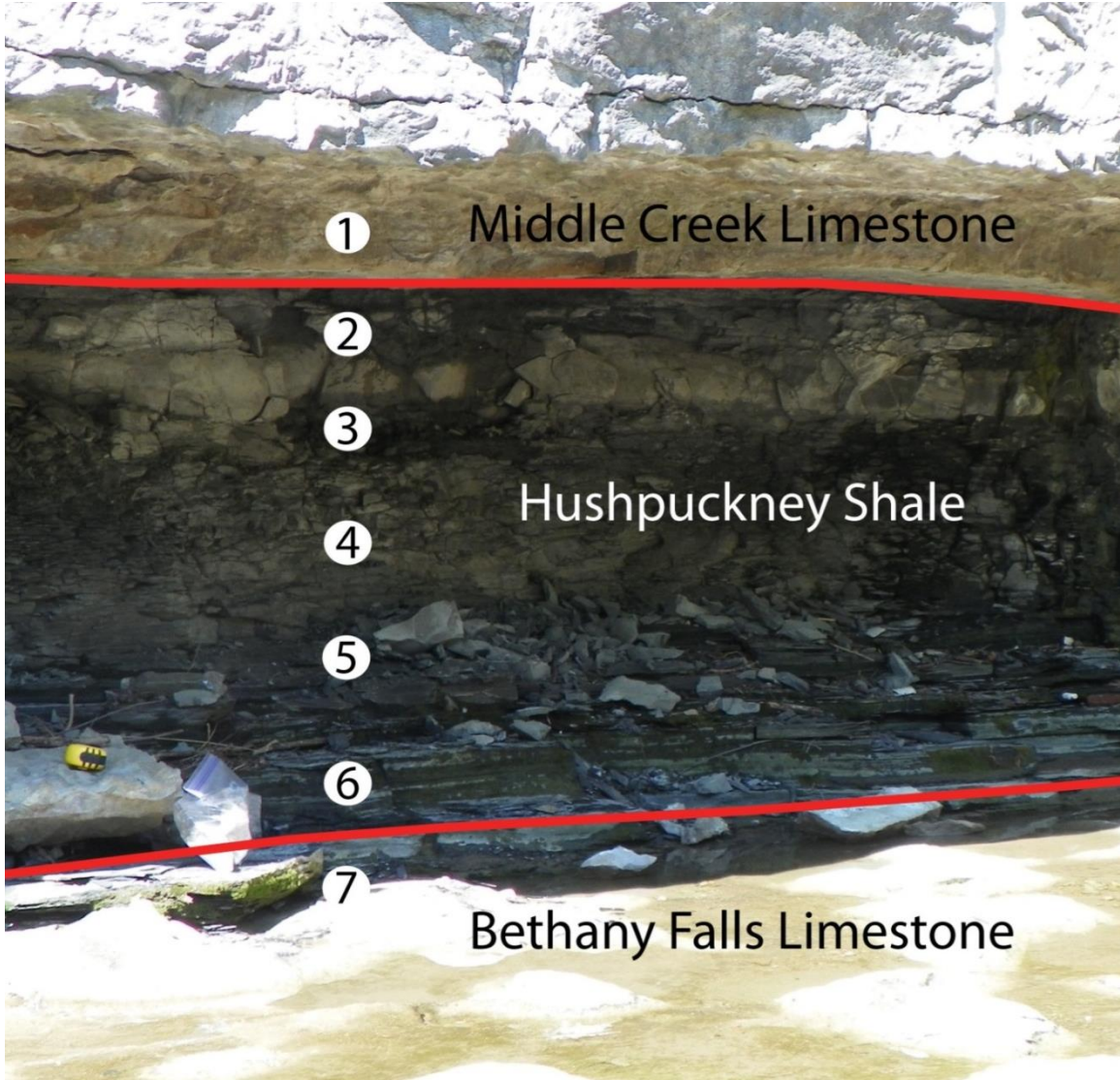


Figure 32. Outcrop photo of the Hushpuckney Shale Member with sample locations.

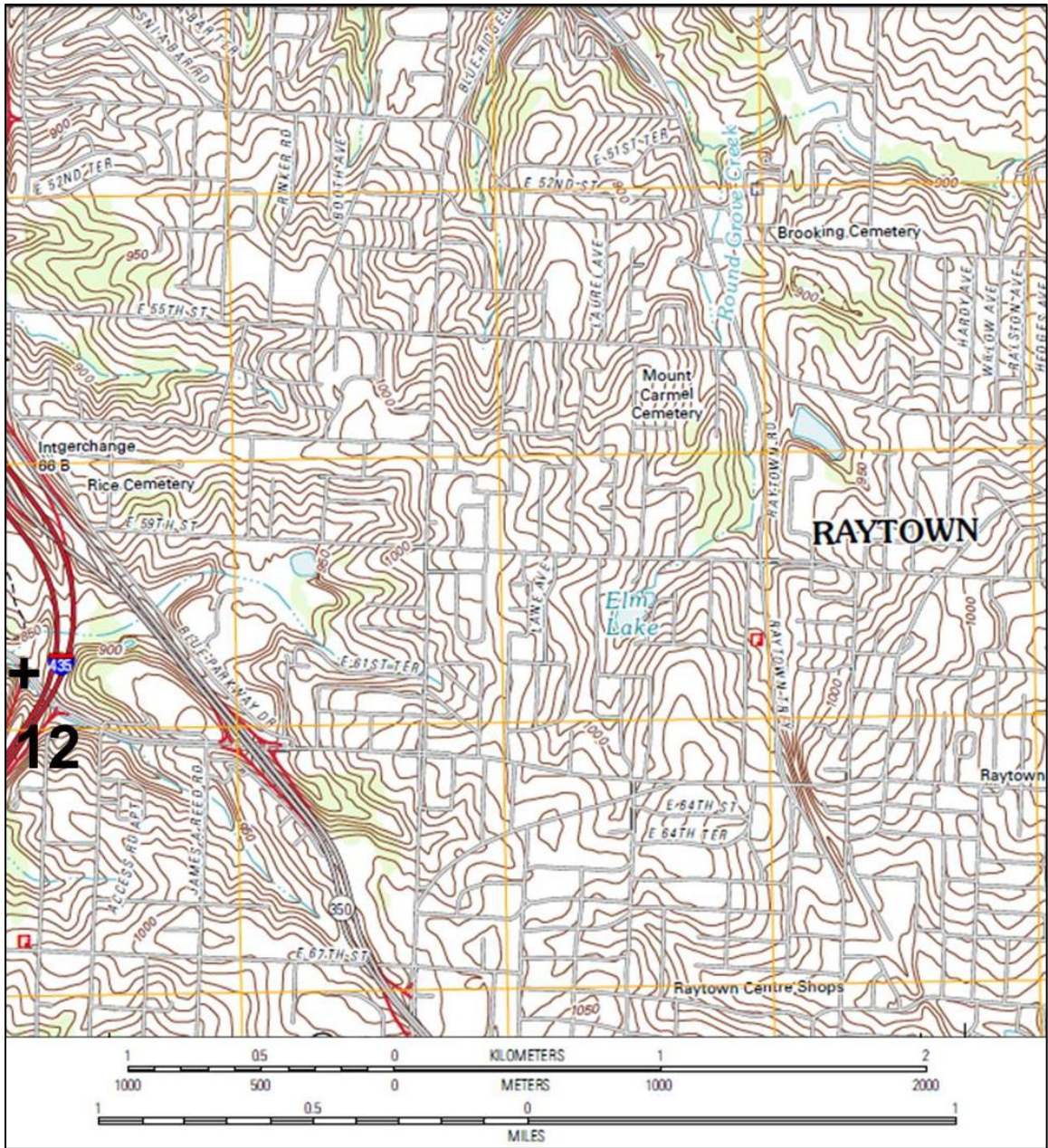


Figure 33. Topographic map of Locality #12, Jackson County, Missouri.

13. Hushpuckney Shale Member and Mound City Shale Member, Tacket Formation, Kansas City Group – Nowata County, OK (Bennison, et. al., 1996, Stop #5)

Location: South Line of Sec. 13, T28N, R25E, Delaware Quadrangle

GPS Coordinates: 36°54'09.6"N 95°39'22.7"W

- Samples:
1. black fissile shale, Hushpuckney Shale Member
 2. black fissile shale, Hushpuckney Shale Member
 3. gray shale, Hushpuckney Shale Member
 4. black calcareous shale, Hushpuckney Shale Member
 5. interbedded dark gray shale and packstone, Middle Limestone Member
 6. interbedded dark gray shale and wackestone, Middle Limestone Member
 7. black shale, Mound City Shale Member
 8. concretion, Mound City Shale Member
 9. black shale, Mound City Shale Member
 10. black fissile shale, Mound City Shale Member

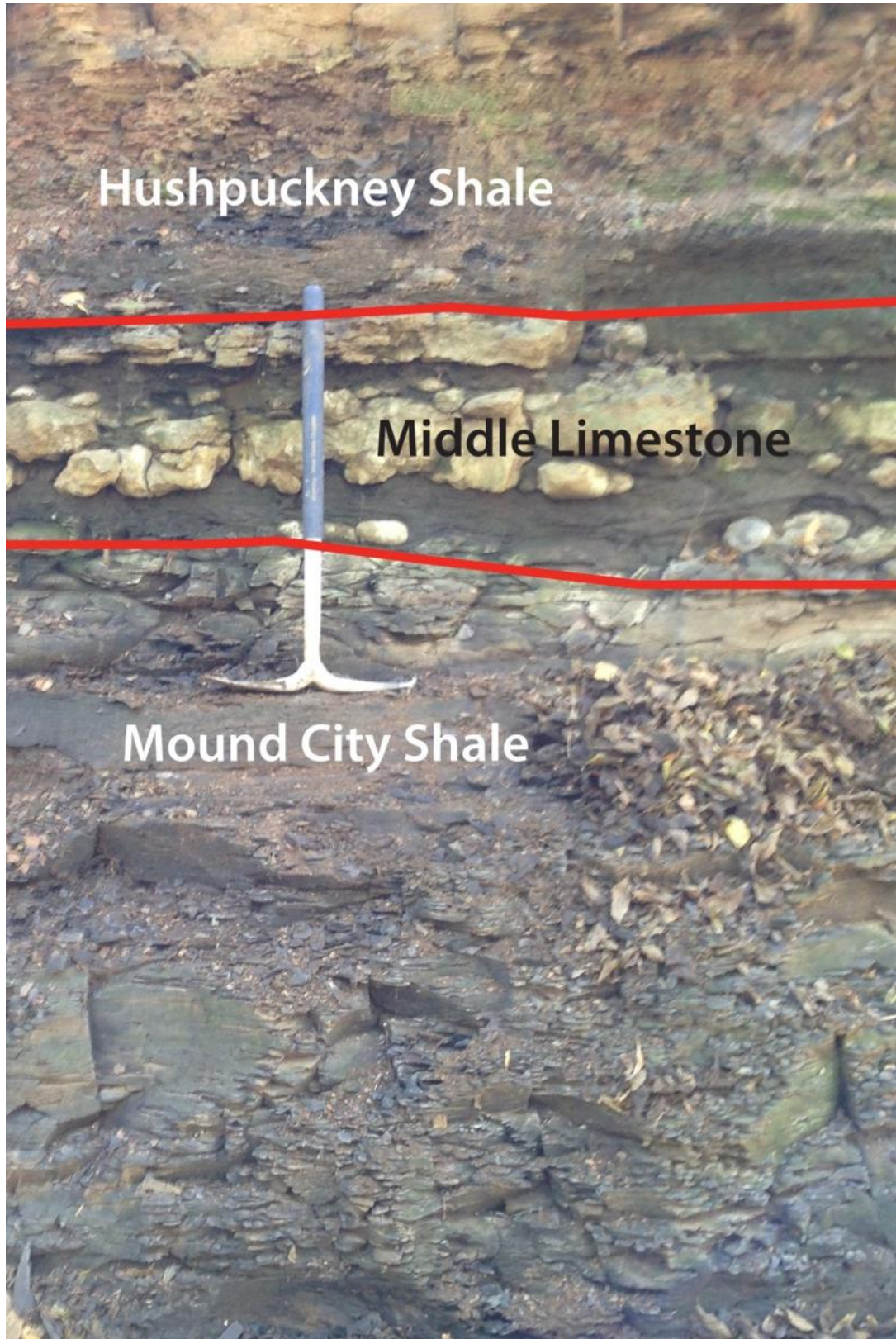


Figure 34. Outcrop photo of the Hushpuckney Shale Member and Mound City Shale Member.

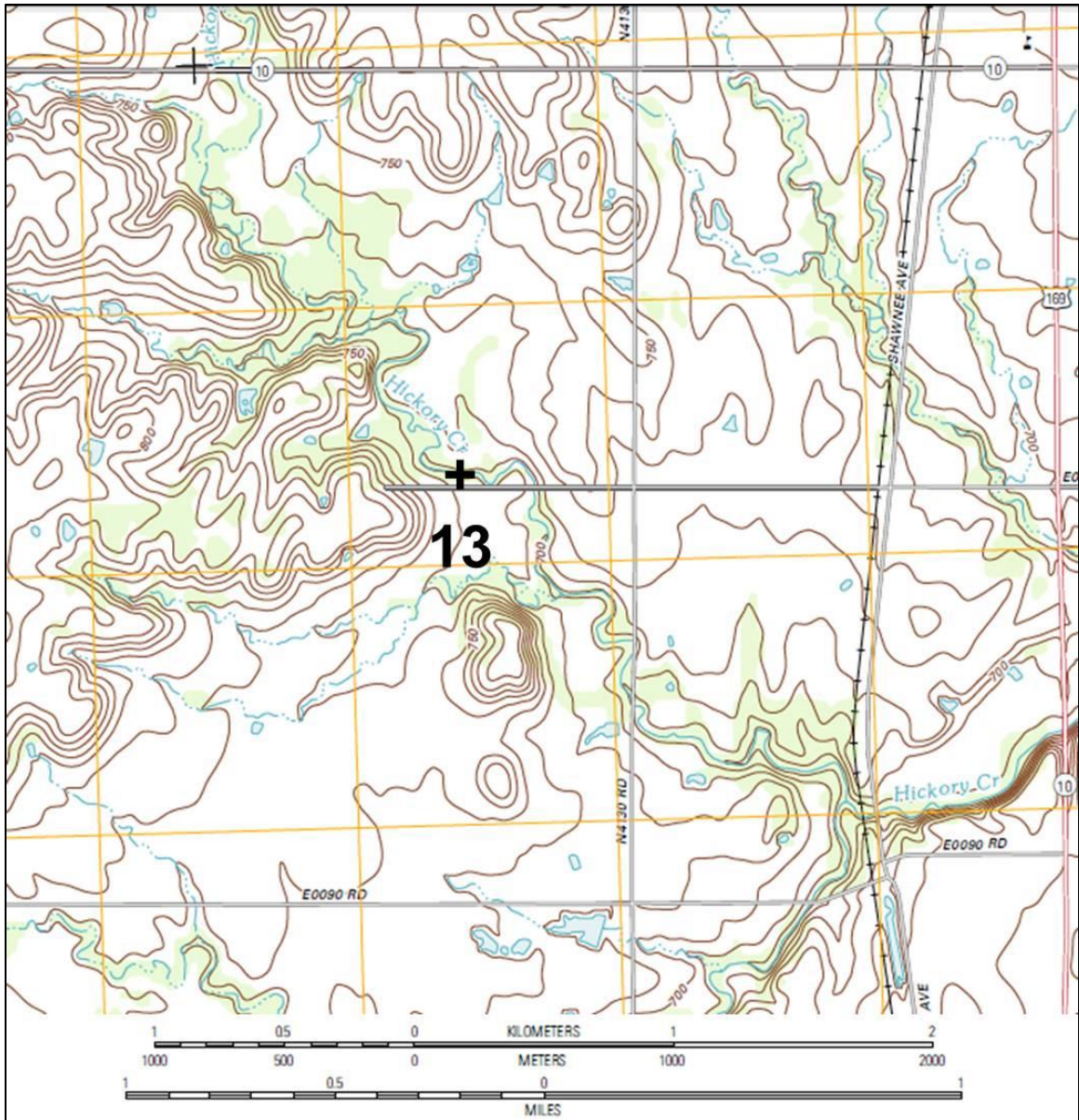


Figure 35. Topographic map of Locality #13, Nowata County, Oklahoma.

14. Mound City Shale Member, Hertha Limestone, Kansas City Group – Bourbon County, KS
(Heckel and Watney, 2002, p. 14)

Location: North Line of Sec. 7, T25S, R23E, Xenia Quadrangle

GPS Coordinates: 37°53.515'N 94°55.449'W

- Samples:
1. gark gray shale, Mound City Shale Member
 2. black fissile shale with limestone concretions, Mound City Shale Member
 3. black fissile shale, Mound City Shale Member
 4. black fissile shale, Mound City Shale Member
 5. dark gray shale, Mound City Shale Member
 6. gray clay shale, Mound City Shale Member

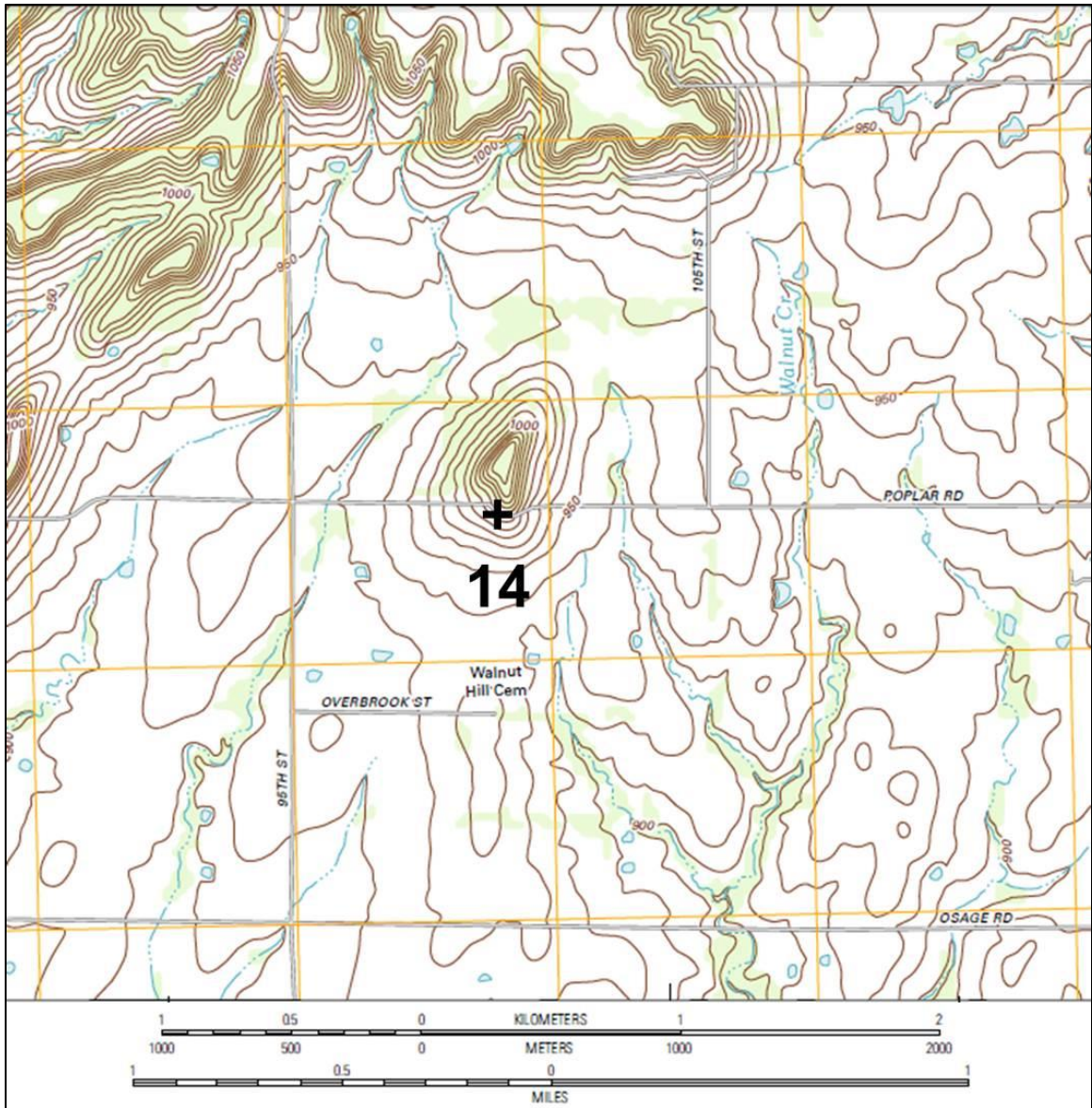


Figure 36. Topographic map of Locality #14, Bourbon County, Kansas.

15. Mound City Shale Member and Nuyaka Creek Shale Member, Hertha Limestone, Kansas City Group – Madison County, IA (Pope, 2012, p. 62)

Location: SW, NE, SW, Sec. 5, T75N, R27W, Patterson Quadrangle

GPS Coordinates: 41°19'11.6"N 93°59'16.7"W

- Samples:
1. gray wackestone, Sniabar Limestone Member
 2. gray clay shale, Mound City Shale Member
 3. gray clay shale, Mound City Shale Member
 4. yellow clay shale, Mound City Shale Member
 5. yellow clay shale, Mound City Shale Member
 6. gray clay shale, Mound City Shale Member

- Samples:
1. yellow clay shale, Nuyaka Creek Shale Member

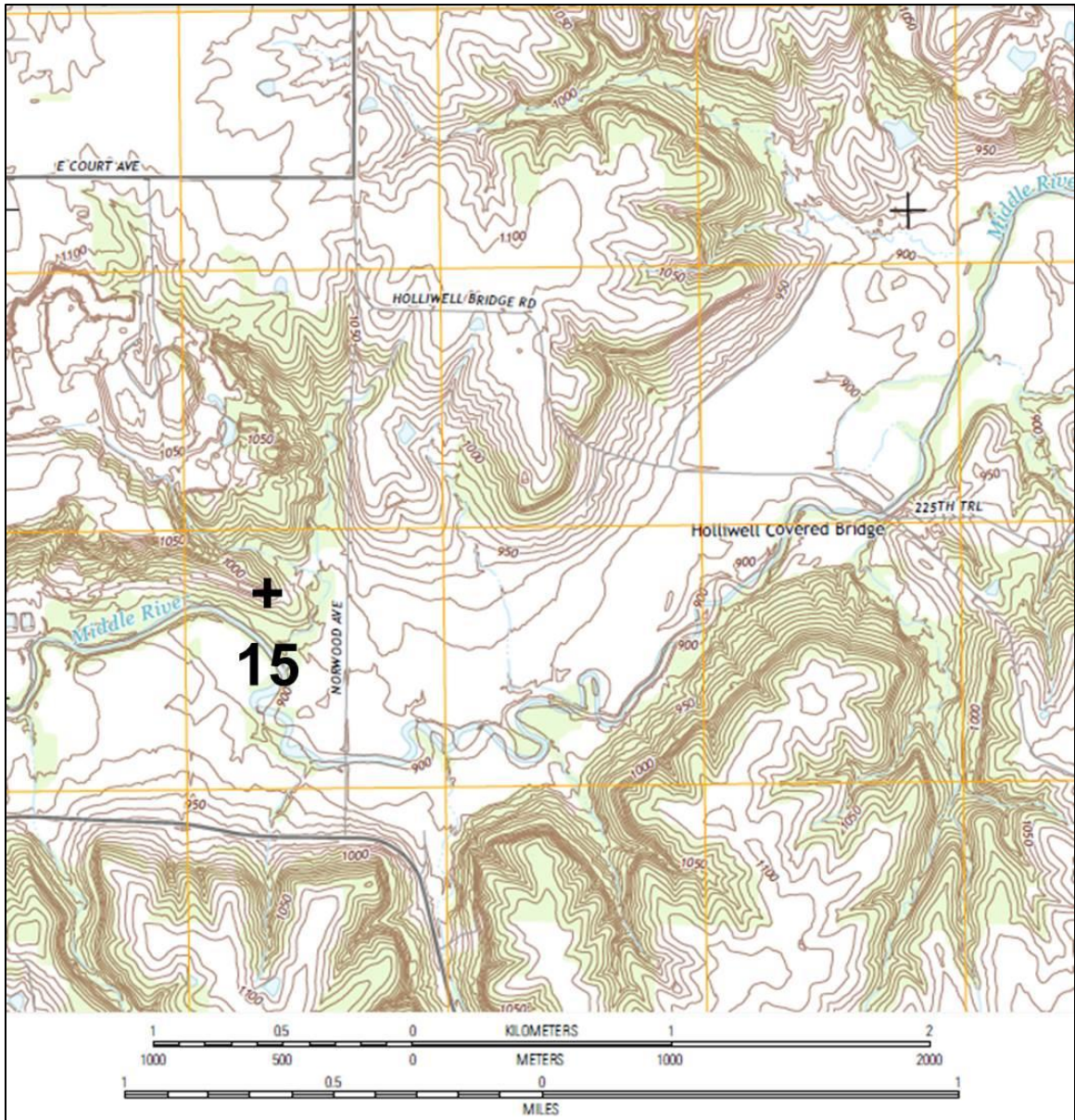


Figure 37. Topographic map of Locality #15, Madison County, Iowa.

16. Norfleet Limestone Member, Lenepah Limestone, Marmaton Group – Montgomery County, KS (Bennison, et. al., 1996, Stop #6)

Location: NE, NE, NW, Sec. 18, T35S, R17E, Coffeerville East Quadrangle

GPS Coordinates: 37°00'20.4"N 95°35'29.8"W

- Samples:
1. gray wackestone, Idenbro Limestone Member
 2. gray wackestone, Idenbro Limestone Member
 3. green, gray shale with limestone nodules, Perry Farm Shale Member
 4. green, gray shale with limestone nodules, Perry Farm Shale Member
 5. gray calcareous shale, Norfleet Limestone Member
 6. gray calcareous shale, Norfleet Limestone Member

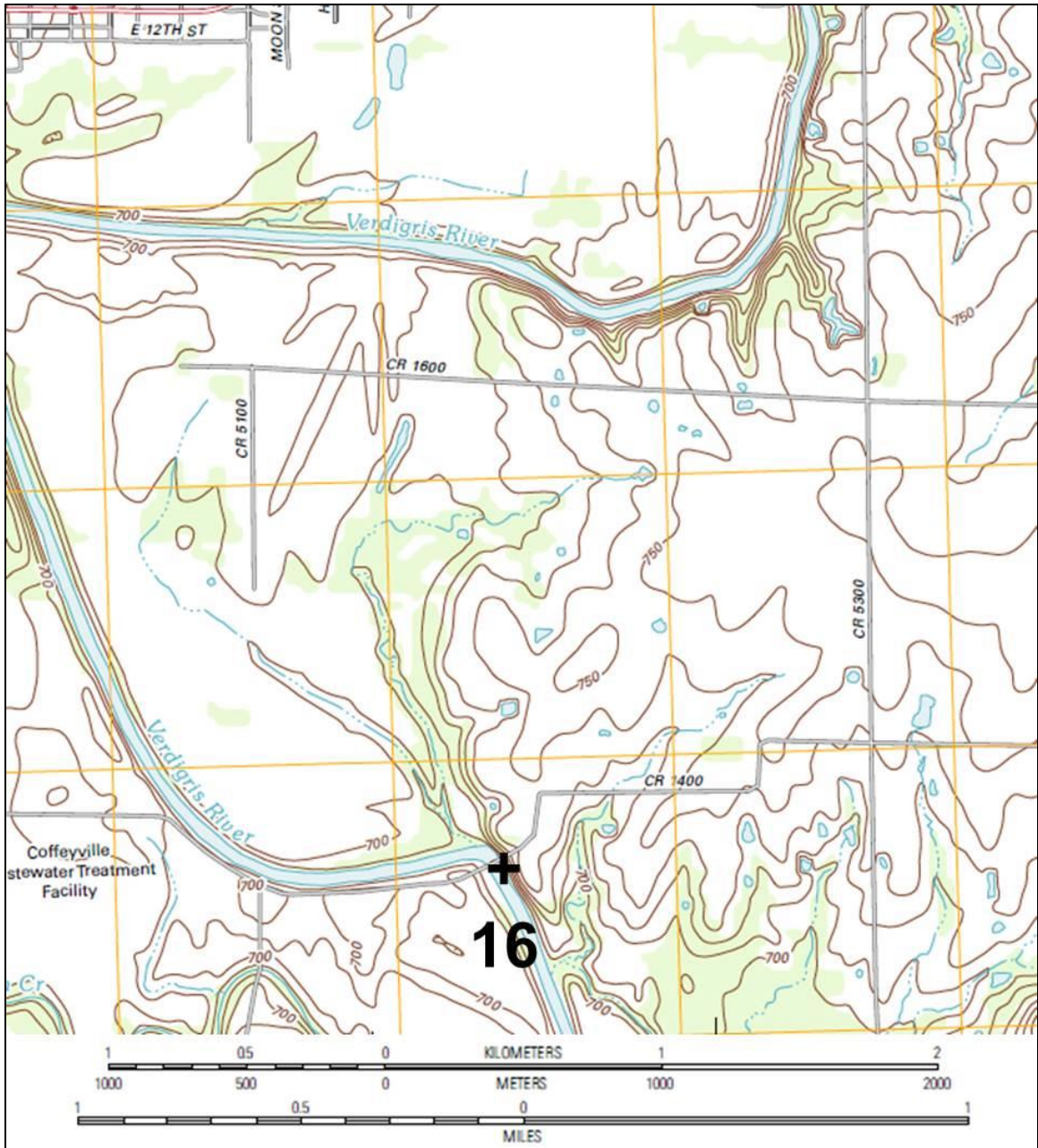


Figure 38. Topographic map of Locality #16, Montgomery County, Kansas.

17. Lake Neosho Shale Member, Altamont Limestone, Marmaton Group – Nowata County, KS
(Leavell, 1993, p. 158, Location 8)

Location: NE, SW, SE, Sec. 10, T 27N, R16E, Childers Quadrangle

GPS Coordinates: 36°49'56"N 95°35'02.7"W

- Samples:
1. gray, brown wackestone, Worland Limestone Member
 2. gray clay shale, Lake Neosho Shale Member
 3. gray shale, Lake Neosho Shale Member
 4. black shale, Lake Neosho Shale Member
 5. black shale, Lake Neosho Shale Member
 6. black fissile shale, Lake Neosho Shale Member
 7. black fissile shale, Lake Neosho Shale Member
 8. black fissile shale, Lake Neosho Shale Member
 9. gray wackestone, Amoret Limestone Member
 10. dark gray mudstone, Bandera Shale



Figure 39. Outcrop photo of the contact of the Worland Limestone Member and Lake Neosho Shale Member.



Figure 40. Photo of the base of the Lake Neosho Shale Member and contact of Amoret Limestone Member.

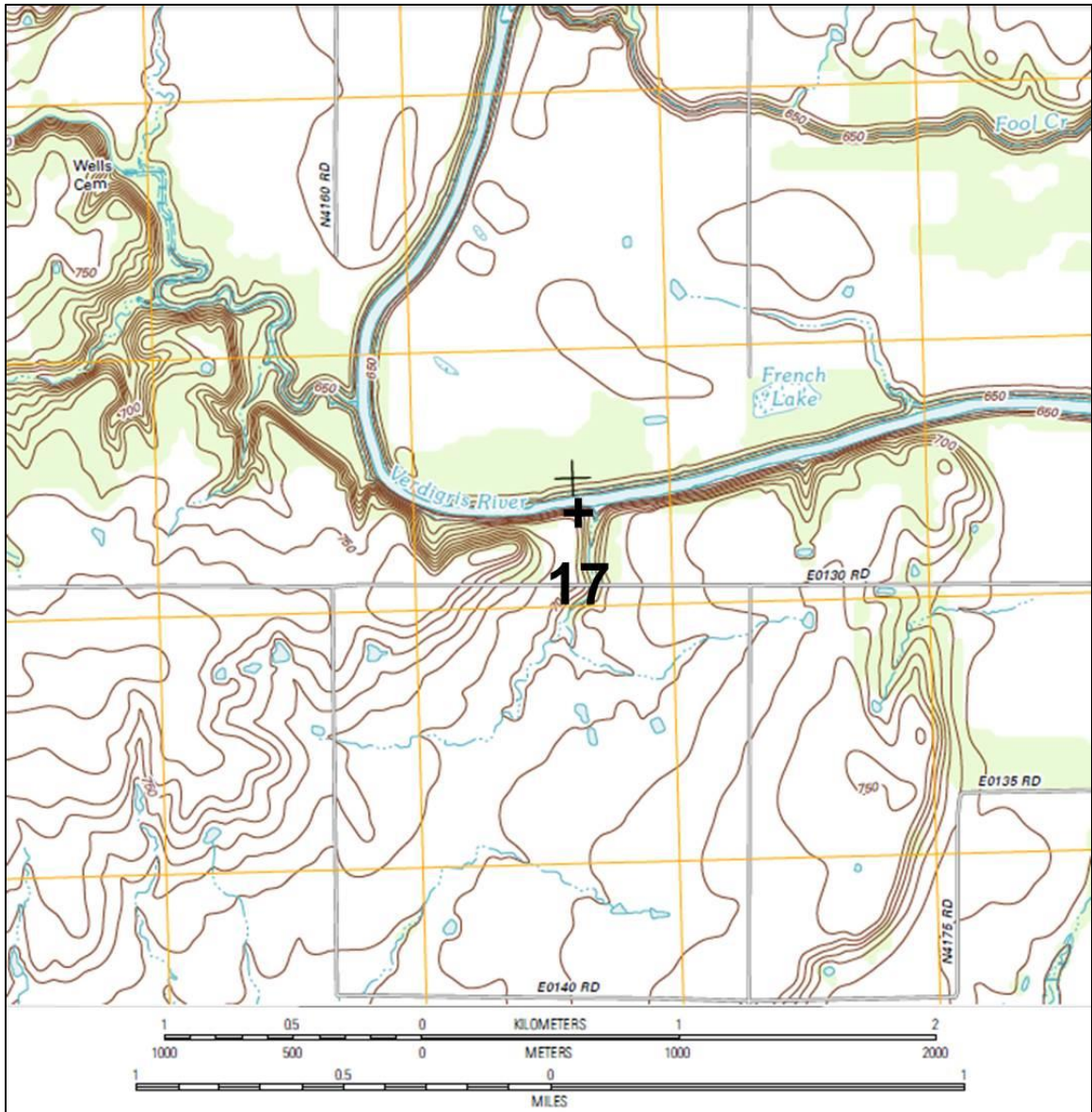


Figure 41. Topographic map of Locality #17, Nowata County, Kansas.

18. Anna Shale Member, Pawnee Formation, Marmaton Group – Madison County, IA (Pope, 2012, p. 77)

Location: SE, SW, Sec. 23, T75N, R26W, Saint Charles Quadrangle

GPS Coordinates: 41°16'06"N 93°50'16"W

- Samples:
1. gray wackestone, Myrick Station Limestone Member
 2. gray clay shale, Anna Shale Member
 3. black shale, Anna Shale Member
 4. gray clay shale, Anna Shale Member

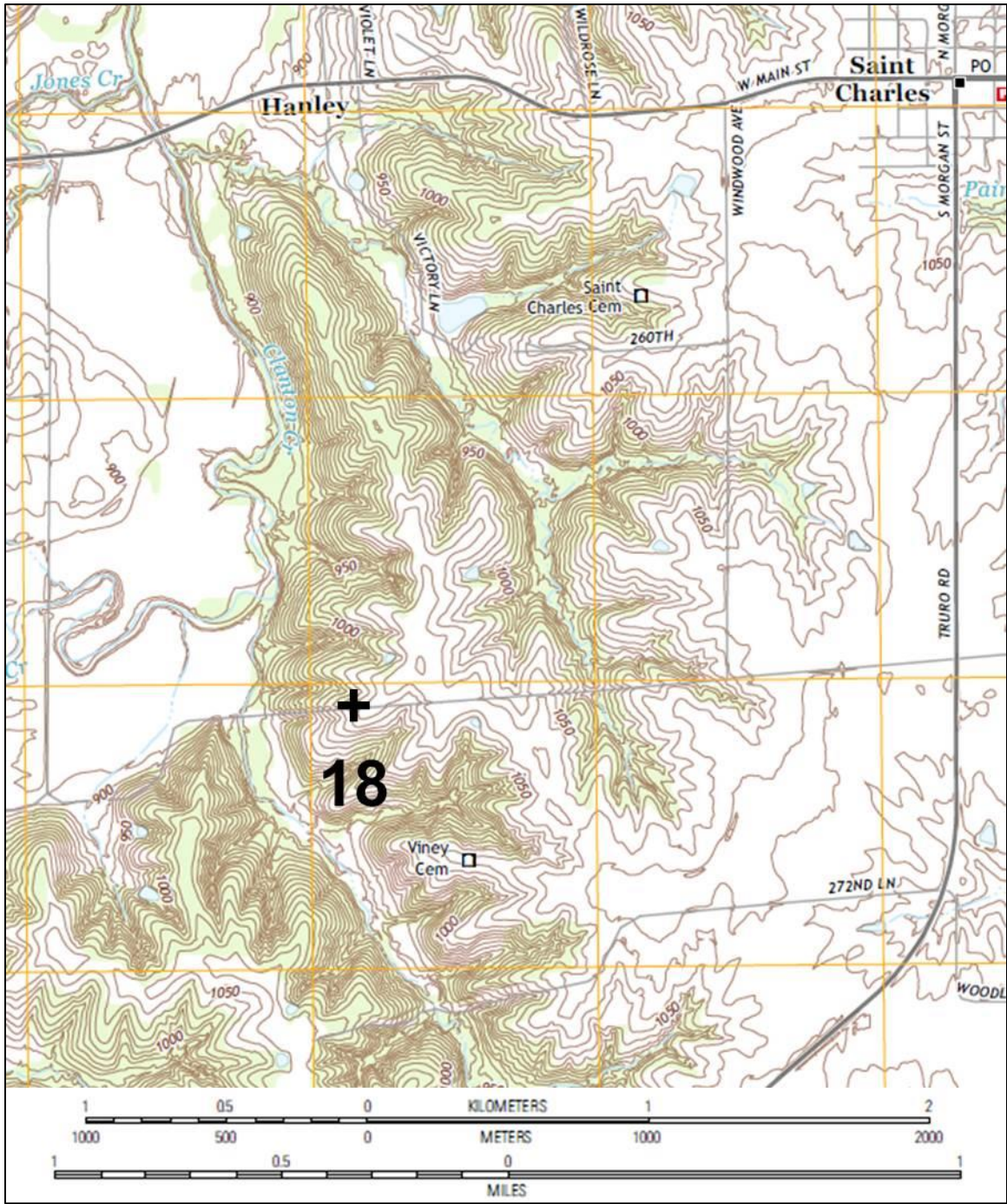


Figure 42. Topographic map of Locality #18, Madison County, Iowa.

19. Anna Shale Member, Pawnee Limestone, Marmaton Group – Rogers County, OK

Location: SW, SW, Sec. 34, T21N, R14E, Collinsville Quadrangle

GPS Coordinates: 36°15.253'N 95°47.147'W

- Samples:
1. gray clay shale, Anna Shale Member
 2. black fissle, phosphatic shale, Anna Shale Member
 3. dark gray shale, Anna Shale Member
 4. gray packstone, Childers School Limestone Member
 5. gray wackestone, Childers School Limestone Member

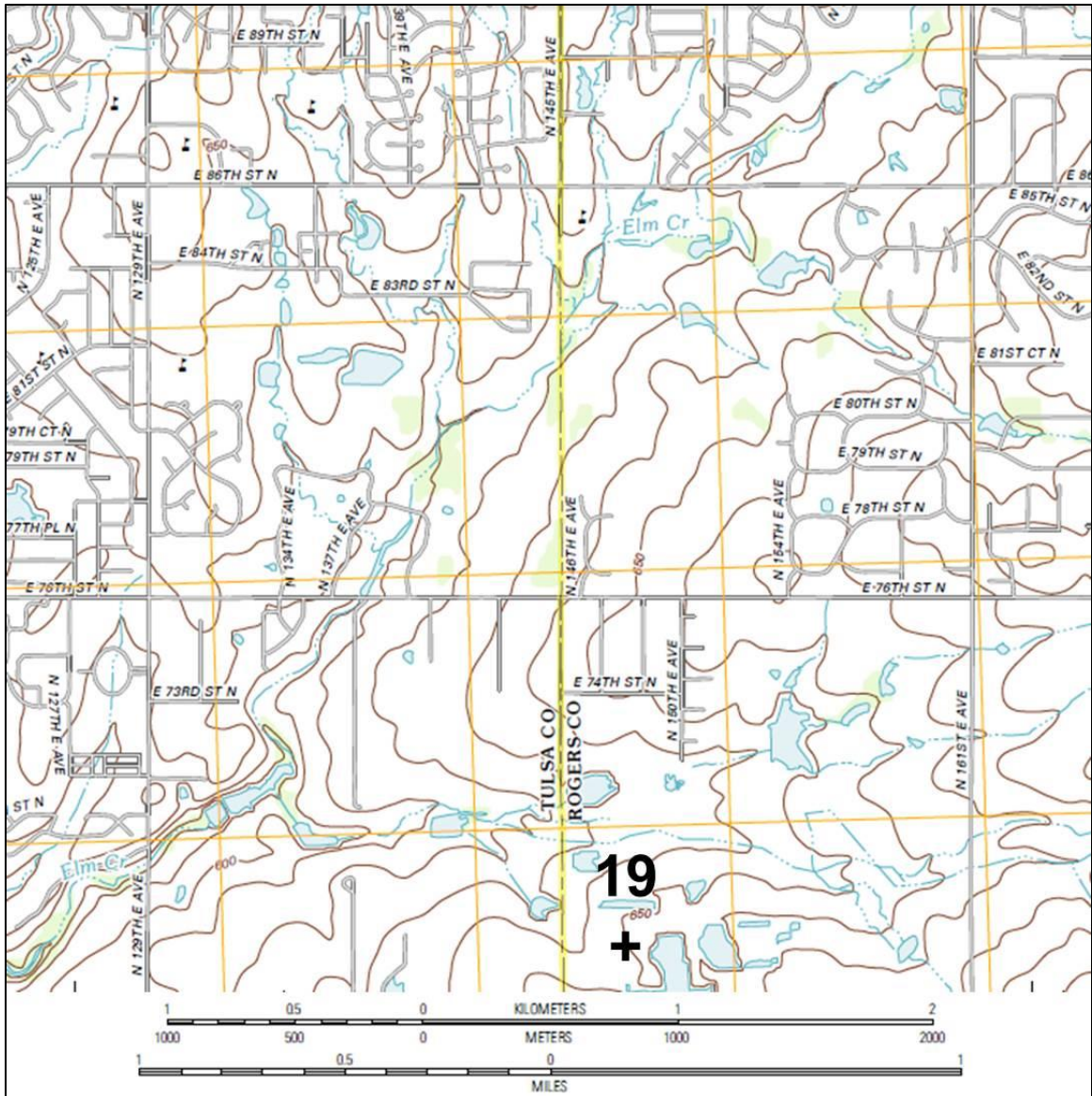


Figure 43. Topographic map of Locality #19, Rogers County, Oklahoma.

20. Little Osage Shale Member, Stephens Forest Formation, Marmaton Group – Madison County, IA (Pope, 2012, p. 81)

Location: East line of SW, NW, SW, Sec. 21, T78N, R27W, Waukee Quadrangle

GPS Coordinates: 41°32'15"N 93°58'25"W

- Samples:
1. gray shale, Little Osage Shale Member
 2. black shale, Little Osage Shale Member
 3. gray shale, Little Osage Shale Member

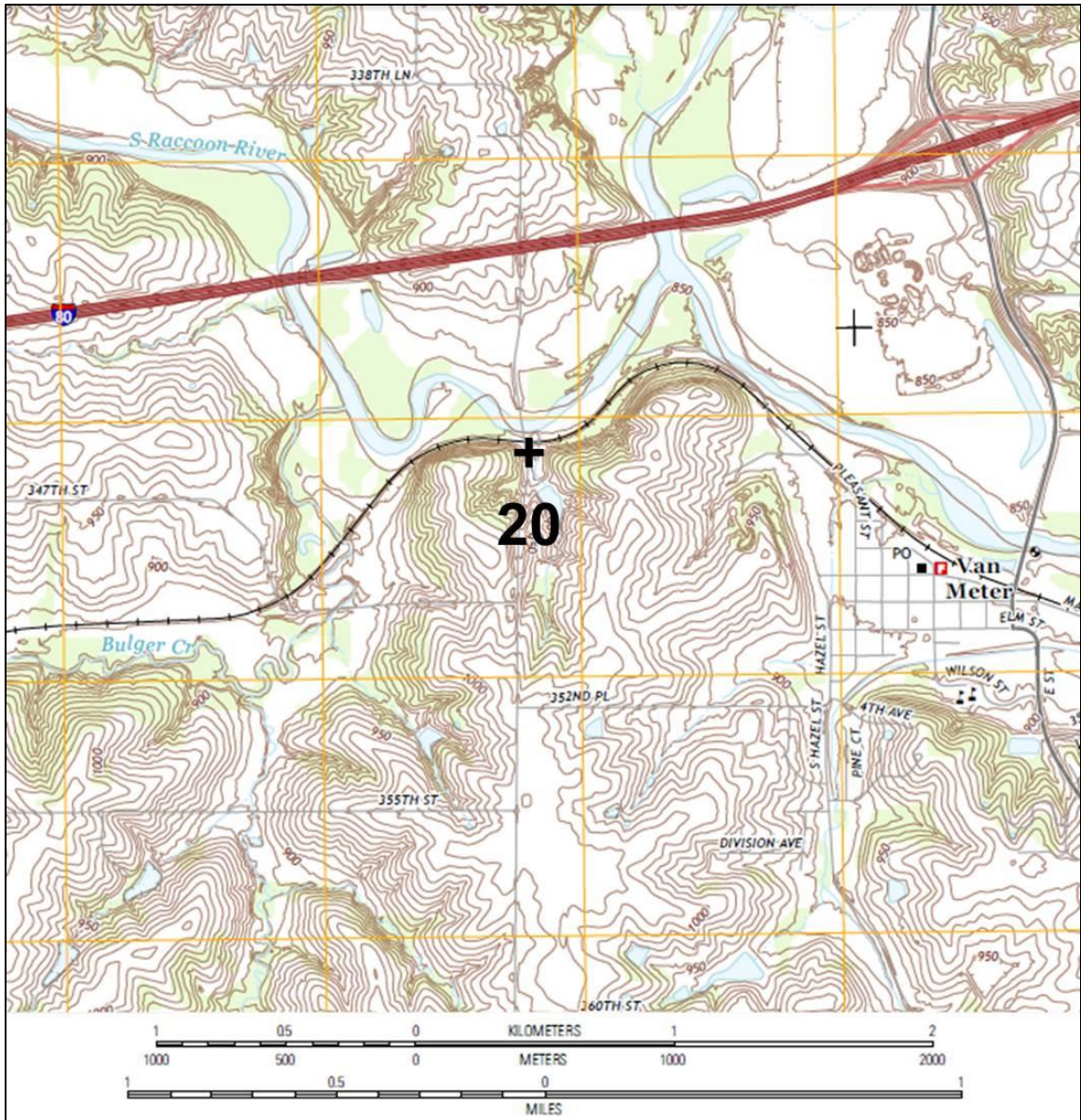


Figure 44. Topographic map of Locality #20, Madison County, Iowa.

21. Little Osage Shale Member, Fort Scott Limestone, Marmaton Group – Crawford County, KS

Location: East line of SE of Sec. 6, T28S, R25E, Cato Quadrangle

GPS Coordinates: 37°37.134'N 94°42.239'W

- Samples:
1. gray wackestone, Higginsville Limestone Member
 2. gray fissile shale, Little Osage Shale Member
 3. black fissile shale, Little Osage Shale Member
 4. black fissile shale, Little Osage Shale Member
 5. gray clay shale, Little Osage Shale Member
 6. gray wackestone, Blackjack Creek Limestone Member

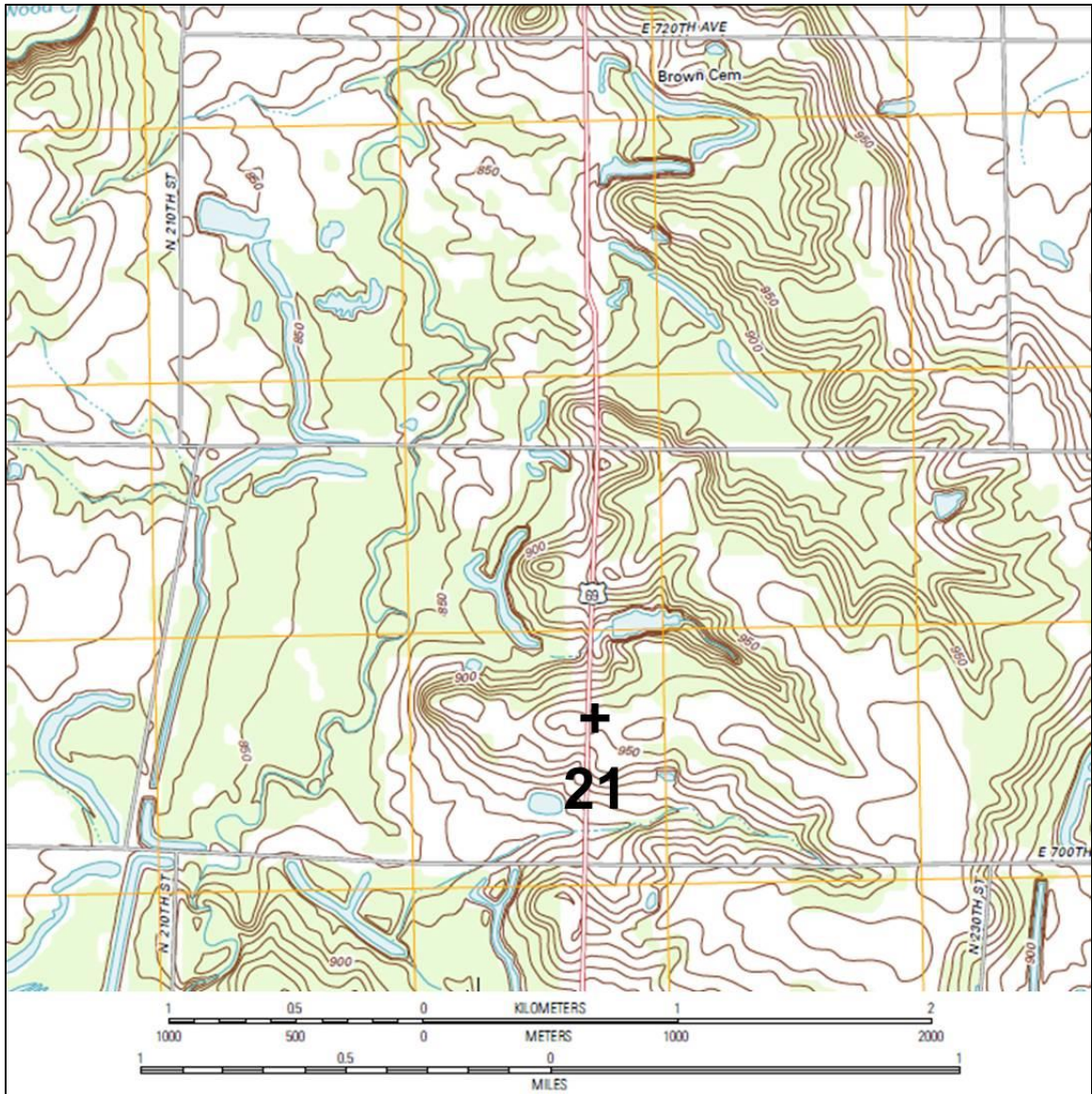


Figure 45. Topographic map of Locality #21, Crawford County, Kansas.

22. Excello Shale Member, Fort Scott Limestone, Marmaton Group – Crawford County, KS

Location: East line of SE of Sec. 7, T28S, R25E, Arma Quadrangle

GPS Coordinates: 37°38.072'N 94°42.205'W

- Samples:
1. gray wackestone, Blackjack Creek Limestone Member
 2. black phosphatic fissile shale, Excello Shale Member
 3. black phosphatic fissile shale, Excello Shale Member
 4. black phosphatic fissile shale, Excello Shale Member
 5. black phosphatic fissile shale, Excello Shale Member

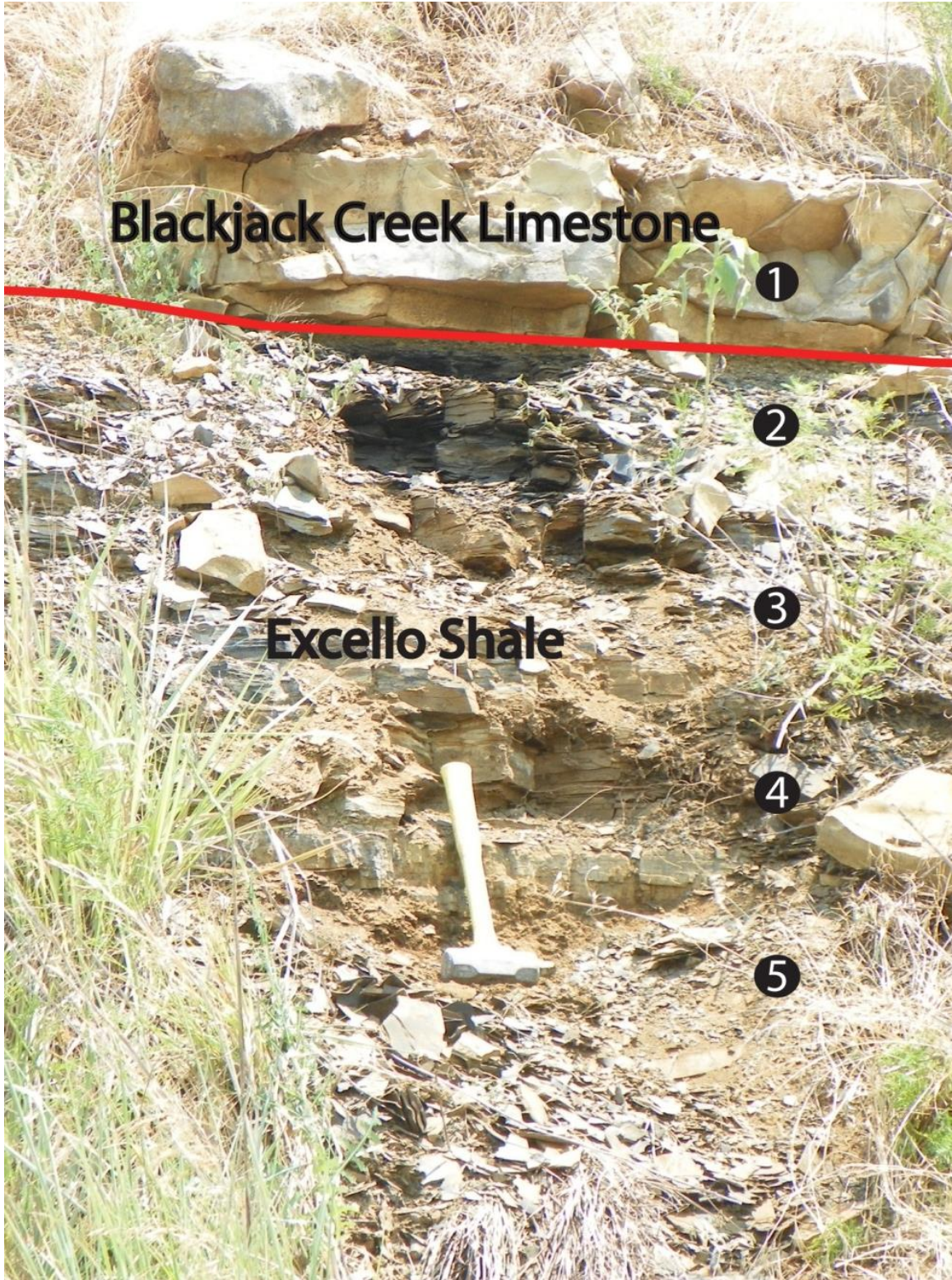


Figure 46. Outcrop photo of the Excello Shale Member with sample locations.

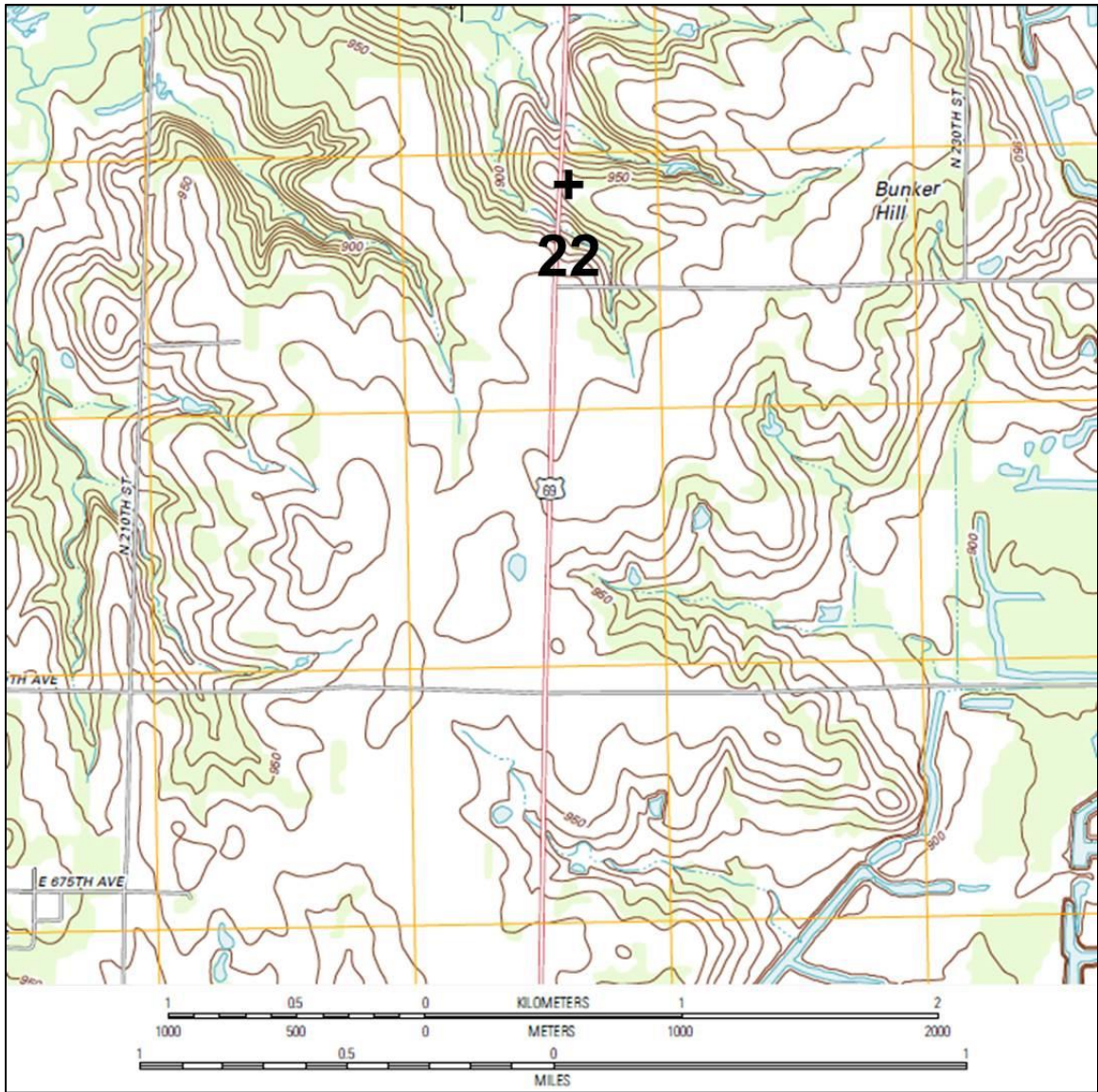


Figure 47. Topographic map of Locality #22, Crawford County, Kansas.

23. Excello Shale Member, Mouse Creek Formation, Marmaton Group – Dallas County, IA (Pope, 2012, p. 83)

Location: C, N/2, Sec. 29, T78N, R26W, Waukee Quadrangle

GPS Coordinates: 41°31'51"N 93°52'30"W

- Samples:
1. gray wackestone, Blackjack Creek Limestone Member
 2. light gray clay shale, Excello Shale Member
 3. gray clay shale, Excello Shale Member
 4. gray clay shale, Excello Shale Member
 5. black clay shale, Excello Shale Member

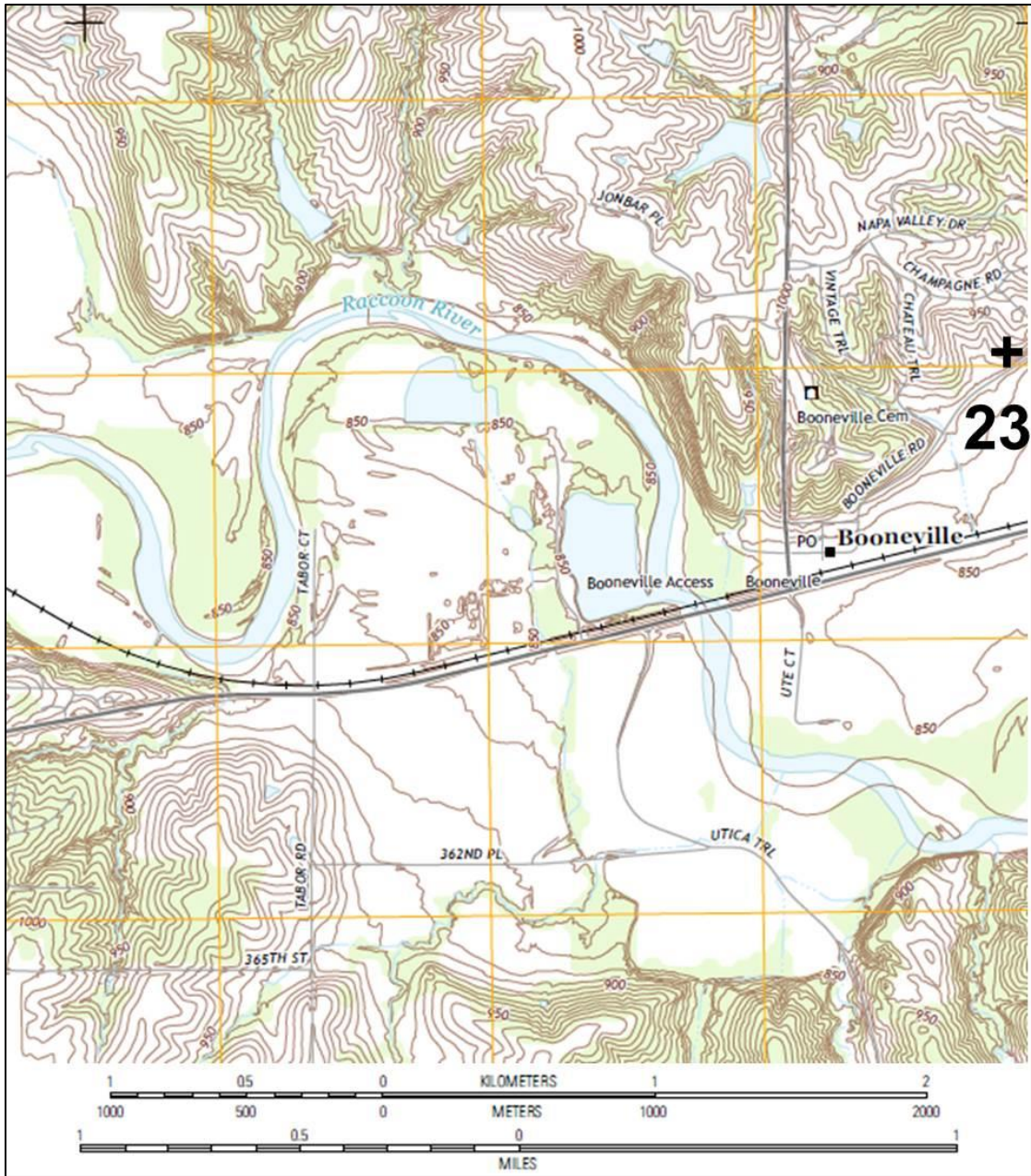


Figure 48. Topographic map of Locality #23, Dallas County, Iowa.

24. Oakley Shale Member, Verdigris Limestone, Cherokee Group – Wagoner County, OK

Location: W/2, SW, NE Sec. 2, T16N, R14E, Leonard Quadrangle

GPS Coordinates: 35°53'42.7"N 95°47'31.6"W

- Samples:
1. gray wackestone, Ardmore Limestone Member
 2. dark gray shale, Oakley Shale Member
 3. black fissile shale, Oakley Shale Member
 4. black fissile shale, Oakley Shale Member

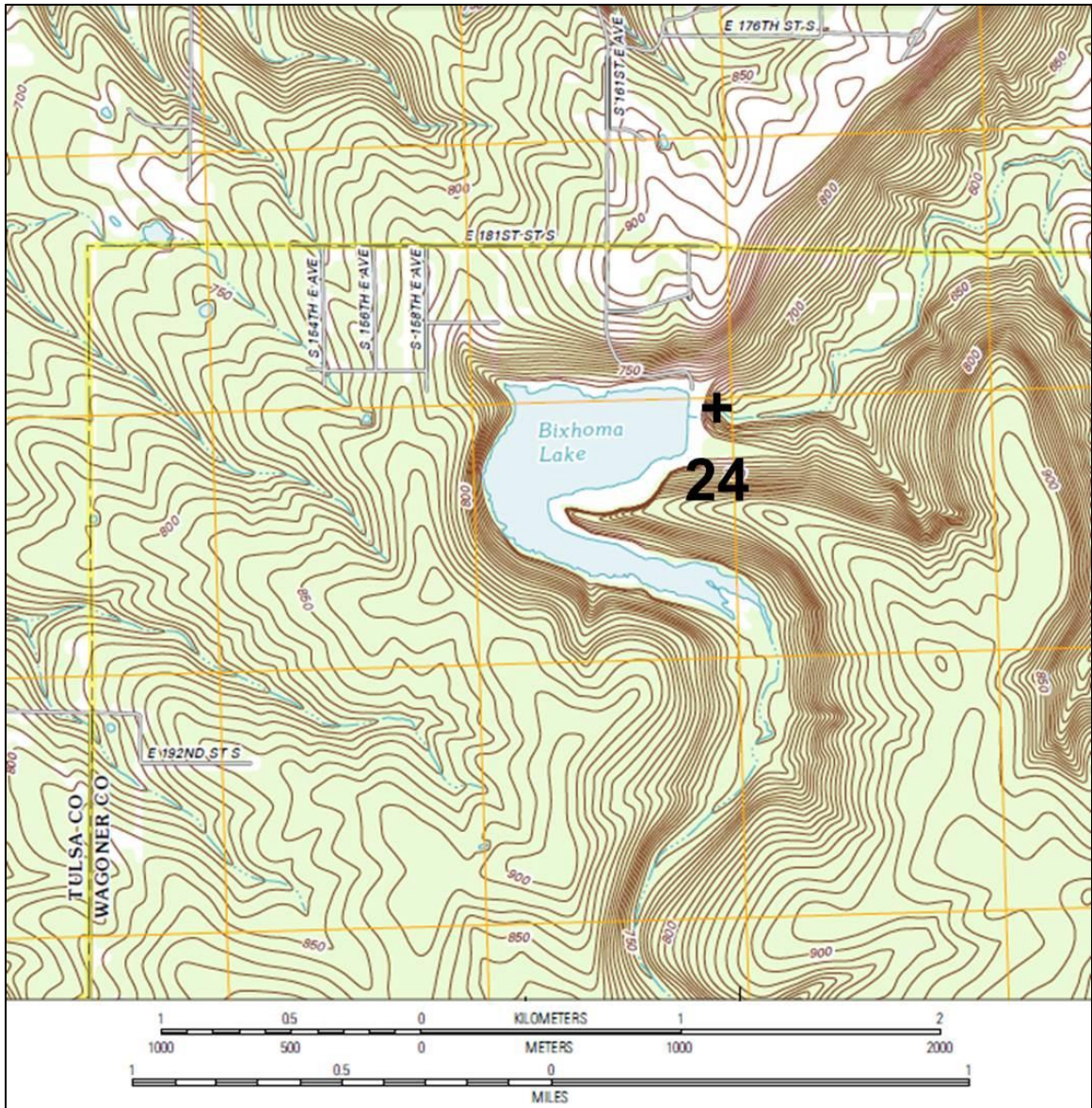


Figure 49. Topographic map of Locality #24, Wagoner County, Oklahoma.

APPENDIX B

Subsurface Data

1. "Tonkawa" Hot Shale Marker – Grady County, OK

Well ID: 35051206480000

Operator: Tenneco Oil

Well Name: Smallwood 2

Location: Sec. 30, T7N, R7W

Core Depth: 8608 ft – 8650 ft

Sampled Depth: 8619 ft – 8643 ft

- Samples:
1. gray fossiliferous shale
 2. gray fossiliferous shale
 3. gray fossiliferous shale
 4. gray interbedded silt and shale
 5. gray interbedded silt and shale
 6. light gray shale
 7. light gray fossiliferous limestone
 8. light gray fossiliferous limestone
 9. light gray fossiliferous limestone

2. "Tonkawa" Hot Shale Marker – Grady County, OK

Well ID: 35051219510000

Operator: Apache

Well Name: McClure 3

Location: Sec. 26, T7N, R7W

Core Depth: 8135 ft – 8243 ft

Sampled Depth: 8141 ft – 8148 ft

- Samples:
1. dark gray shale
 2. dark gray shale
 3. dark gray shale
 4. dark gray shale
 5. dark gray shale

3. Eudora (Avant) Hot Shale Marker – Roger Mills County, OK

Well ID: 35129000080000

Operator: Gulf Oil Corporation

Well Name: Vera Sprawls 1

Location: Sec. 28, T13N, R23W

Core Depth: 12172 ft – 12193 ft

Sampled Depth: 12174.3 ft – 12184.6

- Samples:
1. black shale
 2. black shale
 3. black shale
 4. black shale
 5. black shale
 6. black shale
 7. black shale

4. Muncie Creek (Lower Avant) Hot Shale Marker – Caddo County, OK

Well ID: 35015224090000

Operator: EOG Inc.

Well Name: W Verden Hoxbar Unit 14

Location: Sec. 34, T8N, R9W

Core Depth: 9817 ft – 9846 ft

Sampled Depth: 9830 ft – 9836 ft

- Samples:
1. black shale
 2. black shale
 3. black shale



Figure 50. Core photos of the sampled interval in the W Verden Hoxbar Unit 14 well.

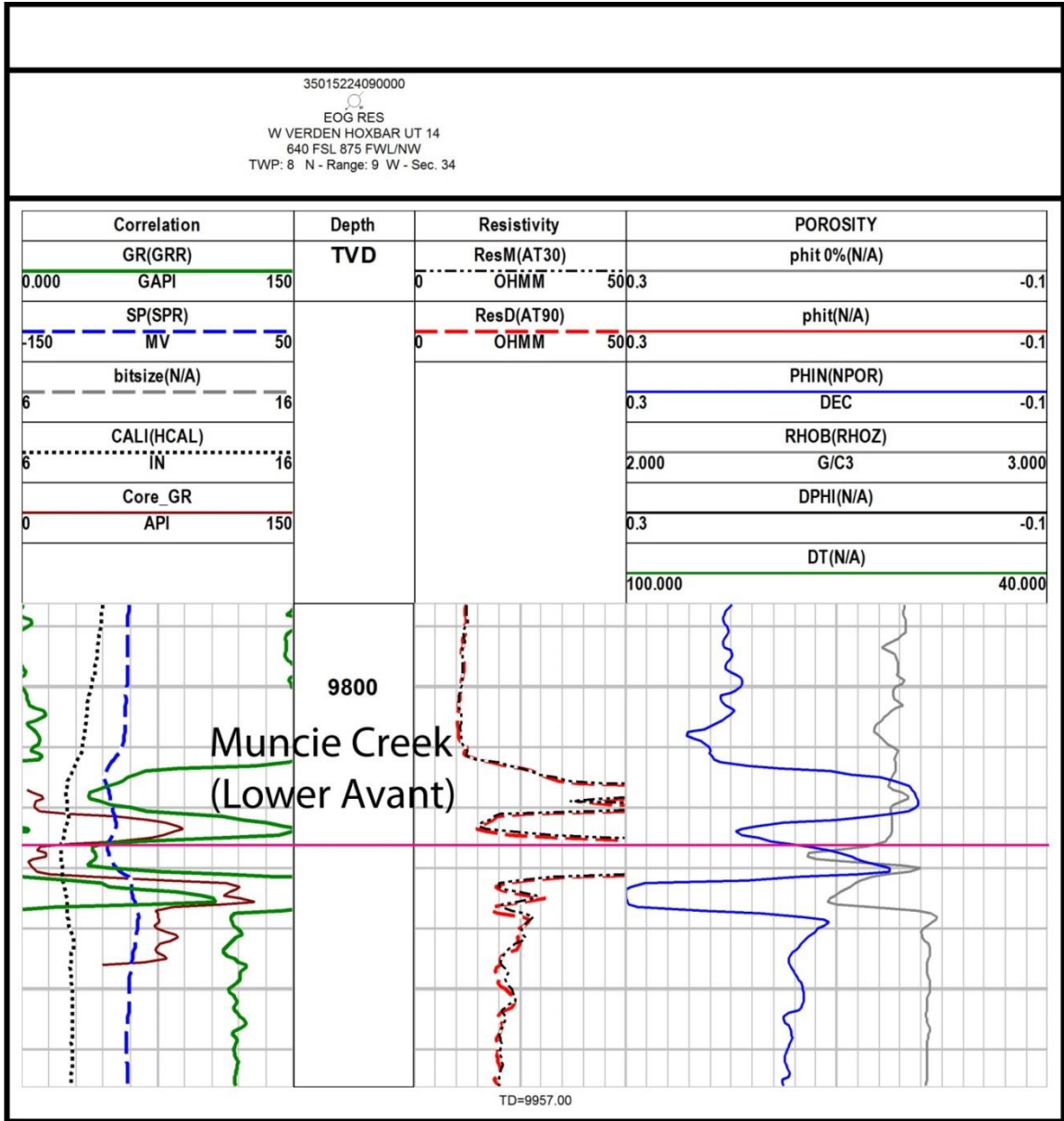


Figure 51. Core gamma scan and well-logs of the Muncie Creek (Lower Avant) condensed section in the W Verden Hoxbar Unit 14 well.

5. Quivira (Upper Hogshooter) Hot Shale Marker – Caddo County, OK

Well ID: 35015216900000

Operator: Amoco Production Co.

Well Name: Armstrong Unit 2

Location: Sec. 22, T10N, R9W

Core Depth: 9297 ft – 9369 ft

Sampled Depth: 9354.5 ft – 9356 ft

Samples: 1. black shale

2. black shale

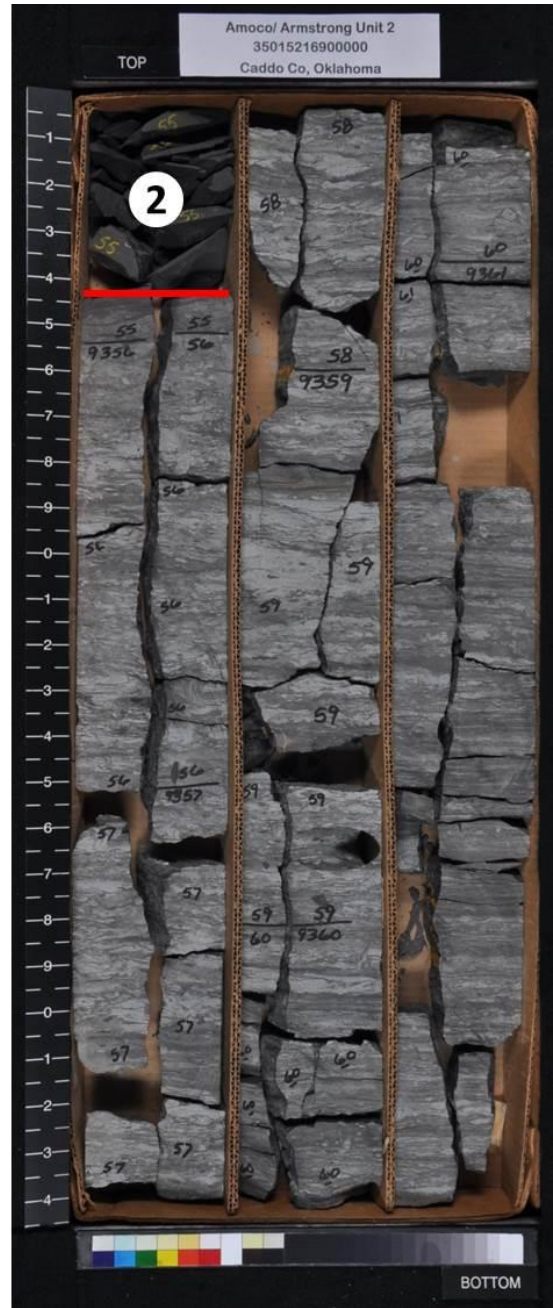


Figure 52. Core photos of the sampled interval in the Armstrong Unit 2 well.

35015216900000
 AMOCO PROD CO
 ARMSTRONG UNIT 2
 1370 FSL 1370 FWL/SW
 TWP: 10 N - Range: 9 W - Sec. 22

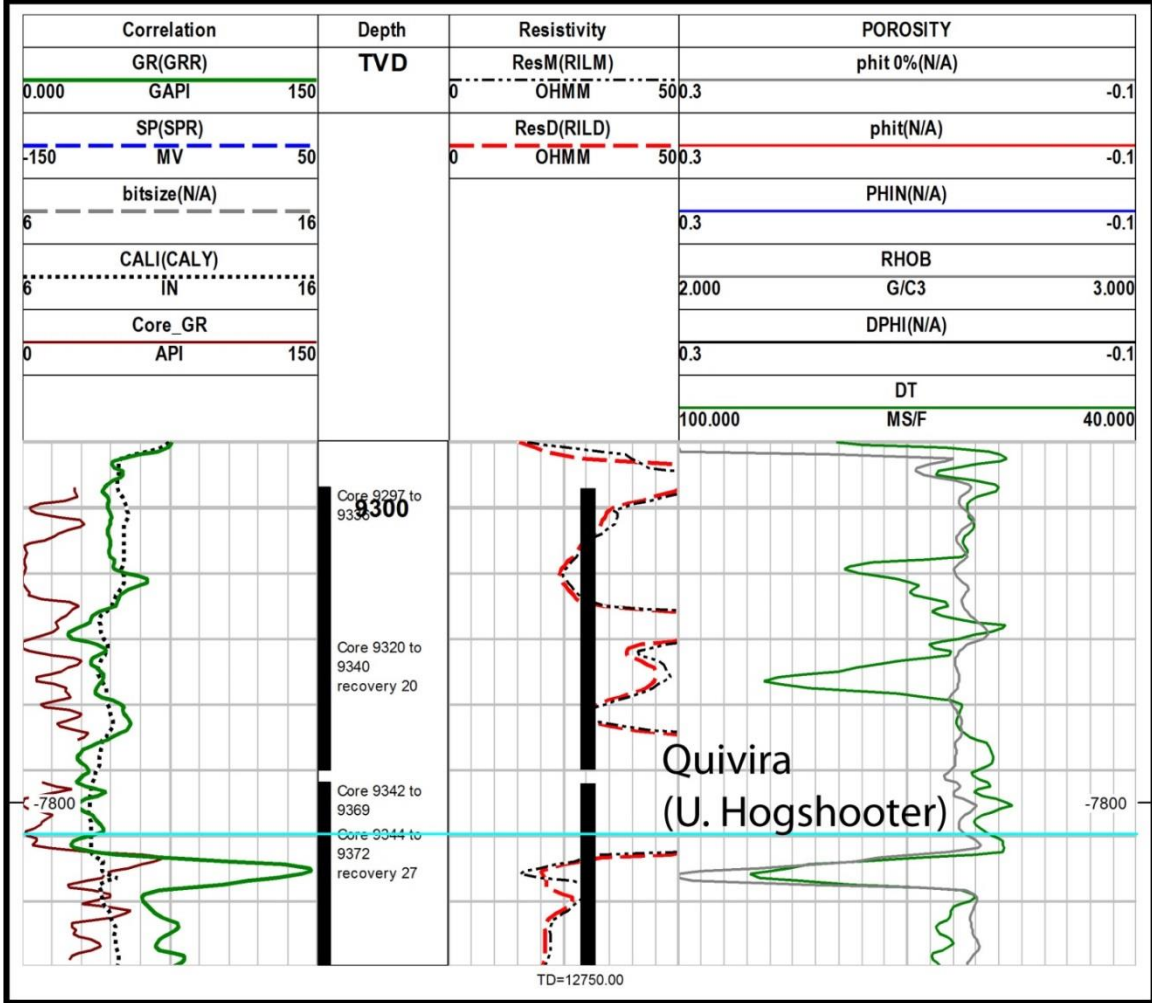


Figure 53. Core gamma scan and well-logs of the Quivira (Upper. Hogshooter) condensed section in the Armstrong Unit 2 well.

6. Quivira (Upper Hogshooter) Hot Shale Marker – Roger Mills County, OK

Well ID: 35129205290000

Operator: GHK Corporation

Well Name: Poston 1

Location: Sec. 18, T12N, R21W

Core Depth: 10830 ft – 10855 ft

Sampled Depth: 10830 ft – 10833 ft

- Samples:
1. dark gray shale
 2. dark gray shale

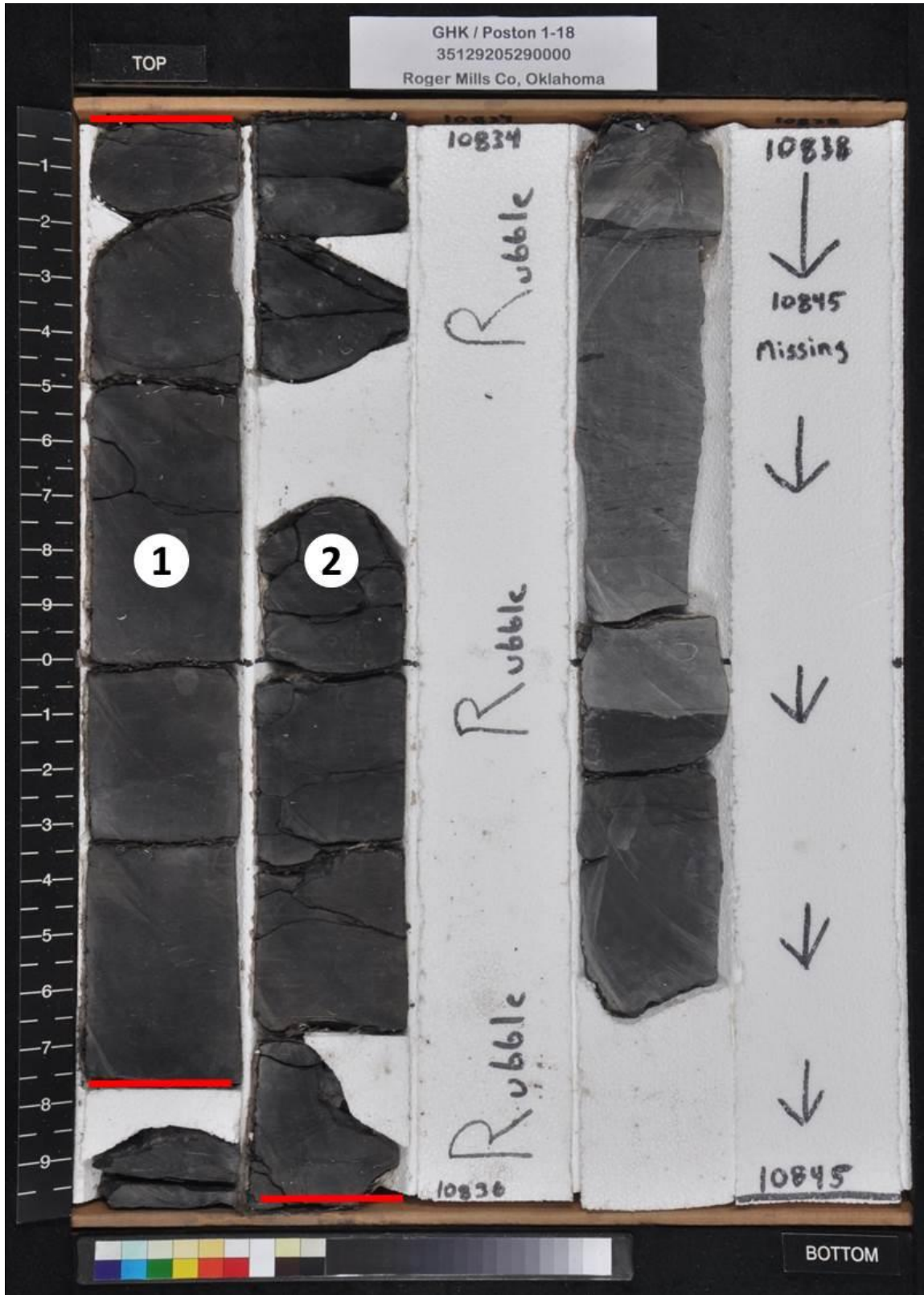


Figure 54. Core photo of the sampled interval in the Poston 1 well.

35129205290000
 GHK CORPORATION
 POSTON 1-18
 1320 FSL 1320 FEL
 TWP: 12 N - Range: 21 W - Sec. 18

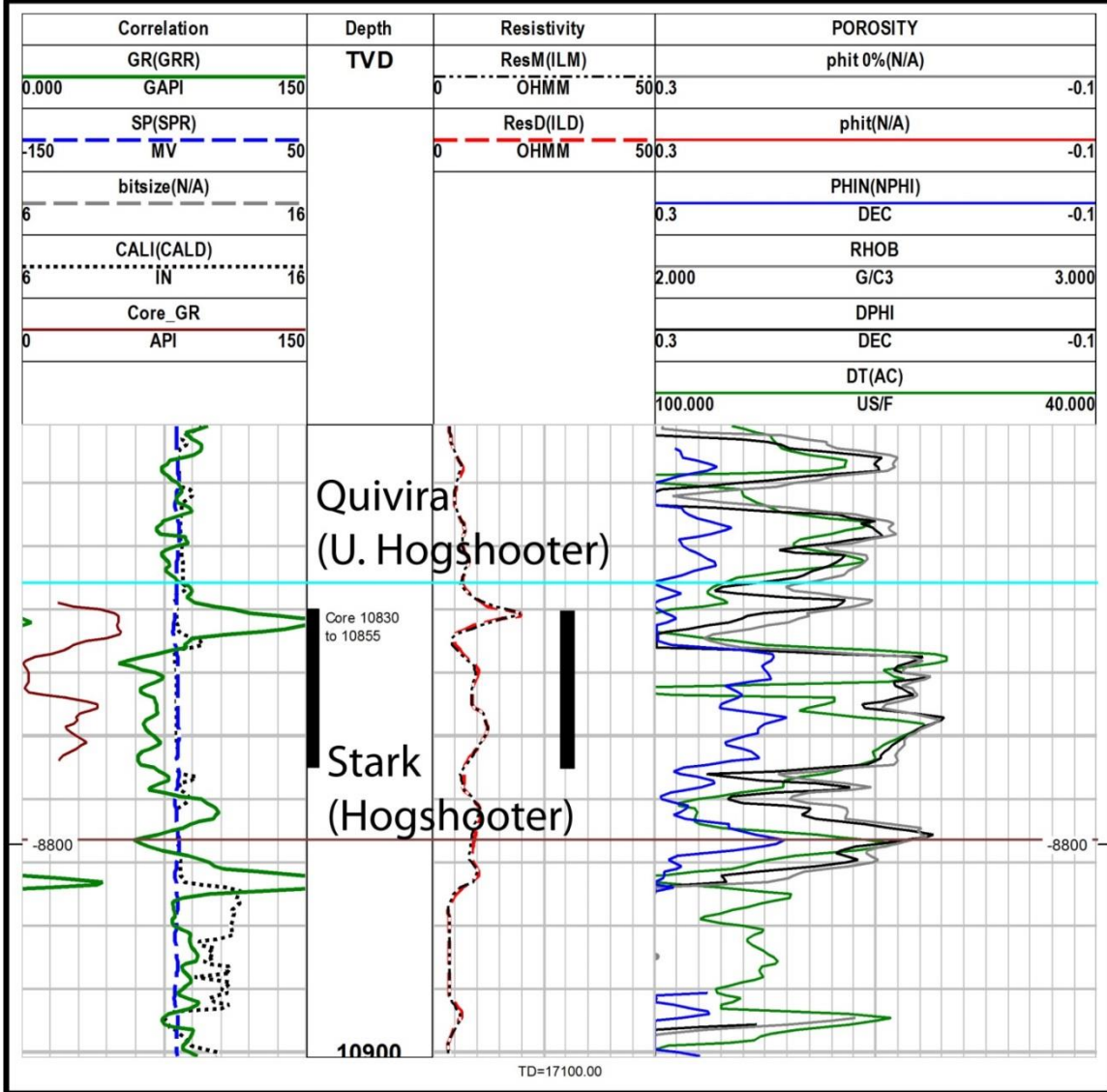


Figure 55. Core gamma scan and well-logs of the Quivira (U. Hogshooter) condensed section in the Poston 1 well. The Stark (Hogshooter) condensed section is also shown.

7. Stark (Hogshooter) Hot Shale Marker – Caddo County, OK

Well ID: 35015205800000

Operator: Helmerich & Payne Inc.

Well Name: Citco 1

Location: Sec. 14, T10N, R10W

Core Depth: 9730 ft – 9767 ft

Sampled Depth: 9730 ft – 9733 ft

- Samples:
1. dark gray shale
 2. dark gray shale

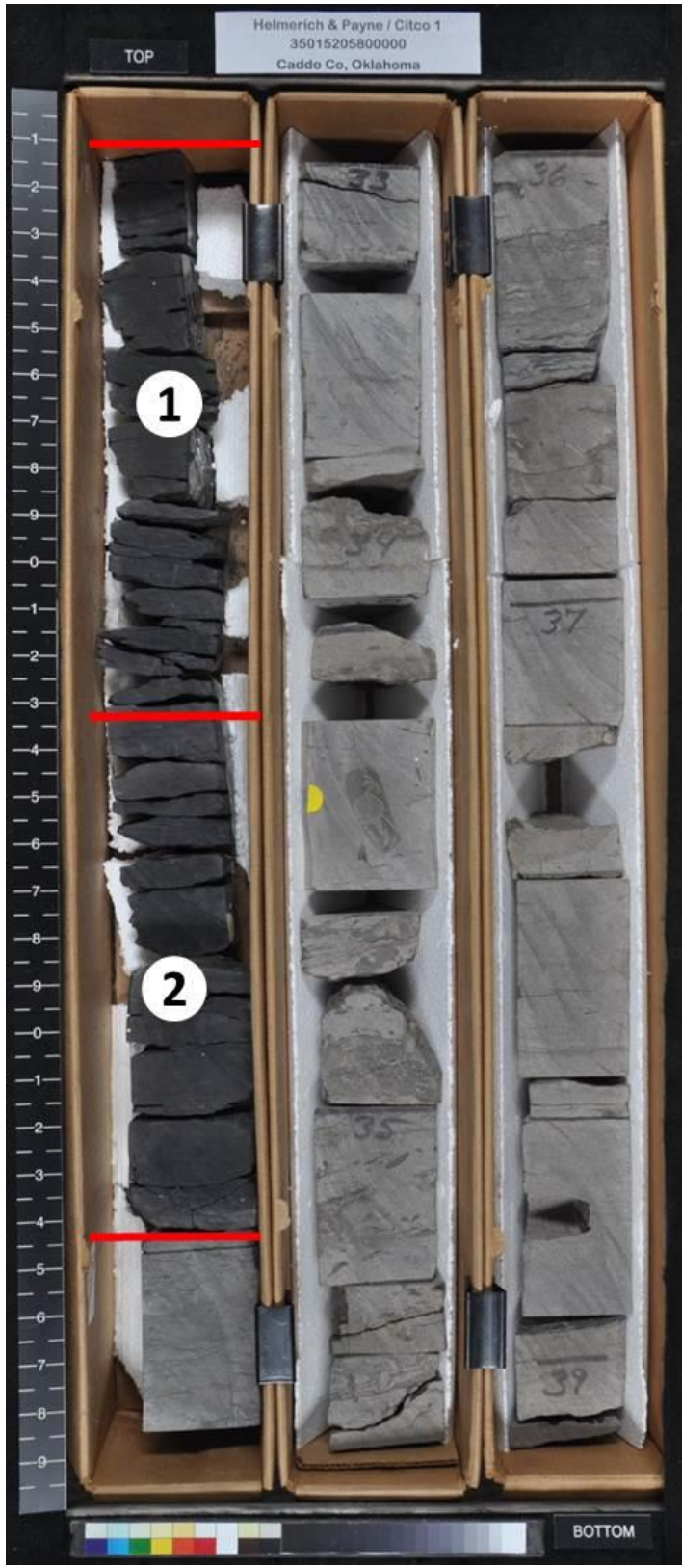


Figure 56. Core photo of the sampled interval in the Citco 1 well.

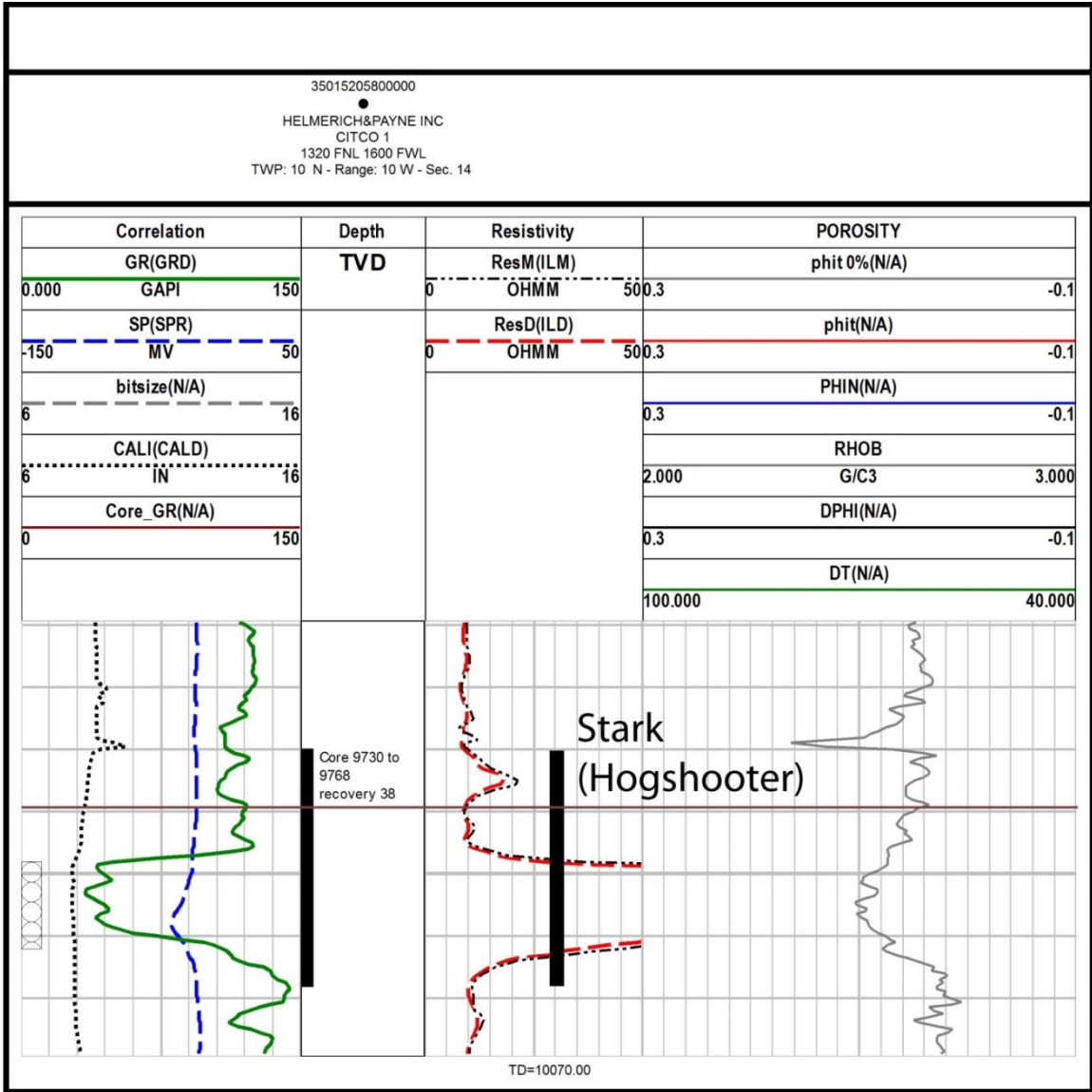


Figure 57. Core gamma scan and well-logs of the Stark (Hogshooter) condensed section in the Citco 1 well.

8. Stark (Hogshooter) Hot Shale Marker – Caddo County, OK

Well ID: 35015219250000

Operator: ANR Production Co.

Well Name: Hotz 2

Location: Sec. 5, T10N, R10W

Core Depth: 9898 ft – 9928 ft

Sampled Depth: 9822 ft – 9828 ft

- Samples:
1. black calcareous shale
 2. black calcareous shale

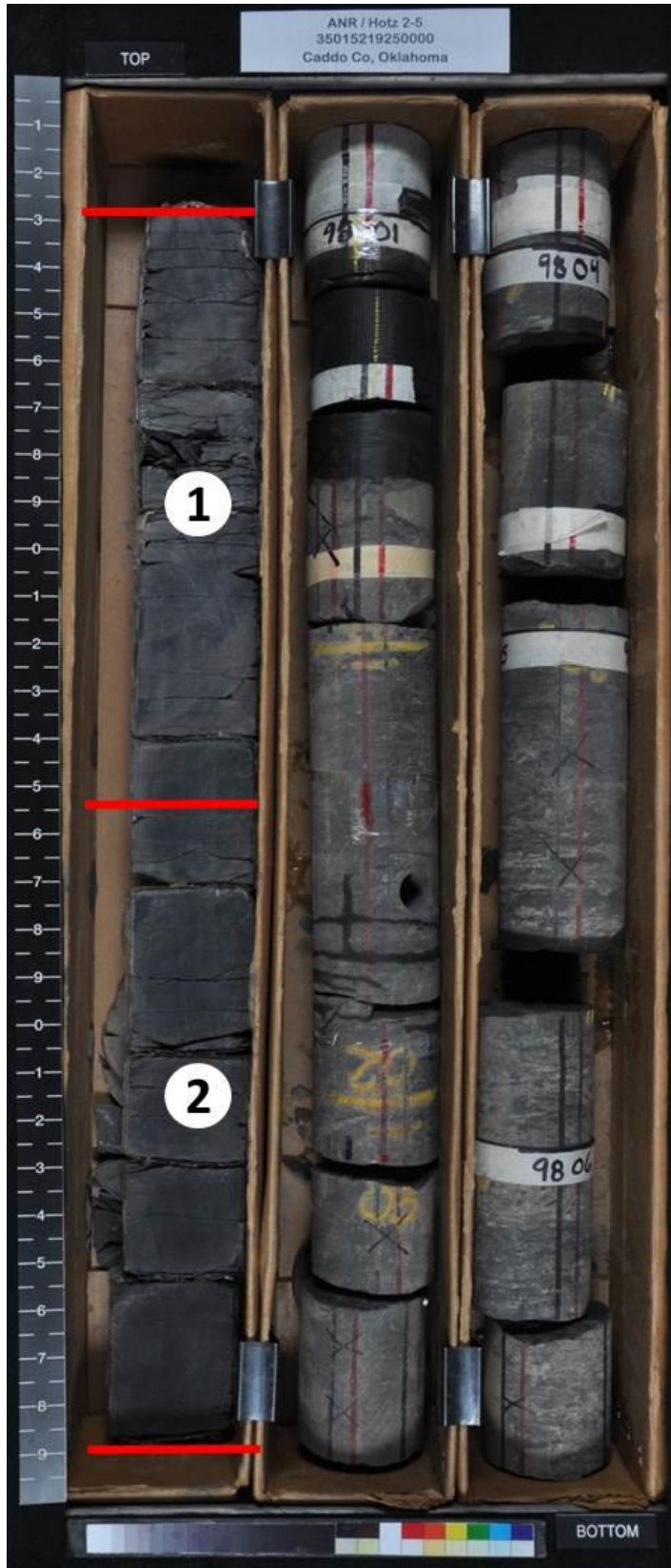


Figure 58. Core photo of the sampled interval in the Hotz 2 well.

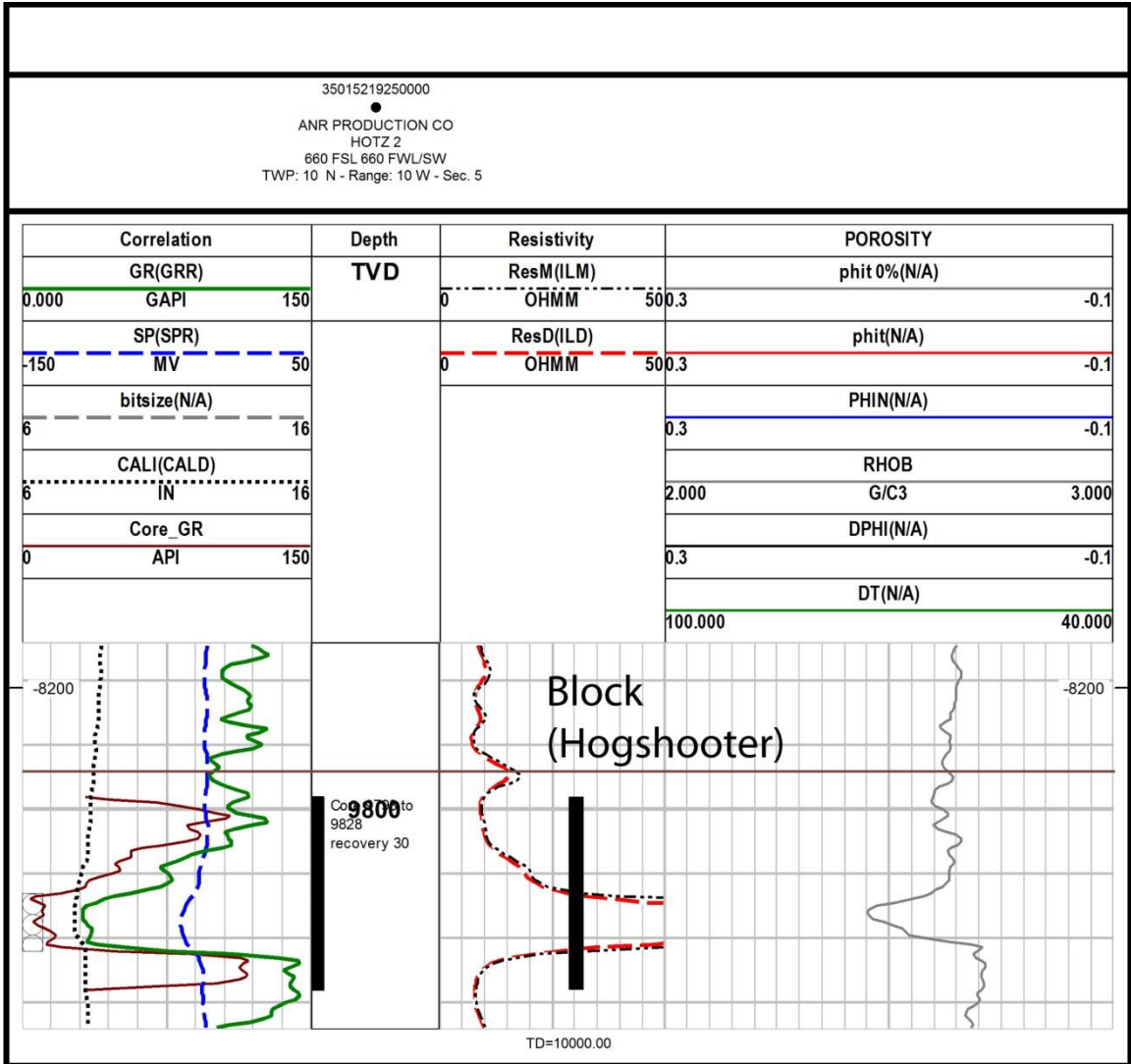


Figure 59. Core gamma scan and well-logs of the Stark (Hogshooter) condensed section in the Hotz 1 well.

9. Hushpuckney (Checkerboard) Hot Shale Marker – Caddo County, OK

Well ID: 35015207790000

Operator: Shell Oil Co.

Well Name: Dugger 1

Location: Sec. 4, T8N, R11W

Core Depth: 10622 ft – 10830 ft

Sample Depth: 10622 ft – 10628 ft

- Samples:
1. dark gray to black shale
 2. dark gray to black shale
 3. dark gray to black shale
 4. dark gray to black shale

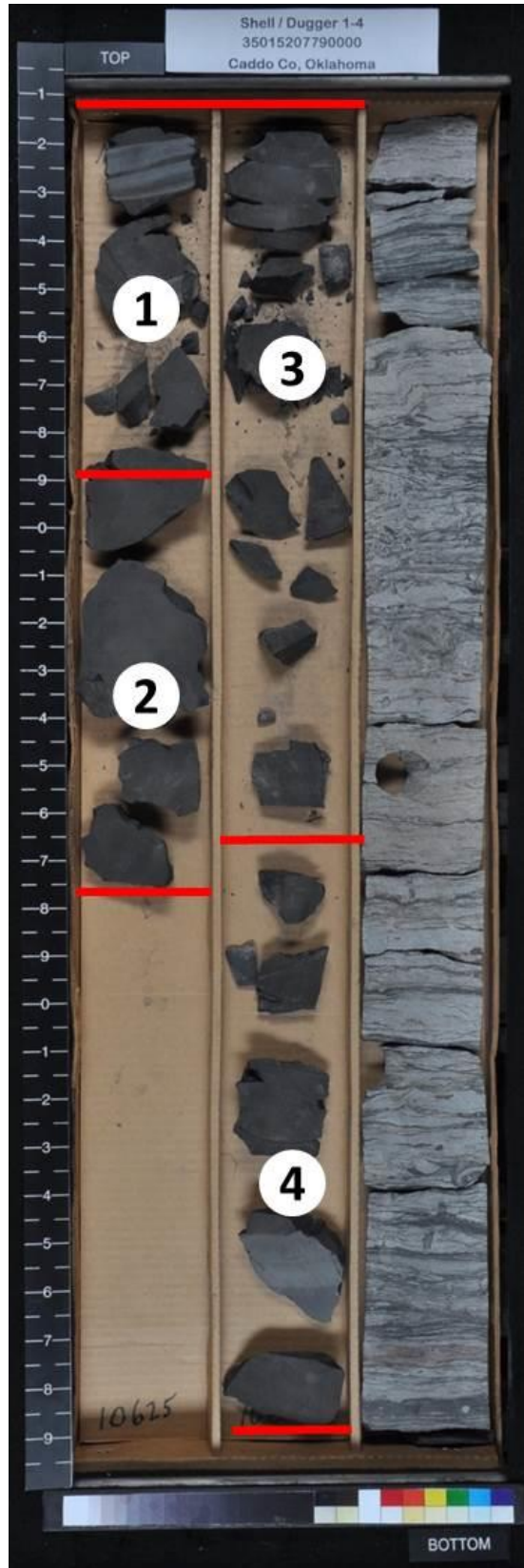


Figure 60. Core photo of the sampled interval in the Dugger 1 well.

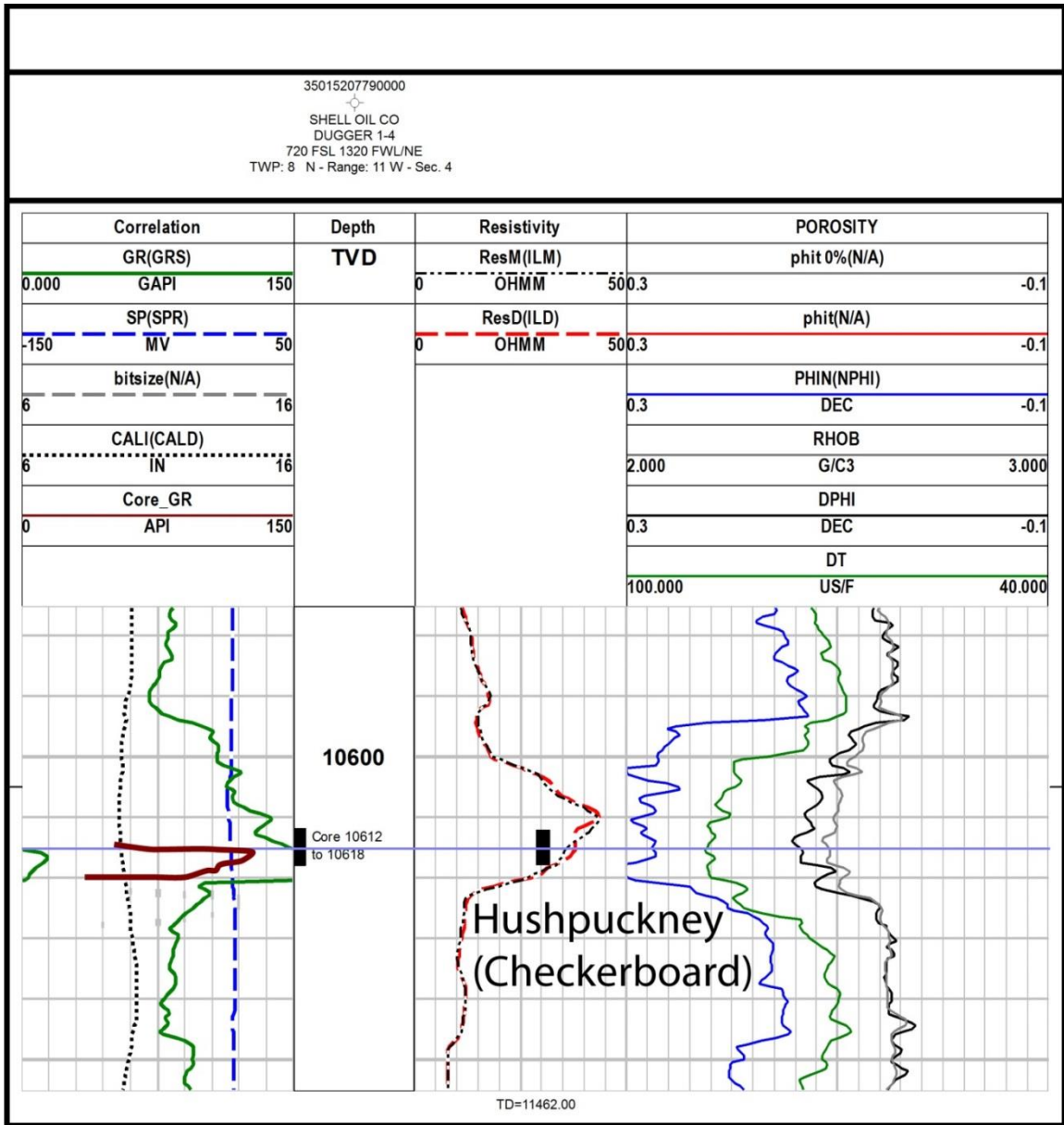


Figure 61. Core gamma scan and well-logs of the Hushpuckney (Checkerboard) condensed section in the Dugger 1 well.

10. Hushpuckney (Checkerboard) Hot Shale Marker – Grady County, OK

Well ID: 35051201370000

Operator: Shell Oil Co.

Well Name: Watson 1

Location: Sec. 6, T8N, R8W

Core Depth: 9849 ft – 9963 ft

Sampled Depth: 9849 ft – 9860.4 ft

- Samples:
1. black shale
 2. black shale
 3. black shale
 4. black shale
 5. black shale
 6. black shale

11. Nuyaka Creek (Marmaton) Hot Shale Marker – Dewey County, OK

Well ID: 35043000430000

Operator: Humble Oil & Refining Co.

Well Name: Smith-Barnes Unit 1

Location: Sec. 6, T17, R18W

Core Depth: 8930 ft – 9030 ft

Sampled Depth: 8955 ft – 8958.3 ft

- Samples:
1. black shale
 2. dark gray to black shale

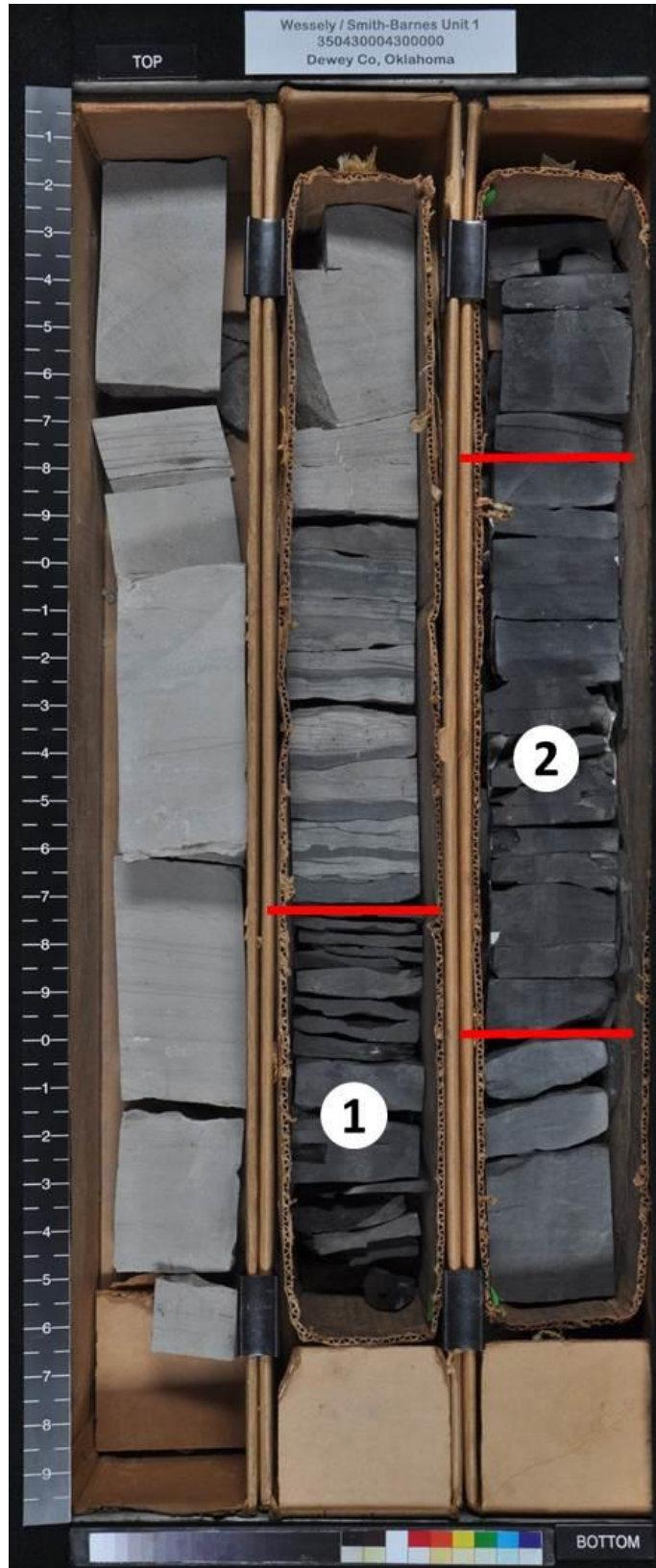


Figure 62. Core photo of the sampled interval in the Smith-Barnes Unit 1 well.

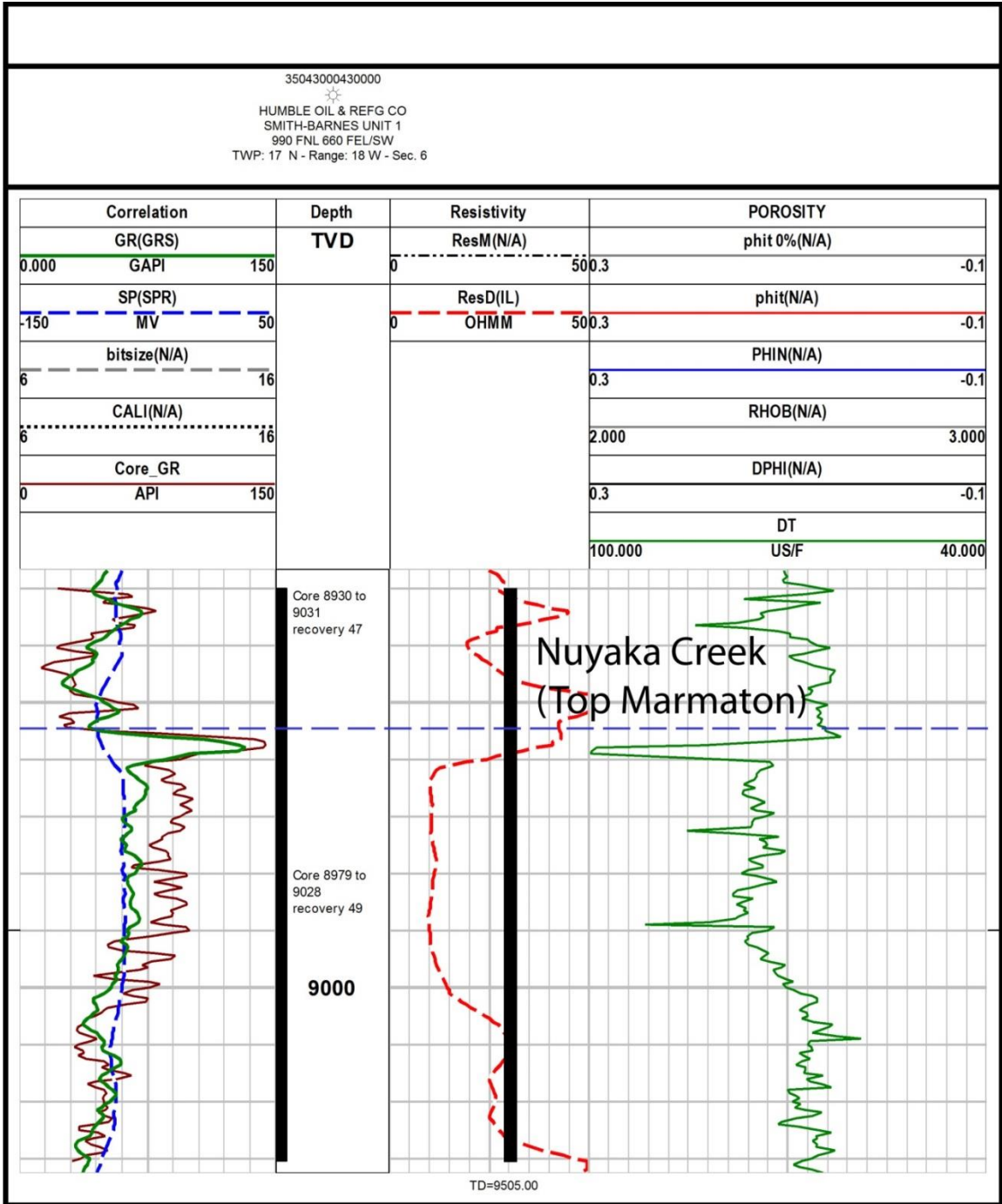


Figure 63. Core gamma scan and well-logs of the Nuyaka Creek (Top Marmaton) condensed section in the Smith-Barnes Unit 1 well.

12. Muncie Creek (Lower Avant) Hot Shale Marker – Caddo County, OK

Well ID: 35015223110000

Operator: EOG Inc.

Well Name: Venable 1

Location: Sec. 20, T8N, R9W

Core Depth: 9840 ft – 9874 ft

Samples: Core was not processed.

13. Hushpuckney (Checkerboard) Hot Shale Marker – Grady County, OK

Well ID: 35051203810000

Operator: Cleary Petroleum

Well Name: McDonald 1

Location: Sec. 28, T6N, R8W

Core Depth: 10830 ft – 10855 ft

Samples: Core was not processed.

14. Eudora and Muncie Creek (Avant and Lower Avant) Hot Shale Marker – Ellis County, OK

Well ID: 35045205280000

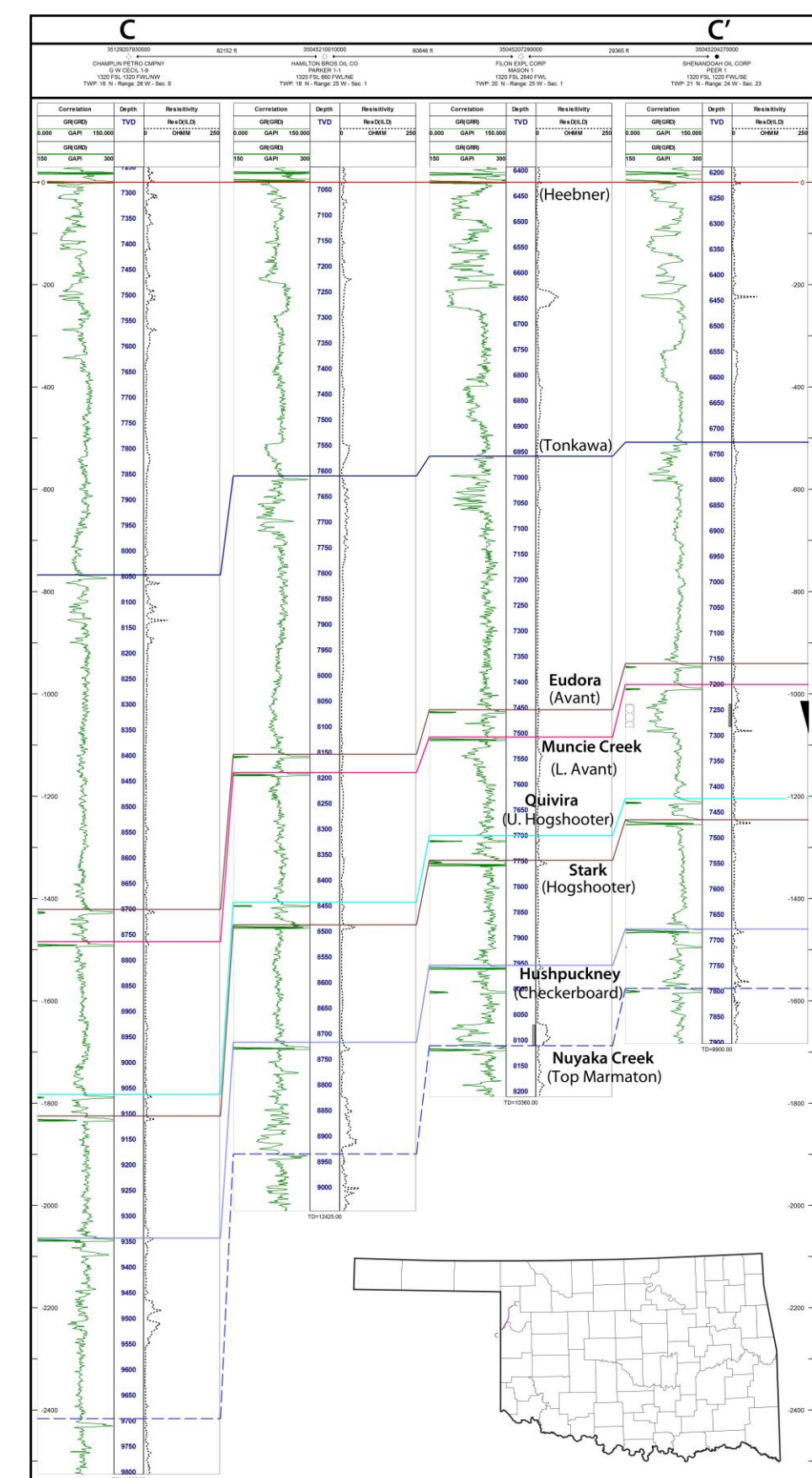
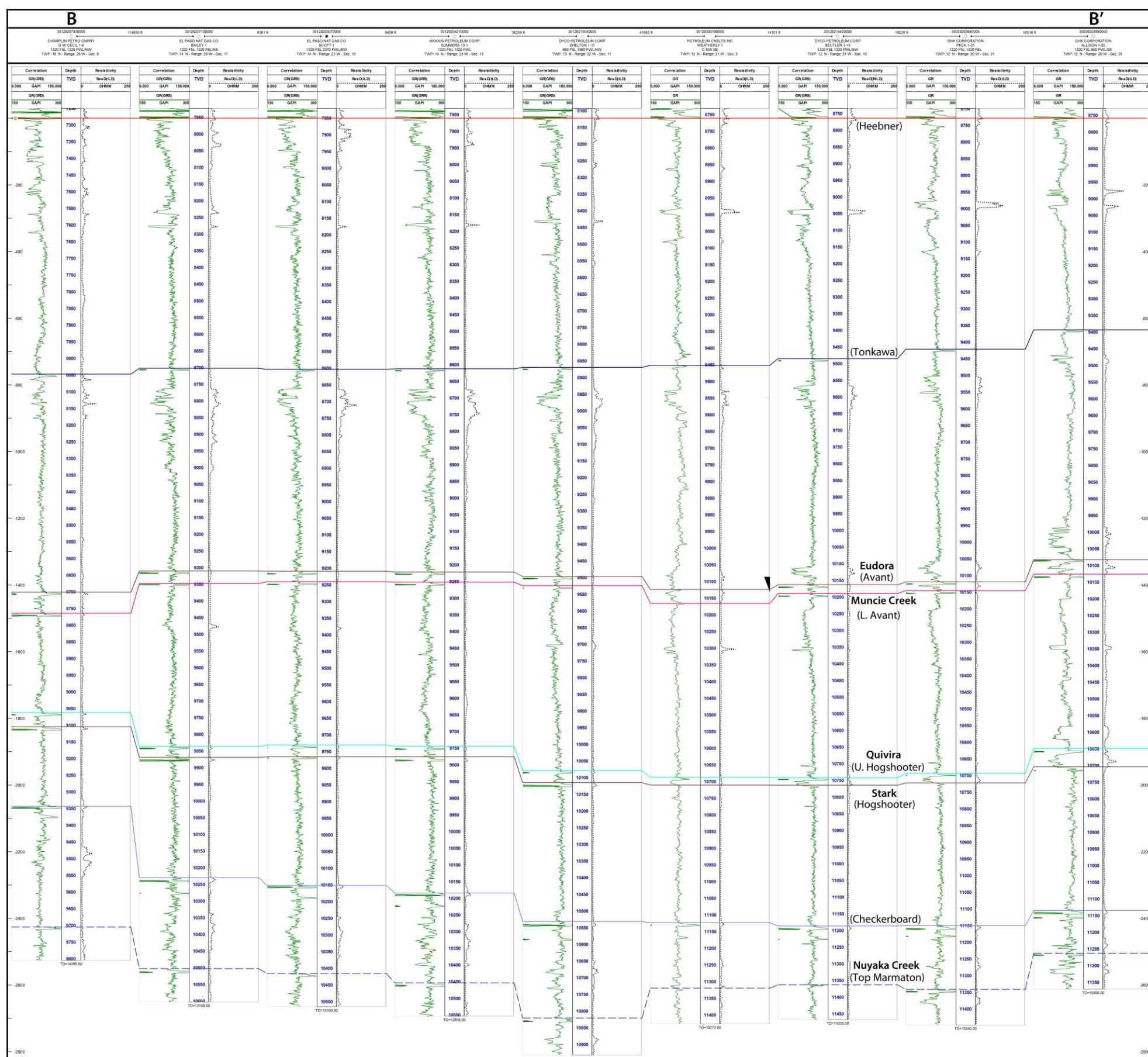
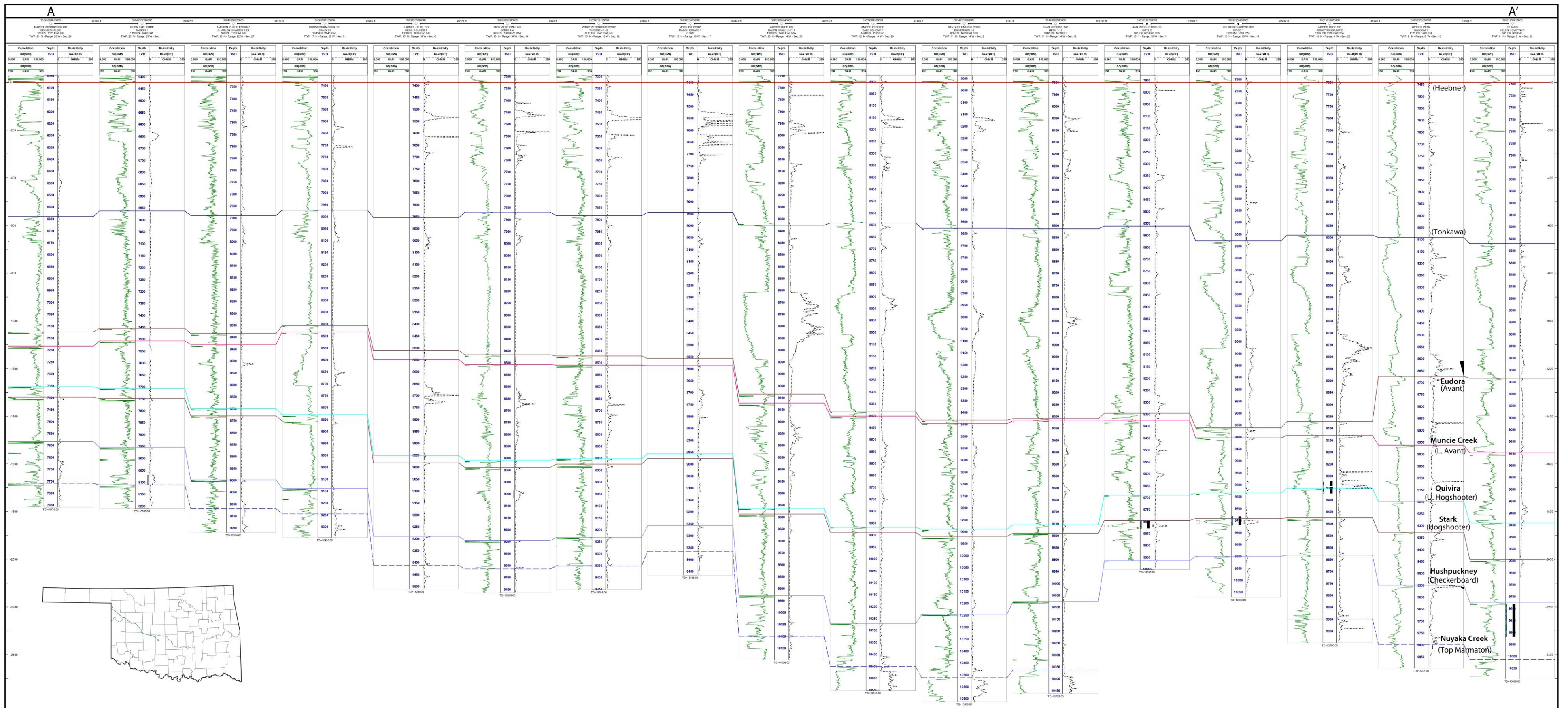
Operator: May Petroleum Company Inc.

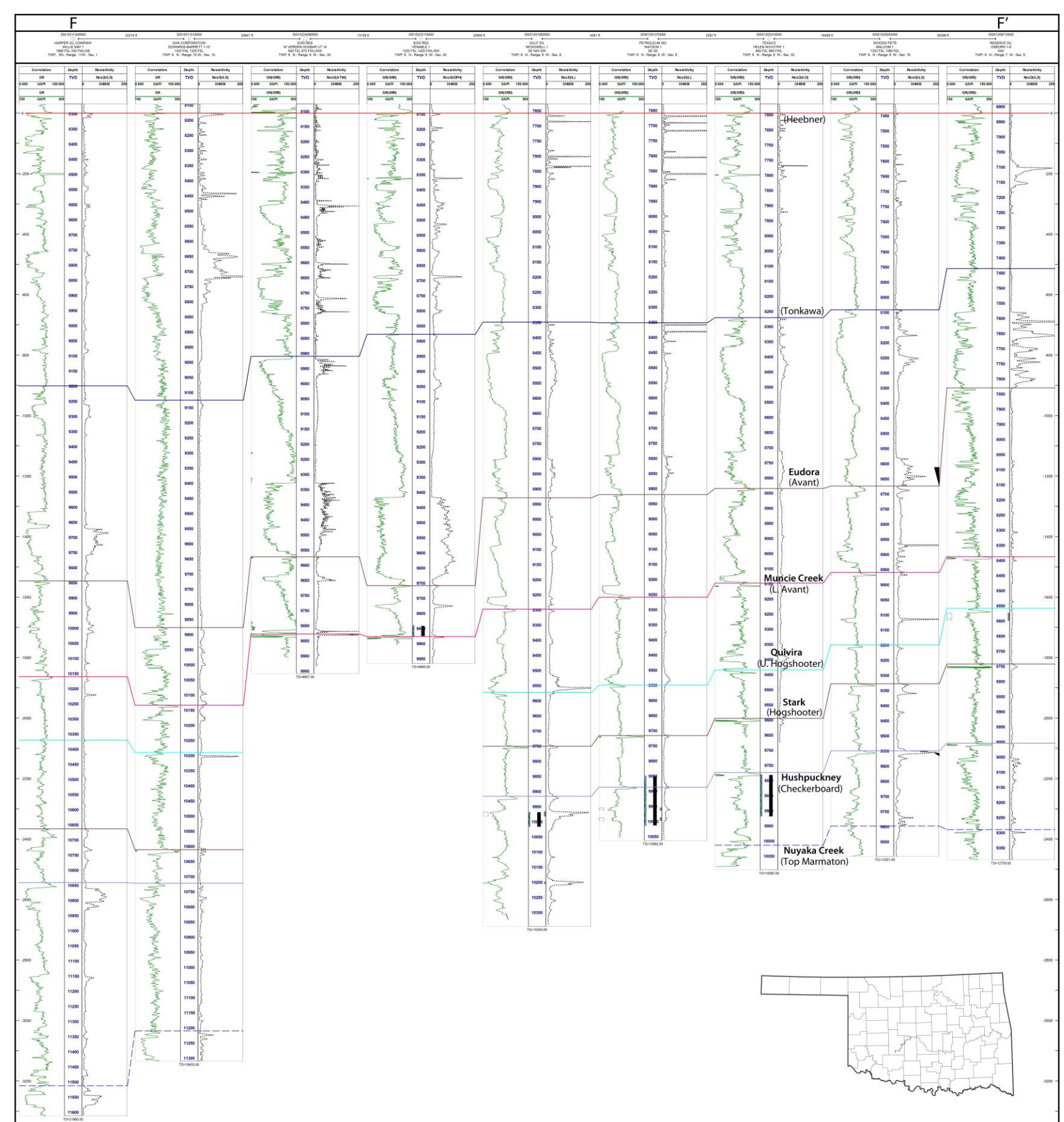
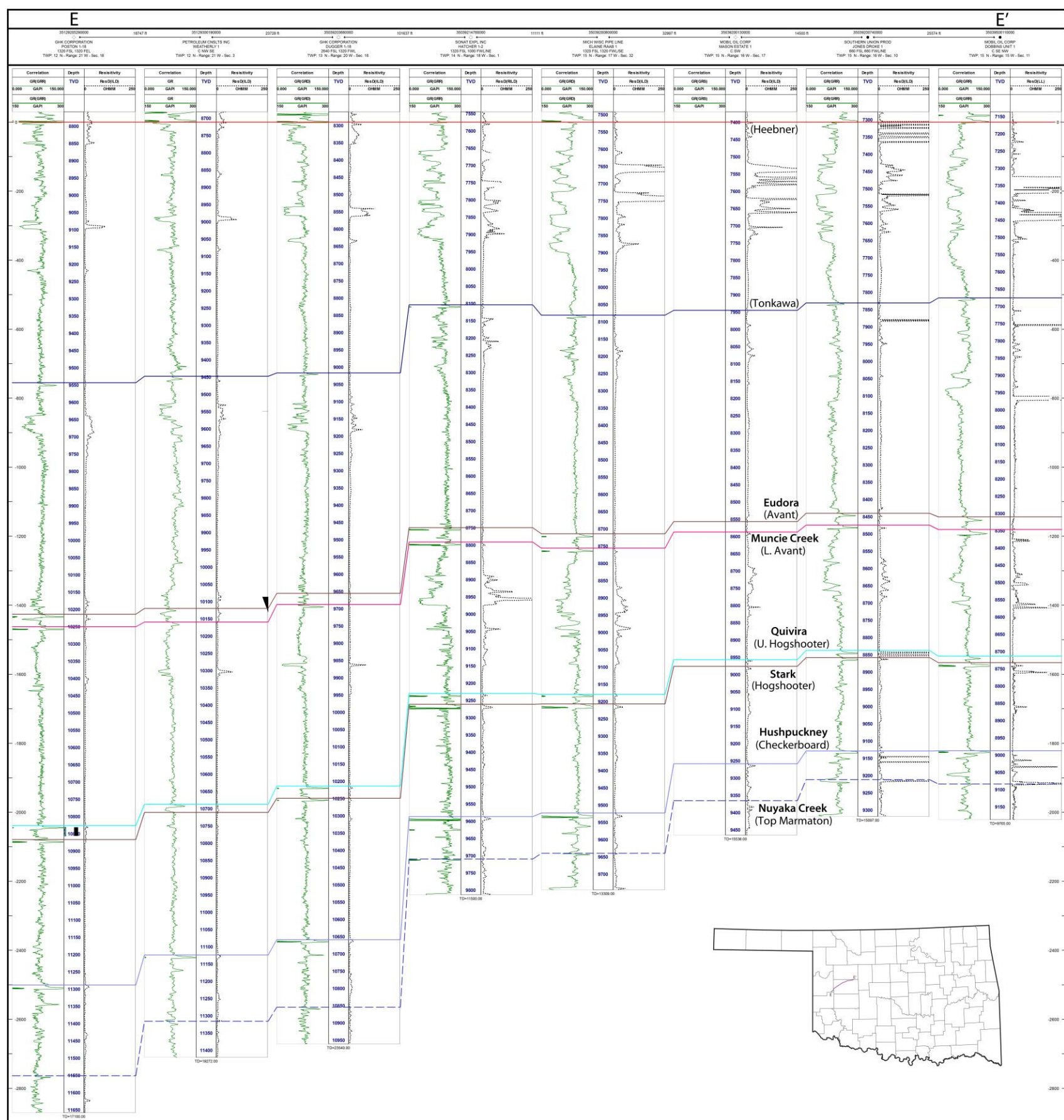
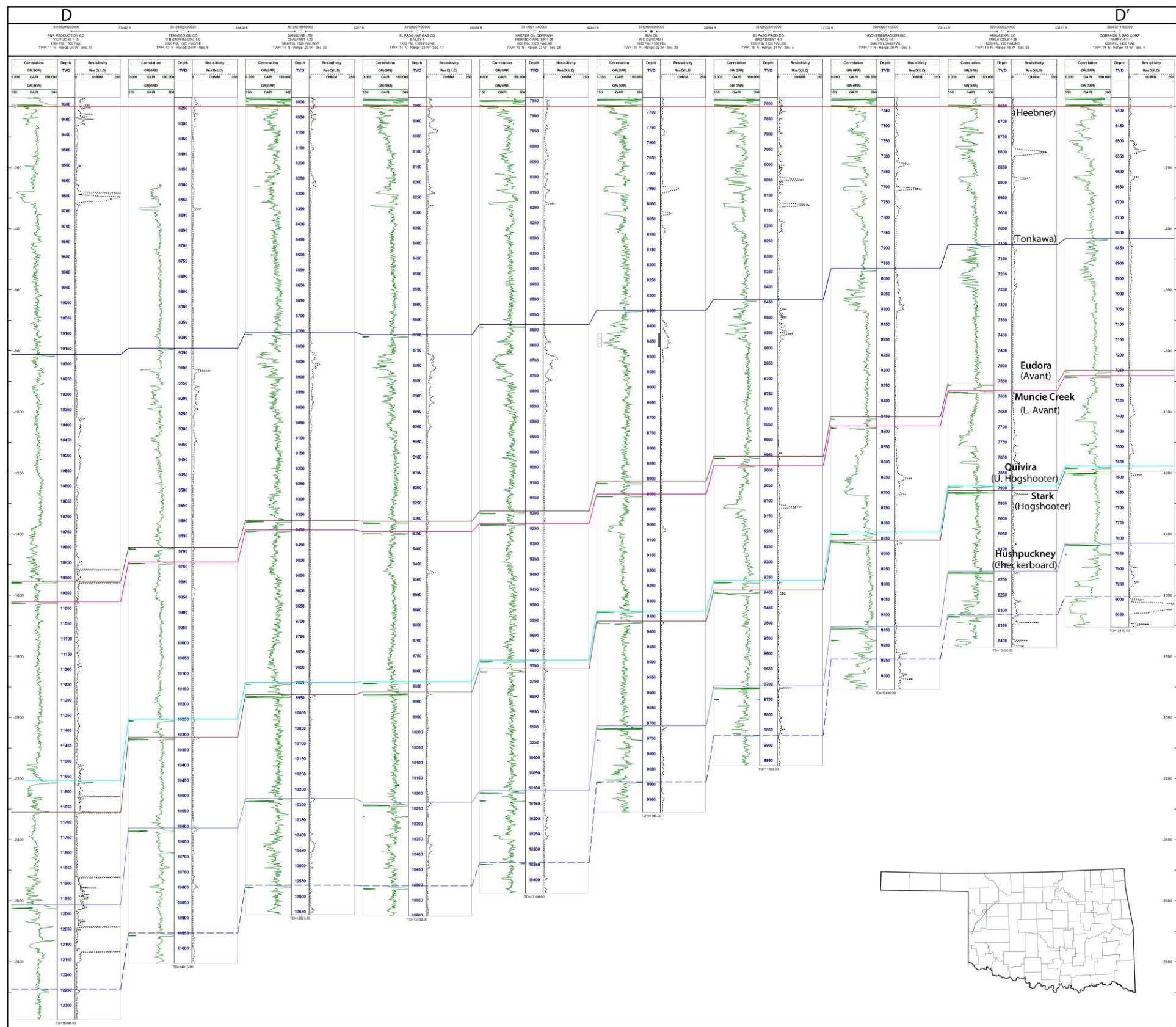
Well Name: Jacoby 1

Location: Sec. 32, T21N, R24W

Core Depth: 7293 ft – 7409 ft

Samples: Core was not processed.





VITA

Jared Drake Morris

Candidate for the Degree of

Master of Science

Thesis: HIGH RESOLUTION CORRELATION OF PENNSYLVANIAN MARINE CONDENSED SECTIONS FROM OUTCROP TO SUBSURFACE

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Biographical:

Personal Data: Born in Austin, Texas, on October 18, 1988, the son of Gregory and Beatrice Morris.

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Experience: Interned for Whiterock Energy, Barling, Arkansas, Summer 2010. Interned for EOG Resources, Oklahoma City, Oklahoma, Summer 2012. Interned for EOG Resources, Tyler, Texas, Summer 2013. Employed by Oklahoma State University, Boone Pickens School of Geology as a graduate teaching assistant, 2012 to 2014.

Professional Memberships: American Association of Petroleum Engineers (AAPG). Geological Society of America (GSA).