DEPOSITIONAL ENVIRONMENTS AND DISTRIBUTION OF THE PRUE SANDSTONE IN NORTHERN NOWATA COUNTY, OKLAHOMA

By

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INTRODUCTION

The Pennsylvanian (Desmoinesian) Prue Sandstone is an important oil and gas reservoir in central and northeastern Oklahoma. The name "Prue Sandstone" refers to strata in the subsurface, equivalent to the Lagonda Sandstone in outcrop. In southeastern Kansas, the Prue is known as the "Squirrel" and "Cattleman" Sandstones (Stoeckinger, 2002). Prue Sandstone, within incised valleys that were eroded through the Verdigris Limestone and Oakley Shale markers, is commonly mistaken for the Upper Skinner Sandstone. In northeastern Oklahoma the Bartlesville Sandstone is the most productive reservoir of petroleum; however, recent production from the Prue Sandstone indicates economic potential as an oil and gas reservoir. The Prue has long been an important producing reservoir in Osage County, Oklahoma and in Kansas to the north. However, little is documented regarding production from the Prue in Nowata County, Oklahoma. In Nowata County, the Prue Sandstone fills valleys that eroded potentially productive coals, creating a need for coal-bed methane operators to know the locations of these valleys.

The purpose of this study was to investigate the lithologic characteristics, internal stratigraphy, distribution and geologic history of the Prue sandstone. This study was selected because of the wealth of recently acquired data (provided by Devon Energy) that resulted from coal-bed methane activity. The information presented should help oil and gas operators who are engaged in conventional exploration to understand the distribution of the Prue Sandstone. The study will also assist in the development of coal-bed methane in and around this study area by providing insight into the locations of valleys that eroded several coal seams.

Objectives

The primary objectives of this study were:

1. to delineate the trends of Prue sandstone bodies and to interpret their depositional environment(s);
2. to refine the stratigraphy of the interval between the Excello Shale and the Oakley Shale;
3. to examine the effects of the Prue depositional system on the distribution and physical continuity of coals and of other regional markers; and
4. to establish a sequence stratigraphic framework and describe the depositional processes of the Prue interval.

Location of Study Area

The area of study includes approximately 195 square miles in six townships in northern Nowata County, Oklahoma (Figure 1). The study area is on the Northeast Oklahoma Platform, a relatively tectonically stable area that is bordered on the south by the Arkoma Basin, north by the Bourbon Arch, east by the Ozark Uplift and west by the Nemaha Uplift. Specifically, Township(s) 27 through 29 North and Range(s) 15 through 17 East, in Nowata County, were studied in detail. This is an area of active coal-bed

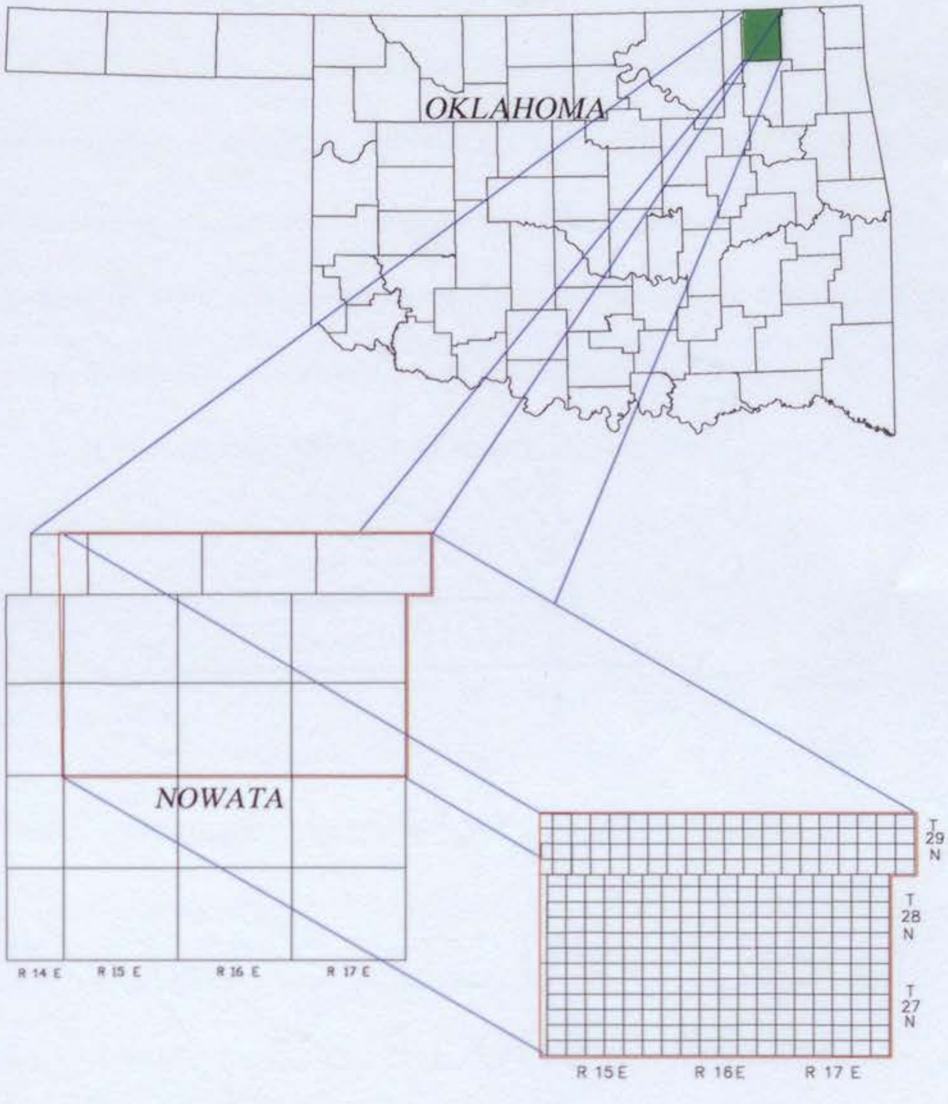


Figure 1: Location of Study Area.

methane exploitation; approximately 275 wells have been drilled within the past eight years.

Methods and Procedures

The primary purpose of this study was to interpret the depositional environment of the Prue Sandstone in a portion of northeastern Oklahoma by use of well logs, subsurface mapping, core, and surface data. To achieve this, an area in Nowata County, Oklahoma was selected. A wealth of new data from recent drilling for coal-bed methane is available; moreover, the area is close to outcrops of the Cherokee Group that include the Lagonda Sandstone.

Most interpretation of the subsurface was based on interpretation of wireline logs supplied by Devon Energy Corporation and the Oklahoma City Geological Society Library. All wireline logs were scanned and depth-registered in a geological software package called GeoGraphix©. Regional marker beds, which include the Higginsville Limestone, Excello Shale, Breezy Hill Limestone, Verdigris Limestone, Oakley Shale, and Tiawah "Pink" Limestone were correlated with other wireline logs, to establish a stratigraphic framework for Prue deposition. Characteristics used to identify these markers are described in the following chapter on stratigraphy. Detailed examination of each wireline log allowed high-resolution correlation, which was necessary to establish the temporal and spatial relationship of the Prue depositional system to the underlying regional stratigraphic markers. This high-resolution stratigraphic framework facilitated delineation of incised valley trends and the documentation of coal continuity. Geometry of the Prue Sandstone and the distribution of regional markers permitted correlations within areas located outside of the valley (interfluve) and allowed the identification of valley fill trends.

Structural contour maps were constructed of the Oswego Limestone, Excello Shale, Oakley Shale, and the Tiawah "Pink" Limestone to determine the structural configuration of the area and to examine any effects of the Prue system manifest in younger strata. All elevations used in construction of structural contour maps were derived from wireline logs. Interval isopach maps were constructed of the strata overlain by the Excello Shale and underlain by the Tiawah "Pink" Limestone. An isopach of the Prue Sandstone was made to delineate areas of thicker sandstone. Once areas of thicker sandstone were identified, an outline of the sandstone could be developed to show the trends and widths.

Analysis of a core from the Devon Energy Corporation, Forest 29-1 well (located 660 ft. from the south line and 1980 ft. from the west line, Sec. 29, T. 28 N., R. 16 E.) was used to develop an understanding of the general stratigraphy of wells located in the interfluve areas. Depositional features in the core were compared to the outcrop descriptions and biostratigraphy, investigated by Marshall (2002). The purpose of this endeavor was to establish the relationship between lithofacies and depositional conditions.

The general depositional-setting of the upper part of the Cabaniss Group was established by using a combination of studies by Heckel (1977, 1983), Krumme (1981), Denesen (1985), Ropp (1991), and Marshall (2002). These studies helped define each depositional cycle (cyclothem) in the study area. Once the cycles were identified, the depositional environment of each cyclothem could be inferred with information gathered from core analysis, wireline logs and interpretation in the literature.

Information for the section on petroleum geology was gathered from data recorded in PI Dwights Plus on CD® (2004), allowing the identification of wells that were drilled in the study area. Further records were "filtered" for information about production objectives such as conventional gas, oil, and coal-bed methane. Once the production objectives were identified, total and individual well production information could be determined. This data provided a foundation for interpreting the amount of exploration and exploitation activity in the area. Numerous wireline logs were used to interpret and delineate the Prue Sandstone and evaluate its potential for oil and gas production.

Previous Investigations

Compared to the lower Cherokee interval, which contains the Bartlesville Sandstone, relatively few investigations directly address the Prue Sandstone located in northeastern Oklahoma and southeastern Kansas. Oakes (1953) described the composition of the Cherokee Group as two groups, the Krebs Group and the Cabaniss Group; the upper part of the Cabaniss includes the Prue Sandstone interval. Stoeckinger (2002) recognized the Cattleman/Squirrel sandstone in eastern Kansas as being equivalent to the Prue, and described the gas potential of this reservoir. Other investigations that directly address the Prue (Cattleman/Squirrel) sandstone unit are Lardner (1984), Denesen (1985), Ropp (1991) and Hemish (2001). Krumme (1981) studied the Prue/Calvin sandstone over much of central and eastern Oklahoma. Brenner

(1989) compiled data from theses and other investigations into a report for the Kansas Geological Survey on the "Cherokee" Group that emphasized petrology and paleogeography. Marshall (2002) investigated the "Cherokee" stratigraphy using outcrops located in eastern Kansas and Oklahoma. Marshall (2002) concentrated on biostratigraphy of shales and provided valuable information regarding depositional settings and sequence stratigraphy.

Other researchers addressed the stratigraphic framework and depositional style of the Pennsylvanian System without providing much detail regarding the Prue sandstone. Howe (1956) studied the southeastern Kansas "Cherokee" Group stratigraphy in detail. Branson (1962) investigated each Pennsylvanian Series and correlated them throughout the Mid-Continent. Visher, Saitta B. and Phares (1971) noted the patterns of Pennsylvanian deltas and their impacts on petroleum production in eastern Oklahoma. Ebanks (1979) correlated Pennsylvanian sandstones in western Missouri, eastern Kansas and Oklahoma. Walton (1996) examined the depositional history of the "Cherokee" sandstones and their correlation to oil reservoirs.

STRATIGRAPHY

In Oklahoma, the Prue Sandstone is considered to be part of the Pennsylvanian Cabaniss Group (Figure 2). In Kansas, the Cattleman/Squirrel/Prue sandstone is classified as part of the Desmoinesian Cabaniss Subgroup, which is part of the Cherokee Group. The Cherokee Group unconformably overlies rocks of the Mississippian System and conformably underlies rocks of the Marmaton Group (Brenner, 1989). In 1953, a conference was held in Nevada, Missouri, to determine acceptable stratigraphic nomenclature of Desmoinesian rocks. Representatives from Iowa, Kansas, Missouri, Nebraska, and Oklahoma reached an agreement on division, classification, and nomenclature of Desmoinesian beds in these states (Figure 2) (Brenner, 1989). The term "Cherokee Group" was replaced by two group names, Krebs and Cabaniss (Howe, 1956). After the 1953 conference, the Kansas Geological Survey readopted the name "Cherokee" and classified the Krebs and Cabaniss as subgroups. The Oklahoma Geological Survey retained the two group names and the term "Cherokee" has not been recognized as a formal stratigraphic term (Brenner, 1989).

Cyclic depositional patterns comprise most of the Pennsylvanian section of northeast Oklahoma and southeast Kansas. These patterns are called transgressive/regressive couplets or cyclothems (Heckel, 1977). In ascending order, the cyclothem (defined for eastern Kansas outcrops) includes a (1) sandy (outside) shale, (2) middle limestone, (3) black (core) shale, and (4) an upper limestone. The lowermost rock

System	Series	Group	Formation	**Oklahoma Nomenclature**
Pennsylvanian	Desmoinesian	Marmaton	Fort Scott	Higginsville Limestone
				Little Osage Shale
				Blackjack Creek Limestone
		Cabaniss	Senora	Excello Shale
				Breezy Hill Limestone
				Kinnison Shale
				Iron Post Coal
				Prue Sandstone
				Verdigris Limestone
				Oakley Shale
				Croweburg Coal

System	Series	Group	Sub-group	Formation	**Kansas Nomenclature**
Pennsylvanian	Desmoinesian	Marmaton		Fort Scott Limestone	Higginsville Limestone
					Little Osage Shale
					Blackjack Creek Limestone
		Cherokee	Cabaniss	Mulky	Excello Shale
					Breezy Hill Limestone
					Kinnison Shale
				Lagonda	Iron Post Coal
					Cattleman, Lagonda or Squirrel Sandstone
				Verdigris	Verdigris Limestone
					Oakley Shale
				Croweburg	Croweburg Coal

Figure 2: Subsurface Stratigraphic Nomenclature for Oklahoma and Kansas (modified from Moore, Frye, Jewett, Lee, and O'Conner (1951), and Hemish (2001).

unit of the overlying cycle is shale. Stratigraphy of these cyclothems in eastern Oklahoma was modified by Marshall (2002); in ascending order, the general sequence is (1) coal, (2) black "hot" shale, (3) limestone, (4) siltstone or sandstone (when present), and (5) underclay. As a result of long-lived, repetitious deposition, numerous "marker" beds are in the Pennsylvanian section. These "marker" bed limestones and "hot" (highly radioactive) shales facilitate correlation and help the geologist distinguish continuous strata from discontinuous ones. The "hot" shale is equivalent to the "core" shale of Heckel (1977); the shale is rich in organic material, contains phosphate nodules, and has a gamma-ray signature greater than 150 API units.

This study focuses on the lower part of the Marmaton Group and on the upper part of the Cabaniss Group. The upper part of the Cabaniss is defined as extending from the base of the Oakley Shale to the top of the Excello Shale (Ropp, 1991); it includes the Verdigris, post-Bevier, and Breezy Hill cyclothems of Marshall (2002). In areas where erosion removed the Oakley Shale, the base of the sandstone will be defined as the bottom of the Prue stratigraphic unit. Figure 3 illustrates the well log signatures (gamma-ray response and density porosity response) for a normal (non-eroded) stratigraphic section.

Oakley Shale

The Oakley Shale is the basal stratigraphic unit of the study interval. It is dark-colored shale that is 2-4 feet above the Croweburg Coal. The Oakley is characterized by a "hot" gamma-ray response along with a density porosity value of 20-30%. The Oakley consists of dark gray shale that becomes grayish black to black fissile shale containing oblate spheroidal dark-gray phosphate nodules and conodonts (Brenner, 1989 and

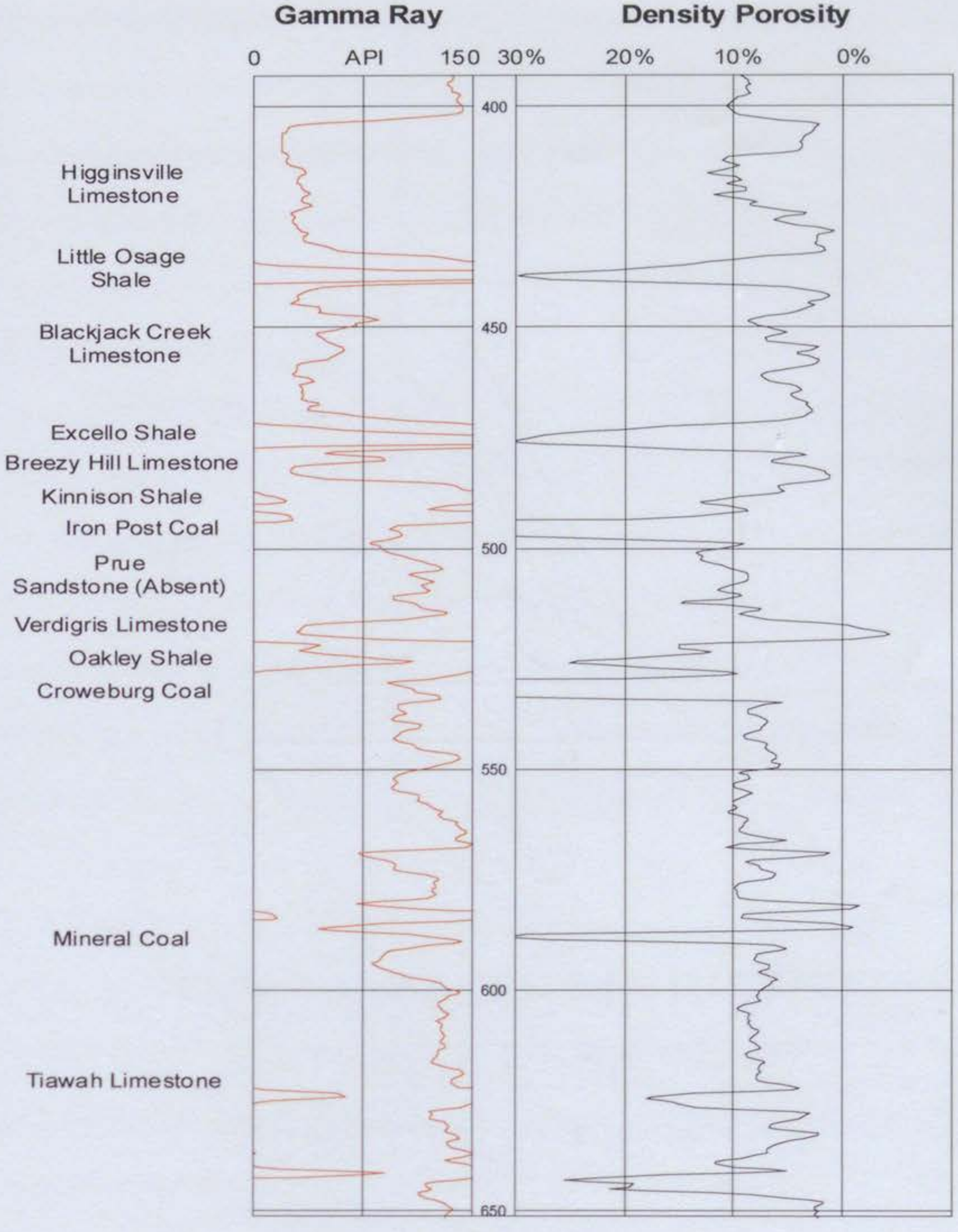


Figure 3: Log Signatures of the stratigraphic sequence from the Higginsville Limestone Member, Ft. Scott Limestone, to the Tiawah Limestone, Devon Energy Corporation, Forest 29-1, Sec. 29, T. 28 N., R. 16 E.

Marshall, 2002). Marshall (2002) identified the conodonts *Idiognathodus* and *Idioprioniodus*, these he took as evidence that the dark gray-black shale records deposition within a deep marine setting where water depth exceeded 200 meters. The Oakley is overlain by the Verdigris Limestone.

Verdigris Limestone

The Verdigris Limestone, which is equivalent to the Verdigris Limestone on the surface, has a low "clean" gamma-ray response of 30 API units with density porosity of less than 2%. The Verdigris is 1 to 5 feet thick and consists of olive gray to dark olive gray, dense biomicrite that contains marine brachiopods, bryozoa, echinoderm debris, corals, and algal fragments (Brenner, 1989). Marshall (2002) identified *Idiognathodus* conodonts, encrusting and calcareous foraminifera, indicating a shallow marine environment.

Prue Sandstone

The Prue Sandstone interval is underlain by the Verdigris Limestone and overlain by the Iron Post Coal. In some localities, the Prue Sandstone fills valleys that eroded both the Verdigris Limestone and the Oakley Shale. The Prue interval contains shales, silty shales, and sandstone. The sandstone, which is found to be almost 130 feet thick in the study area, can be identified on wireline logs by its "clean" gamma-ray deflection (less than 70 API units) and density porosity values of 12 to 20%. Denesen (1985) described the Prue from an outcrop located in the SW¼ SW¼ SW¼, Sec. 16 T. 20 N., R. 15 E., Rogers County, Oklahoma, approximately 50 miles south of the study area. The Prue was interpreted as deltaic distributary sandstone. This channel-filling sandstone is medium-grained, light brown, with SW-SE-trending sets of high-angle cross beds interrupted by layers of thin-bedded, rippled siltstones. The sandstone exhibits an erosional basal contact (Denesen, 1985). Ropp (1991) described the Prue of Lincoln County, central Oklahoma. Ropp (1991) described a core from the Gulf Oil Corporation, Hamm No. 1 well, in Sec. 19, T. 13 N., R. 5 E., as being light brown, moderately sorted to well sorted; very-fine to fine-grained sandstone. The rock contains medium-scale tabular planar cross-beds and small scale trough cross-beds. Ropp (1991) interpreted this sandstone as being part of a channel-fill within an incised valley.

Iron Post Coal

The Iron Post Coal is located immediately above the uppermost development of the Prue Sandstone. Usually less than 2 feet thick, the Iron Post Coal pinches out in the northern portion of the study area. On wireline logs, the coal is recognizable by its relatively "clean" gamma-ray response and density porosity of more than 30%. In a core, the Iron Post Coal contains carbonaceous shale banding (banding is calcite-rich) with layers rich in organic material, that are abundant. These layers contain pyrite (Ticora Geosciences, Inc., 2002).

Kinnison Shale

The Kinnison Shale is a wedge of dark gray shale that overlies the Iron Post Coal and underlies the Breezy Hill Limestone. This shale, typically 2 to 4 feet thick, has a gamma-ray response of 120 to 150 API units; density porosity is 6 to 10%. Marshall (2002) described the Kinnison Shale in outcrop as being grayish black, fissile, soft and carbonaceous. The shale yielded the deep-water foraminifera *Reophax* and other marine fossils (Marshall, 2002).

Breezy Hill Limestone

The Breezy Hill Limestone is immediately above the Kinnison Shale. This 6-10-foot-thick limestone can be recognized on wireline logs by its "clean" gamma-ray profile (15-30 API units) and density porosity that ranges from 0 to 6%. The Breezy Hill is the limestone of the "hot" shale-limestone combination that is an easily recognizable marker throughout the study area and much of eastern Kansas and Oklahoma. The Breezy Hill Limestone contains crinoid stems, brachiopods, holothurian sclerites, and calcareous sponge spicules (Marshall, 2002). The shallow-marine Breezy Hill Limestone is overlain by the Excello Shale.

Excello Shale

The Excello Shale is the last "hot" shale that is encountered in the Cabaniss Group. The dark-colored Excello Shale rests on the Breezy Hill Limestone creating a marked change in color that is evident in core and outcrop. This 4-5 foot thick shale is overlain by the Blackjack Creek Limestone, member of the Fort Scott Limestone, which is the first formal unit and limestone in the Marmaton Group. The Excello Shale is an excellent continuous marker throughout the study area. The Excello Shale is easily identified on wireline logs by its "hot" (API gamma-ray value in excess of 300 API units) gamma-ray response and a density porosity response that exceeds 24%. The Excello consists of numerous 0.10-0.5 inch spherical to oval grayish black phosphate nodules in bedding planes and *Idiognathodus* conodonts, indicating a deep marine setting (Marshall, 2002). The Excello core has high mineralization of pyrite and the presence of nodular calcite mineralization (Ticora Geosciences, Inc., 2002).

Markers used to construct structural and thickness maps

Two markers outside the study interval were used in the construction of interval thickness and structure maps. These are the Tiawah "Pink" Limestone and the Oswego Limestone.

Tiawah Limestone

The Tiawah Limestone is known as Pink Limestone in subsurface economic nomenclature. The Pink is approximately 100 feet below the base of the Oakley Shale. The Pink Limestone is bound on top and bottom by "hot" shales that are easily recognizable on wireline logs by gamma-ray (>150 API units) and >20% density porosity responses. This limestone marker can be correlated throughout the Northeast Oklahoma Platform and into central Oklahoma. The bounding "hot" shales are correlatable in areas where the limestone lithofacies are not apparent on log signatures.

Oswego Limestone

The Oswego Limestone is a subsurface name for the Fort Scott Limestone. The Oswego is used as a marker throughout northeastern Oklahoma and southeastern Kansas. Located immediately above the Excello Shale, the Oswego Limestone has a "clean" gamma-ray (less than or equal to 30 API units) curve and a 0 to 10% density porosity response. The Oswego Limestone is bound on top by shale that is equivalent to the Labette Shale in outcrop and below by the Excello Shale.

DEPOSITIONAL SETTING

Tectonic Setting

The area of investigation lies on the Northeast Oklahoma Platform between the Nemaha Uplift to the west, the Ozark Uplift to the east, and the Arkoma Basin to the south (Figure 4). The Nemaha Ridge is an uplift that extends from central Oklahoma, across Kansas and into Nebraska. The Nemaha Ridge was gradually onlapped and finally buried by Pennsylvanian strata, but it subsided more slowly than the sea floor on either side and its presence is reflected by thinning in most of the covering strata (Pennsylvanian and Permian) (Krumme, 1981). Desmoinesian sediments were deposited upon the Cherokee shelf, a tectonically-stable depositional platform (Brenner, 1989). During the Early Pennsylvanian, the shelf was divided into two depositional elements: the Cherokee shelf (Northeast Oklahoma Platform) in southeastern Kansas and northeastern Oklahoma and the Forest City Basin in northeastern Kansas, southeastern Nebraska, northwestern Missouri, and southwestern Iowa. These depocenters were separated from each other by the Bourbon arch, a low relief feature that trends northwest-southwest through east central Kansas into Missouri (Merriam, 1963, and Brenner, 1989). The Ozark uplift, located to the east of the study area, was a positive feature in the Paleozoic Era that influenced deposition patterns to the west.

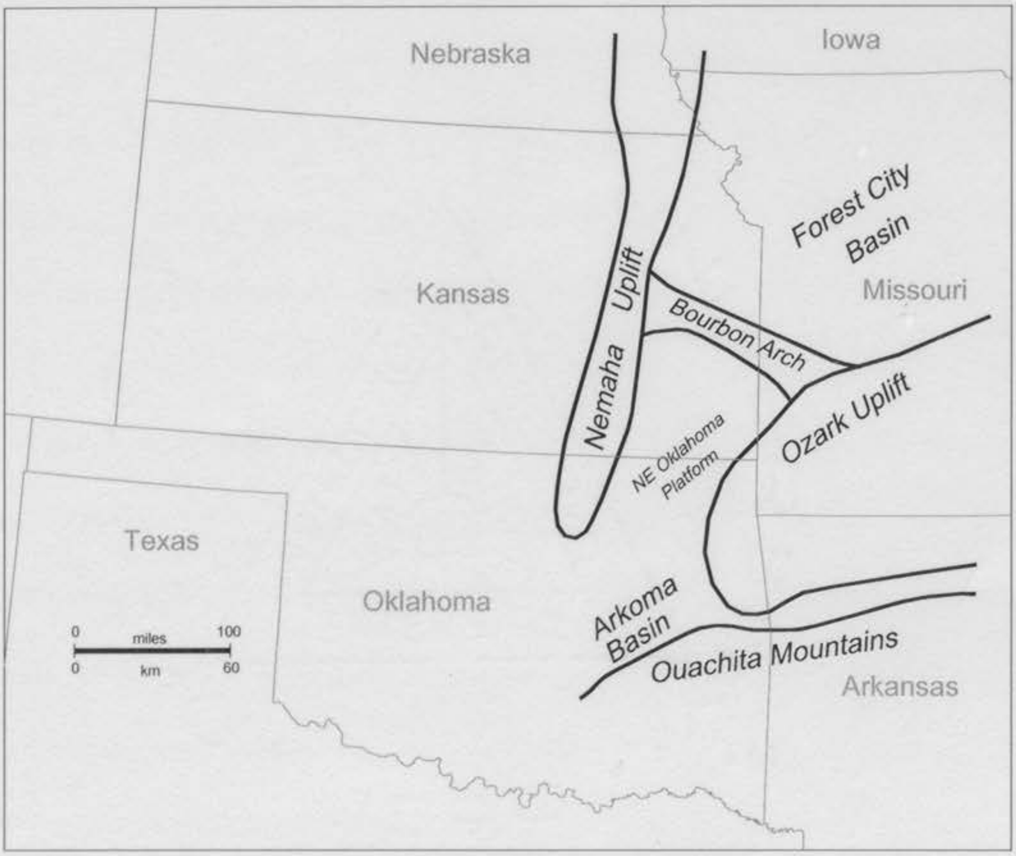


Figure 4: Middle Pennsylvanian tectonic features of northeastern Oklahoma and southeastern Kansas (modified from Lardner, 1984).

Sediment Dispersal

Many studies have shown that the Pennsylvanian System located in southeast Kansas and northeast Oklahoma is comprised of numerous fluvial-deltaic systems. These systems were identified by their lithofacies, sandstone distribution patterns, geometry and relative position to the shelf and the basin. The cyclical patterns of the Pennsylvanian system include a series of transgressive and regressive events that allowed patterns of deposition that resulted in coals, "hot" shales, and limestones. These coals, shales, and limestones suggest that paleotopography was of very low relief and that sediment types reflect slight changes in the relative position of sea level during Pennsylvanian time. Krumme (1981) investigated the Prue/Calvin sandstone on the northeast Oklahoma platform and concluded that the source of the Prue Sandstone was located to the northeast (Figure 5). Ropp (1991) defined the Prue Sandstones on the Northeast Oklahoma Platform as being fine to very fine grained sub-angular to sub-rounded, quartz-arenite, sublitharenite, or subarkose with muscovite-bearing metamorphic rock fragments. Ropp (1991) suggested that the metamorphic-rock fragments indicate the Prue source was the Transcontinental Arch to the northeast. The grain size and roundness of the Prue sediment indicates long transportation distances from the cratonic source (Ropp, 1991). Since the cratonic source of the Prue Sandstone is located to the northeast, the regional tectonism favored a pathway for sediment dispersal between the Nemaha and Ozark uplifts and down into the Arkoma and Anadarko basins.

Figure 6 illustrates the paleogeography during Prue deposition. Ropp (1991) suggested deposition of the Prue sediments occurred within a (1) deltaic/delta fringe setting during the waning of sea level after deposition of the Verdigris carbonate and (2)

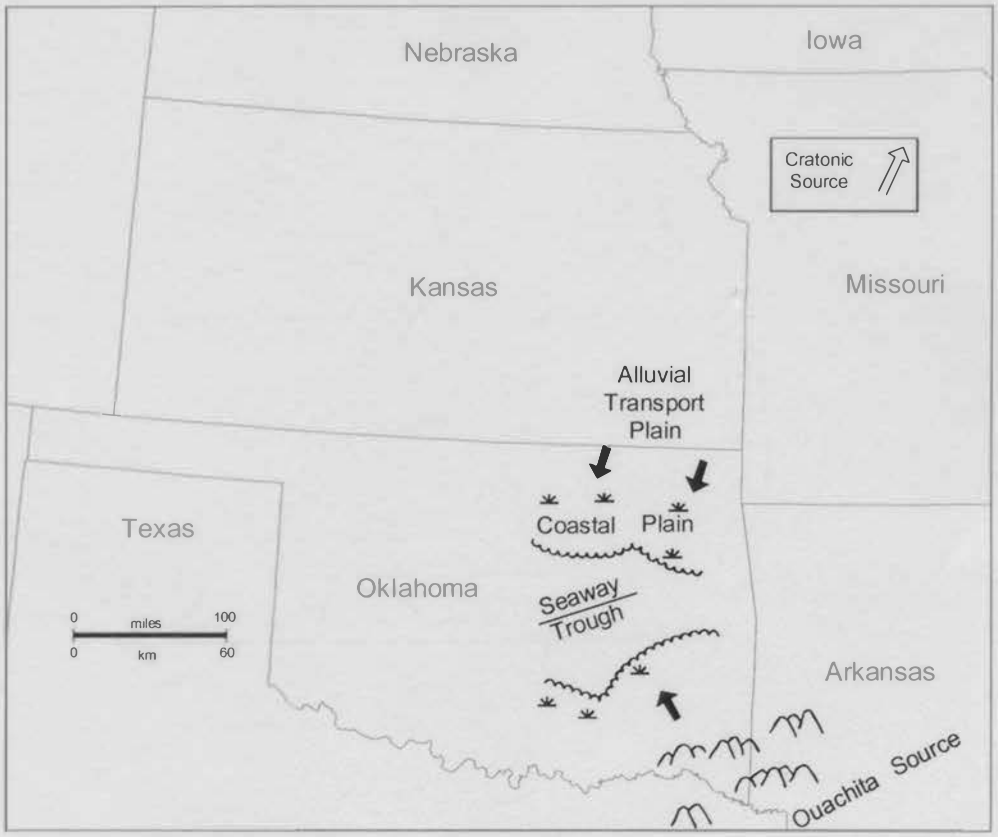


Figure 5: Generalized paleogeography, Central Mid-continent region, during deposition of Prue sediments (from Krumme, 1981).

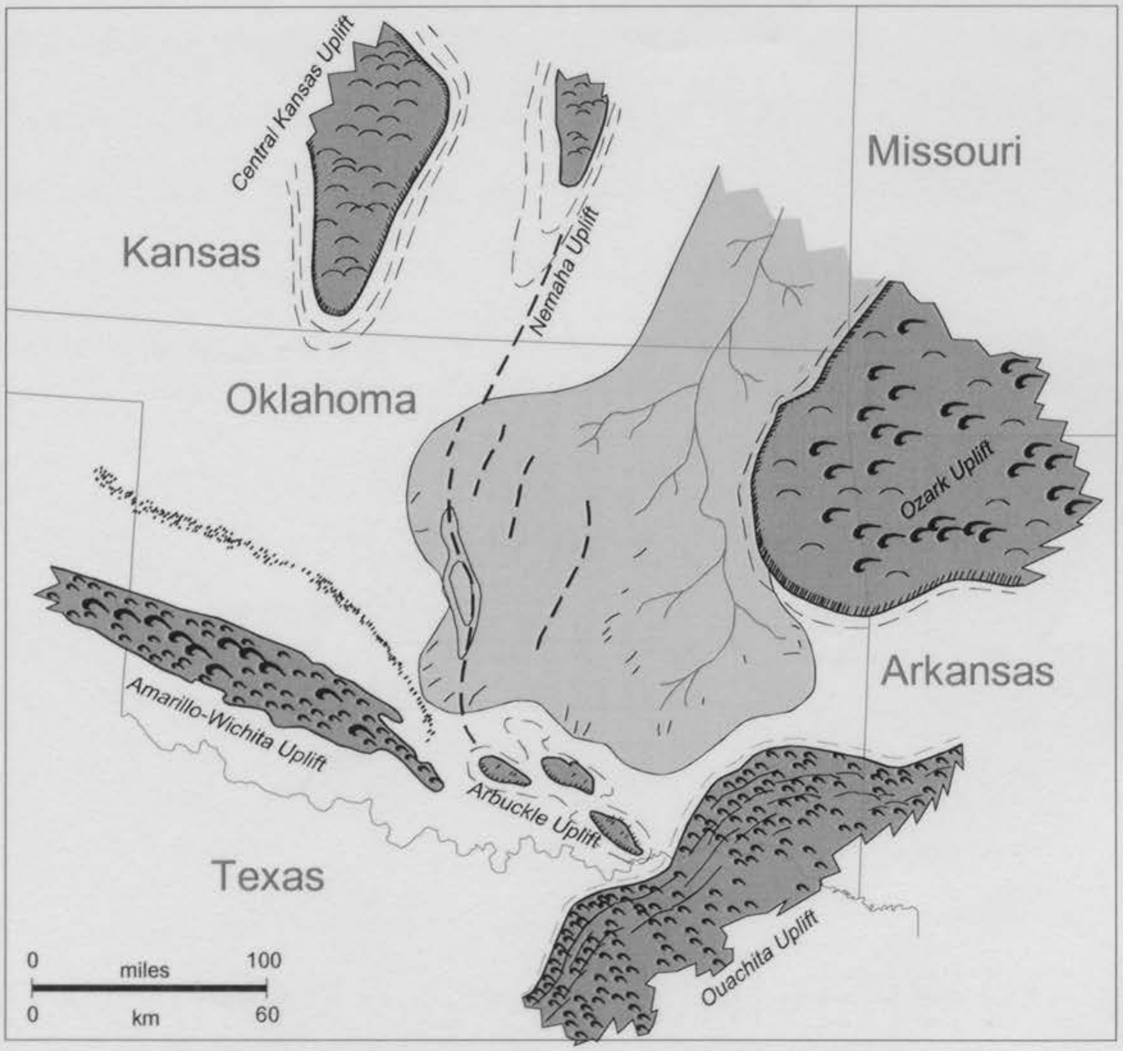


Figure 6: Paleogeography during deposition of the Prue fluvial deltaic complex (Denesen, 1985; Ropp, 1991; Puckette and Gerken, 2003).

as incised valley-fill following a sea level drop. These incised valleys formed in two phases, erosion and then deposition. Ropp (1991) cited evidence of erosion by the cutout of underlying markers such as the Verdigris Limestone. Ropp (1991) theorized that deposition of the Prue sand occurred because a relative rise in sea level forced filling of the incised valleys. Evidence for marine fill within the valley was provided by glauconite grains found in the Prue Sandstone in the Hamm no. 1 core. Denesen (1985) also suggested deposition within a combination of a deltaic/incised valley system.

PRUE ELECTROFACIES

Recognition and interpretation of depositional processes within the Prue Sandstone interval were achieved using numerous recently-obtained wireline logs that provided gamma-ray and density porosity curves. The well-defined marker beds in the Cabaniss interval formed a framework for high-resolution stratigraphic correlations. Channel-filling intervals have characteristic erosive basal contacts. When a well is located in an interfluve, local and regional markers are present and the wireline log signature is similar to the signature shown in Figure 3. The Prue interval, without active channel fill, has a silty/sandy gamma-ray log signature and low (less than 8%) density porosity. In contrast, Figure 7 represents a well located in an area that accommodated Prue sand. In this example, channel erosion did not affect the underlying Verdigris Limestone and Oakley Shale. The log signature (Figure 7) shows a sharp basal contact between the sandstone and the underlying shale. A fining-upward character is expressed by increasing gamma-ray measurement toward the top of the sandstone. The fining-upward signature reflects an upward decrease in grain size, suggesting that the kinetic energy of the water that deposited Prue sand decreased upward. The sharp basal contact for the sandstone suggests erosion of underlying sand and shale and depositional juxtaposition of coarse-grained fluvial sand on the underlying clay-rich distal-delta/marine sediments/rock. The cleaner gamma-ray signature at the base indicates coarser grained or "clean" sandstone. Though no cores were available in the channel-fill

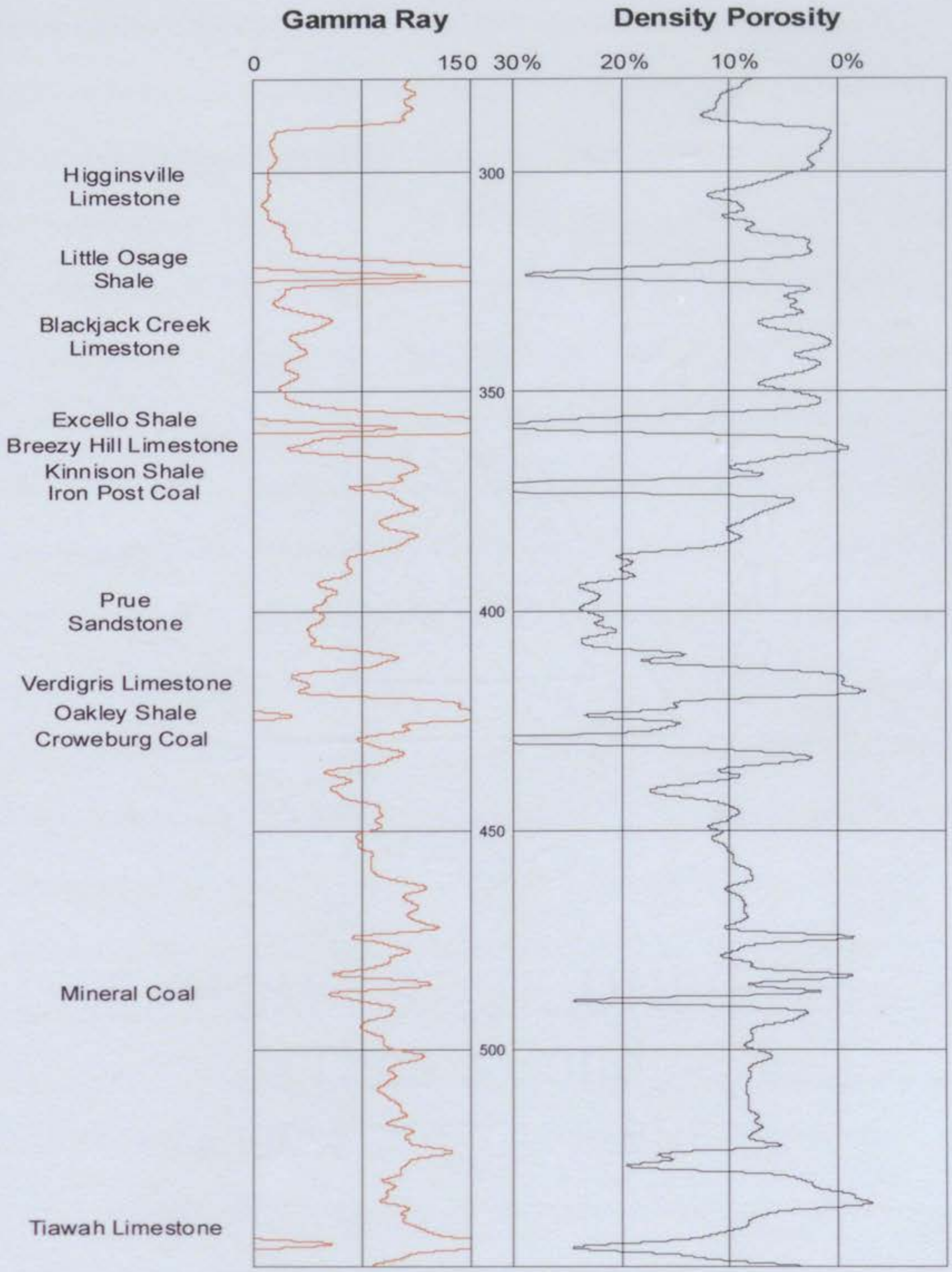


Figure 7: Log Signatures of the stratigraphic sequence from the Higginsville Limestone Member, Ft. Scott Limestone, to the Tiawah Limestone, Devon Energy Corporation, K&B Farms 3-1, Sec. 3, T. 27 N., R. 16 E.

electrofacies in the study area and adjacent counties in Oklahoma and Kansas, information regarding depositional environment and electrofacies were derived from Denesen (1985) and Ropp (1991). Denesen (1985) described the outcrop located in SW¼ SW¼ SW¼ of sec. 16, T. 20 N., R. 15 E., as having SW-SE trending cross sets interrupted by thin layers of thin-bedded, rippled siltstones. Prue Sandstone has an erosional basal contact into the underlying siltstone. Densen (1985) also noted that the outcrop of Prue sandstone and log signatures were characteristic of distributary channels. Ropp (1991) also suggested that the Prue represented channel-fill deposition. Based on the Hamm no. 1 core, located in sec. 19, T. 13 N., R. 5 E., wireline log signatures and extensive mapping, Ropp (1991) concluded the Prue-filled valleys that incised a deltaic complex. The wireline log pattern or geometry of Prue Sandstone in this study is consistent with channel-fill deposition. Figure 8 is a wireline well log that illustrates the full erosive potential of the Prue channel. The log signature shows a sharp base and a fining-upward signature that is characteristic of the channel-fill electrofacies. However, in this case, the channel eroded two major regional markers, the Verdigris Limestone and the Oakley Shale. This thick Prue Sandstone suggests that the particular well is located toward the part of the channel where the thickest accumulation of coarser-grained (sand) sediment occurred.

The regional marker beds have distinct log signatures and can be correlated throughout the area. Five regional markers in the upper part of the Cabaniss Group and one in the overlying Marmaton Group were utilized in this study. These are the Oswego Limestone, Excello Shale, Breezy Hill Limestone, Iron Post Coal, Verdigris Limestone, and Oakley Shale. The two markers beneath the Prue Sandstone, the Verdigris

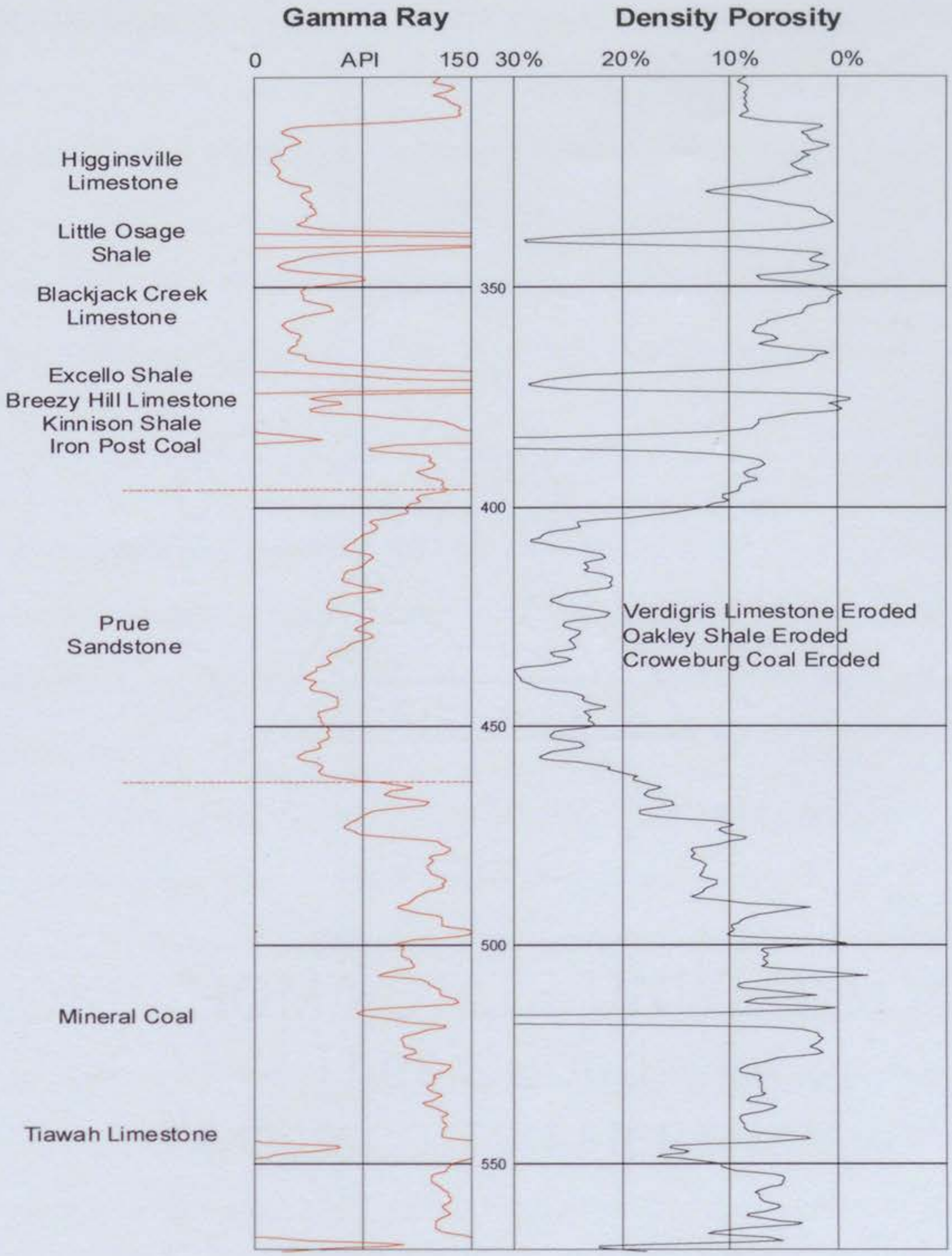


Figure 8: Log Signatures of the stratigraphic sequence from the Higginsville Limestone Member, Ft. Scott Limestone, to the Tiawah Limestone, Devon Energy Corporation, Kottke 24-1, Sec. 24, T. 28 N., R. 16 E.

Limestone and Oakley Shale, were eroded in areas of major down cutting. Figure 9 (Plate 2) shows the locations of wells in which the (1) channel-fill sandstone is present, (2) the Verdigris is eroded, and (3) Verdigris and Oakley are missing. The Iron Post Coal, which is located immediately above the Prue Sandstone interval, is not affected by the Prue Channel. Since the Prue channel does not erode the Iron Post Coal, this suggests that the Prue channel erosion occurred immediately prior to the deposition of the Iron Post peat.

Through detailed correlations using many wireline logs and the research results of previous studies, a depositional model can be constructed for the Prue interval. The overall generalized depositional setting is fluvial deltaic (Figure 6). The evidence was provided by wireline logs, core descriptions, outcrop descriptions, surface and subsurface mapping.

Wireline log signatures correlated to cores indicate three general types of electrofacies that represent specific environments. These are assigned to the following types, (1) interfluve, (2) channel-fill and (3) channel-fill associated with major incision. Type (1) wells lack well-developed Prue channel-fill sandstone. These wells are located in the interfluvial environment where deposition was dominated by clay, silt and very fine sand. The grain size indicates the area was possibly low energy delta plain or an interdistributary bay. Type (2) wells contain channel-filling sandstone, but the channel does not erode regional markers. This environment represents distributary entrenchment or minimum incision into the underlying bedrock. Channel down-cutting is only enough to allow incision of a small portion of underlying sediment/rock. Type (3) wells are characterized by major erosion and deep incision. The two regional markers (Verdigris

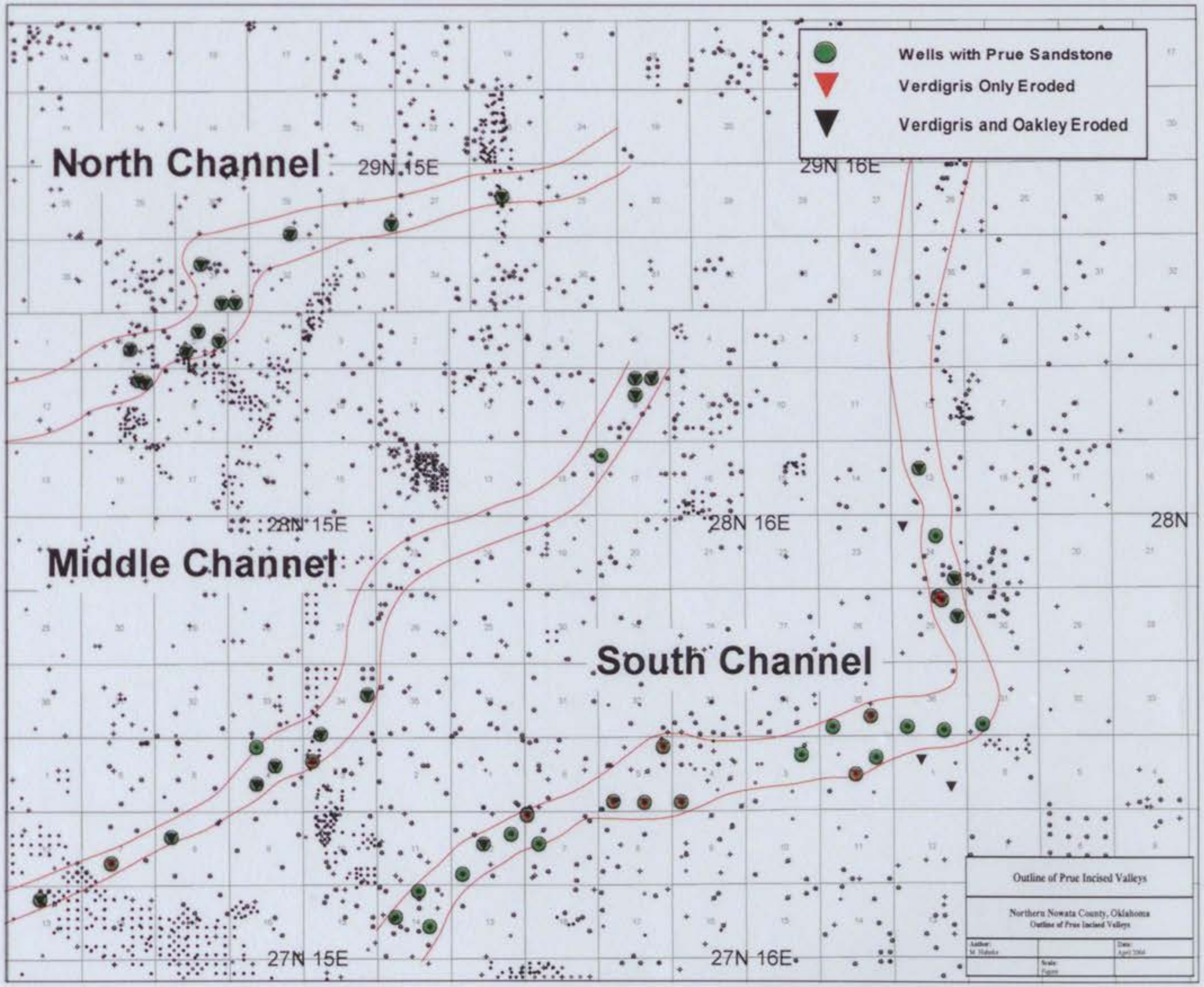


Figure 9: Location of Wells that Contain the Prue Sandstone (see Plate 2).

and Oakley) are eroded, indicating maximum erosion and subsequent valley filling that resulted in thick sediment fill in the Prue valley.

Core and Outcrop Description

The Forest 29-1 well located in section 29 of Township 28 North and Range 16 East cored Pennsylvanian rocks. Description of a portion of the core follows and is shown on Figures 10-15 (coals found in the core were taken for analysis by Devon Energy Corporation). The interval (531'-533'depth below surface) just below the Croweburg Coal is defined as an underclay or paleosol. The paleosol contains oxidized material that indicates sub-aerial exposure. Above the paleosol is the Croweburg Coal (529.5'-531'), which is missing from the core, but was described by Ticora Geosciences Inc. The bottom portion of the coal contains slight calcite and pyrite mineralization and is moderately vitreous while the top portion of the coal contains slight organic lenses with extreme calcite mineralization (Ticora Geosciences Inc., 2002).

Overlying the Croweburg Coal is dark gray carbonaceous shale (526.5'-529.5'). The Oakley Shale, located from 520.5'-526.5', is missing from the core box (took for analysis by Devon Energy Corporation). The Verdigris Limestone (516'-520.5'), which is light gray in color, is above the Oakley Shale. Directly overlying the Verdigris Limestone is the Prue interval. In this core, the interval starts with a thinly-bedded silty/shale layer, which is present from 515'-516'. Overlying the shale from 511'-515' is a highly weathered zone that may indicate a sub-aerial exposure, but due to weathering of the rock (core was left in the elements), description was difficult. The 509'-511' zone is dark gray marine shale, which is unconsolidated from the weathering of this particular

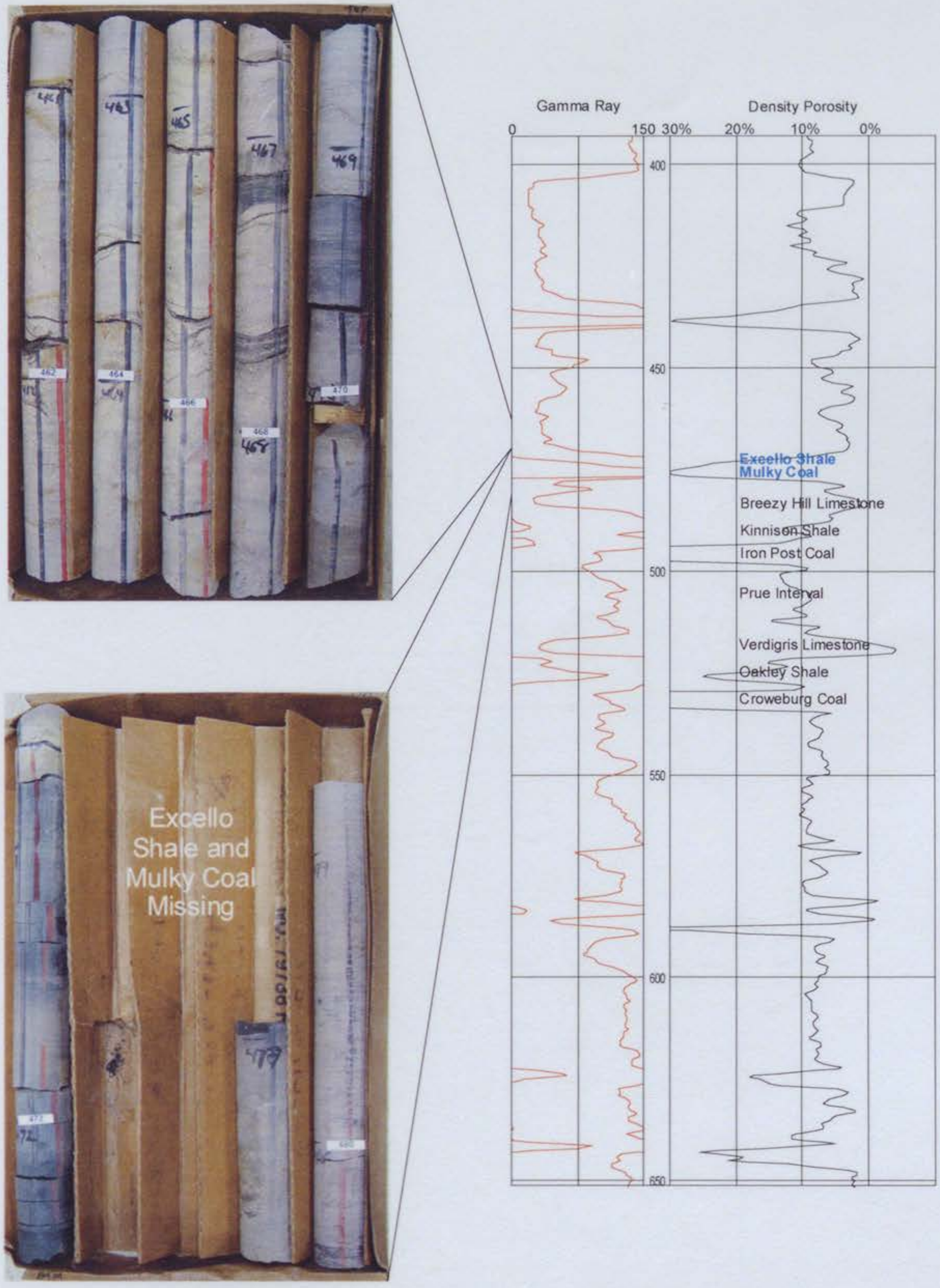


Figure 10: Blackjack Creek Limestone to Breezy Hill Limestone interval, Devon Energy Corporation, Forest 29-1, Sec. 29, T. 28 N., R. 16 E.

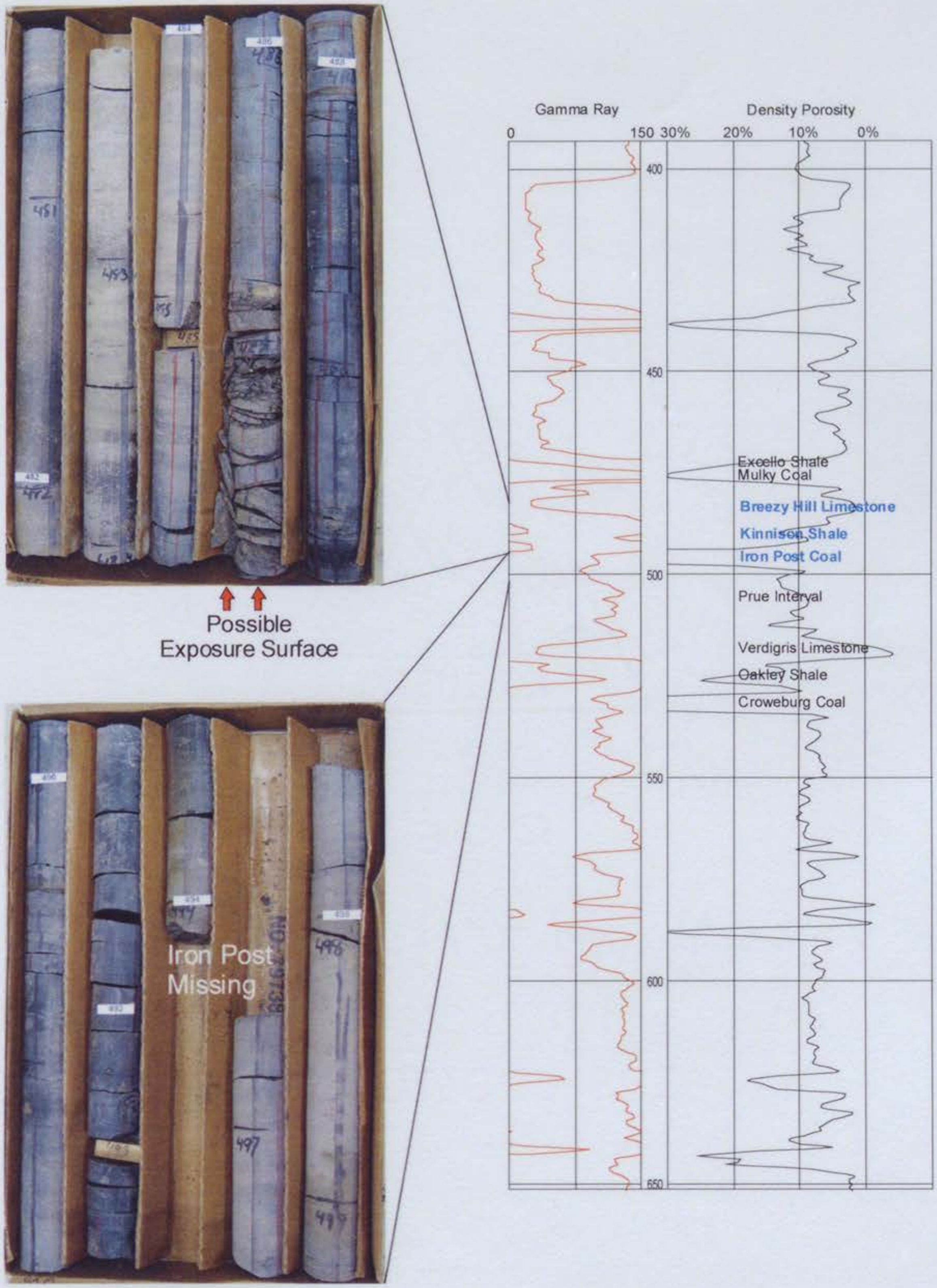


Figure 11: Breezy Hill Limestone to top of Prue interval, Devon Energy Corporation, Forest 29-1, Sec. 29, T. 28 N., R. 16 E.

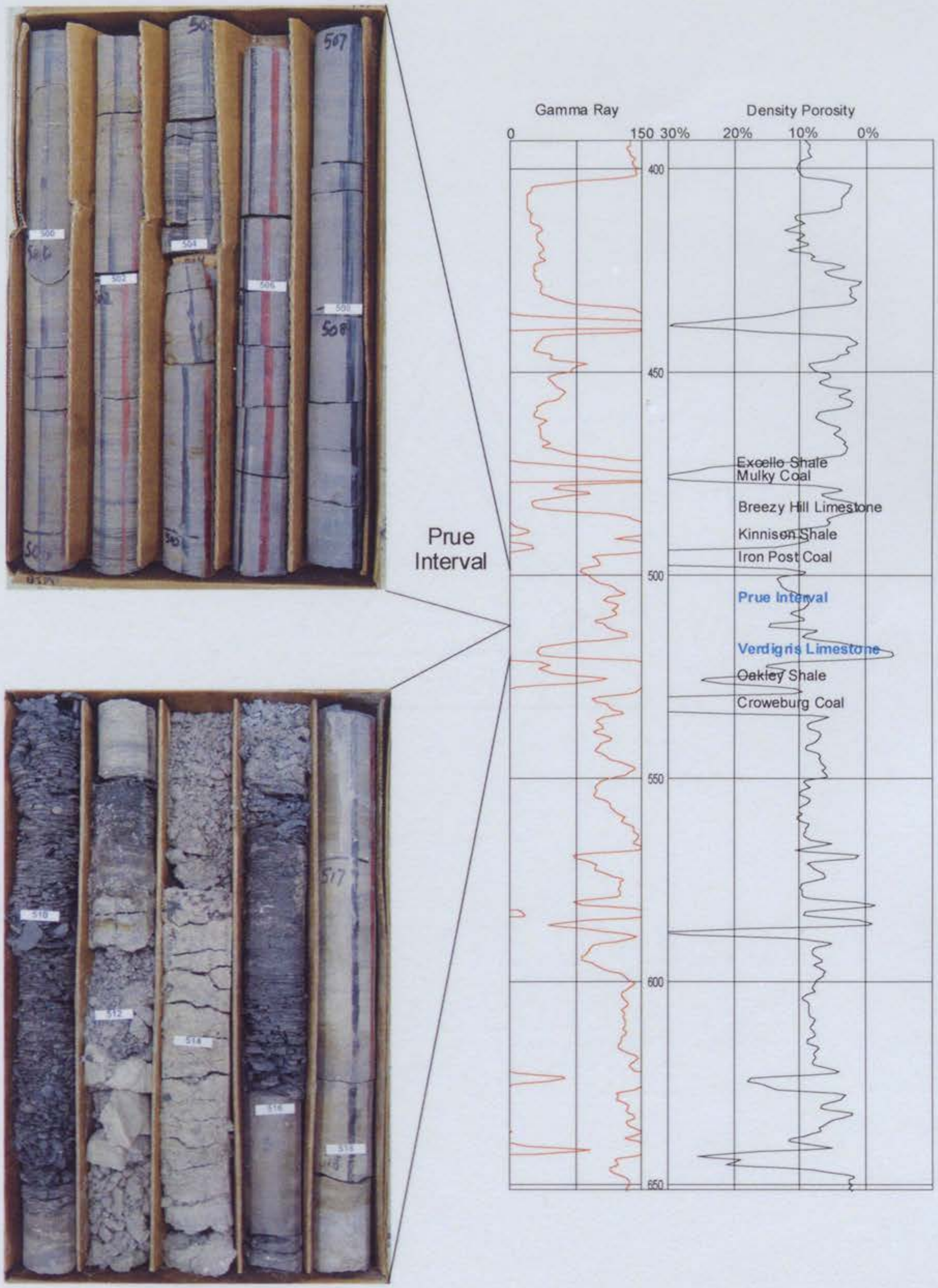


Figure 12: Top of Prue to Verdigris Limestone interval, Devon Energy Corporation, Forest 29-1, Sec. 29, T. 28 N., R. 16 E.

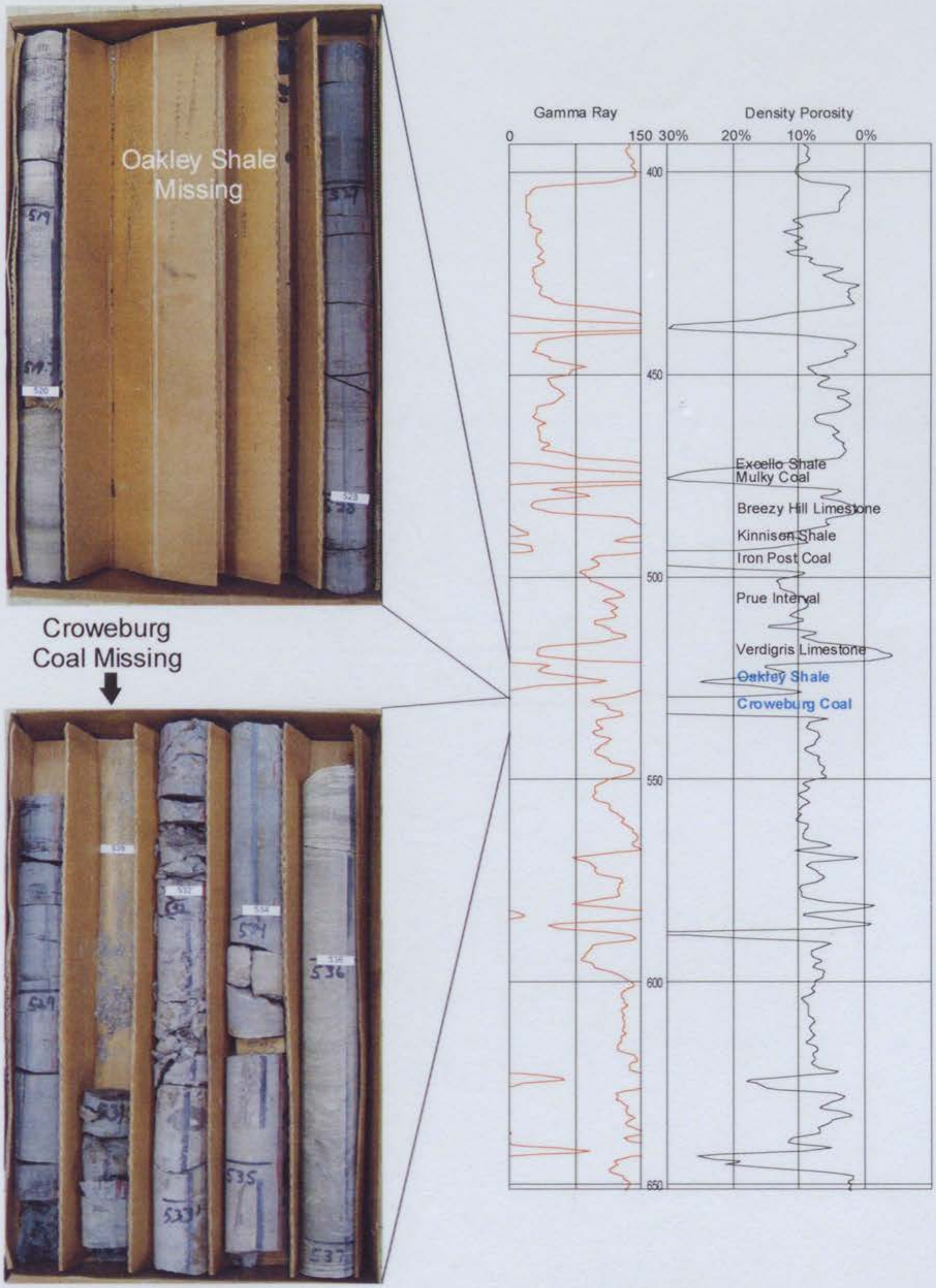


Figure 13: Verdigris Limestone to below the Croweburg Coal interval, Devon Energy Corporation, Forest 29-1, Sec. 29, T. 28 N., R. 16 E.

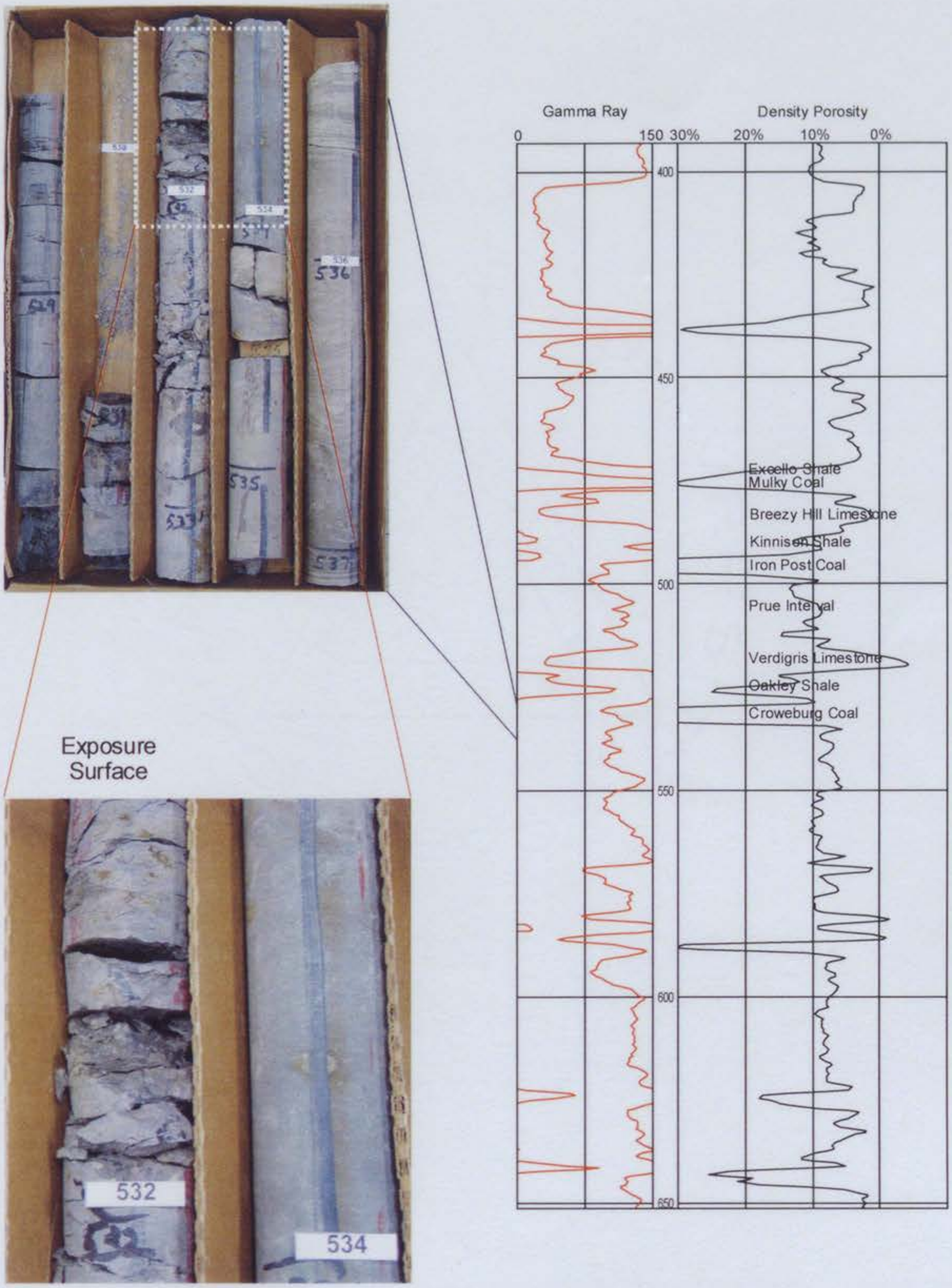


Figure 14: Exposure surface below the Croweburg Coal interval, Devon Energy Corporation, Forest 29-1, Sec. 29, T. 28 N., R. 16 E.

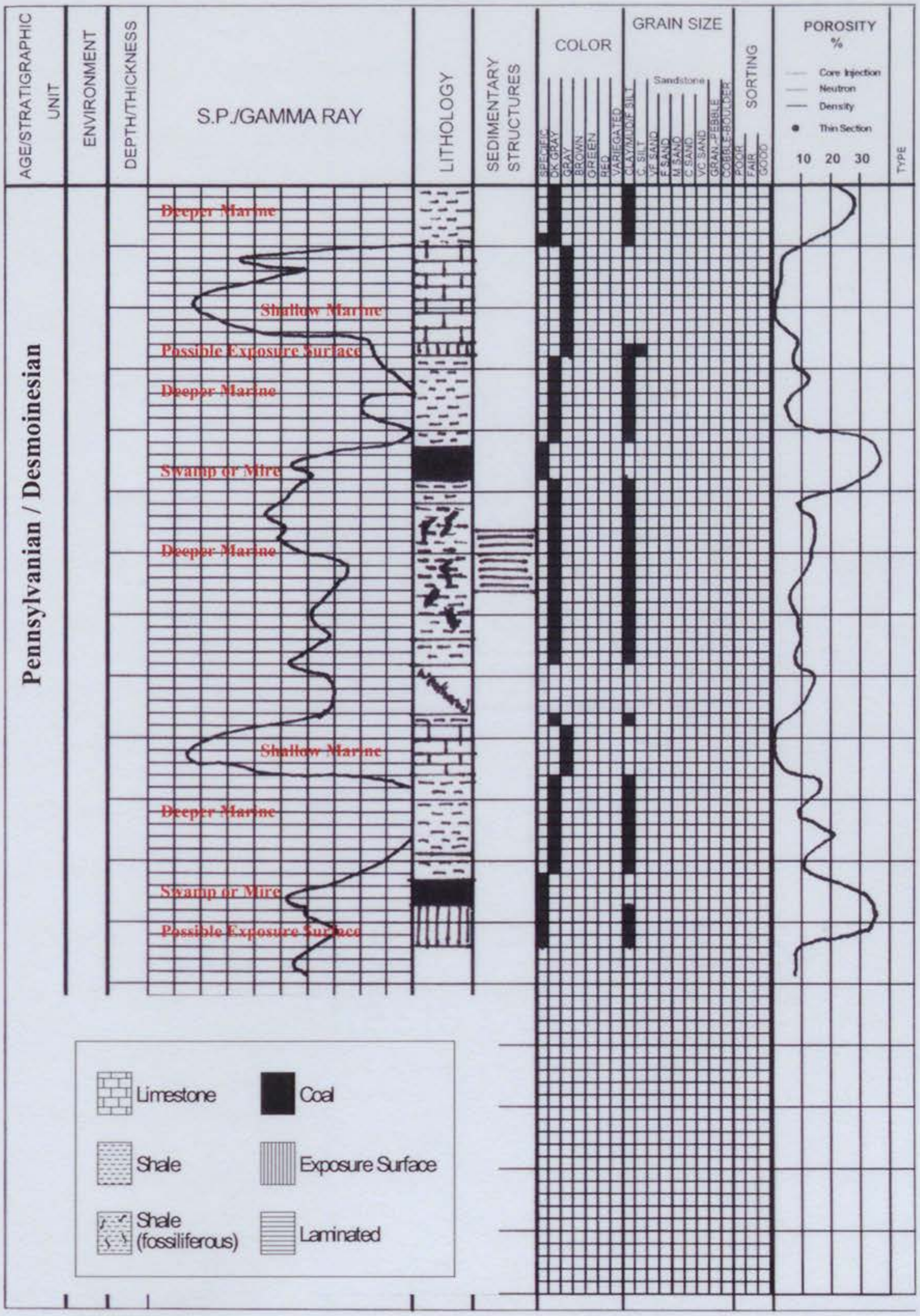
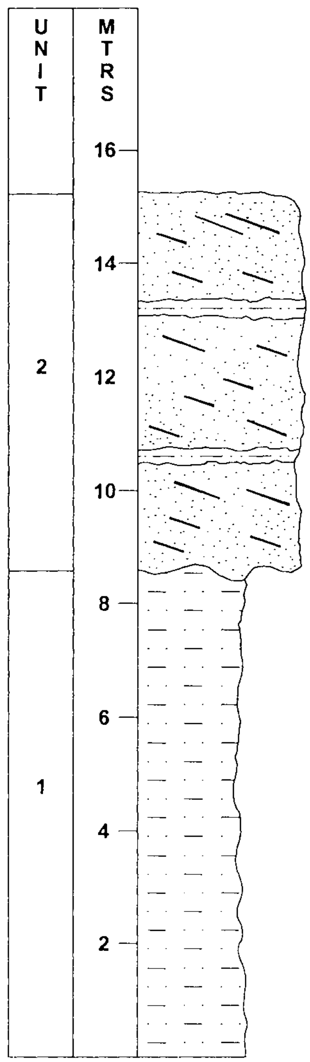


Figure 15: Petrolog for the studied interval, Devon Energy Corporation, Forest 29-1.

box. Just above this zone (498'-509') is dark gray, laminated shale containing macroinvertebrate fossils (marine in origin). The 496.5'-498' zone is dark gray carbonaceous shale. This bed concludes the Prue interval. The Iron Post Coal, present from 494'-496.5', has calcite mineralization along the fractures, pyrite and calcite filaments in the matrix, and is vitreous at the bottom (Ticora Geosciences, Inc., 2002). Overlying the Iron Post is the Kinnison shale from 488'-494', which is a dark gray marine shale. The zone from 487'-488' is a questionable exposure surface that could represent the regression from marine shale to subaerial exposure and then transgression into the Breezy Hill Limestone. Breezy Hill Limestone is present from 477'-487', containing abundant macroinvertebrate fossils. The Excello Shale (469'-477') overlies the Breezy Hill Limestone and is described as having high pyrite mineralization and the presence of nodular calcite mineralization (Ticora Geosciences, Inc., 2002).

Denesen (1985) described the Prue and underlying siltstone/shale interval in an outcrop located in SW¼ SW¼ SW¼ of sec. 16, T. 20 N., R. 15 E (Figure 16). The siltstone/shale is medium gray in color with well developed wavy fissility. The overlying Prue sandstone was described as medium-grained, light brown and massive, with SW-SE-trending high-angle planar cross sets interrupted by layers of thin-bedded, rippled siltstone. Red-clay ironstone concretions are aligned along planes of cross stratification. The sandstone has an irregular, erosional basal contact (Denesen, 1985).

A core containing the Prue Sandstone was studied by Ropp (1991). The well (Hamm no. 1) is located in sec. 19, T. 13 N., R. 5 E., Lincoln Co., Oklahoma (Figure 17). The well has a cored interval of 3698-3715 feet. "The rock is light brown, moderately-sorted to well-sorted sandstone. Grain size varies from very fine to fine-grained.



Unit 2 (8.7-15.4 M): Sandstone; medium-grained; light brown; massive, with SW-SE-trending high-angle planar cross sets interrupted by thin layers of thin-bedded, rippled siltstone; red clay ironstone concretions are aligned along planes of cross stratification; irregular, erosional basal contact.

Unit 1 (0-8.7 M): Siltshale; medium gray; well developed wavy fissility; lower contact not exposed.

Figure 16: Measured section in roadcut, located SW¼ SW¼ SW¼ sec. 16, T. 20 N., R. 15 E., Rogers County, Oklahoma (from Denesen 1985)

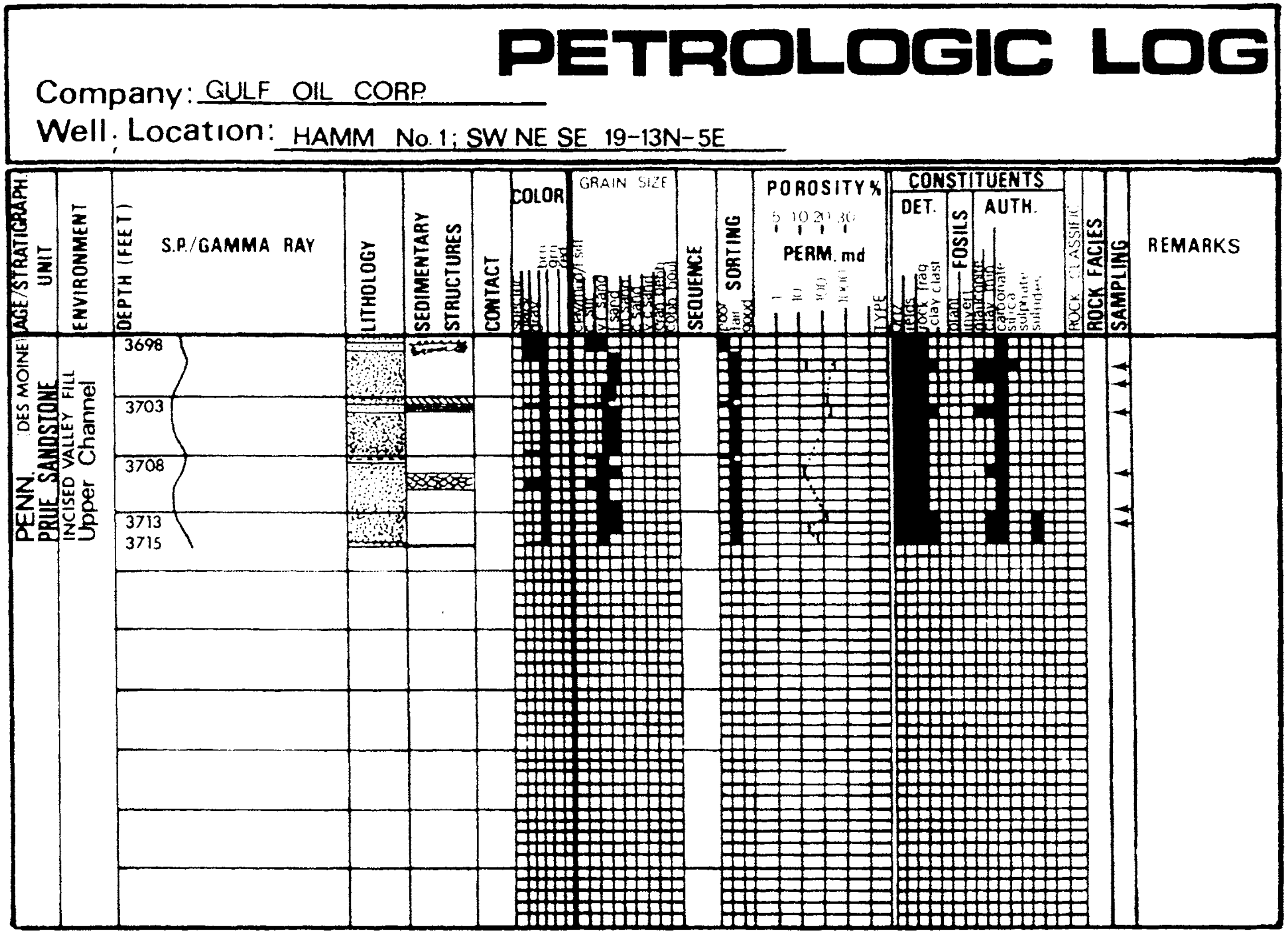


Figure 17: Petrolog for Gulf Oil Corporation, Hamm no. 1 (from Ropp, 1991).

Sedimentary structures include medium-scale tabular planar cross-bedding, small-scale trough cross-bedding, as well as massive and planar bedding. Bioturbation is present in the top two feet of the cored interval in a finely laminated sandy shale. The sandstone contains siderite clasts that were apparently transported and reworked. The sandstone contains muscovite, carbonaceous laminae, and calcite cement" (Ropp, 1991).

The outcrop description by Denesen (1985) and core description by Ropp (1991) both indicate deposition of the sands was the result of filling channels. Ropp (1991) further concluded the Prue filled valleys that incised a deltaic complex.

Subsurface Mapping

Subsurface maps were constructed to help determine the depositional environment and structural attitude of the Prue interval. The first map constructed in this study area was the gross isopach map of the Prue Sandstone. The top and base of the sandstone were determined using a combination of the gamma-ray and density porosity curves. Sandstone was identified as having a gamma-ray deflection of 70 API units or less combined with density porosity values of greater than or equal to 14%. In well logs that only provided gamma-ray wireline curves, correlation to an analog with both curves was used to establish the parameters for estimating thickness from only gamma-ray. After the thickness values were established for each well containing the Prue Sandstone, isopach values were plotted on a map and contoured (Figure 18; Plate 1). Construction of the isopach was important for two reasons. First, the Prue isopach values define the distribution of thicker sandstone trends, which used in conjunction with sandstone geometry and stratigraphic position, allow the interpretation and delineation of

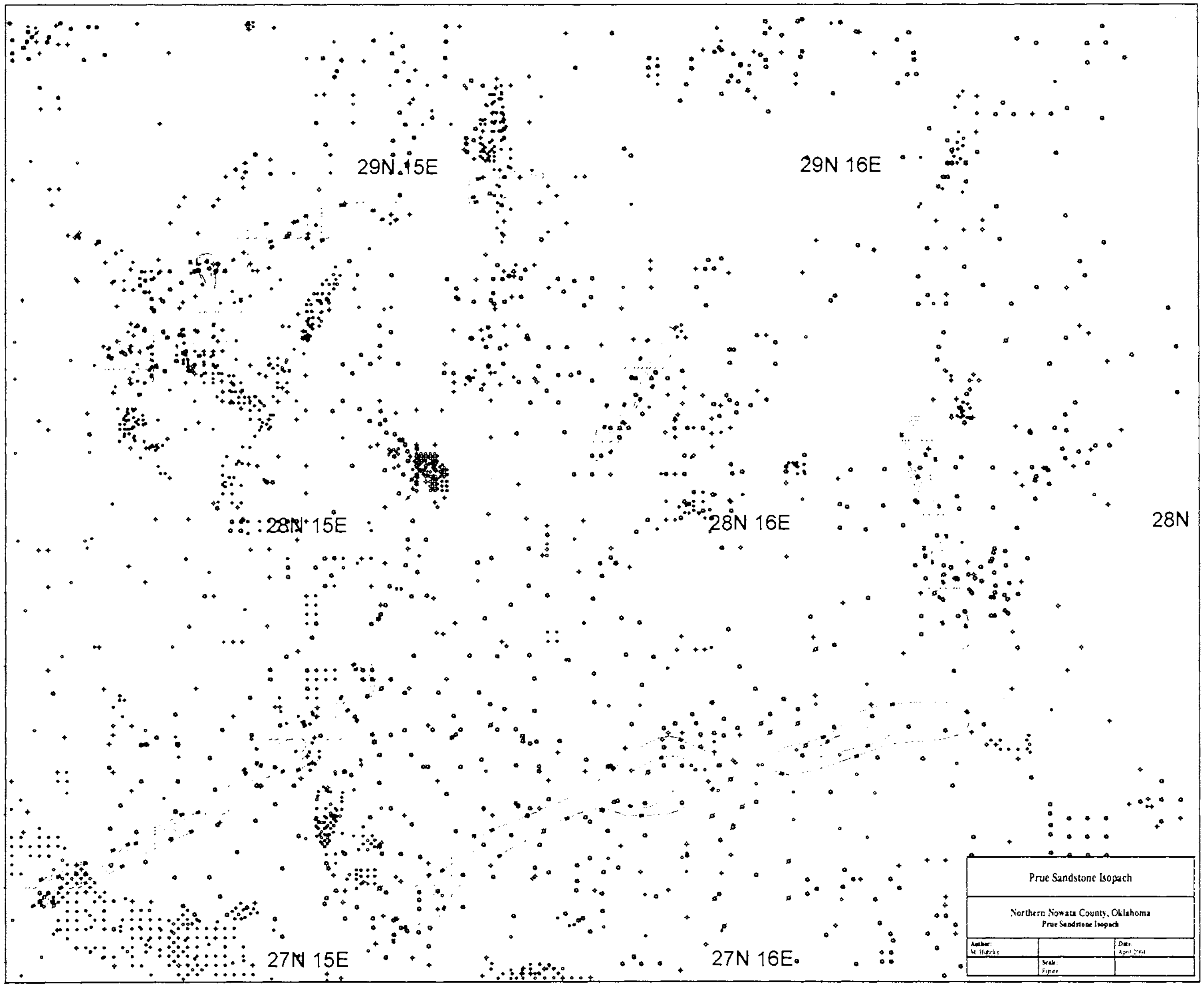


Figure 18: Prue Sandstone Isopach (see Plate 1).

depositional environments. Second, knowing the outline of the channel (Figure 19; Plate 2) will help predict (1) the locations of thicker Prue Sandstone reservoir and (2) where the important coals such as Croweburg and Bevier are missing as a result of incision.

Structure maps were created for three regional markers. These maps are the structure of the (1) Tiawah "Pink" Limestone (Figure 20; Plate 3), (2) Excello Shale (Figure 21; Plate 4) and (3) Oswego Limestone (Figure 22; Plate 5). The structure maps of the Excello Shale and the Oswego Limestone are very similar when overlain on each other, indicating that structure following deposition of the Prue changes little, moving from the Cabaniss Group to the Marmaton Group. Structural noses on both maps are shown to have a tendency to point in the direction of Prue depositional trends. Overlaying channel trends and structure suggests that structural noses are related to Prue Sandstone thickness. The extent of the noses is localized to the area surrounding those wells containing the Prue Sandstone. The noses are usually as wide as the outline of the channels. The thickest Prue Sandstone, where most of the section was eroded and subsequently filled with sand, coincides with structural noses. As a result, the noses may be used to predict locations containing thicker Prue Sandstone and concurrently serve as a mechanism that contributes to trapping oil and gas.

The structural map on the top of Tiawah "Pink" Limestone is used to interpret the structure of the area and determine the impact of the Prue sand deposition on structure. This map indicates the Pink Limestone structure is similar to the structure of post-Prue markers, such as Excello Shale. The difference between the Pink and Excello maps is shown by the extent of the anticlinal structural noses. The noses defined on the Pink Limestone map are not as prominent as the anticlinal noses found in the Excello and

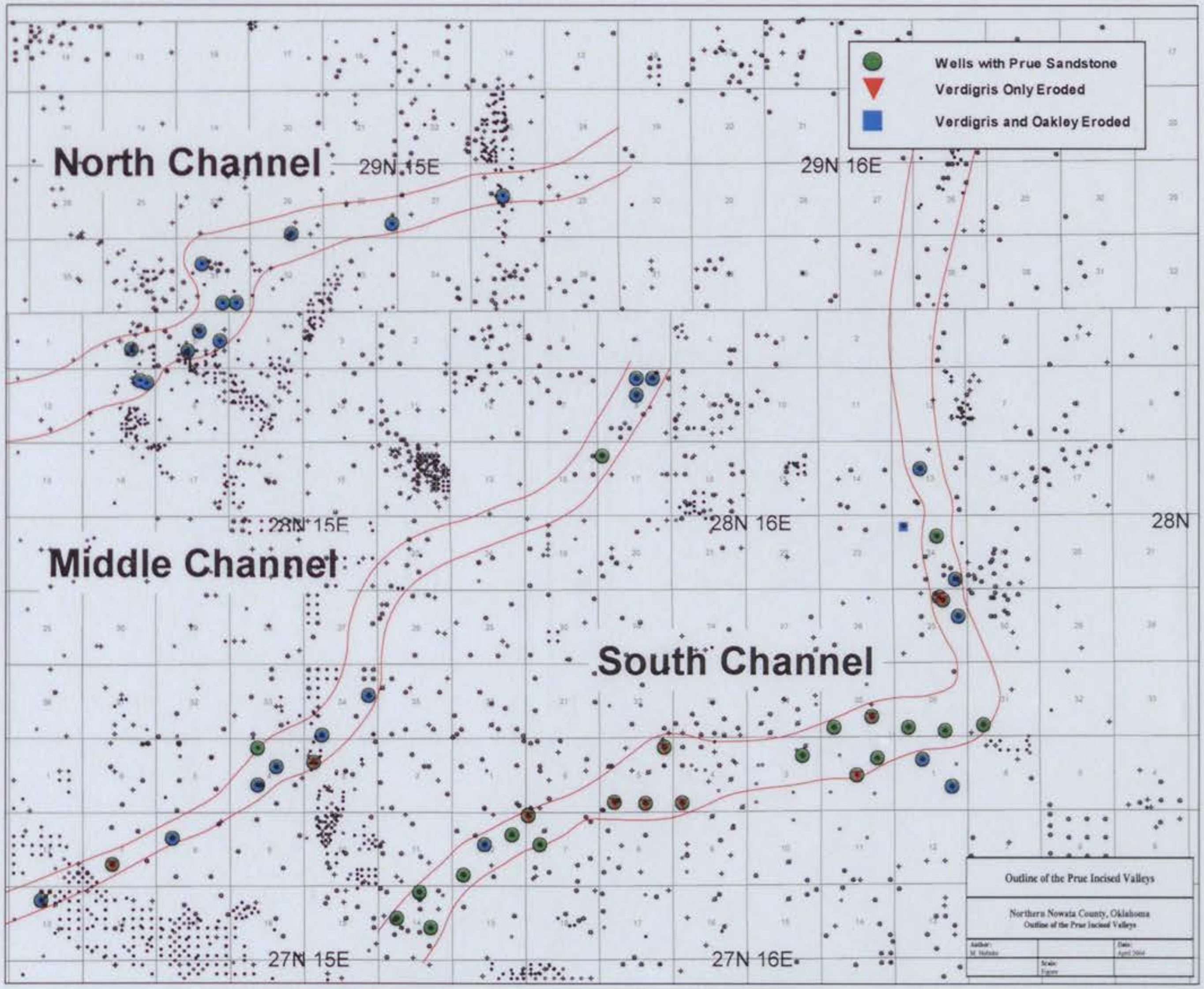


Figure 19: Outline of the Prue Incised Valleys (see Plate 2).

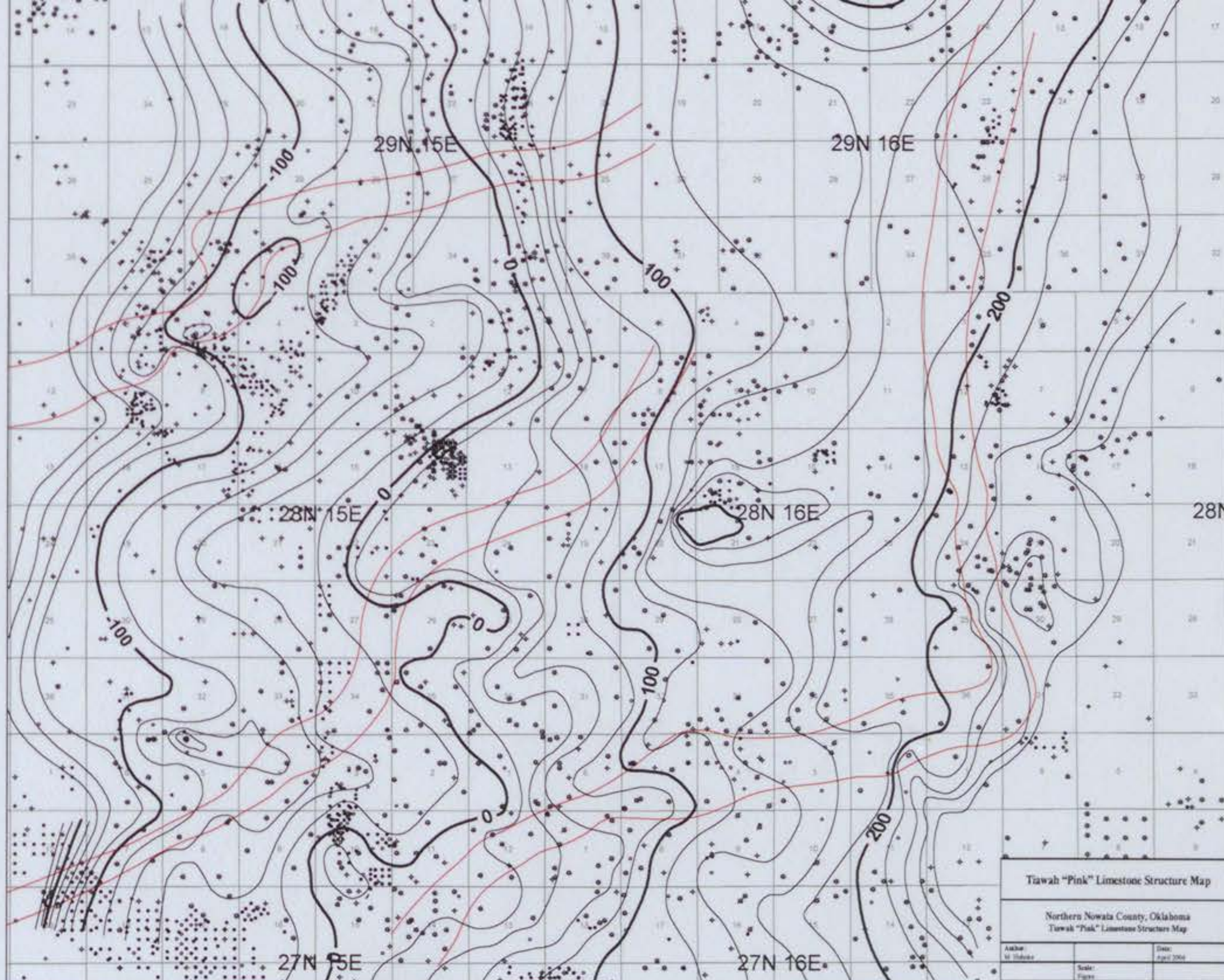


Figure 20: Tiawah "Pink" Limestone Structure Map (see Plate 3).

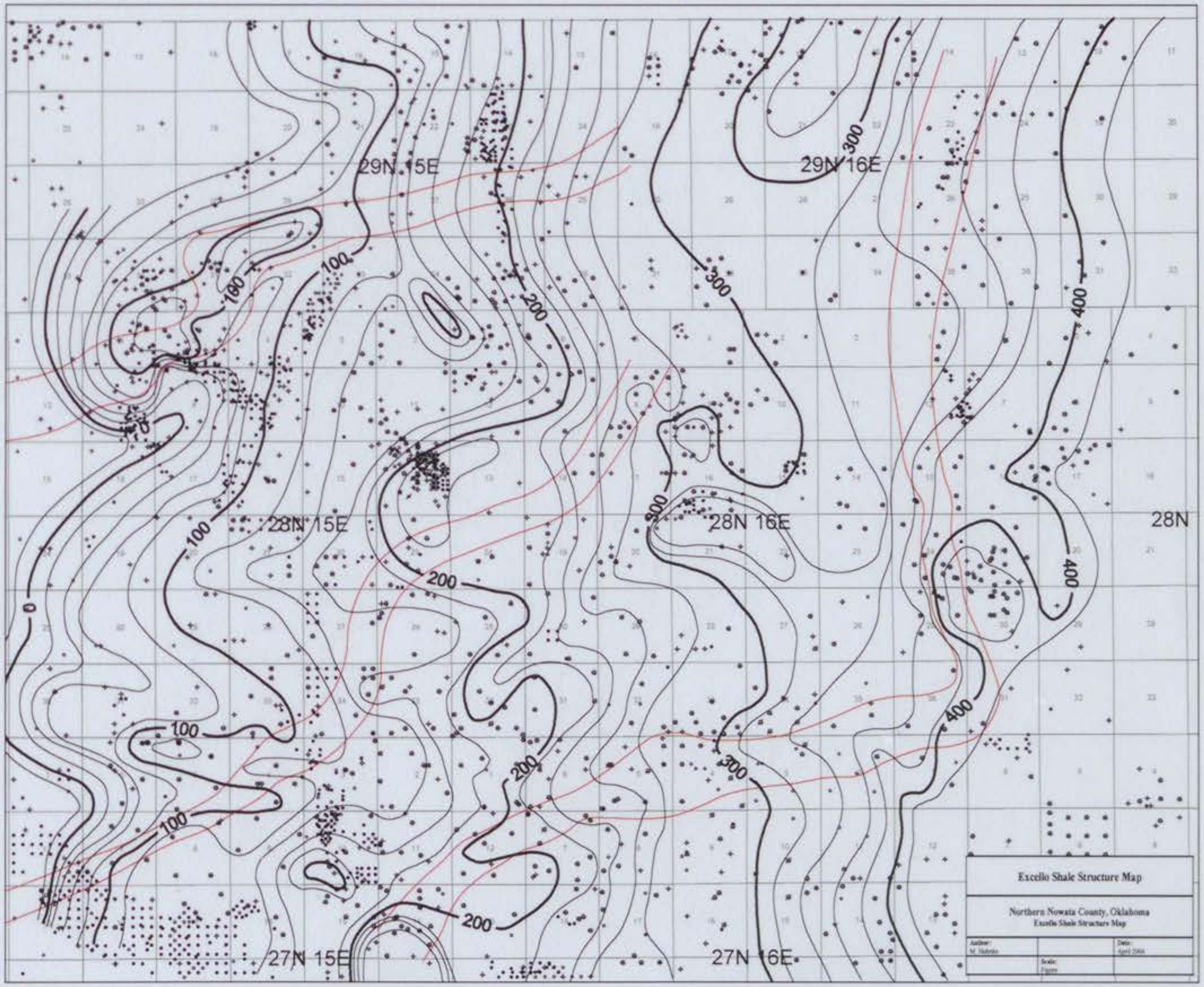


Figure 21: Excello Shale Structure Map (see Plate 4).

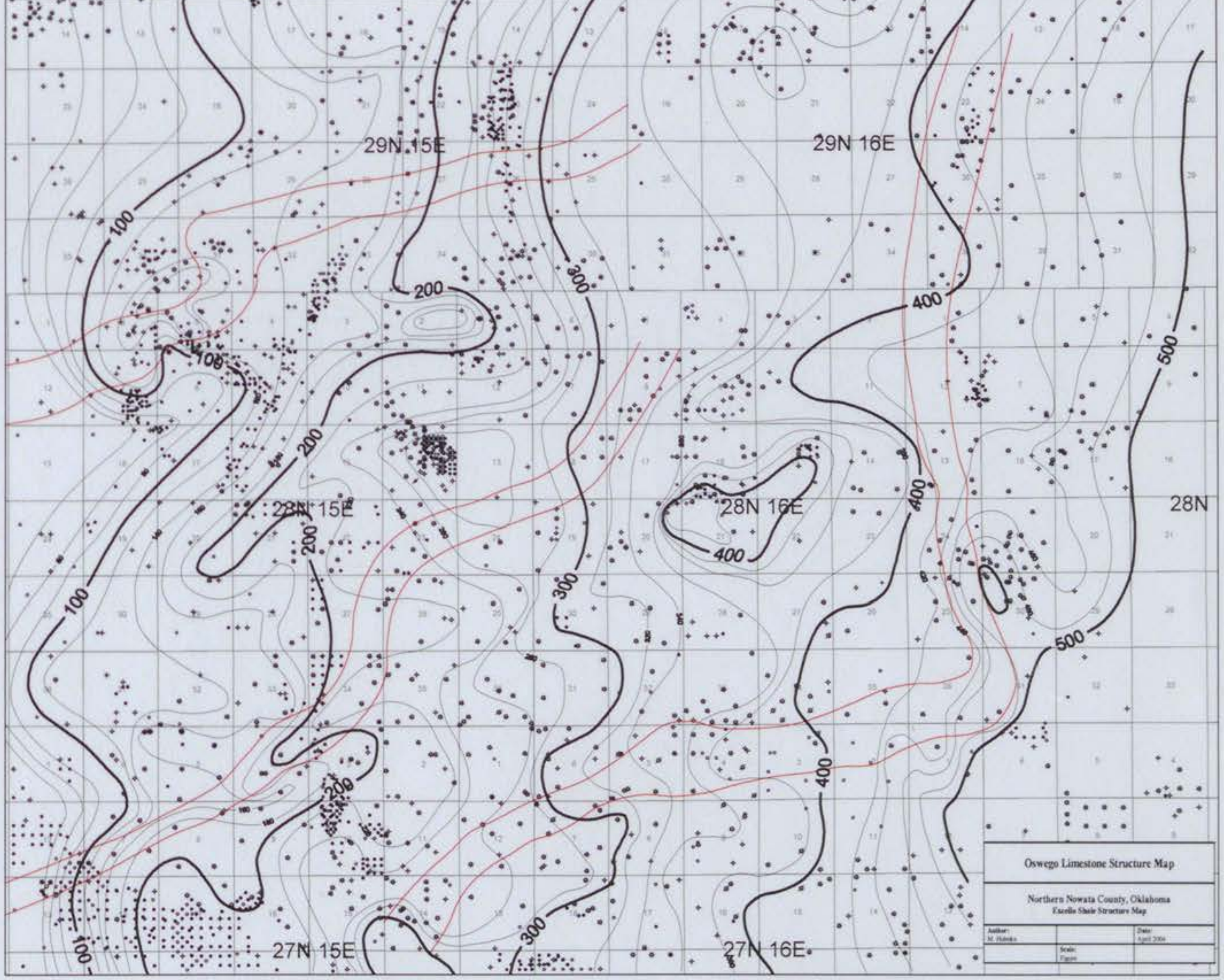


Figure 22: Oswego Limestone Structure Map (see Plate 5).

Oswego sections. The anticlinal noses evident on the Pink Limestone map are somewhat randomly distributed throughout the study area. In contrast, some anticlinal noses found on the Excello and Oswego maps have trends that follow the outline of the Prue channels. This difference in anticlinal noses is attributed to the thickness of the Prue Sandstone interval and differential compaction of Prue sediment. The differential compaction can be explained by examining compaction ratios for various sediments. Sandstone is estimated to undergo 20% reduction of pore space as compared to shale, which undergoes approximately 70% reduction of pore space due to compaction (Personal communication with Dr. Stan Paxton, 2004). Consequently, sand maintains a larger thickness and forms topographical high features during concurrent Prue deposition and compaction.

An interval isopach map (Figure 23 and Plate 6) of the thickness between the top of the Excello Shale and the top of the Tiawah "Pink" Limestone was constructed to compare thickness variations between wells that contain Prue Sandstone and those that do not. Examination of this interval isopach map revealed that wells located within the Prue incised valley had higher interval thickness values. This also suggests that the deposition of the Prue sands contributed to differential compaction and caused thickening of the Tiawah to Excello interval where thick sand was present.

Superimposing the Prue incised valleys over the interval isopach shows an obvious relationship between valleys and thickening. This suggests that in areas outside this study area, the isopach of the thickness between the Tiawah Limestone and the Excello Shale may indicate areas of Prue sandstone deposition. The use of scout cards, which contain the values for the Excello Shale top and the Tiawah Limestone top, could provide a quick look method to delineate the location and trend of Prue incision. This

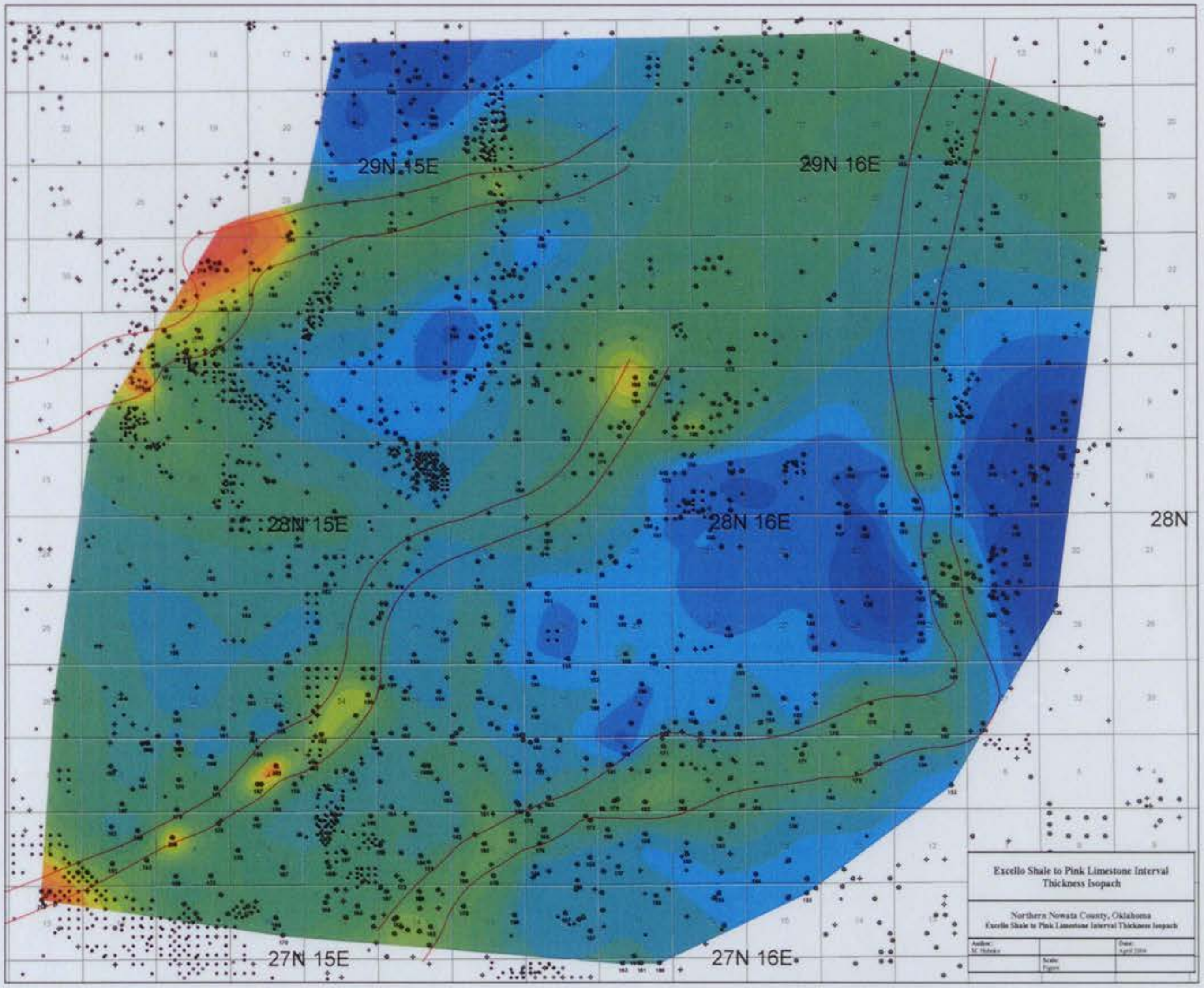


Figure 23: Tiawah “Pink” to Excello, Interval Thickness Map (see Plate 6).

method could provide coal-bed methane operators a tool to identify areas of coal erosion (Bevier and Croweburg Coal) and conventional play operators a means to identify areas that could contain thicker oil- and gas-bearing Prue sandstone.

Three separate Prue valley incisions were located and identified in the study area (Figure 19 and Plate 2). These incisions are roughly one-half to three-quarters of a mile wide. One is located in the southern and eastern portion of the study area. This incised valley appears to be a continuation of a valley located in southeastern Kansas described by Stoeckinger (2002). From the Kansas-Oklahoma border, the channel continues southward before making a southwesterly change in direction in the lower part of T. 28 N., R.16 E. and T. 28 N., R. 17 E. From there, it continues into the upper portion of T. 27 N., R. 16 E. The direction change is consistent with the overall direction of sediment transportation to the southwest during Desmoinesian time. Two wells (Ames 1-1, NW sec. 1, T. 27 N., R. 16 E. and Kimrey 1-1, SE sec. 1, T. 27 N., R. 16 E.), which are located immediately south of the mapped bend in sandstone thickness in the southern part of this incised valley trend, also suggest directional change. The wireline well logs for both wells show that the Verdigris Limestone and the Oakley Shale were eroded. Although this erosion indicates incision, evidence of deposition of "clean" sand is not present. The gamma-ray and density porosity log signatures reveal log patterns that were consistent with sandy shale/silty shale content. This absence of the underlying markers indicates the trend of the channel that eroded underlying sediments or bedrock, but "clean" sand was not deposited. These wells may have encountered the thalweg of the channel and missed the thicker accumulation of sand against the inside of the channel bend. Sediment deposition against the outer bank of the bend is representative of lower energy, and dominated by clay, silt and very fine-grained sand.

The incised valley located in the middle of the study area trends in a southwesterly direction that is consistent with the other incisions. This valley most likely continues north of the Kansas-Oklahoma border or connects to the other incisions. On the map (Figure 19), the middle channel begins in the north portion of Township 28N-16E and meanders through T. 28 N., R. 15 E., T. 27 N., R. 15 E. and the extent of the study area in T. 27 N., R. 14 E. The third valley is the northern incision. This incised valley either connects to other valleys or extends beyond the Kansas-Oklahoma border. The valley begins in the eastern portion of T. 29 N., R. 15 E. and meanders through the northwest portion of T. 28 N., R. 15 E. and extends into T. 28 N., R. 14 E., which is the extent of the study area. It contains the thickest sediments discovered to date in the three incisions. The thickness of the Prue Sandstone increases in moving from the southern incised valley to the northern incised valley. This suggests that depositional energy and sediment supply are apparently greater in the northern portion of the study area.

SEQUENCE STRATIGRAPHY

Pennsylvanian sediments were deposited in cyclical patterns called "cyclothems." Heckel (1977) used the term cyclothems to apply to the cyclical pattern of Pennsylvanian sediments in the Mid-continent region. In ascending order, the sequence is described as, (1) thick, sandy nearshore to near marine ("outside") shale; (2) thin transgressive ("middle") limestone; (3) thin nonsandy offshore ("core") shale, commonly with phosphatic black fissile facies; (4) thicker regressive ("upper") limestone; and (5) thick, sandy nearshore shale ("outside") (Heckel, 1977). These classic cyclic patterns were initially used to describe cyclothems evident in outcrop in Kansas and Iowa. They were subsequently modified and are useful in describing sedimentation patterns evident in Oklahoma.

Most "hot" shales located in the study area immediately overlie or are within a few feet of a coal seam. This pattern suggests the transgression of sea level from a swampy environment to a low energy, deeper marine setting. The Croweburg Coal is within 2-4 feet of the Oakley Shale. This Croweburg cycle or cyclothem is the base of the interval examined. The underclay (in the study area) represents an exposure surface, shoreline regression, and probable drop in sea level. Minimum inundation related to high-frequency cycles or lobe-shifting allowed for the formation of peat bogs or swamps that produced thick layers of organic matter. The Croweburg Coal likely represents the "outside" non-marine formation. Widespread transgression, as a result of sea-level rise, encouraged deposition of peat in slightly elevated swamps or mires (Clymo, 1987; McCabe, 1987). Further transgression of sea-level began the deposition of the Oakley muds.

The Oakley Shale is black fissile shale that contains the phosphatic facies as described by Heckel (1977). A "core" shale, it represents a time of maximum sea-level rise, anoxic depositional conditions, and organic preservation that resulted in "hot" shale. The sea level rise was then succeeded by a minor drop in sea level and regression. This regression allowed for the deposition of Verdigris carbonate, which is interpreted to be the regressive "upper" limestone described by Heckel (1977). The limestone contains fossils representing a period of relative low energy marine environment, allowing for the deposition of the carbonates.

The Verdigris is succeeded by a thin marine shale and exposure surface that may represent the Bevier cycle described by Marshall (2002). The Prue interval begins with near-shore or prodelta facies, described by Heckel (1977) as an "outside" shale. There are two depositional styles associated with the Prue delta. The first is low energy, which most likely represents interdistributary bays, prodeltas, and marginal marine. This style is dominated by shale, mudstone, and/or siltstone. The second style represents distal deltaic deposits or deposition in distributary channels. These distributaries are not evident in the study area.

The incised valleys that are evident in the study area contain the thick channel-fill Prue Sandstone. There are two phases to deposition of the Prue sediments in the valleys. First, a sea-level drop allowed entrenchment of distributary channels and eventual incision of older marine deposits. The incision eroded the Bevier Coal, but did not affect the Iron Post Coal. This indicates the relative age of the Prue incision is post Bevier and pre-Iron Post. As indicated on Figures 7, 8 and Plates 9-14, some parts of valleys eroded the Bevier, while others eroded through the Verdigris, Oakley, and Croweburg. One incision apparently down-cut to the Pink marker (Plate 9). The second phase is the deposition of sediment found in the valley. Characterized by a sharp basal contact and a fining-upward character, the Prue sand was deposited as the energy within the valleys began to wane. The sediments found at the base of the sandstone are most likely larger grained sands with grain size decreasing upward through the Prue Sandstone section. Areas with eroded underlying Croweburg, Oakley and Verdigris, without the presence of Prue Sandstone, were within the incision, but were part of a meander that was filled with mud and silt.

Further transgression, resulting from a relative rise in sea level, contributed to the formation of bogs and fresh-water marshes that favored deposition of the Iron Post peat. The Iron Post Coal represents the start of another cyclothem (Marshall, 2002). The transgression of sea level continued, resulting in the coal being overlain by a dark shale called the Kinnison Shale. This shale is deeper marine, according to Marshall (2002).

The deposition of the Breezy Hill, representing the "upper" limestone and a regression of sea level, was deposited in a low energy, shallow marine environment. The Breezy Hill is analogous to the Verdigris Limestone in the earlier cyclothem.

Following the Breezy Hill, the formation of a swampy area resulted in deposition of peat and the formation of a thin coal called the Mulky. This coal represents the end of the second cyclothem and the beginning of the third. Following the Mulky, sea level abruptly rose and the Excello mud was deposited in a deeper marine environment. The Excello is described as being black fissile, "hot" shale or "core" shale (Heckel, 1977).

Heckel (1977) describes a sequence of events that create cyclothems. When correlating his work into northeast Oklahoma, one environment that is common to Kansas, but is not found in the Oklahoma cyclothems is the second unit of the cycle described as the thin "middle" limestone. This thin limestone is missing because conditions were not conducive to carbonate deposition. Instead, coal swamps formed and peats were deposited. Rapid transgression of sea level is indicated by the contrast of "core" shale and underlying coals.

Modification of the Heckel cyclothem for application in northeast Oklahoma is the cyclical pattern of (1) coal deposition; (2) deep marine "core" shale; (3) shallow marine "upper" limestone; and (4) near shore to shore, deltaic deposition, (5) sea-level drop and incision, (6) transgression and filling of the valley, and (7) peat deposition. These cycles are described in detail by Marshall (2002) (Figure 24).

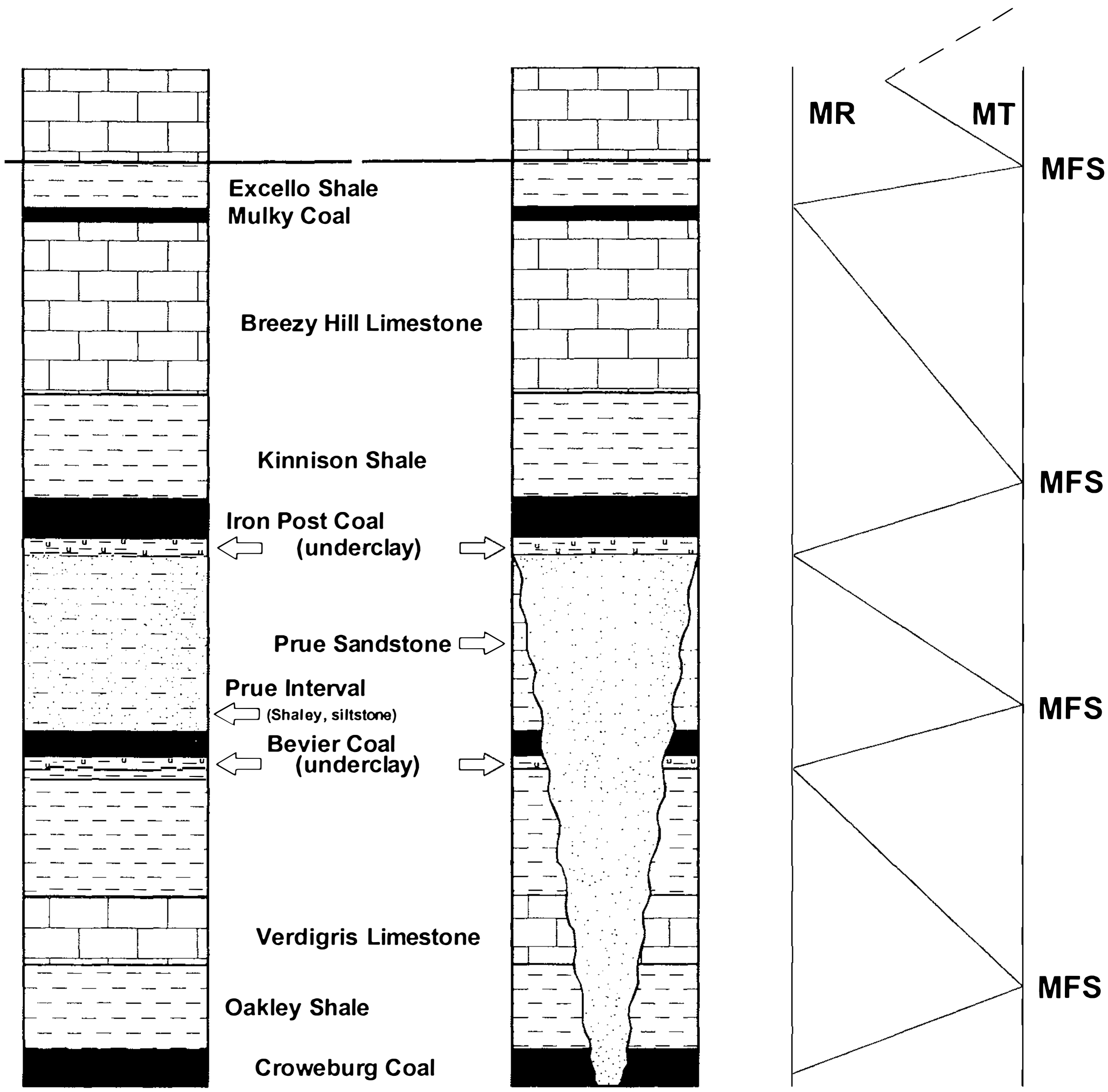


Figure 24: Generalized type sections and sea-level curve (from Marshall, 2002) for wells located in the study area.

PETROLEUM GEOLOGY

Production in northern Nowata County dates back to the early days of the oil and gas industry. Many of the wells located in the study area were drilled in the early 1900's. Early production in northern Nowata County is predominately from the Bartlesville Sandstone. Other produced reservoirs include the Mississippian limestone and chat, and Peru sandstone (often mistaken for the Prue Sandstone). Beginning in 1997, coal-bed methane wells were drilled into the abundant coal seams in the Pennsylvanian section. These seams along with dark shale have been produced from single or commingled completions. The coals are the Riverton, Rowe, Bluejacket, Tebo, Croweburg, Bevier, Iron Post, and Mulky coals. The dark shales are the Excello and the Summitt. To date, the Oakley has not been completed. According to PI Dwights Plus on CD® (2004), approximately 2,550 wells have been drilled within the study area. Of these, 424 wells are still productive with 294 producing coal-bed/dark-shale methane.

Cumulative production for all wells in the study area is estimated at 16 Bcf (billion cubic feet) of gas and 2.2 MMBO (million barrels of oil) (information from PI Dwights Plus on CD®, 2004). Most of the oil production is from the Bartlesville Sandstone. Of the gas produced to date, 9.7 Bcf has been produced from coal-bed methane wells. This volume accounts for 61% of the recorded gas production in this area from the early 1900's to present day. As of November 2003, coal-bed methane wells had cumulated 3.2 Bcf for the year. Coal-bed methane is a major play in this study area and the Cherokee basin of Oklahoma and Kansas.

The Prue incised valley has impacted coal reserves by virtue of the erosion which has removed the Croweburg and Bevier Coal. Both of these coals are commingled with other coals in a typical coal-bed methane completion. Another effect of the Prue incision is that the Prue Sandstone is usually present in the incised valley. As described in Chapter II, the Prue sandstone has a "clean" gamma-ray curve (less than 70 API units) and density porosity values of greater than 12%. These values indicate Prue Sandstone is a potential reservoir if found in a structural position favorable for trapping oil and gas. Most wells that encounter the Prue Sandstone exhibited low resistivity values, indicating a possible brine-bearing zone. If the Prue reservoir can be located structurally high to these "wet" wells, there is potential to produce the Prue Sandstone reservoir. This Prue potential could compensate for the coal-bed methane volume lost to coal erosion.

Production of the Prue Sandstone is limited to about 10 wells located in the study area. Cumulative production values for these wells are 44 MBO (thousand barrels of oil) and 43 MMCF (million cubic feet) of gas. While production from these wells is very limited, the potential to use updated data and technology to find and complete additional Prue Sandstone wells could have a positive impact on the existing coal-bed methane exploration.

Outside the study area in sections 21 and 22 of Township 27 North and Range 14 East, two new wells produce from the Prue Sandstone (PI Dwights Plus on CD®). The first well, Doenges #1 (API#: 35105298050000), located in C NE NW of section 22 has produced 29 MMCF of gas since its completion date of September 2001 to October 2003.

The second well, Doenges Ranch #1 (API#: 35147270090000), located in N/2 NE NE of section 21 produced 150 MMCF of gas between its completion date of March 2002 to October 2003. Production from these wells indicates the potential productivity of valley fill sandstone reservoirs.

CONCLUSIONS

The following are conclusions derived from this study.

1. Prue Sandstone represents deposition with incised-valleys. Trends of these valleys may be established by mapping the thickness of the Excello Shale to Tiawah "Pink" Limestone interval.
2. Three different Prue Sandstone filled valleys can be traced in the study area. These valleys are recognized by the incision of the Bevier, Verdigris, Oakley, and Croweburg markers.
3. Regional time markers such as the Tiawah "Pink" Limestone/Shale, Excello Shale and the Oswego Limestone can be correlated throughout the study area. The Oakley Shale and Verdigris Limestone are also regional markers and their absence indicates the location of the Prue incised valley.
4. Wireline-log signatures constrained by core and outcrop data were used to generate a depositional model for the Prue interval.
5. The Prue valley formed in two phases: (1) erosion of underlying sediment/rock and (2) filling of the incised valley with sediment.
6. Structure maps on regional markers above and below the Prue interval helped identify changes in depositional structure. Some structural noses appear to reflect the direction of Prue sediment deposition and indicate the location of thicker sandstones

7. Differential compaction can explain the thickness of the Excello to Tiawah interval when the Prue Sandstone is present.
8. Prue maps help to establish the locations of thick Prue sandstones, possible conventional gas reservoirs, and locations where the coal seams were eroded by Prue valley.
9. Analysis of core, wireline logs, and literature was used to develop the sequence stratigraphy and depositional history of the Prue interval.

REFERENCES

Andrews, Richard D., 1996, Fluvial-Dominated Deltaic (FDD) Oil Reservoirs in Oklahoma: The Skinner and Prue Plays: Oklahoma Geological Survey Special Publication, no. 96-2, 106 p.

Baker, Donald R., 1962, Organic Geochemistry of Cherokee Group in Southeastern Kansas and Northeastern Oklahoma: AAPG Bulletin, v. 46, no. 9, p. 1621-1642.

Boggs, Jr., Sam, 1995, Principles of Sedimentology and Stratigraphy: Prentice-Hall, Inc., 774 p.

Branson, Carl C., 1962, Pennsylvanian System of the Mid-Continent: AAPG Special Publication, no. 23, p. 431-460.

Brenner, Robert L., 1989, Stratigraphy, petrology, and paleogeography of the upper portion of the Cherokee Group (Middle Pennsylvanian, eastern Kansas and northeastern Oklahoma: Kansas Geological Survey, Geology Series 3, 70 p.

Busch, Daniel A., 1974, Stratigraphic Traps in Sandstones-Exploration Techniques, American Association of Petroleum Geologists, Memoir 21, 174 p.

Cleaves, Arthur W., 1996, Applied Sequence Stratigraphy for Mid-Continent Reservoirs: Systems tracts, reservoirs, and mapping strategies: Oklahoma City Geological Society Short Course, 100 p.

Cleaves, Arthur W., 1984, Terrigenous Clastic Depositional Systems of Paleozoic Rocks in the Mid-Continent Region: Oklahoma City Geological Society Short Course, 101 p.

Clymo, R.S., 1987, Rainwater-fed Peat as a Precursor of Coal: Geological Society Special Publication Classics; Coal and Coal-bearing Strata: Recent Advances, p. 17-23.

Denesen, Stephen L., 1985, Stratigraphy, Petrography, and Depositional Environments of the Banzet Formation (Middle Pennsylvanian) in Southeastern Kansas and Northeastern Oklahoma: unpublished Masters thesis, University of Iowa, 141 p.

Ebanks, W.J., Jr., 1979, Correlation of Cherokee (Desmoinesian) Sandstones of the Missouri-Kansas-Oklahoma tri-state area, *in* N. J. Hyne, ed., Sequence stratigraphy of the mid-continent: Tulsa Geological Society Special Publication, no. 1, p. 295-312.

Galloway, W.E., and Hobday, D.K., 1996, Terrigenous Clastic Depositional Systems: 2nd Edition: Springer-Verlag, Berlin, 489 p.

Heckel, Philip H., 1977, Origin of the Phosphatic Black Shale Facies in the Pennsylvanian Cyclothems of Mid-continent North America: American Association of Petroleum Geologists Bulletin, v. 61, p. 1045-1068.

Heckel, Philip H., 1983, Diagenetic Model for Carbonate Rocks in Midcontinent Pennsylvanian Eustatic Cyclothems: Journal of Sedimentary Petrology, v. 53, no. 3, p. 733-759.

Hemish, Leroy A., 2001, Coal Stratigraphy of the Northeast Oklahoma Shelf Area, with an Overview of Arkoma Basin Coal Geology, in Oklahoma coalbed-methane workshop 2001, Oklahoma Geological Survey, Open-File Report 2-2001, p. 72-92.

Howe, Wallace B., 1956, Stratigraphy of Pre-Marmaton Desmoinesian (Cherokee) Rocks in Southeastern Kansas: State Geological Survey of Kansas Bulletin, no. 123.

Jewett, John M. and Muilenburg, Grace, 1957, Field Conference in Eastern Kansas: Kansas Geological Society Guidebook, 21st Field Conference, 126 p.

Krumme, George W., 1981, Stratigraphic Significance of Limestones of the Marmaton Group (Pennsylvanian, Desmoinesian) in Eastern Oklahoma: Oklahoma Geological Survey Bulletin, no. 131.

Lardner, James E., 1984, Petrology, Depositional Environment and Diagenesis of Middle Pennsylvanian (Desmoinesian) 'Lagonda Interval' Cherokee Group in East-Central Kansas: unpublished Masters thesis, University of Iowa, 156 p.

Marshall, T.R., 2002, Outcrop-based cyclic stratigraphy of the Cherokee Group (Desmoinesian, Pennsylvanian): unpublished Masters thesis, Oklahoma State University, 437 p.

McCabe, Peter J., 1987, Facies Studies of Coal and Coal-Bearing Strata: Geological Society Special Publication Classics; Coal and Coal-bearing Strata: Recent Advances, p. 51-66.

Merriam, D.F., 1963, the Geologic History of Kansas: Kansas Geological Survey Bulletin, no. 162, 311 p.

Moore, Raymond C., Frye, John C., Jewett, John M., Lee, Wallace, and O'Connor, Howard G., 1951, The Kansas Rock Column, State Geological Survey of Kansas Bulletin, no. 89, 132 p.

Oakes, Malcolm C., 1953, Krebs and Cabaniss Groups of Pennsylvanian Age, in Oklahoma: AAPG Bulletin, v. 37, no. 6, p. 1523-1526.

Paxton, S.T., Szabo, J.O., Ajdukiewicz, J.M., and Klimentidis, R.E., 2002, Construction of an Intergranualr Volume Compaction Curve for Evaluating and Predicting Compaction and Porosity Loss in Rigid-Grain Sandstone Reservoirs: AAPG Bulletin, v. 86, no. 12, p. 2047-2067.

Perrier, Raymond and Quiblier, Jacques, 1974, Thickness Changes in Sedimentary Layers during Compaction History; Methods for Quantitative Evaluation: AAPG Bulletin, v. 58, no. 3, p. 507-520.

PI Dwights Plus on CD®, 2004, Version 1.5.1, IHS Energy™, Data current through November 2003.

Puckette, J., and Gerken, L., 2003, Skinner Sandstone: Depositional History, Reservoir Distribution and Sequence Stratigraphy: Oklahoma Geology Notes, V. 63, no. 2, p. 95.

Ropp, Cheryl R., 1991, Facies, Diagenetic, and Subsurface Evaluation of the Prue Sandstone on the Central Oklahoma Platform: unpublished Masters thesis, Oklahoma State University, 90 p.

Scholle, Peter A. and Spearing, Darwin, 1982, Sandstone Depositional Environments: American Association of Petroleum Geologists, 410 p.

Stoeckinger, William T., 2002, Gas in an Incised Valley, Upper Cherokee, Southeastern Kansas: Oklahoma Geological Survey Circular, no. 108, p. 111-118.

Ticora Geosciences, Inc., 2002, Devon Energy Corporation, Forest 29-1; Core Analysis.

Van Wagoner, J.C., Mitchum, R.M., Campion, K.M., and Rahmanian, V.D., 1990, Siliciclastic Sequence Stratigraphy in Well Logs, Cores, and Outcrops: AAPG Methods in Exploration Series, no. 7, 52 p.

Visher, Glenn S., Saitta B., Sandro, and Phares, Roderick S., 1971, Pennsylvanian Delta Patterns and Petroleum Occurrences in Eastern Oklahoma: AAPG Bulletin, v. 55, no. 8, p. 1206-1230.

Walker, Roger G., 1984, Facies Models Second Edition: Geoscience Canada Reprint Series 1, 317 p.

Walton, Anthony W., 1996, Depositional Framework and Representative Oil Reservoirs of the Cherokee Group (Atokan-Desmoinesian, Middle Pennsylvanian), Eastern Kansas: Oklahoma Geological Survey Circular, No. 98, p. 168-187.

Weller, Marvin J., 1959, Compaction of Sediments: AAPG Bulletin, v. 43, no. 2, p. 273-310.

Ye, Liangmiao (Scott), and Kerr, Dennis, 2000, Sequence Stratigraphy of the Middle Pennsylvanian Bartlesville Sandstone, Northeastern Oklahoma: A Case of an Underfilled Incised Valley: AAPG Bulletin, v. 84, no. 8, p. 1185-1204.

VITA

MATTHEW LAMAR HUHNKE

Candidate for the Degree of

Masters of Science

Thesis: DEPOSITIONAL ENVIRONMENTS AND DISTRIBUTION OF THE PRUE SANDSTONE IN NORTHERN NOWATA COUNTY, OKLAHOMA

Major Field: Geology

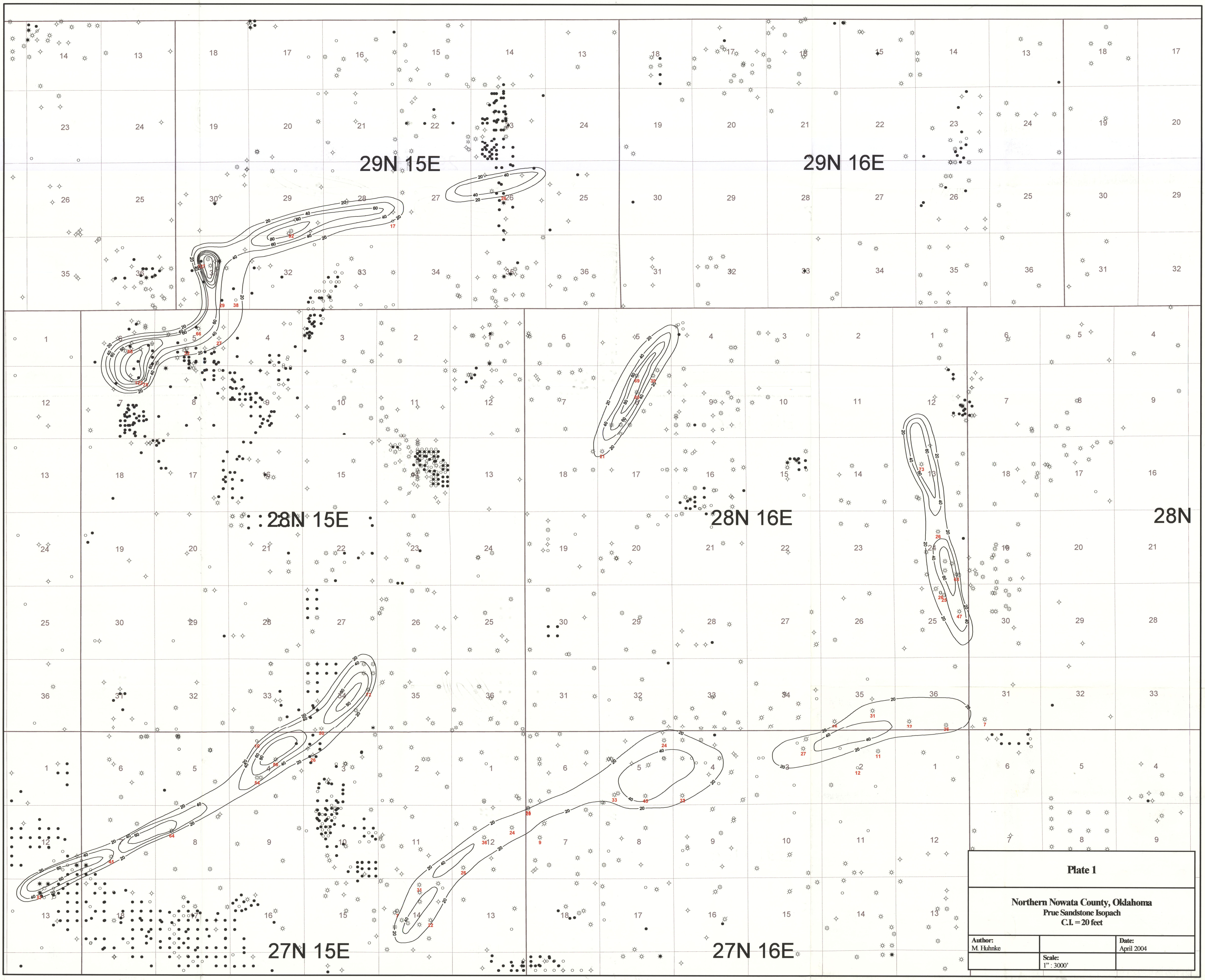
Biographical:

Personal Data: Born June 23, 1978, in Ames, Iowa, the son of Raymond L. and Sandra J. Huhnke.

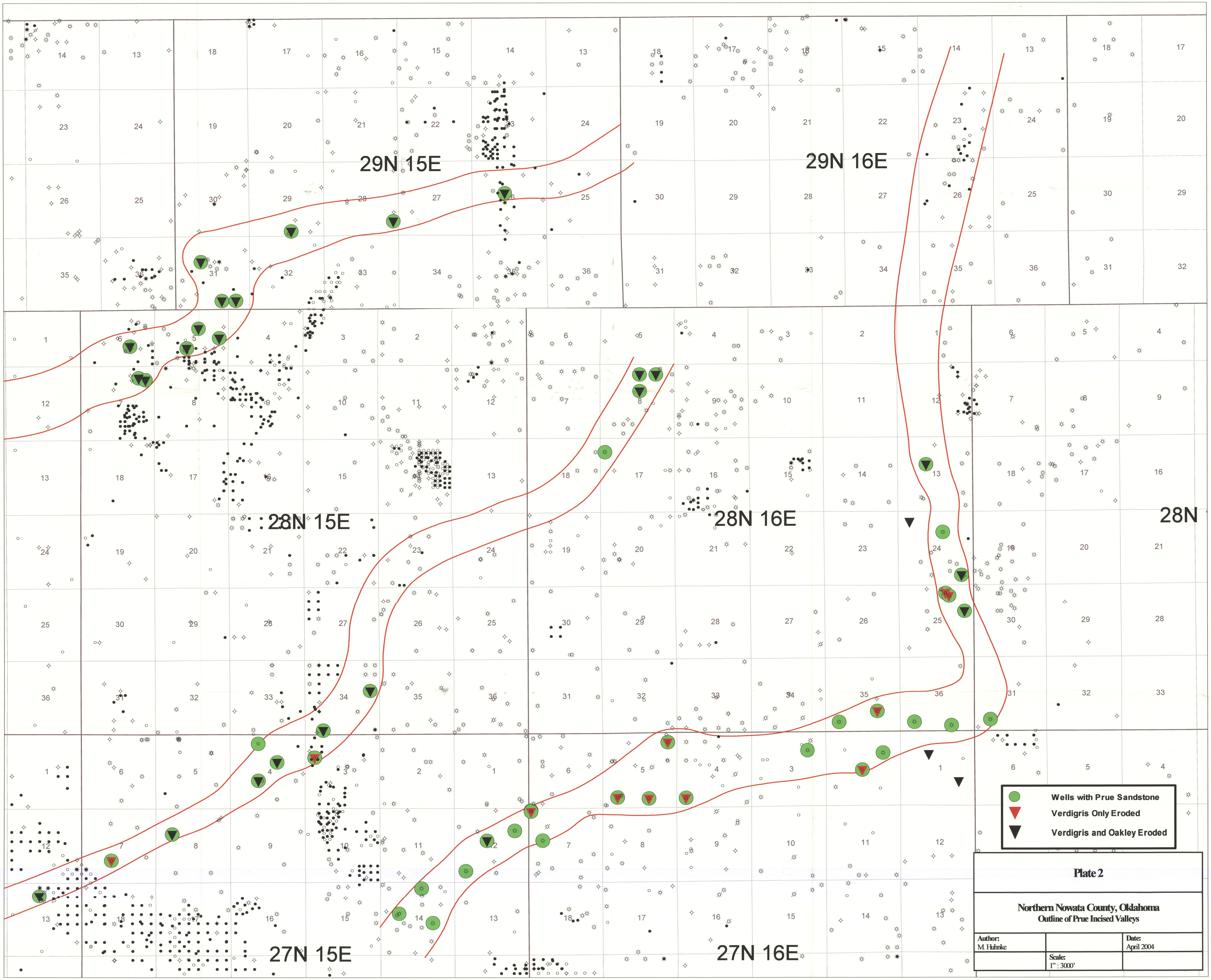
Education: Graduated from Stillwater High School, Stillwater, Oklahoma, 1996; received Bachelor of Science degree in Geology from Oklahoma State University, Stillwater, Oklahoma, 2001; completed requirements for Master of Science Degree at Oklahoma State University in May, 2004.

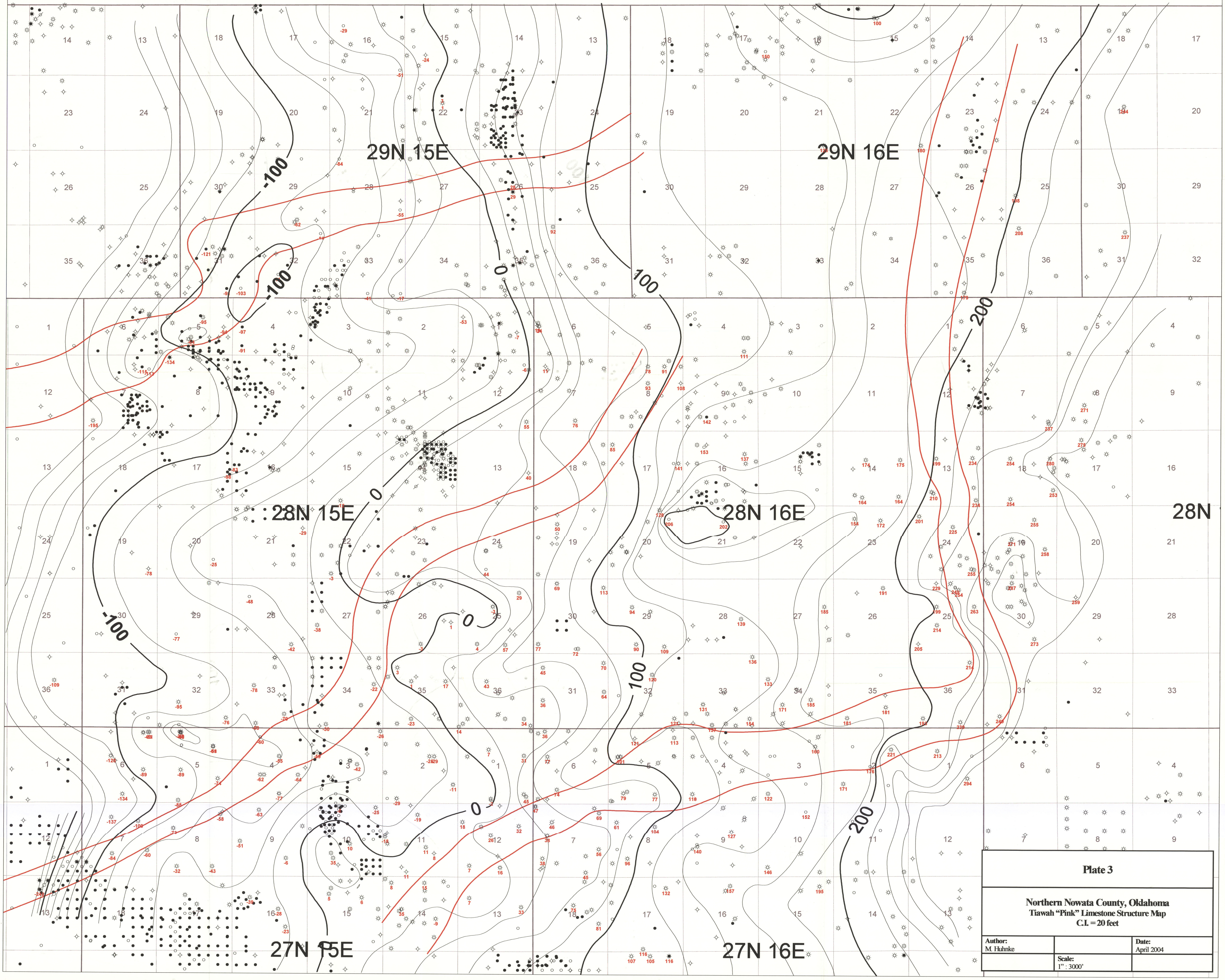
Professional Experience: Geological Technician, Devon Energy Corporation, Oklahoma City, Oklahoma, 2001 – present.

Professional Memberships: American Association of Petroleum Geologists.



29N 15E
29N 16E
28N 15E
28N 16E
28N
27N 15E
27N 16E
Plate 1
Northern Nowata County, Oklahoma
Prue Sandstone Isopach
C.I. = 20 feet
Author:
M. Huhnke
Date:
April 2004
Scale:
1" : 3000'


29N 15E
29N 16E
28N 15E
28N 16E
28N
27N 15E
27N 16E
Wells with Prue Sandstone
Verdigris Only Eroded
Verdigris and Oakley Eroded
Plate 2
Northern Nowata County, Oklahoma
Outline of Prue Incised Valleys
Author:
M. Hulmke
Date:
April 2004
Scale:
1" : 3000'



29N 15E
29N 16E
28N 15E
28N 16E
28N
27N 15E
27N 16E
-100
0
100
200
Plate 3
Northern Nowata County, Oklahoma
Tiawah "Pink" Limestone Structure Map
C.I. = 20 feet
Author:
M. Huhnke
Scale:
1" : 3000'
Date:
April 2004

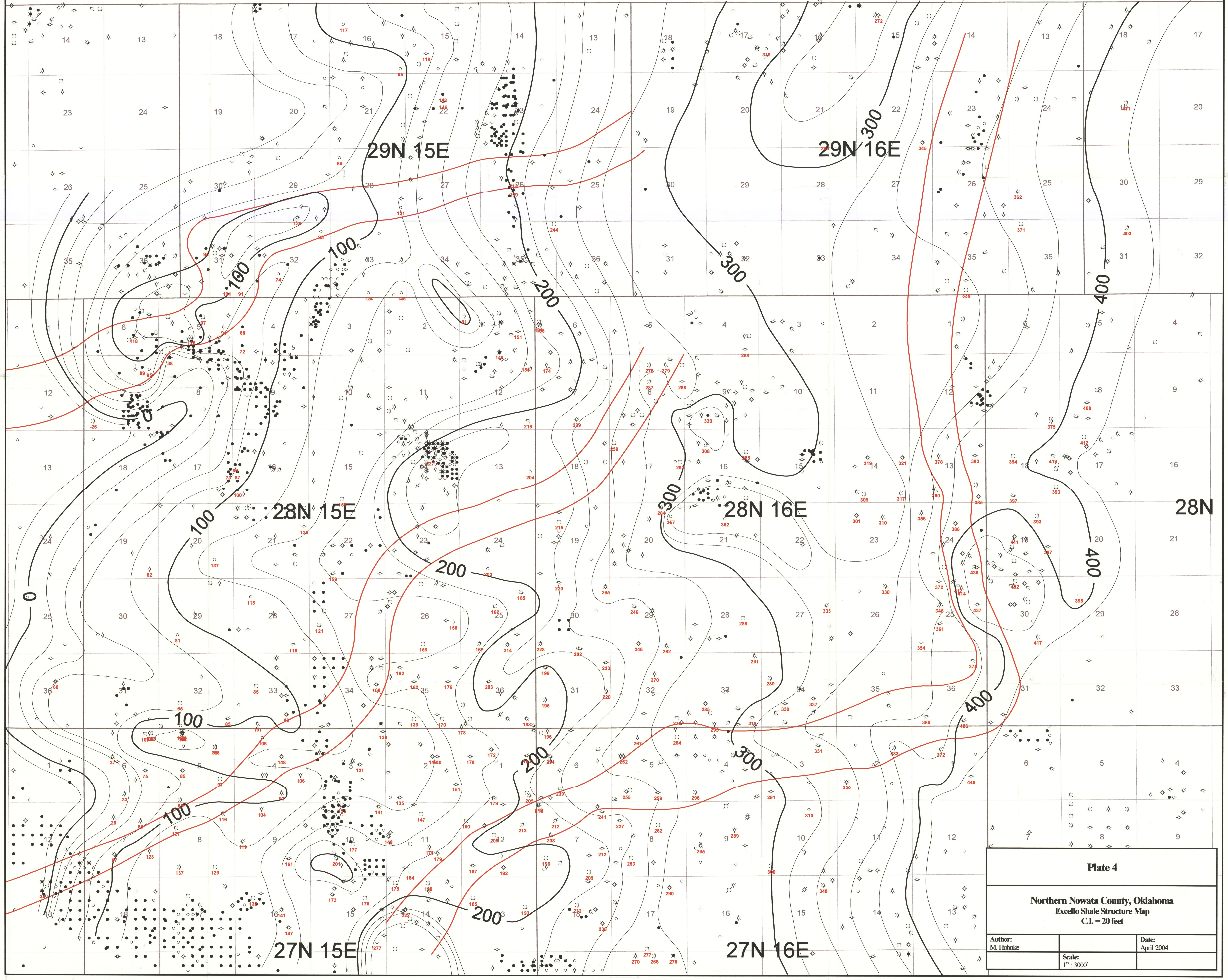


Plate 4

Northern Nowata County, Oklahoma
Excello Shale Structure Map
C.I. = 20 feet

Author: M. Huhnke

Date: April 2004

Scale: 1" : 3000'

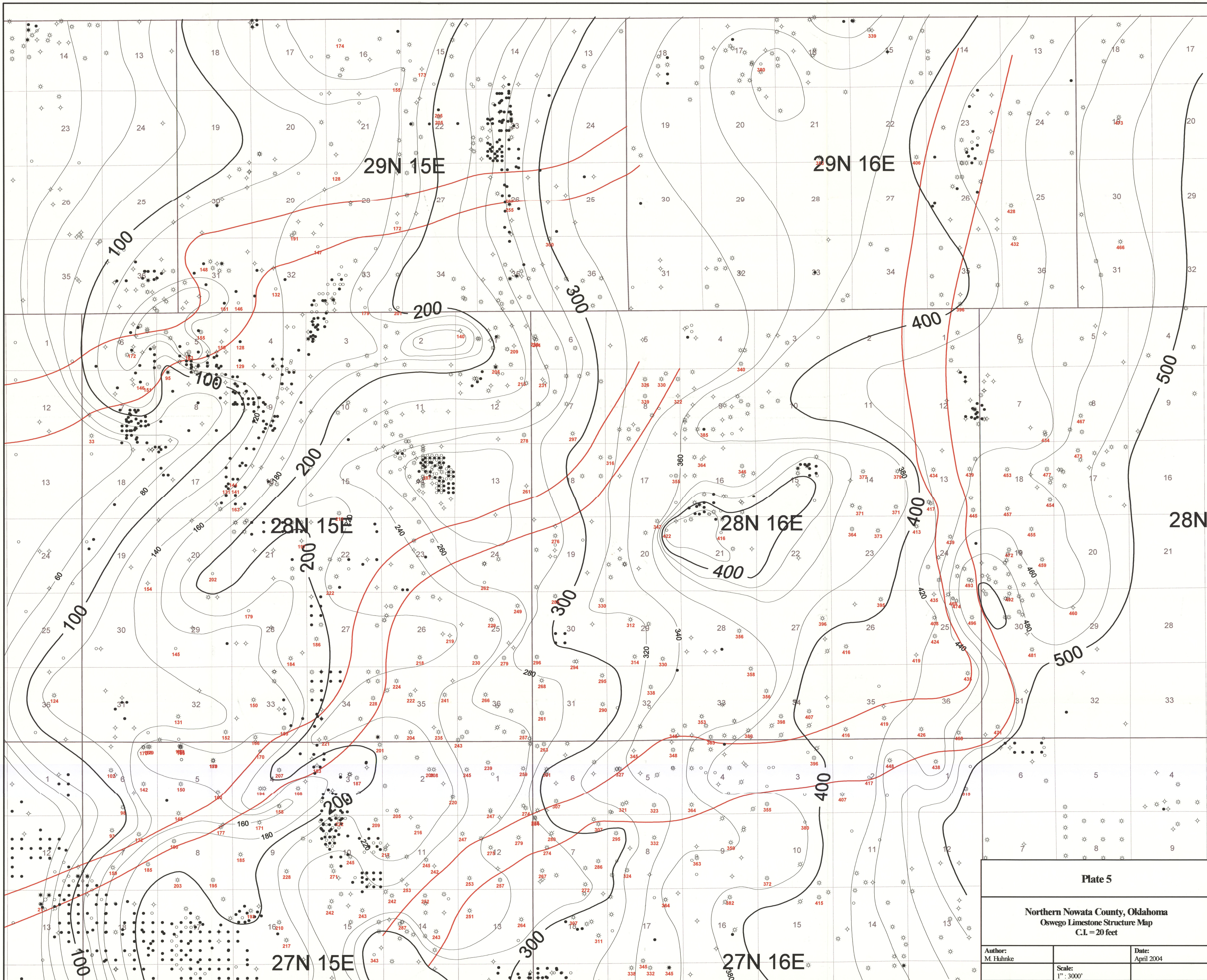
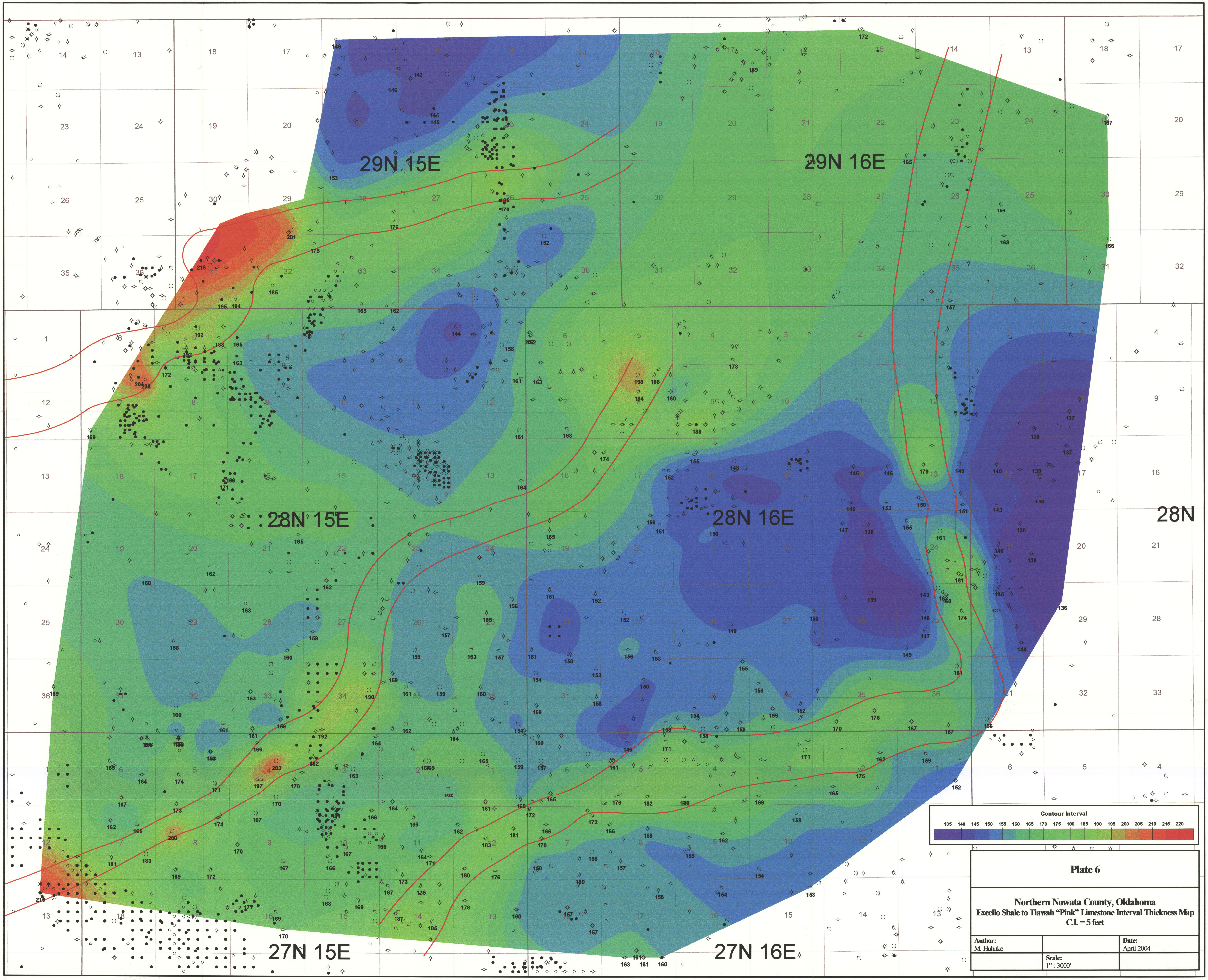


Plate 5

Northern Nowata County, Oklahoma
Oswego Limestone Structure Map
C.I. = 20 feet

Author:		Date:
M. Huhnke	Scale: 1" : 3000'	April 2004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29N 16E
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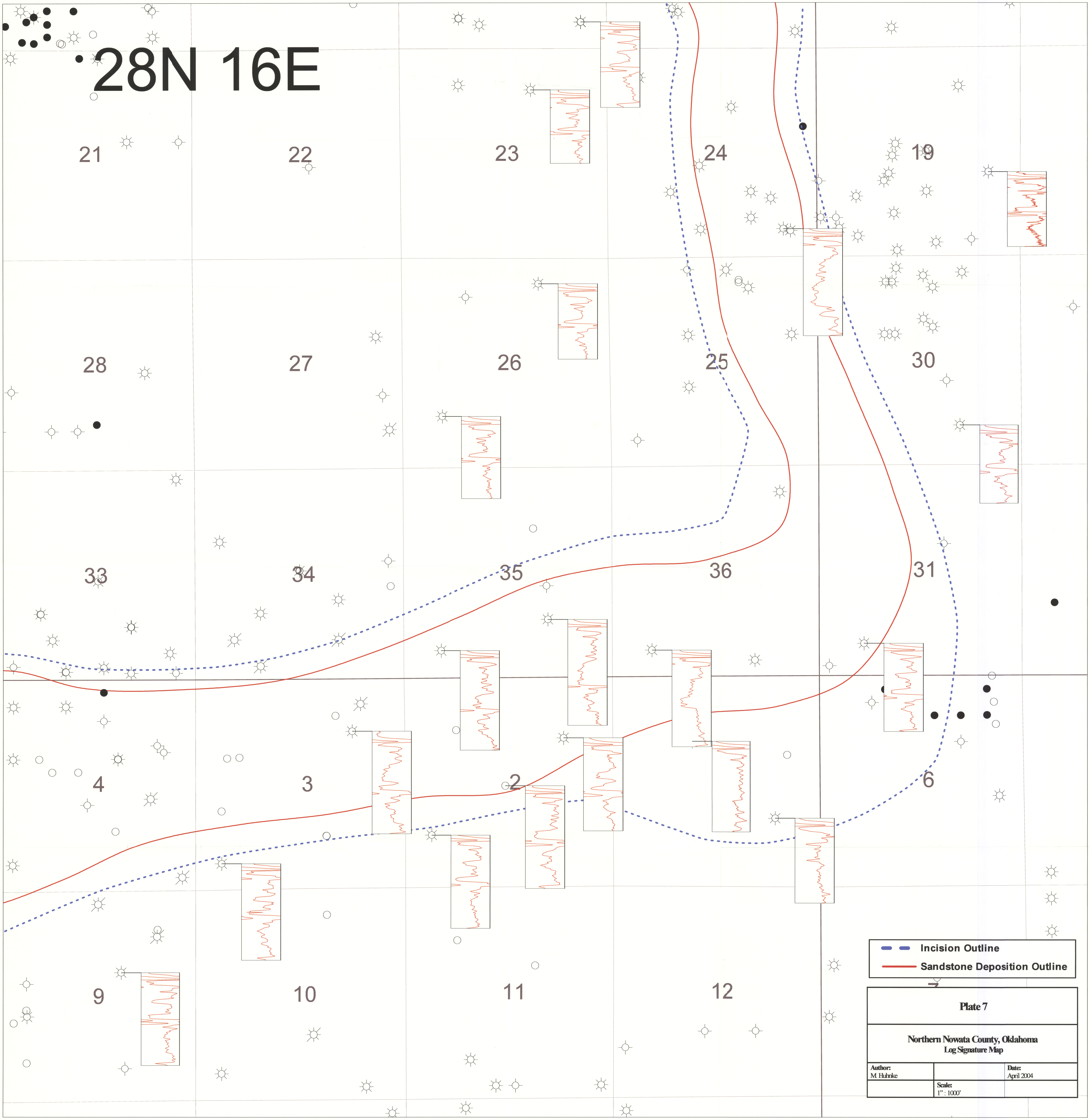
28N
27N 15E
27N 16E
Contour Interval
135 140 145 150 155 160 165 170 175 180 185 190 195 200 205 210 215 220
Plate 6
Northern Nowata County, Oklahoma
Excello Shale to Tiawah "Pink" Limestone Interval Thickness Map
C.I. = 5 feet
Author: M. Huhnke
Date: April 2004
Scale: 1" : 3000'



28N 16E
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4
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2
1
6
9
10
11
12
7
Incision Outline
Sandstone Deposition Outline
Plate 7
Northern Nowata County, Oklahoma
Log Signature Map
Author:
M. Huhnke
Date:
April 2004
Scale:
1" : 1000'

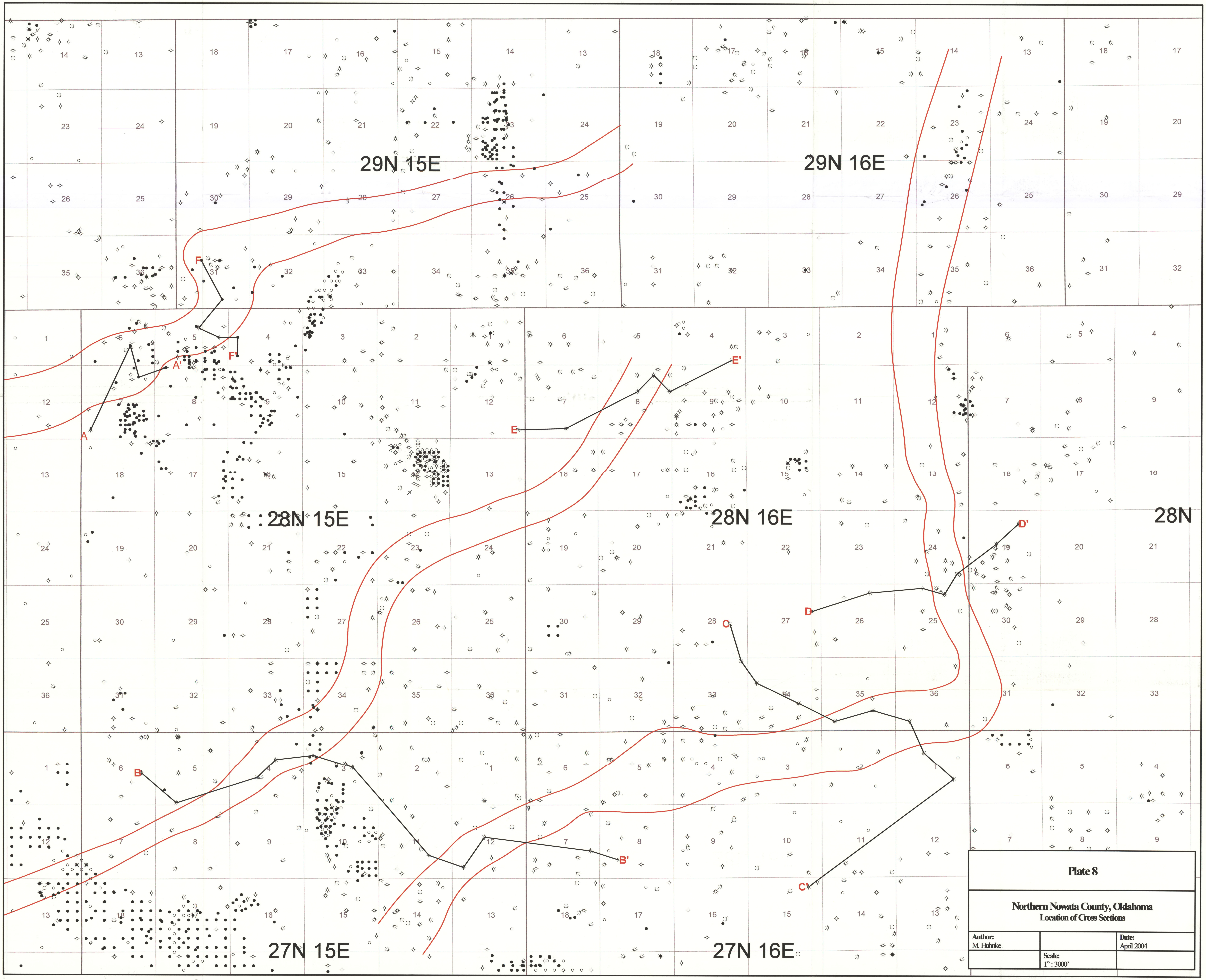

Plate 8

Northern Nowata County, Oklahoma
Location of Cross Sections

Author: M. Huhnke

Scale: 1" : 3000'

Date: April 2004

Cross Section A-A'

Stratigraphic Cross Section (Datum: Oswego Limestone)

Plate 9

Northern Nowata County, Oklahoma
Cross Section A - A'

Author: M. Huhnke

Date: April 2004

Cross Section B-B'
Stratigraphic Cross Section (Datum: Oswego Limestone)

Plate 10

Northern Nowata County, Oklahoma
Cross Section B - B'

Author: M. Huhnke		Date: April 2004

Cross Section C-C'

Stratigraphic Cross Section (Datum: Oswego Limestone)

Plate 11

Northern Nowata County, Oklahoma
Cross Section C - C'

Author: M. Huhnke		Date: April 2004

Cross Section D-D'
Stratigraphic Cross Section (Datum: Oswego Limestone)

Plate 12		
Northern Nowata County, Oklahoma Cross Section D - D'		
Author: M. Huhnke		Date: April 2004

Cross Section E-E'
Stratigraphic Cross Section (Datum: Oswego Limestone)

Plate 13		
Northern Nowata County, Oklahoma Cross Section E - E'		
Author: M. Huhnke		Date: April 2004

Cross Section F-F'
Stratigraphic Cross Section (Datum: Oswego Limestone)