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U.S. Energy Information Administration

Permian Basin

Part 2

Wolfcamp and Spraberry Shale Plays of the Midland Sub-Basin

Geology review

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Contents

Introduction

This document contains updated information and maps for the Wolfcamp and Spraberry plays of the Midland Basin, which is a part of the larger Permian Basin. The geologic features characterized include contoured elevation of the top of the formations (structure), contoured thickness (isopach), paleogeographic elements, and tectonic features as well as geological cross sections and play boundaries.

These geologic elements are documented and integrated into a series of maps. The Midland Basin maps consist of layers of geologic and production information that users can view either as separate thematic maps or as interactive layers of the U.S. Energy Mapping System. Data sources include Enverus DrillingInfo Inc. (DI), a commercial oil and natural gas well database; the United States Geological Survey (USGS); Texas Bureau of Economic Geology; U.S. Energy Information Administration (EIA) reports; peer-reviewed research papers; and academic theses.

Currently, EIA has access to well-level data, including more than 24,000 well logs from the Midland Basin, which we use for map construction. This report contains the Wolfcamp and Spraberry play sections, including subsections on the Wolfcamp and Spraberry benches in the Midland Basin. EIA will add spatial layers on structure, thickness, and production maps as well as corresponding report sections describing major plays of the Midland Basin in the future as we create additional maps.

Permian Basin

The Permian Basin of West Texas and Southeast New Mexico has produced hydrocarbons for about 100 years and has supplied more than 35.6 billion barrels of oil and about 125 trillion cubic feet of natural gas as of January 2020. Implementing hydraulic fracturing, horizontal drilling, and completion technology advancements during the past decade has reversed the production decline in the Permian Basin, and the basin has exceeded its previous production peak, set in the early 1970s. In 2021 Permian Basin production accounted for more than 41% of total U.S. crude oil production and more than 15% of total U.S. natural gas production. As of 2019, EIA estimates remaining proven reserves in the Permian Basin exceed 12.1 billion barrels of oil and 49.9 trillion cubic feet of natural gas, making it one of the largest hydrocarbon-producing basins in the United States and the world (EIA, 2019).

Regional tectonic setting and geologic framework

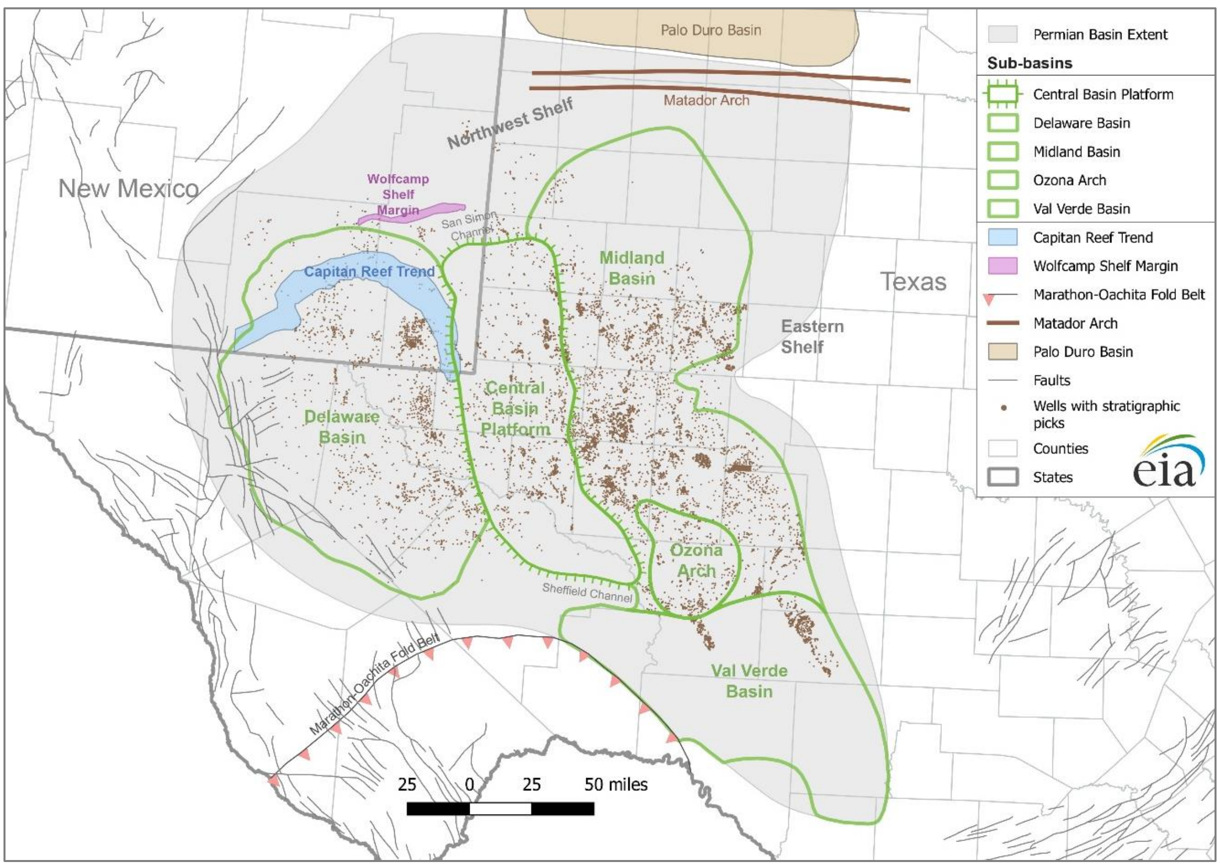
The Permian Basin is a complex sedimentary system located in the foreland of the Marathon-Ouachita orogenic belt. It covers more than 75,000 square miles and extends across 52 counties in West Texas and Southeast New Mexico.

The Permian Basin is now an asymmetrical, northwest-to-southeast-trending sedimentary system bounded by the Marathon-Ouachita orogenic belt to the south, the Northwest shelf and Matador Arch to the north, the Diablo platform to the west, and the Eastern shelf to the east (Beaumont, 1981; Gardiner, 1990, 1992; Ewing, 1991; Frenzel, et al., 1988; Hills, 1985). The basin is comprised of several sub-basins and platforms: the three main subdivisions include the Delaware Basin, Central Basin Platform, and the Midland Basin (Figure 1). Detailed Permian Basin stratigraphy, geologic framework and tectonic settings are presented in the [Permian Basin Report, Part 1.]()

Midland Basin

The Midland Basin is bounded to the east by the Eastern shelf through a series of north-south trending fault segments, to the north by the Northwest shelf, and to the west by uplifted areas of the Central Basin Platform. Southward, Midland Basin formations thin out into the Ozona Arch, an extension of the Central Basin Platform, which separates the Delaware and Midland Basins (Galley, 1958; Hoak et al., 1998; Mazzullo et al., 1989; Yang et al., 1995)

Figure 1. Major structural and tectonic features in the region of the Permian Basin



Wolfcamp Formation

The Wolfcamp Shale, a Wolfcampian-age organic-rich formation, extends in the subsurface in all three sub-basins of the Permian Basin (Delaware Basin, Midland Basin, and Central Basin Platform) and is the most prolific oil and natural gas-bearing tight formation contained within (Dolton et al., 1979; Dutton et al., 2005; Jacobs, 2013; Robinson, K., 1988). The Wolfcamp Shale is divided into four sections, or benches, known as the Wolfcamp A, B, C, and D (Gaswirth et al., 2016; Gupta et al., 2018).

In the Midland Basin, the four benches of the Wolfcamp formation each display different characteristics in terms of lithology, fossil content, porosity, total organic content, and thermal maturity. Overall, basement tectonics patterns influence Wolfcamp structure and thickness (Figures 2-5).

USGS estimates undiscovered, continuous, hydrocarbon resources of the Wolfcamp formation in the Midland Basin to be in excess of 19 billion barrels of oil, 15 trillion cubic feet of natural gas, and 1.5 billion barrels of natural gas liquids (NGL), making it one of the largest hydrocarbon plays in the United States (Gaswirth, et al., 2016). Like other continuous plays, key geologic and technical criteria that control play boundaries and productivity include thermal maturity, total organic carbon (TOC), formation thickness, porosity, depth, pressure, and brittleness.

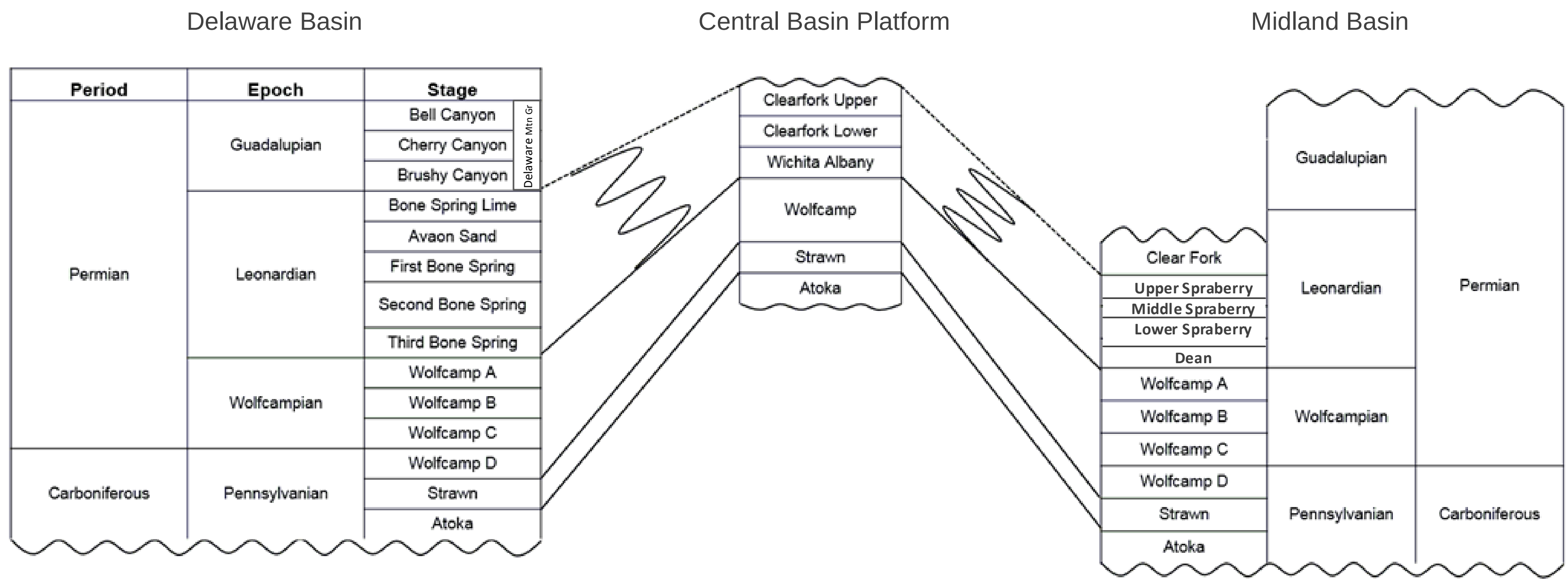
EIA constructs contoured elevation maps of subsea depth to the top of a geologic formation (also called structure maps) from point-measurement depths referenced to sea level (well observations) for the formation in the subsurface. These elevation measurements provide the third dimension for characterizing the depth or elevation of a reservoir on an otherwise two-dimensional map. Enverus DrillingInfo Inc. provides these stratigraphic picks, or formation depths, based on well log interpretation (well observations).

Regional stratigraphy and lithology of the Wolfcamp formation

The Early Permian (Wolfcampian-Leonardian) Wolfcamp interval of the Permian Basin in West Texas is a mixed siliciclastic-carbonate succession that holds one of the most prolific unconventional oil and natural gas plays in the world. Wolfcamp strata comprise stacked, cyclic gravity flow deposits separated by hemipelagic mudstone and siltstone. Lower Permian (Wolfcampian and Leonardian Series) stratigraphy indicates accumulation in a deepwater basin surrounded by shallow-water carbonate platforms. On the basin floor, siliciclastic, turbidite depositional systems alternate with calcareous shale enriched with biogenic material (Baumgardner et al., 2016; Brown, 1969; Meissner, 1972; Hamlin et al., 2012).

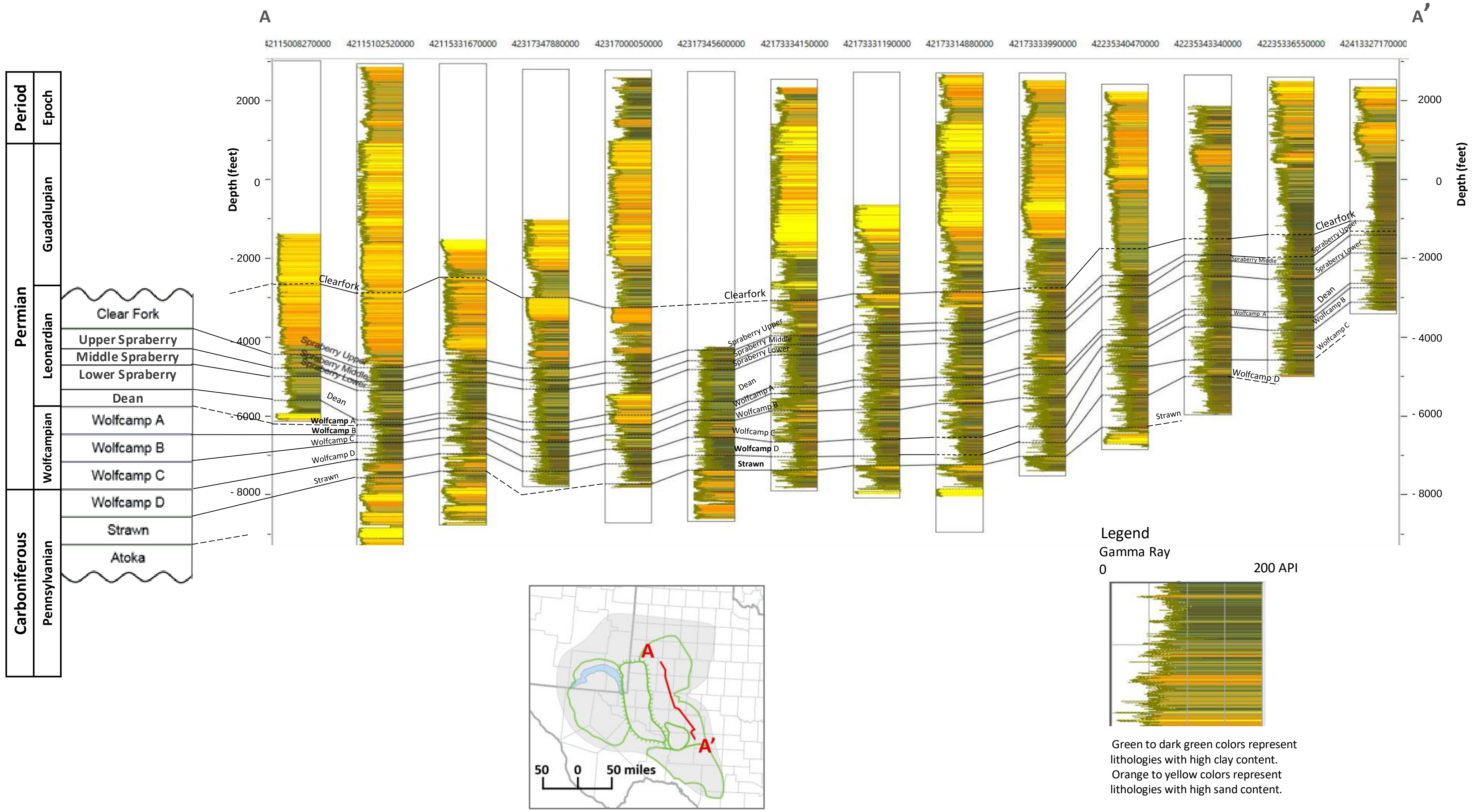
The Wolfcamp formation, deposited during late Pennsylvanian through late Wolfcampian time, is distributed across the entire Permian Basin. The paleogeographic setting was a deepwater ocean basin surrounded by shallow carbonate platforms. The Wolfcamp formation is a complex unit consisting mostly of organic-rich shale and argillaceous carbonates intervals near the basin edges. Depth, thickness, and lithology vary significantly across the basin. Depositional and diagenetic processes control this formation’s heterogeneity (Hamlin et al., 2012; Mazzullo et al., 1989; Meissner, 1972; Murphy, 2015). Stratigraphically, the Wolfcamp is a stacked play with four intervals, designated top-down as the A, B, C, and D benches (Gaswirth, 2017). Porosity of the Wolfcamp formation varies between 2.0% and 12.0% and averages 6.0%; however, average permeability is as low as 10 millidarcies, which requires multistage hydraulic fracturing (Baldwin, 2016; Murphy, 2015). Figures 2–5 show the regional stratigraphy of the Permian interval, including representation of Wolfcamp benches.

Figure 2. Generalized stratigraphic schema of Upper Carboniferous through Upper Permian intervals for the Permian Basin



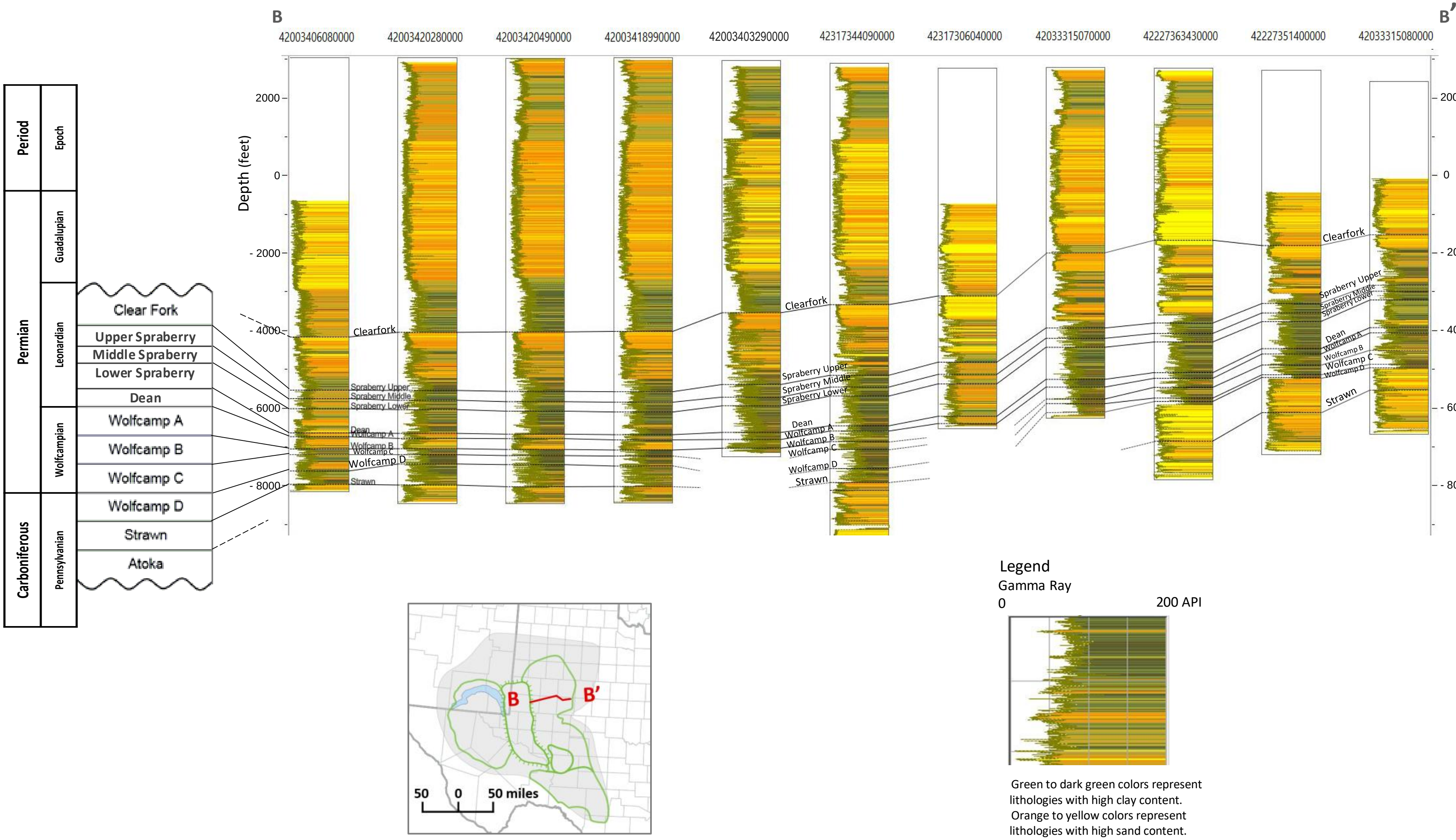
Source: U.S. Energy Information Administration, based on Enverus Inc. and the U.S. Geological Survey

Figure 3. North to south geologic cross sections through the Midland Basin



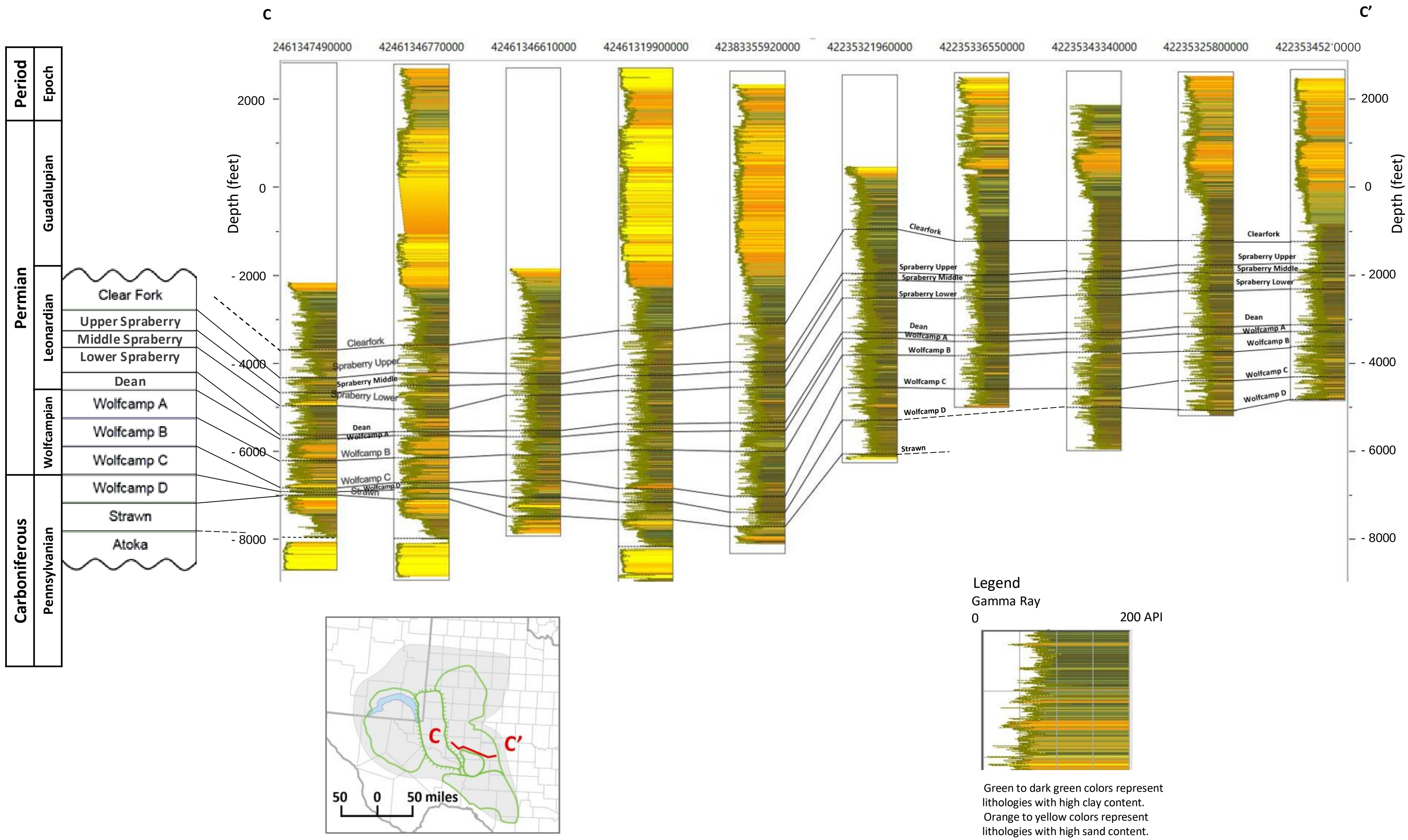
Source: U.S. Energy Information Administration, based on Enverus Inc. and the U.S. Geological Survey

Figure 4. East to west geologic cross sections through the northern part of the Midland Basin



Source: U.S. Energy Information Administration, based on Enverus Inc. and the U.S. Geological Survey

Figure 5. East to west geologic cross sections through the southern part of the Midland Basin



Source: U.S. Energy Information Administration, based on Enverus Inc. and the U.S. Geological Survey

Wolfcamp formation in the Midland Basin

In the Midland Basin, shallow-water shelf facies of the Wolfcamp formation consist of carbonate, evaporite, and siliciclastic material. Seaward these depositional facies grade into mixed shale, carbonate, and lime mudstone. Basinal sediments include dark shale, lime mudstone, and carbonate debris. Carbonate detritus from the shallow shelf was delivered to submarine valleys and formed a succession of fan systems. Fan deposits are cut by a series of narrow channels consisting of clastic flow material also derived from the shelf. The presence of deepwater dark, organic rich shales interbedded with siliciclastic sediments indicates that debris and channel deposition advanced into the area during times of sea level lowstand (Handford and Loucks, 1993; Meissner, 1972).

In a hemipelagic paleoenvironment, siliciclastic material and organic matter accumulated as background sedimentation interrupted by episodic deposition of gravity flows derived from the surrounding highlands. Cyclicity is observed in individual, upward-fining trends of relatively coarse-grained material overlain by calcareous or siliceous mudstone, or both (Meissner, 1972). It is interpreted that the majority of gravity flows occurred during lowstands of relative sea level. Widespread pyrite and phosphatic nodules and total organic carbon (TOC) content as high as 8% indicate that low oxygen levels prevailed during the accumulation of these sediments (Jarvie et al., 2001; Jarvie, 2017)

Sea-level fluctuation predominantly controlled sediment influx into the basin. During sea-level lowstands, platforms were exposed, and siliciclastic material was conveyed directly into the basin. During sea-level highstands, sediment input to the basin comprised platform-derived carbonate and aeolian silt and clay. A siliciclastic series includes the lower Wolfcamp interval. This lowstand interval contains submarine fan deposits that extend across the basin floor. The lower Wolfcamp interval forms a west- and north-thinning wedge of siliciclastic sediments transported from highland source areas to the east and south. A calcareous series includes the upper Wolfcamp interval. This highstand interval contains widespread alternating layers composed of calcareous mudrocks and detrital carbonate deposits. Calcareous layers are predictably thicker near the platforms that provided the carbonate detritus. In the central parts of the basin, calcareous intervals are mudrock dominated and include thin, permeable strata of coarse-grained siliciclastic material (Brown, 1969; Helm, 2015; Mazzullo et al., 1989).

Total organic carbon content of the Wolfcamp formation

Large amounts of organic material that accumulated in the deep, poorly oxygenated areas of the Midland Basin later converted to hydrocarbons. Analytical results from well core samples indicate that TOC content in the Wolfcamp formation ranges from less than 1.0% to 8.7% (Murphy, 2015; Baumgardner at al., 2016). TOC is facies-dependent (highest in siliceous mudrock) and varies widely across the basin. Most organic matter in the Wolfcamp interval is in the oil-production window and has matured to Type II-III kerogen. Known good source rocks typically contain mostly 2.0% TOC or higher. As such, the Wolfcamp formation has sufficient TOC content compared with other low permeability plays. Based on their TOC content, the basinal siliceous mudrocks have the highest potential for hydrocarbon generation (Baldwin, 2016; Hackley at al., 2020).

Wolfcamp play boundaries and production

In the Midland Basin Wolfcamp play, boundaries are controlled by the main tectonic features of the Permian region. The play boundaries are outlined to the south by the Marathon-Ouachita fold and thrust belt, to the north by the Northwest shelf, and to the east by the Eastern shelf, and the western play boundary traces the eastern margin of the Central Basin Platform. The changes in depth and thickness along the play boundaries reflect the amount of differential movements that set off subsidence within the basin and the uplift of the surrounding highlands.

By the 1960s, the Wolfcamp formation had become a major conventional target with wells targeting mostly calcareous sandstone members. By 2010, more than 246 million barrels of oil and 568 billion cubic feet of natural gas were produced from the Wolfcamp play in the Midland Basin. Because of the introduction of hydraulic fracturing and horizontal drilling, production has increased significantly, and it is now one of the fastest-developing unconventional plays in the United States. Between 2010 and 2020 875 vertical, 12 directional, and 2,190 horizontal wells had been drilled in the reservoir. The Wolfcamp formation generated more than 202 million barrels of oil and 125 billion cubic feet of natural gas during the past decade.

The Wolfcamp formation is a very attractive unconventional target because it has many pay zones, high TOC, and large formation thickness (average of 1,800 feet). A combination of abundant organic carbon, favorable rock mechanical properties, permeable thin beds, and modern well stimulation and completion technology has unlocked the entire Lower Permian interval to production. Wolfcamp basin-floor stratigraphy contains alternating layers of siliciclastic and calcareous facies spread out across the basin. In comparison with overlying Dean and Spraberry formations, the Wolfcamp interval is more calcareous where carbonate debris flows are interbedded with carbonate turbidites and organic-rich calcareous mudrocks (Dutton et al., 2005; Meissner, 1972).

The Wolfcamp formation has been described as a hybrid shale oil system with organic-rich source rocks alternated with organic-lean coarse-grained reservoir intervals. The Wolfcamp play produces oil and associated gas from organic-rich siliciclastic mudstones interbedded with carbonate-rich turbidite deposits. The lowest reservoir quality is associated with mainly grainy carbonate facies, and the highest reservoir quality is associated with siliceous mudstones. As a result, the better reservoirs are discovered where muddy deposits are thickest and dominate carbonate debris flows (Meissner, 1972; Murphy, 2015).

The Wolfcamp Shale is divided into four sections, or benches, known as the Wolfcamp A, B, C, and D (Gaswirth, 2017). In the Midland Basin, the four benches of the Wolfcamp formation each display different characteristics in terms of lithology, fossil content, porosity, total organic content, and thermal maturity. Overall, basement tectonics patterns influence Wolfcamp structure and thickness (Figures 2–13). EIA's analysis of well logs and productivity suggests the best reservoir quality corresponds with the following characteristics:

The Wolfcamp A areas

- Thickness is more than 300 feet
- Subsea depth to the formation top is more than 2,500 feet
- Neutron porosity ranges from 7% to 22%
- Density ranges from 2.45 grams per cubic centimeter (g/cm3) to 2.60 g/cm^3
- Estimated total organic carbon ranges from 2.0% to 8.0%

- Deep resistivity ranges from 20 ohmmeter to 290 ohmmeter

The Wolfcamp B areas

- Thickness is more than 150 feet
- Subsea depth to the formation top is more than 3200 feet
- Neutron porosity ranges from 6.0% to 20.0%
- Density ranges from 2.45 g/cm3 to 2.61g/cm^3
- Estimated total organic carbon ranges from 1.2% to 7.0%
- Deep resistivity ranges from 12 ohmmeter to 275 ohmmeter

The Wolfcamp C areas

- Thickness is more than 300 feet
- Subsea depth to the formation top is more than 3,750 feet
- Neutron porosity ranges from 2.5% to 16.5%
- Density ranges from 2.48 grams per cubic centimeter (g/cm^3) to 2.62g/cm^3
- Estimated total organic carbon ranges from 1.0% to 7.0%
- Deep resistivity ranges from 14 ohmmeter to 260 ohmmeter

The Wolfcamp D areas

- Thickness is more than 150 feet
- Subsea depth to the formation top is more than 4,000 feet
- Neutron porosity ranges from 4.0% to 17%
- Density ranges from 2.48 g/cm^3 to 2.55 g/cm^3
- Estimated total organic carbon ranges from 2.0% to 7.0%
- Deep resistivity ranges from 13 ohmmeter to 275 ohmmeter.

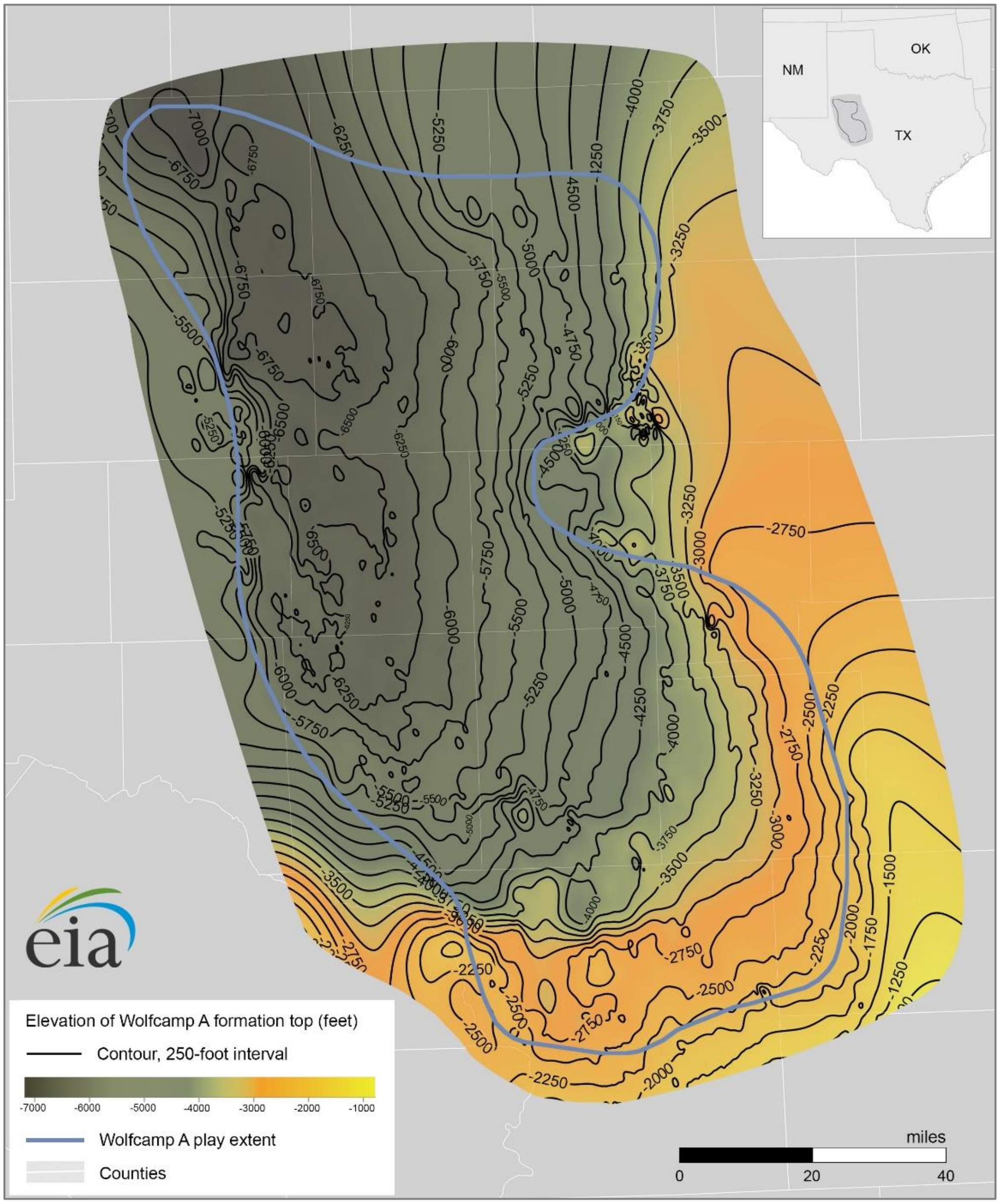
Wolfcamp formation benches

The Wolfcamp A, B, C, and D benches are widespread throughout the entire Midland Basin, but they exhibit maximum development along the basin's southern slope. Along the margin of the Central Basin Platform, they are silty and carbonate rich. Admittedly, during deposition of the Wolfcamp succession, a depocenter was located in the northwestern and central parts of the Midland Basin next to the Central Basin Platform. Most of the current drilling activities in the Midland Basin target low permeable organic rich reservoirs of the entire Wolfcamp interval.

Structure and thickness maps of Wolfcamp A in the Midland Basin

EIA constructed the Wolfcamp A structure map in the Midland Basin from subsurface point measurements (well observations) of the depth to the formation top. These stratigraphic picks include well log interpretations from 5,060 wells drilled in the Midland Basin. Subsea depth of Wolfcamp A in the Midland Basin varies from -1,000 feet in the southeast to -6,750 feet in western areas (Figure 6).

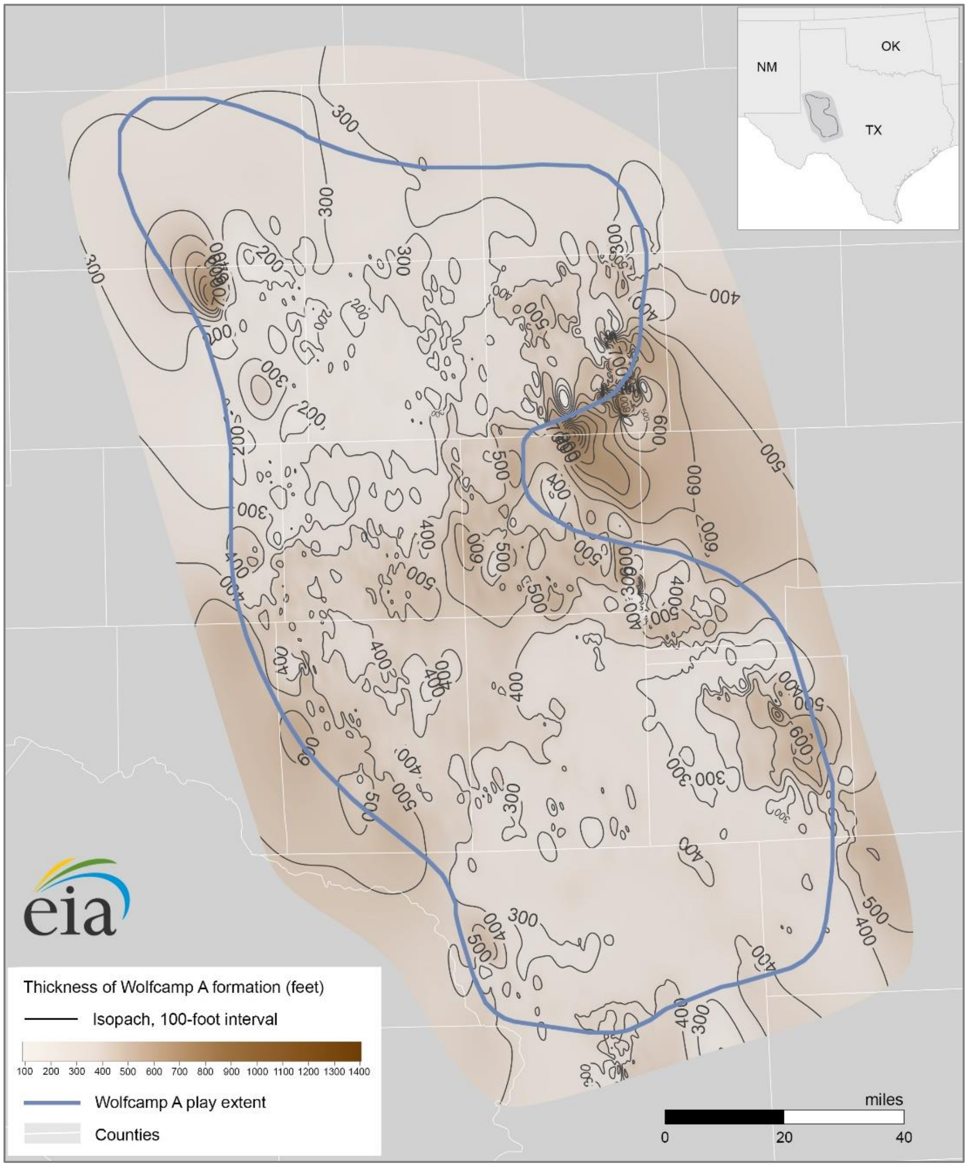
Figure 6. Structure map of Wolfcamp A (Midland Basin)



Source: Map by the U.S. Energy Information Administration, based on data from Enverus Inc.

EIA constructed the Wolfcamp A thickness map in the Midland Basin from subsurface point measurements from 4,220 wells that include both depth to the top and to the base of the Wolfcamp A bench. Thickness ranges from about 200 feet to more than 500 feet thick, except in the isolated areas in northwest and eastern central part of the basin, where the Wolfcamp A is more than 1,000 feet thick (Figure 7).

Figure 7. Thickness map of Wolfcamp A (Midland Basin)



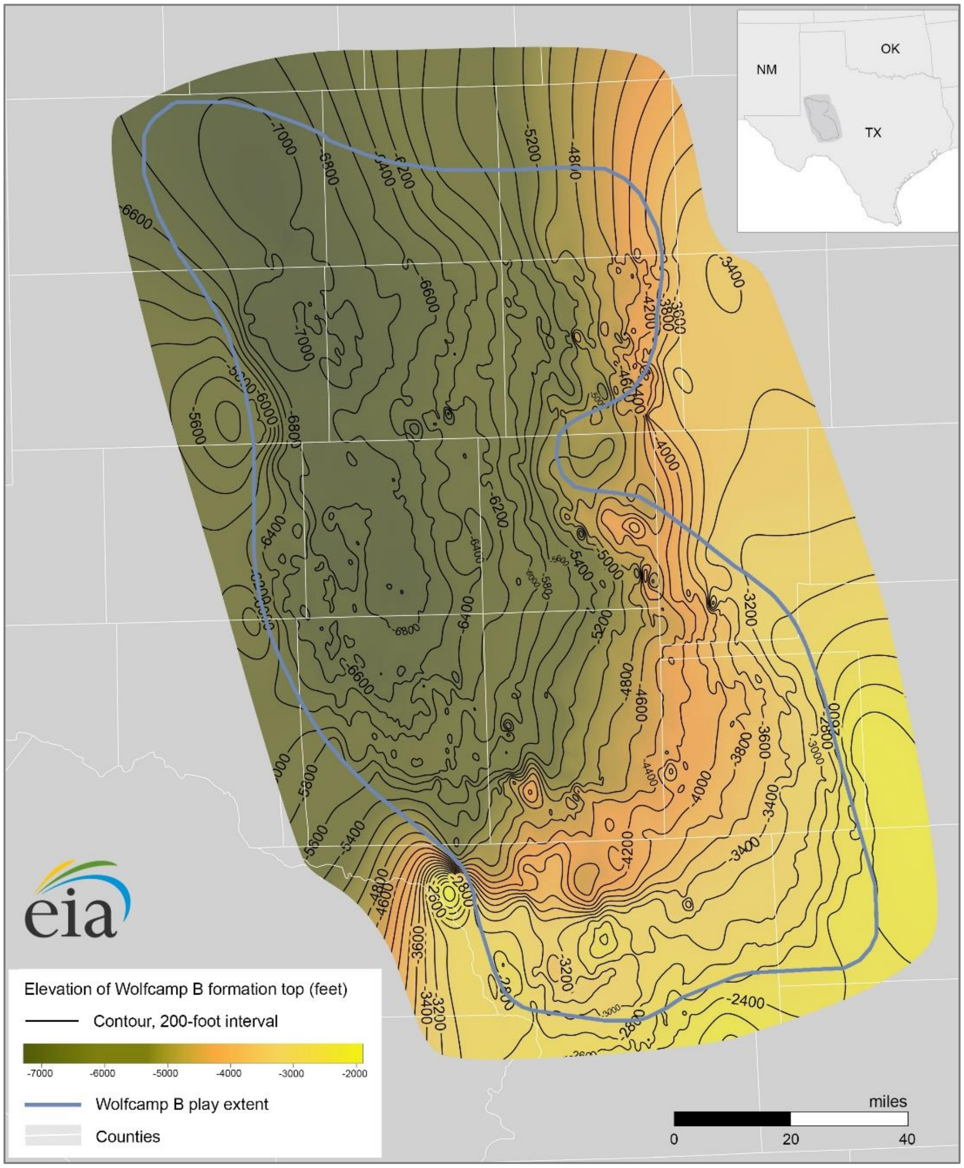
Source: Map by the U.S. Energy Information Administration, based on data from Enverus Inc.

Structure and thickness maps of Wolfcamp B in the Midland Basin

EIA constructed the Wolfcamp B structure map in the Midland Basin from subsurface point measurements of the depth to the formation top. These stratigraphic picks include well log interpretations from 4,220 wells. Subsea depth of Wolfcamp B in the Midland Basin varies from -2,400 feet in the west to more than -7,000 feet in the northeastern areas (Figure 8).

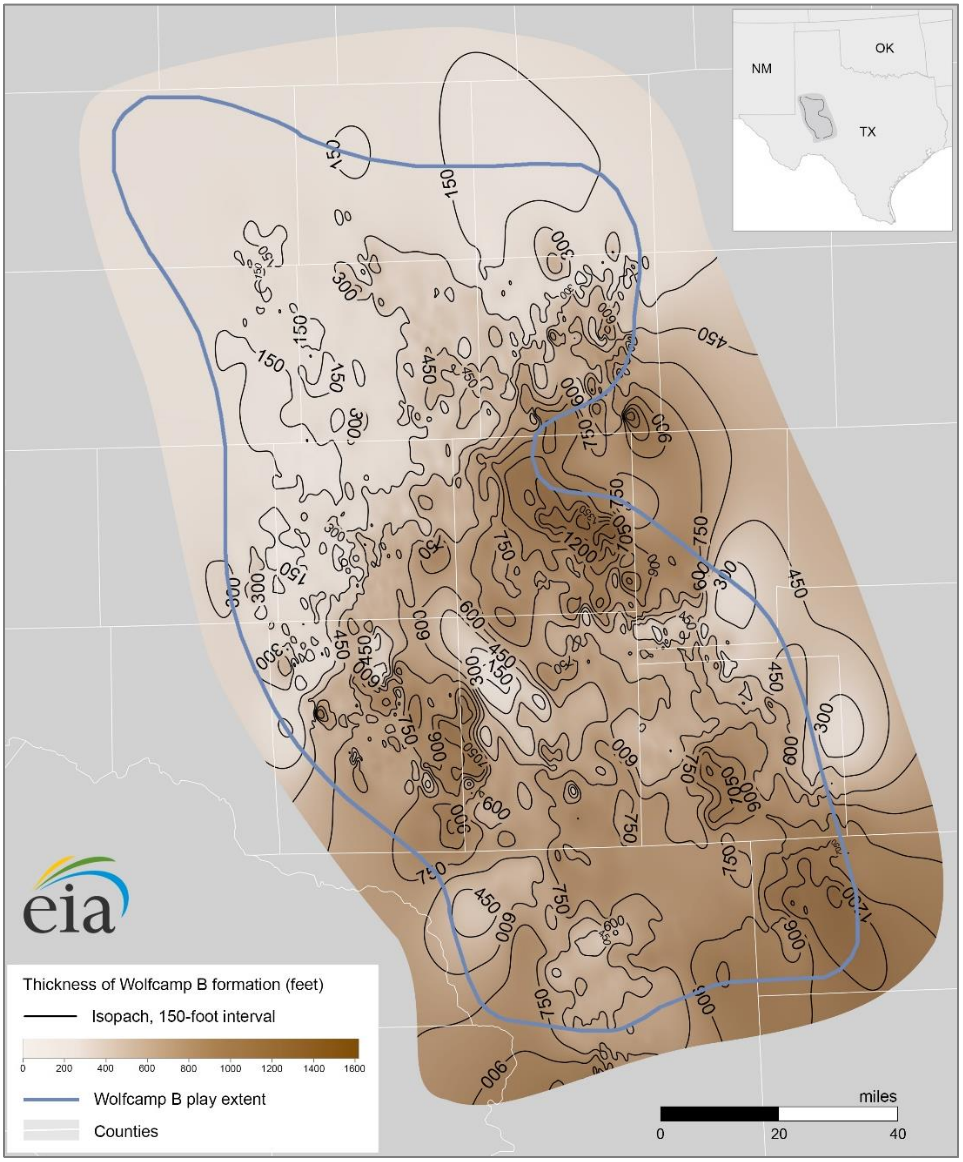
EIA constructed the Wolfcamp B thickness map based on stratigraphic picks from 3,940 wells that include both depth to the top and to the base of the Wolfcamp B bench. Thickness ranges from about 150 feet to more than 1,200 feet thick across the Midland Basin (Figure 9).

Figure 8. Structure map of Wolfcamp B (Midland Basin)



Source: Map by the U.S. Energy Information Administration, based on data from Enverus Inc.

Figure 9. Thickness map of Wolfcamp B (Midland Basin)

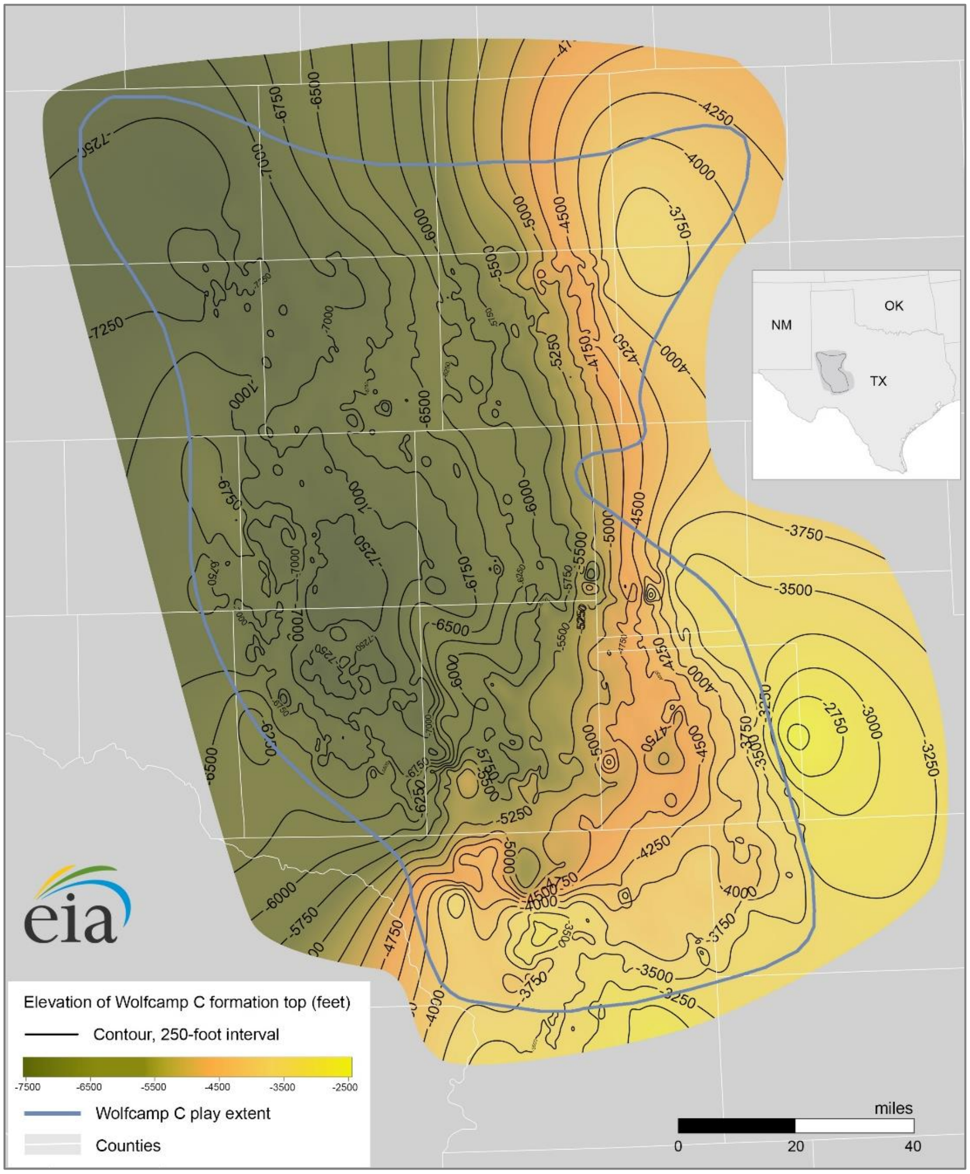


Source: Map by the U.S. Energy Information Administration, based on data from Enverus Inc.

Structure and thickness maps of Wolfcamp C in the Midland Basin

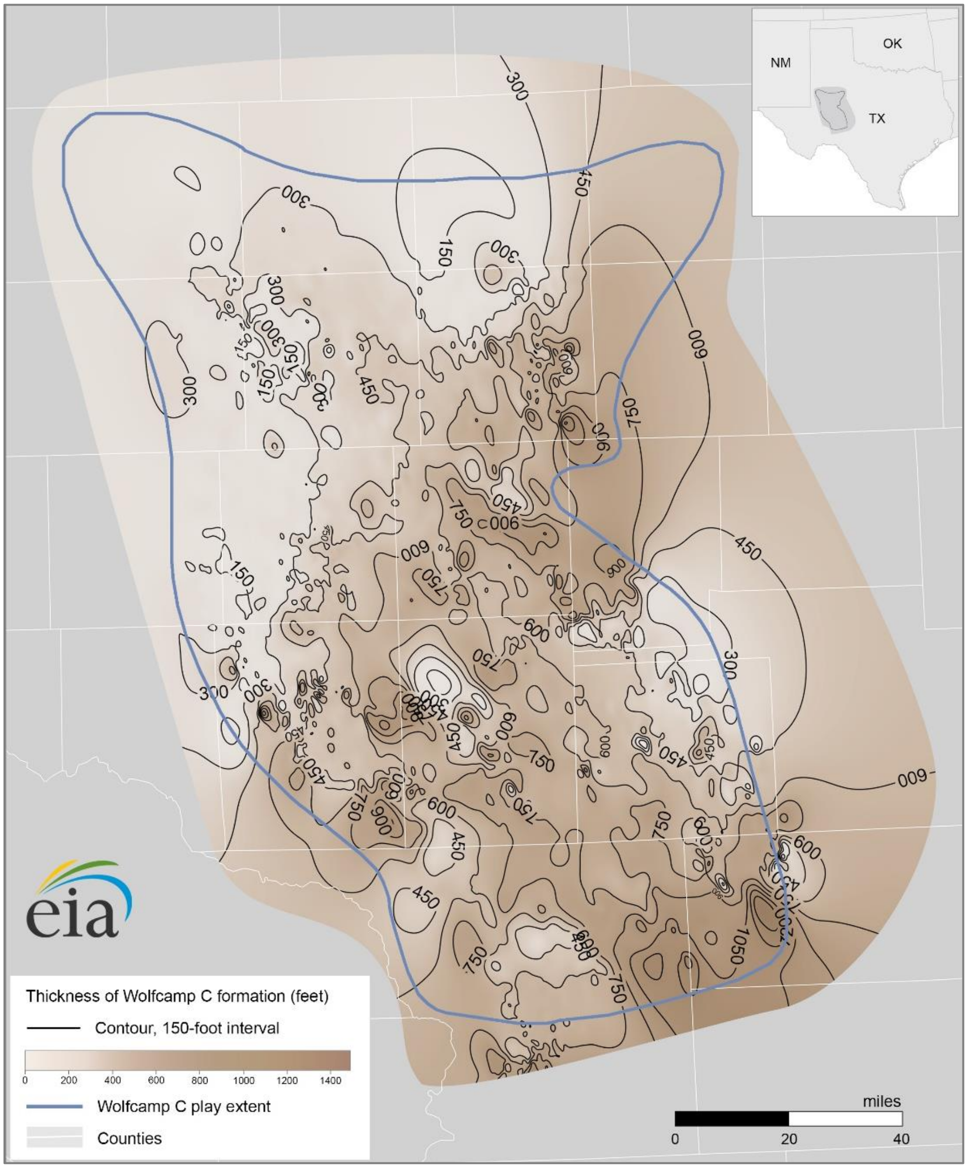
EIA constructed Wolfcamp C structure and thickness maps in the Midland Basin based on stratigraphic picks from 2,990 wells. Subsea depth of Wolfcamp C in the Midland Basin varies from -3,200 feet in the south to -7,300 feet in the eastern part of the basin in areas next to the Central Basin Platform (Figure 10). Thickness ranges from about 150 feet to more than 1,000 feet thick in the central and southern areas of the Midland Basin (Figure 11).

Figure 10. Structure map of Wolfcamp C (Midland Basin)



Source: Map by the U.S. Energy Information Administration, based on data from Enverus Inc.

Figure 11. Thickness map of Wolfcamp C (Midland Basin)

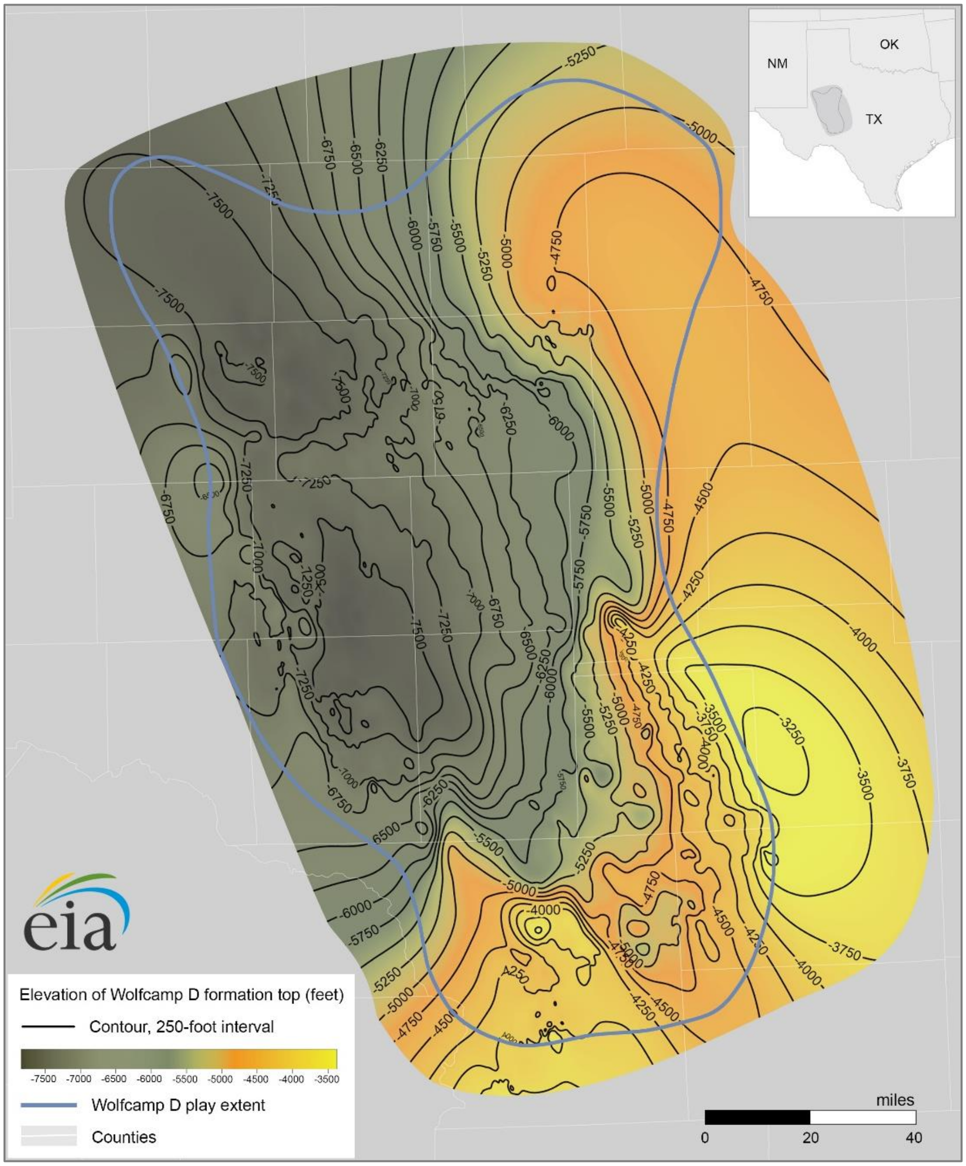


Source: Map by the U.S. Energy Information Administration, based on data from Enverus Inc.

Structure and thickness maps of Wolfcamp D in the Midland Basin

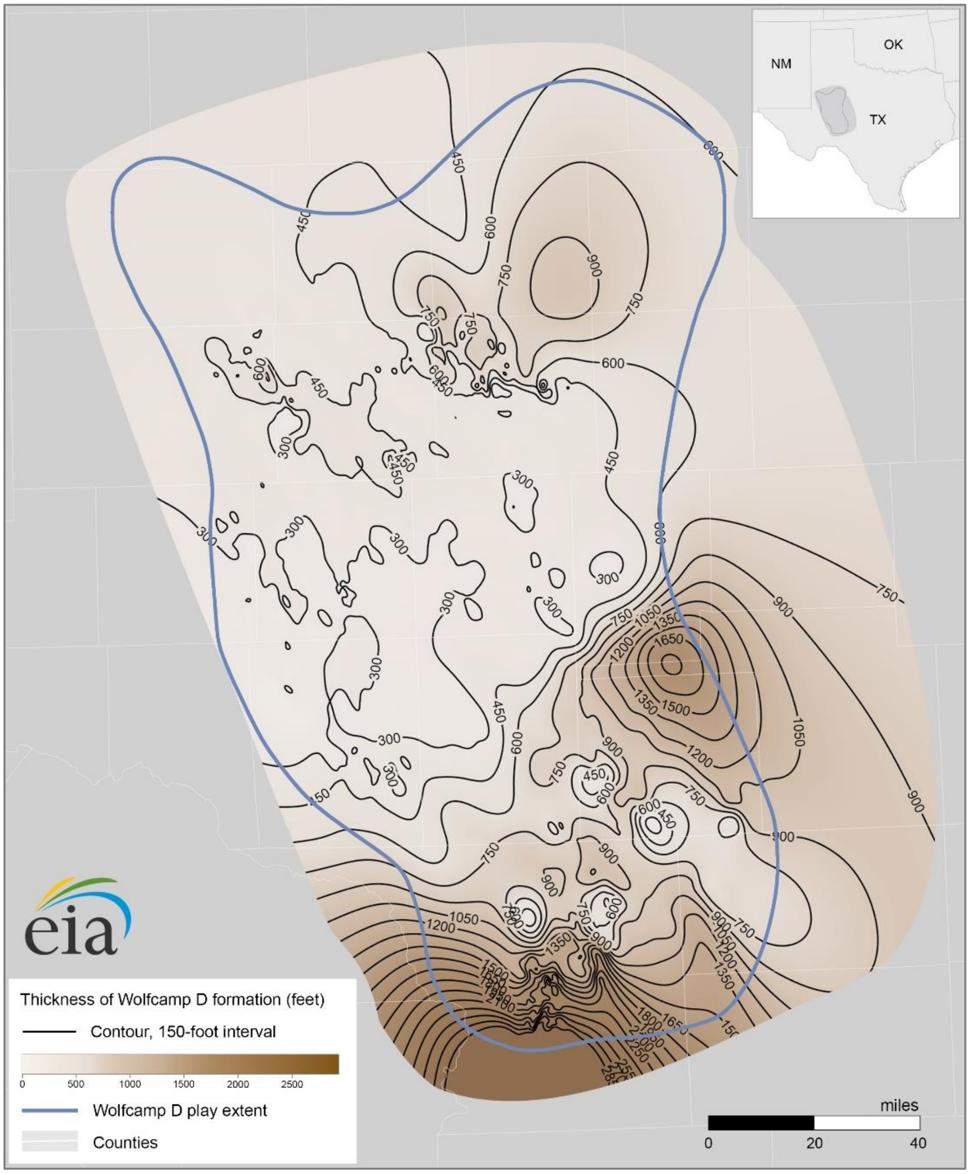
EIA constructed Wolfcamp D structure and thickness maps in the Midland Basin based on stratigraphic picks from 2,700 wells. Subsea depth of Wolfcamp D in the Midland Basin ranges from -3,500 feet in the west to more than -7,500 feet in the eastern part of the basin (Figure 12). Thickness ranges from about 300 feet to more than 1,500 feet thick across the Midland Basin. (Figure 13).

Figure 12. Structure map of Wolfcamp D (Midland Basin)



Source: Map by the U.S. Energy Information Administration, based on data from Enverus Inc.

Figure 13. Thickness map of Wolfcamp D (Midland Basin)



Source: Map by the U.S. Energy Information Administration, based on data from Enverus Inc.

Spraberry Formation

The Leonardian-age Spraberry formation, which is spread across the Midland Basin in the western part of Texas, has long been known for its low-permeability, low-recovery reservoirs. It was once seen as the world's largest uneconomical oil field. Historically, development of the conventional Spraberry play revealed the natural fracturing in the stacked silty sandstone reservoirs with very poor recovery (Handford, 1981). The Spraberry interval is divided into three sections, or benches, known as the Spraberry Upper, Spraberry Middle, and Spraberry Lower (Gaswirth et al., 2017).

USGS estimates undiscovered, continuous, hydrocarbon resources of the Spraberry formation in the Midland Basin to be 4.2 billion barrels of oil, 3.1 trillion cubic feet of natural gas, and 0.3 billion barrels of natural gas liquids (NGL). The majority of these resource estimates are associated with the two continuous assessment units: Spraberry Middle and Spraberry Lower (Gaswirth et al., 2017). Like with other low permeability reservoirs, key geologic and technical criteria that control play boundaries and productivity include thermal maturity, total organic carbon (TOC), formation thickness, porosity, depth, pressure, and rock brittleness.

We generate contoured elevation maps of subsea depth to the top of a geologic formation (also called structure maps) from point-measurement depths referenced to sea level based on well observations. These elevation measurements provide the third dimension for characterizing the depth or elevation of a reservoir on an otherwise two-dimensional map. Enverus Inc. provides these stratigraphic picks, or formation depths, based on well log interpretation.

Regional stratigraphy and lithology of the Spraberry formation

The Spraberry formation of West Texas was deposited in the early-middle Leonardian age of the Middle Permian Period and is distributed throughout the main part of the Midland Basin. The Spraberry formation is composed of siltstones, very fine-grained sandstones, mudstones, and argillaceous limestones. Many of the siltstones are laminated, and sandstones are frequently burrowed, reducing overall reservoir quality; however, more massive sandstones also occur, most often in stacked or amalgamated channels. Thin, laterally continuous black shales with high TOC content are also present (Montgomery et al., 2000). This clastic sequence of alternating layers of siltstones, fine-grained sandstones, shales, and carbonates accumulated in a deep basin under stagnant conditions with hydrocarbons formed throughout the 1,600 feet of sedimentary rocks.

Based on regional stratigraphic correlation and percentage of sandy content, the formation consists of three genetic stratigraphic sequences, known as the Spraberry Upper, Middle, and Lower benches. The Dean formation is stratigraphically under the Lower Spraberry. The Upper and Lower benches have thicker, more widely spread siltstone and fine-grained sandstone layers with intermitted silty shale, whereas the Middle bench is composed of calcareous shale, limestone, and thinner, more locally developed fine-grained sandstone (Guevara, 1988).

In the Leonardian age, vast carbonate-evaporite platforms with shelf-margin reef complexes surrounded the Midland Basin to the west, north, and east, whereas the low-relief basin floor was the site of carbonate mud deposition periodically interrupted by episodes of clastic influx related to submarine-fan development. During periods of sea level fall, eolian material was possibly delivered via channels to existing submarine canyons (Montgomery et al., 2000).

The Spraberry formation appears to represent a largescale, basin-floor submarine fan system consisting of stacked fan series. This system was apparently generated by eolian-sourced turbidity. Fan deposits are cut by a succession of narrow channels comprised of clastic flow material. The fine-grained, mud-rich fan complex of the Spraberry is found to have an abundant sediment supply through its extensive network of leveed channels (Handford, 1981; Tyler and Gholston., 1988). We estimate that the Spraberry formation extends for as much as 150 miles southward from the northern margin of the Midland Basin and covers an area of about 15,000 square miles.

Altogether, the Wolfcamp and Spraberry successions represent a distinctive depositional system, wherein carbonate sediment is mainly generated and conveyed throughout the basin during sea-level highstands, and clastic sediment is deposited during sea-level lowstands (Wilson et al., 2020).

Total organic carbon content of the Spraberry formation

Large amounts of organic material that accumulated in the deep, poorly oxygenated areas of the Midland Basin later converted to hydrocarbons. Analytical results from well core samples indicate that TOC content in the Spraberry formation ranges from less than 1.0% to 8.7% (Murphy, 2015; Baumgardner at al., 2016). TOC is facies-dependent (highest in siliceous mudrock) and varies widely across the basin. Most organic matter in the Spraberry interval is in the oil-production window and has matured to Type II-III kerogen. Known good source rocks typically contain mostly 2.0% TOC or higher. As such, the Spraberry formation has sufficient TOC content compared with other low permeability plays. Based on their TOC content, the basinal siliceous mudrocks have the highest potential for hydrocarbon generation (Rogers, 2017).

Spraberry play boundaries and production

In the Midland Basin Spraberry play, boundaries are constrained by the main tectonic features of the Permian region. Regionally, the play is bounded by the Northwest Shelf to the north, the Ozona Arch to the south, the Eastern Shelf to the east, and uplifted areas of the Central Basin Platform to the west. The changes in depth and thickness along the play boundaries indicate the scale of differential movements that cause the subsidence within the basin and the uplift of the adjacent highlands.

Large reserves of oil were discovered in the sandy intervals of the Spraberry formation in the Midland Basin of West Texas in 1949, and they were mostly depleted by the end of the 20th century. The Spraberry produced 1,287 million barrels (MMb) of oil from January 1949 through December 2000. For the same period, the recovery efficiency of Spraberry reservoirs ranged from 8% to 10% (Montgomery et al., 2000). From 2001 through 2010, the Spraberry mostly produced from vertical wells and produced 312 MMb of oil and 1.5 billion cubic feet (Bcf) of natural gas during that decade. The combined drilling of the Spraberry and Wolfcamp, known as the Wolfberry play across the Midland Basin, allowed commingling of multiple intervals of the Spraberry and Wolfcamp formations to occur.

Starting in 2011, the Spraberry formation was mainly developed as an unconventional play using horizontal drilling, coupled with hydraulic fracturing. Between 2010 and 2021, 330 vertical, 27 directional, and 2,899 horizontal wells had been drilled in the reservoir. Operators have been focused on horizontal exploitation of the Spraberry Middle and Lower benches, primarily targeting the Spraberry Lower due to its larger thickness and higher organic content. From 2011 through 2021, the Spraberry play produced 900 MMb of oil and 2.2 Bcf of natural gas. Of these production totals, 76% of oil and 61% of natural gas production comes from horizontal wells. In 2021, combined Spraberry production from horizontal and vertical wells was 130 MMb of oil and 0.4 Bcf of natural gas; 92% of oil and 90% of natural gas came from horizontal wells.

Spraberry rocks possess well-developed natural fracturing despite insignificant local faulting and folding within a relatively stable geologic setting. Natural fractures typically strike from northeast to southwest and generate fracture-controlled permeability anisotropy in Spraberry reservoirs along a strike trend with observed local deviations. Horizontal core study results show that several substantially different systems of natural fractures exist in otherwise alike, nearby reservoirs. Variability in the production potential of different zones across the play may be linked to the unique interconnectivity (intersecting or nonintersecting fractures) and conductivity (degree of mineralization) of the different fracture systems within the Spraberry formation (Lorenz, et al., 2002).

Spraberry reservoirs occur at a subsea depth range of approximately -2,000 feet to -6,000 feet and consist of interbedded, fine-grained sandstones, siltstones, and organic-rich shales up to 1,600 feet thick.

Spraberry formation benches

The Spraberry formation is divided into three sections, or benches, known as the Spraberry Upper, Middle, and Lower (Gaswirth at al., 2017). In the Midland Basin, the three benches of the Spraberry formation each exhibits distinctive reservoir characteristics and production patterns.

Our analysis of well logs and productivity for the Spraberry Upper, Middle, and Lower benches suggests the best reservoir quality corresponds with the following characteristics:

The Spraberry Upper bench

- Thickness is more than 210 feet
- Subsea depth to the formation top is more than 3,500 feet
- Neutron porosity ranges from 7% to 22%
- Density ranges from 2.44 grams per cubic centimeter (g/cm3) to 2.60 g/cm^3
- Estimated TOC ranges from 2.0% to 8.0%
- Deep resistivity ranges from 20 ohmmeter to 290 ohmmeter

The Spraberry Middle bench

- Thickness is more than 225 feet
- Subsea depth to the formation top is more than 3,650 feet
- Neutron porosity ranges from 6.0% to 20.0%
- Density ranges from 2.45 g/cm3 to 2.61g/cm^3
- Estimated TOC ranges from 1.2% to 7.0%
- Deep resistivity ranges from 12 ohmmeter to 275 ohmmeter

The Spraberry Lower bench

- Thickness is more than 700 feet
- Subsea depth to the formation top is more than 3,750 feet
- Neutron porosity ranges from 5.5% to 16.5%
- Density ranges from 2.48 grams per cubic centimeter (g/cm^3) to 2.62g/cm^3

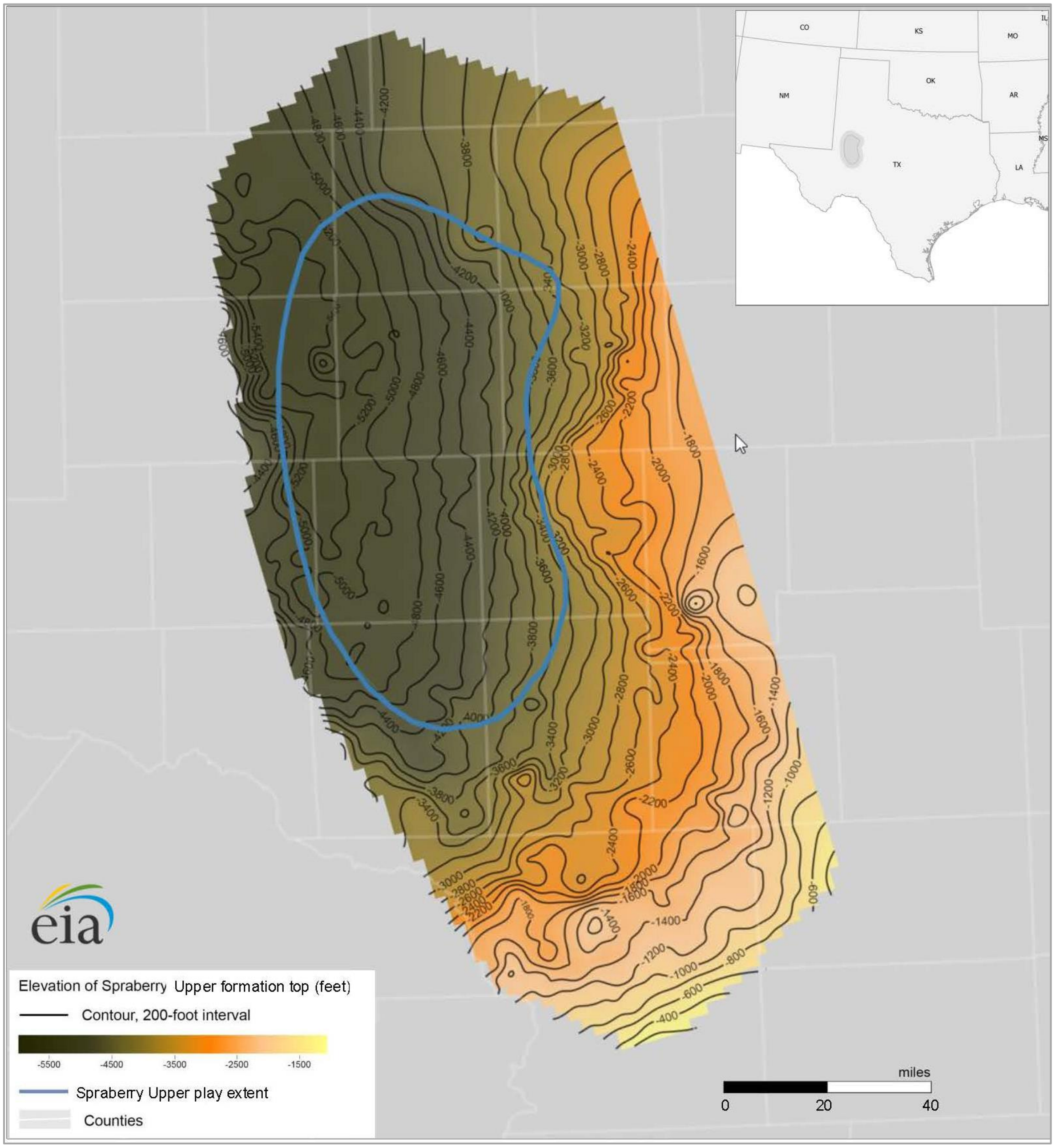
- Estimated TOC ranges from 1.0% to 7.0%
- Deep resistivity ranges from 14 ohmmeter to 260 ohmmeter

The Spraberry Upper, Middle, and Lower benches are widespread throughout the entire Midland Basin. In the areas adjacent to the Central Basin Platform, they are silty and carbonate rich. During the Leonardian age, a depocenter was located in the northwestern and central parts of the Midland Basin to the east of the Central Basin Platform margin. Most of the current drilling activities target thick and organic rich reservoirs in the Spraberry Lower bench.

Structure and thickness maps of Spraberry Upper in the Midland Basin

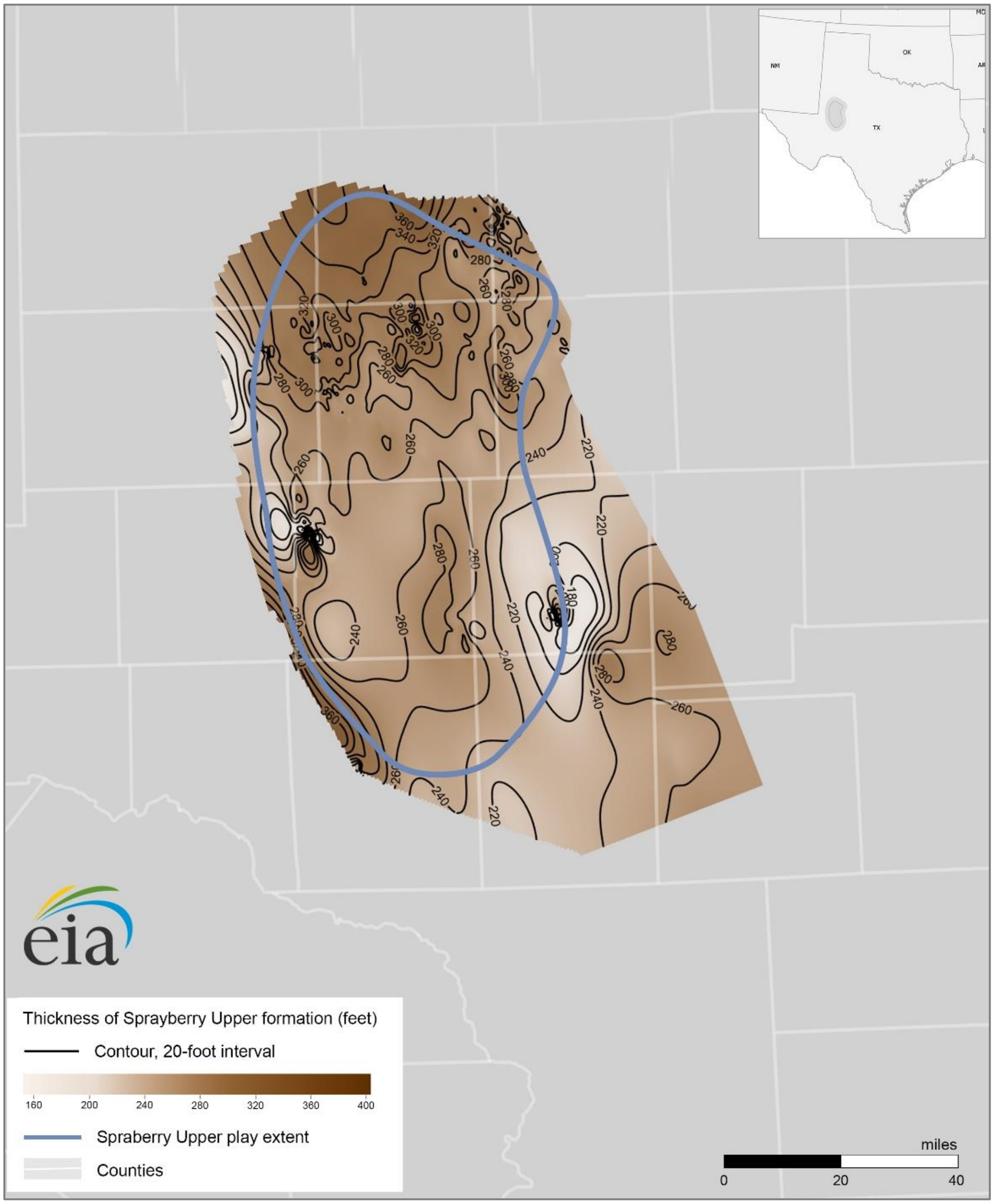
We constructed the Spraberry Upper structure map in the Midland Basin from subsurface point measurements (well observations) of the depth to the formation top. These stratigraphic picks include well log interpretations from 7,040 wells drilled in the Midland Basin. Subsea depth of the Spraberry Upper bench in the Midland Basin varies from -3,100 feet in the southeast to -5,400 feet in western areas (Figure 14).

Figure 14. Structure map of Spraberry Upper (Midland Basin)



Source: Map by the U.S. Energy Information Administration, based on data from Enverus Inc.

Figure 15. Thickness map of Spraberry Upper (Midland Basin)



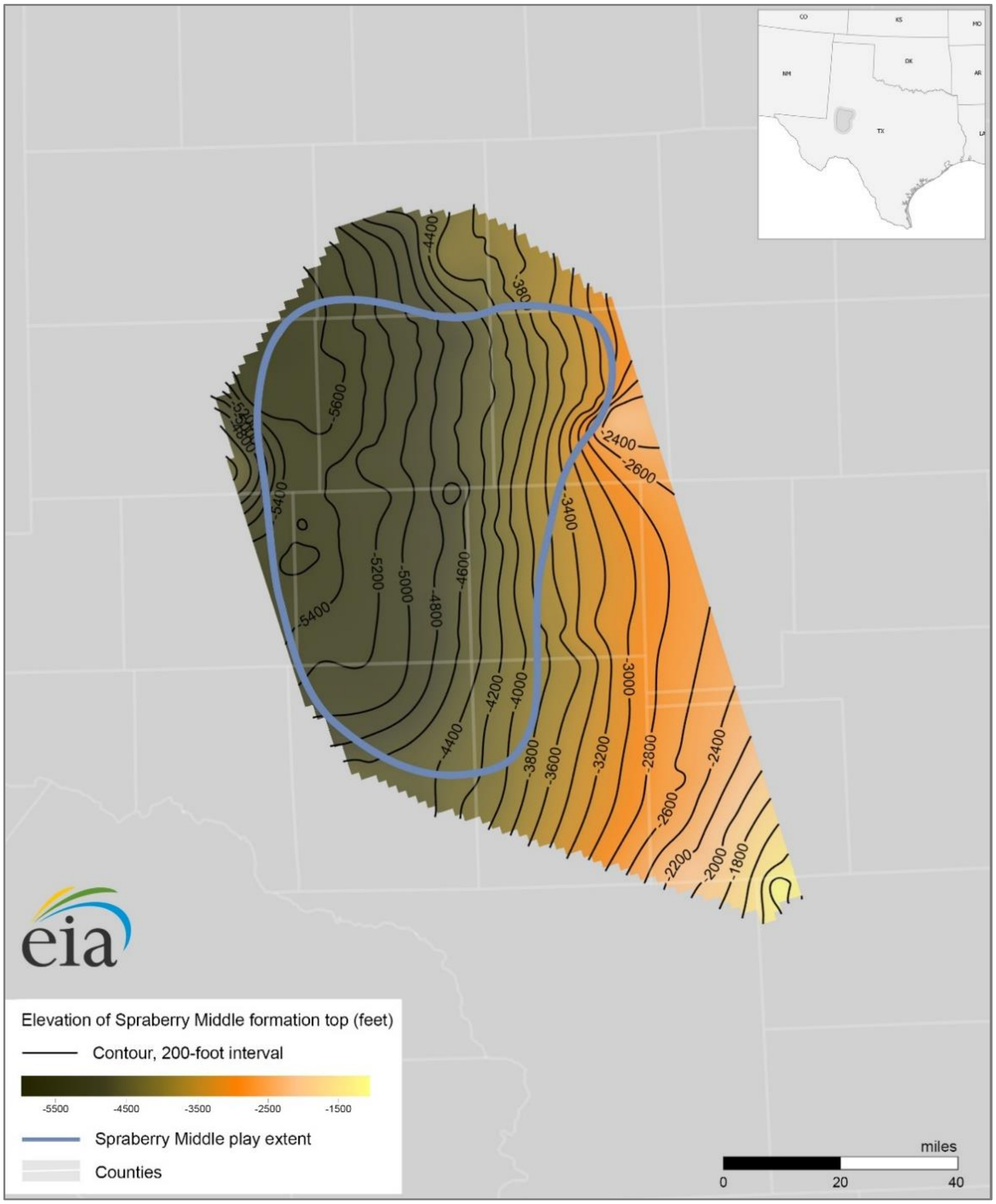
Source: Map by the U.S. Energy Information Administration, based on data from Enverus Inc.

We constructed the Spraberry Upper thickness map in the Midland Basin from subsurface point measurements from 6,220 wells that include both depth to the top and to the base of the Spraberry Upper bench. Thickness ranges from about 220 feet to more than 280 feet thick, except in the isolated areas in northwest and eastern central part of the basin, where the Spraberry Upper bench is more than 360 feet thick (Figure 15).

Structure and thickness maps of Spraberry Middle in the Midland Basin

We constructed the Spraberry Middle structure map in the Midland Basin from subsurface point measurements of the depth to the formation top. These stratigraphic picks include well log interpretations from 5,220 wells. Subsea depth of the Spraberry Middle bench in the Midland Basin varies from -2,400 feet in the east to more than -5,600 feet in the northwestern areas (Figure 16).

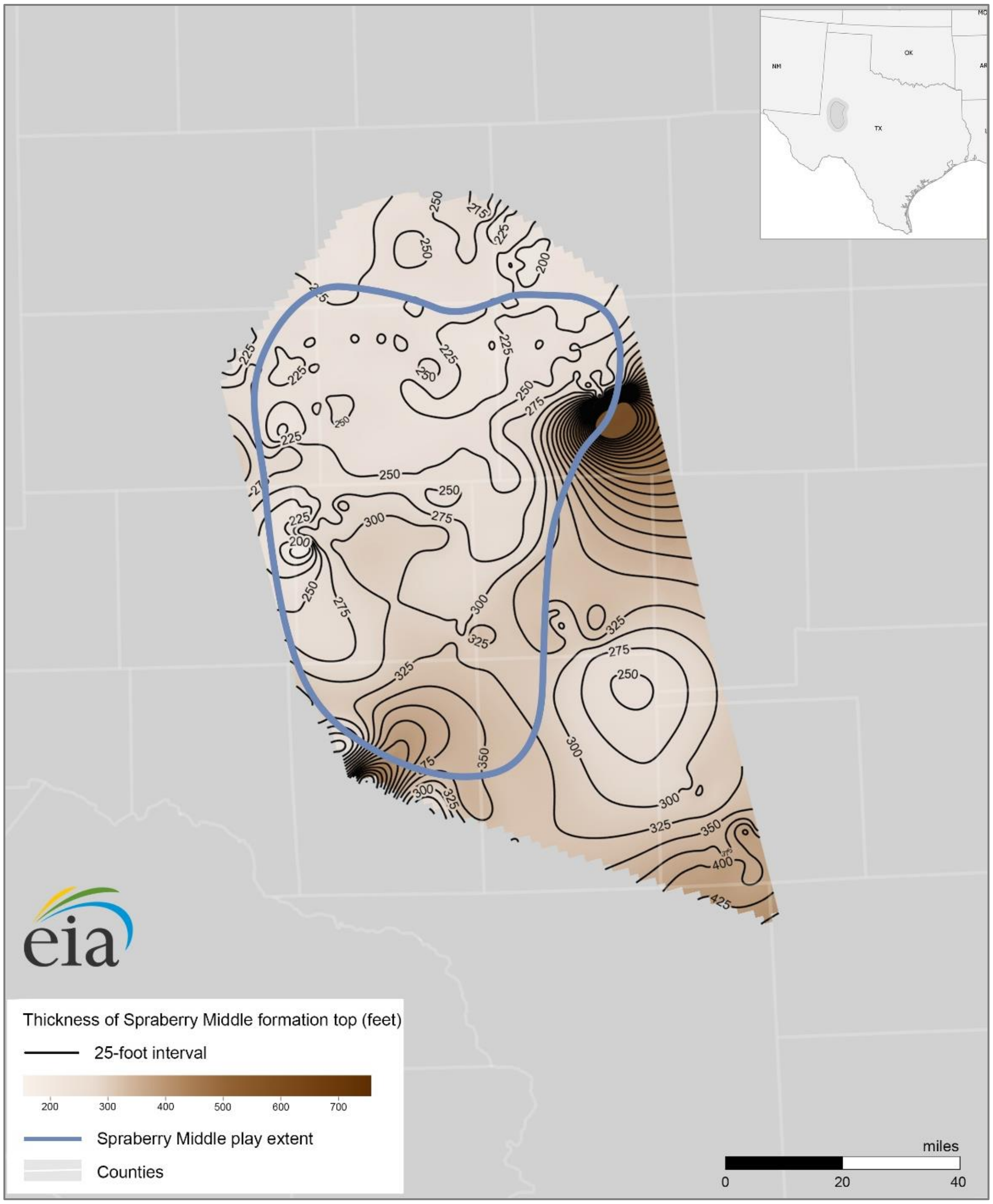
Figure 16. Structure map of Spraberry Middle (Midland Basin)



Source: Map by the U.S. Energy Information Administration, based on data from Enverus Inc.

We constructed the Spraberry Middle thickness map based on stratigraphic picks from 4,940 wells that include both depth to the top and to the base of the Spraberry Middle bench. Thickness ranges from about 200 feet to more than 330 feet thick across the Midland Basin (Figure 17).

Figure 17. Thickness map of Spraberry Middle (Midland Basin)

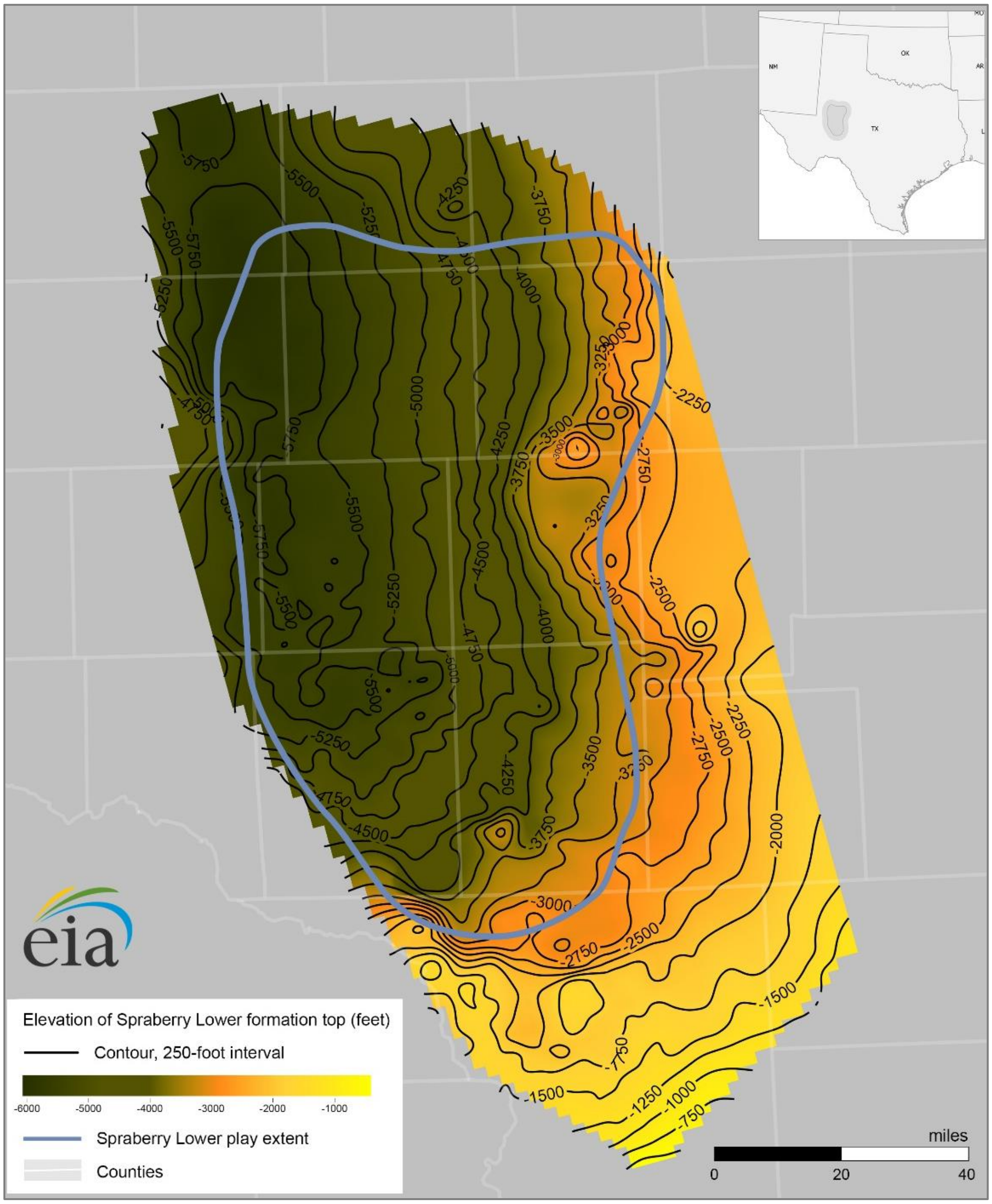


Source: Map by the U.S. Energy Information Administration, based on data from Enverus Inc.

Structure and thickness maps of Spraberry Lower in the Midland Basin

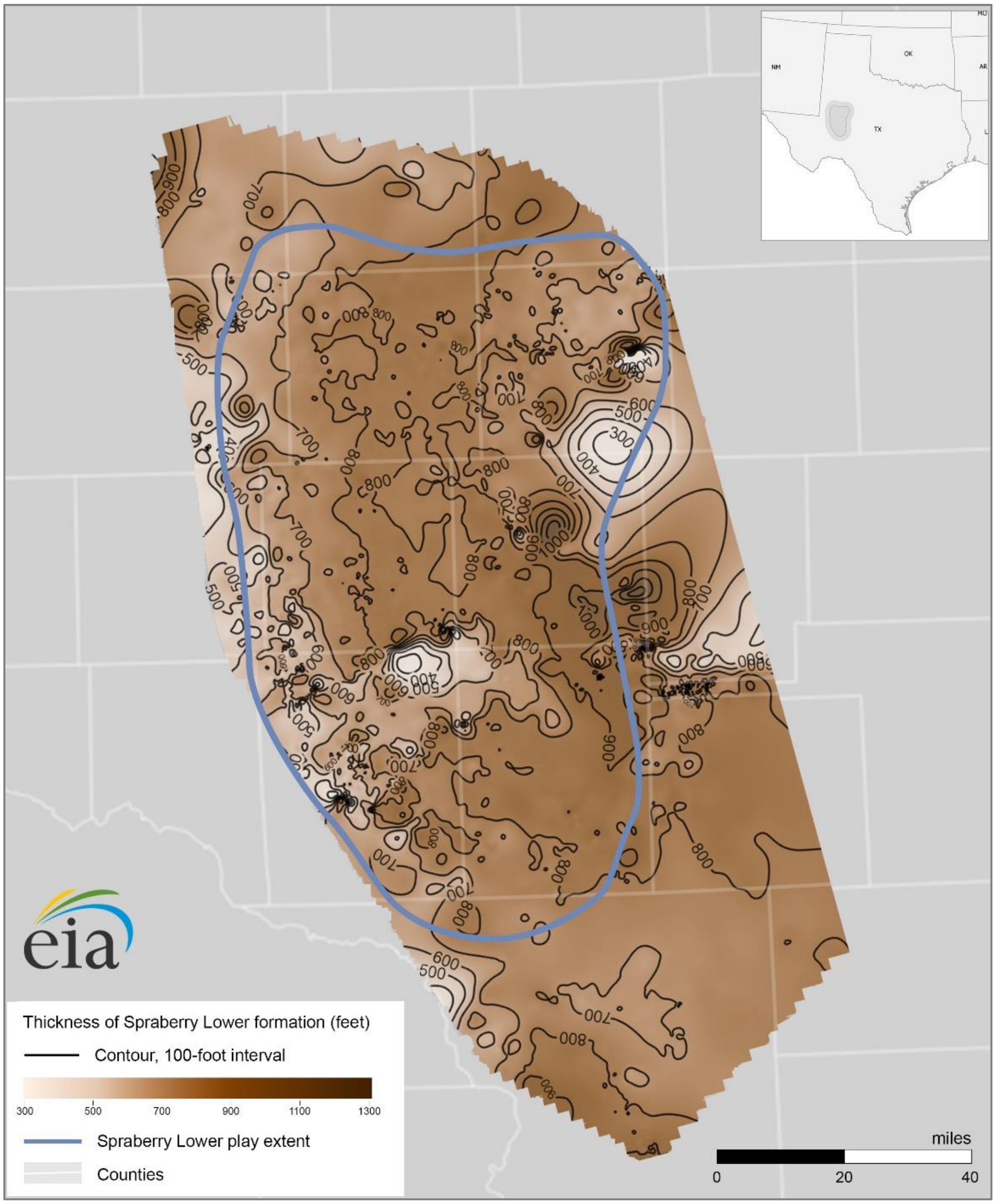
We constructed Spraberry Lower structure and thickness maps in the Midland Basin based on stratigraphic picks from 4,940 wells. Subsea depth of the Spraberry Lower bench in the Midland Basin varies from -2,250 feet in the south to -6,000 feet in the western part of the basin in areas next to the Central Basin Platform (Figure 18). Thickness ranges from about 600 feet to more than 900 feet thick. In some isolated areas in the central and eastern areas of the Midland Basin thickness is less than 400 feet (Figure 19).

Figure 18. Structure map of Spraberry Lower (Midland Basin)



Source: Map by the U.S. Energy Information Administration, based on data from Enverus Inc.

Figure 19. Thickness map of Spraberry Lower (Midland Basin)



Source: Map by the U.S. Energy Information Administration, based on data from Enverus Inc.

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