Oklahoma Shale Resource Plays

By Brian J. Cardott

INTRODUCTION

The petroleum system concept includes the generation, migration, and accumulation of hydrocarbons (Magoon and Dow, 1994; Magoon and Beaumont, 1999). Campbell and Northcutt (2001) described the petroleum systems of sedimentary basins in Oklahoma. Black, organic-rich shales are an important part of a petroleum system, serving as hydrocarbon source rocks, cap rocks, and reservoirs. The most important criteria for hydrocarbon source rocks are organic matter type (oil or gas generative), quantity (determined by Total Organic Carbon (TOC) content), and thermal maturity (e.g., oil, condensate, or gas window). Cardott (2012a) provided an introduction to vitrinite reflectance as a thermal maturity indicator. Known hydrocarbon source rocks in Oklahoma were described by Johnson and Cardott (1992), Wavrek (1992), and Schad (2004).

Shale resource systems (i.e., shale gas and tight oil) for gas, condensate, and oil are self-contained systems (hydrocarbon source, migration pathway, reservoir, and seal; Breyer, 2012; Jarvie, 2012a, b; Hackley and Cardott, 2016). Of those four aspects, the hydrocarbon source rock is the most important; without the hydrocarbon source, there is no hydrocarbon accumulation. In addition to hydrocarbon source potential, the shale reservoir must also have a brittle lithology to

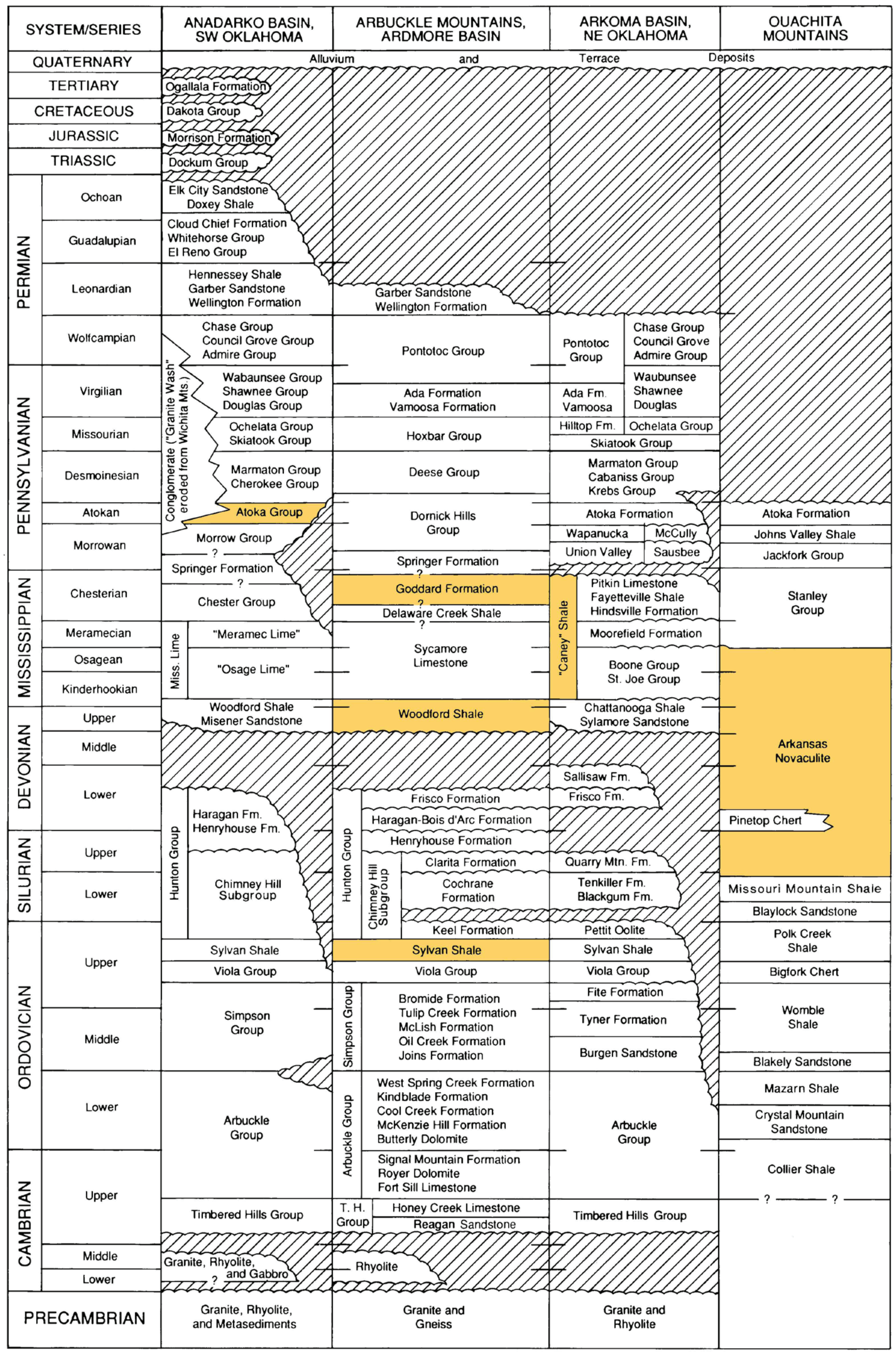

Figure 1. Generalized correlation of rock units in Oklahoma highlighting shale resource plays (modified from Johnson and Cardott, 1992).

generate natural and induced fractures for primary hydrocarbon migration (Cardott, 2006, 2008; Dong et al., 2017).

The objective of this article is to provide a brief summary of the primary shale resource plays of Oklahoma (Caney Shale, Woodford Shale, lower Springer/Goddard shale; Figure 1). Cardott (2013b) described the Sylvan Shale, Arkansas Novaculite, Barnett Shale, Atoka shale, and Pennsylvanian shale plays of Oklahoma and they will not be discussed here. The term "shale gas" refers to the production of thermogenic or biogenic methane from organic-rich shale/mudstone, while the term "tight oil" (aka shale oil, shale-hosted

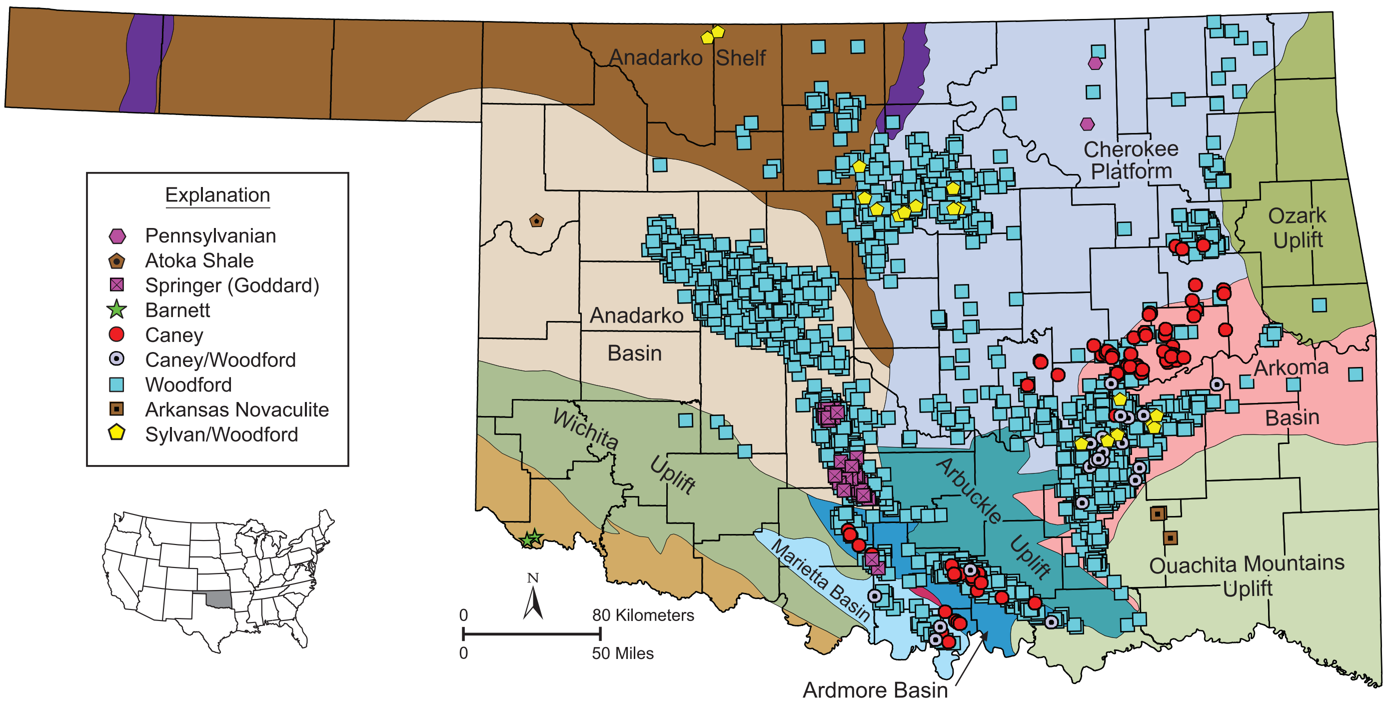

Figure 2. Map showing Oklahoma shale gas and tight oil well completions (1939–2016) on a geologic provinces map of Oklahoma (modified from Northcutt and Campbell, 1998).

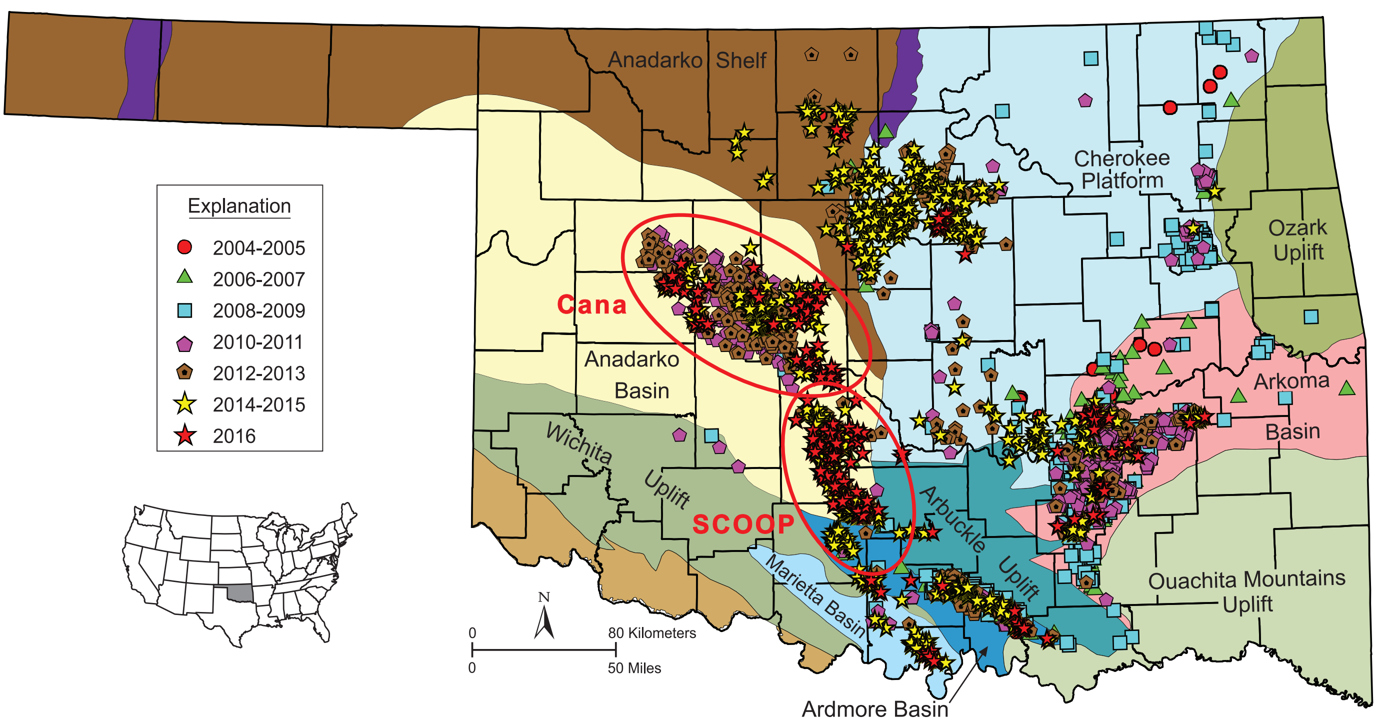

Figure 3. Map showing Woodford Shale-only gas and oil well completions (2004–2016) by year on a geologic provinces map of Oklahoma.

oil) refers to oil/condensate generated and produced from organic-rich shale/mudstone or adjacent, continuous organic-lean intervals (Jarvie, 2012a, b; Boak, 2014). Shale gas and tight oil are projected to be an important part of future U.S. gas and oil production (EIA, 2017).

METHODS

The Oklahoma Geological Survey maintains a database of all Oklahoma shale gas and tight oil well completions (http://www.ou.edu/content/ogs/research/energy/oil-gas.html) compiled from the Oklahoma Corporation Commission Form 1002A completion report. The database of 4,624 well completions from 1939 to February 2017 contains the following shale formations (in alphabetical order) and number of completions: Arkansas Novaculite (3), Atoka Group shale (1), Barnett Shale (2), Caney Shale or Caney Shale/Woodford Shale (125), Excello Shale/Pennsylvanian shale (2), Goddard Shale (lower Springer shale) (61), Sylvan Shale or Sylvan Shale/Woodford Shale (21), and Woodford Shale (4,409). Shale wells commingled with non-shale lithologies are not included. The database was originally restricted to shale-gas wells. Tight-oil wells have been added since 2005.

DISCUSSION

Caney Shale

Figure 2 shows 4,624 Oklahoma shale gas and tight oil well completions (1939–2016) on a geologic provinces map of Oklahoma. The first shale resource play in Oklahoma was the Mississippian-age Caney Shale (age equivalent to the Barnett Shale of Texas and Fayetteville Shale of Arkansas). The Caney Shale contains Type II kerogen (oil-generative organic matter) to Type III kerogen (gas-generative organic matter) with <1–9.79 wt.% TOC in eastern Oklahoma (Schad, 2004; Kamann, 2006; Maughan and Deming, 2006a). Well completions to the ductile, clay-rich Caney Shale in the Arkoma Basin in eastern Oklahoma (Hughes, McIntosh, Okfuskee, Pittsburg, Wagoner counties) in 2001–2010 resulted in relatively poor gas wells (initial potential (IP) gas rates of a trace to 1,125 thousand

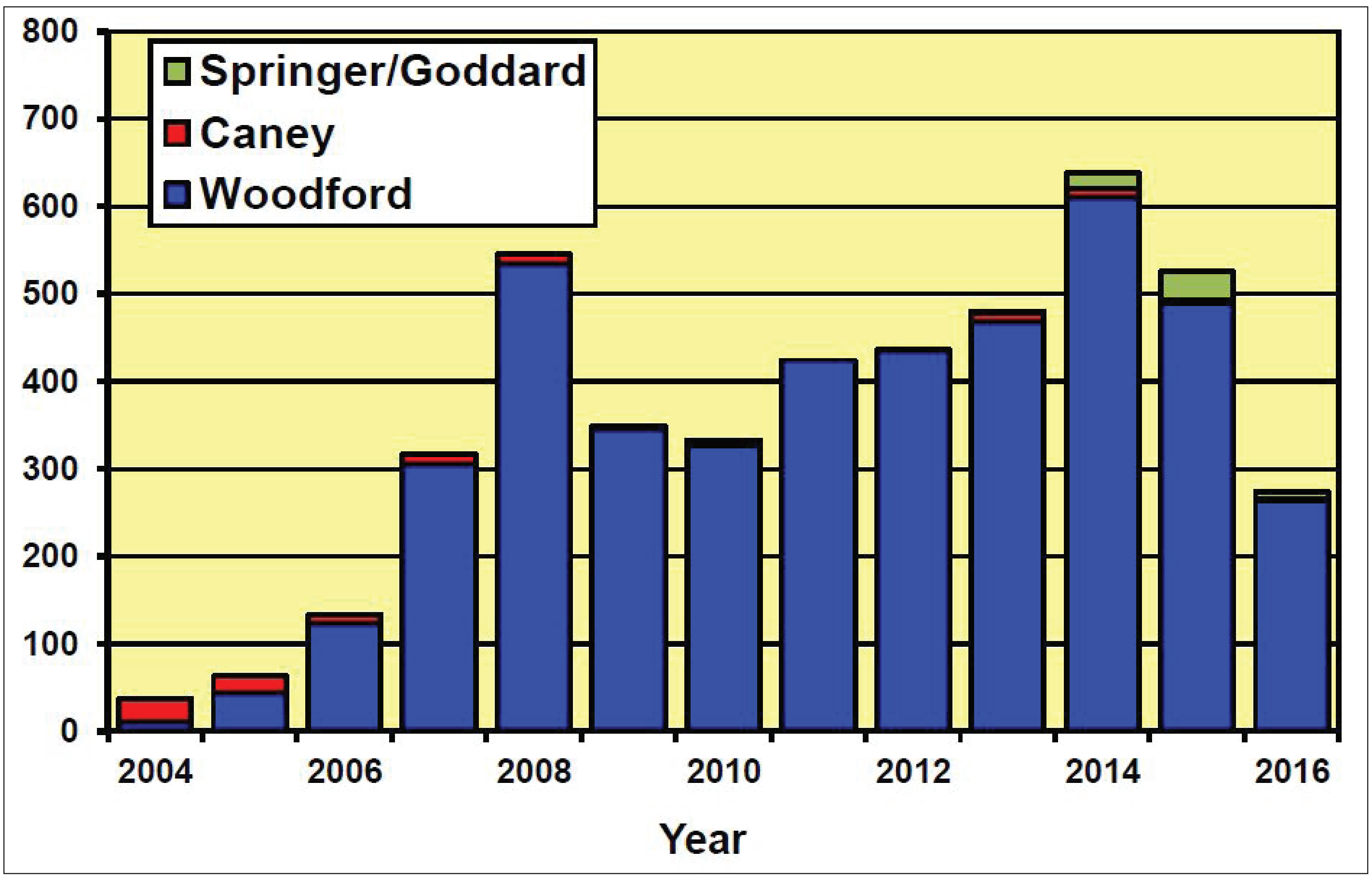

Figure 4. Histogram showing numbers of Woodford Shale, Caney Shale, and Springer/Goddard Shale well completions, 2004–2016.

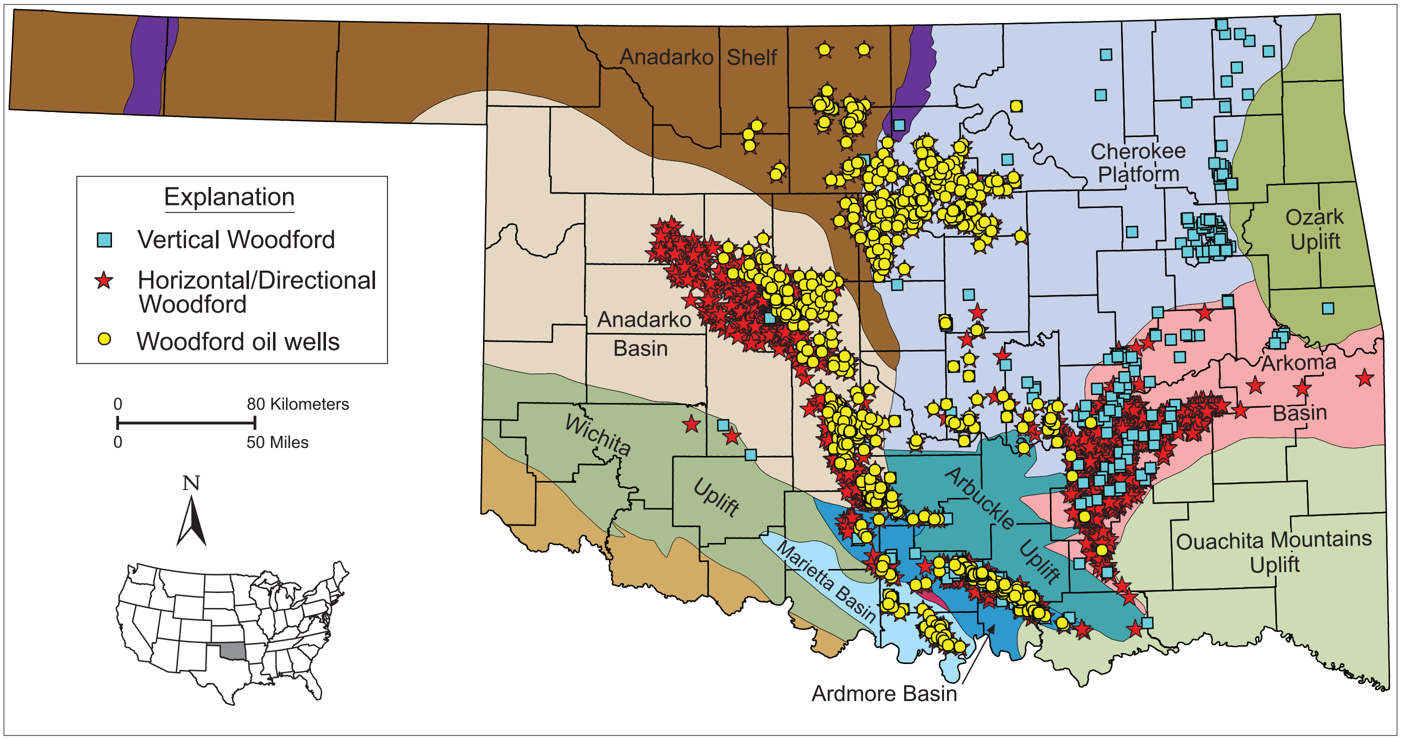

Figure 5. Map showing 4,389 Woodford Shale-only gas and oil well completions (2004–2016) by well type on a geologic provinces map of Oklahoma.

cubic feet per day (Mcfd); Schad, 2004; Maughan and Deming, 2006a, b; Andrews, 2007), while recent drilling (2012–present) in the Caney Shale in southern Oklahoma (Carter, Johnston, Love, Marshall, Stephens counties) have been more successful (IP gas rates of 57–2,801 Mcfd and IP oil/condensate (37–54° API gravity) rates of 11–620 barrels of oil per day (bopd)). Andrews (2007) showed that the best gas-producing Caney Shale well in the Arkoma Basin (Citrus Energy 1 Wild Turkey; IP 1,125 Mcfd) by 2005 was completed in siltstone facies instead of the predominant shale facies; the best gas and oil producing Caney Shale well in the Ardmore Basin (Mack Energy 1-31 Hickory Sticks; IP 296 Mcfd and 24 bopd) by 2005 was completed in limestone and siltstone/sandy-siltstone facies of the Caney Shale and Sycamore Limestone. All of the oil-producing Caney-only wells are in southern Oklahoma.

Woodford Shale

Cardott (2013a) provided an overview of the Late Devonian-Early Mississippian-age Woodford Shale: from hydrocarbon source rock to reservoir. The Woodford Shale contains Type II kerogen with <1–14 wt.% TOC with intervals as high as 25 wt.% TOC (Johnson and Cardott, 1992; Roberts and Mitterer, 1992).

Since 2004, well completions to the brittle, silica-rich Woodford Shale play of Oklahoma have expanded from primarily one (Arkoma Basin) to four geologic provinces (Anadarko Basin, Ardmore Basin, Arkoma Basin, and Cherokee Platform) and from primarily gas to gas, condensate, and oil wells. The Woodford Shale gas play began in the gas window (>1.4% vitrinite reflectance, VRo) in the Arkoma Basin in 2004 (Cardott, 2012b). The low price of natural gas beginning in 2009 shifted the focus of the Woodford Shale resource plays more toward condensate and oil areas. Figure 3 illustrates the expansion of the Woodford Shale oil/condensate play in the Anadarko Basin which began in the "Cana" (western Canadian County) area in 2007 and the "SCOOP" (South Central Oklahoma Oil Province) area in 2012.

The annual peak of 610 Woodford Shale well completions occurred in 2014 (Figure 4). The recent drop in oil prices beginning in mid-2014 has resulted in a significant decline in Woodford Shale completions (265 in 2016). Of the 4,389 Woodford-only well completions from 2004–2016, 91% (3,990 wells) are horizontal/directional wells and 9% (399 wells) are vertical wells; 1,204 Woodford Shale wells are classified as oil wells based on a gas-to-oil ratio <17,000:1 (Figure 5). Total vertical depths range from 368 ft

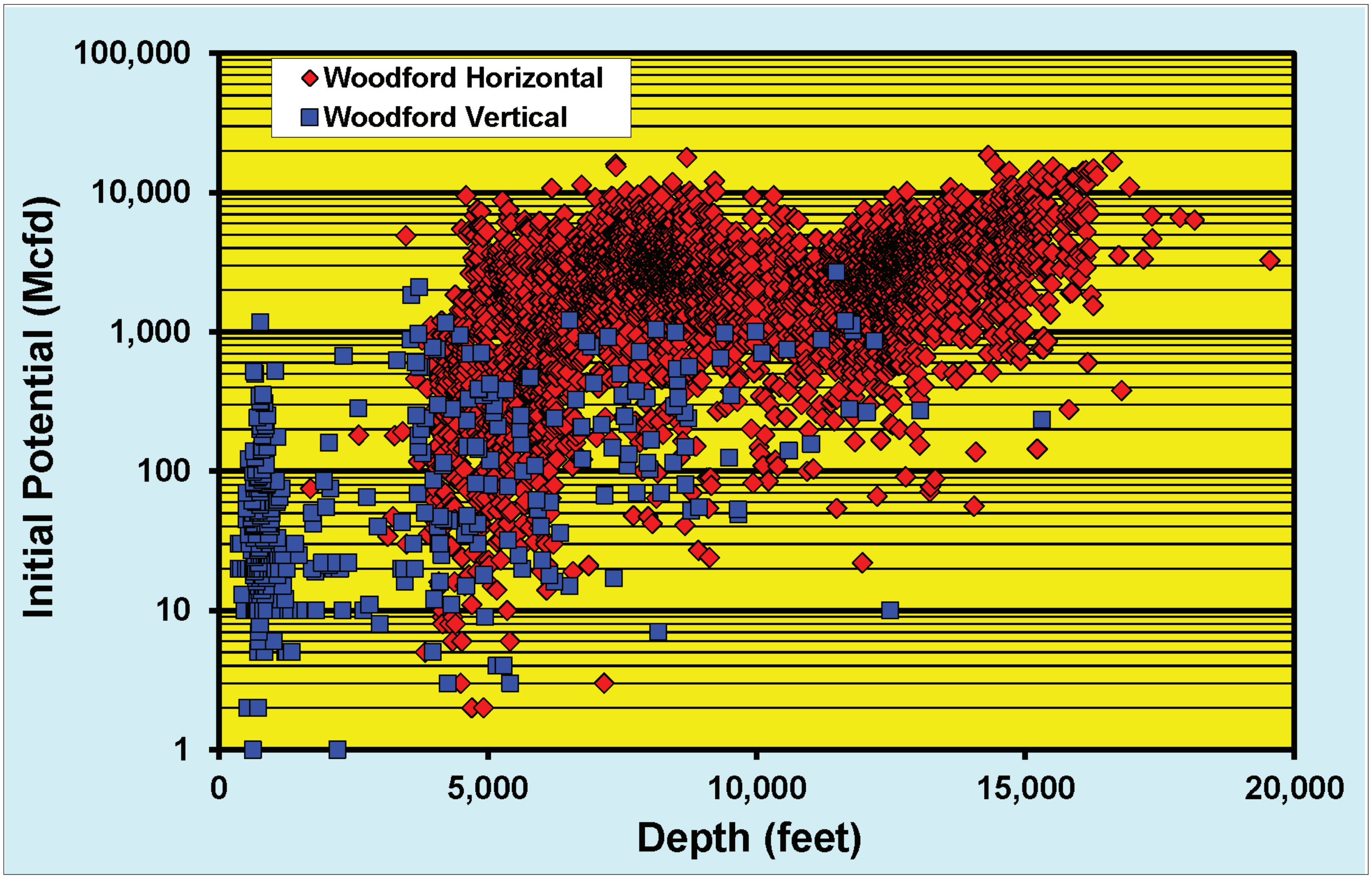

Figure 6. Chart showing initial potential gas rate vs. Woodford Shale total vertical depth (3,908 horizontal wells; 368 vertical wells).

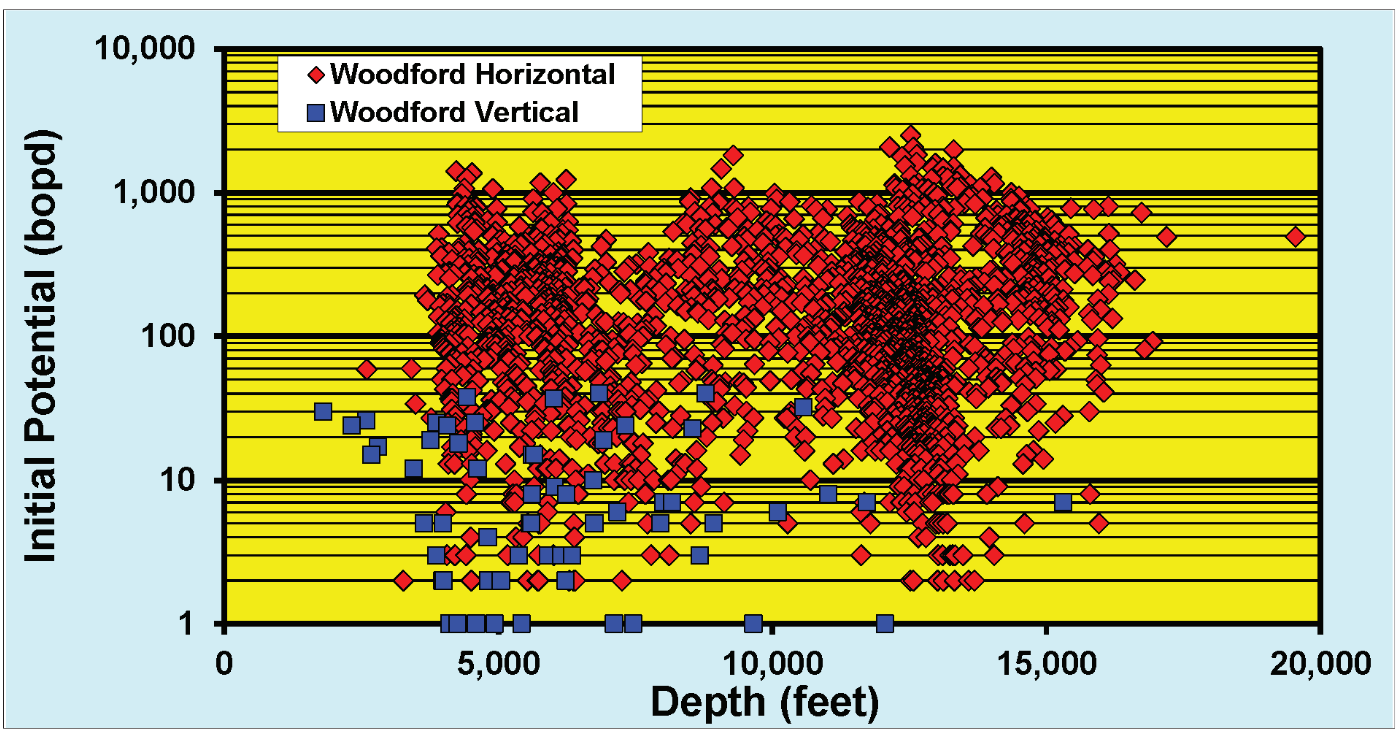

Figure 7. Chart showing initial potential oil/condensate rate vs. Woodford Shale total vertical depth (2,243 horizontal wells; 63 vertical wells).

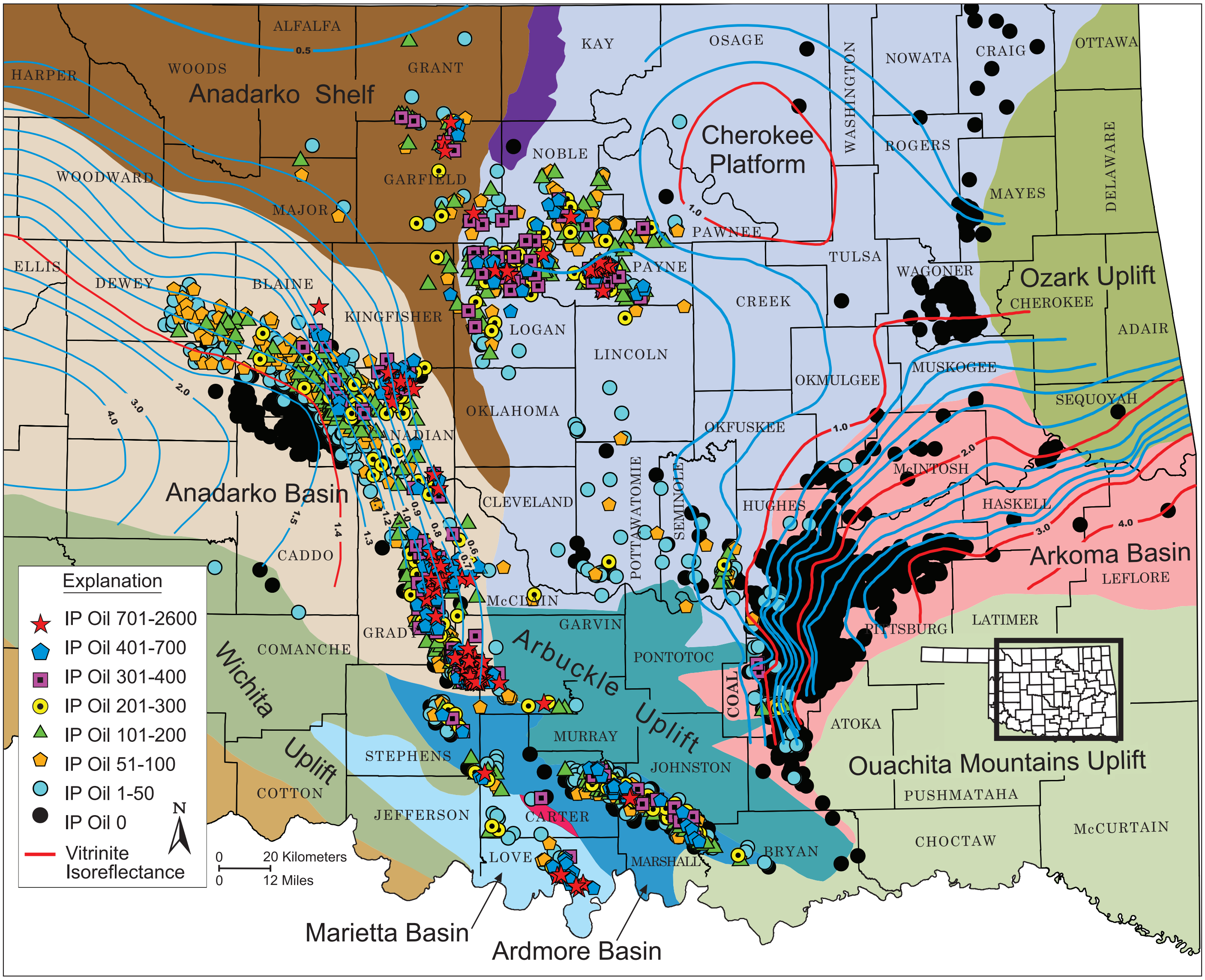

Figure 8. Map showing Woodford Shale-only initial potential oil rates on a geologic provinces map of Oklahoma with vitrinite isoreflectance contours (revised from Cardott, 2012b).

(Mayes Co.) to 19,547 ft (Grady Co.). IP gas rates range from a trace to 18.6 million cubic feet per day. IP oil/condensate rates range from a trace to 2,505 bopd (Garvin County). Reported oil gravities range from 21 to 67 API degrees (49 API degrees is the approximate boundary between oil and condensate). Figures 6 and 7 compare gas and oil/condensate initial potential rates to total vertical depth in vertical and horizontal Woodford Shale wells, illustrating the advantage of horizontal wells.

Jarvie and others (2005) proposed the following thermal maturity limits for the Barnett Shale (<0.55% VRo, immature; 0.55–1.15% VRo, oil window; 1.15–1.40% VRo, condensate–wet-gas window; >1.4% VRo, dry-gas window). The four Woodford shale plays in Oklahoma are as follows (Figure 8):

1) western Arkoma Basin in eastern Oklahoma with thermogenic methane production at thermal maturities from <1% to >3% VRo and oil/condensate production up to 1.67% VRo (Cardott, 2012b);

2) Anadarko Basin (Cana and SCOOP plays) in western Oklahoma with thermogenic methane production at thermal maturities from <1% to >1.6% VRo and oil/condensate production at thermal maturities up to ~1.5% VRo. See Cardott (2014) for a discussion of Woodford Shale oil production related to thermal maturity.

3) Ardmore and Marietta Basins in southern Oklahoma with oil, condensate, and thermogenic methane production at thermal maturities <1.8% VRo, primarily in the oil window;

4) north-central Oklahoma (Cherokee Platform and Anadarko Shelf) with oil and thermogenic methane production at thermal maturities <1.0% VRo. Cardott (2015) described a Woodford Shale thermal anomaly in Osage County.

Three recent U.S. Geological Survey oil and gas assessments have included the Woodford Shale in Oklahoma. Houseknecht and others (2010) conducted an assessment of the natural gas resources of the Arkoma Basin Province in which they determined a Woodford Shale Gas assessment unit total undiscovered resource of 10.7 trillion cubic feet of gas (Tcf). Higley and others (2014) conducted an oil and gas assessment of the Anadarko Basin Province in which they determined a Woodford Shale Oil assessment unit total undiscovered oil resource of 393 million barrels of oil (MMbo) and a Woodford Shale Gas assessment unit total undiscovered gas resource of 16.0 Tcf. Drake and others (2015) conducted an oil and gas assessment of the Cherokee Platform Province of Kansas, Missouri, and Oklahoma. The Woodford/Chattanooga Total Petroleum System included the Woodford Shale Oil assessment unit (total undiscovered oil resource of 460 MMbo and total undiscovered gas resource of 644 billion cubic feet (Bcf)) and Woodford Biogenic Gas assessment unit (total undiscovered resource of 416 Bcf).

Springer/Goddard shale

The newest shale resource play in Oklahoma (2013–present) is the Mississippian-age lower Springer shale (Goddard shale; Andrews, 2003) in the SCOOP area in the southeastern Anadarko Basin (Figures 1 and 2). Wang (1993) and Wang and Philp (1997, 2001) reported 36 Springer shale samples in the Anadarko Basin contained Type III kerogen with an average TOC value of 1.60 wt.% (range of <1–4.31 wt.%). Schad (2004) reported Goddard samples had 1.05–8.17 wt.% TOC from the New Dominion LLC 1 Beebe core from McIntosh County in the Arkoma Basin. Pearson (2016) concluded that the Goddard shale in the Anadarko Basin had Type II kerogen with <1–7.77 wt.% TOC.

Of 58 horizontal Springer/Goddard shale well completions in Carter, Garvin, Grady, and Stephens counties in 2013–2016, IP gas rates were 4–4,311 Mcfd and IP oil/condensate rates (41–54° API gravity) were 10–2,785 bopd at vertical depths of 11,332–14,618 ft. The Springer/Goddard shale play is held by production so operators in the play in 2015 indicated no new drilling was planned for the year thereby holding on for higher oil prices (Toon, 2015b). Summaries of the play are in Bates (2015), Darbonne (2015), Nash (2014), Redden (2015), and Toon (2015a).

ACKNOWLEDGEMENTS

I thank Rick Andrews (OGS retired petroleum geologist) for a critical review of the manuscript and Jim Anderson (OGS Cartography Manager) for preparation of the maps.

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About the Author

Brian established the Organic Petrography Laboratory (OPL) at the Oklahoma Geological Survey in 1981. His primary research involves gas shales and tight oil (primarily the Late Devonian–Early Mississippian Woodford Shale), coalbed methane, and the petrologic characterization of coals, hydrocarbon source rocks, and solid hydrocarbons (e.g., asphaltites and asphaltic pyrobitumens) of Oklahoma.

Brian has written more than 60 articles and books on coal, coalbed methane, gas shales, unconventional energy resources, hydrocarbon source rocks, solid hydrocarbons, organic weathering, vitrinite reflectance, and graptolite reflectance.

Brian is a member of The Society for Organic Petrology (serving as President, 1995-1996), International Committee for Coal and Organic Petrology, American Association of Petroleum Geologists (serving as President of the Energy Minerals Division, 2004-2005), Geological Society of America, Oklahoma City Geological Society, and Tulsa Geological Society.