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OKLAHOMA GEOLOGY NOTES

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CONSERVING OKLAHOMA'S FIRST GEOLOGIC MAP

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OKLAHOMA GEOLOGICAL SURVEY

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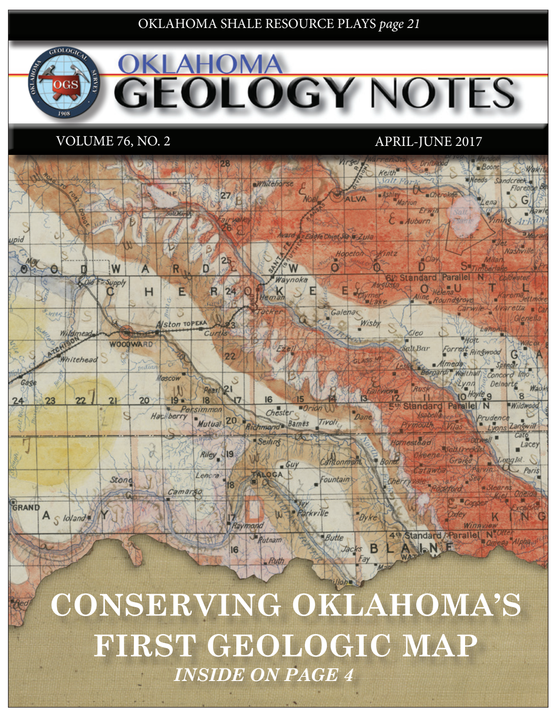


Cover: A zoomed in look at part of Oklahoma's first geologic map. (Designed by Ted Satterfield)

From The Director

A Historic Map and Oklahoma's Shale Resource Plays

This issue of the Oklahoma Geology Notes reports on the efforts to properly conserve, and prominently display, the first geologic map of the Oklahoma Territory, prepared by Charles N. Gould, who was a geologist for the Oklahoma Territorial Geological and Natural History Survey, and later became the first director of the Oklahoma Geological Survey (OGS). The map was drawn in 1904, just four years after Gould came to Oklahoma, and just six years after the creation of the Territorial Survey. Old maps are a remarkable source of fascination for many geologists. We are commonly impressed by how careful, perceptive, and productive early geologists were. Gould and his team had very little prior information, yet they mapped a significant fraction of the state in those four years. The next geologic map, which covered the entire state, was prepared by Hugh Miser in 1927. Miser updated this map in 1954, and even though he was guided by a much more refined stratigraphic column, many contacts match up fairly well with Gould's map drawn 50 years earlier.

Jeremy Boak
OGS Director

The new map the OGS is preparing, which is estimated to be completed within the next 10 years, will continue the refinement of Gould's original, and reflect the important evolution of sedimentary geology and of our understanding of the evolution of the earth over nearly 70 years, including the revolutionary effects of plate tectonics on that understanding. Yet, the hard and thoughtful work of our predecessors will continue to be reflected in the product. No matter how the interpretations change, good data are still good data, and must be incorporated in our maps, reports, and other publications. Gould's contributions will be memorialized in the Laurence S.Youngblood Energy Library, but also in the minds of the geologists who stand on his shoulders. All are invited to visit and view this vital piece of Oklahoma history.

The second part of this edition of the Notes is a discussion of the formations that constitute the shale resources of Oklahoma from organic petrologist, coal geologist and source rock expert, Brian Cardott. He focuses on the three most important shale formations, as measured by the number of shale gas and tight oil wells completed in them: the Woodford, Caney, and Goddard/lower Springer shale units. The Woodford particularly has long been known as a source rock, but has come into its own as a reservoir with the development of long reach horizontal wells and multistage hydraulic fracturing. The current boom in the South Central Oklahoma Oil Province (SCOOP) and the Sooner Trend Anadarko Canadian Kingfisher (STACK – also a convenient reference to its multiple stacked target zones) plays depends in large part upon production from the Woodford. It is also producing from overlying limestone of the Mississippian (in the STACK) that was charged largely by the Woodford source rocks, as well as the more recently developed Springer Shale (in the SCOOP). These shale gas and especially tight oil plays have taken on great importance as lower oil prices and restrictions on produced water injection have slowed production from other plays that had their own boom in the earlier part of this decade — the Hunton and Mississippian Limestone plays in central and northwestern Oklahoma.

As always, the OGS welcomes comment on these articles and input on topics of interest to the Oklahoma geologic community. Feel free to communicate directly with the authors, or with me if you have questions or thoughts on the land, mineral, water, and energy resources that keep our geologists questing for new knowledge of the earth beneath us.

Conserving Oklahoma's First Geologic Map

BY BRITTANY PRITCHETT WITH JIM ANDERSON

THE DISCOVERY

THE first geologic map of Oklahoma underwent professional conservation and preservation these last two years and will soon be on display in the Laurence S. Youngblood Energy Library in Sarkeys Energy Center (Figure 1). After decades of residing in an Oklahoma Geological Survey (OGS) storeroom, hidden under miscellaneous maps and boxes, OGS cartographer Jim Anderson and I re-discovered the map in June 2014 while searching for other maps. Looking at the map with the handwritten notes, contacts, and water coloring, Anderson and I immediately knew we had something special. The colors were vibrant, and, with the exception of three damaged areas, it appeared to be in decent shape. The printed title and date on the paper read "Map of Oklahoma Territory, 1898", nine years before statehood, but a handwritten note in the margin read "Preliminary Geological map of Oklahoma, 1904", followed by "Chas. N. Gould".

THE HISTORY

The early 1900s in Oklahoma were a time of great change for the territory. Just a decade prior, the land run of 1889 and its successors opened up the unassigned lands to new settlers. With Native American resettlement on-going since the 1830s, coupled with the onslaught of settlers in the 1890s, the population of the fledgling territory grew rapidly during the 19th and early 20th centuries. From the years 1890 to 1907 alone, the population of Oklahoma Territory swelled from 78,475 up to 733,062 people (US Census, 1907). Hastened along with a push for statehood, the territory

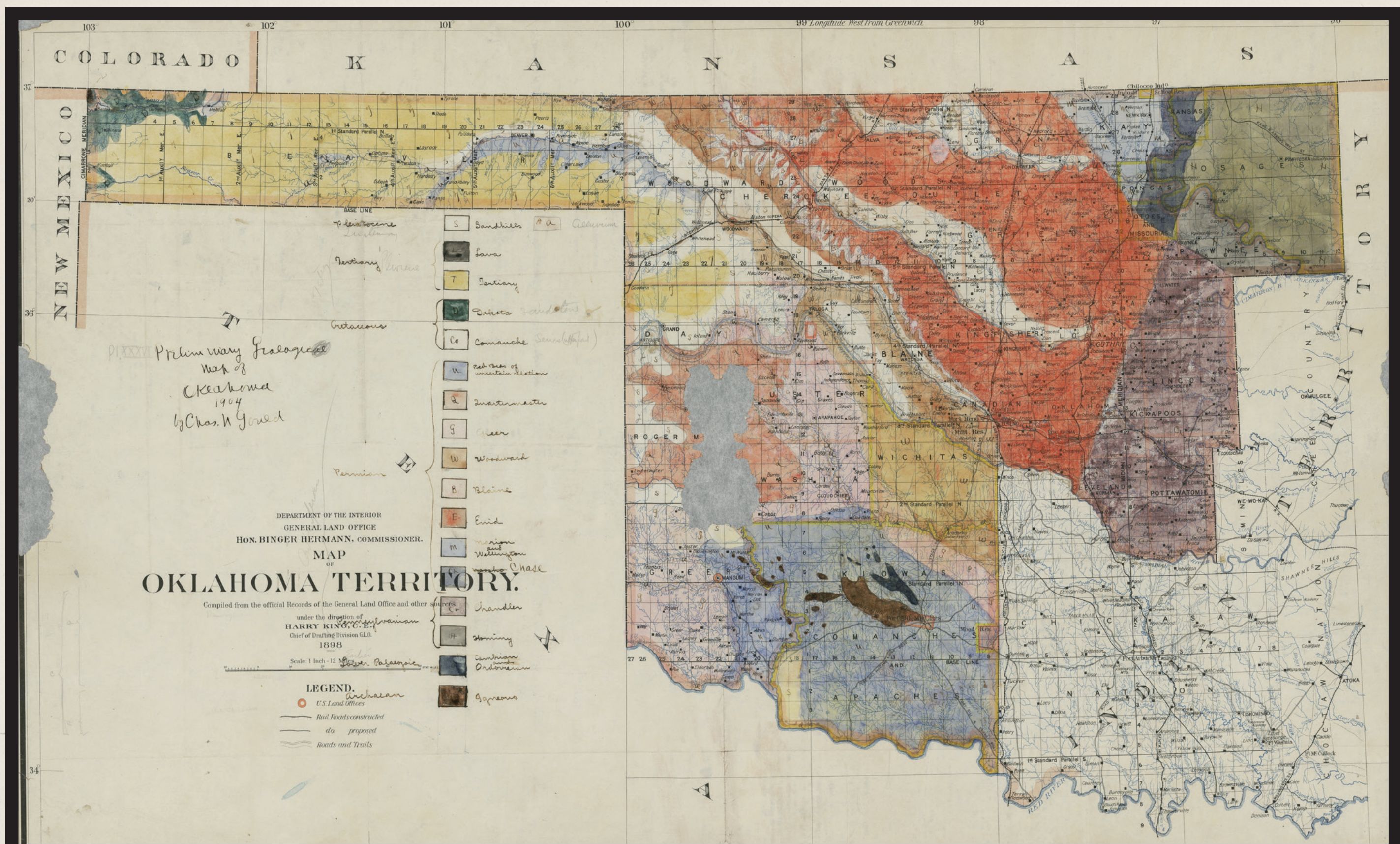
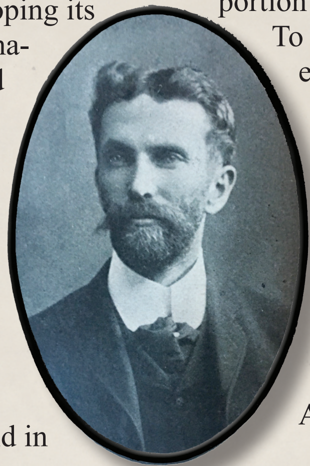


Figure 1. The first geologic map of Oklahoma created by Charles Gould. See large version of map on pages 16-17.

and federal government recognized the need to investigate the water and mineral resources in order to lay the groundwork for infrastructure, agriculture, and industry for the future state. In 1898, an act by the fifth session of the Legislative Assembly of Oklahoma Territory established the Oklahoma Territorial Geological and Natural History Survey "for the purpose of beginning and continuing the geological and scientific survey of this territory, and of discovering and developing its natural resources, and disseminating information in regard to its agriculture, mining, and manufacturing advantages" (Van Vleet, 1902, p. 9).



Dr. Charles Gould

Charles N. Gould, "the father of Oklahoma geology" (Figure 2), came to Oklahoma in 1900 to serve as a geologist for the Oklahoma Territorial Geological and Natural History Survey and to found the University of Oklahoma's School of Geology. This historic map, drawn by Gould in 1904, was the result of less than four years of geologic mapping and reconnaissance by the Territorial Survey. The final version of the map was published in 1905 in Gould's United States Geological Survey (USGS) Water-Supply Paper (WSP) 148: Geology and Water Resources of Oklahoma. WSP 148 also served as Gould's PhD dissertation at the University of Nebraska, where the thesis on file is a USGS printed copy of WSP 148.

According to the letter of transmittal at the beginning of WSP 148, the goal of the paper was to "[shed] light upon the water resources of this section, regarding which but little has hitherto been known, and will be of considerable value in the development of this portion of the country" (Newell in Gould, 1905) To accomplish this goal, Gould needed to first examine the geology of Oklahoma Territory: "As the conditions of the water supply depend almost wholly upon the character and position of the rocks, it is necessary to outline the geology of the Territory before giving a detailed description of the water supply" (Gould, 1905, p. 22).

Before 1900, very little geologic information was known about the territory. According to an account by Gould:

"When I came to the University of Oklahoma in 1900 and organized the department of Geology there was need for a geologic map, but none was available. In fact at that time there was almost nothing known regarding the geology of either Oklahoma or Indian territory. At that time it was

Figure 2. Charles Gould, "the father of Oklahoma geology", is shown here collecting fossils at a site near Perry during an early expedition. This photo, and the photo of Gould above and of Joseph A. Taff on pg. 9, are courtesy of the Western History Collections on the University of Oklahoma campus in Norman.

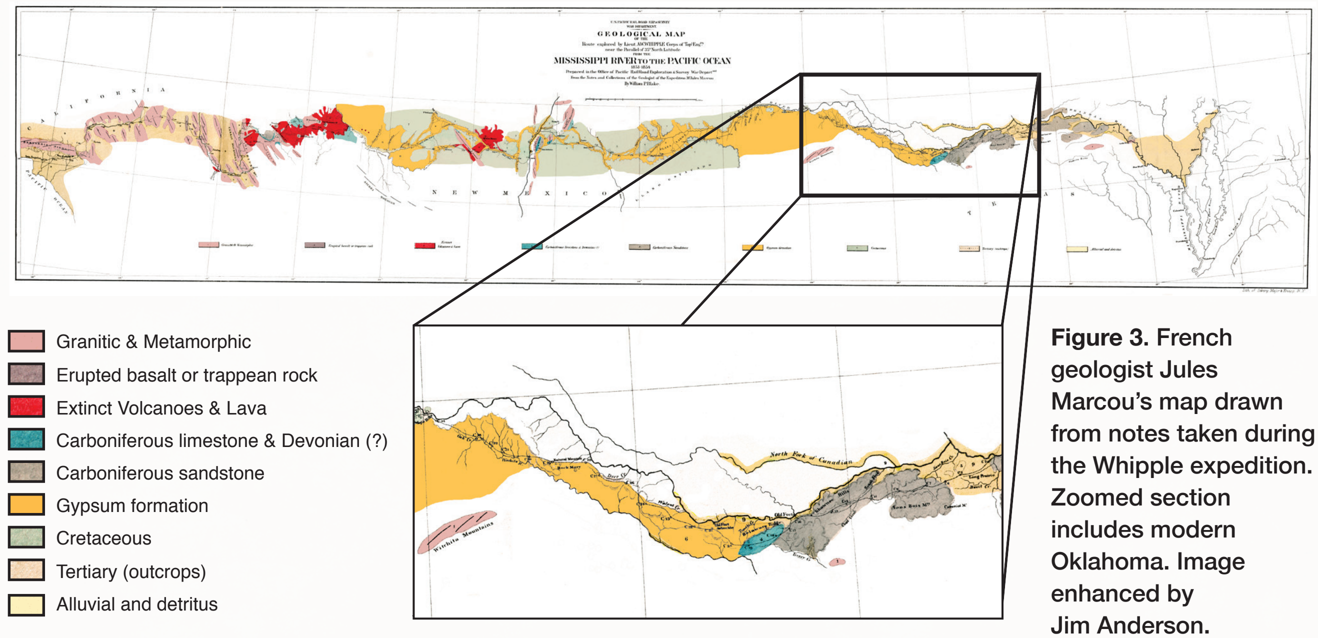


Figure 3. French geologist Jules Marcou's map drawn from notes taken during the Whipple expedition. Zoomed section includes modern Oklahoma. Image enhanced by Jim Anderson.

Figure 4. Gould and members of his team standing next to his covered wagon. Gould is on the far right, wearing the white shirt. Photo courtesy of the Western History Collections on the University of Oklahoma campus in Norman.

a virgin field, all unexplored." (Gould, 1927, University of Oklahoma Western History Collection).

American military expeditions crisscrossed the territory in the 19th century, and French and Spanish explorers before that, taking rudimentary notes on the geology of Oklahoma. Prior to Gould, the most extensive study was undertaken by French geologist Jules Marcou in 1853 when he accompanied the Whipple expedition through modern day Oklahoma (Whipple, 1856; Marcou 1856; Hill, 1887). The Whipple expedition was charged by the U.S. Secretary of War—and future Confederate President—Jefferson Davis with exploring along the 35th parallel for a railroad route to the Pacific. The Expedition traveled from the Mississippi River in Louisiana to the Pacific Ocean near Los Angeles (Figure 3). Their Oklahoma traverse followed a route resembling modern day Interstate 40, moving along the Canadian River from Fort Smith, Arkansas to the Antelope Hills in Ellis County, Oklahoma. Along their 1,892 mi. route, Marcou took detailed notes and mapped in swaths ranging from 25- to 50-mi. wide for the U.S. War Department (Whipple, 1856). The Whipple expedition was actually one of five parallel expeditions, now known as the Pacific Railroad Surveys. In the end, the private railroad companies decided to build the transcontinental railroad along a route from Council Bluffs, Iowa to San Francisco, California. Nevertheless, the federal surveys provided valuable new topographic, geologic, biologic, and anthropologic data across approximately 400,000 sq. mi. of the western United States.

While Marcou mapped along a narrow 25- to-50-mi-wide swath in Oklahoma, roughly 24 million acres of Oklahoma Territory still laid predominately unexamined by Marcou or other scientists by 1900. Exploring in their covered wagon (Figure 4), Gould and his team traversed remote areas, occasionally benefitting from "old" established routes such as the Camp Supply Trail and the Chisholm Trail. Gould described the field party's transportation:

"The first Geological Survey Party started in June 1900 from the campus of the University of Oklahoma here at Norman and travelled by covered wagon drawn by two cow ponies, in the northern and western parts of the territory of Oklahoma. If we made 20 miles a day we were doing well. Each summer from 1900 until statehood in 1907 was spent in the field securing data for a geologic map." (Gould, 1927, University of Oklahoma Western History Collection).

Gould relied on Marcou's map and notes when in the vicinity of the Whipple route and even located some geologic sites that Marcou had visited:

"From Taloga we kept on south to Arapaho, where we had the horses shod, and then drove several miles west where we found, in the hills along Barnitz Creek, large deposits of fossil oyster shells. In 1853, Jules Marcou…had found the same deposits of shells along this creek, which he called Comet Creek." (Gould, 1959, p. 89).

Gould named these rocks the Comanche Series, which included all of the Lower Cretaceous rocks in Oklahoma. If you look closely at Gould's map of western Oklahoma, you can see small "Co"s dotting the geologic map where Gould identified his Comanche Series. He described it as such:

"In general the Comanche or Lower Cretaceous rocks in Oklahoma consist of limestone and shales. In many of the western counties these deposits are found on hillsides and are known locally as 'shell rock,' because they are composed largely of fossil shells belonging chiefly to some member of the oyster family. Outcrops of the Comanche series are known to occur in the following counties: Woodward, Dewey, Custer, Day, Washita, Roger Mills, and Beaver. In every instance these rocks lie on the eroded surface of the old red beds floor, and in many instances apparently upon the flank of a former pre-Cretaceous red beds hill." (Gould, 1905, pg. 78).

These same scattered Cretaceous fossil oyster deposits were most recently discussed by OGS geologist Neil Suneson in 2012. Gould's Comanche Series is now recognized as the Lower Cretaceous Kiowa Limestone and Dakota Sandstone (Suneson, 2012).

However, Gould and his team were not alone in their quest to map modern-day Oklahoma. A contemporary to Gould, USGS geologist Joseph A. Taff mapped in nearby Indian Territory and is responsible for many of our familiar formation and group names in the southeast part of the state. Taff also contributed to Gould's 1904 map by helping Gould map the Wichita Mountains in 1901. While Taff is not credited on the

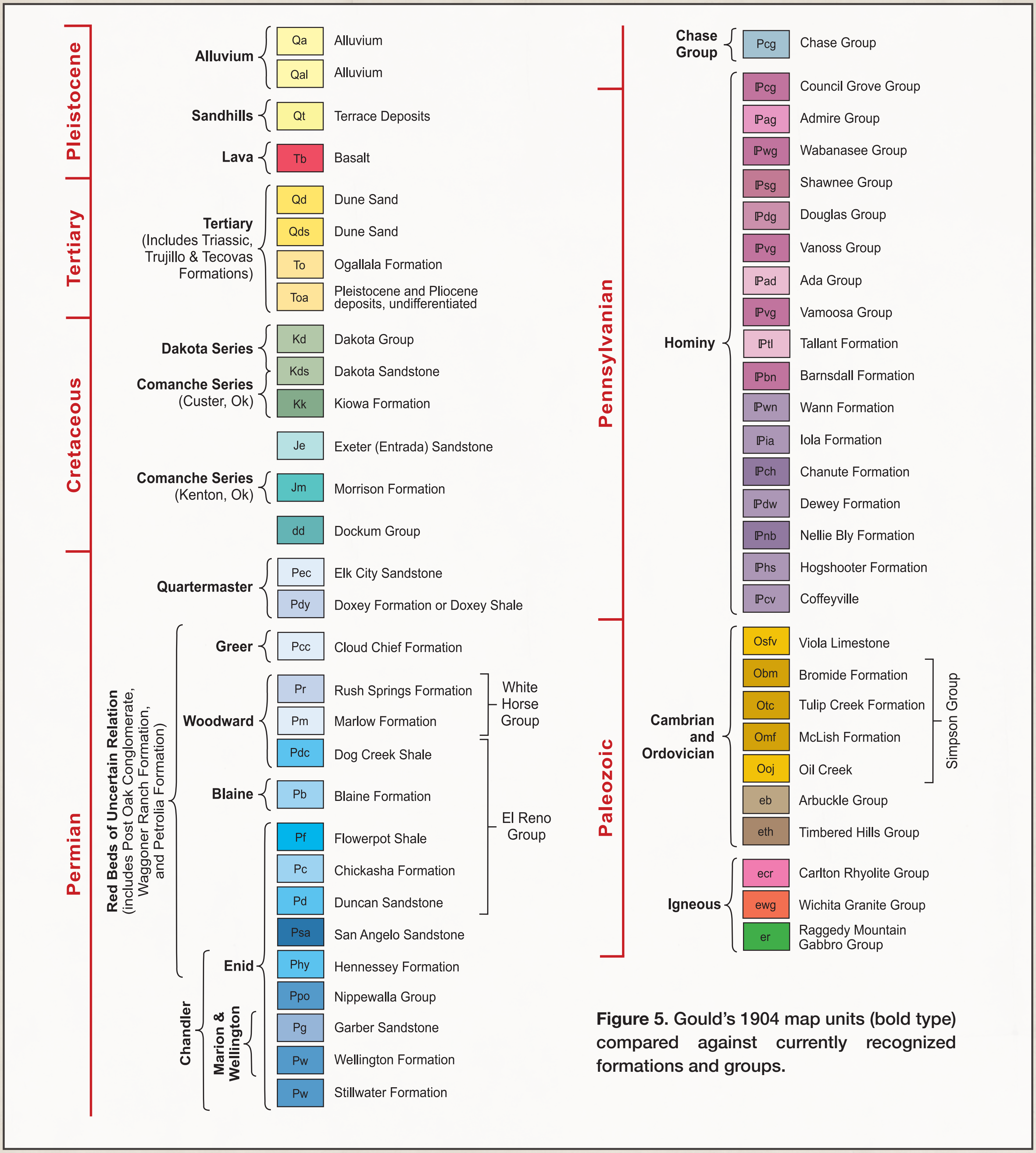


Figure 5. Gould's 1904 map units (bold type) compared against currently recognized formations and groups.

geologic map of Oklahoma Territory, Gould did cite Taff in the sources section of his WSP 148 in which the map was printed: "…in 1901, in connection with Mr. Joseph A. Taff, [I] spent a month making a map of the Wichita Mountains" (Gould, 1905, pg. 11). From their 1901 field work Taff and Gould produced a detailed map of the Wichita Mountains entitled "Geologic Map of the Wichita Mountain Region" that was first published in Taff's 1904 USGS Professional Paper No. 31 (PP 31) "Preliminary Report on the Geology of the Arbuckle Mountains in Indian Territory and Oklahoma". On the map, Taff is listed as first author and Gould as second. In the report, Taff cites Gould's collaboration and notes:

> *"With the assistance of Mr. Gould all the*

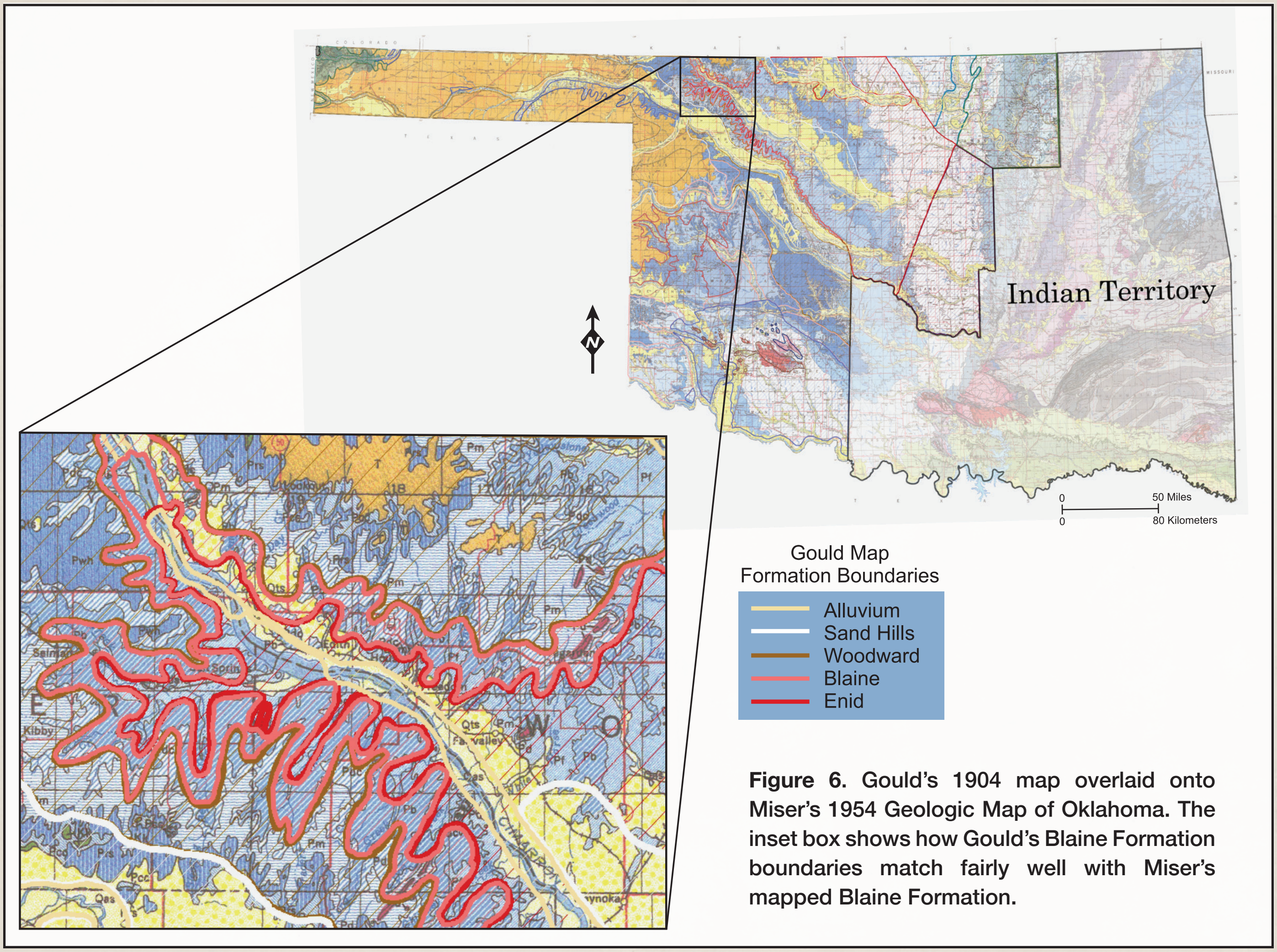
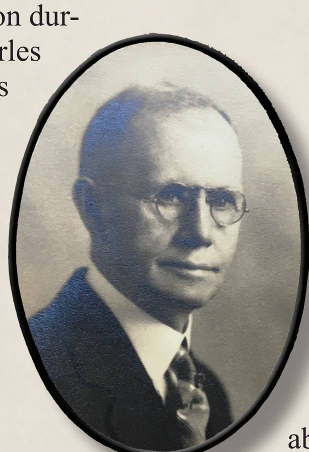


Figure 6. Gould's 1904 map overlaid onto Miser's 1954 Geologic Map of Oklahoma. The inset box shows how Gould's Blaine Formation boundaries match fairly well with Miser's mapped Blaine Formation.

known igneous areas and the contacts between the igneous masses and the formations of stratified rocks were mapped by traverse surveys, checked by locations on section and quarter-section corner stones." (Taff, 1904, pg. 53).

Gould and Taff stayed in communication during their mapping years, during which Charles Gould also reviewed an early draft of Taff's PP 31. His review is available in the Gould collection in the University of Oklahoma's Western History Collection. Additionally, Taff and Gould's "Geologic Map of the Wichita Mountain Region" was published a second time in Gould's WSP 148.



Joseph A. Taff

THE GEOLOGY

Gould ended up dividing Oklahoma's geology into 17 different groups, formations, and what he named "districts" to describe large areas of land with repetitious formations. Some of the groups and formations are familiar today such as the Chase Group and Blaine Formation. However, most of the unit names/terms used on the Gould map have since been divided into more formations and formalized (e.g., Gould's "Igneous" is now defined as the Wichita Granite Suite, The Raggedy Mountain Gabbro Group, and the Carlton Rhyolite).

I correlated the Gould units used in the 1904 map with modern units using the Oklahoma Geologic Quadrangle (OGQ) maps (Figure 5). I also overlaid Gould's contacts onto Miser's 1954 Geologic Map of Oklahoma for comparison using ArcGIS (Figure 6). Gould's original 17 units can be correlated with 59 currently recognized formations and/or groups. While Gould's units were much more general than current ones, many of his contacts line up remarkably well with units on modern maps — especially considering that Gould's base map did not contain topographic data. The 1904 map was originally drafted on an 1898 General Land Of-

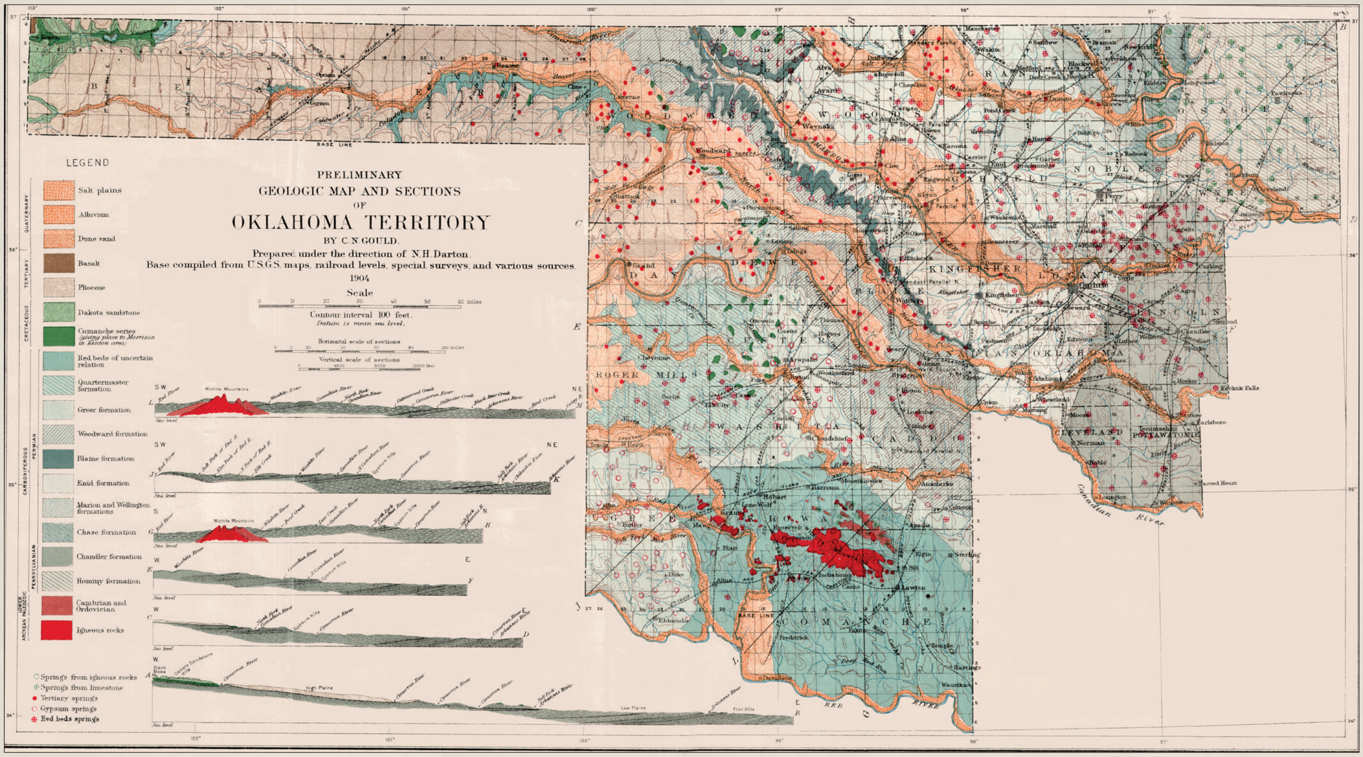


Figure 7. This is the finished geologic map published in 1905 in the USGS Water Supply Paper (WSP) No. 148.

fice (GLO) map made by Harry King, the chief of the drafting division of the GLO. This base map contained information on relief, drainage, Native American territories, districts, roads, trails, and railroads, but not topographic data. However, the final published map used a different base, which did include general topographic data (Figure 7).

The geologic map of Oklahoma published in WSP 148 in 1905 used a USGS base compiled from "USGS maps, railroad levels, special surveys, and various sources" (Gould, 1905). Additional information on the sources was not published in the report or on the map. When Gould mapped for his WSP 148, most of Oklahoma territory did not have USGS topographic maps available. Oklahoma City, Stillwater, and Norman were some of the earliest (1892-1893) locations to have topographic maps (Map available on OGS website). Many parts of western Oklahoma did not have published USGS topographic maps until the 1940s and 1950s. It is likely that the 1905 USGS base map for WSP 148 was made specifically for that publication. Since Gould's 1904 GLO base map had drainage information, his geologic contacts near the river systems match the contours on the 1905 USGS map. However, his contacts in the Wichita Mountains don't closely line up with the contour data on the 1905 USGS map, suggesting that the contour data were added after Gould had already mapped the geology.

Despite not having topographic data to locate himself and draw his geologic contacts on, Gould's first mapping attempt was reasonably accurate, especially in the western half of the territory. The Blaine Formation, Quartermaster (Doxey Shale), Tertiary, and Alluvium contacts were particularly close to modern ones (Figure 6). The biggest difference between Gould's map and the OGQs are his Hominy and Chandler Districts in the east.

Running over 100 mi., Gould's contact between his Pennsylvanian Chandler District and Permian Enid Formation is startlingly straight. The Pennsylvanian Chandler-Hominy contact is also a straight line. In stark contrast to the detailed mapping in western Oklahoma, the easternmost part of the map is blocky and generalized. Straight lines are not often found in nature, so why would Gould draw these particular contacts this way? Gould himself answered this question in his WSP 148:

> *"The line of separation between the Pennsylvanian and the Permian, which make up the greater part of the Territory, has never been sharply drawn. For reasons discussed later this line can not [sic] be drawn with any degree of accuracy until considerable work has been done in the way of tracing formations in northeastern Oklahoma and until fossils have been collected*

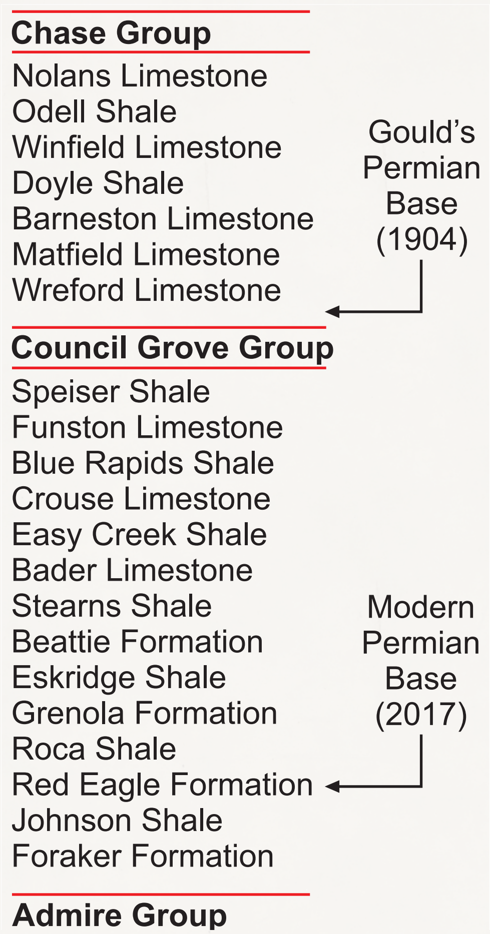


Figure 8. Stratigraphic column showing Gould's Permian base versus the modern Permian base.

and identified." (Gould, 1905, pg. 28).

Essentially, Gould was not sure where the Penn-Perm boundary was south of Osage County so he drew a straight line as a space holder until they could figure it out. At the time Gould mapped, there was great debate about the location of the Penn-Perm boundary. In Kansas prominent workers placed it at the base of the Wreford Limestone of the Chase Group. In Texas, the boundary was not yet identified. Gould, familiar with Kansas geology, recognized the Wreford in Osage county and adopted this as his Penn-Perm boundary:

> *"According to the classification of the Kansas geologists, notably Prosser, the line of separation between the Carboniferous and Permian in Kansas has been drawn at the base of the Wreford limestone, a ledge typically exposed near Junction, Kans., on Kansas River."* (Gould, 1905 pg. 34).

For reference, the Penn-Perm boundary in Oklahoma and Kansas is now considered to be within the Red Eagle Limestone in the underlying Council Grove Group, making Gould's Penn-Perm boundary stratigraphically higher than the currently accepted one (Figure 8). Gould correctly mapped the Wreford's location, using it as his contact between his Hominy District and Chase Formation. Gould also correctly noted that Kansas limestones below the Wreford disappear as you head south of the Arkansas River:

> *"The Hominy district includes the area of outcrop of all the Carboniferous rocks of the Osage and Kaw Reservation which lie below the Wreford Limestone. The formations exposed in this district include the southern extension into Oklahoma of the Pottawatomie, Douglas, Shawnee, Wabaunsee, Cottonwood, and Neosho formations of the Kansas geologists and have a thickness of over 1500 feet… To the south the limestones thin out, and in the vicinity of Arkansas River change into red shales."* (Gould, 1905 pg. 33).

Geologic units in the early 1900s were typically mapped by lithology and not time equivalency. Therefore, Gould noted that while he believed his Hominy and Chandler districts to be time equivalent, he separated them by lithology, drawing his contact just south of where the Osage limestones cease:

> *"The line of separation between the two kinds of Pennsylvanian rocks can never be sharply drawn, for the reason stated above, that while all the rocks are in regular succession they vary in lithologic character along the strike."* (Gould, 1905, pg. 32).

The disappearance of the limestone beds at the Arkansas River, including the Wreford limestone, perplexed Gould as he tried to find the Penn-Perm boundary south of Osage County. Gould noted that there is increasing shale and thinner limestones near the Arkansas River, but he mistakenly thought that the Wreford continued south and that with more mapping it, along with the Penn-Perm boundary, could be located:

> *"If the Wreford limestone be accepted* [sic] *as the base of the Permian in Kansas,*

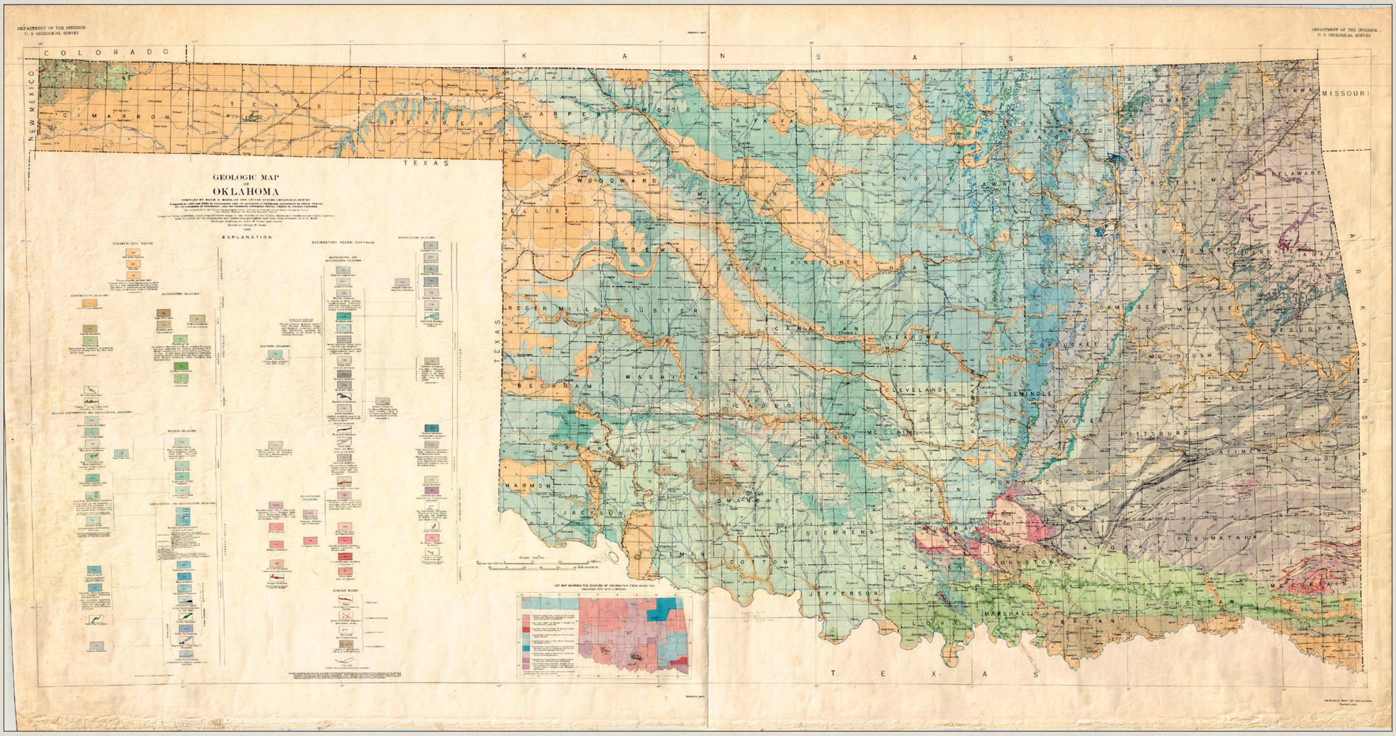


Figure 9. This is the USGS "Geologic Map of Oklahoma" published in 1927, which was the first color geologic map of the whole state. Map courtesy of Ted Satterfield.

ONLINE EXTRAS

View larger versions of Gould's map and other Oklahoma Geologic maps mentioned in this article on the OGS website: www.ou.edu/ogs

the location of the line of separation is a matter of the location of the Wreford in Oklahoma…It is probably represented south of the river in one of the ledges of limestone which are known to occur in the eastern part of Noble County, but until it is definitely located the line of separation can only be approximated." (Gould, 1905, pg. 31).

Gould also assumed the NE-SW strike of his Penn-Perm boundary in Osage County stayed the same and carried it in a straight line all the way to the Canadian River to approximate the Penn-Perm boundary south of his Hominy District.

"For the present, then, it will be drawn roughly through eastern Noble, western Payne, eastern Logan and Oklahoma, and western Cleveland counties, approximately paralleling the Atchison, Topeka and Santa Fe Railroad on the east as far as the vicinity of Oklahoma City, near which place it crosses that line of road and strikes South Canadian River in the Western part of the Chickasaw country, west of the Arbuckle Mountains, and if carried across the Red River, will finally reach the region of the western limit of the known Pennsylvanian in Texas." (Gould, 1905, pg. 31-32).

Gould's approximated Penn-Perm boundary was significantly west of the modern accepted boundary. Most of the rocks in his Pennsylvanian Chandler District are in fact now recognized as stratigraphically higher than the Wreford Limestone (his Permian base)—including here in Norman where the Permian Garber Sandstone and Wellington Formation are exposed at the surface. Most rocks of his Chandler District are now described as belonging to the Permian Garber Sandstone or Wellington Formation with just a few small eastern areas belonging to the Pennsylvanian Vanoss Formation (Miser, 1954).

As with any initial work though, Gould knew that his early attempts would need revision. In some of

Figure 10. Lyzanne Gann of Dallas, Texas removed the back on the map using a micro-blade.

his notes about the soon-to-be-published 1927 color geologic map of Oklahoma by Hugh D. Miser, Gould discusses his WSP 148 map:

> ***"****In 1905 the government published a bulletin entitled Water Supply Paper No. 148 of the U.S. Geological Survey, entitled "Geology and water resources of Oklahoma",. [sic] This bulletin contained a colored map setting forth our knowledge of what was then the territory of Oklahoma. Incomplete as it was, and full of errors yet, it represented our best knowledge as of that date, and up to this good year, 1927, no other colored geologic map of the state has ever been published.****"*** (Gould, 1927, University of Oklahoma's Western History Collection).

Not long after the 1905 WSP publication, Oklahoma statehood in 1907 required a new map that covered all of the combined Oklahoma and Indian Territories. A generalized black and white geologic map of Oklahoma was produced by Gould in 1911 (Map available on OGS website). However, as stated by Gould above, another color geologic map was not published until 1926-27 when Hugh Miser with the USGS published his "Geologic Map of Oklahoma" (Figure 9). Miser later updated his map in 1954, and it is still in use as our state geologic map. Tom Stanley, geologist with the OGS, leads the current State Map program, through which 93 quadrangles of the state are complete and available on our website (www.ou.edu/ogs/). The program's end goal is to have an updated geologic map of Oklahoma within the next 10 years.

CONSERVATION

The Gould Map is a manuscript map, which is a working version of a map prior to publication. The map appears to have been folded and rolled at one time, probably for transportation to and from the field or the USGS offices. According to a few OGS employees, the Gould map hung on the wall in Gould Hall before the survey moved to Sarkeys Energy Center.

The map was in dire need of conservation when found in 2014. The frame it was in was broken and falling apart. The canvas backing on the map had been glued with two different types of glue that were causing the map paper to deteriorate and shear, and the three areas of paper loss were losing more paper with each movement of the map. The conservation work was performed by Lyzanne Gann Preservation Services in Dallas, Texas. She removed the backing on the map using a micro-blade, gently removing it piece by piece (Figure 10). The front of the map was cleaned to remove a century's grime and a new Japanese rice paper backing was adhered to the map for strength,

Figure 11. TOP LEFT: Kristi Wyatt of FJJMA works on hinging for the map restoration. TOP RIGHT: Weights holding glued strips of rice paper to the map to dry. MIDDLE LEFT: Kristi Wyatt works on gluing the rice paper. MIDDLE CENTER: Jim Anderson and Kristi Wyatt add matting to the map. MIDDLE RIGHT: A corner is fitted to the Gould map during the framing process at The Frame Shop in Norman. BOTTOM LEFT: Brittany Prichett and Jim Anderson hold up the Gould map after all conservation and framing was complete.

stability, and to prevent future paper loss from the three damaged areas. The map was expertly scanned before and after conservation on an oversized flatbed scanner by the OU Digitalization Laboratory. Both images are available on the OGS website. Fred Jones, Jr. Museum of Art (FJJMA) provided expert advice and references for the conservation work, recommending Lyzanne Gann. Kristi Wyatt of FJJMA assisted with the hinging of the map, a necessary step in the framing process (Figure 11). The map was then framed by The Frame Shop here in Norman. The map is scheduled to be mounted in the Laurence S. Youngblood Energy Library later this spring (A press release will be issued to announce the date of the map hanging).

Charles Gould went on to found the Oklahoma Geological Survey in 1908. He worked for the survey until 1911 when he left to work in the oil and gas industry. While consulting, Gould discovered several prolific oil fields including the Panhandle Oil Field in Texas, which has since produced over 1.4 billion barrels of oil (Smith, 2017). He returned to the OGS in 1924 to become the survey's fourth director and served until 1931 when Governor "Alfalfa" Bill Murray defunded the survey by vetoing state appropriations. Gould then became a regional geologist for the National Park Service. For his contribution to western US geology, Gould Mountain in Glacier National Park is named in his honor.

Charles Gould recognized that his work, and that of his colleagues, was only the beginning of the process to unravel the geology of Oklahoma:

> *"In the very nature of the case, all pioneer work is crude work. We…are only like advanced scouts…peering through the forest and across the plains, trying to discover what manner of land is this—the land of Oklahoma. It is for the younger generation, men who come after us, men whose grandfathers will not be born for another hundred years, to do the constructive work, the quantitative work, on the geology of Oklahoma." (Gould, 1927, OGS Circular 16 pg. 16).*

As Gould predicted 90 years ago, the constructive and quantitative work continues…

ACKNOWLEDGEMENTS

We would like to thank G. Randy Keller for green-lighting this project, Neil Suneson for reviewing an earlier version of this manuscript, Tom Stanley for helpful discussion on stratigraphy, Heather Ahtone and Gail Anderson with Fred Jones Jr. Museum of Art for advice on conservation, Jody Foote and the Laurence S. Youngblood Energy Library for helpful discussions on the display, Kristi Wyatt for hinging the map, and all those that contributed to the conservation and presentation of the Gould Map.

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B E A V E R
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ROGER M
G R E E
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Mineral
Kimball
Metcalf
Tyrone
Shade
Peoria
Nye
Murdock
Paladora
BEAVER
Riverside
Alpine
Hereford
Lansing
Cline
Gate
Buffalo
Optima
Layrock
Preston
Hardesty
Grand Valley
Boyd
Sunlite
Clear Lake
Benton
Elmwood
Custer
Bluegrass
Fulton
Logan
Lockwood
Ivanhoe
Venus
Eubank
Roy
Caple
Range
Redpoint
Laverne
Cupid
May
Wildmead
Whitehead
Shattuck
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Goodwin
GRAND
ANTELOPE HILLS
Ioland
Redmoon
Sweetwater
Jester
Bloomington
Francis
Madge
Reed
Dryden
Witt
Martin
Greer
Duke
Looney
Granville
Louis
Purvis
Poe
Eldorado
Beaver Cr.
Wolf Cr.
Salt Fork of Red
S Sandhills
A a Alluvium
Pleistocene
Tertiary Pliocene
L Lava
T Tertiary
D Dakota sandstone
Cretaceous
Co Comanche
Senes (Upper part)
u Red Beds of uncertain relation
Q Quartermaster
G Greer
W Woodward
Permian
B Blaine
E Enid
M Marion and Wellington
Ch Chase
Cr Chandler
Pennsylvanian
H Hominy
Cambrian and Ordovician
Lower Paleozoic
Igneous
Archaean
Pl. XXXVI
Preliminary Geological Map of Oklahoma 1904 by Chas. N. Gould
DEPARTMENT OF THE INTERIOR
GENERAL LAND OFFICE
HON. BINGER HERMANN, COMMISSIONER.
MAP
OF
OKLAHOMA TERRITORY.
Compiled from the official Records of the General Land Office and other sources
under the direction of
HARRY KING, C. E.
Chief of Drafting Division G.L.O.
1898
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LOGAN
KINGFISHER
BLAINE
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LINCOLN
KICKAPOOS
CLEVELAND
POTTAWATOMIE
WICHITAS
WASHITA
CUSTER
WOODWARD
CHEROKEE OUTLET
KIOWAS
COMANCHES AND APACHES
CHICKASAW NATION
CHOCTAW NATION
SEMINOLES
CREEK COUNTRY
SHAWNEE HILLS
GUTHRIE
KINGFISHER
EL RENO
Fort Reno
NORMAN
TECUMSEH
ALVA
ENID
PERRY
STILLWATER
CHANDLER
WATONGA
TALOGA
ARAPAHOE
CLOUD CHIEF
MANGUM
OKMULGEE
WE-WO-KA
TISHOMINGO
ATOKA
PAWHUSKA
NEWKIRK
POND CREEK
Fort Sill Milit. Res.
Fort Arbuckle
Ft. Washita
Ft. McCulloch
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About the Authors

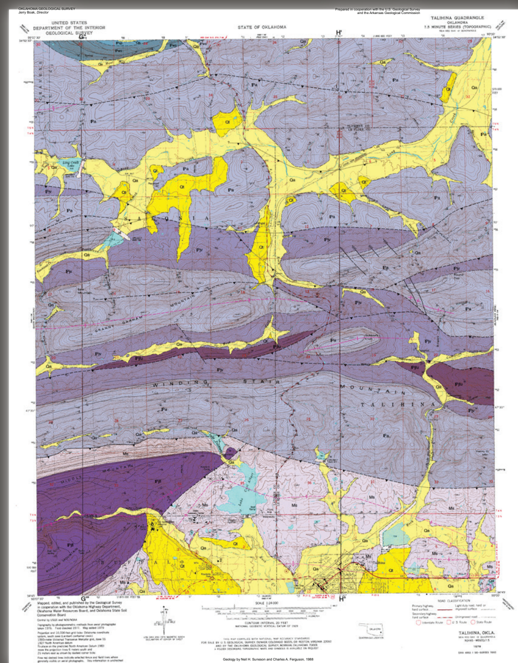
Brittany Pritchett is a petroleum geologist who began working at the Oklahoma Geological Survey in 2012. Her professional interests include petroleum geology, stratigraphy, clay mineralogy, geochemistry, and planetary science. Brittany holds two degrees from the University of Oklahoma, a Bachelor’s of Science in Geology and a Master’s of Science in Geology. She is a member of AAPG, GSA, and the OCGS. Her most recent work at the OGS has been updating Oklahoma oil and gas field maps, co-writing a guidebook for a field trip about the Simpson Group in southern Oklahoma, a guidebook of Oklahoma guidebooks not published by the OGS, and is nearing completion on a guidebook of all OGS guidebooks.

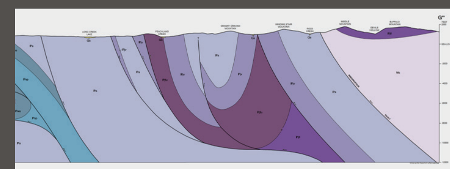
A longtime resident of Oklahoma, **Jim Anderson** is a graduate of the University of Oklahoma class of 1981. He has been involved in graphic design and map making since 1979. Some of his work includes The Historical Atlas of Louisiana, The Historical Atlas of Oklahoma, and various work on state atlases for the University of Oklahoma Press. He is currently the Manager of Cartography at the Oklahoma Geological Survey and involved with publications and the state digital geologic mapping program.

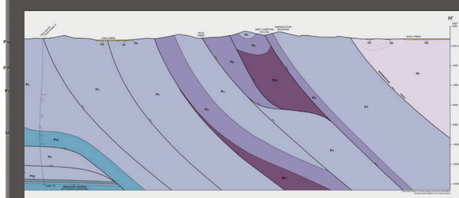
A CALL FOR VOLUNTEERS

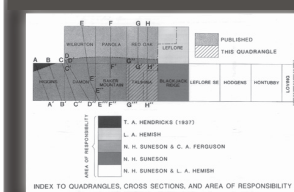
The Oklahoma Geological Survey's (OGS) STATEMAP program needs you, or a representative of your company or institution, to become a member of the Oklahoma Geological Mapping Advisory Committee (OGMAC).

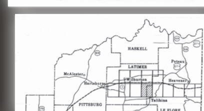
The STATEMAP program is a state geologic-mapping component of the National Cooperative Geologic Mapping Program of the United States Geological Survey (USGS), which provides federal matching funds to State Geological Surveys to achieve their mapping goals.

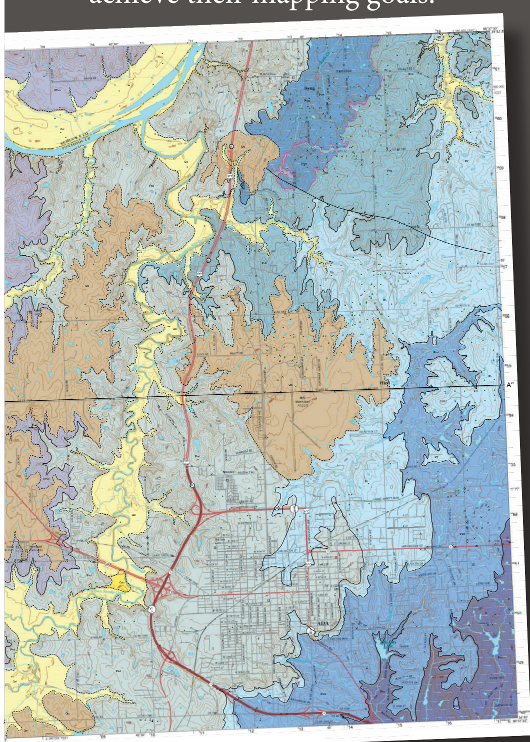








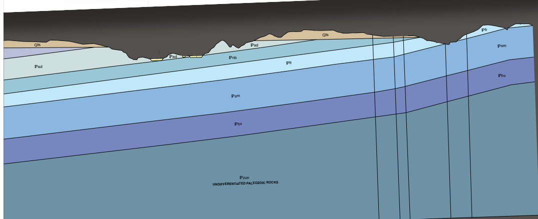




Part of the stipulation for the STATEMAP program by the USGS is the establishment of an Oklahoma Geological Mapping Advisory Committee (OGMAC), consisting of representatives from various university, state and local governments, tribal, private businesses, and even individual citizens. The purpose of the committee is to have broad, statewide interests that can be applied to directing the STATEMAP program. The committee would have the responsibility of establishing priorities for geologic mapping in Oklahoma that reflect multiple interests and goals.

As a committee member, the OGS would be soliciting your input and recommendations concerning regions, areas, or specific quadrangles that you, or a representative of your agency or company, feel have the highest priority for geologic mapping.

The committee would only meet once a year for two to four hours at some location in central Oklahoma.



If you wish to become a member of OGMAC or have additional questions, contact
Dr. Tom Stanley, tmstanley@ou.edu; 405-325-7281.

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

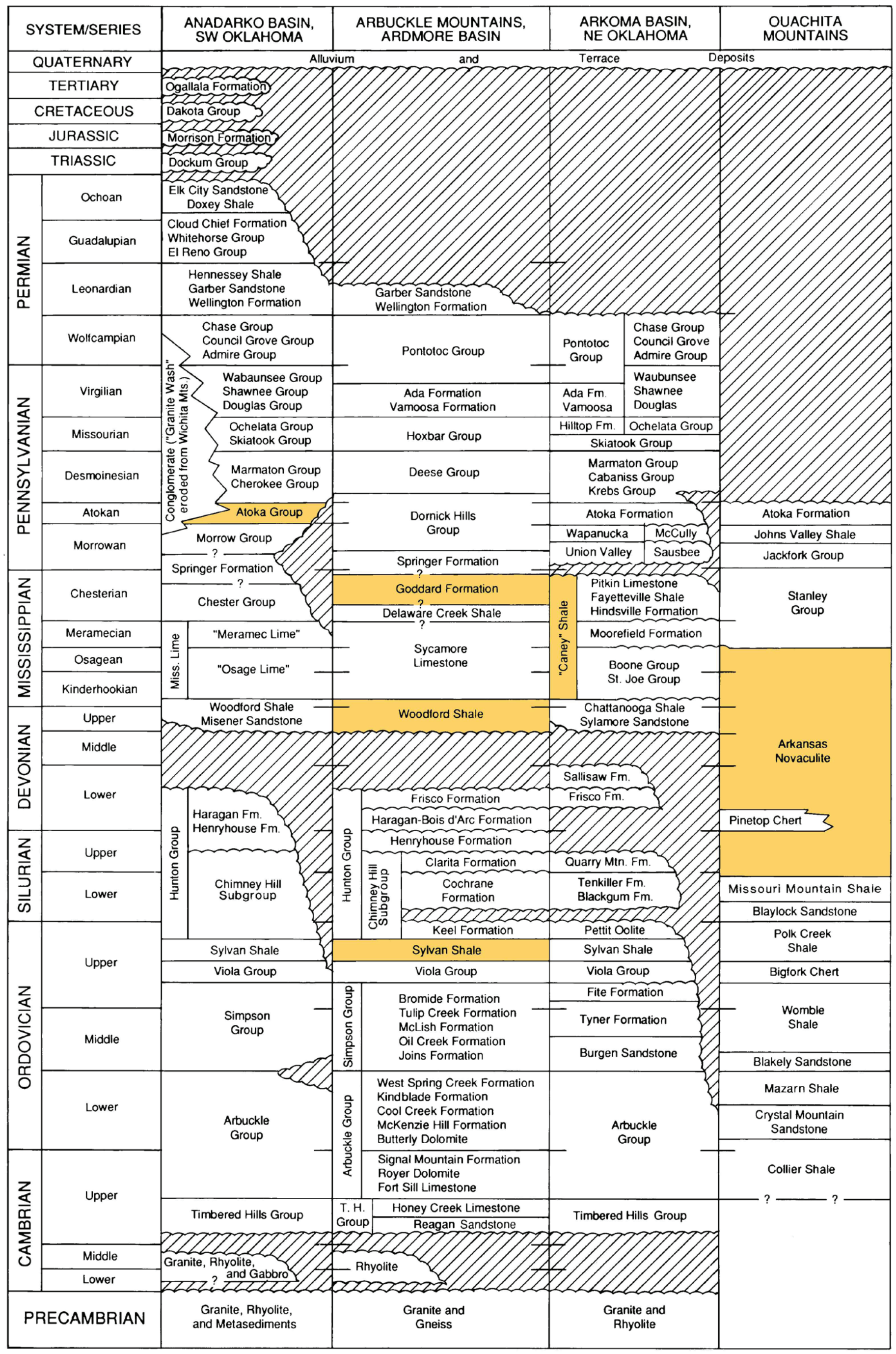


Figure 1. Generalized correlation of rock units in Oklahoma highlighting shale resource plays (modified from Johnson and Cardott, 1992).

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

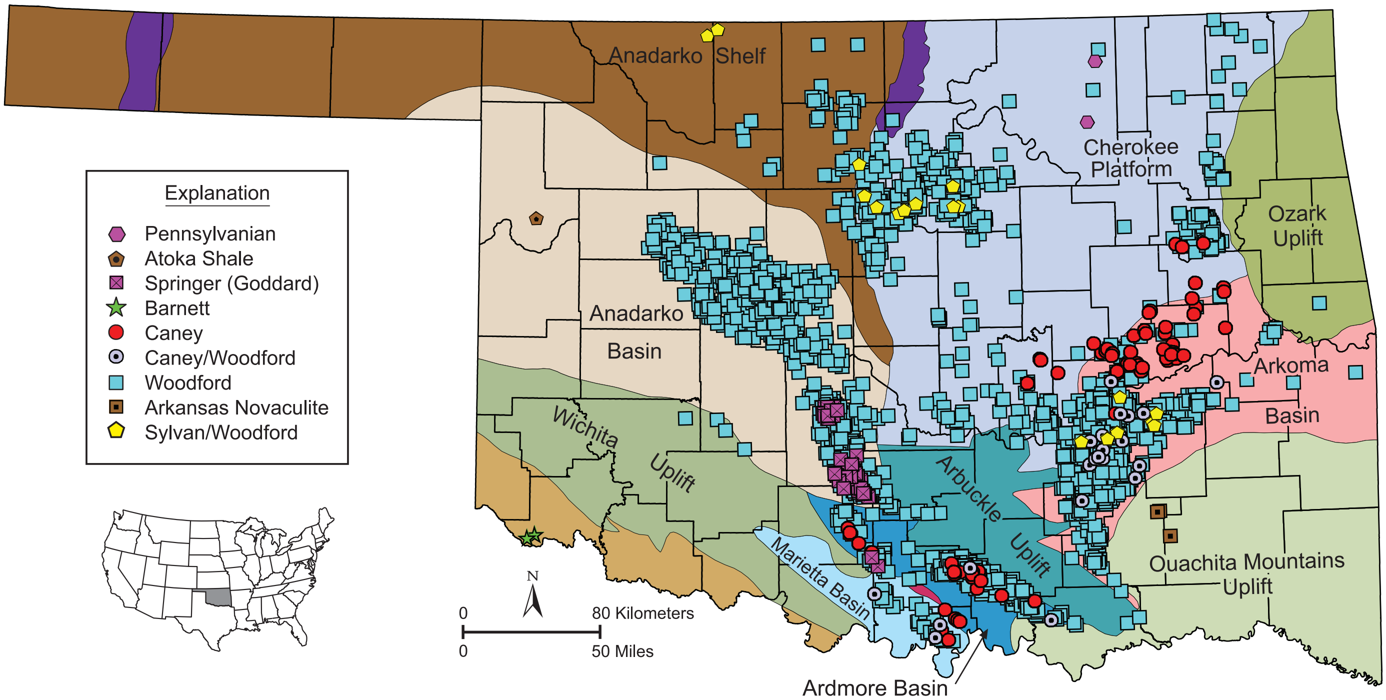


Figure 2. Map showing Oklahoma shale gas and tight oil well completions (1939–2016) on a geologic provinces map of Oklahoma (modified from Northcutt and Campbell, 1998).

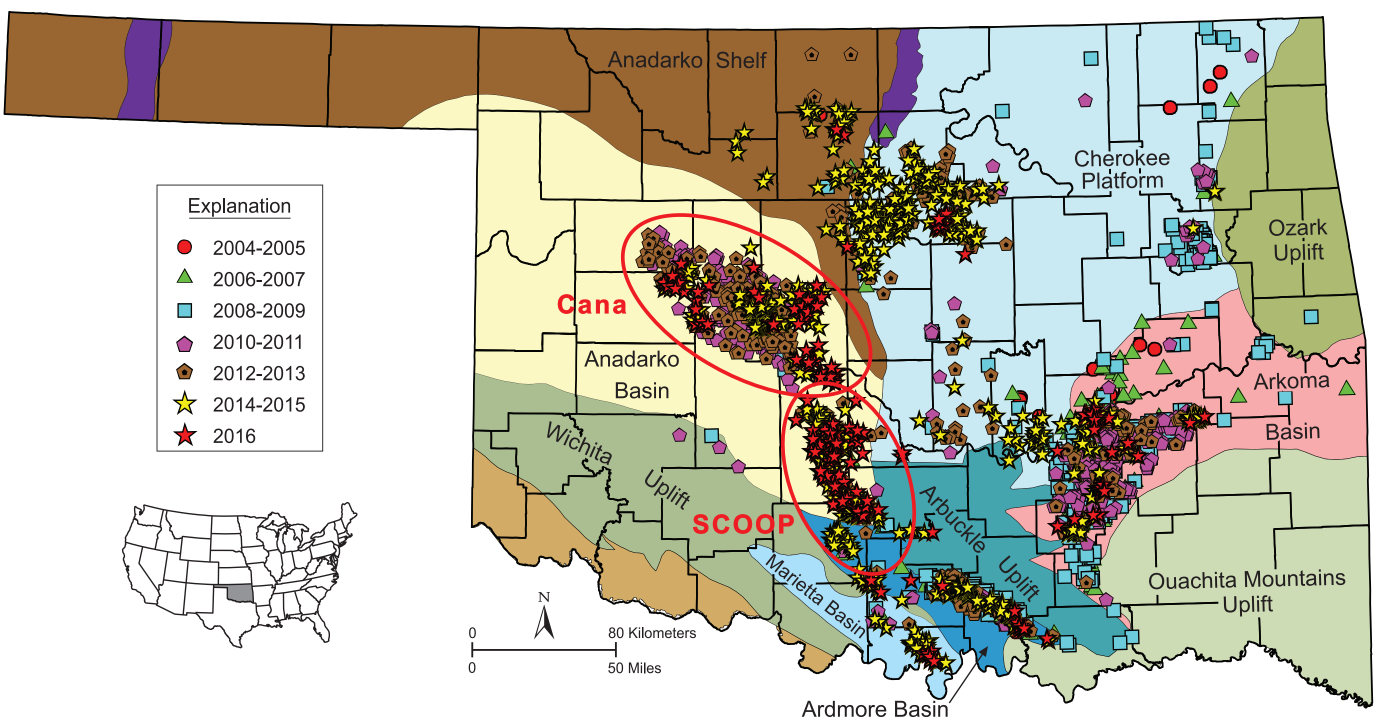


Figure 3. Map showing Woodford Shale-only gas and oil well completions (2004–2016) by year on a geologic provinces map of Oklahoma.

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

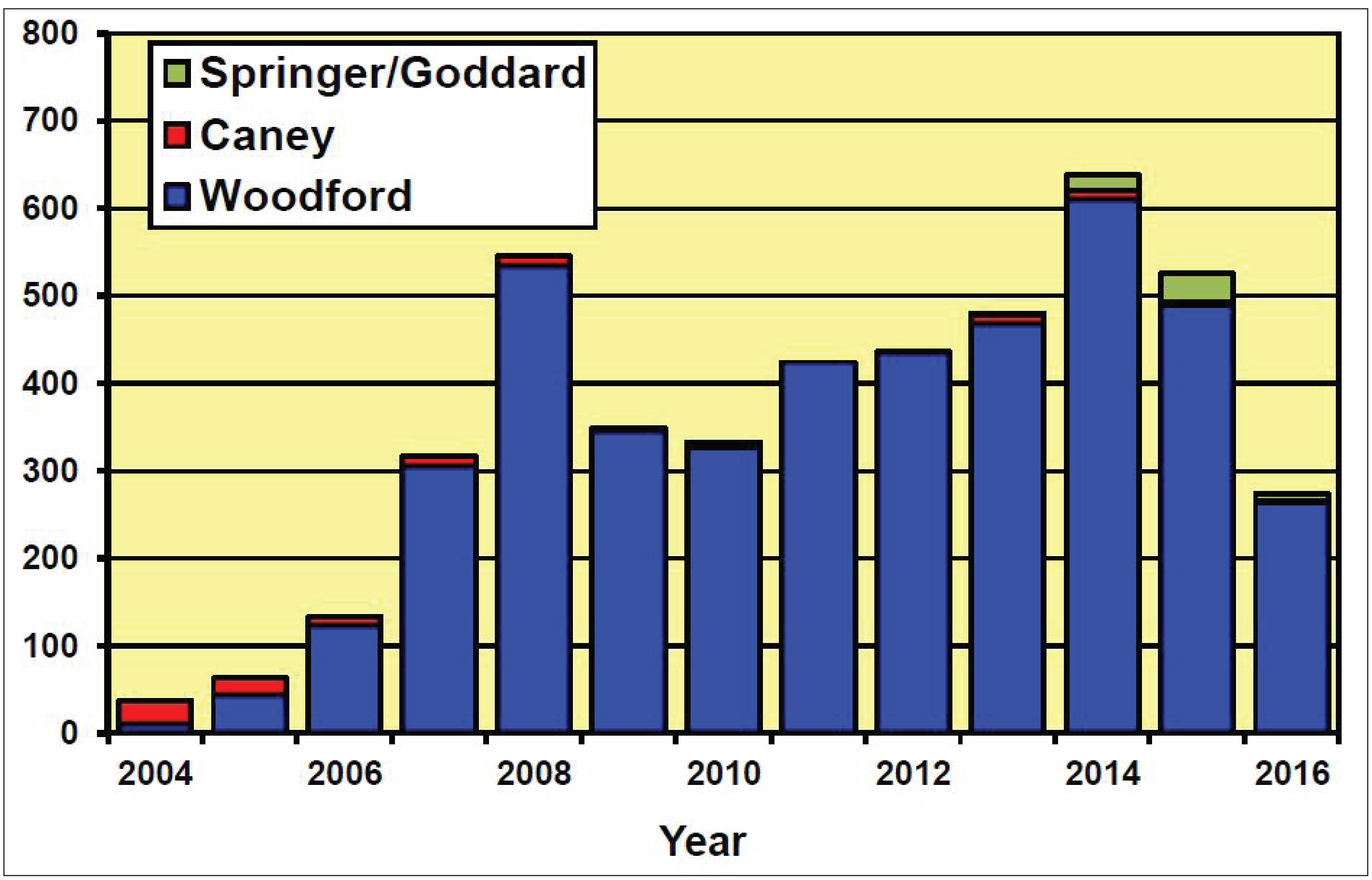


Figure 4. Histogram showing numbers of Woodford Shale, Caney Shale, and Springer/Goddard Shale well completions, 2004–2016.

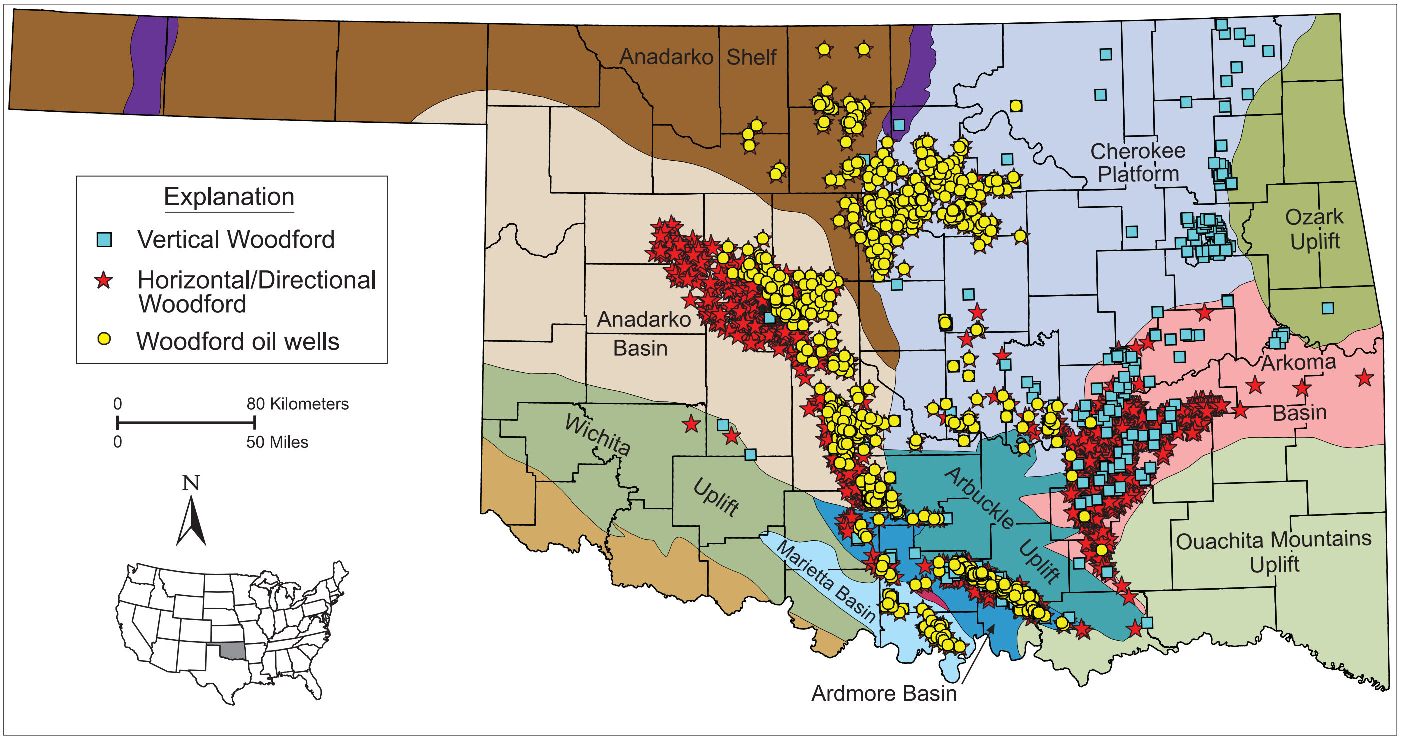


Figure 5. Map showing 4,389 Woodford Shale-only gas and oil well completions (2004–2016) by well type on a geologic provinces map of Oklahoma.

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

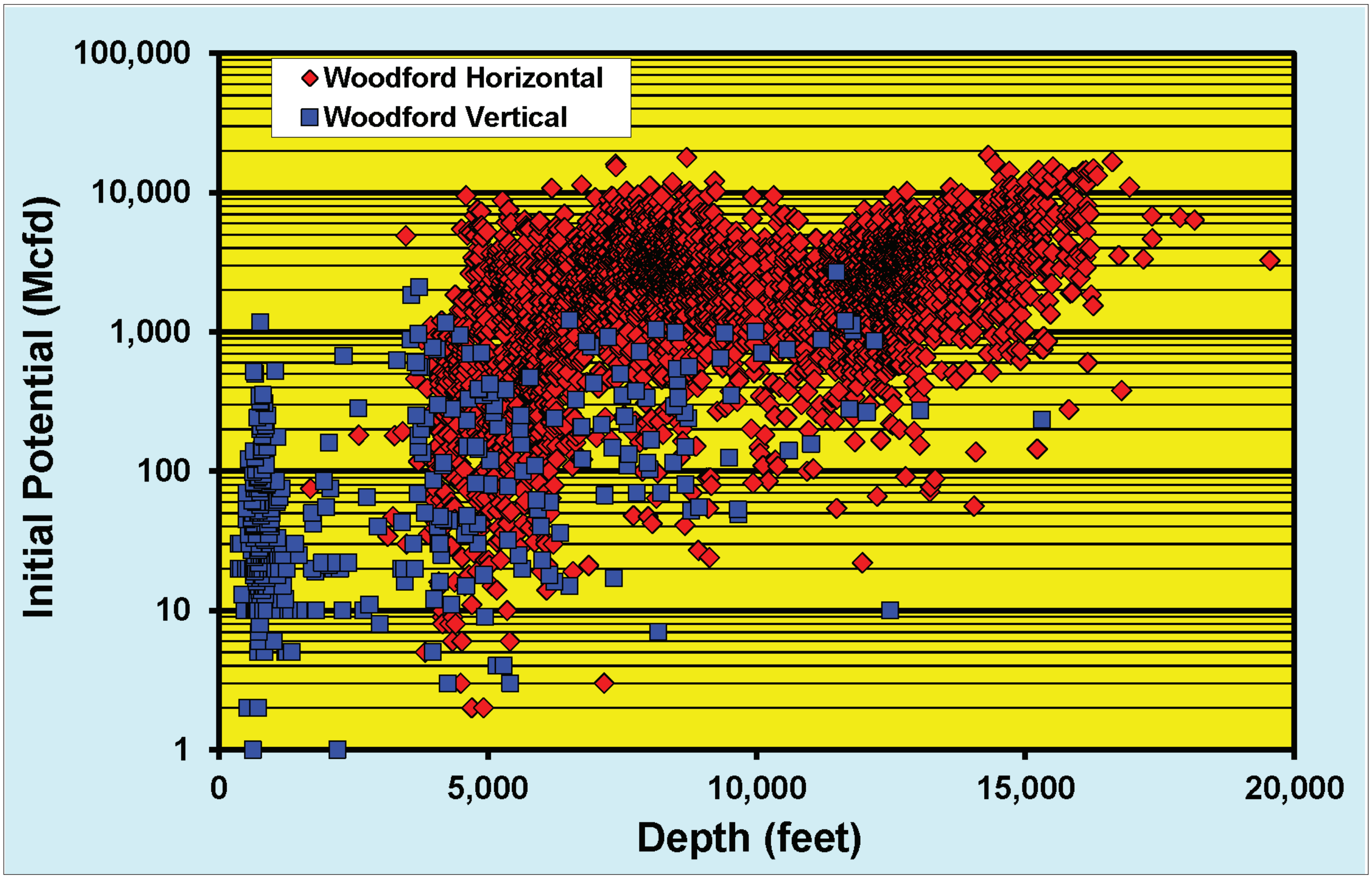


Figure 6. Chart showing initial potential gas rate vs. Woodford Shale total vertical depth (3,908 horizontal wells; 368 vertical wells).

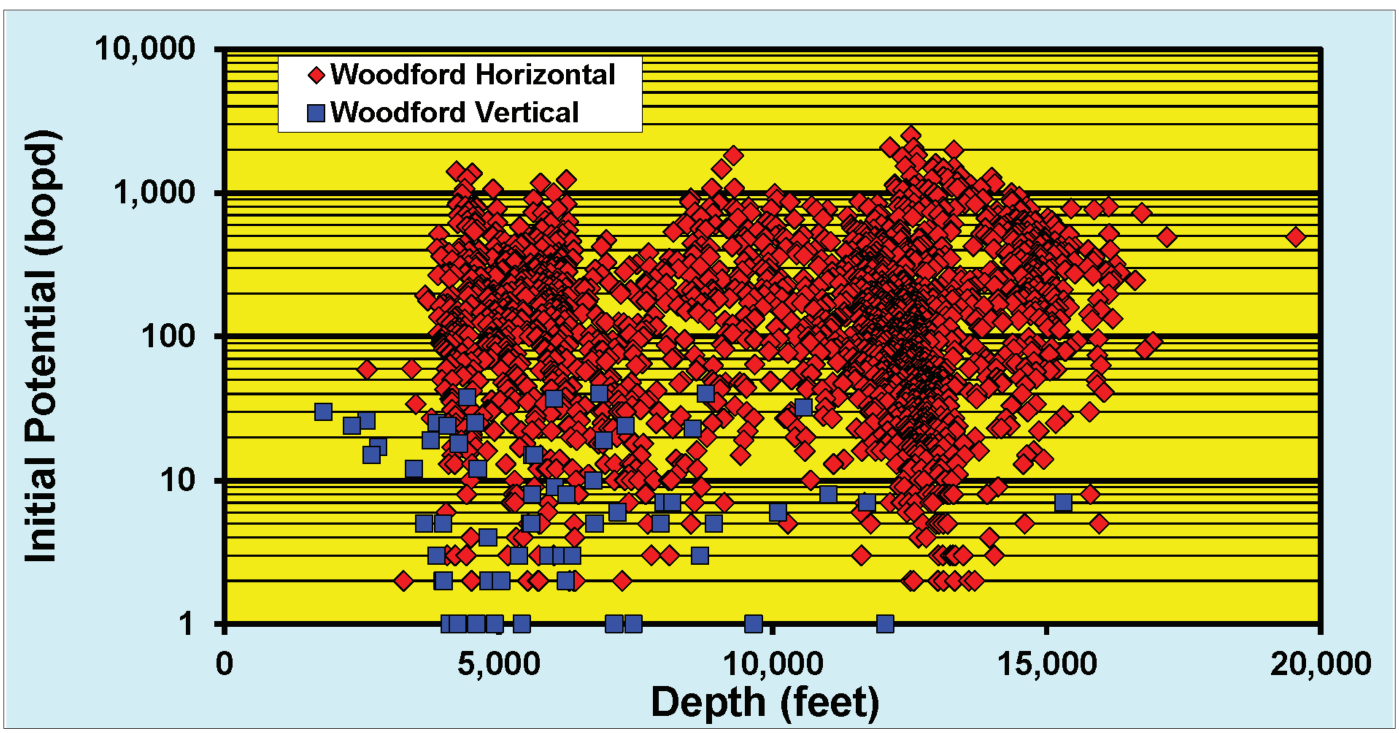


Figure 7. Chart showing initial potential oil/condensate rate vs. Woodford Shale total vertical depth (2,243 horizontal wells; 63 vertical wells).

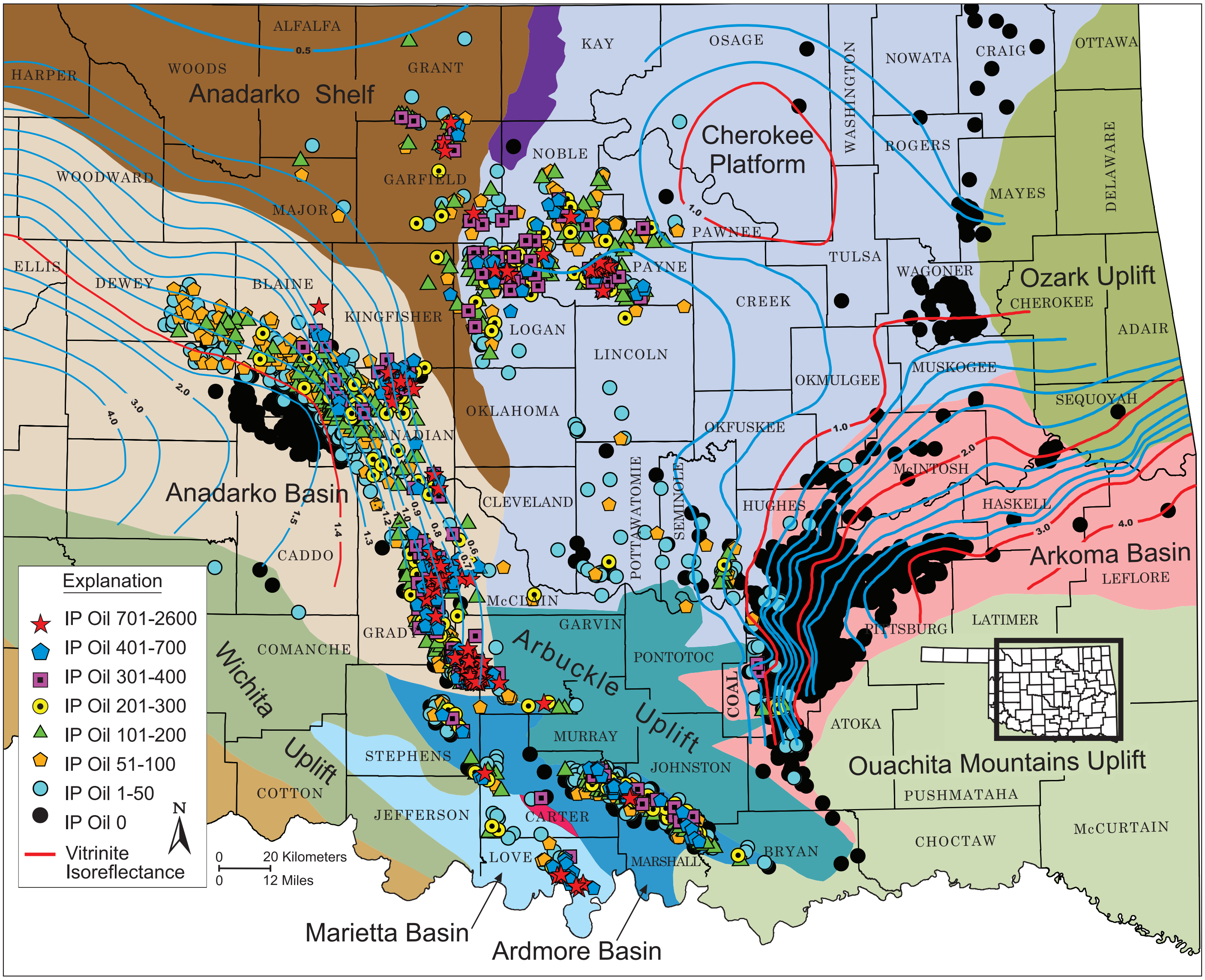


Figure 8. Map showing Woodford Shale-only initial potential oil rates on a geologic provinces map of Oklahoma with vitrinite isoreflectance contours (revised from Cardott, 2012b).

(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).

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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.

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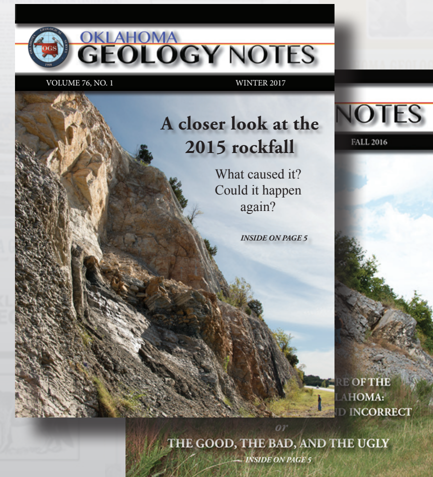

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