The Oklahoma Geological Survey,
The Petroleum Technology Transfer Council and
The University of Oklahoma

Present

The Marine Tonkawa Sands:
Natural Gas and Associated Liquids Production
In The Anadarko Basin

Part 1
Regional Synthesis of Marine Tonkawa Sand
in the Anadarko Basin
Carlyle Hinshaw
Petroleum Geologist
Geo Information Systems

Part 2
Waynoka NE Field
Tonkawa Sand Reservoir Study
Kurt Rottmann
Consulting Geologist

Oklahoma Geological Survey
Open File Report 3-97
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July 9, 1997

U. S. Postal Training Center
Norman, Oklahoma
Figure R1

Type Log Marine Tonkawa.

The well used is the Tenneco (Tidewater) Ashby-1, NE SW SW NE Sec 36-14n-15w, DF 1656, TD 16580, Weatherford N Fld, in eastern Custer Co., OK. The log is a Dual Induction Focused Log with Gamma Ray. The Tonkawa sands are in the Douglas Group of the Virgilian Series. The portion shown is the interval from the Heebner Shale of the Shawnee Group to the upper part of the Missourian Series. This well was chosen because it has Tonkawa sands in the lower, middle and upper parts of the Douglas Group. In addition, the “lower” and “middle” sands were cored, plus, the well is in Panel 2 of the E-W regional cross-section.
Figure R2

**Tonkawa Production Map.**

Tonkawa sand oil and gas production is limited to the Anadarko Basin, the Nemaha Uplift and the Nemaha Fault Zone. In Kansas, the equivalent sands are called Stalnaker. In the southeast corner of the Anadarko Basin, in the Cement area, the term Niles is used. In the Texas Panhandle, sands that may elsewhere be considered “upper” Tonkawa could be called Douglas. Production depths are as shallow as 2,075 feet on the Pauls Valley Uplift in Garvin County, Oklahoma to 10,420 feet in the southwestern corner of Roger Mills County, Oklahoma. The northeastern most production is in Sedgwick County, Kansas, near Wichita and the farthest west field is in Sherman County, Texas.
Table R1

Production From The Tonkawa Sands
Kansas - Stalnaker reservoirs - Barber, Butler, Cowley, Harper, Kingman and Sumner Counties

<table>
<thead>
<tr>
<th></th>
<th>Oil</th>
<th>Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leases</td>
<td>67</td>
<td>79</td>
</tr>
<tr>
<td>Cumulative 1970-1995</td>
<td>1,081,422 Bbl.</td>
<td>46,275,231 MCF</td>
</tr>
</tbody>
</table>

Oklahoma - FDD reservoirs - Alfalfa, Garfield, Grant, Kay, Lincoln, Logan, Noble, Osage, Pawnee and Payne Counties.

<table>
<thead>
<tr>
<th>Tonkawa reservoirs only:</th>
<th>Oil</th>
<th>Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leases</td>
<td>62</td>
<td>82</td>
</tr>
<tr>
<td>Cumulative 1/1/79-12/31/96</td>
<td>1,598,159 Bbl.</td>
<td>48,040,811 MCF</td>
</tr>
</tbody>
</table>

Oklahoma - Marine reservoirs - Beaver, Canadian, Custer, Dewey, Ellis, Garvin, Grady, Harper, Kingfisher, Major, Oklahoma, Roger Mills, Woods and Woodward Counties.

<table>
<thead>
<tr>
<th>Tonkawa reservoirs only:</th>
<th>Oil</th>
<th>Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leases</td>
<td>434</td>
<td>662</td>
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<tr>
<td>Cumulative 1/1/79-12/31/96</td>
<td>4,617,972 Bbl.</td>
<td>411,385,982 MCF</td>
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</tbody>
</table>

Texas - Marine reservoirs - Hansford, Hemphill, Hutchinson, Lipscomb, Ochiltree Sherman Counties.

<table>
<thead>
<tr>
<th>729 wells</th>
<th>Oil</th>
<th>Gas</th>
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</thead>
<tbody>
<tr>
<td>Cumulative to 12/31/96</td>
<td>33,662,186 Bbl.</td>
<td>578,367,441 MCF</td>
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</table>

Figure R3

**Structure Map of the Heebner Shale.**

Of the Virgilian subsurface markers, the Heebner Shale in the lower Shawnee Group is by far the one listed most by operators. Tonkawa workers may favor mapping on the Haskell Limestone in the upper Douglas Group but it is usually absent on a basinwide basis. A marker zone is frequently used in lieu of a developed limestone bed. As a matter of fact, most of the Douglas and lower Shawnee limestones are sporadically developed over the area of Tonkawa production. The contour interval is 250 feet. Dip is southerly and an increase in rate of dip occurs at the -3750 foot contour. Source of data is the NRIS well database.
Published and Publicly available studies addressing Marine Depositional Environments.

Publications directed primarily at the Tonkawa are rather sparse and only a few of these address depositional environments. All but one of the environment articles listed have core descriptions. There are two AAPG bulletin papers, two Oklahoma State masters theses, one West Texas State University thesis, one article in the bulletin of the South Texas Geological Society and Part 2 of this Oklahoma Geological Survey’s Open File Report. The two Texas articles cover the same land area almost exactly.
PUBLISHED AND PUBLICLY AVAILABLE STUDIES ADDRESSING MARINE DEPOSITIONAL ENVIRONMENTS

FIGURE R4
Figure R5

Core Descriptions.

Pate’s interpretation of the depositional history of the Tonkawa interval is also shown on this map. On the shallow shelf in far northwestern Oklahoma and southwestern Kansas, a facies change from siliciclastic deposition to a carbonate shelf edge is postulated for the very uppermost Missourian Series. As a result, Pate envisions the Tonkawa sands to be Missourian in age rather than Virgilian.

In eastern Custer County, Kumar and Slatt interpreted a core from the lower Tonkawa to be from a submarine fan complex. A core from the middle Tonkawa in the same well was interpreted to be from a sequence deposited on the basin slope. Kumar and Slatt also described a middle Tonkawa core in southwestern Dewey County as being a slope deposit. They propose a Tonkawa age that spans the Missourian/Virgilian boundary.

In southwestern Dewey County, Padgett’s work, which also covers the northwest quarter of Kumar and Slatt’s study, five cores from the middle Tonkawa were described. One of the cores is the same one used by Kumar and Slatt above. His depositional environment interpretation for the sands is one of a delta front prograding basinward, resulting in lobate, elongate sand bodies oriented primarily northeast-southwest. Padgett places the Tonkawa sands in the Virgilian.

Billingsley, et. al, in the Bechthold field of northwestern Lipscomb County, Texas, interpreted a middle Tonkawa core as being representative of a deep marine environment with submarine currents forming bar-shaped sand deposits.
In the same field as above, Whitaker studied middle Tonkawa cores in three different wells. He states that the middle Tonkawa sandstone represents the transition from deep marine basin deposition to slope/shelf deposition during a time of regression. Whitaker states that the Tonkawa Formation is upper Missourian in age. To the north and west of his study area, Whitaker states that the sandstone grades into shale and then into shelf carbonates of the Lansing Group.

Fies described four middle Tonkawa cores in Harper and Woods counties. His studies suggest a high-constructive, lobate delta depositional environment. Fies assigns the Tonkawa sands to the Virgilian Series.

Rottmann did the mapping and J. A. Campbell described the cores for the Waynoka NE Field reservoir study in south-central Woods County. The cores were the same two used by Fies (above). They interpret the depositional environment to be one of shallow marine shelf to open marine. Rottmann considers the Tonkawa to be in the Virgilian Series.

Thin section and scanning electron photomicrograph studies were made on several of the cores. Chemical processes were the primary factors affecting reservoir quality of the sands. Secondary porosity caused by dissolution is the main factor affecting the reservoirs. Precipitation of authigenic minerals in the pore spaces frequently reduced and even closed systems. As a result, porosity and permeability values are highly variable in the marine Tonkawa fields.
Table R2

Location of Marine Tonkawa core descriptions.

1. Tenneco (Tidewater) 1-Ashby, NE 36-14N-15W, Custer Co.
2. McCulloch 1-Craig, SE 6-17N-20W, Dewey CO.
3. Texas Oil and Gas 1A-Saylor SE 24-17N-18W, Dewey Co.
5. Wessely 2-Farris, NW 2-16N-19W, Dewey Co.
6. Wessely 2-Farris, NE 7-16N-18W, Dewey Co.
7. Sarkey’s 1-Fancher, SW 17-16N-18W, Dewey Co.
Index Map Regional Cross Sections.

The regional cross sections were compiled from 1”=100’, mostly Gamma Ray Induction logs, taped together (there is no horizontal scale). The sections were made in panels of mostly five logs each for easier handling in making overheads for projection at the Tonkawa Workshop. The reader may tape the panels together for a complete section. Both are stratigraphic sections with the Heebner Shale as the datum.

The W-E section starts on the east end in northeastern Logan Co. with the southernmost well of J. A. Campbell’s N-S FDD regional section B-B’. It extends east-west across the basin using one to two wells per county, ending up with two wells on the N-S regional cross section. The section has two panels.

A type log from Clark County, Kansas is included as Figure R9.

The N-S section starts in 29N-26W in Harper County, Oklahoma near the Kansas state line and extends southward to 10N-26W in Beckham County. The section has 23 wells with at least one well per township. As a result, there is one well about every six miles. There are five panels covering the N-S section.
W-E Cross Section - Panel 1.

This panel primarily illustrates the “upper” and “middle” Tonkawa intervals. The “lower” Tonkawa section pinches out between the Dreyfus Markus-1 and the Holke Carey-1. The Marjo Donoghue-1 is used to show the mapping interval for the regional thickness map which is from the Heebner Shale and the top of the Missourian Series. Sand development is indicative of the many delta lobes that occur in the Tonkawa interval. The lower part of the section is generally a deeper water shale section that starts to coarsen upward at the beginning of the “middle” Tonkawa interval. The two right hand or easternmost wells illustrate transition to delta front and offshore bar deposits capped by open marine carbonate and shale deposits. A repeat of the cycle is seen in the “upper” Tonkawa interval. The Dreyfus Markus-1 well is a good example of the lobate, progradational (regressive) nature of the depositional environments. The Haskell interval is replaced by a lobe starting out with a non-marine (delta) sand followed by delta front cycles and finally capped with an open marine limestone. Of note on this section is the location of the Avant Limestone which is not the top of the Missourian.
Figure R8  In Pocket

W-E Cross Section - Panel 2.

This section shows the only area that contains "lower" Tonkawa sands. The Tenneco Ashley-1 is the marine type log for this report and was cored both in the "lower" and "middle" Tonkawa sands. The "lower" sand is a slope to basin fill of fine to coarse turbidites having as much as 35% chert. This deposit probably was sourced from the Ouachita uplift. The uppermost core is from the top of a coarsening upward delta front sequence.
Figure R9

Type Log - Clark County, Kansas
N-S Cross Section - Panel 1.

The northernmost or left hand log correlates with the Clark County, Kansas Type Log. Both illustrate the shelf limestone buildup in the upper Missourian. The “lower” Tonkawa interval contains no sand while the “middle” and “upper” zones have generally very thin delta front sands. The Douglas sea, on an overall basis, is one of mostly mud. The southernmost well is used to illustrate the interval of the regional thickness map.
N-S Cross Section - Panel 2

Nearly all of the Tonkawa production in the three state area is from the “middle” zone and this panel shows that most of the sand is in this interval. The two rightmost wells are in the same township and Pintex Linscott-1 produces from the Tonkawa. The sequence here indicates that a non-marine channel cuts into pro delta shale and is followed by delta front and perhaps offshore bar deposits.
N-S Cross Section - Panel 3.

Again, most of the sand is in the "middle" zone although delta front sequences occurring in the "upper" interval. The sand development is shown as the finish of a classical upward coarsening sequence. The Tonkawa produces in the southernmost well.
Figure R13      In Pocket

**N-S Cross Section - Panel 4**

Again, the sand development is limited to the “middle” portion of the Tonkawa with one to several delta front pulses occurring. Two wells produce from the “middle” Tonkawa on this panel. The E-W regional cross section connects to this panel at the northernmost well.
**N-S Cross Section - Panel 5.**

This short and last panel shows the basin axis during the period studied. The sands are limited to the “middle” part of the Tonkawa. At this position, the influence of the Wichita uplift is seen. The section ends in T10N-R26W. In the next township to the south (T9N-R26W), the influx of granite wash makes it difficult to impossible to correlate the Virgilian. In T8N-R26W, Permian sits on granite. The deepest Tonkawa production comes from the Exxon well.
Thickness Map of the interval Heebner Shale to top Missourian.

Because the Heebner and the top of the Missourian are marine deposits, the data are limited to the marine portion of the Anadarko Basin. Both are correlative sedimentary markers over most of the basin. As a result, the map is indicative of the filling of the basin during Douglas time. Major siliclastic sourcing was northerly from the Canadian Shield area although southeastern, southwestern and western highlands were contributors. Source of data is the NRIS well database.
Summary
The marine Tonkawa sands in the Anadarko Basin are in the Douglas Group of the Virgilian Series. These sands are located primarily in northwest Oklahoma and the Texas panhandle. There are three general parts of the Douglas where the sands are found, the “lower”, “middle” and “upper”. “Lower” Tonkawa sands are limited to a fairly small area centered in southeastern Custer County, Oklahoma. These “lower” sands are deep water slope and/or basinal turbidite deposits. “Middle” Tonkawa marine sands are shallow water shelf deposits at the delta front and in the offshore areas. Gas and oil production is limited to these “middle” sands. The “upper” sands are deposits similar to those in the “middle” section.

Over most of the producing area, the sands are fine to very fine in grain size. Sediments providing much of the basin fill came from the Canadian Shield. Other source areas are highlands to the southeast, southwest and west,

The combination of depositional environments resulting in marine bar development and diagenetic processes operating on the sands resulted in the development of stratigraphic traps across the northwest shelf of the Anadarko Basin in Oklahoma and Texas.

Tonkawa explorers need to focus their work on interpretation of the depositional environment framework. Part 2 to follow is an excellent example.
References Cited
Acknowledgements
The author appreciates the efforts of Dr. Charles Mankin and Mary Banken for their support with funds and facilities from the Oklahoma Geological Survey, the Petroleum Technology Transfer Council and Geo Information Systems to carry out this research project.

Jock Campbell with the Oklahoma Geological Survey, Rick Andrews with Geo Information Systems and Bob Northcutt, Independent Geologist, provided important insight to depositional systems of the Tonkawa.

Craig Wahl of PI/Dwights provided production data from the Tonkawa in the Texas panhandle.
Waynoka NE Field
Tonkawa Sand Reservoir Study

T. 25 N., R. 14–17 W.
Woods County, Oklahoma

By
Kurt Rottmann, Consulting Geologist
July 9, 1997
Figure W1. Regional position of the Waynoka NE field study with respect to all production from Tonkawa sand. The reservoir study area is located in the gas producing province of the Tonkawa sand, which was deposited primarily under marine conditions in the subject area. Sincere appreciation is extended to Mr. Randy Haley and Mr. Tom Farrell of RDH Enterprises, Inc. for their assistance with and support of this report. Special thanks also to Mr. Matt Garber of Schlumberger Well Services, for his assistance in interpretation of the FMI log used for this report.
Figure W2. Location of the Waynoka NE field study area, Woods County, Oklahoma.
Figure W3. Symbols used for the maps included in the Waynoka NE field study area, Woods County, Oklahoma.
Figure W4 (in envelope). Index map identifying wells used to evaluate the Tonkawa sandstone reservoir in the Waynoka NE field study area. Producing formations for the productive wells are indicated by abbreviation. The discovery well, reference log, and the cored wells are marked and will be discussed in the following figures. The study area is larger in areal extent than most of the field studies associated with the FDD workshop series, in order to better understand the geometry of sandstone reservoirs, and depositional environments within the Tonkawa sand.

Figure W5 (in envelope). Structure map contoured on the top of the Haskell Limestone. The field study area occurs within a gentle homocl ine, with dip to the south at a rate of approximately 20 ft/mile. A closure located in section 31, T. 25 N., R. 14 W. produces from a number of formations, including the Tonkawa sand. A smaller closure is also present in sections 9, 10, and 11, T. 25 N., R. 16 W. This closure may be associated with compaction and draping of the Haskell Limestone over a local thick area of Tonkawa sandstone.

Figure W6. Reference log for the Tonkawa sand in the Waynoka NE field study area, Woods County, Oklahoma. Location of this well is shown on Figure W5. The Tonkawa sand occurs in the Vamoosa Formation, and the shale below the Tonkawa sand is probably in the Tallant Formation. However, the exact boundary between the two formations in the subsurface is not clear. A more detailed description of this relationship can be found in the general stratigraphy portion of the regional overview of the Tonkawa FDD workshop (Oklahoma Geological Survey, SP 97-3).

The Tonkawa sand has been separated into six regionally correlatable layers, which have been labeled in descending order 1st sandstone through 6th sandstone. The six layers are mapped individually. The primary characteristic of these layers is their consistent stratigraphic presence, and uniformity of thickness with respect to the Tonkawa interval. Cut and fill deposits seem to be lacking within the Tonkawa, as all of the layers seem to be associated with conformable, non-eroded interfaces. This concept has important application to hydrocarbon production from several Tonkawa producing layers, as will be shown in more detail in the following figures.
<table>
<thead>
<tr>
<th><strong>Tonkawa Sand</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Reservoir size (Oil)</td>
<td>Not Applicable</td>
</tr>
<tr>
<td>Reservoir size (Gas)</td>
<td>Variable</td>
</tr>
<tr>
<td>Well spacing (gas)</td>
<td>640 acres</td>
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<tr>
<td>Oil/water contact</td>
<td>Not Applicable</td>
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<tr>
<td>Gas/water contact</td>
<td>Variable</td>
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<tr>
<td>Porosity</td>
<td>8 - 20 %</td>
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<tr>
<td>Permeability</td>
<td>Unknown</td>
</tr>
<tr>
<td>Water saturation</td>
<td>~24 % - ~55%</td>
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<td>Gas to Oil Ratio</td>
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<tr>
<td>Thickness (net sand) (Ø &gt;8%)</td>
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</tr>
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<td>Unknown (Condensate)</td>
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<td>Initial reservoir pressure</td>
<td>~2000 PSI</td>
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<tr>
<td>Initial gas formation-volume factor</td>
<td>0.006</td>
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<tr>
<td>Original Oil in Place (volumetric)</td>
<td>(Condensate)</td>
</tr>
<tr>
<td>Cumulative condensate</td>
<td>Unknown</td>
</tr>
<tr>
<td>Recovery efficiency (oil)</td>
<td>Not Applicable</td>
</tr>
<tr>
<td>Cumulative gas</td>
<td>54.2 BCFG</td>
</tr>
</tbody>
</table>

Table W1. Geologic and engineering data for the Tonkawa sand reservoirs in the Waynoka NE field study area, Woods County, Oklahoma. Several of the data fields are variable because of the large number of separate reservoirs in the multiple layers of the Tonkawa sand.
Gulf Oil Corporation
No. 1 Shade
NE SE SW Sec. 31, T. 25 N., R. 14 W.
Woods County, Oklahoma

Core: 5,178–5,201 ft; rec. approx. 23 ft

5,178–5,201  Sandstone, fine to very fine grained, micaceous. Bedding essentially horizontal and commonly indistinct. Small-scale ripple-bedding also common. Partings of organic matter occur mainly in association with ripple-bedding.

- Red clay partings and/or clasts, 5,178.2–78.3; 5,180.3; 5,183.3; 5,198.9; and 5,201.3 ft
- Minor soft-sediment deformation at 5,190.05 and 5,195.70 ft
- Significant partings of brownish-black organic matter, 5,189.2; 5,190.1; 5,193.7–93.8; 5,196.0–96.3; and 5,199.9 ft
- Small coal clast at 5,198.6 ft

Summary: Core represents sand deposition on a shallow-marine shelf; an offshore bar (?)

Table W2. Description of core of Tonkawa sand in the #1 Shade well. The presence of micas in both cores indicates a granitic source, probably in the northern mid-continent.
Gulf Oil Corporation
No. 1 Shade
NE SE SW Sec. 31, T. 25 N., R. 14 W.
Woods County, Oklahoma

T.D. 7,995 ft

Core: 5,178–5,201 ft

Completed 2-14-1957
DST Tonkawa, 5,174–5,201: Rec. 120 ft sli. GCM;
Did not perforate Tonkawa
Completed in Hunton and Sylvan
IPF 51 BOPD and 54 BWPD
1. 5,055 Black shale

2. 5,056.0–5,057.9 Gray limestone, fossiliferous

3. 5,058.0–5,061.1 Interbedded black silty shale and gray, micaceous siltstone to very fine-grained sandstone. Flat-beded with small-scale cross-bedding in layers 0.1 in. to 1 in. thick.
   - Red oxidized clay (0.5 in. thick) at 5,058 ft
   - Soft-sediment deformation at 5,060.8

4. 5,061.2–5,064.8 Sandstone, fine-grained, silty, slightly micaceous, with indistinct, flat bedding

5. 5,064.9–5,069.6 Interbedded black silty shale and gray siltstone to very fine-grained, micaceous sandstone. Flat-beded with small-scale cross-bedding.
   - Soft-sediment deformation at 5,064.8 ft
   - Bioturbation at 5,065.4–65.6 ft
   - Shale oxidized at 5,067.4–67.6 ft

6. 5,069.7–5,076.4 Sandstone, fine-grained, silty and micaceous. Ripple bedding with common partings of dark organic matter.

7. 5,076.5–5,091.0 Interbedded very-fine-grained sandstone, slightly micaceous siltstone and black, silty shale. Variation from thin lamina (~0.1 in.) to 8 in. thick layers of sandstone. Bedding flat except for small-scale cross-bedding within layers.
   - Soft-sediment deformation at 5,075.5 and 5,080.8
   - Bioturbation at 5,077.8–77.9 and 5087.2–87.4 ft

8. 5,091.1–5,111.0 Black shale with local thin (~0.1–0.5 in.) partings of gray siltstone with local bioturbations.

Summary: Most of core represents shallow marine deposition.

Open marine: Intervals 1 and 2
Shallow marine shelf: Intervals 3 through 7
   Intervals 4 and 6 are offshore bars; thinner sandstones within intervals 3, 5, and 7 were deposited as incipient bars or sand waves
Open marine: Interval 8

Intervals approximate; original core depths not well marked.
Core is about 7 ft low with respect to wireline log

Table W3. Description of core of Tonkawa sand in the #1 Curtis-Stark well.
Earlsboro Oil and Gas Company
No. 1 Curtis-Stark
C SE NE Sec. 20, T. 25 N., R. 15 W.
Woods County, Oklahoma

T.D. 5,552 ft

Core: 5,055–5,116 ft

Completed 7-23-1970

Perforated Cottage Grove Sandstone, 5,508–5,528 ft
Acidized/800 gal 15%
CAOF 2,432 MCFGPD
Table 4 - Gas Production Statistics for the Tonkawa Sand
Waynoka NE Field Study Area,
T. 25N., R. 15-17 W., Woods County, Oklahoma

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of Gas Wells</th>
<th>Annual Gas Production Per Well (MCF)</th>
<th>Average Annual Gas Production (MCF)</th>
<th>Average Daily Gas Production Per Well (MCF)</th>
<th>Cumulative Gas Production (MCF)</th>
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<td>1967</td>
<td>11</td>
<td>386,980</td>
<td>35,180</td>
<td>96</td>
<td>386,980</td>
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<td>1968</td>
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<td>135,638</td>
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<td>2,014,631</td>
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<td>1969</td>
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<td>2,837,544</td>
<td>202,682</td>
<td>554</td>
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<td>142,674</td>
<td>390</td>
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<td>1971</td>
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<td>2,985,974</td>
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<td>429</td>
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<td>1972</td>
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<td>166,638</td>
<td>455</td>
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<td>1974</td>
<td>20</td>
<td>4,400,794</td>
<td>220,040</td>
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<td>1975</td>
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<td>3,482,436</td>
<td>165,830</td>
<td>453</td>
<td>24,102,053</td>
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<td>1976</td>
<td>21</td>
<td>2,530,199</td>
<td>120,486</td>
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<td>26,632,252</td>
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<td>1977</td>
<td>22</td>
<td>2,369,109</td>
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<td>294</td>
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<td>2,717,628</td>
<td>123,529</td>
<td>338</td>
<td>31,716,989</td>
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<td>1979</td>
<td>23</td>
<td>1,953,007</td>
<td>84,913</td>
<td>232</td>
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<td>1980</td>
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<td>64,486</td>
<td>176</td>
<td>35,090,691</td>
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| 1996 | 23                  | 889,507                             | 38,674                            | 106                                         | 54,158,832                     

Table W4. Natural gas production statistics for the Waynoka NE field study area.
Figure W7 (in envelope). North–south stratigraphic cross section A–A'. Location shown on Figure W5. Cross section includes the reference log and identifies all six layers of the Tonkawa sand. Persistence, uniformity, and log character of intervals 1 through 6 indicates a marine depositional environment. There are no apparent cut and fill relations.

Figure W8 (in envelope). West–northeast stratigraphic cross section B–B'. Location shown on Figure W5. The #1 Claude Seaman Unit is the tie well for the two cross sections. The Tonkawa sand has been cored in the #1 Shade and the #1 Curtis-Stark wells (Tables W2 and W3). The #3-1 Lancaster was logged using Schlumberger's FMI tool (Figures W10, W12, W13, W15, W17 and W18).

Figure W9 (in envelope). Isopach of the 6th sandstone layer of the Tonkawa sand. Stratigraphic position of the sandstone is shown on both cross sections A-A' and B-B'. The sandstone exceeds 100 ft. in thickness in the central part of the study area, and is bounded by open marine silty and sandy shales. The immediate direction of sediment transport was probably from the southeast. The layer is not productive, however, this may be due to positions of existing wells, or lack of testing in the structurally updip part of the sandstone. The contact between the 6th and 5th sandstone layers over the study area is characterized by a regionally correlatable, non-erosional interface. This implies that a few feet of shale between these layers would be a permeability barrier that would isolate the two layers as separate reservoirs. This relationship can be seen on cross section A-A' (Figure W7) between the #2 Fox and the #1 Stallings. The thin sandstone lenses of the 6th layer in the #1 Fox may locally have lower water saturations than those for the 5th layer located immediately above it. Therefore, it is possible that commercial gas reserves will be found below water bearing zones, which are separated by only a few feet of impermeable, non-fractured strata. This is an extremely important concept for Tonkawa exploration and development. The basal part of the 6th layer in the extreme northeastern part of the study area contains stringers of limestone. That limestone is mapped on Figure W9.
Contact between 5th sandstone and 6th sand interval

Figure W10. Part of FMI (Formation Imaging) log of the #3-1 Lancaster. The same interval is presented as the Lancaster gamma-ray and resistivity log on cross section B-B' (Figure W8). The contact between the 5th and 6th layer is at 5030.0'. The basal part of the 5th sandstone is composed of thinly laminated siltstone and shale streaks. These were deposited under very low energy conditions.
Figure W11 (in envelope). Isopach of the 5th sandstone layer of the Tonkawa sand. The sandstone was deposited as a marine bar with the immediate source of sediment from the southeast. An apparent tidal channel separates the bar into two parts. The areas referred to as “low energy deposits” consist of thin shale and siltstone that are probably impermeable. The axis of the bar deposit is characterized by cleaner, better sorted and significantly more permeable siltstone and sandstone. Commonly abundant micas in the sandstone indicate that the ultimate sediment source was from the north. The 5th sandstone was not productive within the Waynoka NE field study area at the time of the preparation of this report.
Figure W12. Part of FMI log of the #3-1 Lancaster. The same interval is presented as the gamma-ray and resistivity log on cross section B-B' (Figure W8). The interval 4980 to 4984 ft is interpreted to be shale on the gamma ray curve, but appears as siltstone or very-fine grained sandstone on the FMI Log. The gamma-ray log is probably responding to radioactive materials present in the sandstone lenses.
Figure W13. Part of FMI log of the #3-1 Lancaster well of Figure W8 illustrates the contact between the 4th and 5th sandstone layers. The lower part of the 4th sandstone is characterized by a slightly higher energy environment as suggested by the shale clasts embedded in that layer. The same interval is presented as the gamma-ray and resistivity log on cross section B-B' (Figure W8).
Figure W15. Part of the FMI log from the #3-1 Lancaster well of Figure W8 illustrates the contact between the 3rd and 4th sandstone layers. The very thin sandstone and shale laminations are sometimes known as tidal couplets. These deposits are interpreted to occur in a very shallow, low energy tidal environment.
Figure W14 (in envelope). Isopach of the 4th sandstone layer of the Tonkawa sand. This layer was the first reservoir to be productive in the Waynoka NE field study area. The reservoir boundary of the group of producing wells labeled Reservoir C, located in the center of the study area, is bounded to the north, northeast, and east by shales filling the apparent tidal channel. The reservoir boundary to the northwest and west contains deposits of siltstone and very-fine grained sandstone that have been identified as "low-energy deposits". These deposits are characterized by an increase in the frequency of shale laminations and by generally low porosity values. The low-energy deposits are probably impermeable, which completes the reservoir seal to the west and northwest of Reservoir C. The presence of isolated commercial reservoirs sealed by impermeable strata located intermittently in the middle of large sandstone bodies is of great significance for Tonkawa exploration and development.
Figure W12. Part of FMI log of the #3-1 Lancaster. The same interval is presented as the gamma-ray and resistivity log on cross section B-B' (Figure W8). The interval 4980 to 4984 ft is interpreted to be shale on the gamma ray curve, but appears as siltstone or very-fine grained sandstone on the FMI Log. The gamma-ray log is probably responding to radioactive materials present in the sandstone lenses.
Figure W13. Part of FMI log of the #3-1 Lancaster well of Figure W8 illustrates the contact between the 4th and 5th sandstone layers. The lower part of the 4th sandstone is characterized by a slightly higher energy environment as suggested by the shale clasts embedded in that layer. The same interval is presented as the gamma-ray and resistivity log on cross section B-B’ (Figure W8).
Figure W14 (in envelope). Isopach of the 4th sandstone layer of the Tonkawa sand. This layer was the first reservoir to be productive in the Waynoka NE field study area. The reservoir boundary of the group of producing wells labeled Reservoir C, located in the center of the study area, is bounded to the north, northeast, and east by shales filling the apparent tidal channel. The reservoir boundary to the northwest and west contains deposits of siltstone and very-fine grained sandstone that have been identified as "low-energy deposits". These deposits are characterized by an increase in the frequency of shale laminations and by generally low porosity values. The low-energy deposits are probably impermeable, which completes the reservoir seal to the west and northwest of Reservoir C. The presence of isolated commercial reservoirs sealed by impermeable strata located intermittently in the middle of large sandstone bodies is of great significance for Tonkawa exploration and development.
Figure W15. Part of the FMI log from the #3-1 Lancaster well of Figure W8 illustrates the contact between the 3rd and 4th sandstone layers. The very thin sandstone and shale laminations are sometimes known as tidal couplets. These deposits are interpreted to occur in a very shallow, low energy tidal environment.
Figure W16 (in envelope). Isopach of the 3rd sandstone layer of the Tonkawa sand. The layer is composed of shale and isolated sandstone bars deposited in an open marine environment. Such a sandstone produces minor amounts of gas in section 30, T. 25 N., R. 15 W.
Figure W17. Part of FMI log of the #3-1 Lancaster illustrates the contact between the 2nd and 3rd sandstone layers. The 2nd sandstone layer is the productive interval of the #3-1 Lancaster. The same interval is presented as the gamma-ray and resistivity log on cross section B-B' (Figure W8).
Figure W18. Part of FMI log of #3-1 Lancaster. The upper part of the 2nd sandstone layer is productive. The environment of deposition is noted on the log. The same interval is presented as the gamma-ray and resistivity log on cross section B-B' (Figure W8).
Figure W19 (in envelope). Isopach of the 2nd sandstone layer of the Tonkawa interval. Geometry of the 2nd sandstone suggests a marine bar complex, dissected by a series of north–south tidal channels. The impermeable deposits of the tidal channels probably separates the reservoirs labeled A and B. The discovery well for the Waynoka NE field study area is the King Resources #1-4 Schmolcke, NW SE section 4, T. 25 N., R. 16 W. Completed in December of 1965, this well had an initial potential of 5.8 MMCFGPD.

Figure W20 (in envelope). Isopach of the 1st sandstone layer of the Tonkawa sand. This layer was deposited as marine shales and small offshore marine bars. The small size of the sandstone features suggests that the amount of clastic material available was decreasing. The Haskell Limestone is normally deposited directly over the 1st sandstone. The sandstone produces locally, and may be prolific, assuming the data for wells completed in the 1st sandstone is accurate.

Figure W21 (in envelope). Isopach of the interval from the top of the Haskell Limestone to the top of the "Avant lime". The "Avant lime" is commonly regarded as the base of the interval within which the Tonkawa sand occurs (Figure W6). Minor thickening that is attributed to the presence of sandstone in the 5th and 6th layers is present in the center of the study area. Elsewhere, the isopach exhibits relatively uniform thickness except for thinning in the northwestern part of the field study area.

Figure W22 (in envelope). Natural gas production from Tonkawa sand for in the Waynoka NE field study area. The plat illustrates cumulative gas and condensate production, initial and final pressure test data with dates, and the production period for each well.
Figure W23. Decline curve for all natural gas Tonkawa production in T. 25 N., R. 15–17 W., of the Waynoka NE field study area.
Figure W24. Decline curve for the producing wells in Reservoir A on Figure W19.
Figure W25. Decline curve for the producing wells in Reservoir B on Figure W19.
Figure W26. Decline curve for the producing wells in Reservoir C on Figure W14.
Figure W7
Figure W20