Overview of Oklahoma Shale Resource Plays

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Oklahoma Geological Survey

Oklahoma Shale Gas
and Oil Workshop

November 20, 2013
Outline of Presentation

- Basic parameters needed for shale resource plays
- Known hydrocarbon source rocks of Oklahoma
- Oklahoma Shale Gas and Oil Wells
- Evaluation (oldest to youngest) of Sylvan, Arkansas Novaculite, Woodford, Caney, Barnett, Atoka, and Pennsylvanian shales
Conventional Wisdom
[Non-Negotiable Parameters]
Necessary for Shale Gas and Oil

- Hydrocarbon Source Rock
  (Hydrocarbon Generation, Storage, and Preservation)
- Brittle lithology to generate fractures (permeability) or “conventional” reservoir lithology
Hydrocarbon Generation: Organic-Rich Black Shale

- **Organic Matter Type:**
  Type II (oil generative) Kerogen
  [All gas shales have Type II Kerogen]

- **Organic Matter Quantity:** minimum of 2% TOC (Total Organic Carbon content depends on thermal maturity since TOC decreases with increasing thermal maturity)

- **Thermal Maturity:** oil, condensate, or dry gas windows
Known Hydrocarbon Source Rocks of Oklahoma

<table>
<thead>
<tr>
<th>SYSTEM</th>
<th>PRODUCING INTERVAL</th>
<th>HYDROCARBON-SOURCE ROCK</th>
<th>KEROGEN TYPE</th>
<th>TOC %</th>
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<tbody>
<tr>
<td>PERMIAN</td>
<td>PERMIAN (UNDIFFERENTIATED)</td>
<td>UPPER AND MIDDLE PENNSYLVANIAN</td>
<td>II III</td>
<td>&lt;1-25</td>
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<td>PENNSYLVANIAN</td>
<td>VIRGILIAN</td>
<td>MORROWAN</td>
<td>III</td>
<td>0.5-3.4</td>
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<tr>
<td></td>
<td>DESMOINESIAN</td>
<td>SPRINGER FORMATION</td>
<td>III</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ATOKAN</td>
<td>MORROWAN</td>
<td>III</td>
<td></td>
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<tr>
<td></td>
<td>MORROWAN</td>
<td>SPRINGER FORMATION</td>
<td>III</td>
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<tr>
<td>MISSISSIPPIAN</td>
<td>SPRINGER FORMATION</td>
<td>PRE-CHESTER MISSISSIPPIAN (UNDIFFERENTIATED)</td>
<td>II</td>
<td>1-8</td>
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<tr>
<td></td>
<td>WOODFORD SHALE</td>
<td>SYLVMAN SIMPSON GROUP</td>
<td>II III</td>
<td>&lt;1-14</td>
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<tr>
<td></td>
<td>HUNTON GROUP</td>
<td>SIMPSON GROUP</td>
<td>II</td>
<td>&lt;1-9</td>
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<tr>
<td></td>
<td>ARBUCKLE GROUP</td>
<td></td>
<td>I II</td>
<td></td>
</tr>
</tbody>
</table>

Best Ordovician samples are from Kansas

Modified from Johnson and Cardott, 1992
Anadarko Basin oil and hydrocarbon source-rock study by Burruss and Hatch, 1989
Anadarko Basin Source-Rock TOC

Burruss and Hatch, 1989
<table>
<thead>
<tr>
<th>Period</th>
<th>Group</th>
<th>Formation</th>
<th>Oils</th>
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<tbody>
<tr>
<td>Cretaceous</td>
<td>Trinity</td>
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<tr>
<td>Permian</td>
<td>Pontotoc</td>
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<td></td>
<td>Hoxbar</td>
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<tr>
<td>Pennsylvanian</td>
<td>Deese</td>
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<tr>
<td></td>
<td>Dornick Hills</td>
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<tr>
<td></td>
<td>Springer</td>
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<tr>
<td>Mississippian</td>
<td>Goddard</td>
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<td>25</td>
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<td></td>
<td>Caney</td>
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<td></td>
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</tr>
<tr>
<td>Devonian</td>
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<td>Sylvan</td>
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<tr>
<td>Ordovician</td>
<td>Viola</td>
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<td>53</td>
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<td></td>
<td>Simpson</td>
<td></td>
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</tr>
<tr>
<td>Cambrian</td>
<td>Arbuckle</td>
<td></td>
<td>61</td>
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</tbody>
</table>

Figure 2. Stratigraphic distribution of 385 oil samples.

Source Facies:

A  Pennsylvanian (Atoka?)
B  Mississippian (Goddard, Caney, Sycamore)
C  Devonian-Mississippian (Woodford)
D  Upper Ordovician (Viola Group)
E  Middle Ordovician (Simpson Group)
F & G  Mixed

Figure 11. Frequency distribution of oil types reservoired in the Ardmore and Marietta basins.

Wavrek, 1992
Anadarko Basin Source Rock and Oil Study (Wang and Philp, 1997)

Figure 3—Map of the Anadarko basin within the state of Oklahoma showing the locations of source rock and oil samples collected for this study.

**LEGEND**
- ▲ Source Rocks Viola & Sylvan
- ◀ Source Rocks Lower Mississippian Lime
- □ Source Rocks Springer, Chester, & Morrow
- ● Crude Oils
Figure 4—Kerogen typing using III vs. T_max of Pyran Level-I pyrolysis system. The T_max value of Pyran is systematically 85°C higher than that of Rock-Eval pyrolysis, but the principles are the same.

Figure 5—S_2 vs. TOC (total organic carbon) plot for five formations or groups. The Sylvan, Springer, and Morrow shales have similar slopes and their data are plotted together.
Gas production is reported by the Oklahoma Corporation Commission by WELL.

Oil/condensate production is reported by the Oklahoma Tax Commission by LEASE [production by well is only on single-well leases]

(Production data supplied by PI/Dwights LLC, © 2013, IHS Energy Group)
The Bakken Shale (Late Devonian-Early Mississippian; North Dakota & Montana) is the analog for shale oil plays. However, the reservoir of the Bakken is a permeable, non-shale middle member.

Other formations considered shale oil plays (mostly carbonates) are the Eagle Ford Shale (Late Cretaceous; Texas) and Niobrara Shale (Late Cretaceous; Rocky Mountains).

“The preferred rock type for a shale-oil play is a hybrid—that is, a formation with a good mix of non-shale lithologies, particularly carbonates”

(Darbonne, 2011)
Eagle Ford Shale Porosity and Permeability

“The greater connectivity of interparticle pores in limestones is important to higher hydrocarbon producibility in these rocks relative to mudstones, which is why the limestones are critical components of overall hydrocarbon fluid transmissivity system in the formation. Furthermore, the abundant authigenic calcite in the limestones provided the overall brittle mechanical nature of the limestones compared to the more TOC-rich and ductile mudstones.”

Fishman and others, 2013
Oklahoma Geologic Provinces

MAJOR FAULTS

Surface faults

Subsurface faults

Normal faults identified by hachures on relatively downthrown block.

Thrust faults identified with solid barbs on hanging wall block.

Geologic provinces from Northcutt and Campbell, 1995
Oklahoma Shale Gas/Oil Completions (1939-2013)

2,996 completions
Sylvan Shale (Ordovician) [2008-2013]

10 Sylvan and Woodford
Pre-Woodford Geologic Map

From Amsden, 1980
Pre-Woodford Geologic Map

Modified from OGS GM-9

Sylvan Shale
Sylvan Shale Isopach Map (in meters)

THICKNESS AND DOMINANT LITHOLOGIES, SYLVAN-CASON SHALE
(UPPER ORDOVICIAN, CASON SHALE IN ARKANSAS ALSO INCLUDES LOWER SILURIAN)

By
Thomas W. Amsden

Modified from Amsden (1975, 1980), Merriam (1963), and Wise and Caplan (1979)

From Johnson and others, 1989
Outcrop of Sylvan Shale in Arbuckle Mountains

Weathered Clay-Rich Sylvan Shale
Example of Poor Gas Shale (but Good Frac Barrier)
Abundant dolomite; organic matter type?

Organic-Walled Fossils of the Sylvan Shale

- Acritarchs
- Chitinozoa
- Conodonts
- Graptolites
- Scolecodonts
Sylvan Shale (Ordovician)

Wang (1993): Sylvan Shale is generally organic lean (<1% TOC); mainly Type III kerogen.

Wang and Philp (1997): “The Sylvan Shale is thin and organically lean in the Anadarko Basin, and probably NOT a source rock in the basin.”
There are 10 horizontal Woodford/Sylvan wells in Hughes, Pittsburg, and Payne counties;

One Sylvan-Shale-only vertical well in Woods County:

Chesapeake Operating 1-2 RK Farms (2-28N-13W): completed 8/15/2010 from 5,411-5,460 ft; IP 28 MCFD, 20 BOPD.

Operator indicated producing from Sylvan Dolomite (“Maquoketa”)
Cum: 17.7 MMcf; 10,326 BO

(Oil & gas production data supplied by Petroleum Information/Dwights LLC dba IHS Energy Group, © 2013)
Arkansas Novaculite/Bigfork Chert wells (2009-2010)
Arkansas Novaculite
(Scratch Hill Section, Atoka, OK)
Exploration for the Arkansas Novaculite Reservoir, in the Southern Ouachita Mountains, Arkansas*

Theodore J. Godo¹, Peng Li², and Michael E. Ratchford²

Search and Discovery Article #10337 (2011)
Posted July 12, 2011

*Adapted from oral presentation at AAPG Annual Convention and Exhibition, Houston, Texas, USA, April 10-13, 2011

¹Shell Exploration and Production Company, Houston, TX (ted.godo@shell.com)
²Arkansas Geological Survey, Little Rock, AR.

Abstract

The Arkansas Novaculite, famous for its whetstone characteristic, is also an oil and gas reservoir in the Ouachita overthrust belt of Oklahoma and Texas (Caballos Novaculite). Oil and gas fields such as Isom Springs in Oklahoma and McKay Creek, Pinion and Thistle fields in West Texas found reservoirs in this chert section some 30 years ago. The chert reservoir has shown to be productive when it is highly fractured in complex thrust faults. In Arkansas, outcrops of this chert present along the southern side of the Benton uplift often contain a considerable amount of carbonate. The carbonate can be identified at times as highly abraded fossil fragments but otherwise are found as individual calcium carbonate concretion-like masses and also single dolomite rhombs. When leached, it is referred to tripolitic chert and can have porosity measurements ranging to over 50% percent. Assuming the carbonate is leached in the subsurface, the Arkansas Novaculite would have matrix porosity with fractures, which was the concept for the Shell exploration well that drilled Prospect Rattler.

Prospect Rattler was drilled by Shell with the well named the 1-26 Arivett and is located in Pike County, Arkansas. The Arivett 1-26 well spudded in the Mississippian Stanley Shale and reached a total depth of 10,570 in the Silurian Blaylock Sandstone. The well penetrated a complete section of all three members of the Arkansas Novaculite, as described in the type section at Caddo Gap, Arkansas. This formation has very low dips in an otherwise non-internally faulted section. The well was air/mist drilled and flared several gas shows in sands and novaculite. The upper member of the Arkansas Novaculite contains an unleached carbonate-rich chert section based on cuttings, core analysis, and wireline logging. The results reveal little matrix porosity in the Arkansas Novaculite. However, small amounts of thermally “dead” oil residues or anthraxalite is present in some fractures and some micropores of leached carbonate material. This indicates that a hydrocarbon charge migrated through the Arkansas Novaculite but never accumulated. The vitrinite equivalent reflectance of the Arkansas Novaculite is 3.5%. Even at this high thermal maturity, the middle member shale has up to 4% total organic carbon content and is considered a major source rock. The failure mechanism was most likely a poor reservoir and a poor charge/timing as peak charge occurred before the trap was formed.
Arkansas Novaculite (AN)/Bigfork Chert (BC) wells

- RKI E&P 2-9 Denton-Perrin (1/2009; 9-2S-15E; 6,250 ft; IP 243 Mcf) [AN]

- Longfellow Energy LP 26-3 Wyrick (2/2010; 26-1N-14E; 8,104 ft; IP 2,926 Mcf; cum 1,109 MMcf) [AN/BC]

- Longfellow Energy LP 35-3 Ertman Unit (4/2010; 35-1N-14E; 8,890 ft; IP 2,762 Mcf; cum 282 MMcf) [AN/BC]

(Gas production data supplied by Petroleum Information/Dwights LLC dba IHS Energy Group, © 2013)
Woodford Shale (2004-2013)
Woodford Shale: From Hydrocarbon Source Rock to Reservoir*

Brian J. Cardott

Search and Discovery Article #50817 (2013)**
Posted July 22, 2013

*Adapted from oral presentation given at AAPG Education Directorate Woodford Shale Forum, Oklahoma City, Oklahoma, April 11, 2013.
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ABSTRACT

Being a hydrocarbon source rock and having a brittle (silica-rich) lithologic character makes the Woodford Shale (Late Devonian to Early Mississippian) an important oil and gas shale in Oklahoma. Since 2004, Woodford Shale plays have expanded from producing primarily thermogenic methane in one geologic province to now producing gas, condensate, and oil in multiple geologic provinces.
Caney Shale (1982 to 2013) [age equivalent to the Barnett Shale and Fayetteville Shale]
Oklahoma Shale-Gas Well History

2,815 Woodford + 91 Caney Wells, 2004–2013

Caney/Woodford included with Caney

Rock-Eval Pyrolysis Data from OPIC Cores

Caney cores:
1. Sohio 1 Whitehead
2. Texaco 1 Elliott

Caney
(1) 0.55% VRo, 8.23% TOC, 6,285 ft
(2) 1.14% VRo, 4.83% TOC, 11,465 ft

Woodford
(3) 0.50% VRo, 7.18% TOC, 3,266 ft
(4) 1.23% VRo, 3.76% TOC, 3,709 ft

Rock-Eval data compliments of Humble Geochemical Services
Rock-Eval Pyrolysis Data from OPIC Cores

- Type I Oil Prone (usu. lacustrine)
- Type II Oil Prone (usu. marine)
- Mixed Type II / III Oil / Gas Prone
- Type III Gas Prone

Organic Lean
Dry Gas Prone

REMAINING HYDROCARBON POTENTIAL (mg HC/g Rock)
TOTAL ORGANIC CARBON (TOC, wt.%)

Rock-Eval data compliments of Humble Geochemical Services

Cum: 306.8 MMcf

(Gas production data supplied by Petroleum Information/Dwights LLC dba IHS Energy Group, © 2013)

Oil production from Caney not confirmed from operator. Cum: 224.2 MMcf; 4,538 BO
(1) GLB Exploration 1-29 Hatch well; 29-1S-23W; Jackson Co.; 7,966 TVD; 4/17/2010
(2) Texas Energy Operations 1 Lane well; 2-2S-24W; Jackson Co.; 7,830 TVD; recompleted 4/20/2012
Horizontal Barnett Shale Oil Well
GLB Exploration 1-29 Hatch (Jackson Co.; 29-1S-23W): completed 4/17/2010 to 7,966 TVD; IP 1.1 MMcfd; 216 BO

Oil production from Barnett not confirmed by operator.
Cum: 6.4 MMcf; 2,356 BO

(Oil & gas production data supplied by Petroleum Information/Dwrights LLC dba IHS Energy Group, © 2013)
Atokan Series
Continental Resources 1-22H Shrewder well; 22-18N-23W; Ellis Co.; “Atoka Shale”; 10,926 TVD
A geologist at Continental Resources indicated the well was completed in the Novi, a dolomite-rich member in the Atoka.
Atokan Isopach Map (in meters)

From Johnson and others, 1989
Continental Resources 1-22H Shrewder well; 22-18N-23W; Ellis Co.; “Atoka Shale”; 10,926 TVD; IP 1.255 MMCFD

Oil production from Atoka not confirmed by operator. Cum: 334 MMcf; 3,495 BO

(Oil & gas production data supplied by Petroleum Information/Dwights LLC dba IHS Energy Group, © 2013)
Pennsylvanian Shales (NE OK)
Osage County

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<tr>
<th>OPER:</th>
<th>S-T-R: 28-</th>
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<tr>
<td>PERFORMANCE</td>
<td>27N-11E;</td>
</tr>
<tr>
<td>OPERATING CO</td>
<td>SPOT: SE SW</td>
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<tr>
<td>LLC;</td>
<td>SE;</td>
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<tr>
<td>WELL: 10-32</td>
<td>FOOTAGE:</td>
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<tr>
<td>EDMUNDSON</td>
<td>330 FSL 990</td>
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<td>WEST;</td>
<td>FWL SE;</td>
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<td>API: 35-113-44046;</td>
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FIELD: DOMES-POND CREEK; PROJ DO
DEPTH: 1950; PROJ FM: CHAT; (PMT STATUS:
APP'D 20101012) (FR:20101112 OKC OIL;
NAO/MER) LEASE TYPE: FEE TARGET
OBJ: OIL; OPER ADD: P O BOX 628,
BARNSDALL, OK 74002--0628, (918)847-
2531 EL: 858 GR; ;VERTICAL; L&L Surf:
36.782523131 -96.12146808; PREV OPER:
PERFORMANCE ENERGY R PREV
LEASE: EDMUNDSON W

CONTR: THORNTON AIR, SPUD:20101027 CSG: 8 5/8 IN @ 42 W/8 SACK,4 1/2 IN @
1761 W/230 SACK;LOG TOPS: JONES /SD/ 966-981, WAYSIDE 1040-1056, BIG LIME

1167-1194, OSWEGO 1331, SUMMIT 1362-1368, EXCELLO 1388; TD: 1820; (EXCELLO)
(TD REACHED:20101029) PRODUCING INTERVALS DATA: # 01 PERF (EXCELLO)
1650-1654 W/ 8 SHOTS 1656-1660 W/ 8 SHOTS 1664-1672 W/ 16 SHOTS ; ACID (1650-
1672) W/ 400 GAL ACID 15%; FRACTURING (1650-1672) W/ 390 BBL WATER 20000 LB
MIXED SAND DETAILS: 1 GAL INH, 18 GAL, 300#, 2000# 20/40, 18000# 12/20 SD
ADDITIVE: GELA, KCL OIL: 4 BPD WTR: 50 BBL DTD: 1820; COMPDAT: 20101113;
(EST); # 01 IPP OIL: 4 BPD WTR: 50 BBL PROD ZONE: PERF (EXCELLO) 1650-1672
(GROSS) W/ 32 ; $$

Completion reported as Cherokee completion; NO PRODUCTION
Oklahoma CBM article was published in the 2010 Oklahoma Geology Notes (v. 70, p. 4-14)

1. Horizontal CBM
2. Gas fields by county
3. Recompletions (OWWO)
4. Mulky coal problem
5. CBM with noncoal
6. “Pennsylvanian” CBM
7. Commingled CBM

Excello Shale
Osage County

OPER: CEP MID-CONTINENT  S-T-R: 12-23N-10E;  FIELD: OSAGE COUNTY CBM GAS  DG
LIABILITY CORP;  SPOT: NW  AREA; PROJ DEPTH: 2100; PROJ FM:  STATUS:
WELL: 977  MISSISSIPPIAN; (PMT APP'D 20070725) GAS-CB;
FOOTAGE:  SW SE;  (FR:20070806 OKC RES) TARGET OBJ:
MARSHALL;  FEL SE;  METH; OPER ADD: 1440 SOUTH HAYNIE,
API: 35-113-42654;  L&L Surf: 918.480474465 -96.181909434;
PREV OPER: AMVEST OSAGE INC PREV LEASE: OSAGE

CONTR: PENSE BROTHERS DRILLING, SPUD:20070912 CSG: 7 IN @ 531,4 1/2 IN @
1722;LOG TOPS: CLEVELAND UPPER 1085, NUYAKA 1148, DAWSON UPPER 1153,
CLEVELAND LOWER 1160, LITTLE OSAGE 1477, OSWEGO 1480, MULKY 1520, IRON
POST 1533, VERDIGRIS 1587, OAKLEY COAL 1594, CROWEBERG 1599, MINERAL
COAL 1652; TD: 1735; (MINERAL COAL) (TD REACHED:20070919) 1722 PBTD
PRODUCING INTERVALS DATA: # 01 PERF (NUYAKA) 1150-1154 PERF (MULKY)
1522-1524 1531-1533 PERF (OAKLEY COAL) 1596-1599; ACID (1150-1154) W/ 500 GAL
ACID 7 1/2% ADDITIVE: HCL; ACID (1522-1533) W/ 500 GAL ACID 7 1/2% ADDITIVE:
HCL; ACID (1596-1599) W/ 500 GAL ACID 7 1/2% ADDITIVE: HCL; FRACTURING (1150-
1154) W/ 145000 CF FOAM 10170 LB SAND DETAILS: 12837 GAL MAVFOAM C70
ADDITIVE: NTGN; FRACTURING (1522-1533) W/ 150000 CF FOAM 10000 LB SAND
DETAILS 9740 GAL MAVFOAM C70 ADDITIVE: NTGN; FRACTURING (1596-1599) W/
107000 CF FOAM 52000 LB SAND DETAILS: 7907 GAL MAVFOAM C70 ADDITIVE:
NTGN GAS: 33 MCFD WTR: 160 BBL DTD: 1735; 1722 PB COMPDATE: 20080110; # 01
IPP GAS: 33 MCFD WTR: 160 BBL PROD ZONE: PERF (NUYAKA) 1150-1154 PERF
(MULKY) 1522-1533 (GROSS) PERF (OAKLEY COAL) 1596-1599 COMMINGLED: $$
Pennsylvanian shale gas well:
CEP Mid-Continent 977 Marshall (Osage Co.; 12-23N-10E): perforated Nuyaka shale, Mulky coal (Excello Shale), and Oakley shale on 1/10/2008; IP 33 Mcfd

Cum: 56.9 MMcf

(Oil & gas production data supplied by Petroleum Information/Dwrights LLC dba IHS Energy Group, © 2013)
Fractured Woodford Shale in outcrop along Highway 77D in the Arbuckle Mountains.