Economic Development of Pennsylvanian Age Granite Wash Reservoirs with Horizontal Wells in the Anadarko Basin*

John Mitchell¹

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Abstract

Economic oil and gas development in Pennsylvanian age Granite Wash reservoirs using horizontal wells in the Anadarko Basin is dependent on a number of geologic and engineering factors. The Granite Wash play is not a “typical” resource play in that it is occurring in a wide variety of reservoirs distributed through a 2,500-5,000 foot thick sedimentary sequence along a 125 mile long trend. This northwest to southeast trend extends from central Roberts County, Texas to northeastern Washita County, Oklahoma. Production depths range from 8,000 feet in Roberts County to more than 14,000 feet in Beckham and Washita Counties. Since 2002 more than 2,000 horizontal wells have been drilled. The vast majority of these wells have been drilled since 2008. Over 80 million barrels of oil/condensate and 1.8 trillion cubic feet of natural gas have been produced through early 2014 from these horizontal wells. These wells were producing approximately 50,000 BO and 1.1 BCFG daily as of early 2014. Approximately 75% of the wells have been drilled in the Texas portion of the play with another concentration of wells in Washita County, OK. Desmoinesian age sandstone and conglomerate reservoirs have been the target of the large majority of the drilling.

Geologic targeting of reservoir horizons along with drilling, completion and production methodologies all play significant roles in determining the economic success operators are having in the horizontal Granite Wash play. This article reviews the distribution of horizontal wells by reservoir unit, location and trap type. Oil and gas production profiles and economic sketches by reservoir are presented along with observations about geological targeting, drilling and completion practices and hazards that industry operators have experienced in the development of this horizontal play.
References Cited


Economic Development of Pennsylvanian Age Granite Wash Reservoirs with Horizontal Wells in the Anadarko Basin

John Mitchell, Managing Partner/Consulting Geologist
Fall River Exploration LLC
Tulsa, Oklahoma
The Granite Wash play extends over 125 miles from Roberts County, Texas southeast to Washita County, Oklahoma along the southwestern side of the Anadarko Basin.

More than a dozen key reservoir units were deposited in three Pennsylvanian stages (Atokan, Desmoinesian and Missourian).

Arkosic sandstone and conglomerate reservoirs are 8000 to 14,500 feet deep in a sedimentary column ranging in thickness from 2500 to 5000 feet.

Production is primarily from stratigraphic traps.

Starting in 2002, over 2200 horizontal Granite Wash wells have been drilled, mostly since 2010.

75% of the horizontal wells have been drilled in the Texas Panhandle.

More than 92 million barrels of oil and 2.0 TCF of gas produced from over 1800 horizontal wells primarily over the last four years.

Estimated 2014 production of 17 MMBO and 305 BCFG.

Daily production in September 2014 of ~ 50,000 BOPD, 1.1 BCFGPD & 110,000+ BWPD.

Operators target reservoirs with high oil/condensate/natural gas liquids content.

In spite of initial annual decline rates in the 75-85% range, the initial high rate of return on investment and low risk provided attractive drilling opportunities.

Successful operations in the horizontal Granite Wash play demand the ability to cope with complexity in geological, engineering and land functions especially in today’s low product price environment.

Significant changes in operators/ownership have occurred in past two years.
HORIZONTAL GRANITE WASH PLAY LOCATION MAP

Pennsylvanian Granite Wash Play Area

Anadarko Basin
Areas in red show locations of Pennsylvanian Granite Wash Oil & Gas Production
Estimated 3.2 TCFG + 126 MMBO Cumulative Production from more than 4000 vertical wells since 1947
Stars show locations of horizontal Granite Wash wells

2.0 TCFG + 92 MMBO Cumulative Production from more than 1800 horizontal wells since 2002 (primarily since 2009)
Low Relief Land

Shallow Marine to Deltaic

Deep Marine

Shallow Marine

Carbonates - Shallow Marine

Ouachita Thrust Belt

Middle Pennsylvanian Geography

Texas

Oklahoma

Kansas

Colorado

New Mexico

Anadarko Sea-way

Deep Granite Wash Producing Area

Deep Granite Wash

Amarillo-Wichita Uplift

Ancestral Rockies

Modified from Moore, 1979
Deepwater Submarine Fan Lobes (Proximal to Medial to Distal)

Fan Delta

Distal Fan Lobe

NORTHWEST

Proximal to Medial to Distal

Adapted From Bouma, 2000
GRANITE WASH PLAY SCHEMATIC CROSS SECTION

- Pennsylvanian
- Virgilian
- Missourian
- DesMoinesian
- Morrowan
- Mississippian
- Springeran
- Morrow Chert Wash
- Atoka Wash
- Skinner Wash
- Cottage Grove, Hogshooter & Checkerboard Washes
- Shawnee Wash

South

North

FEET

15 MILES
### THE STRATIGRAPHIC COLUMN

**Translation Chart for Texas Wash Stratigraphic Nomenclature**

**Missourian Stage:**
- Cottage Grove = Lansing
- Hogshooter = Upper Kansas City
- Checkerboard = Lower Kansas City

**Desmoinesian Stage:**
- Marmaton “B” = Carr or Caldwell
- Marmaton “C” = Caldwell or Britt
- Marmaton “D” = Granite Wash “A”
- Marmaton “E” = Granite Wash “B”
- Marmaton “F” = Granite Wash “C”
- Upper Skinner = Granite Wash “D”
- Lower Skinner = Granite Wash “E”

<table>
<thead>
<tr>
<th>SERIES / STAGE</th>
<th>GROUP</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>VIRGILIAN</strong></td>
<td>Shawnee/Cisco</td>
<td>Shawnee Wash, Heebner Sh</td>
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<td>Douglas/Cisco</td>
<td>Haskell Sh, Tonkawa Ss</td>
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<td><strong>MISSOURIAN</strong></td>
<td>Lansing/Hoxbar</td>
<td>Cottage Grove Wash</td>
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<td>Kansas City/Hoxbar</td>
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<tr>
<td><strong>DESMOINESIAN</strong></td>
<td>Marmaton</td>
<td>Marmaton Wash</td>
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<tr>
<td></td>
<td>Cherokee</td>
<td>Upper Skinner Shale, Upper Skinner Wash, Lower Skinner Shale (Pink Ls Marker), Lower Skinner Wash, Red Fork Ss &amp; Sh</td>
</tr>
<tr>
<td><strong>ATOKAN</strong></td>
<td>Atoka</td>
<td>Atoka Wash 13 Finger Ls</td>
</tr>
<tr>
<td><strong>MORROWAN</strong></td>
<td>Morrow</td>
<td>Upper Morrow Squawbelly Ls, Lower Morrow (Primrose)</td>
</tr>
</tbody>
</table>
Type Log in the Missourian Wash, Deep Anadarko Basin, Texas & Oklahoma; Chesapeake #1-28 Mary K well, Sec. 28, T11N R23W, Beckham Co., Oklahoma

1300+ feet of Missourian Series sediments with three distinct Granite Wash sections

Missourian Wash Has Produced 27 MMBO and 119 BCFG from 364 Horizontals Since 2010
Type Log
Desmoinesian Wash, Deep Anadarko Basin, Texas & Oklahoma: Devon #16-4 Truman-Zybach, Sec. 16, Block R&E Survey, Wheeler Co., Texas

2000+ feet of Desmoinesian Series
Granite Wash section

Desmoinesian Wash Has Produced 58 MMBO and 1.6 TCFG from 1357 Horizontals Since 2002
NUMBER OF PENNSYLVANIAN GRANITE WASH HORIZONTAL WELLS BY TARGETED STRATIGRAPHIC INTERVALS

IDENTIFIED HORIZONTAL TARGET ZONES

Desmoinesian
Missourian
Atokan
Isopach Map: Cottage Grove Wash (Missourian) (Lansing Wash)

Contour Interval: 40/100 Ft

Interval Isopach Map
Contour Interval: 40/100 Ft
Isopach Map: Cottage Grove Wash (Missourian) (Lansing Wash)

Contour Interval: 40/100 Ft

Interval Isopach Map
Contour Interval: 40/100 Ft
Isopach Map: Cottage Grove Wash (Missourian) (Lansing Wash)

LEGEND
Isopach Map
Cottage Grove Wash (Lansing)
Missourian
Contour Interval: 40 Feet

Cottage Grove Wash Horizontal
Geologist: John Mitchell
October 2014

Interval Isopach Map
Contour Interval: 40/100 Ft
Map: Initial Potential (BOEPD)
Cottage Grove Wash (Upper Missourian)

Average Initial Potential: 699 BOEPD (118 Wells)

Structure Map
Contour Interval: 400 Ft
Map: Net Payout 1st Year
Cottage Grove Wash (Upper Missourian)

Average % Payout In 1st Year: 103%
(77 Wells)

Structure Map
Contour Interval: 400 Ft
Isopach Map: Hogshooter Wash (Missourian) (Upper Kansas City Wash)

Interval Isopach Map
Contour Interval: 40/100 Ft

12 Miles

10% POROSITY
90 API
Isopach Map: Hogshooter Wash (Missourian) (Upper Kansas City Wash)

Interval Isopach Map
Contour Interval: 40/100 Ft

LEGEND
Isopach Map
Hogshooter Wash (Kansas City) Missourian
Contour Interval: 40 Feet

Geologist: John Mitchell
October 2014

Interval Isopach Map
Contour Interval: 40/100 Ft

12 Miles
Isopach Map: Hogshooter Wash (Missourian) (Upper Kansas City Wash)

12 Miles

Interval Isopach Map
Contour Interval: 40/100 Ft
Map: Initial Potential (BOEPD)  
Hogshooter Wash (Middle Missourian)

Average Initial Potential: 780 BOEPD  
(207 Wells)

Structure Map  
Contour Interval: 400 Ft
Map: Net Payout 1st Year
Hogshooter Wash (Middle Missourian)

Average % Payout In 1st Year: 96% (129 Wells)
Isopach Map: Marmaton “B” Wash (Desmoinesian) (Carr or Dunn Zone)

Contour Interval: 40/100 Ft

Shale Basin

Legend:
Isopach Map
Marmaton ‘B’ Wash (Carr Zone)
(Upper Desmoinesian)
Contour Interval: 40 Feet

Geologist: John Mitchell
October 2014

Interval Isopach Map
Contour Interval: 40/100 Ft
Isopach Map: Marmaton “B” Wash (Desmoinesian) (Carr or Dunn Zone)

Contour Interval: 40/100 Ft

Shale Basin

LEGEND
Isopach Map
Marmaton ‘B’ Wash (Carr Zone)
(Upper Desmoinesian)
Contour Interval: 40 Feet

Geologist: John Mitchell
October 2014

Interval Isopach Map
Contour Interval: 40/100 Ft

12 Miles
Isopach Map: Marmaton “B” Wash (Desmoinesian) (Carr or Dunn Zone)
Map: Initial Potential (BOEPD)
Marmaton ‘B’ Wash (Upper Desmoinesian)

Average Initial Potential: 599 BOEPD (168 Wells)

Structure Map
Contour Interval: 400 Ft
Map: Net Payout 1st Year
Marmaton ‘B’ Wash (Upper Desmoinesian)

Average % Payout In 1st Year: 97% (90 Wells)

Structure Map
Contour Interval: 400 Ft
Isopach: Marmaton “C” Wash (Desmoinesian) (Britt or Caldwell Zones)

LEGEND
Isopach Map
Marmaton “C” Wash (Britt or Caldwell Zone) (Upper Desmoinesian) Contour Interval: 40 Feet

Interval Isopach Map
Contour Interval: 40/100 Ft

12 Miles
Isopach: Marmaton “C” Wash (Desmoinesian) (Britt or Caldwell Zones)

LEGEND
Isopach Map
Marmaton ‘C’ Wash
(Britt or Caldwell Zone)
(Upper Desmoinesian)
Contour Interval: 40 Feet

Geologist: John Mitchell
October 2014

Horizontal Producers

Shale Basin

Interval Isopach Map
Contour Interval: 40/100 Ft

12 Miles
Isopach: Marmaton “C” Wash (Desmoinesian) (Britt or Caldwell Zones)

Interval Isopach Map
Contour Interval: 40/100 Ft
Map: Initial Potential (BOEPD)
Marmaton ‘C’ Wash (Upper Desmoinesian)

Average Initial Potential: 578 BOEPD (397 Wells)

Structure Map
Contour Interval: 400 Ft
Map: Net Payout 1st Year
Marmaton ‘C’ Wash (Upper Desmoinesian)

Average % Payout In 1st Year: 84%
(319 Wells)
Isopach Map: Marmaton “D” Wash (Desmoinesian) (Granite Wash “A” Zone)
Isopach Map: Marmaton “D” Wash (Desmoinesian) (Granite Wash “A” Zone)

Contour Interval: 40/100 Ft
Isopach Map: Marmaton “D” Wash (Desmoinesian) (Granite Wash “A” Zone)

Interval Isopach Map
Contour Interval: 40/100 Ft

LEGEND
Isopach Map
Marmaton 'D' Wash
(Granite Wash 'A' Zone)
(Upper Desmoinesian)
Contour Interval: 40 Feet

Marmaton 'D' Wash Horizontal
Geologist: John Mitchell
October 2014
Map: Initial Potential (BOEPD)
Marmaton ‘D’ Wash (Upper Desmoinesian)

Average Initial Potential: 518 BOEPD (560 Wells)

Structure Map
Contour Interval: 400 Ft
Map: Net Payout 1st Year
Marmaton ‘D’ Wash (Upper Desmoinesian)

Average % Payout In 1st Year: 83%
(417 Wells)

Structure Map
Contour Interval: 400 Ft
Isopach Map: Atoka Wash

Interval Isopach Map
Contour Interval: 200 Ft
Isopach Map: Atoka Wash

Interval Isopach Map
Contour Interval: 200 Ft

Shale Basin

LEGEND
Isopach Map
Atoka Wash Interval
(Atokan)
Contour Interval: 200 Feet

Geologist: John Mitchell
October 2014

12 Miles
Isopach Map: Atoka Wash

LEGEND
Isopach Map
Atoka Wash Interval
(Atokan)
Contour Interval: 200 Feet
Atoka Wash Horizontal
Geologist: John Mitchell
October 2014

Shale Basin

Interval Isopach Map
Contour Interval: 40/100 Ft

12 Miles
Map: Initial Potential (BOEPD)  
Atoka Wash (Atokan)

Average Initial Potential: 354 BOEPD  
(207 Wells)
Average % Payout In 1st Year: 54% (141 Wells)
TOTAL SPUDDED WELLS BY COUNTY

HRZ WELL STARTS BY YEAR THROUGH DECEMBER 31, 2014

DRILLING DATA FOR PENNSYLVANIAN GRANITE WASH HORIZONTAL WELLS

Drilling & Production Data from IHS Enerdeq
DRILLING RESULTS FOR PENNSYLVANIAN GRANITE WASH HORIZONTAL WELLS – JANUARY 2015

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<td>STARTED</td>
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<td>PERMITTED</td>
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<td>DRY</td>
<td>77</td>
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<td>TOTAL</td>
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Drilling & Production Data from IHS Enerdeq
ANNUAL OIL PRODUCTION

22 MMBO

Est. 17 MMBO

ANNUAL OIL & GAS PRODUCTION FROM PENNSYLVANIAN GRANITE WASH HORIZONTALS

14 MMBO (thru Sept-Oct 2014)

ANNUAL GAS PRODUCTION

Est. 370 BCFG

305 BCFG (thru Sept-Oct 2014)

ESTIMATED DAILY HORIZONTAL GRANITE WASH PRODUCTION

SEPTEMBER 2014:

51,000 BOPD

1.1 BCFGPD

FROM 1827 WELLS
### OIL PRODUCTION BY INTERVAL

#### Cumulative Oil Production From Horizontal Granite Wash Wells By Interval Through September 2014

<table>
<thead>
<tr>
<th>Group</th>
<th>Cumulative Production</th>
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<tr>
<td>Atoka</td>
<td>4,664,501</td>
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<tr>
<td>Hogshooter</td>
<td>13,816,873</td>
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<tr>
<td>Cottage Grove</td>
<td>11,805,006</td>
</tr>
<tr>
<td>Skinner</td>
<td>721,284</td>
</tr>
<tr>
<td>Marmaton</td>
<td>58,217,110</td>
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#### Stratigraphic Chart

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<td>Douglas/Cisco</td>
<td>Haskell Sh, Tonkawa Ss</td>
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<td>Lansing/Hoxbar</td>
<td>Cottage Grove Wash, Hoxbar Wash/Shale, Hogshooter Wash, Checkerboard Wash, Cleveland Wash</td>
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<td>Kansas City/Hoxbar</td>
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<td>Marmaton Wash, Upper Skinner Wash, Upper Skinner Shale (Pink Ls Marker), Lower Skinner Wash, Red Fork Ss &amp; Sh</td>
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<td>Atoka Wash, Upper Morrow, Squawbelly Ls, L. Morrow (Primrose)</td>
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**ANADARKO BASIN - MOUNTAIN FRONT - OKLAHOMA**
### ECONOMIC PROFILES: INITIAL POTENTIAL & GOR

#### Stratigraphic Chart

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<td></td>
<td>Morrow</td>
<td>Upper Morrow, Squawbelly Ls, L. Morrow (Primrose)</td>
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#### Missourian Wash
- **Avg. Initial Potential**: 615 BOPD
- **1.6 MMCFGD**
- **GOR = 2610**
- **348 Wells**

Increasing Gas/Oil Ratio & Oil Gravity

#### U. Desmoinesian Wash
- **Avg. Initial Potential**: 245 BOPD
- **4.7 MMCFGD**
- **GOR = 19,183**
- **1328 Wells**

#### Atokan Wash
- **Avg. Initial Potential (Deep)**: 42 BOPD & 7.5 MMCFGD
- **GOR 178,571**
- **57 Wells**
- **Avg. Initial Potential (Shallow)**: 179 BOPD & 1.9 MMCFGD
- **GOR = 10,838**
- **147 wells**

**Drilled Horizontally To Date**
Conversion Factor for Converting Gas and NGL to Barrels Oil per Day Is Based Upon Revenue Values in October 2014
Oil Price: $90/bbl
Gas Price: $7.00/mcf (Missourian); $5.50/mcf (Marmaton)
NGL/MMcf: 150 bbls (Missourian); 100 bbls (Marmaton & Atokan)
ECONOMIC SKETCH: AVERAGE DECLINE RATE (OIL) 1ST YEAR

DATE POINTS:
COTTAGE GROVE – 77 WELLS
HOGSHOOTER – 129 WELLS
MARMATON “B” – 90 WELLS
MARMATON “C” – 319 WELLS
MARMATON “D” – 417 WELLS
ATOKA – 141 WELLS
Well Costs: $7.1 MM (Missourian) and $7.8 MM (Marmaton)
Oil Price: $90/bbl
Gas Price: $7.00/mcf (Missourian); $5.50/mcf (Marmaton)
NGL/mmcf: 150 bbls (Missourian); 100 bbls (Marmaton)
Net Revenue: 80%
Monthly Operating Costs: $8000 including compression

As the horizontal wells develop longer production histories it will be interesting to see the ultimate recoveries and economic performances of the various reservoirs. Overall it is likely that the play will be characterized by high initial rates of return but more limited ultimate return on capital due to the steep decline rates on the wells. The collapse of oil prices in late 2014 may lead to shorter than anticipated well lives and returns on capital!
Drilling Issues

- Inaccurate surface elevation surveys (it happens!)
- Surface management issues due to multiple horizontal wells from same location
- Getting intermediate casing set through lost circulation zones in L. Permian
- Building/drilling the curve through unstable shale intervals
- Avoiding shales to get stuck in while drilling the lateral
- Avoiding lost circulation zones (depletion zones) in target horizons causing differential sticking of bottom hole assemblies
- Avoiding existing vertical wells along well path
- Correct bit selection appropriate for rock types and drilling demands
- Slow/expensive penetration rates due to abrasive/hard formations
- Expensive wells: Current costs (September 2014) to drill and complete Granite Wash horizontals $7.0 - $8.0 MM not counting train wrecks!
- Lateral lengths ~5000‘ long; extended laterals rare due to land, regulatory and drilling issues
Completion & Production Issues and Economics

- Acquiring/managing water for hydraulic fracturing of reservoirs
- Dealing with large amounts of flow back water after stimulation
- High temperature gas streams into pipeline
- Getting frac water off of formation as soon as possible after stimulation
- Handling/disposing of large volumes of produced formation water
- Expediting gas/oil sales immediately after stimulation
- Avoiding reserve losses (10-40%) in existing horizontals due to damage from hydraulic fracturing in new offset wells
- Installation and maintenance of artificial lift systems (gas lift) as flowing wells begin to load up with liquids (oil and water)
- Cost of gas compression and operating costs late in well life
- Management of surface facilities, flow lines, pipelines on leases with multiple laterals in stacked pay zones
- Maintaining and extending the productive lives of horizontal wells after large declines in rate and pressures by 2nd year and beyond
- Ultimate recoveries of wells will vary significantly because of reservoir quality, evolution of stimulation technology, date wells drilled
- EUR’s and economics highly variable because of the complexity!
Major divestitures through property sales occurred in 2013-2014. Apache, Newfield, Linn, QEP, Forest, SM Energy, Pogo, Plains and others have eliminated or greatly reduced their holdings in the play. This has resulted in establishing Enervest/Four Point and Le Norman as significant operators in the Granite Wash play.
Granite Wash Play Today and in the Future

- Consolidation through major property sales occurred in 2013-2014 resulting in establishing Enervest/Four Point and Le Norman as major operators in the Granite Wash play. Apache, Newfield, Linn, QEP, Forest, SM Energy, Pogo, Plains and others have eliminated or greatly reduced their holdings in the play.
- With the 50%+ drop in oil and gas prices as of January 2015, operators in the Granite Wash play face difficult economic challenges.
- Until drilling and completion costs decline significantly, the horizontal Granite Wash play is uneconomic for most industry players.
- Significant oil and gas resources remain in various areas of the Granite Wash play in very fine grained sandstone, siltstone and shale reservoirs as well as in the lightly exploited gas prone Atokan Wash horizons.
- A “time out” in drilling activity will allow companies an opportunity to review the geological and engineering factors that have created economically successful opportunities; these lessons will be applied to the Wash play when economic conditions improve.
CONCLUSIONS

- The Granite Wash play extends over 125 miles from Roberts County, Texas southeast to Washita County, Oklahoma, along the southwestern side of the Anadarko Basin.
- More than a dozen key reservoir units were deposited in three Pennsylvanian stages (Atokan, Desmoinesian and Missourian).
- Arkosic sandstone and conglomerate reservoirs are 8000 to 14,500 feet deep in a sedimentary column ranging in thickness from 2500 to 5000 feet.
- Production is primarily from stratigraphic traps.
- Starting in 2002, over 2200 horizontal Granite Wash wells have been drilled, mostly since 2010.
- 75% of the horizontal wells have been drilled in the Texas Panhandle.
- More than 92 million barrels of oil and 2.0 TCF of gas produced from over 1800 horizontal wells primarily over the last four years.
- Estimated 2014 production of 17 MMBO and 305 BCFG.
- Daily production in September 2014 of ~ 50,000 BOPD, 1.1 BCFGPD & 110,000+ BWPD.
- Operators target reservoirs with high oil/condensate/natural gas liquids content.
- In spite of initial annual decline rates in the 75-85% range, the initial high rate of return on investment and low risk provided attractive drilling opportunities.
- Successful operations in the horizontal Granite Wash play demand the ability to cope with complexity in geological, engineering and land functions especially in today’s low product price environment.
- Significant changes in operators/ownership have occurred in past two years.
THANKS!

Many thanks to several colleagues who generously gave me their time and insights into the Granite Wash play. Also, eternal thanks to my lovely wife Carol Mitchell for her support and patience with my many long nights at the office over my career.