Fluid Migration and Accumulation within the Mississippian: Why 2% oil cut here, 15% oil cut one mile away

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Outline

- Mississippi Lime Play - definition
- Relevant structural elements of the Arkoma and Anadarko basins
- Source rocks
- Hydrocarbon migration & accumulation
- Spectrum of lithofacies and reservoir quality
- Conventional reservoir properties
- Unconventional reservoir properties
- Why variations in water cut?
- Summary
Mississippi Lime Play – Definition
-- on Anadarko Basin side of Nemaha Uplift

Regional Structural Features-Horizontal Wells

4,237 Horizontal Completions Thru Feb. 2012

Structure Map from H.G. Davis, 1988

John Mitchell, retired
SM Energy Co.
Tulsa, Oklahoma
March 2012
Paleogeography during mid-Mississippian expressed by water depth

After Gutschick and Sandberg, 1983
Spectrum of potential reservoir lithofacies

Inner Ramp Tripolite to Outer Ramp Basinal Shale Depositional Model


North

- Inner Ramp
- Tripolite
- Cherty dolomite
- Dolomitic spiculite
- Dolomitization
- Subaerial Exposure

South

- Outer Ramp (slope to basin)
- Basinal shale
- Dolomitic siltstone
- Argillaceous, organic dolomitic siltstone
Relevant structural elements of Arkoma and Anadarko Basin

- Concurrent and post Mississippian structural deformation
- Systematic reactivation of basement weaknesses defined by potential fields & basement terrain
- Inherited fracture systems
- Major wrench fault systems directed stress into craton during Late Paleozoic
- Major influence on maturation of organic matter, migration routes and trapping of oil and gas
MLP in southern Kansas

Horizontal wells drilled since January 2011
Mississippian structure (450 ft C.I.) and notable faults (green lines)

http://maps.kgs.ku.edu/co2/
Structural contour map, top Proterozoic surface eastern Kansas and eastern Oklahoma

- after Bill McBee (2003)
- Contours in Kansas and Nebraska modified from Burchett et al. (1981)
- Nemaha fault trace in Kansas adapted from Berendsen and Blair (1992).

Garber Uplift – large restraining bend along Nemaha U.

Historical earthquake activity, central OK

KGS-OGS Current #1, Pontotoc County, OK

Generalized fault framework of the area encompassing the Nemaha Uplift

- En echelon, northwest-southeast surface faults east of the Nemaha zone in Oklahoma (Miser, 1954). - **Transtensional**
- The Nemaha zone originated by strike-slip movements – **right lateral**
- Trace of the Nemaha fault adapted from Berendsen and Blair (1992)

Garber Uplift – large restraining bend along Nemaha U.

**Historical earthquakes, central OK**

--- *En echelon west-east and N-S series of basement faults*

Strike-Slip Faults – flower structures & restraining bends

Flower Structures
Positive (Palm Tree) → Transpression
Right lateral

Restraining Bends - transpressional zones occurring at fault bends
Push Up Ridges

Modified from http://www4.uwsp.edu/geo/faculty/hefferan/geol320/strikeslip.html
Peak Late Paleozoic Tectonism during Morrowan and Atokan

- Elevation (ft) relative to sea level
  - 4000
  - 3000
  - 2000
  - 1000
  - 0
  - -1000
  - -2000
  - -3000
  - -4000

- Nemaha uplift
- Arbuckle anticline
- Oklahoma uplift
- Kansas
- Colorado
- Sierra Grande uplift
- TX
- New Mexico
- OK

- Top of the Early Middle Pennsylvanian (Atokan)
  - Thirteen Finger Limestone
  - View to the southeast
  - Vertical exaggeration = 18x
  - Faults from Rascoe and Adler (1971)
  - Blue outline – Extent of Atokan Thirteen Finger Limestone

- Evidence for left lateral offset (Budnik, 1986)
- Palinspastic restoration oblique slip (left reverse slip) on the uplift bounding faults (McConnell, 1989)

(Higley, 2011)
Proterozoic correlations – Magnetic Field and Phanerozoic Structures

Total Intensity of Magnetic Field Reduced to Pole overlain with configuration of Precambrian surface

- Correspondence of Phanerozoic structures to magnetic anomalies
- Local and subregional changes in strike and dip appear to closely correlate to magnetic map
- Major influence on lithofacies distribution and sequence characteristics

(Cole, 1976; Kruger, 1999)
Chester Isopach delimiting incised valley system (~100 miles long)

Rhombic horst blocks (reverse faults on south and west flanks)

Incised valley

Damme

Pleasant Prairie

Eubank Field

Cutter Field

Shuck Field

(Gerlach, Nicholson, DOE-CO2)
Pleasant Prairie structural block
Fault orientation-right lateral component along restraining bend

Arbitrary Profile A-A', SW – NE

Morrow to basement isochron

Inferred Karst

Morrow
Meramec – U. Ordo. Viola
Arbuckle
basement

Flower structure
Right lateral fault?

2 mi
Major NE-trending faults on the top of Mississippian overlying and on the flanks of the Nemaha Uplift & nearby W-E trending en echelon faults along east side of the Nemaha Uplift.
Seismic Section HW 60 Trend
Shane Matson - “...evidence of extensive wrenched terrain”
AAPG Mississippi Lime Forum, Jan. 31, 2013, Oklahoma City

- Fault zones as splays and resembling flower structures
- Faulting greatly diminished in the overlying Desmoinesian strata with flatter dip
Tectonic Elements in Ozark-Ouachita-Arkoma Basin Exert Strong Control On the Location and Development of the Pb-Zn Mineral Belt

P-M cores
Miami Trough
Seneca Fault
Chesapeake Fault
Mississippian Shelf

Mississippian Basin

Dwight C. Bradley & David L. Leach (2002) Tectonic Controls of Mississippi Valley-Type Lead-Zinc Mineralization in Orogenic Forelands
SW-NE Core Transect of Mississippian Near Miami Trough Fault System – Contemporaneous Faulting and Eustatic Controls

Ramaker et al. (2014)
Depositional Sequences and Complex Progradation -- Upper Meramec to Kinderhook age, Cowley Facies, Inner to Mid Ramp

Ramaker et al. (2014)

Depositional sequences from Handford and Manger (1993)
PM Wells
Episodically Active (Growth) Faulting
During Pennsylvanian and Mississippian

Middle Pennsylvanian Cherokee Group
Tebo Coal bed
Pennsylvanian Cherokee Group
Mississippian

Offset on top of Mississippian ~100 ft
Horizontal length ~10 mi
Vertical Exaggeration ~50 x
Phanerozoic structures are largely derived by reactivation of basement weaknesses

-- MLP developed on southern rhyolite granite Proterozoic terrane cross-cut by the Midcontinent Rift System

Magnetic – reduced to pole, overlain with configuration of Precambrian surface (Cole, 1976; Kruger, 1999)
Potential Fields in Sumner County, KS

-- Strong correlation to the NE-trending Midcontinent Rift System

Wellington Field

Bouguer anomaly values, gridded with a two-pass, 8-directional gridding algorithm & second-order polynomial surface.

Reduced to the pole using inclination of 65 degrees and declination of 7 degrees.

Sumner County Kansas
Gravity with oil and gas fields

Sumner County Kansas
Magnetics with oil and gas fields

http://www.kgs.ku.edu/PRS/PotenFld/County/rs/sumnerMagOg.html

http://www.kgs.ku.edu/PRS/PotenFld/County/rs/sumnerGravOg.html
Third-order structural residual
Top Mississippian
Sumner County, KS

Wellington Field
(NE-SW trending structural high)

Nemaha Uplift

P. Gerlach, DOE-CO2
West side of cross section crosses major basement faults related to the Midcontinent Rift

- Tilt angle total magnetic with top Mississippian structure
- Rust-colored dots are horizontal wells drilled since Jan. 2011
- Green circles – DOE digital type wells with correlated formation tops
- Purple squares – Arbuckle commercial-scale CO₂ simulation sites

http://maps.kgs.ku.edu/co2/
- Cross section on strike with ramp margin
- Major basement faults represented by flexure and faulting in the overlying Phanerozoic strata
- **Notable changes** in Mississippian lithofacies across structural blocks

Proterozoic magnetic-rich Granite intrusive *(as per R. VanSchmus)*

SW-NE Structural Cross Section
Lower Pennsylvanian to Arbuckle and Proterozoic sediment (MRS fill)

J. Victorine KGS
http://www.kgs.ku.edu/stratigraphic/CROSS_SECTION/
Updated horizontal wells (■) and seismic events (●) with tilt angle of total magnetic field and top Arbuckle structure for Harper and Sumner County area.
Source rocks

– Organic richness, maturity, timeframe of generation

“Cowley facies appears to be an oil-prone source rock where it is thermally mature”

4003.7 ft dark cored dolomite (x-nic)

Pierson Ls. Member (Cowley facies) is organic-bearing and thermally mature and probably local source rock for MLP

100 μm

Compiled by K. David Newell (Kansas Geological Survey, University of Kansas, Lawrence, KS, 66045-3736), August 2013
Elevated thermal maturation along NE corner of Anadarko Basin

- Simpson Group Oil Creek Formation layer source rocks (light green) started about 340 Ma.
- Woodford Shale oil generation about 335 Ma.
- Thirteen Finger limestone (blue) about 300 Ma.

Gaswirth & Higley (2013)

Transformation ratios (% TR) on the Woodford Shale layer from the four-dimensional petroleum system model.
Higher gas-oil ratio in south-central and southwest Kansas
-- early oil migration followed by methane

Tilt Angle Bouguer gravity 2-5 mile filter with oil fields overlay western 2/3rd of Kansas

Strong delineation of inferred basement structure and distribution of oil fields

Influence of basement derived fractures and faults

MRS rift axis defined by gravity positive (blue to white)

Kansas Spivey-Grabs Field
Hydrocarbon accumulation in Harper County, KS

- Proximity of source rocks
- Timing
- Mechanism of HC migration

Harper County, Kansas along the OK border
In the heart of the MLP

Cumulative gas production
Cumulative oil production

http://www.kgs.ku.edu/PRS/Ozark/GBubbleMap/GBubbleMap.html

Mainly oil

Gas and oil
Spectrum of lithofacies and quality reservoir rock

• Conventional reservoir
  – deposition, diagenesis, and structural modification
  – hydrocarbon accumulation controlled by capillary pressure (matrix), hydrocarbon column, relative permeability, fracture aperture and spacing
  – reservoir pressure and reservoir energy...

• Unconventional reservoir lithofacies –
  – argillaceous dolomitic cherty argillaceous siltstones
  – tight rocks (fractured?) interbedded with porous nodular chert and spiculite
  – organic-bearing serving as own source rock (regional thermal and local elevated heat flow)
Mississippian oil reservoir (top)
Cored Well, Berexco Wellington KGS #1-32

Top Mississippian to Kinderhookian Northview Shale (410 ft)

Siliceous intercrystalline dolomite (field pay)
Nodular chert, argillaceous dolosilitite
Argillaceous dolosilitite
Spiculite-dolo-packstone
Argillaceous siliceous dolosilitite (pico/nano darcy perm)
Vuggy dolomitic spiculite (oil show)

110 ft. dark Tight dolosiltite
Pierson member/Cowley facies

10% <10md
12%

~20 md
~25% 1-100 md

Freeware: http://www.kgs.ku.edu/stratigraphic/PROFILE/
Amplitude envelope map of the Mississippian reflection

Instantaneous frequency map of the Mississippian reflection

Can we relate real data seismic amplitude and frequency to reservoir thickness as it has been suggested by the modeling?
Porosity inversion of the 3D Seismic Wellington Field

Complex offlapping geometries of porous lithofacies resulting from the westward progradation of the Mississippian -- Looking SW

Porosity Model (log/3D seismic) of the Siliceous Dolomite Reservoir Upper Mississippian, Wellington Field

J. Rush, KGS
Permeability fence diagram of Mississippian oil reservoir within 3D seismic, Wellington Field

---Small faults that tip out above the top of the Mississippian reservoir

- View looks to the northeast
- Fault juxtaposes reservoir and non-reservoir facies (at arrow tip)
- Fault offset ~30 ft
- Faults serve as potential barriers to flow or redirect CO\textsubscript{2} plume depending on fault damage and juxtaposed rocks
- Faults aligned perpendicular to maximum horizontal compressive stress
CO₂ plume from latest simulation of Mississippian pilot injection (26,300 tonnes) -- modeled CO₂ sweep defined contact defined by complex lithofacies distribution and faulting.

New injection well to be drilled -- Wellington KGS #2-32

Elongate N-S CO₂ plume influenced by newly mapped N-NE trending faults acting as both barriers and conduits for CO₂
Permeability profile entire Mississippian

KGS #1-32 Wellington: Estimation of permeability based on *magnetic resonance imaging (MRIL)* using porosity and T2 center-of-gravity versus core Kmax, K90, and Kvert core permeabilities

Doveton & Fazelalavi, July 2012

120 ft (37 m) low k, argillaceous dolosiltite TOC ~2% (caprock, seal)

Sw = 60%
Lowermost porosity in KGS Wellington #1-32-- dolomitic spiculite (*in situ* biostromal accumulation) in lower Cowley facies with oil show
Wellington 4029.73 ft (Cowley facies) deep-water, porous and permeable dolospiculite (oil-bearing)
Oil column in typical conventional reservoirs requires ~75 ft to approach irreducible water saturation and zero water cut based on capillary pressure curves for common Mississippian reservoirs in MLP.

Mercury injection capillary pressure curves are calculated by TecLog™ using NMR data—compared to Osage dolomite reservoir at Schaben Fld., Ness Co. from Dubois et al. (2003).

Approaching irreducible $S_w$
“High bound water saturations in the tripolitic chert have led to difficulty in estimating reserves and determining producible zones. This problem in water saturations is further complicated by difficulty in establishing free water level. While some fields exhibit apparent structural closure greater than 200 feet, the presence of nearly isolated blocks of production within these fields surrounded by nonproductive areas may indicate that there is not a continuous hydrocarbon column and that free water level is independently established for each block”. -- Watney, Guy, Byrnes (2001) ➔ horizontal wells anyone?
“Cowley facies” in SW to NE Cross Section
-- Berexco Wellington KGS #1-32 (left) & #1-28 (right)
(3000 ft distance between wells)

Erosional base

"Cowley facies"

http://www.kgs.ku.edu/stratigraphic/CROSS_SECTION/

Cross Section Java Appet – J. Victorine, KGS, DOE-CO2
Correlations – regional team (Bittersweet), DOE-CO2
Pierson Ls. Member (Cowley facies) is organic-bearing and thermally mature and probably local source rock for MLP

TOTAL ORGANIC CARBON

Client ID  | Well Name | State | County | Top depth (ft) | Formation | Sample Type | Prep | TOC, wt. % | Verified | Lab Id | Comments
---|---|---|---|---|---|---|---|---|---|---|---
Berexco LLC Wellington KGS No. 1-32 | 3605.40 | Core | NOPR | 0.10 | 3402822662 | Penn sh |
Berexco LLC Wellington KGS No. 1-32 | 3738.25 | Core | NOPR | 0.39 | 3402822664 | MSSP |
Berexco LLC Wellington KGS No. 1-32 | 3754.00 | Core | NOPR | 0.19 | 3402822666 | MSSP |
Berexco LLC Wellington KGS No. 1-32 | 3784.50 | Core | NOPR | 1.87 | 3402822668 | MSSP |
Berexco LLC Wellington KGS No. 1-32 | 3937.25 | Core | NOPR | 0.94 | 3402822670 | MSSP |
Berexco LLC Wellington KGS No. 1-32 | 3968.75 | Core | NOPR | 1.28 | 3402822672 | MSSP |
Berexco LLC Wellington KGS No. 1-32 | 3982.00 | Core | NOPR | 0.60 | 3402822674 | MSSP |
Berexco LLC Wellington KGS No. 1-32 | 4024.00 | Core | NOPR | 0.21 | 3402822676 | MSSP |
Berexco LLC Wellington KGS No. 1-32 | 4048.50 | Core | NOPR | 1.11 | 3402822678 | MSSP |
Berexco LLC Wellington KGS No. 1-32 | 4059.75 | Core | NOPR | 0.69 | 3402822680 | MSSP |
Berexco LLC Wellington KGS No. 1-32 | 4065.50 | Core | NOPR | 1.59 | 3402822682 | M-D Chat Sh |

Compilation of Hydrocarbon Source-Rock Analyses for Wells in East-Central and Northeastern Kansas, and adjacent areas in Missouri and Nebraska by K. David Newell (Kansas Geological Survey, University of Kansas, Lawrence, KS, 66046-3738), August, 2013
Local HC maturation of “Cowley facies” and Woodford/Chattanooga
- Potential for charging along fractures
- Displace water
- Increasing oil cut
- Locally, continuous HC column???
Organic bearing dolosiltite
lower Mississippian, Wellington Field

Thin section photomicrograph of the dense, dark, argillaceous dolosiltite at 4001.25 ft that dominated the 110 ft thick interval of Unit D in the lower Mississippian in Wellington Field (Fig. 5). The sample is also incorporated on the nuclear magnetic resonance log in Fig. 8. Interval contains clay (brown) with scattered dolomite rhombs, some that are organic cored, and sponge spicules such as the light colored lenticular shaped interval in the mid portion of the image.
Index for SW to NE Cross Section showing tilt angle of total magnetic field and top Arbuckle structural contours.
Complex lithologic changes in Mississippian Reservoir

Datum = sealevel
Total length of section ~75 mi
No horizontal scale
Index map on previous page
Cross section Java applet, J. Victorine, DOE-CO2
Factors in water cut?

- Prograding and downlapping Osage and Meramec strata along ramp
- Variable pore types along the lateral
- Not simple oil:water contact
- ~135 ft of oil column
- Reservoir pressure, drive?
- Locally charged with thermally mature, underlying Woodford Shale or “Cowley facies”?
- Fractures? Water or oil?
- How was well completed?

Core to Characterization and Modeling of the Mississippian, North Alva Area, Woods and Alfalfa Counties, Oklahoma
Dan Costello1, Martin Dubois2, and Ryan Dayton1
1 Chesapeake Energy Corporation
2 Improved Hydrocarbon Recovery, LLC

2014 Mid-Continent Section AAPG Core Workshop
Summary

- Mississippi Lime Play (complex)
- Structural history of Arkoma and Anadarko Basin (complex)
- Source rocks (several)
- Hydrocarbon migration (regional and local)
- Spectrum of lithofacies and reservoir quality (Yes!)
- Unconventional reservoir (locally)
- Why variations in water cut? (many and varied possibilities)
Q&A with Lynn Watney, Kansas Geological Survey
Help Us Help You!

Please give us your feedback and suggestions

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