Horizontal Drilling – Technology Review, Current Applications, and It's Future in Developing Kansas' Petroleum Resources

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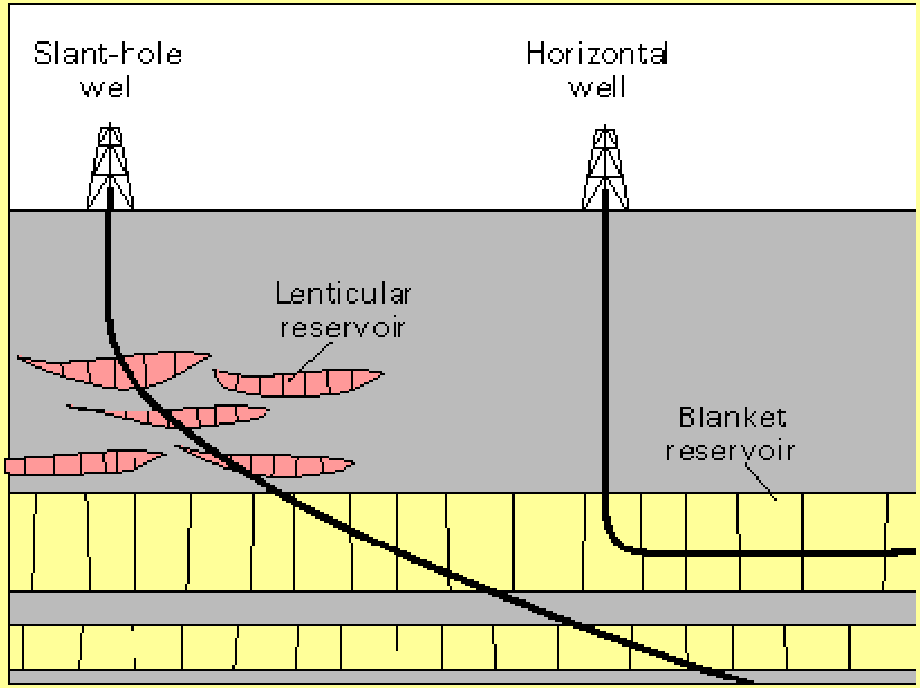
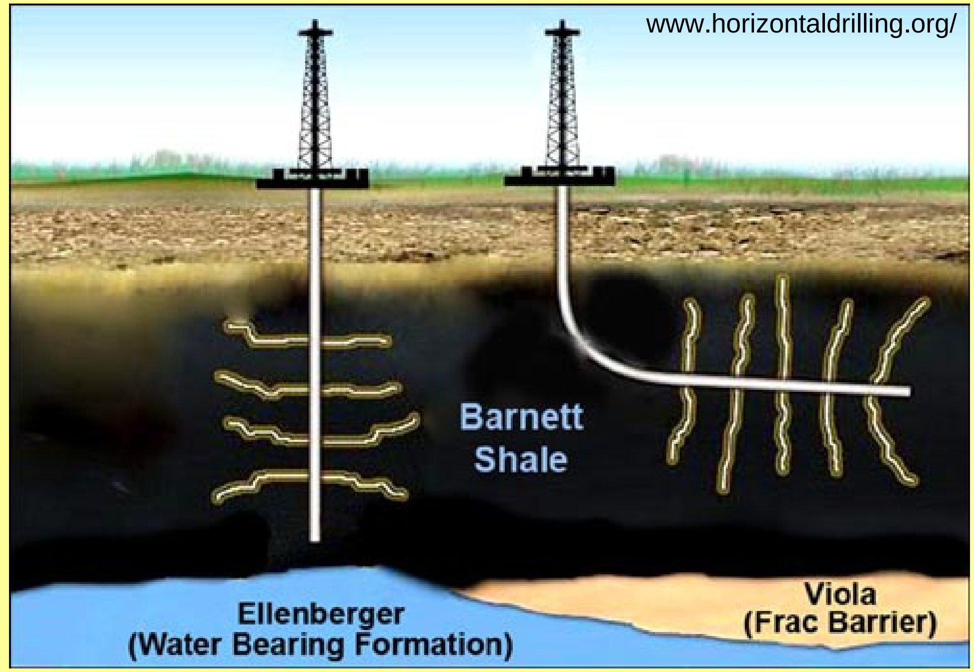
KANSAS GEOLOGICAL SURVEY
The University of Kansas

Outline

- 1. Types of horizontal wells
- 2. Basic engineering and geology that define drainage radius in horizontal wells, design, and evaluation
- 3. Statistics on current horizontal drilling in Kansas and types of reservoirs being drilled with laterals
- 4. Case study in Kansas – New lateral in Hunton dolomite, Unger Field, Marion County
- 5. Expectations for horizontal drilling in the future

1. Types of horizontal wells





Reservoir Applications

- Naturally fractured reservoirs
  - Austin Chalk **Niobrara Chalk (NW KS)**
  - Bakken Shale **Chattanooga Shale (OK)**
- Formations with water & gas coning
  - Gulf of Mexico
  - Elk Hills, California
  - **Arbuckle, Hunton**
  - **Mississippian, Morrow**
- Heavy oil reservoirs/Thermal application
  - California
- **Coal Bed Methane**
  - **Southeast Kansas Cherkee**

Joshi Technologies International, Inc. JTI

Naturally fractured reservoir – Gas-bearing shale

Completion → vertical well with induced lateral fractures
→ horizontal well with induced vertical fractures

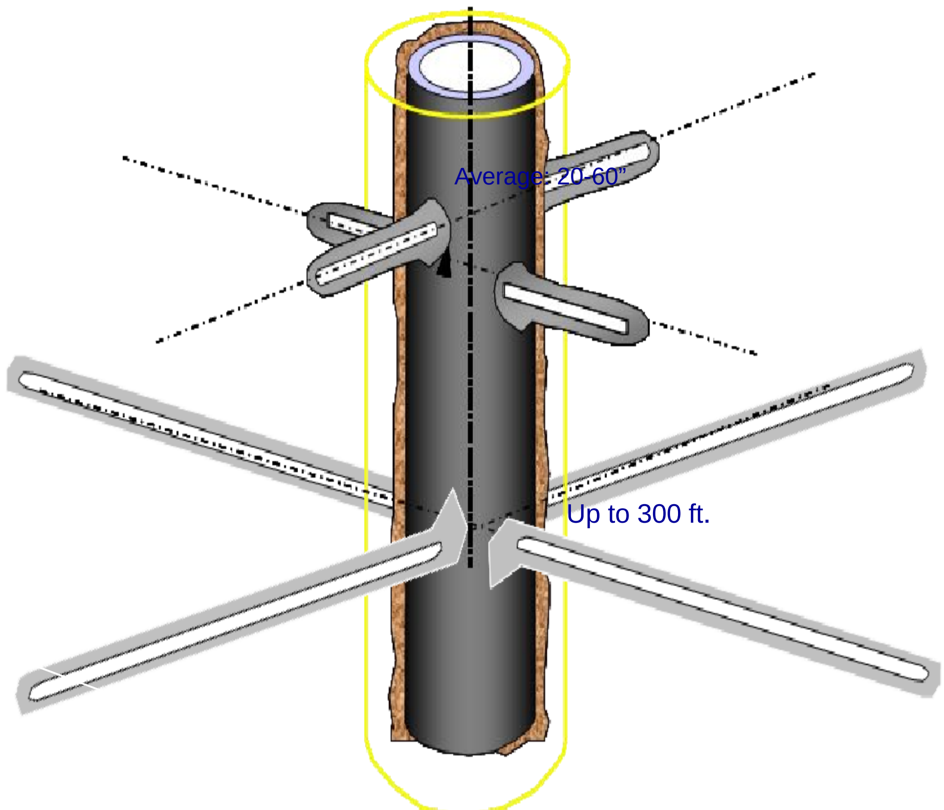
History of Horizontal Wells

- Short Radius
- Medium radius, downhole motors, 1985
- Re-entry drilling, 1995
- Coil tubing drilling – underbalanced
- Rotary steerable system
- Fracture stimulation of horizontal wells

Extended Reach – Option 1
Water-Jetted Laterals

Comparing Radial Drilling Penetration vs. Conventional Perforation

Conventional
Perforation
Average 20”-60”



Radial Drilling
Perforation
Average **Up to 300 ft.**

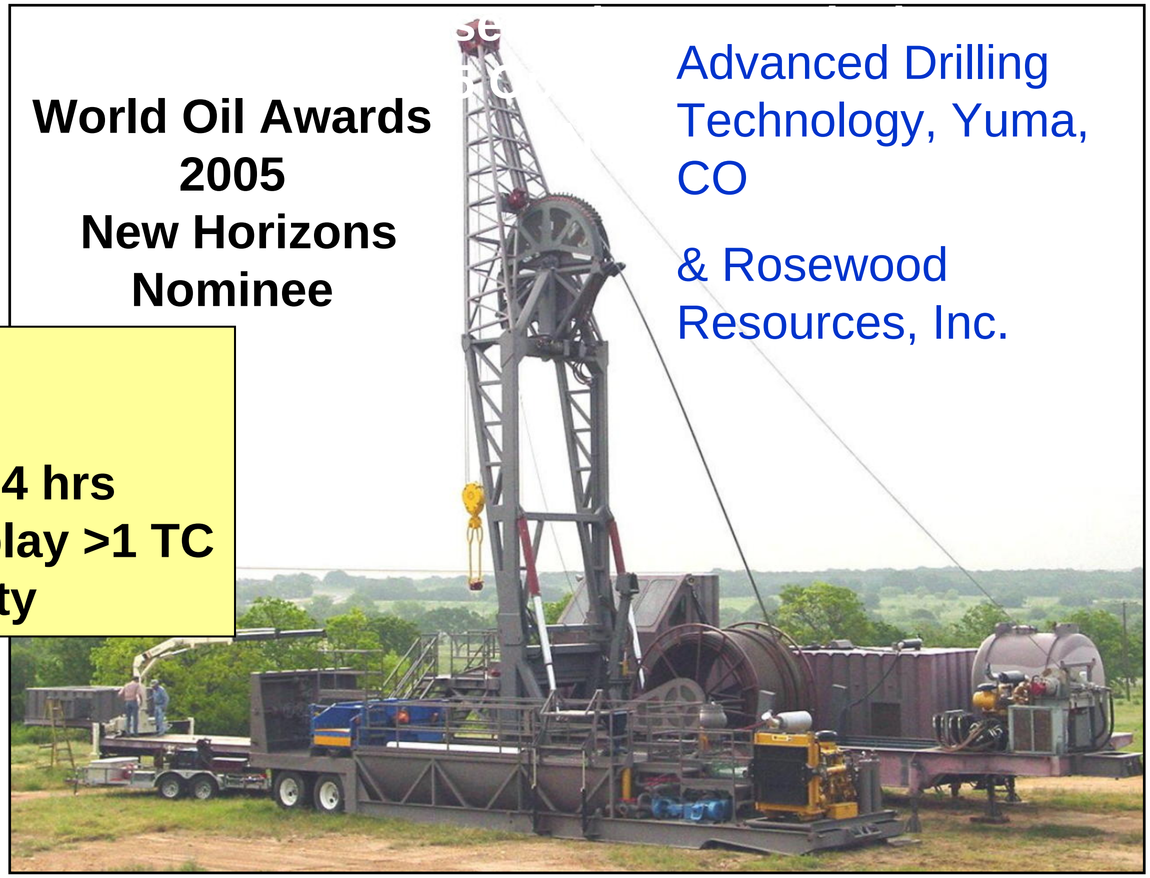
Radcan Energy Services, Inc.

Extended Reach – Option 2

Coil-tubing conveyed horizontal lateral

--First Highly Efficient Hybrid CT Rig

Built and Operating on U.S. Soil



- **Rapid mob/demob**
- **Four trailer loads**
- **2800 ft completed in <24 hrs**
- **Important in Niobrara play >1 TC**
- **Lateral drilling capability**

About 300,000 feet of hole in 7 months
Niobrara Chalk, NW Kansas

Photo courtesy Tom Gipson, Advanced Drilling Technologies, LLC

Extended Reach – Option 3
Lateral Drilling with Conventional Tools

- **Minimal technical risk – mature technology used world wide**
  - Tight directional control
  - Unlimited lateral length – to drain multiple karst compartments
- **Cost-effective in mature field environment**
  - Relative ease to contract conventional rigs – low mobilization costs
  - Easy to get directional tools, drillers, and, tool push logging tools from OK
- **Highest operator comfort – least steep learning curve**
- **Post-drilling tool-push logging helps quantify production potential of the horizontal well and assess level of success**

Horizontal Drilling in Kansas

Definitions & Terms

Common terms used to describe horizontal wells

MWD - "*Measurement While Drilling*"

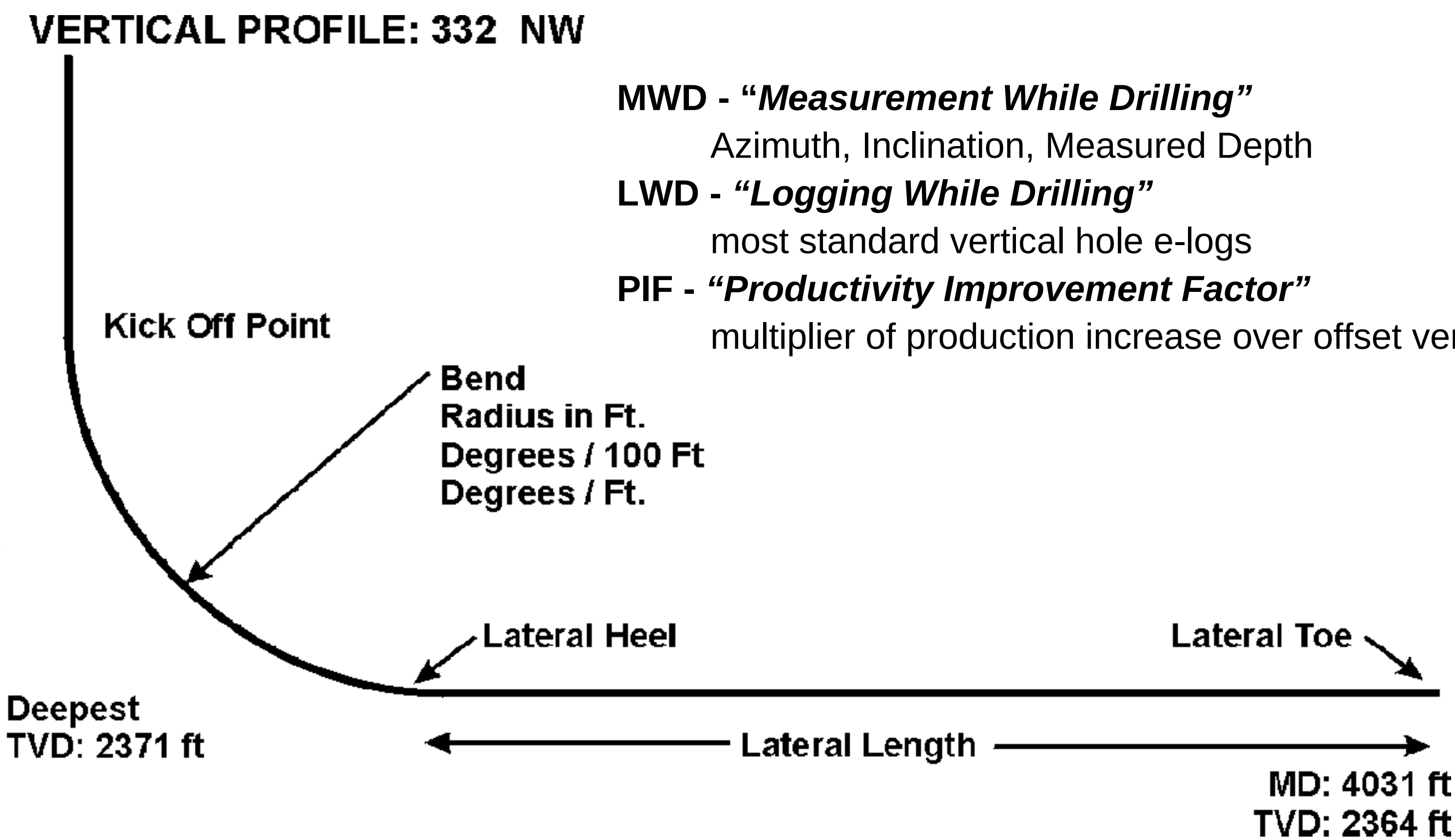
Azimuth, Inclination, Measured Depth

LWD - *"Logging While Drilling"*

most standard vertical hole e-logs

PIF - *"Productivity Improvement Factor"*

multiplier of production increase over offset vertical wells



Gerlach (2000)

Horizontal Well Planning

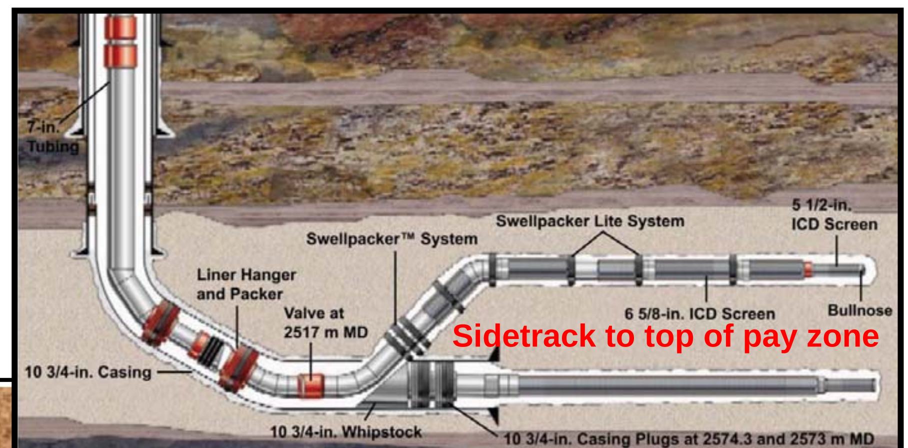
- Well plan
- Target
- Geosteering
- Formation evaluation
- Completion
- Drilling tools, methods - limitations, costs
- Production equipment

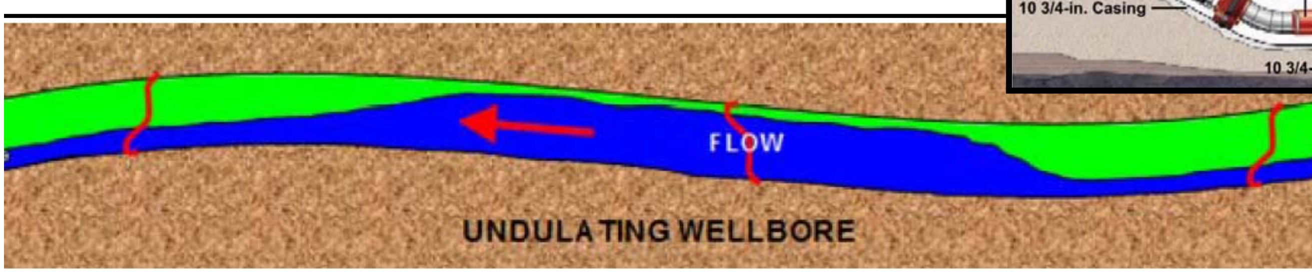
Measurement While Drilling (MWD)

Halliburton
GABI™ Sensor - Gamma/At-Bit Inclination
Azimuthal gamma ray – detect and avoid shale roof rock at top of the oil reservoir

Completion of Horizontal Wells

- Open hole
- Slotted liners
- Case and perforate – to isolate oil and gas bearing intervals
- Install sensor and valves in multilaterals to control flow as laterals water out
- Acidizing
- Fracture stimulation





Lateral drilled in Chester sandstone

most recently released report

Scientific Drilling International

Survey Report

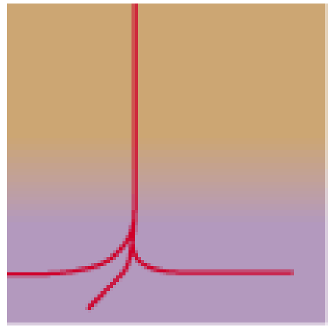
Company: E.O.G. RESOURCES	**Date:** 1/24/2007	**Time:** 09:00:09	**Page:** 2
Field: Seward County Kansas	**Co-ordinate(NE) Reference:** Well: Charles 14 1H, True North		
Site: Section 14 - 34S - 34W	**Vertical (TVD) Reference:** SITE 0.0		
Well: Charles 14 1H	**Section (VS) Reference:** Well (0.00N,0.00E,357.00Azi)		
Wellpath: Original Wellpath	**Survey Calculation Method:** Minimum Curvature		**Db:** Sybase

Survey: Survey #1

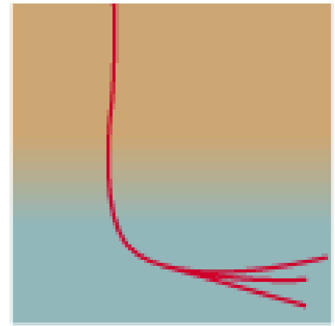
MD ft	Incl deg	Azim deg	TVD ft	+N/-S ft	+E/-W ft	VS ft	DLS deg/100ft	Build deg/100ft	Turn deg/100ft	Tool/Comment
6310.0	73.01	357.45	6112.3	389.0	-91.0	393.3	8.06	8.06	-0.03	
6341.0	75.42	357.27	6120.7	418.8	-92.3	423.1	7.79	7.77	-0.58	
6373.0	77.66	357.54	6128.2	449.9	-93.7	454.2	7.05	7.00	0.84	
6405.0	79.62	357.60	6134.5	481.3	-95.1	485.6	6.13	6.12	0.19	
6436.0	82.05	358.28	6139.4	511.8	-96.2	516.2	8.13	7.84	2.19	
6467.0	84.38	358.61	6143.1	542.6	-97.0	546.9	7.59	7.52	1.06	
6497.0	86.94	359.02	6145.4	572.5	-97.6	576.8	8.64	8.53	1.37	
6528.0	87.48	358.98	6146.9	603.5	-98.2	607.8	1.75	1.74	-0.13	
6560.0	87.71	358.31	6148.2	635.4	-98.9	639.7	2.21	0.72	-2.09	
6591.0	87.38	357.91	6149.5	666.4	-99.9	670.7	1.67	-1.06	-1.29	
6623.0	86.54	357.60	6151.2	698.3	-101.2	702.7	2.80	-2.62	-0.97	
6654.0	88.39	357.51	6152.6	729.3	-102.5	733.6	5.97	5.97	-0.29	
6686.0	89.90	357.70	6153.1	761.2	-103.8	765.6	4.76	4.72	0.59	
6717.0	90.50	357.31	6153.0	792.2	-105.2	796.6	2.31	1.94	-1.26	
6748.0	88.66	356.74	6153.2	823.2	-106.8	827.6	6.21	-5.94	-1.84	
6779.0	89.46	356.50	6153.7	854.1	-108.6	858.6	2.69	2.58	-0.77	
6811.0	91.81	356.24	6153.4	886.0	-110.7	890.6	7.39	7.34	-0.81	
6842.0	93.39	355.69	6152.0	916.9	-112.8	921.6	5.40	5.10	-1.77	
6851.0	93.33	355.86	6151.4	925.9	-113.5	930.6	2.00	-0.67	1.89	
6883.0	93.56	355.57	6149.5	957.7	-115.9	962.5	1.16	0.72	-0.91	
6914.0	93.70	355.65	6147.5	988.6	-118.3	993.4	0.52	0.45	0.26	
6945.0	93.66	355.57	6145.6	1019.4	-120.6	1024.3	0.29	-0.13	-0.26	
6977.0	93.60	356.02	6143.5	1051.3	-123.0	1056.3	1.42	-0.19	1.41	
7006.0	93.39	356.32	6141.8	1080.2	-124.9	1085.2	1.26	-0.72	1.03	
7037.0	93.22	356.22	6140.0	1111.0	-126.9	1116.2	0.64	-0.55	-0.32	
7068.0	93.16	356.35	6138.3	1141.9	-128.9	1147.1	0.46	-0.19	0.42	
7100.0	93.06	356.96	6136.5	1173.8	-130.8	1179.1	1.93	-0.31	1.91	
7131.0	92.56	356.85	6135.0	1204.7	-132.5	1210.0	1.65	-1.61	-0.35	
7163.0	92.22	356.47	6133.7	1236.7	-134.3	1242.0	1.59	-1.06	-1.19	
7195.0	90.67	357.29	6132.9	1268.6	-136.1	1274.0	5.48	-4.84	2.56	
7225.0	88.69	357.63	6133.0	1298.6	-137.4	1304.0	6.70	-6.60	1.13	
7257.0	87.72	358.01	6134.0	1330.5	-138.6	1336.0	3.26	-3.03	1.19	
7289.0	[illegible]	358.28	6135.3	[illegible]	[illegible]	1367.9	0.95	-0.44	0.84	
7320.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1398.9	2.97	2.16	2.03	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1429.9	1.52	1.19	0.94	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1461.8	0.32	0.31	0.06	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1492.8	0.87	-0.74	-0.45	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1524.8	1.70	-0.22	1.69	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1555.7	1.03	-0.65	-0.81	
[illegible]	88.25	359.59	6141.6	1582.4	-142.7	1587.7	0.69	0.09	0.69	
7540.0	88.09	359.58	6142.6	1613.4	-143.0	1618.6	0.52	-0.52	-0.03	
7572.0	87.95	359.67	6143.7	1645.3	-143.2	1650.6	0.52	-0.44	0.28	
7603.0	87.95	0.27	6144.8	1676.3	-143.2	1681.5	1.93	0.00	1.94	
7635.0	88.25	0.32	6145.8	1708.3	-143.0	1713.4	0.95	0.94	0.16	
7667.0	88.66	0.42	6146.7	1740.3	-142.8	1745.4	1.32	1.28	0.31	
7699.0	88.72	0.45	6147.4	1772.3	-142.6	1777.3	0.21	0.19	0.09	
7730.0	88.89	0.53	6148.1	1803.3	-142.3	1808.2	0.61	0.55	0.26	
7762.0	88.89	0.66	6148.7	1835.3	-142.0	1840.2	0.41	0.00	0.41	
7793.0	88.76	0.50	6149.3	1866.3	-141.7	1871.1	0.66	-0.42	-0.52	
7825.0	88.66	0.34	6150.0	1898.2	-141.4	1903.0	0.59	-0.31	-0.50	
7854.0	88.72	0.75	6150.7	1927.2	-141.2	1932.0	1.43	0.21	1.41	
7886.0	88.42	0.58	6151.5	1959.2	-140.8	1963.9	1.08	-0.94	-0.53	
7917.0	88.39	0.85	6152.4	1990.2	-140.4	1994.8	0.88	-0.10	0.87	

Detailed reporting of well trajectory

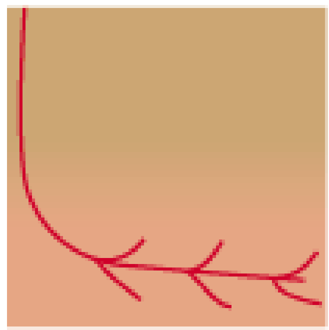
Multilaterals with conventional horizontal drilling technology



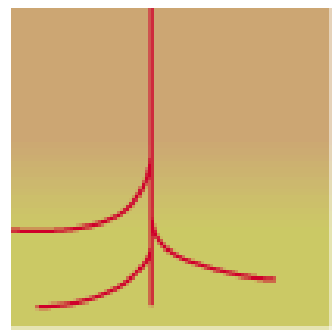
Multibranched



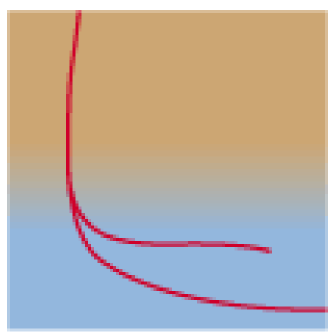
Forked



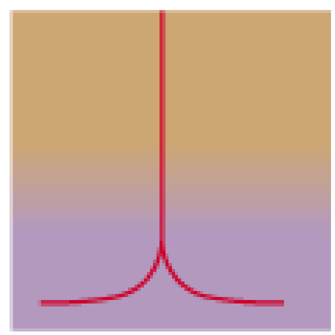
Laterals into horizontal hole



Laterals into vertical hole



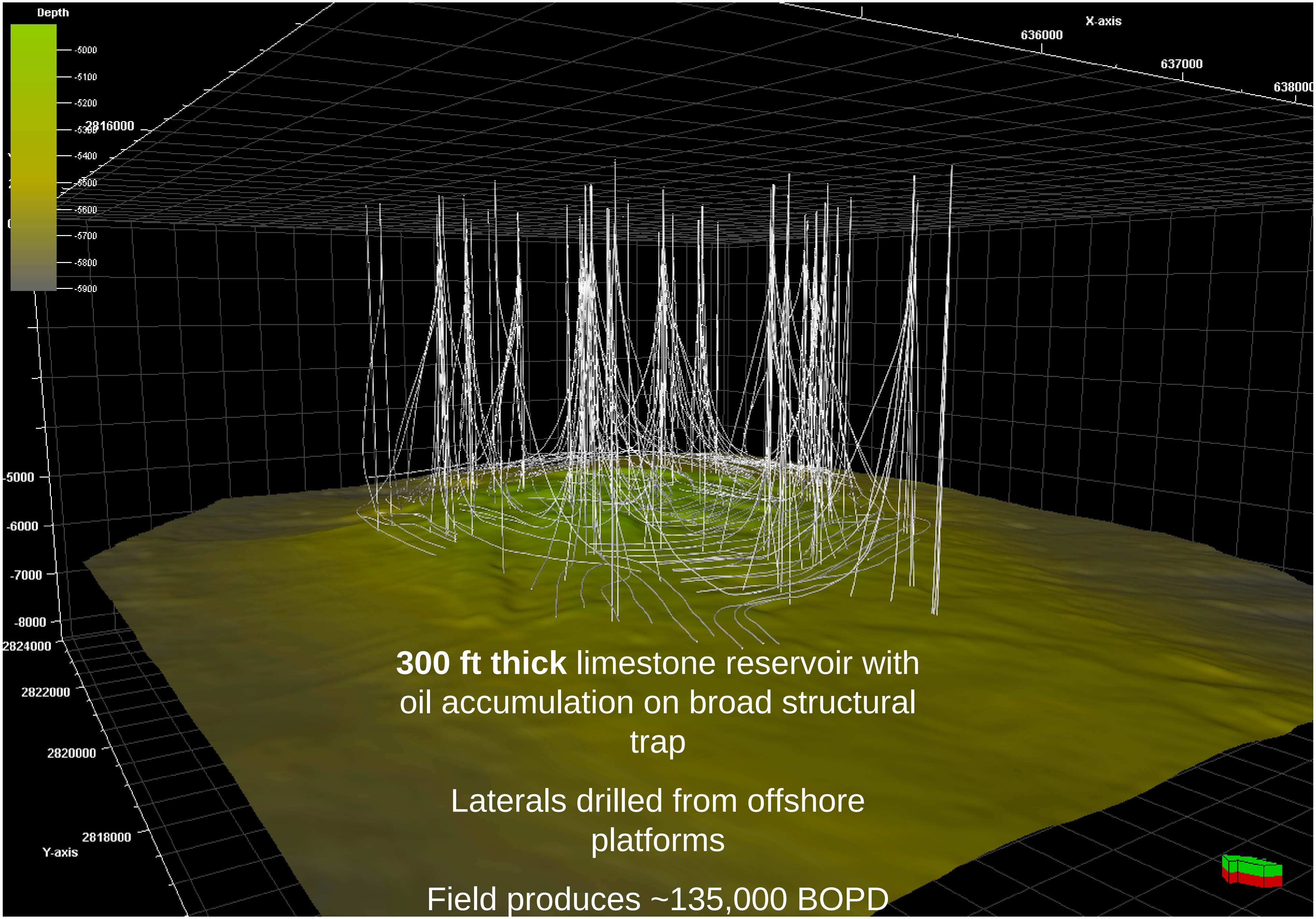
Stacked laterals



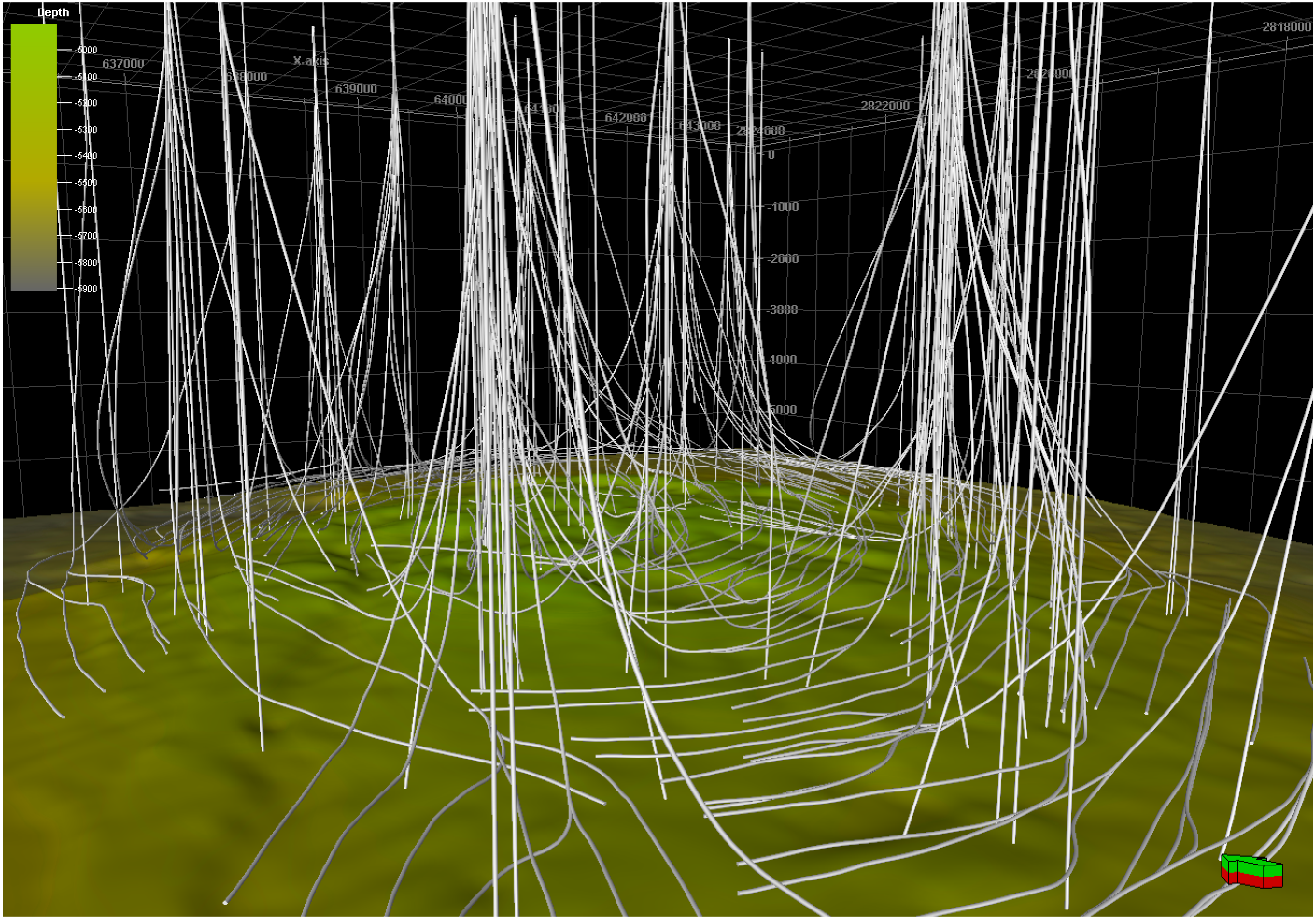
Dual-opposing laterals

Example of Complex Laterals

J. Rush, KGS



Idd El Shargi, J. Rush -KGS



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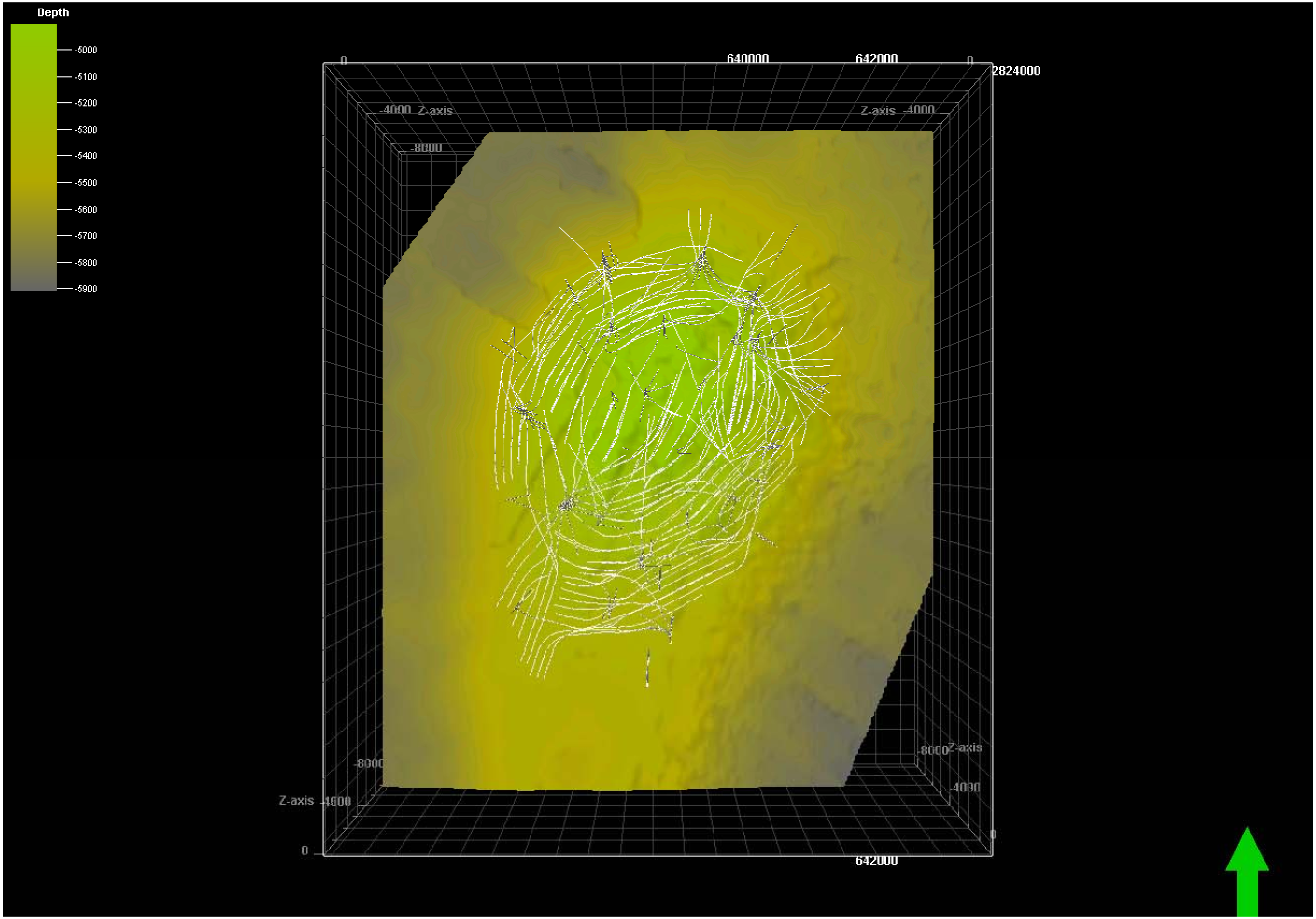
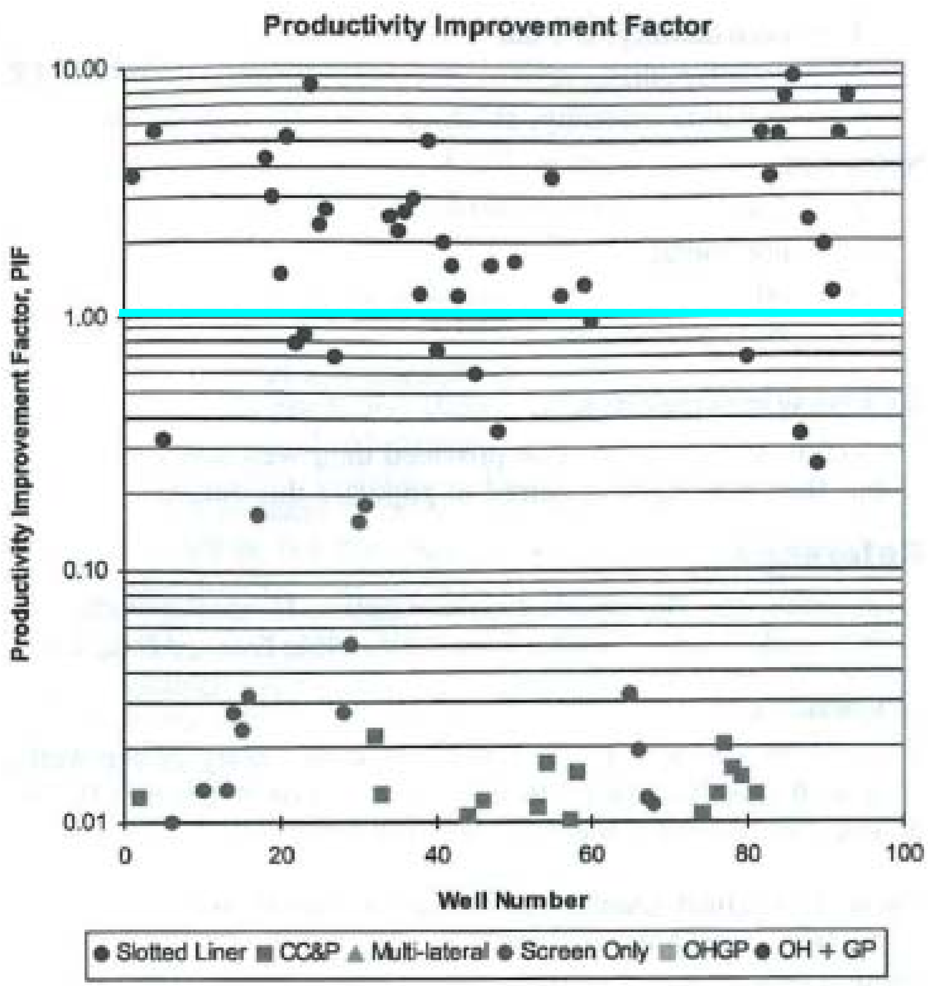


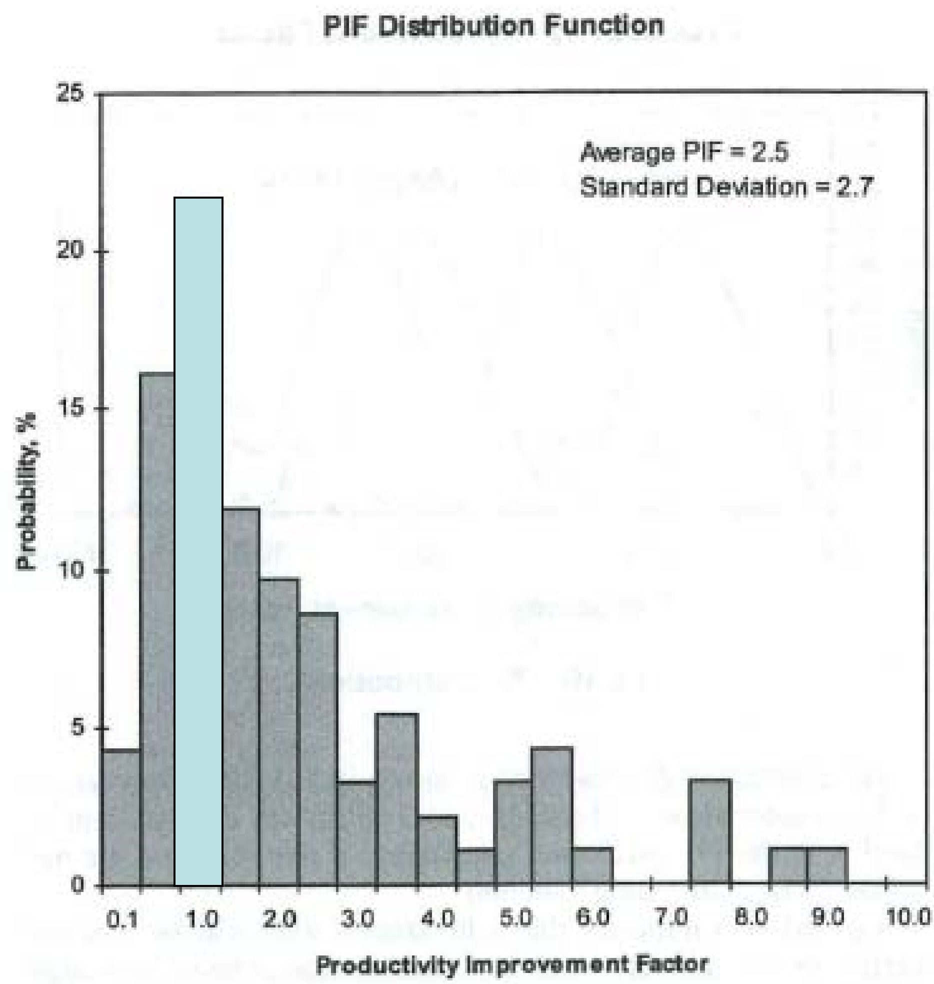
Idd El Shargi, J. Rush -KGS

2) Basic engineering and geology that define drainage radius in horizontal wells, design, and evaluation

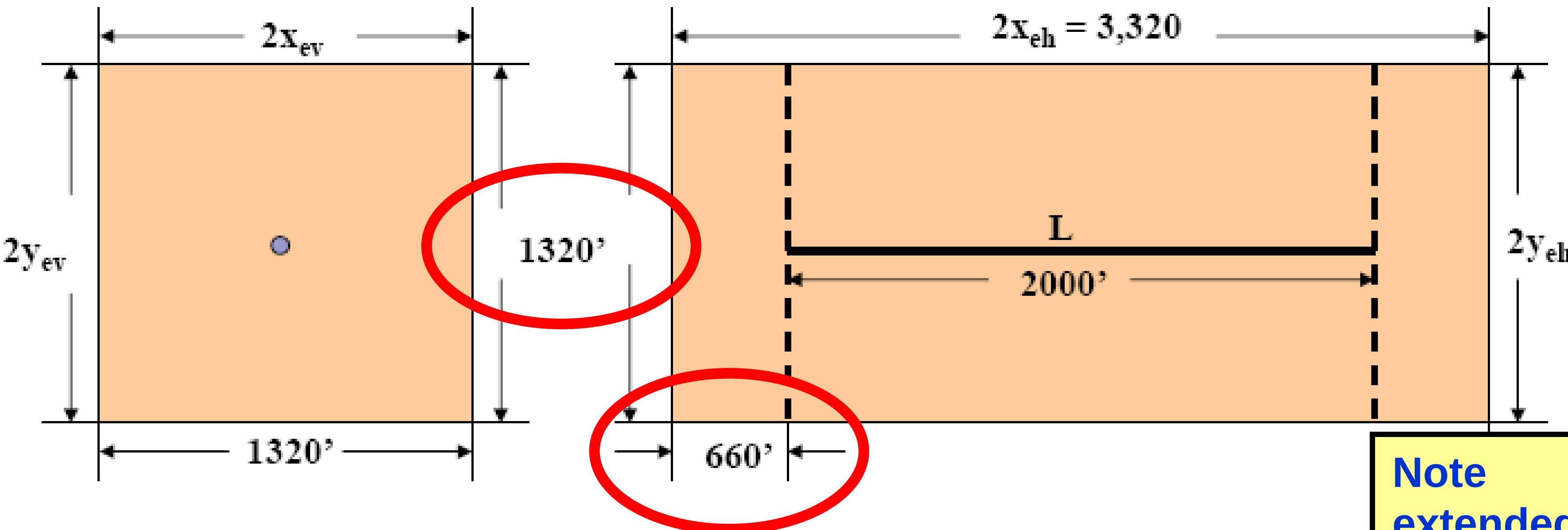
Productivity Improvement Factor

Distribution of Productivity in 96 horizontal wells





Reservoir with Uniform Horizontal Permeability ($k_y/k_x = 1$)



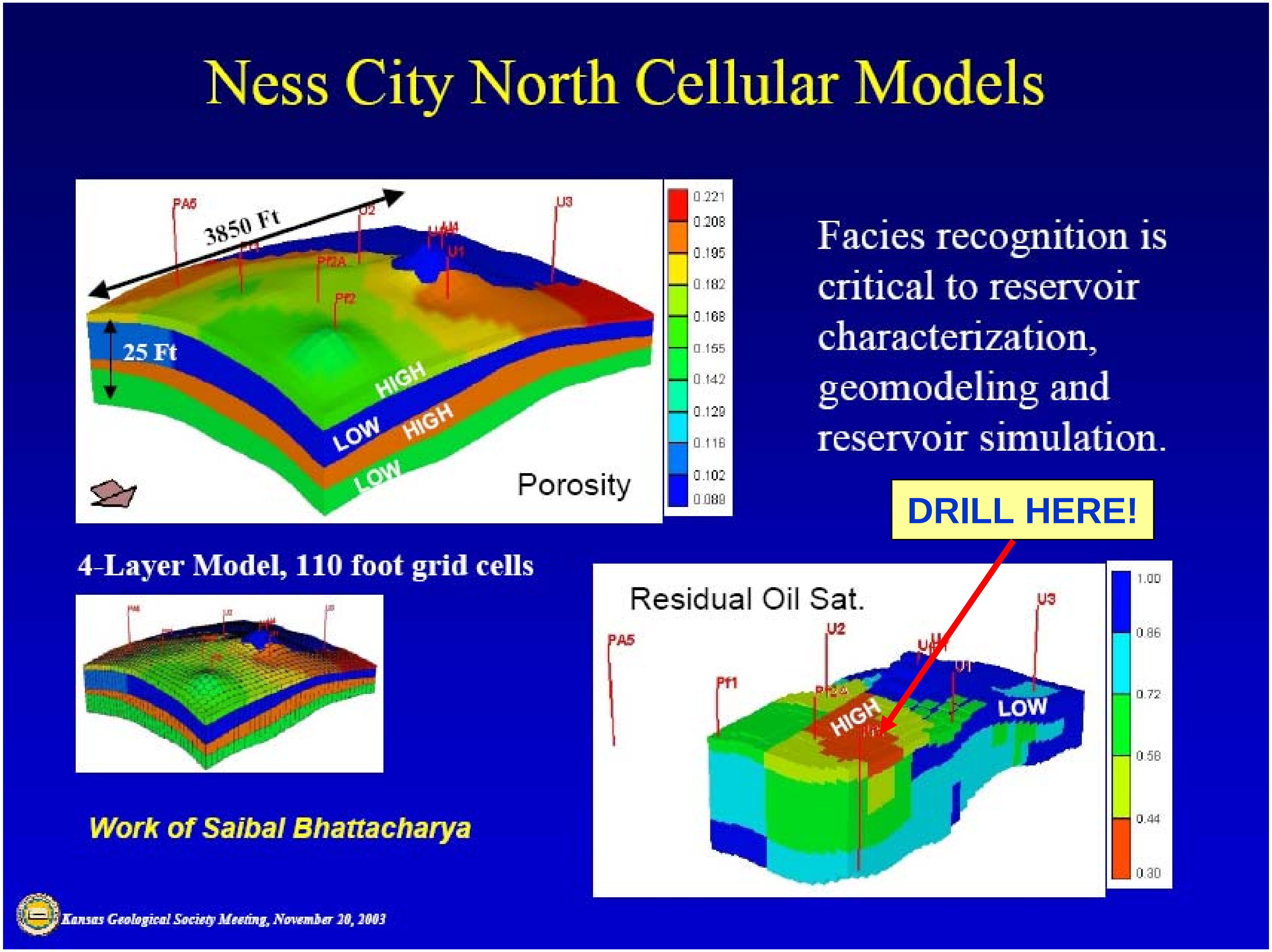
Vertical Well
Drainage Area = 40 Acres
$x_{ev}/y_{ev} = 1$

Horizontal Well
Drainage Area = 100 Acres
$x_{eh}/y_{eh} = 2.5$

Note extended drainage area off ends of the lateral

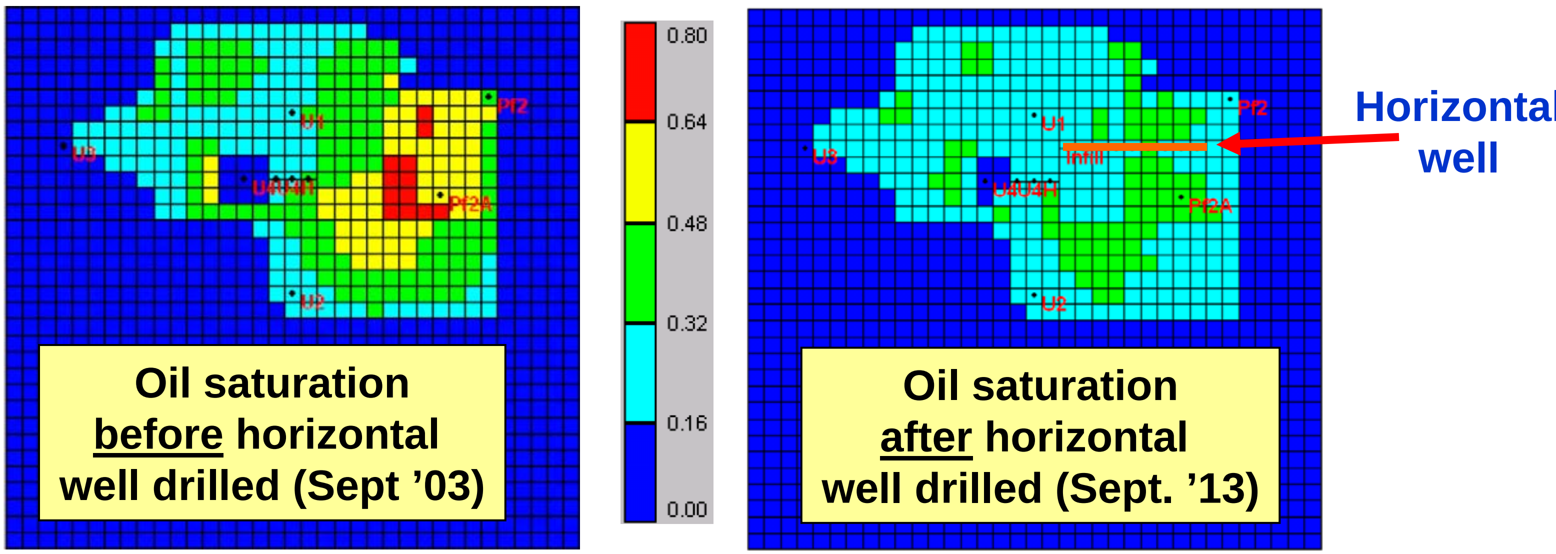
JTI

Models used to predict recovery of a horizontal well



Simulation modeling of drainage and oil recovery from horizontal well -- *Ness City North Field*

Ness City North Horizontal Infill Well – Production Potential, Drainage & Interference on Existing Wells



Ummel 1 (U1) - Prod Loss (Interferrence)

	Ummel 1 Cum Oil, BO No Infill	Ummel 1 Cum Oil, BO Infill E-W	Ummel 1 Prod loss, BO
Jan-2003	220226		
Jan-2006	226409	224401	2008
Jan-2008	229907	226572	3335
Jan-2013	237034	230903	6131

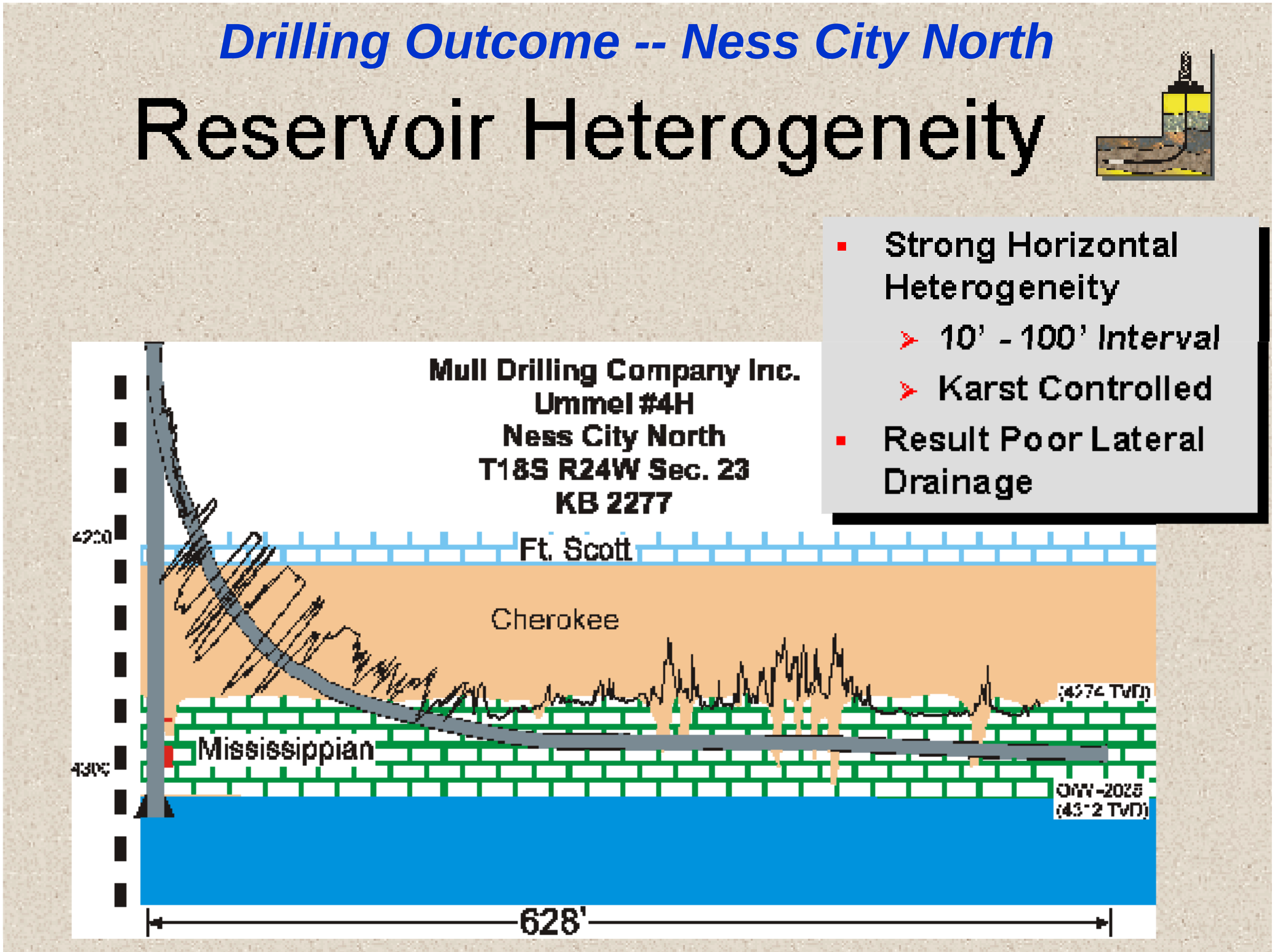
Pf2A-24 - Prod Loss (Interferrence)

	Pf2A-24 Cum Oil, BO No Infill	Pf2A-24 Cum Oil, BO Infill E-W	Pf2A-24 Prod loss, BO
Jan-2003	28,362		
Jan-2006	53,181	42,952	10,229
Jan-2008	64,475	47,448	17,027
Jan-2013	83,750	53,537	30,213

Production Gain from Infill EW (Infill)

Year end	Cum Oil, BO	Cum Wtr, BW
2003	22,237	320,335
2004	34,569	627,966
2006	50,137	1,226,540
2008	59,675	1,798,090
2013	71,272	2,847,120

Reservoir properties strongly affect how horizontal wells behave

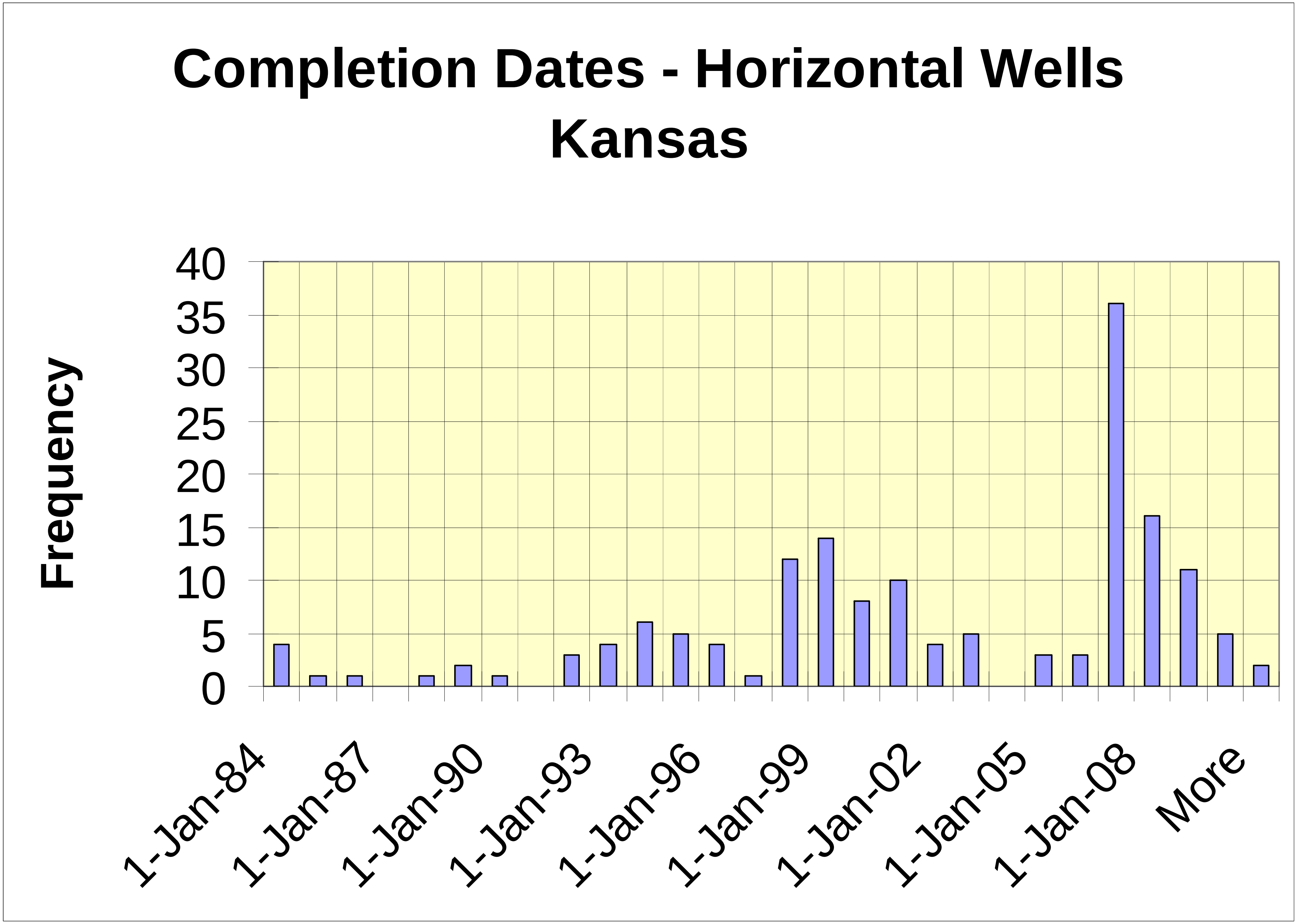


3. Statistics on current horizontal drilling and types of reservoirs being drilled with laterals

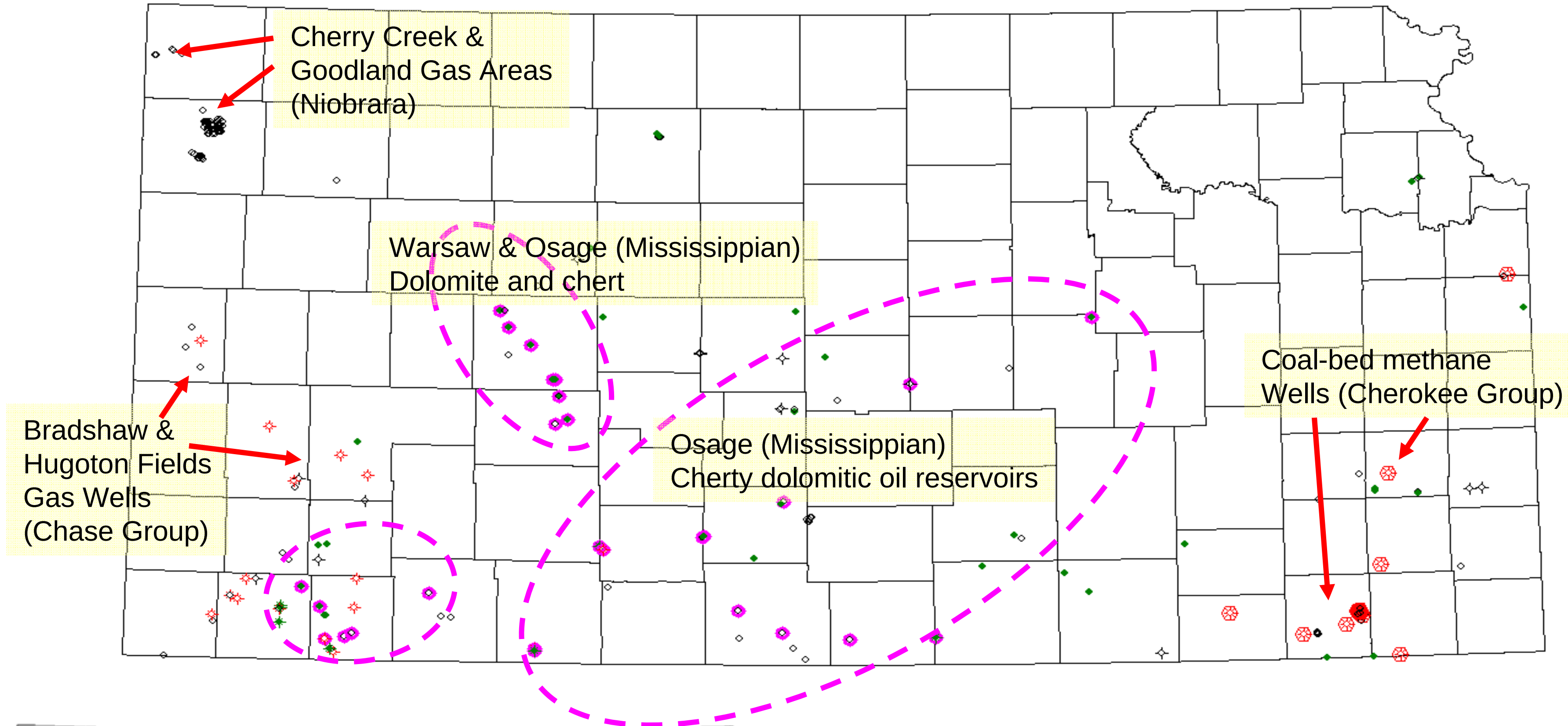
U.S. Horizontal Completions - State Summary

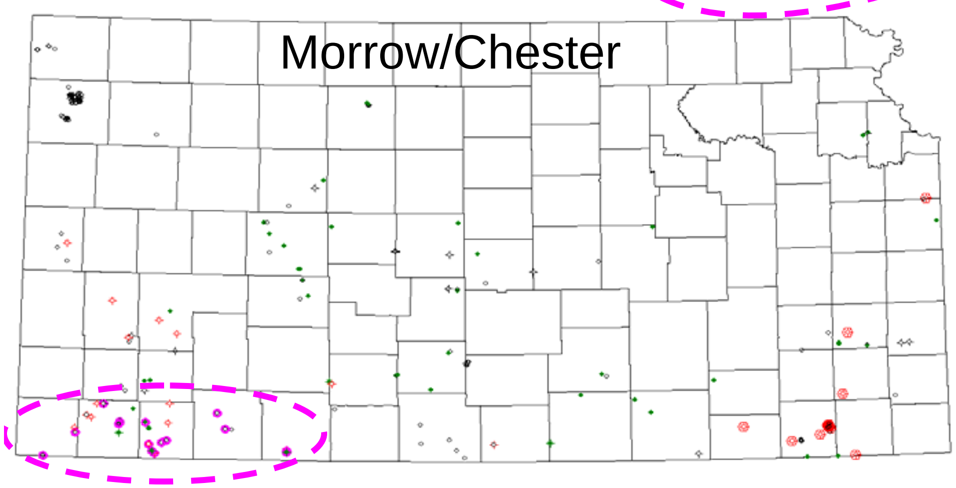
U.S. HORIZONTAL COMPLETIONS – STATE ANNUAL SUMMARY							
	Pre - 2005	2005	2006	2007	2008	2009	TOTAL thru 12/31/09
Alaska	992	158	96	99	67	61	1,473
California	394	135	164	209	239	82	1,223
Montana	1,239	351	353	294	121	20	2,378
North Dakota	1,683	247	386	462	681	402	3,861
Oklahoma	1,183	551	717	775	1057	577	4,860
Texas	13,154	1,616	2,263	3,351	4,208	2,312	26,904
All others	4,255	426	619	1064	1619	1558	9,541
TOTAL US	22,900	3,484	4,598	6,254	7,992	5,012	50,240
Kansas	**86**	**3**	**3**	**36**	**16**	**11**	

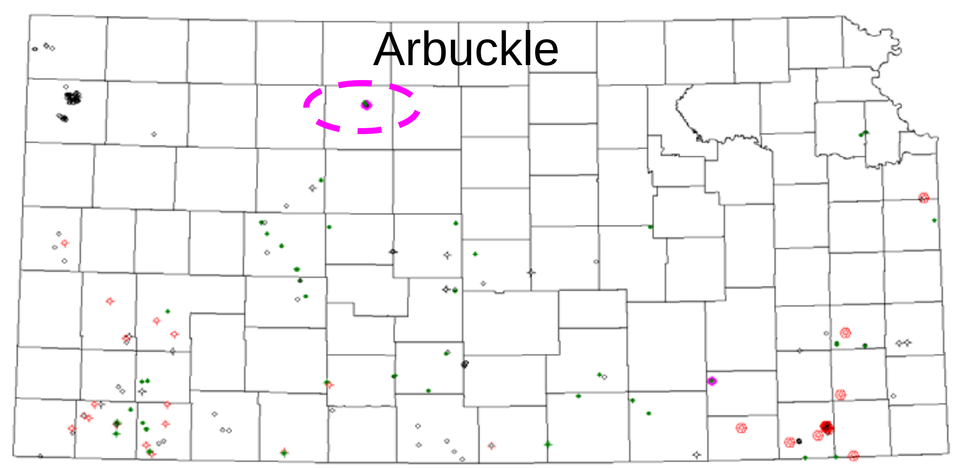
Horizontal Wells Drilled 2000-2010



Horizontal Wells in Kansas (October 2010) – Mississippian highlighted







October 2010

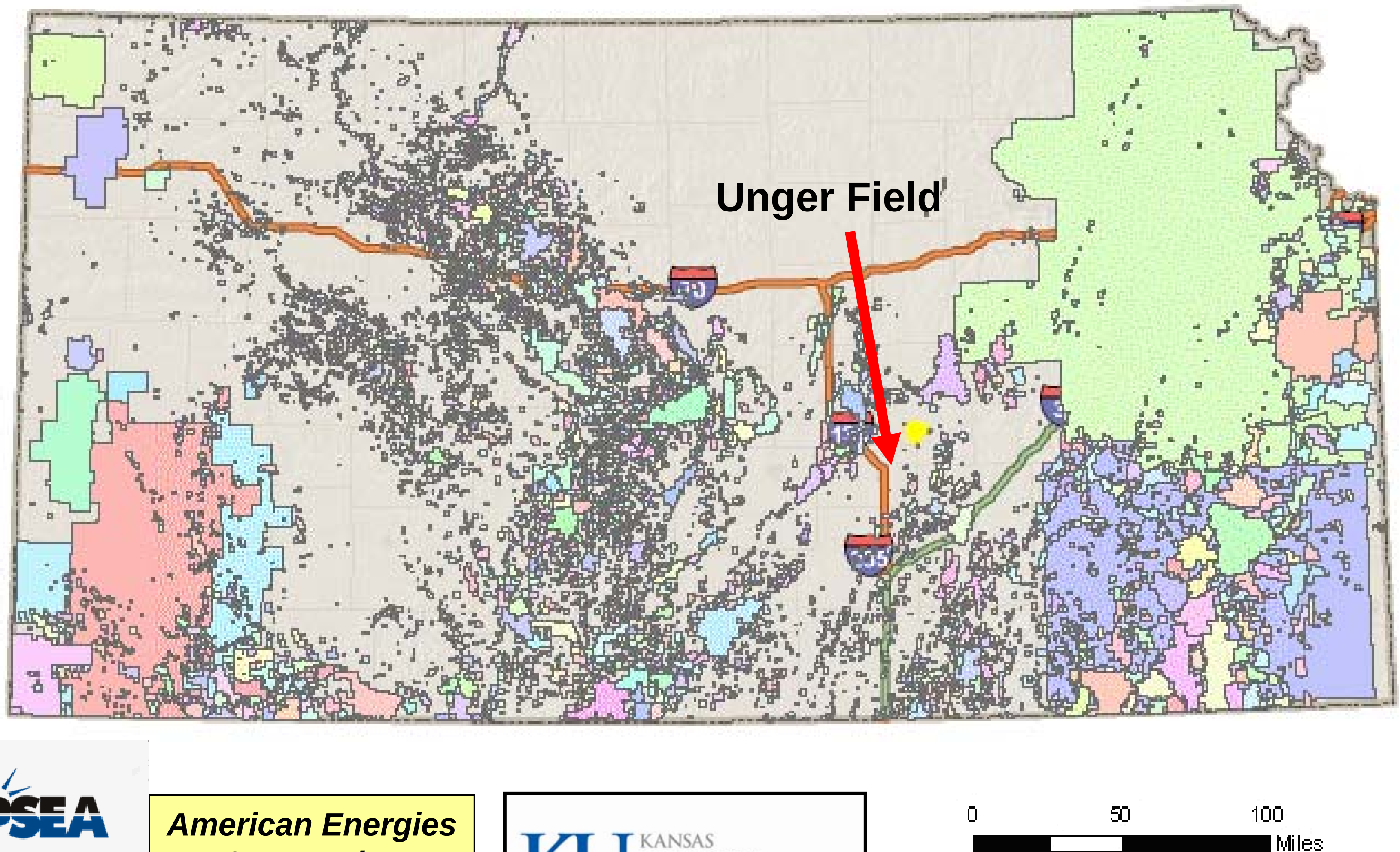
HORIZONTAL WELLS IN KANSAS

		Wells with oil production
Total	**238**	
producing oil wells	**20**	
Success rate (%)	**8.4**	
Niobrara chalk shallow gas	61	
Chase-Council Grove	10	
Lansing-Kansas City	2	0
Cherokee CBM	15	
McLouth Sandstone	9	0
Morrow-Chester	16	4
Mississippian carbonates	22	6
Viola	7	0
Arbuckle	8	3

403,430 bbls -- Best horizontal well drilled in Kansas to date – an infill well drilled in 1997 by Ensign Operating Company in Mississippian Warsaw Dolomite in Aldrich NE Field, Ness County -- 1400 ft lateral drilled and completed open hole by Halliburton services. initially, low productivity due to mud damage; cleaned up with acid for excellent well

4. Case studies in Kansas - Mississippian Warsaw dolomite reservoir in Ness County and Hunton dolomite in Marion County

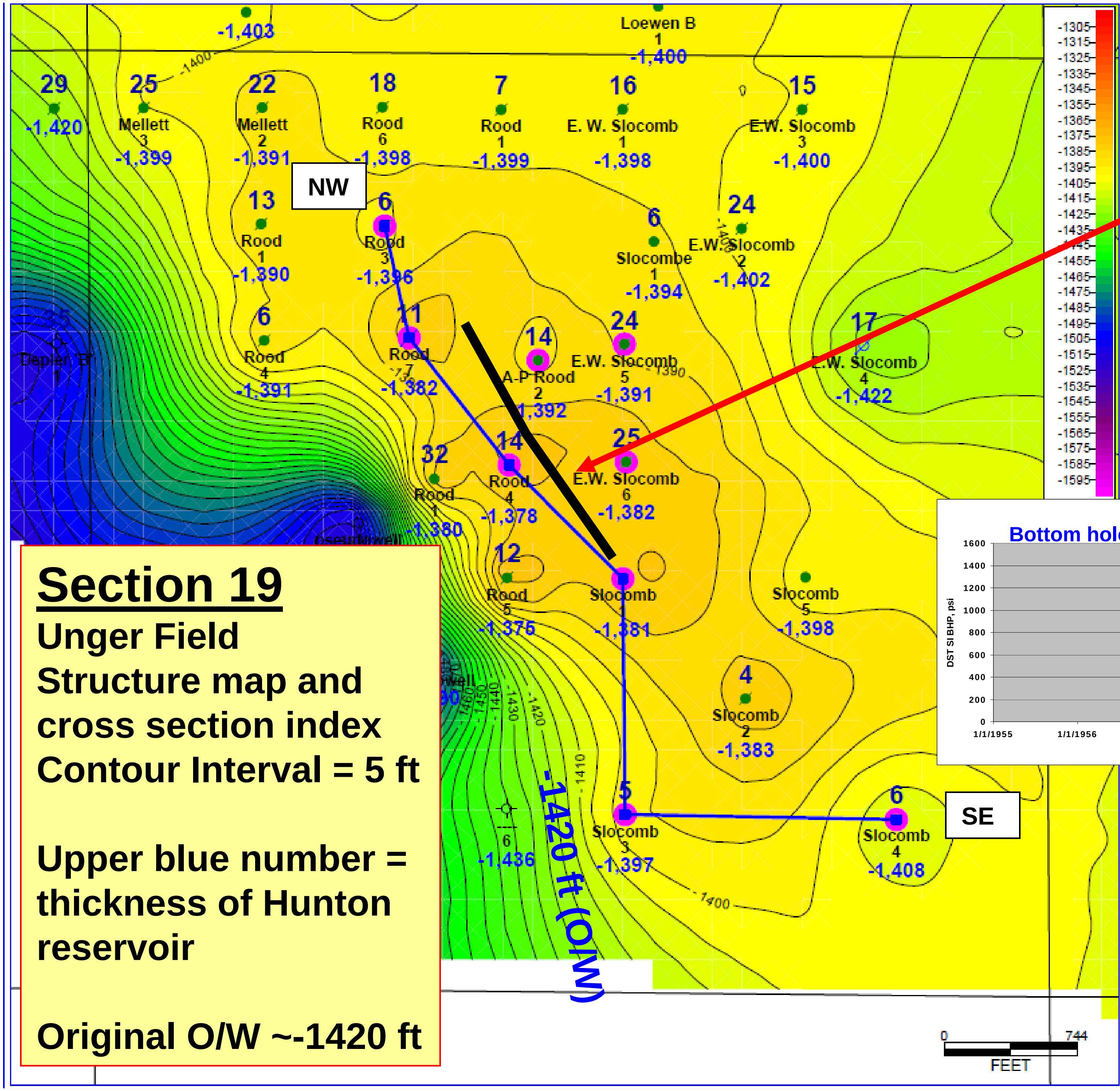
Unger Field
Marion County, Kansas



RPSEA
Research Partnership to Secure Energy for America

American Energies Corporation
Alan DeGood

KU KANSAS GEOLOGICAL SURVEY
The University of Kansas



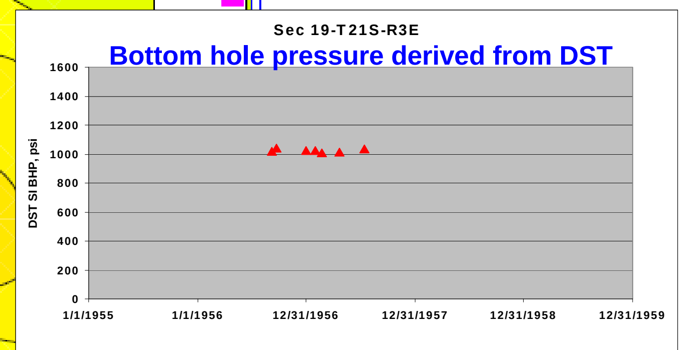
Section 19

Unger Field
Structure map and cross section index
Contour Interval = 5 ft

Upper blue number = thickness of Hunton reservoir

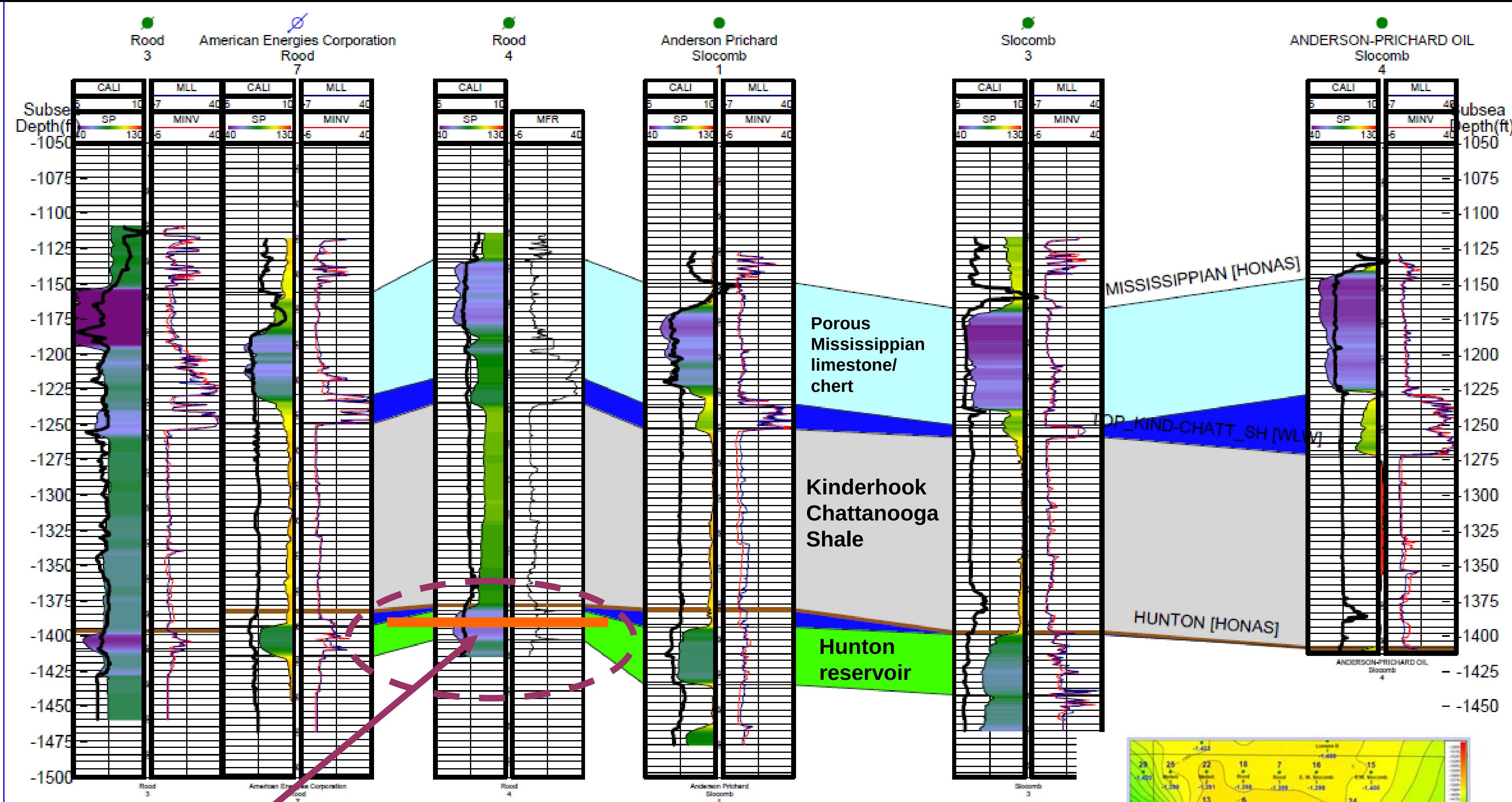
Original O/W ~-1420 ft

Proposed Location of Lateral



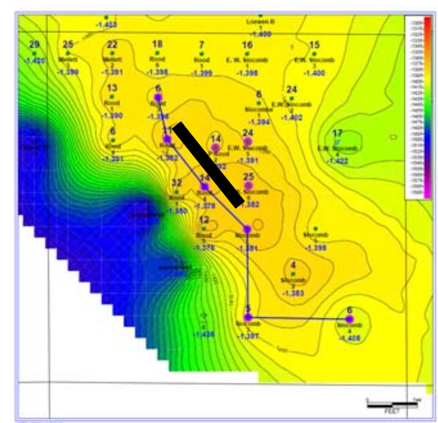
DST data from:
Slocombe 5, 6
Mellot 4
Rood 1, 2, 3, 4, 5, 7

NW-SE Structural Cross Section #1



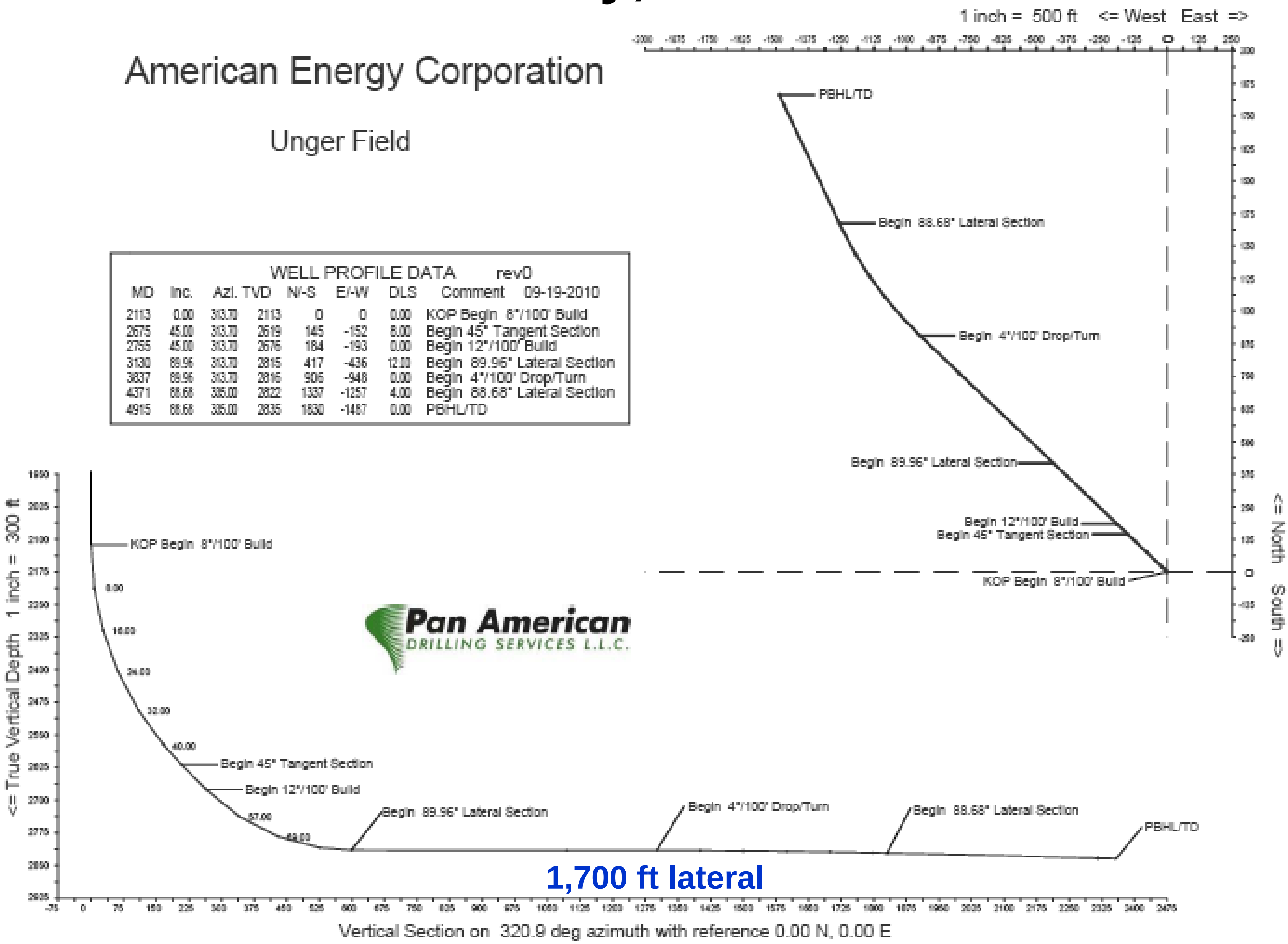
Target zone for lateral Paralleling cross section

900 ft



SP-Caliper-Microlog curves shown – SP depicted in color delimiting magnitude

Horizontal Drilling Plan – Unger Field, Marion County, Kansas



WELL PROFILE DATA rev0

MD	Inc.	Azi.	TVD	N/-S	E/-W	DLS	Comment 09-19-2010
2113	0.00	313.70	2113	0	0	0.00	KOP Begin 8°/100' Build
2675	45.00	313.70	2619	145	-152	8.00	Begin 45° Tangent Section
2755	45.00	313.70	2676	184	-193	0.00	Begin 12°/100' Build
3130	89.96	313.70	2815	417	-436	12.00	Begin 89.96° Lateral Section
3837	89.96	313.70	2816	906	-948	0.00	Begin 4°/100' Drop/Turn
4371	88.68	335.00	2822	1337	-1257	4.00	Begin 88.68° Lateral Section
4915	88.68	335.00	2835	1830	-1487	0.00	PBHL/TD

Partners in Unger Field Drilling

TRES

Tres Management, Inc.
providing outstanding personnel for all your energy projects

Design and well site supervision on over 300 horizontal wells drilled including multi-laterals in Oklahoma Hunton, Arbuckle, Barnett Shale and others – up to 8,000' lateral displacement

Pan American
DRILLING SERVICES L.L.C.

Focus Gamma (sensor) -- To avoid shale caprock above reservoir

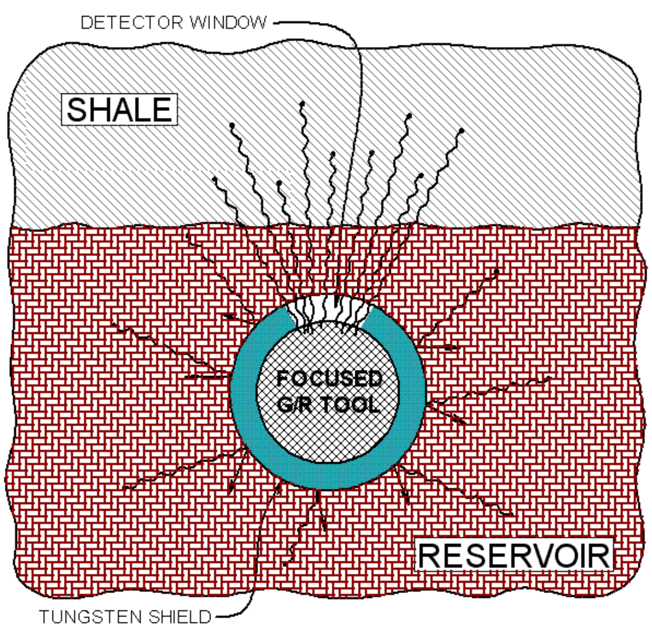
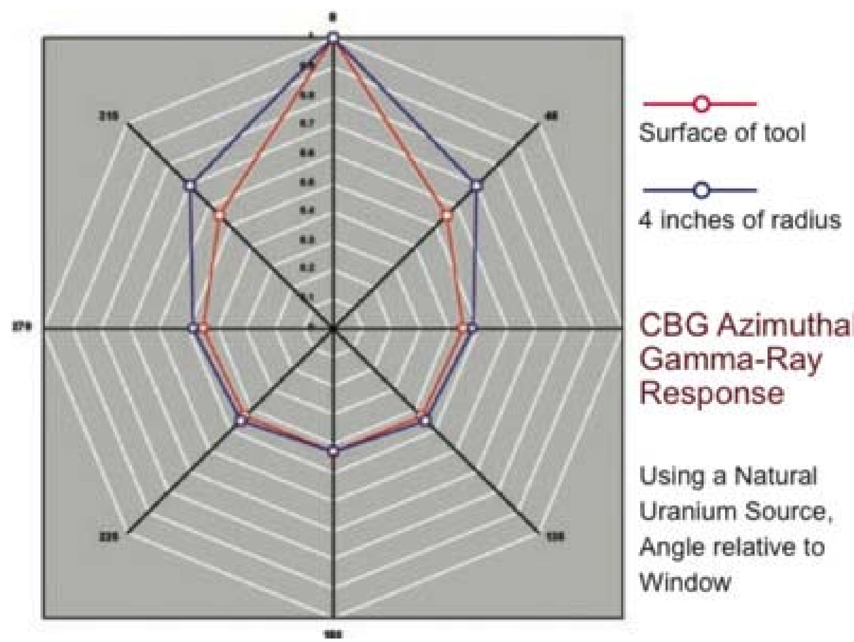


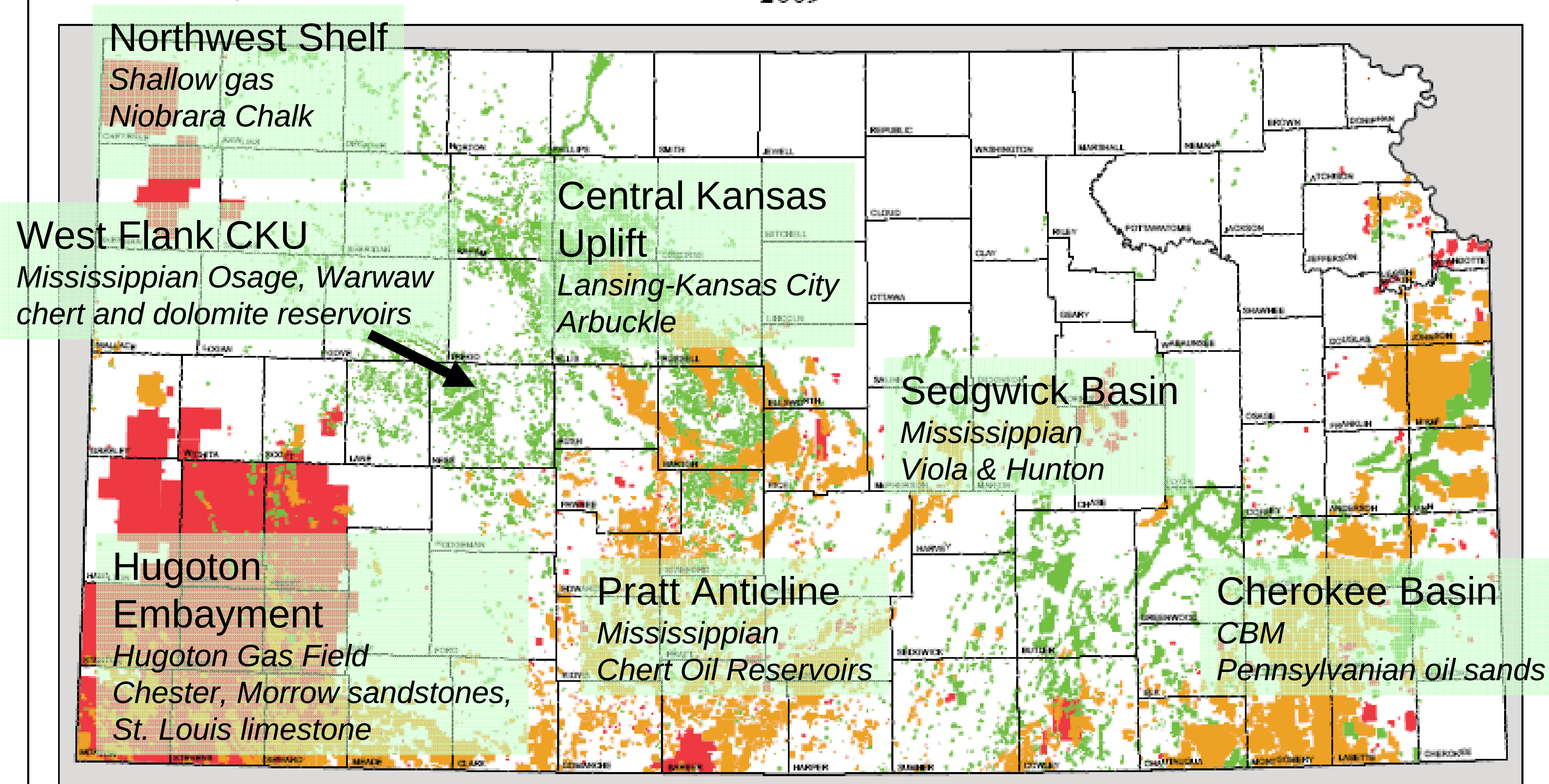
FIG. 1



5. Expectations for horizontal drilling in the future

OIL AND GAS FIELDS OF KANSAS

2009



This map was prepared by the staff of the Kansas Geological Survey and is based on Oil and Gas Fields in Kansas (1967) and subsequent revisions with the same name (1975, 1989, 1990, and 1993). Fields are represented according to their status as of June 1, 2009. Listings of fields by location, name, and cumulative production are found in the Survey's interactive oil and gas map viewer located at http://maps.kgs.ku.edu/oilgas/index.cfm. For viewer instructions, click on the "Help" tab at the top of the page. Due to frequent data updates, field and production area boundaries may differ slightly from those shown on this map. All fields are shown without differentiation between active and inactive. Areas of natural gas production from coal are not included on this map.

As set forth in Kansas Administrative Rule 82-3-102, field boundaries are determined by the Kansas Corporation Commission after considering the recommendations of the Conservation Division, Kansas Corporation Commission, and the Nomenclature Committee, Kansas Geological Society.

SCALE 1:2 600 000

10 0 10 20 30 40 50 mi

10 0 10 20 30 40 50 km

LAMBERT CONFORMAL CONIC PROJECTION
WITH STANDARD PARALLELS AT 33° AND 45°N
CENTRAL MERIDIAN 98°30' W
NORTH AMERICAN DATUM OF 1983

Named Fields

- Oil field
- Gas field
- Oil and gas field

Producibility problems addressed with horizontal wells

- **Mature fields – often have high water cut, strong water drive**
- **Current production practice – use conventional vertical wells**
- **Limited lateral drainage in vertical well**
- **Significant variation in producibility between adjacent wells**
- **Residual pockets of oil possibly located in the interwell areas outside the drainage reach of vertical wells**
- **Often reservoirs are compartmentalized (*karstification and subcropping strata*)**
  - Wells located in small compartment have short production life, uneconomic cumulative volumes
  - Wells located (by chance) in large compartments – long production life
- **Effective pay zones in Kansas are thin (*less than 20 ft*)**
- **Limited resource-reach of operators – financial and technical**

Proposed solution – cost-effective extended reach horizontal lateral

- **Has to be cost-effective – drilling, logging, and completion**
- **Has to be have minimal technical risks – for independent operators to be interested and apply for infill drilling**
- **Must have tight directional control to --**
  - Reach and drain targeted pockets of remaining reserves in the inter well region
  - Have trajectory constrained within thin pay
- **Would have significant added advantage, if one targeted well could drain multiple karst compartments**
- **Needs to produce economic volumes under constrained drawdown in order to reduce water cut**
  - Low water cut – helps keep oil relative permeability high in the near well region
  - Results in better sweep of residual oil