Hydrocarbon Mining

Horizontal Drilling and Hydraulic Fracturing

Carl H. Sondergeld

Mewbourne School of Petroleum and Geological Engineering
Mewbourne College of Earth and Energy
University of Oklahoma

March 29, 2011

Barnett Shale the overnight success that took 18 years!

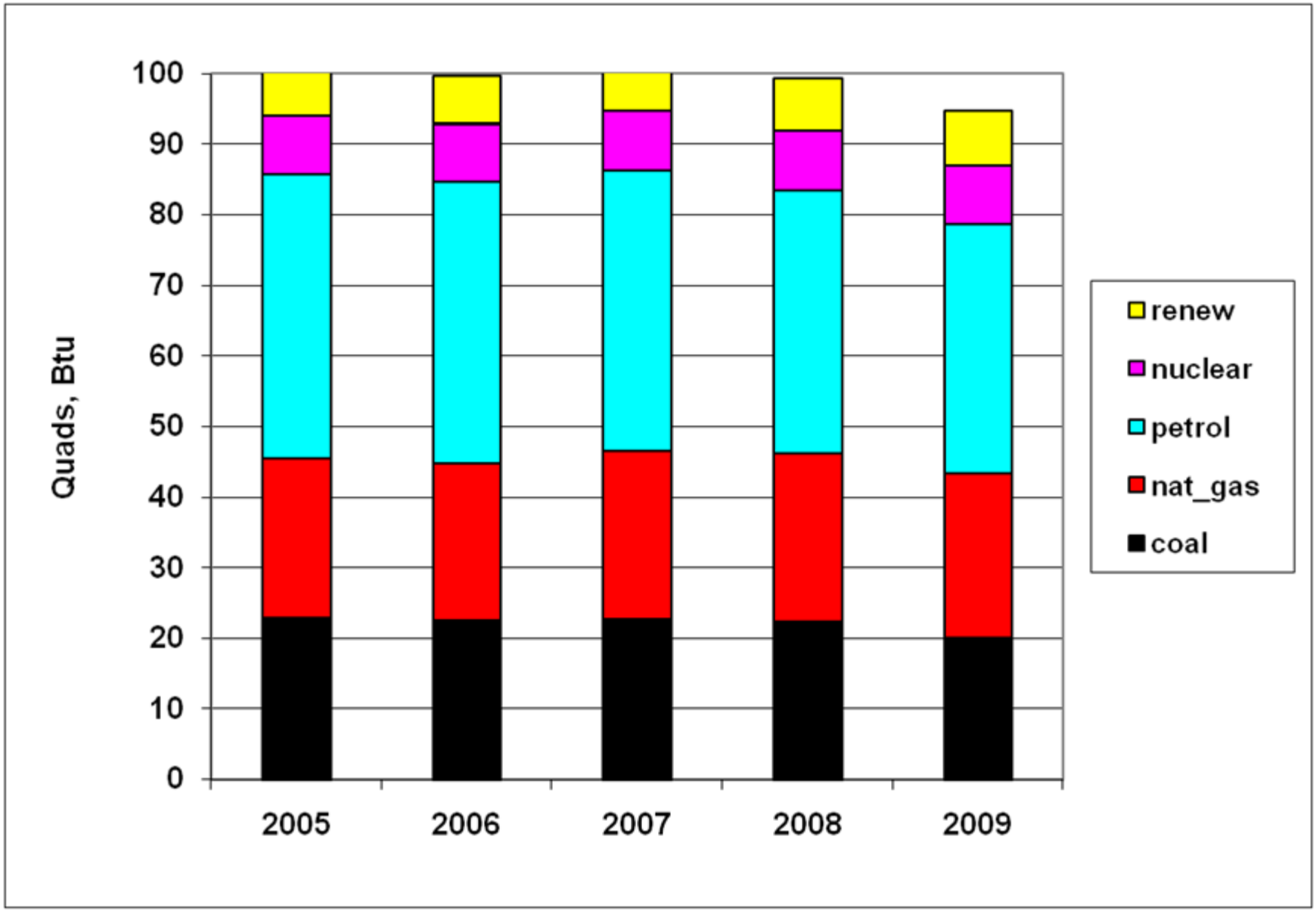
George Phydias Mitchell

Barnett Shale

"It took George Mitchell 18 years to make it work, He is the father of the Barnett Shale. He was tenacious. He started in 1981 and it really didn't take off until 1999. And even then, it took a long time to develop it."

Larry Brogdon, Four Sevens Oil Co.

US Energy Consumption



How Big is a Quad? 1 Quad = 10^{15}

US Energy

Bill Gates
Warren Buffet

100,000,000,000,000,000

Bricks in Empire State Building

Bricks in the Great Wall of China

US National Debt

Shale Gas Plays in the United States

Natural Gas & Condensate

Do we have a cleaner alternative?

Do we have abundant supplies of natural gas world wide?

Do we have abundant domestic supplies of natural gas?

Do we want to stop importing energy supplies?

Do we want energy security?

Do we want new sources of tax revenues or should we just ship our dollars overseas?

Do we want new jobs in the US ?

Foreign companies and countries now realize US can be self sufficient in natural gas this has changed LNG export strategies!

3,700 Tcf; consumption 27 Tcf/yr ➔ 140 yrs supply

How do we unlock, stimulate, gas from very tight formations?

Is there any process more effective and safer than hydraulic fracturing?

Can we make hydraulic fracturing more effective?

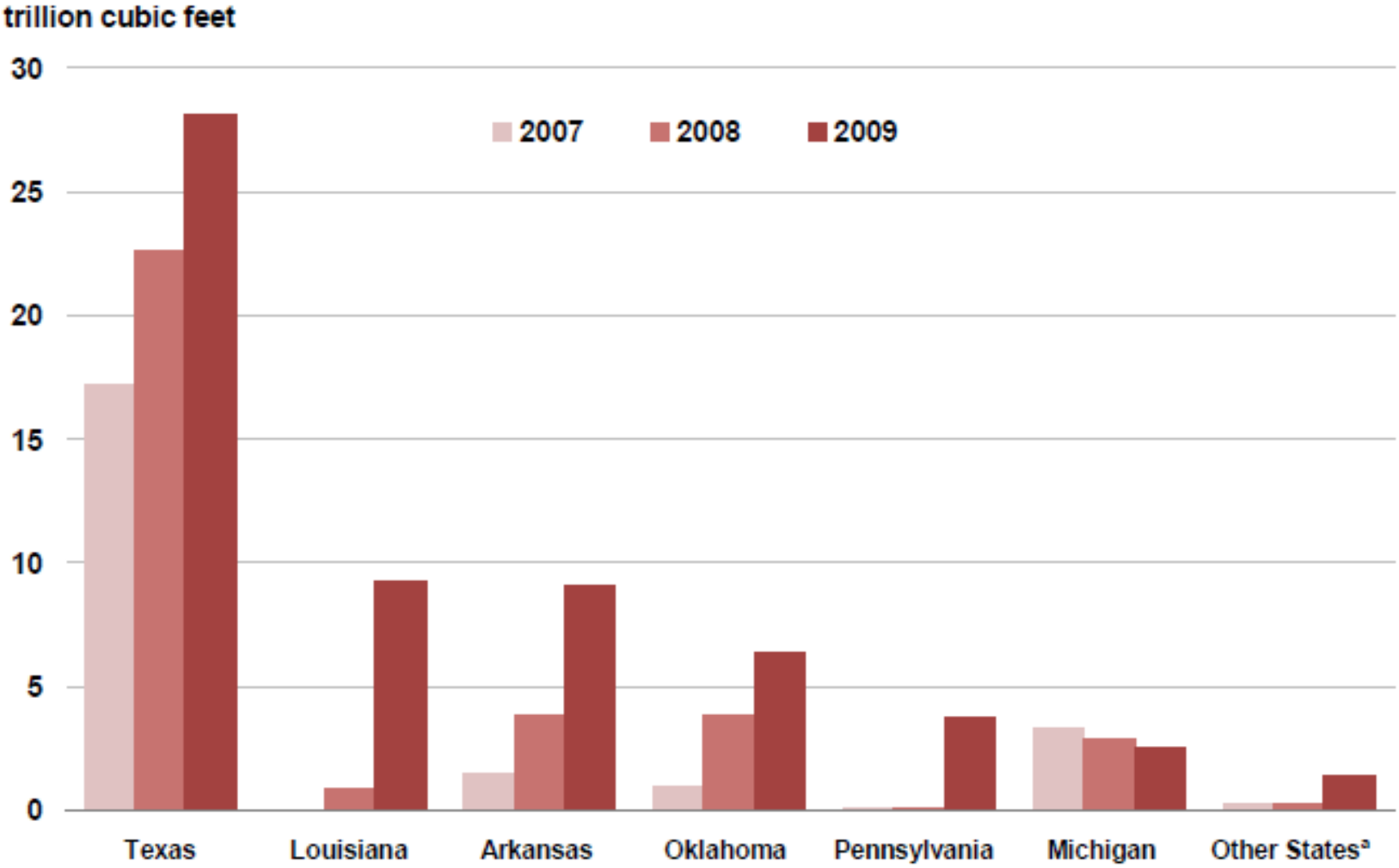
What have we done to address perceived fears?

We are disclosing exactly what is used in fracturing fluids!

We are mapping where our fractures are going using sounds generated during the fracture process.

We are trying to better understand the fracturing processes so we
- can better control it
- use less fluid
- use less horsepower (reduce carbon footprint)

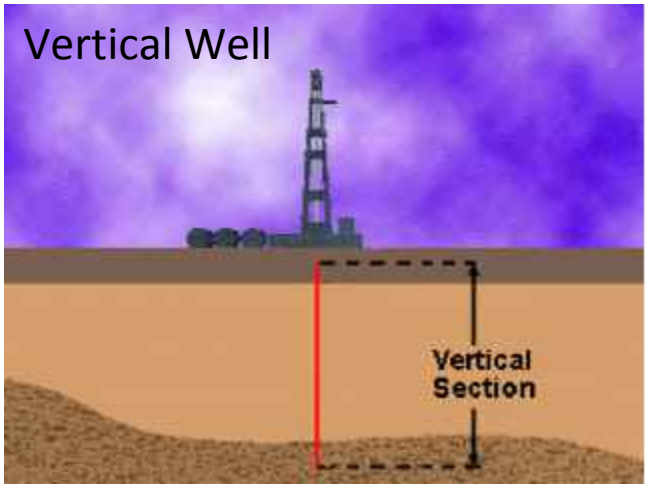
Figure 3. Shale Gas Proved Reserves by Year

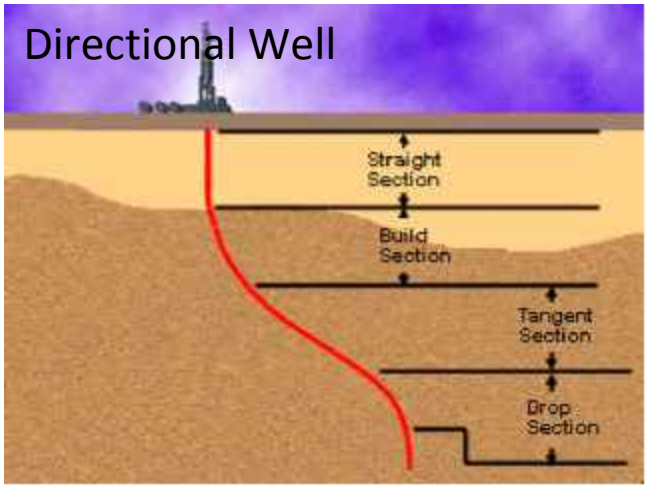


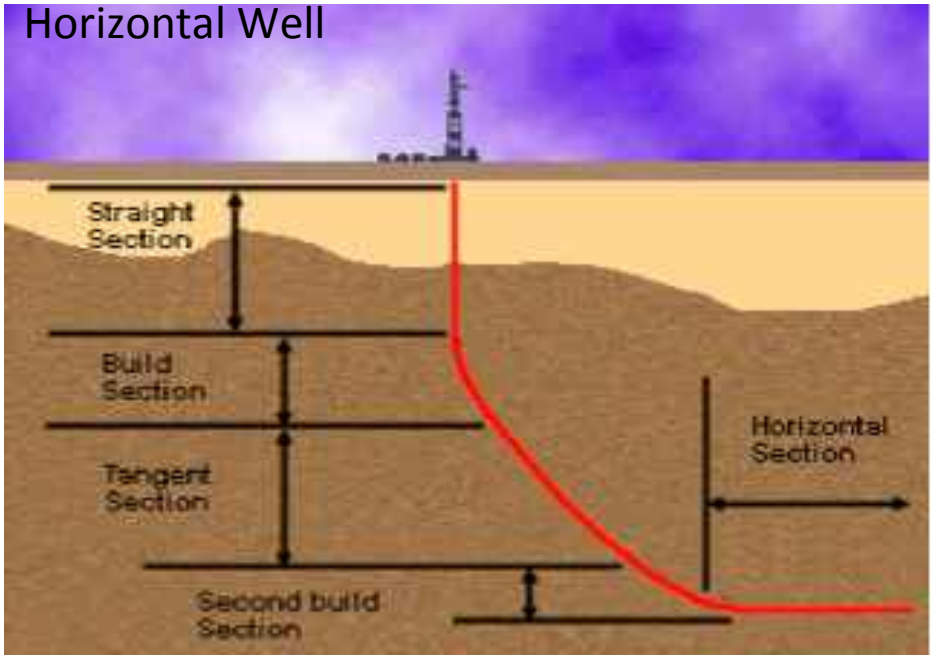
[a] Other States include Indiana, Kentucky, Missouri, North Dakota, Tennessee, and West Virginia.
Source: U.S. Energy Information Administration.

Note: The volumes of shale gas represent only data reported by operators on Form EIA-23, as opposed to complete EIA estimates. The actual total volumes, including estimates for non-surveyed operators, may consequently be different.

Common Well Trajectories

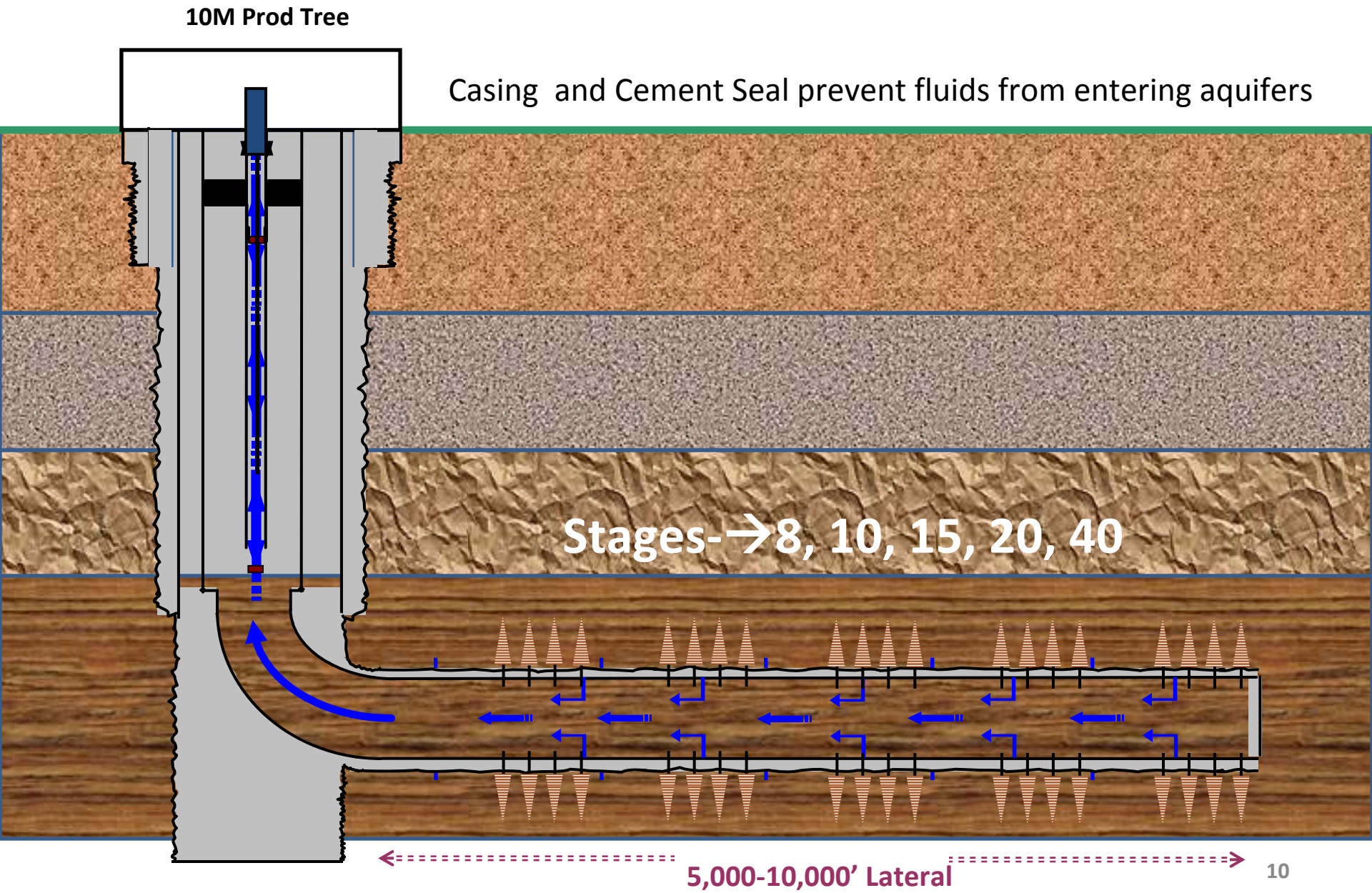




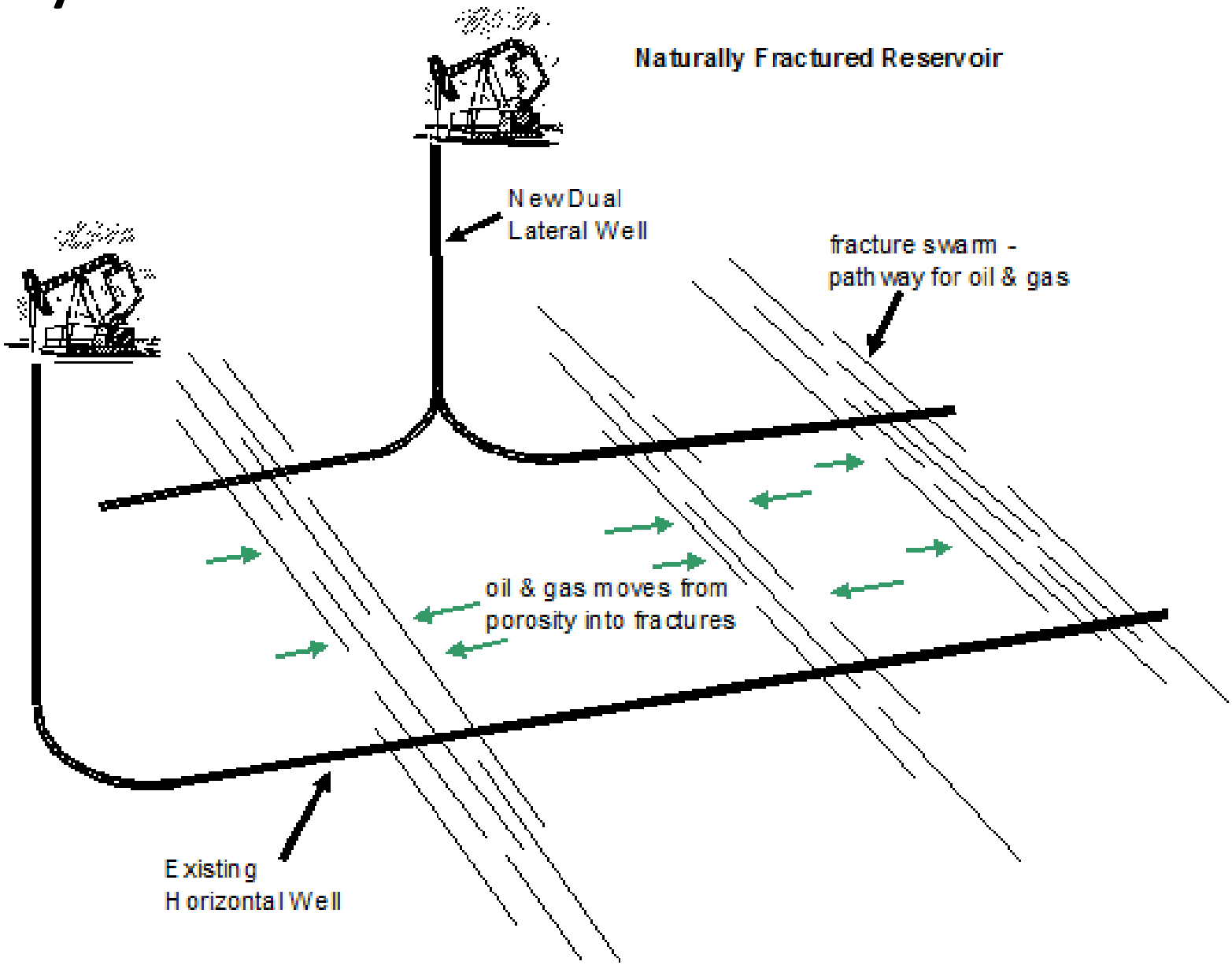


Record: Maersk Oil Qatar-Bd-04A
Total length= 40320 ft
Horiz sect. = 35770 ft
Target 20 ft thick!

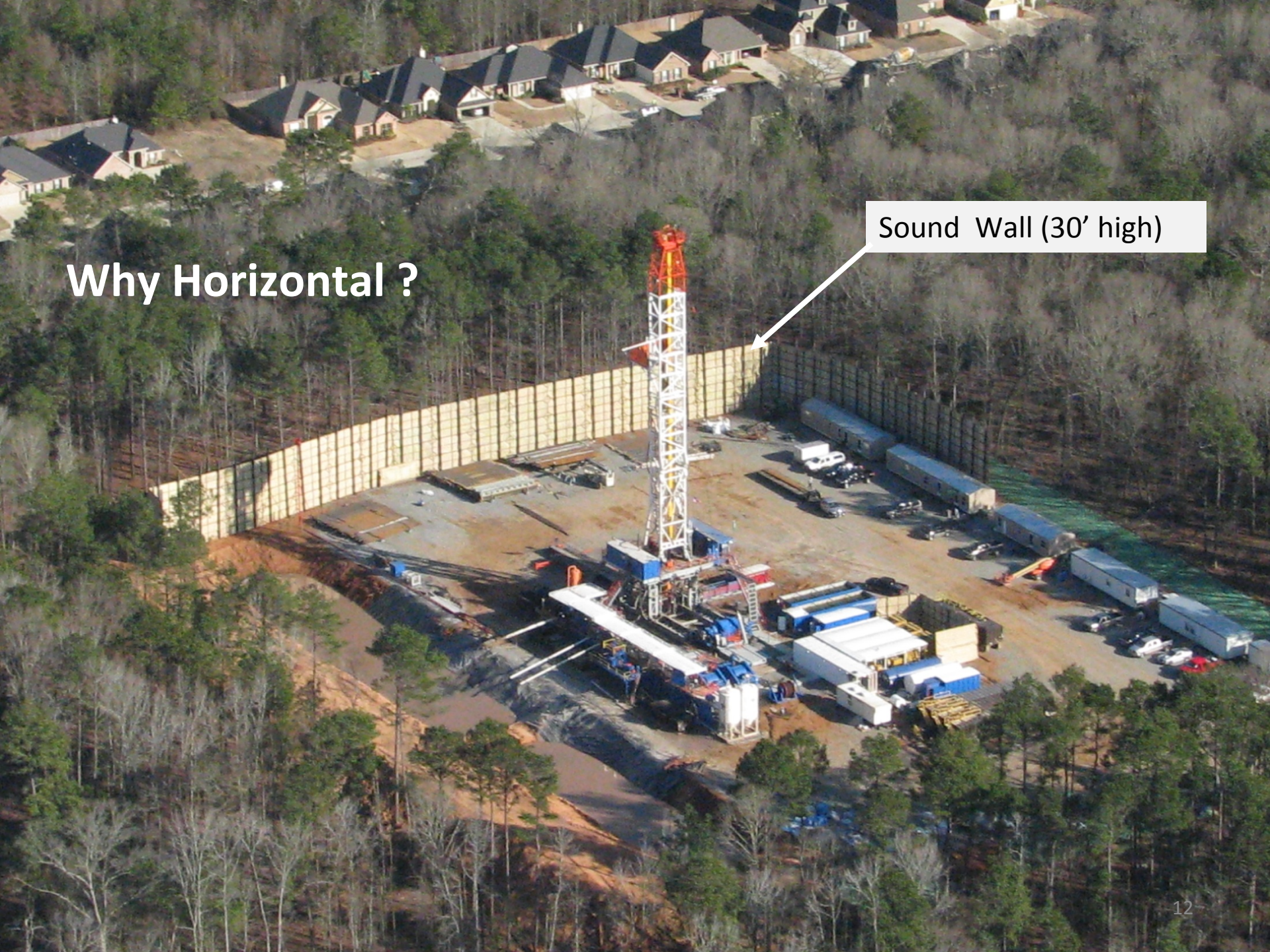
Horizontal Well Plan



Why Horizontal ?

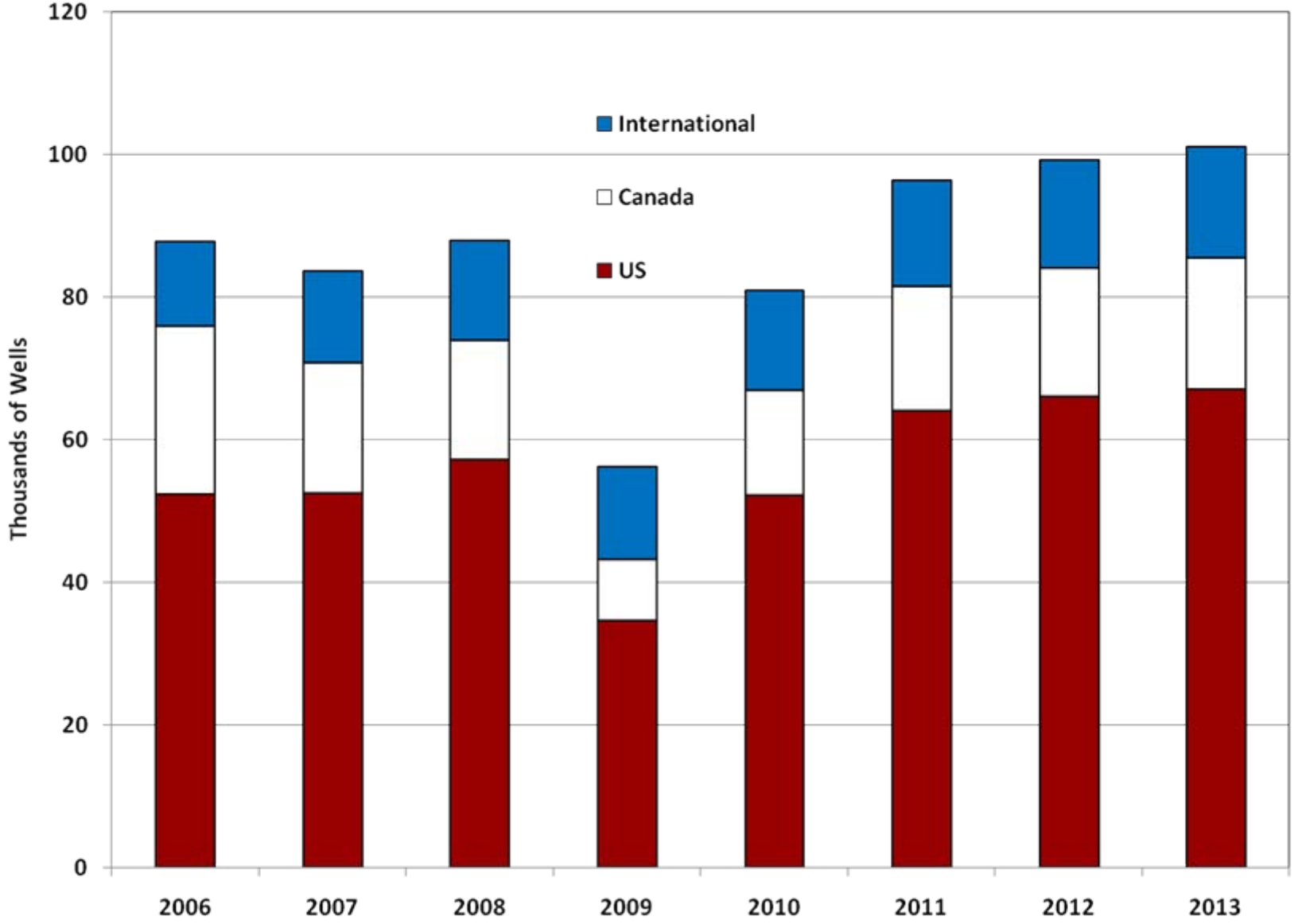


Why Horizontal ?

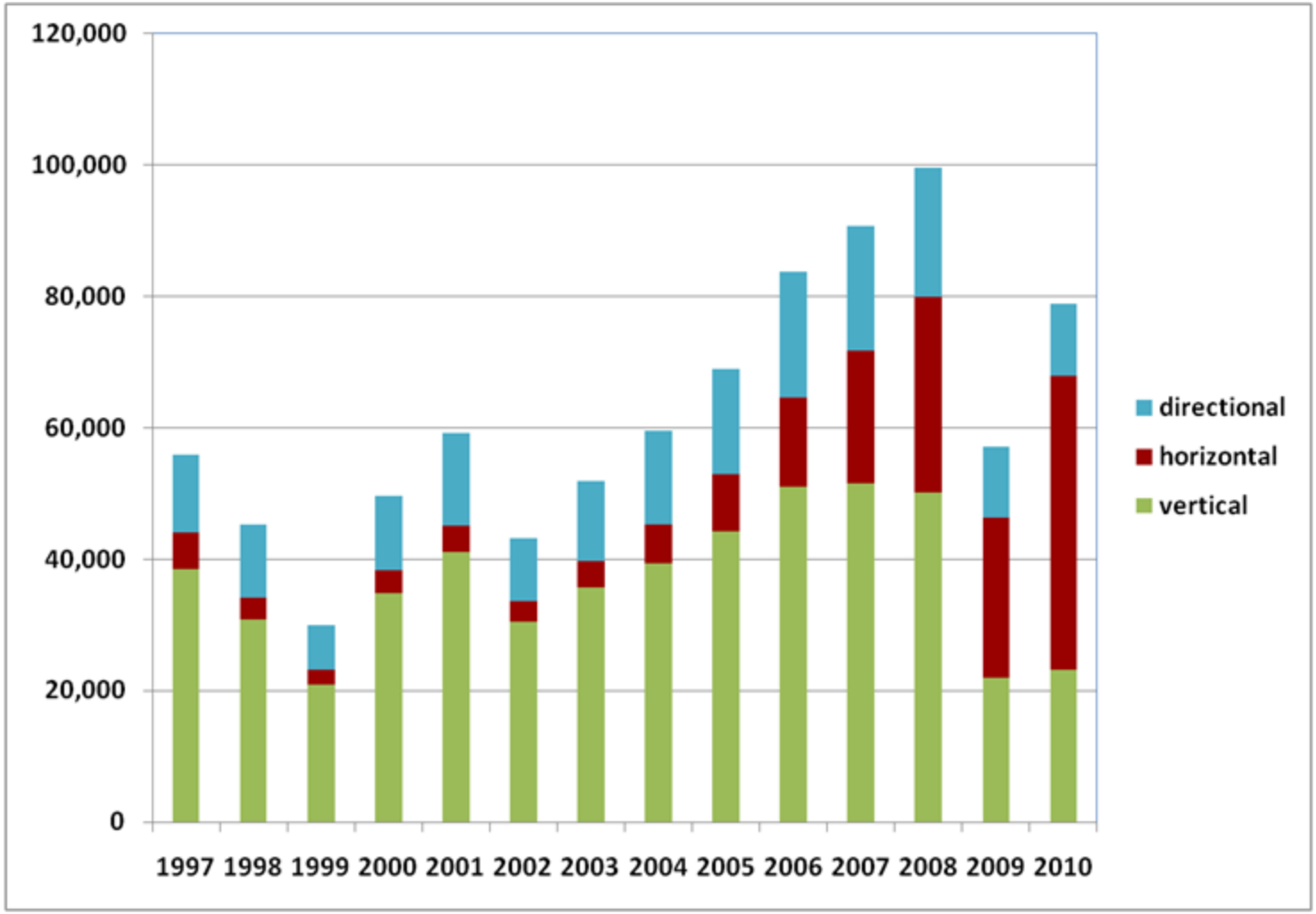


BOTH PARKING
BRAKES MUST
BE SET BEFORE
LEAVING CONSOLE

New Wells Drilled Globally

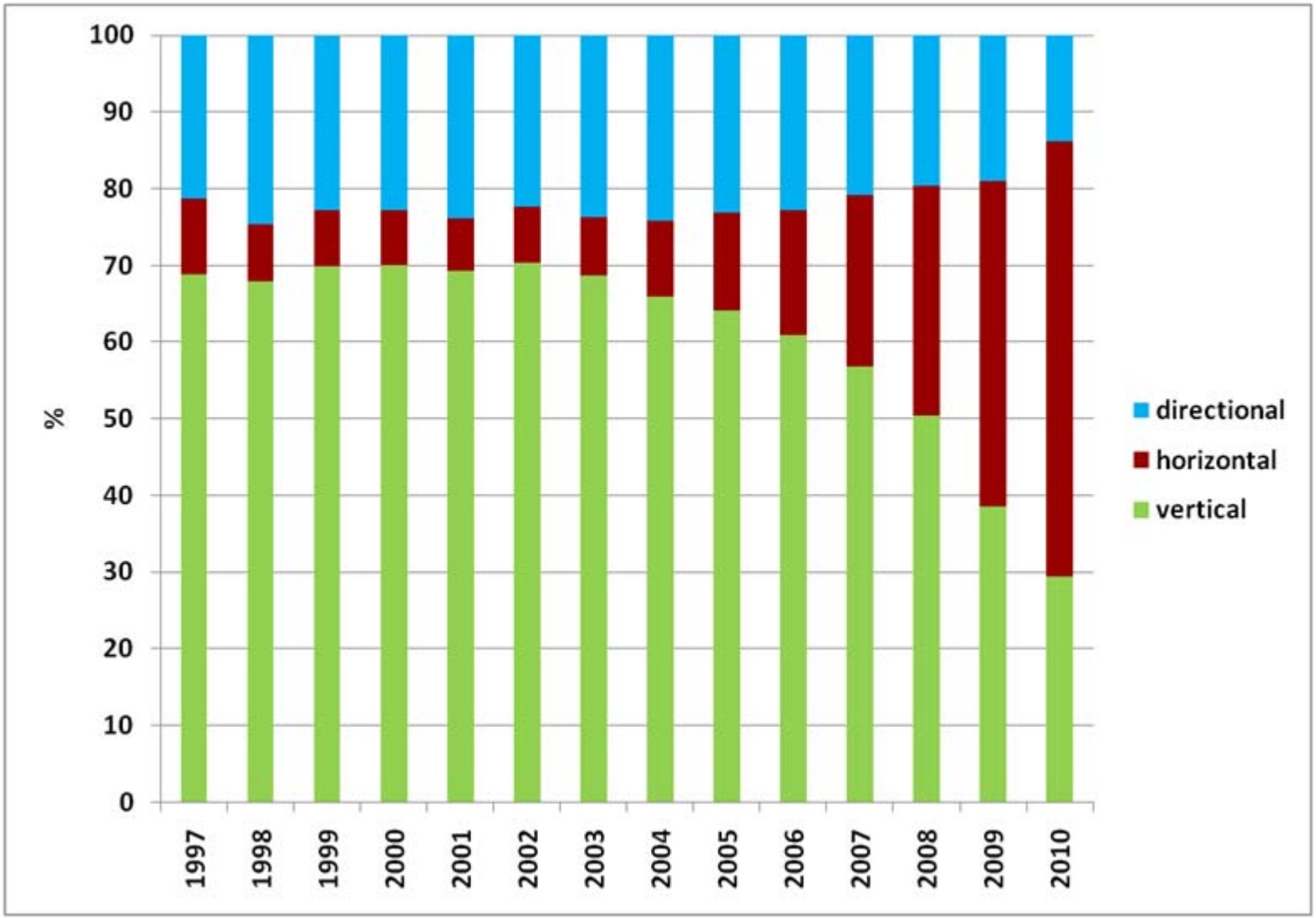


Number of Wells Drilled in U.S.



Smith Bits

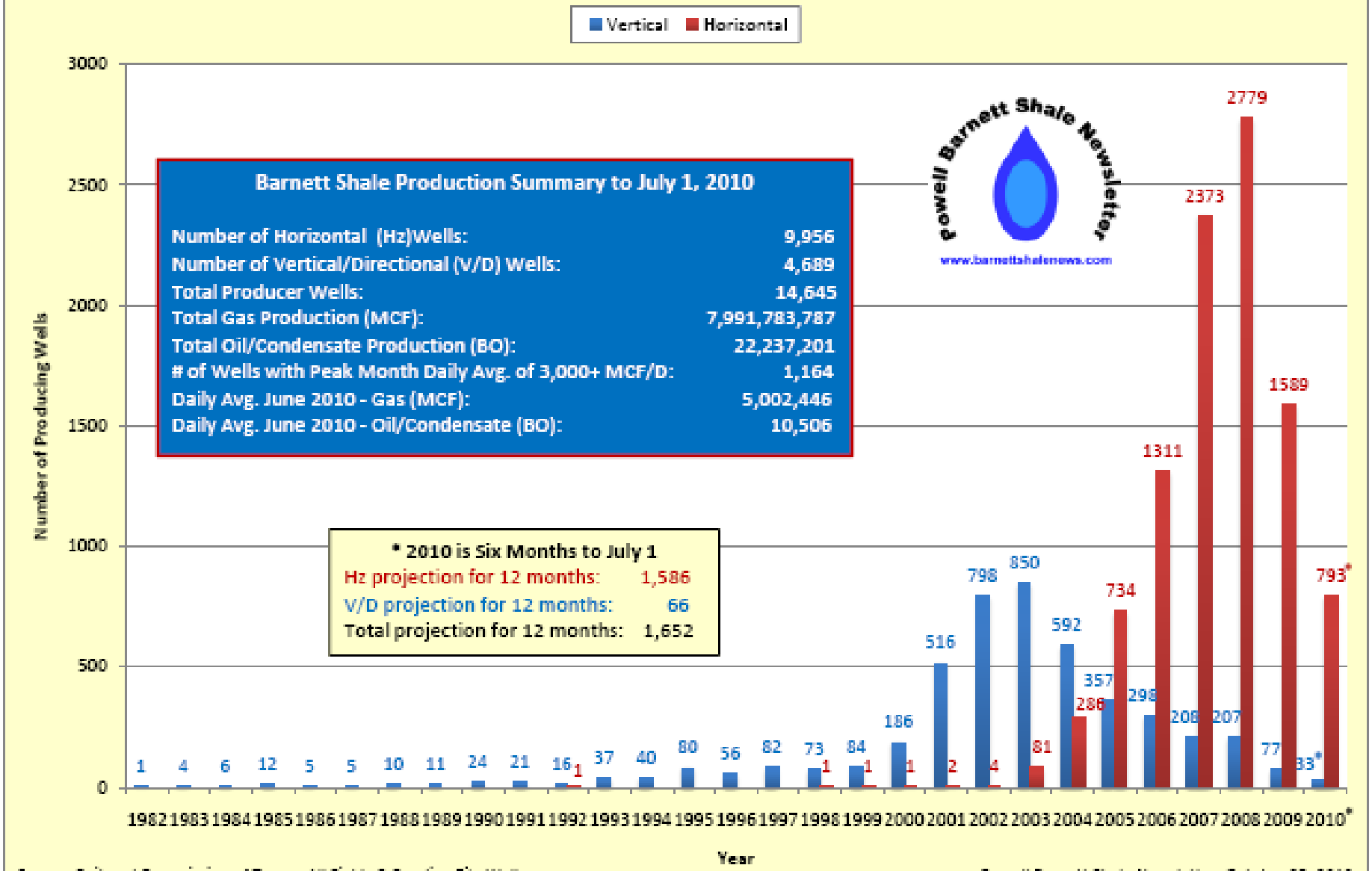
Percentage Horizontal, Vertical and Directional Wells Drilled in U.S.



Smith Bits

Number of New Vertical & Horizontal Producer Wells by Year as of July 1, 2010

All Counties/Fields in the Fort Worth Basin



Source: Railroad Commission of Texas - All Fields & Pending File Wells

Powell Barnett Shale Newsletter, October 25, 2010

Hydraulic Fracturing

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Front Page
Specifications
Claims
Correction

UNITED STATES PATENT OFFICE

23,733

FRACTURING FORMATIONS IN WELLS

Riley F. Farris, Houston, Tex., assignor to Stanolind Oil and Gas Company, Tulsa, Okla., a corporation of Delaware

No Drawing. Original No. 2,596,843, dated May 13, 1952, Serial No. 136,395, December 31, 1949. Application for reissue May 12, 1953, Serial No. 354,668

27 Claims. (Cl. 166—21)

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

1

This invention pertains to the treatment of oil and gas wells. More particularly, this invention

2

fined) in the well opposite the zone to be fractured. Pressure is applied to the low-penetrating

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100%

A HYDRAULIC PROCESS FOR INCREASING THE PRODUCTIVITY OF WELLS

J. B. CLARK, MEMBER AIME, STANOLIND OIL & GAS CO., TULSA, OKLA.

FIG. 1 — SHALLOW WELL HYDRAFRAC JOB, SHOWING (1) FORMATION FRACTURE CONTAINING FRACTURING LIQUID (2) EXPOSED FORMATION PROPPING AGENT AND (3) ROCK ADJACENT TO THE FRACTURE PARTIALLY SATURATED WITH SIMULATED GEL BREAKER SOLUTION

1948

The Original Stimulation Techniques

THE OIL WELL DRILLER 757

The average production of glycerin from 1,500 pounds of acid and 220 pounds of glycerin is about 140 quarts. While nitro-glycerin magazine explosions are not rare, the real cause of the blowing up never becomes known. Those who are close enough to see the cause always go up with the building. The average time for a shooter of nitro-glycerin or maker to remain in the business does not exceed 15 years.

Very few ever recover from a nitro-glycerin accident and those who are killed have their bodies torn to atoms. A great number of persons have been killed by the so-called empty nitro-glycerin tin cans. Beware of the dangerous empty nitro-glycerin cans.

LIST OF NITRO-GLYCERIN TORPEDOES.

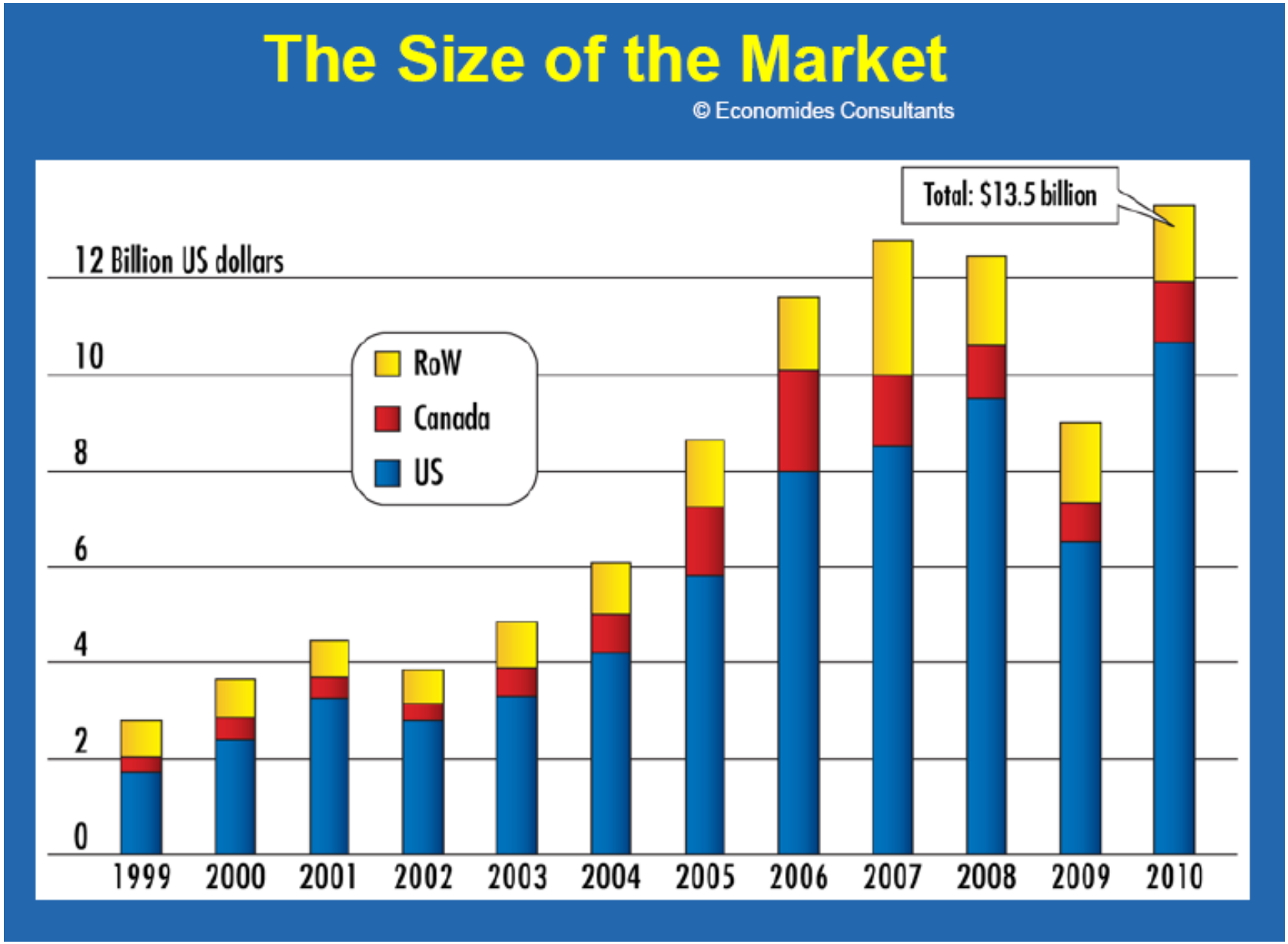
THE OIL-WELL DRILLER

A HISTORY OF
THE WORLD'S GREATEST ENTERPRISE,
THE OIL INDUSTRY

BY
CHARLES A. WHITESHOT
Author of "The History of Oil and Gas," "Oil Sketches," "Oil Notes," etc.

1905

Frac Market Size



Stimulation-Stimulation-Stimulation

Vertical wells

- massive frac treatments
- all sorts of frac fluids

Horizontal Wells

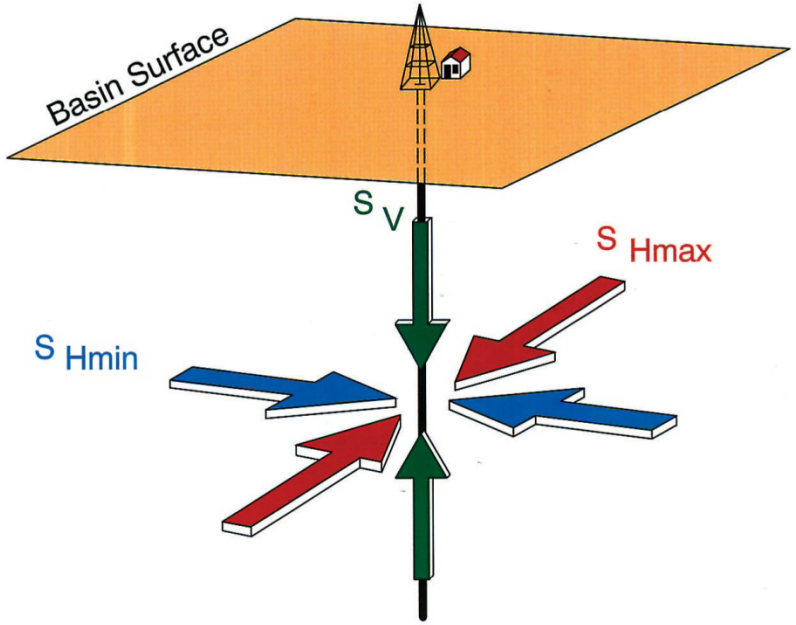
- slick water frac

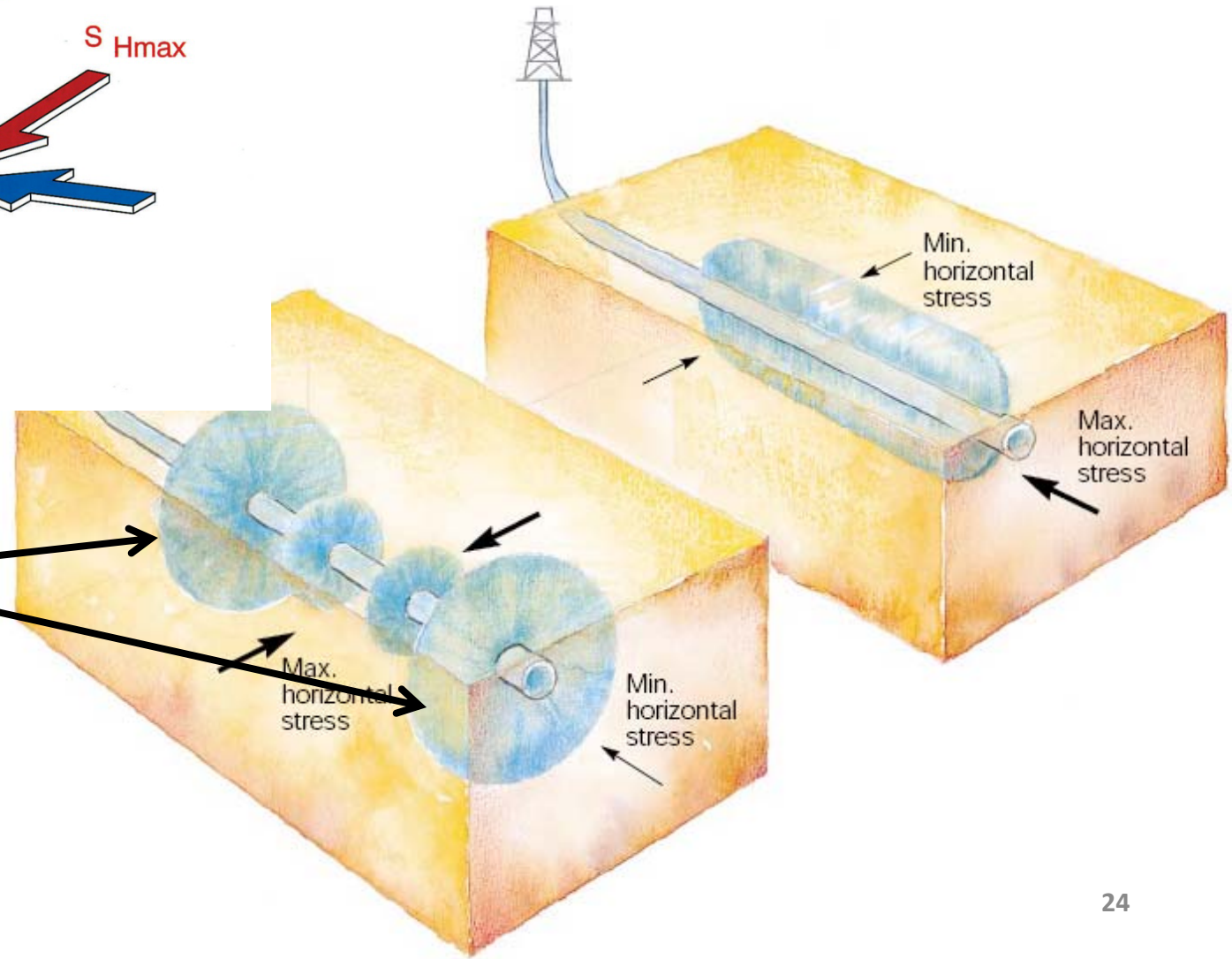
- extended reach 5000’-10000’
- multistage fracs (5-32)
- multilaterals

- simul fracs
- button frac
- zipper fracs

More sand-More Horsepower?

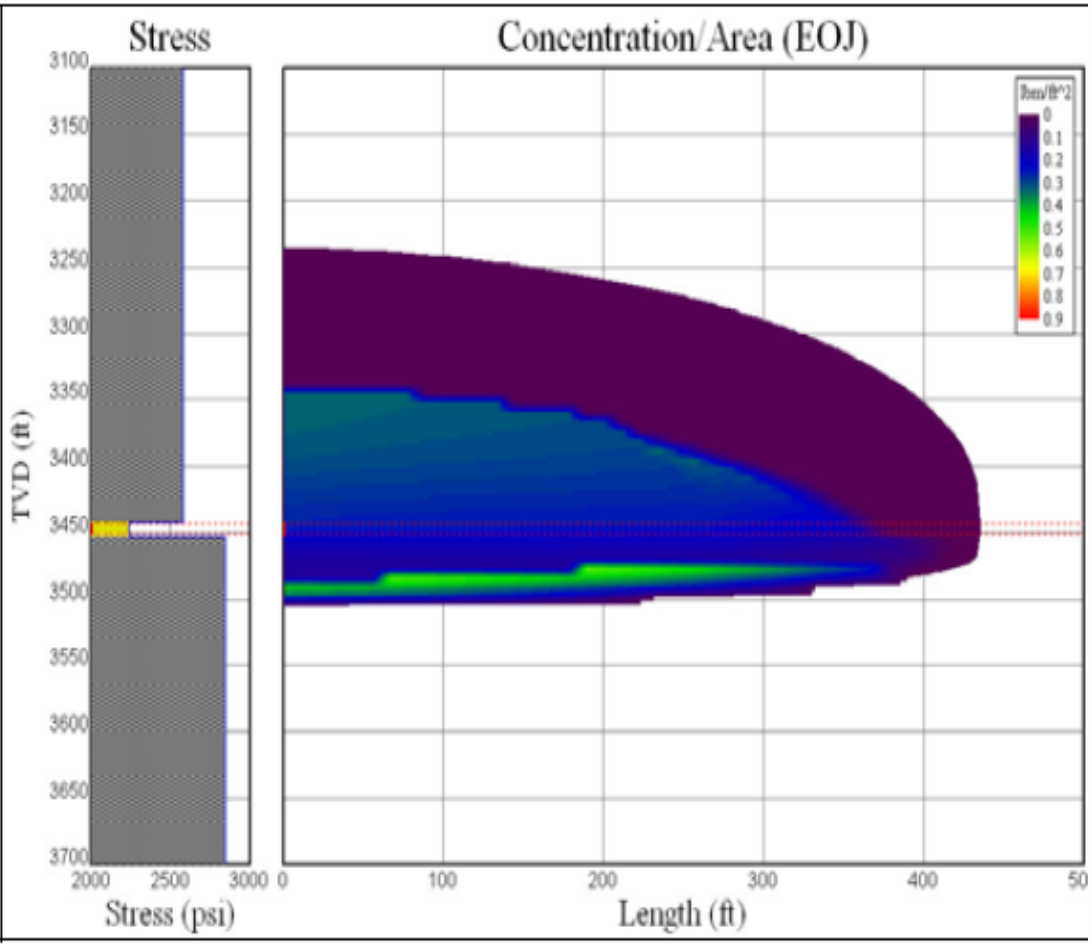
Stress Orientation Controls Fractures

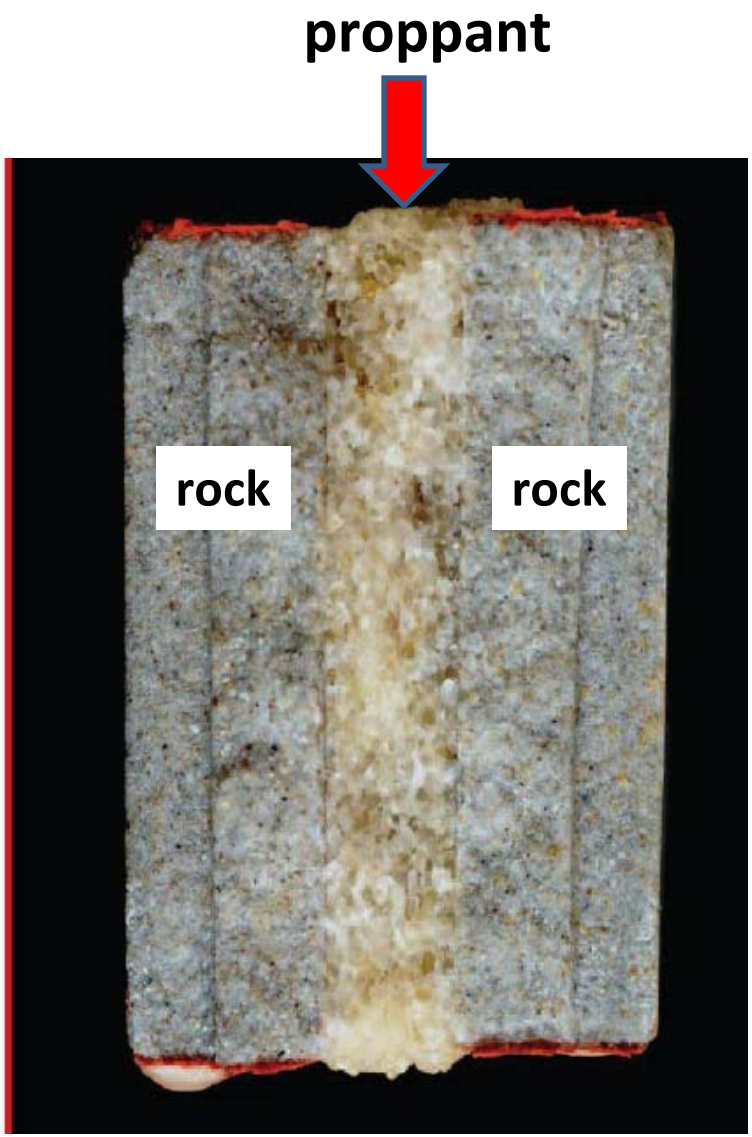


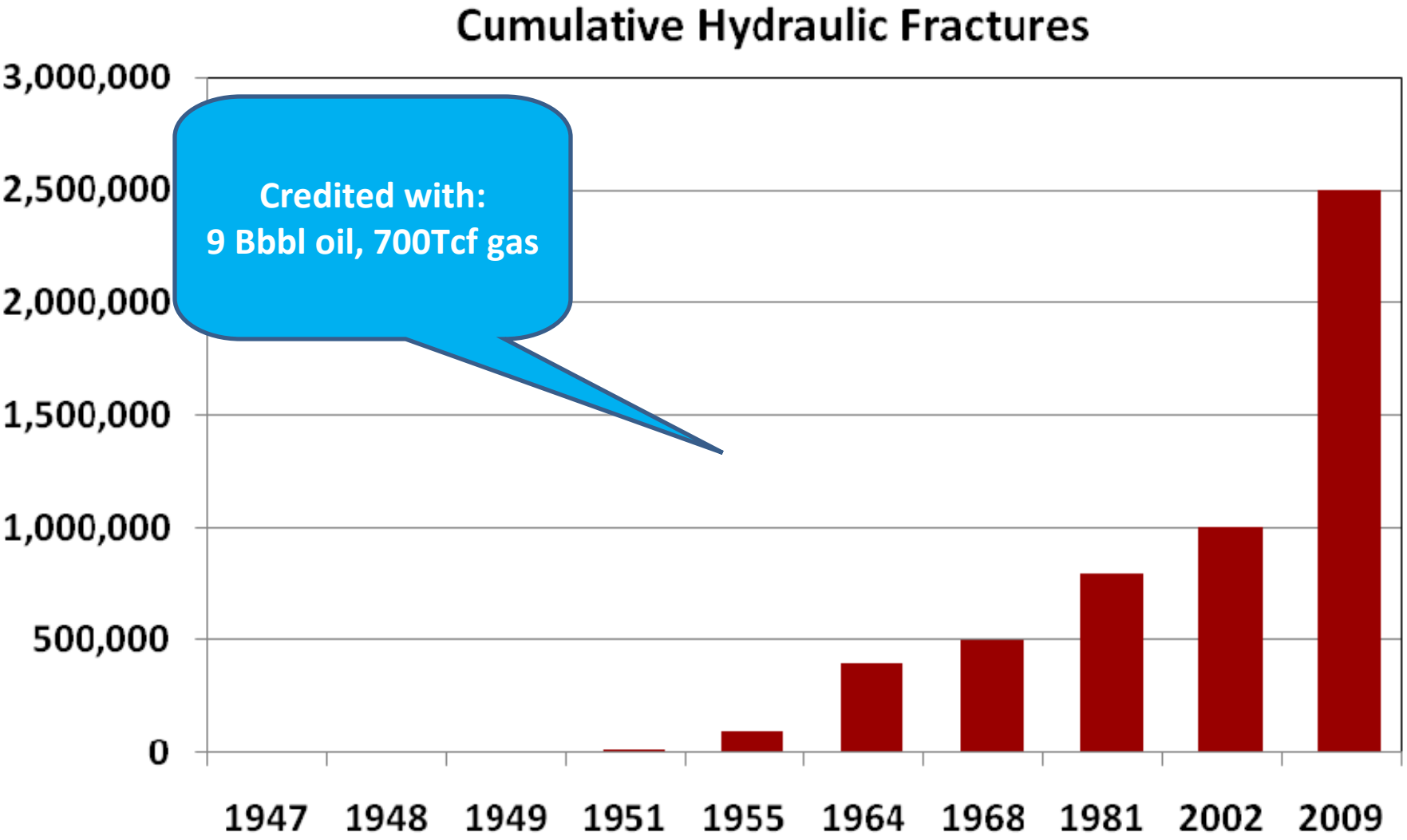


stages

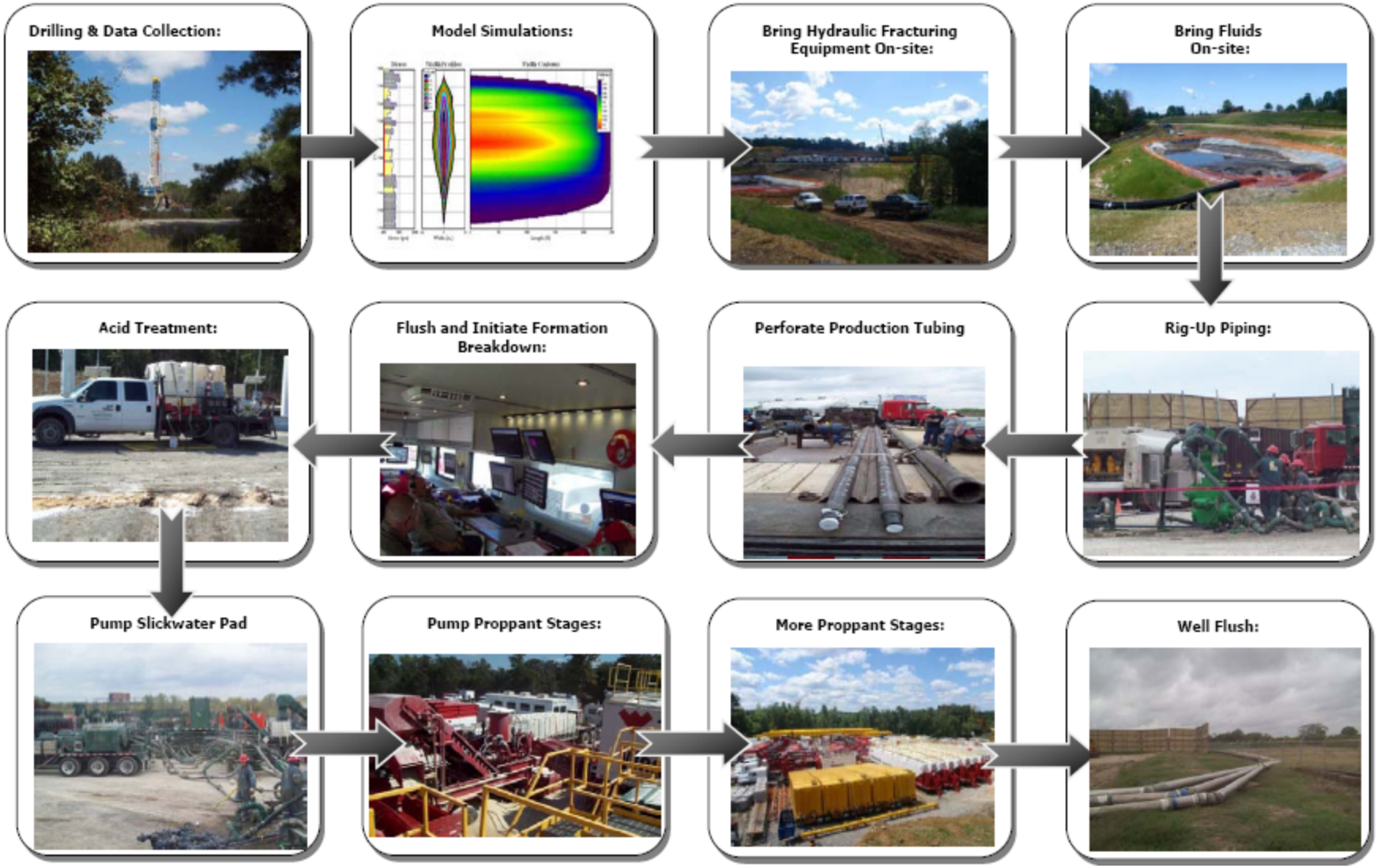
Frac designs and Proppant Placement



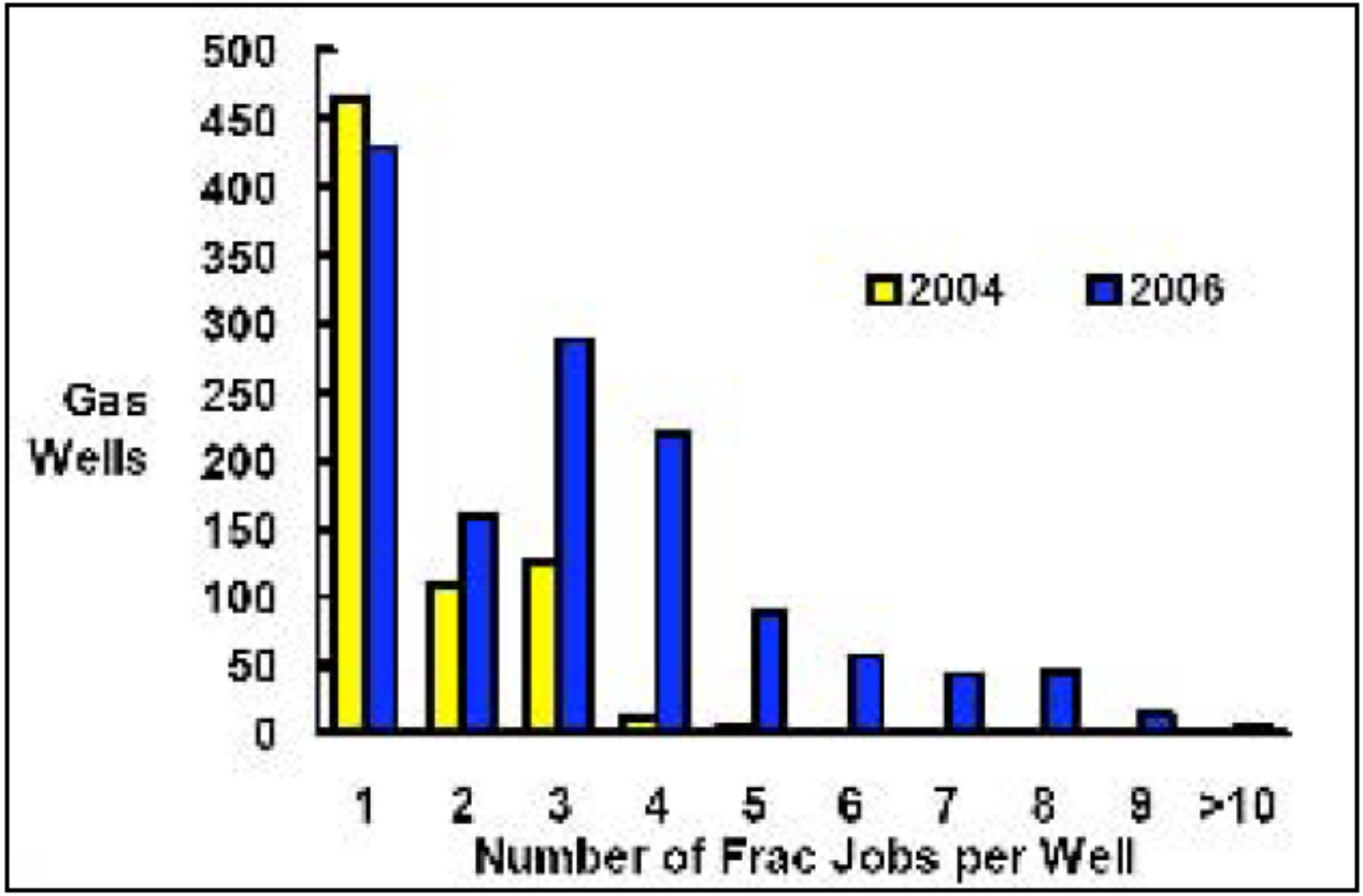



Cumulative Hydraulic Fractures
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
1947
1948
1949
1951
1955
1964
1968
1981
2002
2009
Credited with:
9 Bbbl oil, 700Tcf gas

Hydraulic Fracturing Operations

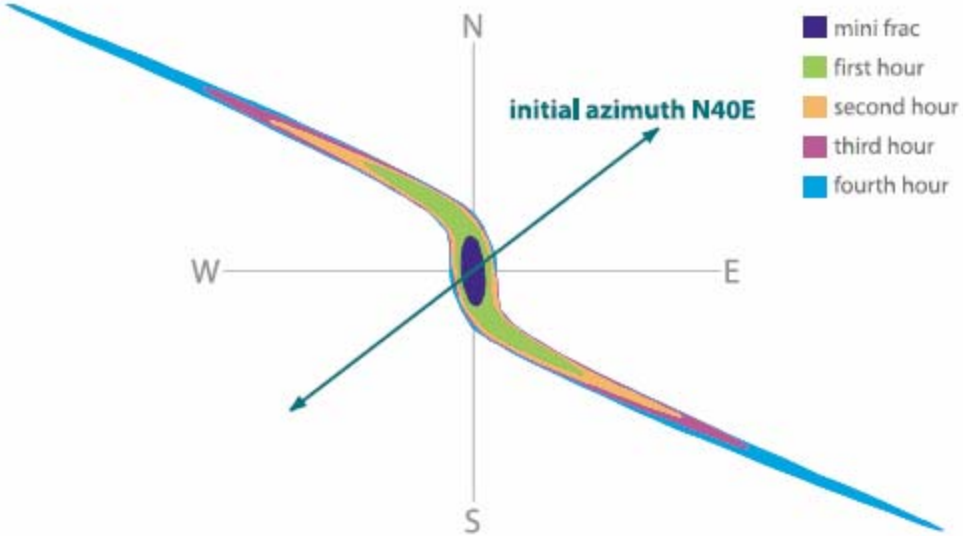


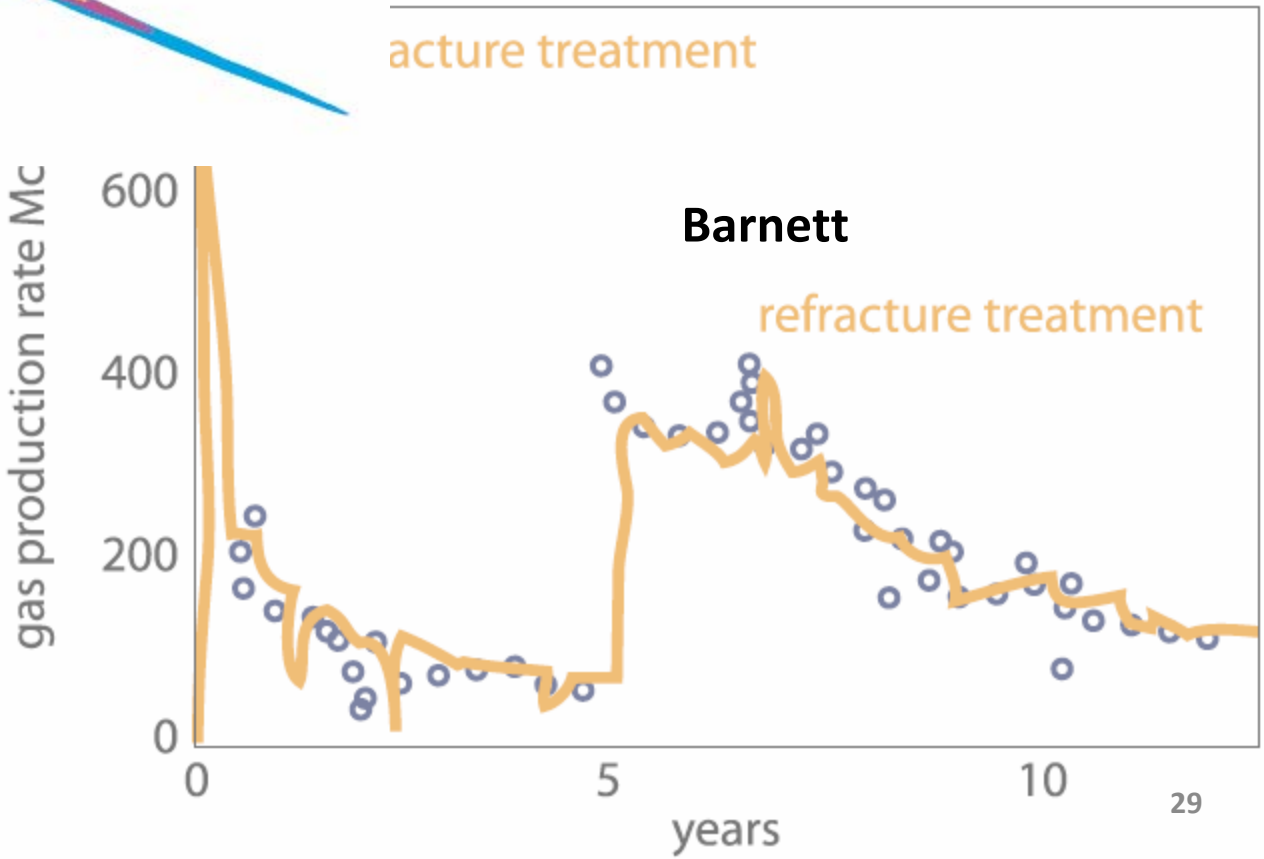
Number of Hydraulic Fracture Stimulations: Barnett Shale



More stages with time !

Refracking


N
W
E
S
initial azimuth N40E
mini frac
first hour
second hour
third hour
fourth hour


acture treatment
Barnett
refracture treatment
gas production rate Mc
600
400
200
0
0
5
10
years

Vertical wells: hydraulic fracture stimulation

Mechanical Aspect

Chemical Aspects

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THE HILL'S Energy & Environment Blog

State Department official says U.S. shale-gas boom has 'transformed global energy markets'

By Ben Geman - 08/24/10 03:54 PM ET

COMMENT | EMAIL | PRINT | SHARE

A senior State Department official said Tuesday that the U.S. boom in producing natural gas from shale rock formations could pave the way for other

Crystalline Silica: Quartz Polyethoxylate (2), Dazomet Polyethylene Glycol Mixtur Diatomaceus Earth Polysaccharide, Eth

assium Hydroxide, Ethoxlated Alcohol Prop-2-yn-1-01, Ethoxylated Alcohol Propan-2-01, Et

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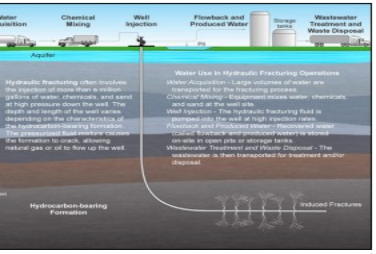

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RIC WESOFF: FEBRUARY 2, 2011

No Fracking Way: Gasland vs. Shale Gas

s hydraulic fracturing of the Marcellus Shale an energy transition strategy, or an environmental disaster in the making?

Natural gas has been getting some good press lately -- and some not-so-good press.

Image Credit: Ruhrfisch, Wikimedia Commons

Natural gas provides 21 percent of U.S. electricity right now and the figure will rise to **40 percent by 2035, according to consulting and construction giant Black & Veatch.**

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By Simone Wilson

Environment

Hydraulic 'Fracking' -- New Oil-Drilling Technique -- Could Create Jobs, Poison Tap Water in California

By Simone Wilson, Thu., Feb. 10 2011 @ 11:10AM

Categories: Environment, Health, Oil

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Fracturing to get close look

But EPA administrator says it's no guarantee

By JENNIFER A. DLOUHY Copyright 2011 Houston Chronicle

Feb. 2, 2011, 7:32PM

WASHINGT close to laun probe doesn' regulate the said Wednes

Jackson said congressiona other states

"We expect, our study fini

The EPA pro technique being used to unlock natural gas from shale nationwide. The process involves injecting mixtures of water, sand and chemicals deep underground and under high pressure to break up

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Contact: Ramona Nye 512-463-4817

COMMISSIONERS APPROVE OF DEVON WATER RECYCLING PROJECT FOR THE BARNETT SHALE

AUSTIN — As part of the Railroad Commission's continuing efforts to encourage industry to conserve and minimize the use of fresh water in a region centered around Fort Worth, Commissioners recently approved a water recycling project proposed by Devon Energy—the largest natural gas producer in the Barnett Shale.

MARKET SECTORS: OIL AND GAS

to treat and reuse frac
o release trapped natural

GE introduces solution to treating shale gas frac water

nd now uses recycled frac
ater distillation recycling
nd produce 588,888

GE has developed a new mobile evaporator to help natural gas producers recycle untreated water from hydraulic fracturing process

overseen by the Railroad

ect in Johnson County. The
is run through a series of
ed from the shale with
Shale formation. The water
cent high concentrate and
acility.

BY: Andrea Marino | Thu Sep 30, 2010

Like | Sign Up to see what your friends like.

TAGS: Appalachian Basin, frac flowback, frac-water recycling, GE, hydraulic fracturing process, Marcellus Shale reservoirs, mobile evaporator, natural gas producers, production rate of oil and gas wells, recycling untreated waters, treating severely impaired waters, wastewater

Protected Mode: On | 100%

Disclosing Frac fluid Contents

OpenFRAC

Family of fluid additive systems

APPLICATIONS

- Hydraulic fracturing operations, including those in stiff, naturally fractured, low-permeability formations such as shale and tight gas sands

BENEFITS

- Ability to recycle and reuse water
- Drag reduction, improving efficiency and reducing costs
- Organic matter treatment in water

FEATURES

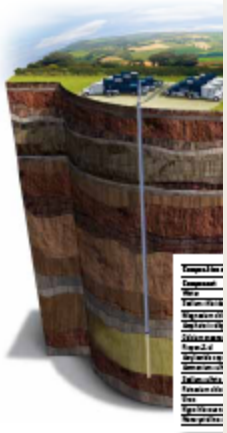
- Fully disclosed fluid additives
- Effective hydraulic fracturing formulations
- Solid performance using a wide range of produced or recycled waters
- Three separate additive systems for crosslink gel, linear gel, and slickwater applications
- Optional components for scale inhibition, load-water recovery, and formation stabilization

Resulting from an extensive development and testing program, the OpenFRAC® family of hydraulic fracturing additive systems assures high performance. Operators receive full disclosure of additive components, a disclosure level similar to that used in the food industry.

Fluid options

Several formulations of OpenFRAC systems are available, addressing:

- crosslink gel
- linear gel
- slickwater.



As part of the Schlumberger hydraulic fracturing portfolio, these assure high performance for a range of applications.

Fracturing Fluid Additives

Additive Type	Main Compound(s)	Purpose	Common Use of Main Compound
Diluted Acid (15%)	Hydrochloric acid or muriatic acid	Help dissolve minerals and initiate cracks in the rock	Swimming pool chemical and cleaner
Biocide	Glutaraldehyde	Eliminates bacteria in the water that produce corrosive byproducts	Disinfectant; sterilize medical and dental equipment
Breaker	Ammonium persulfate	Allows a delayed break down of the gel polymer chains	Bleaching agent in detergent and hair cosmetics, manufacture of household plastics
Corrosion Inhibitor	N,n-dimethyl formamide	Prevents the corrosion of the pipe	Used in pharmaceuticals, acrylic fibers, plastics
Crosslinker	Borate salts	Maintains fluid viscosity as temperature increases	Laundry detergents, hand soaps, and cosmetics
Friction Reducer	Polyacrylamide	Minimizes friction between the fluid and the pipe	Water treatment, soil conditioner
	Mineral oil		make-up remover, laxatives, and candy
Gel	Guar gum or hydroxyethyl cellulose	Thickens the water in order to suspend the sand	Cosmetics, toothpaste, sauces, baked goods, ice cream
Iron Control	Citric acid	Prevents precipitation of metal oxides	Food additive, flavoring in food and beverages; Lemon Juice ~7% Citric Acid
KCl	Potassium chloride	Creates a brine carrier fluid	Low sodium table salt substitute
Oxygen Scavenger	Ammonium bisulfite	Removes oxygen from the water to protect the pipe from corrosion	Cosmetics, food and beverage processing, water treatment
pH Adjusting Agent	Sodium or potassium carbonate	Maintains the effectiveness of other components, such as crosslinkers	Washing soda, detergents, soap, water softener, glass and ceramics
Proppant	Silica, quartz sand	Allows the fractures to remain open so the gas can escape	Drinking water filtration, play sand, concrete, brick mortar
Scale Inhibitor	Ethylene glycol	Prevents scale deposits in the pipe	Automotive antifreeze, household cleansers, and deicing agent
Surfactant	Isopropanol	Used to increase the viscosity of the fracture fluid	Glass cleaner, antiperspirant, and hair color

Note: The specific compounds used in a given fracturing operation will vary depending on company preference, source water quality and site-specific characteristics of the target formation. The compounds shown above are representative of the major compounds used in hydraulic fracturing of gas shales.

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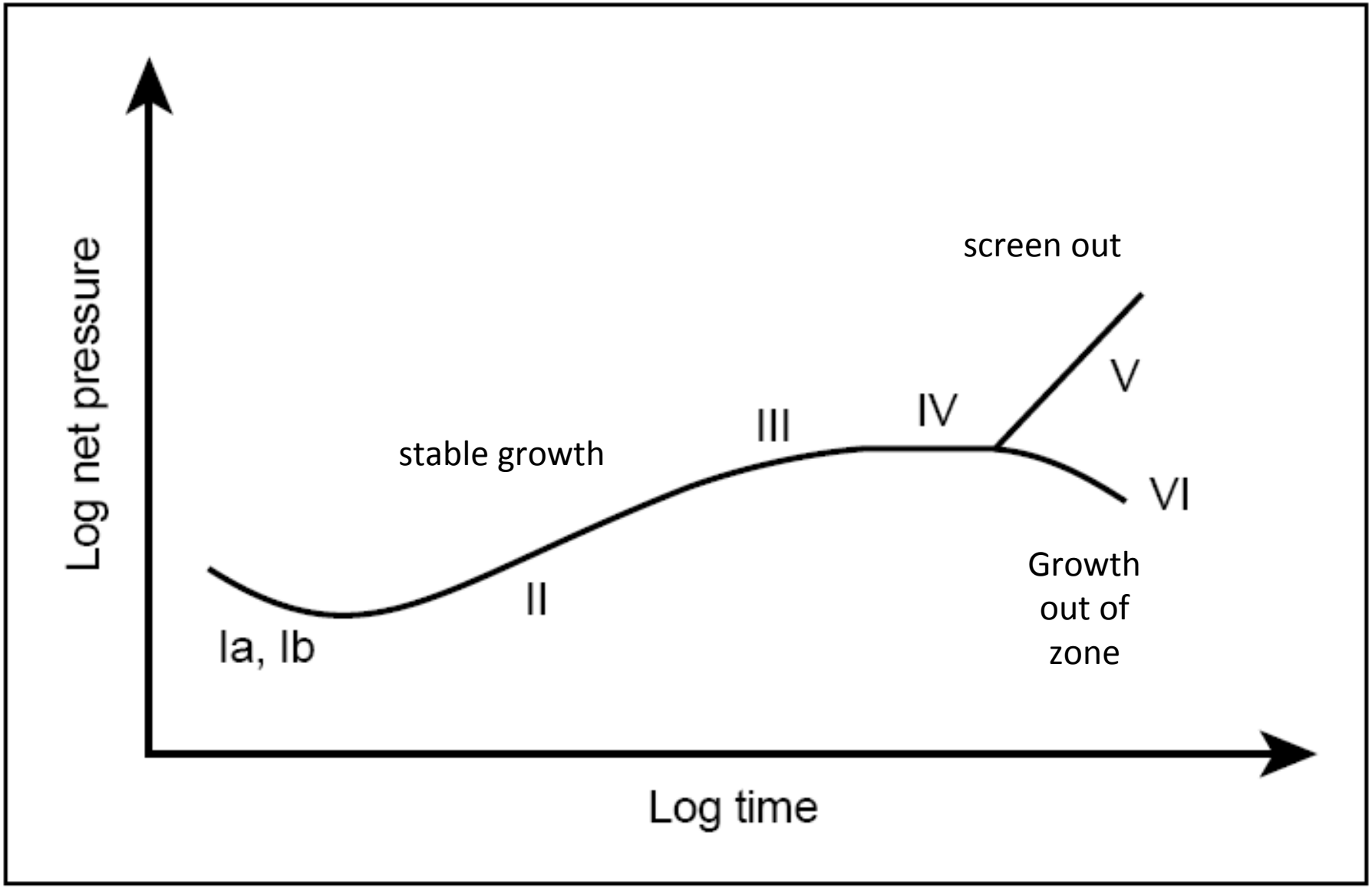
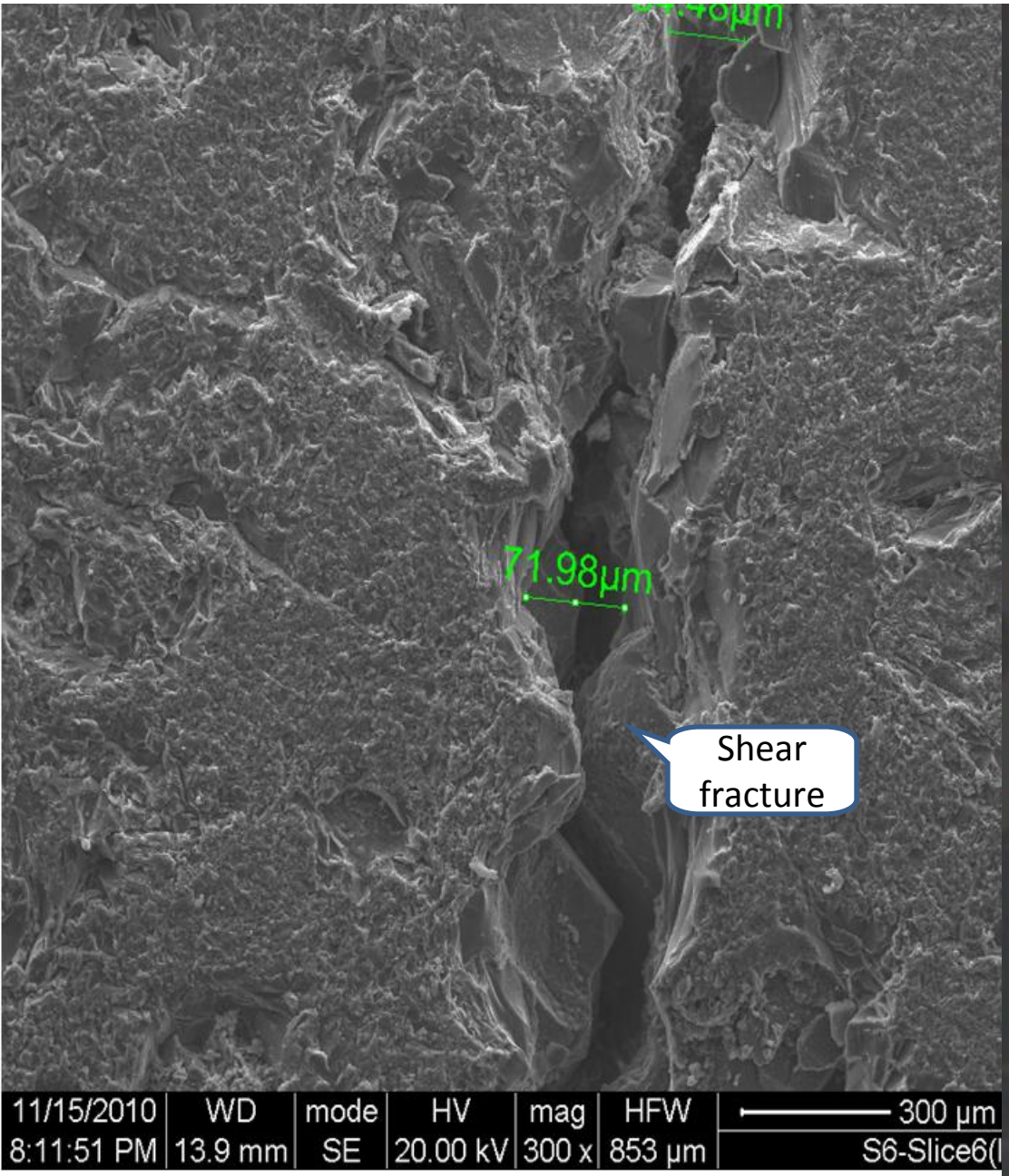
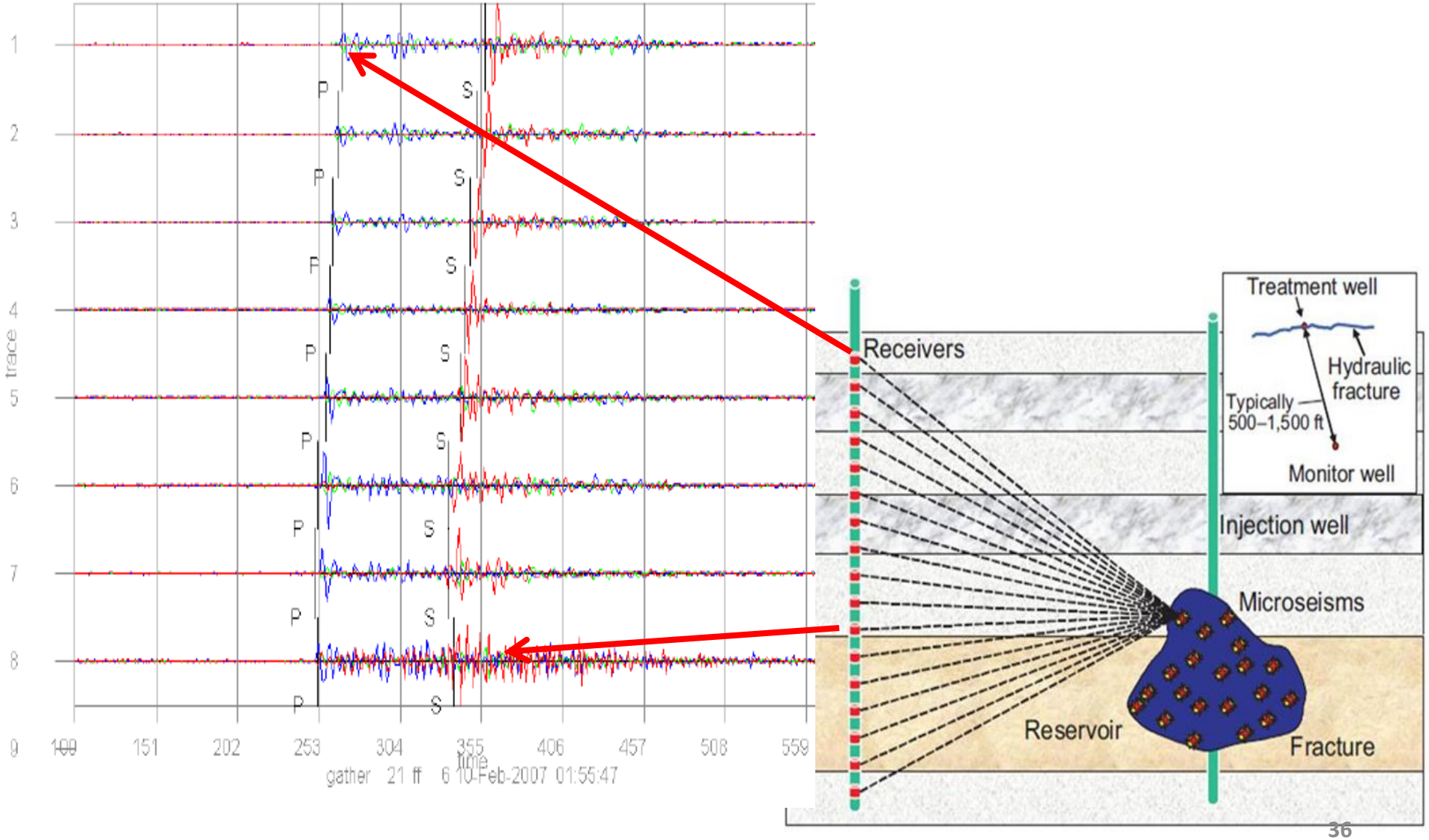
What is a Fracture doing?.....Pressure Monitoring



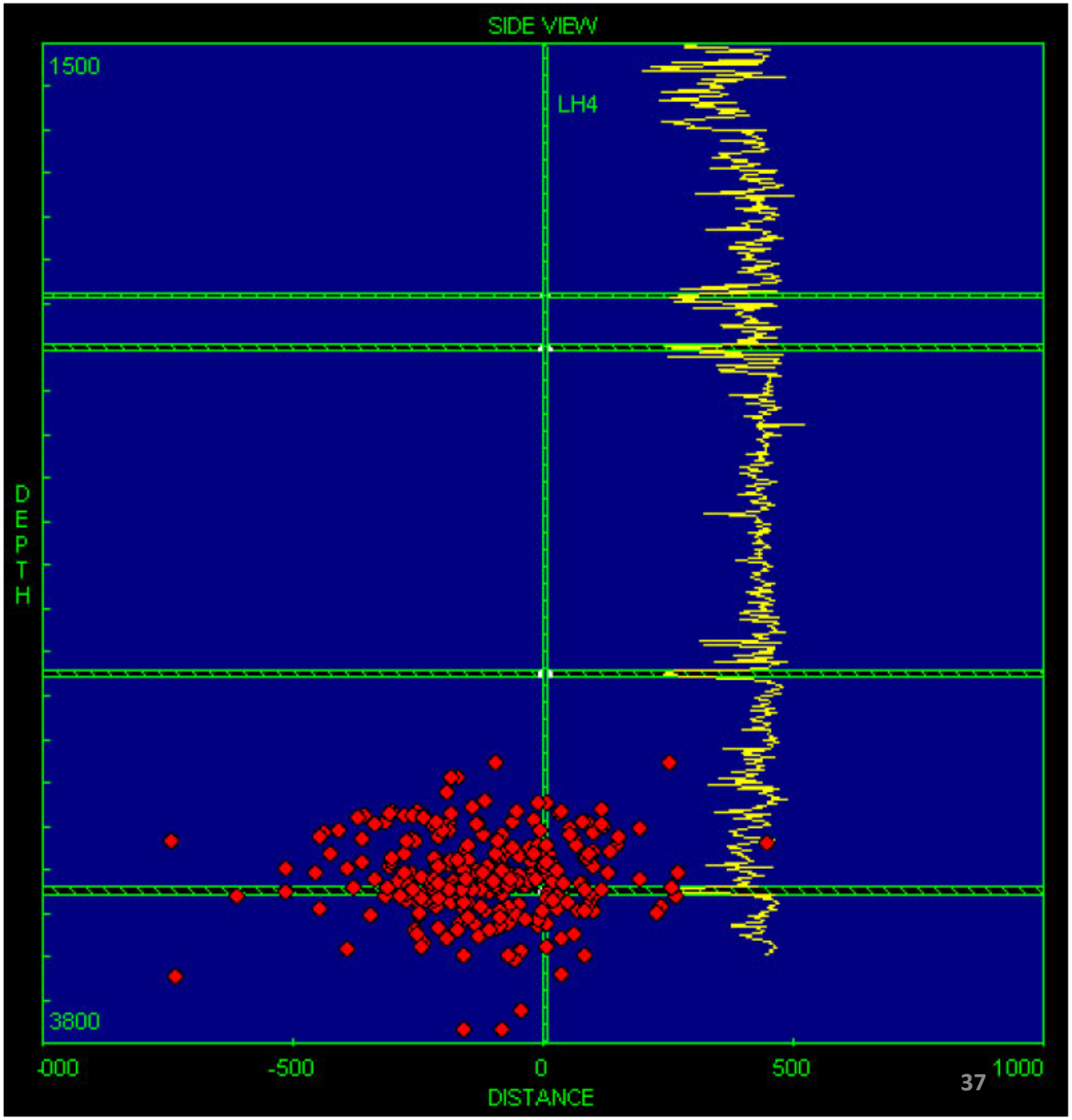
Mine Back Fractures in the Lab and the Field



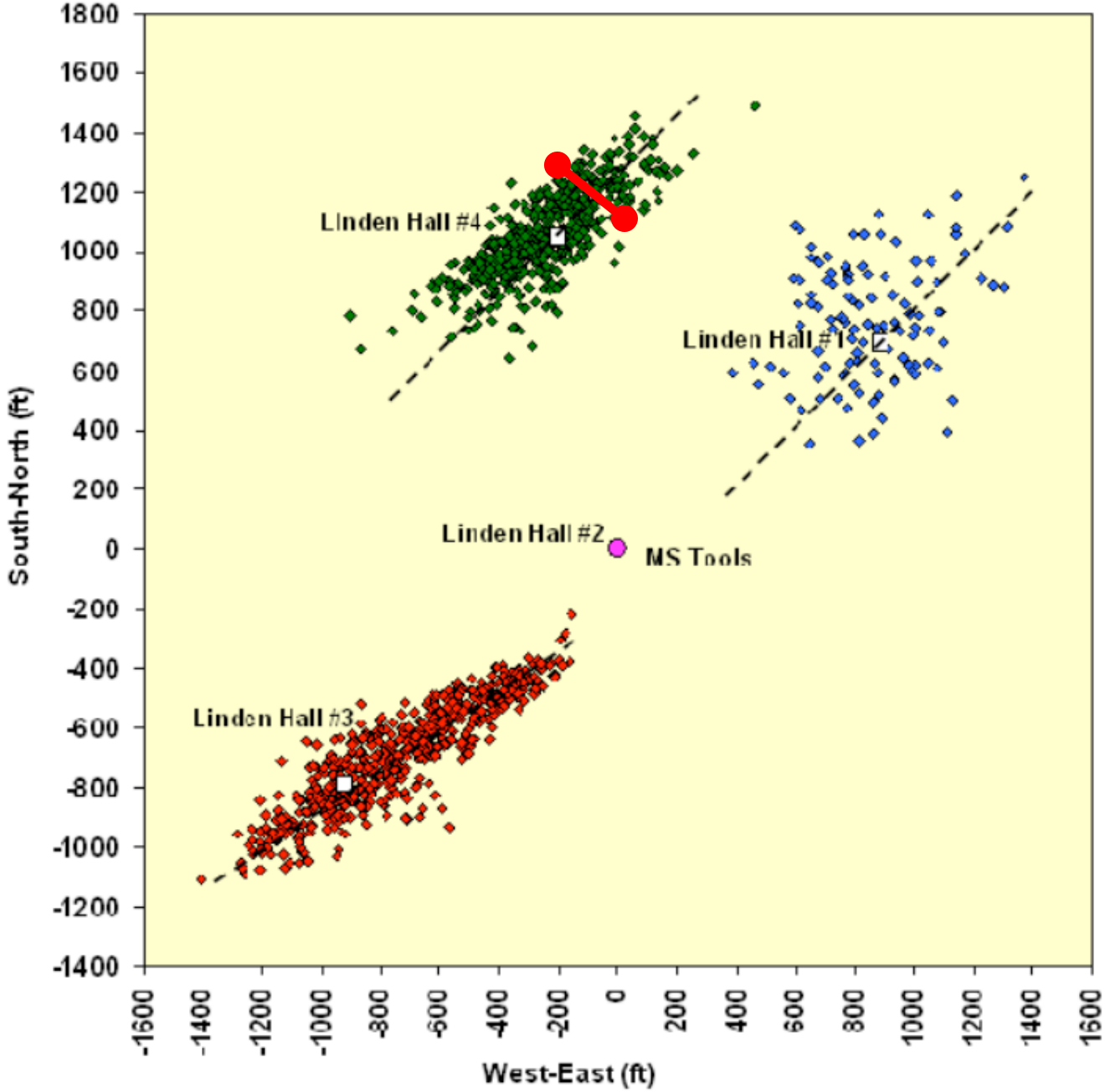
Microseismic Monitoring



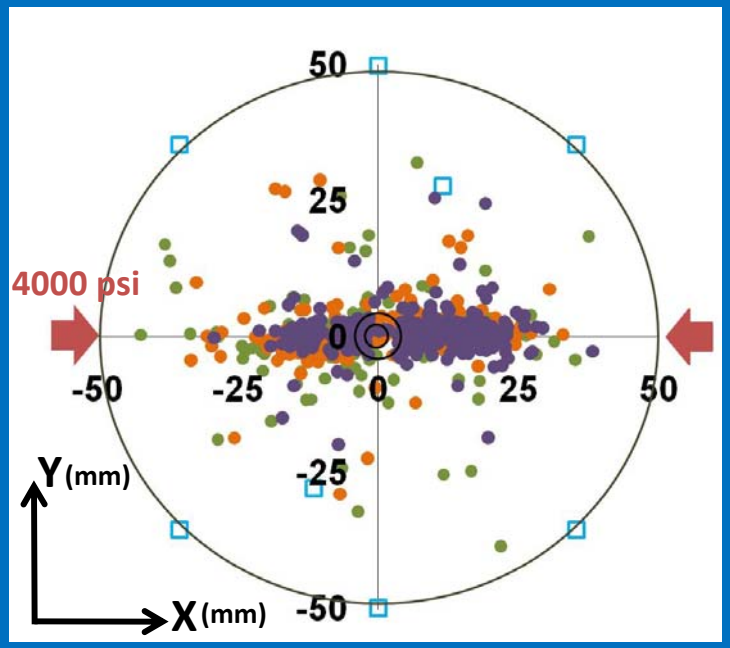
Microseismics Associated with Hydraulic Fracturing



Map View

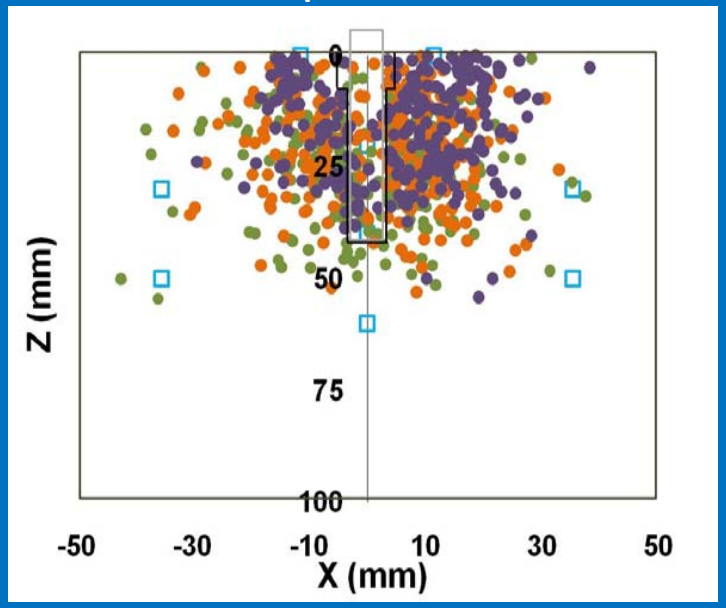

Linden Hall #4
Linden Hall #1
Linden Hall #2
MS Tools
Linden Hall #3
South-North (ft)
West-East (ft)
1800
1600
1400
1200
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
-1200
-1400
-1600
-1400
-1200
-1000
-800
-600
-400
-200
0
200
400
600
800
1000
1200
1400
1600

Laboratory Studies

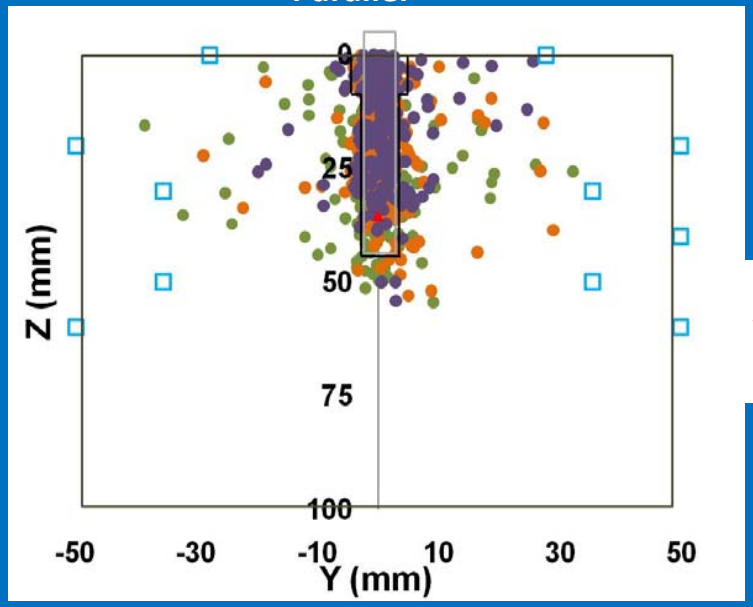


- Fracture aligned with applied stress
- Planar perpendicular to propagation direction
- Zone of microfractures around the main fracture

Perpendicular



Parallel

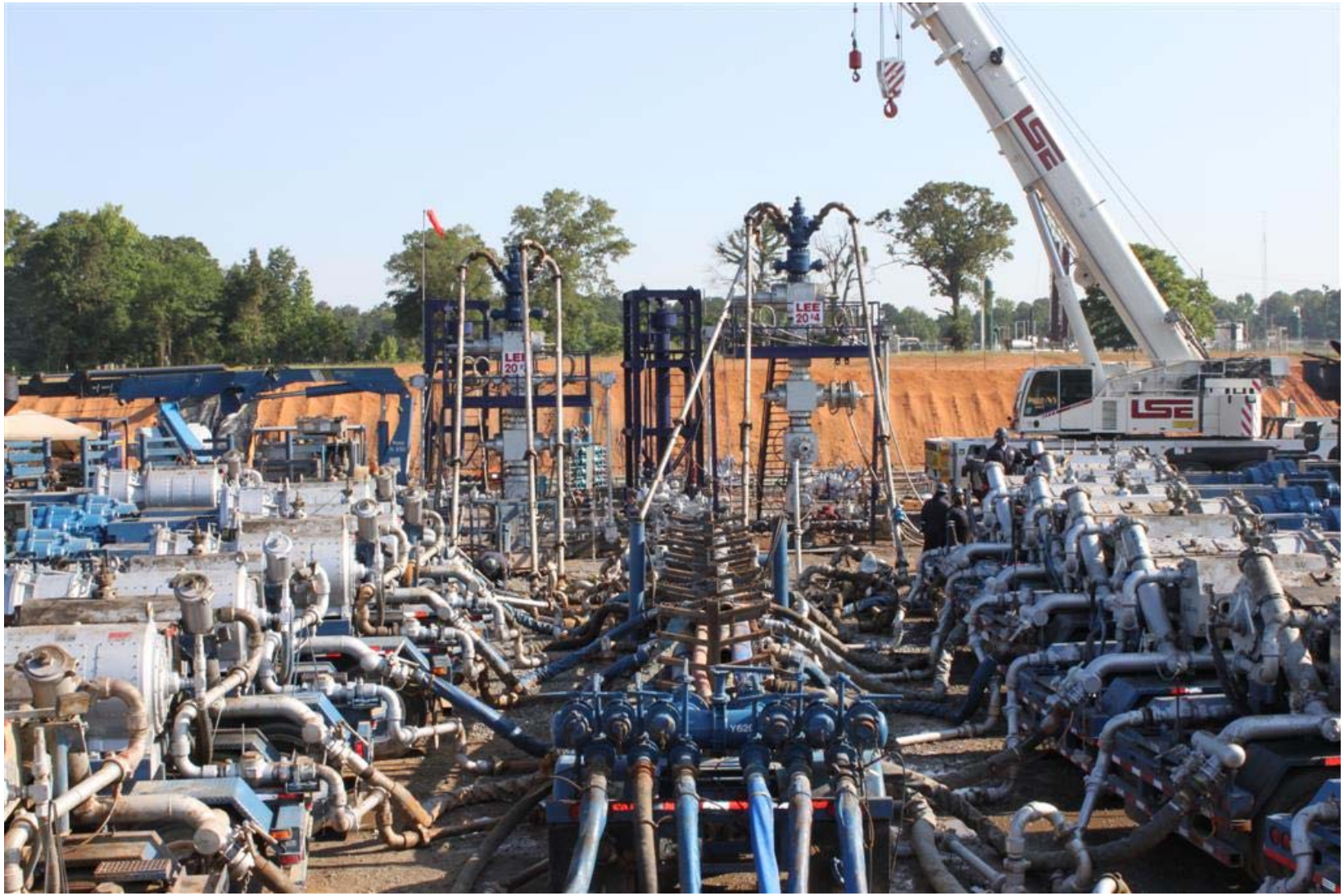


Time

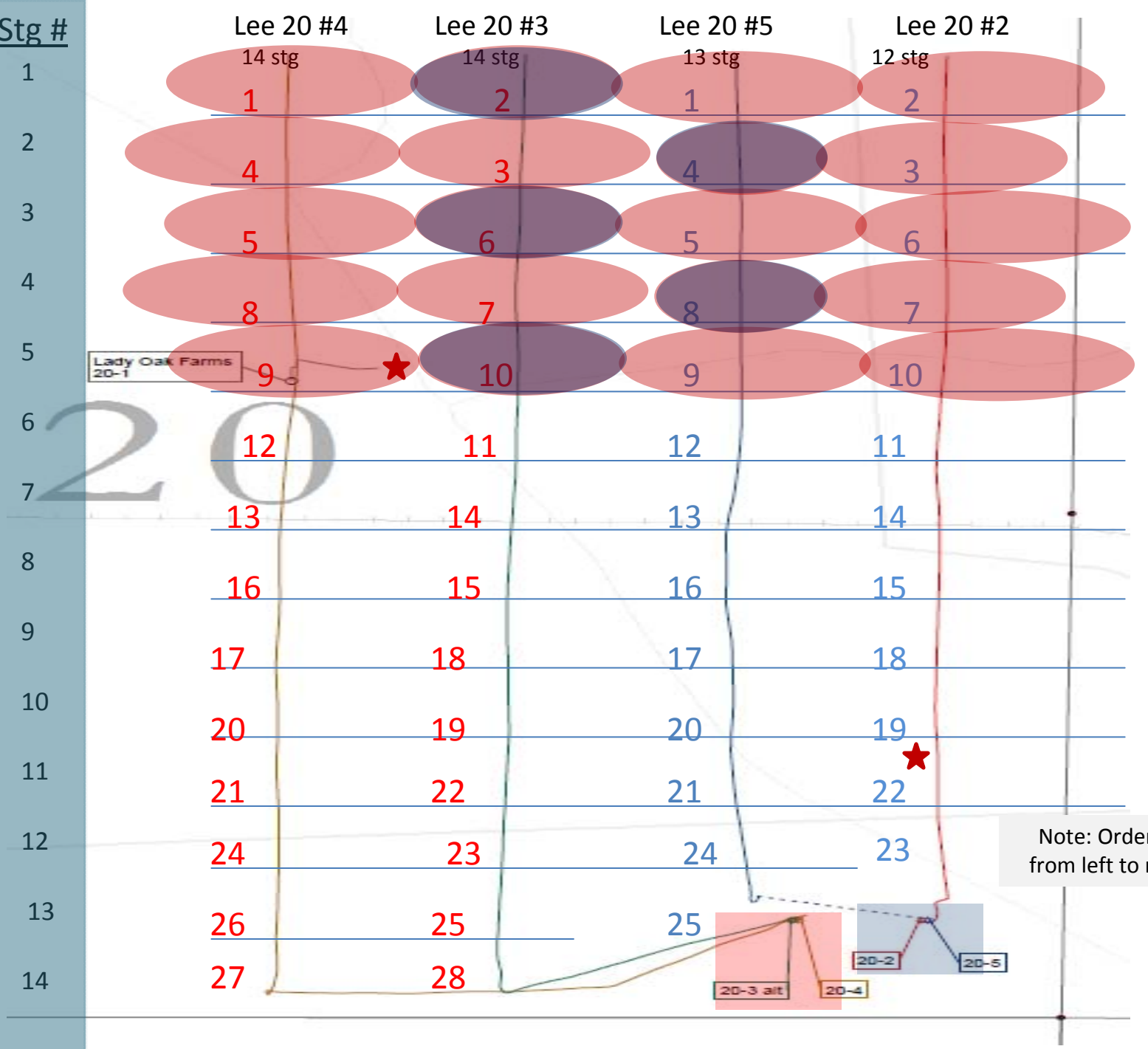
Early
Intermediate
Late

Perforation
Sensor

Simulfrac….two wellheads are connected

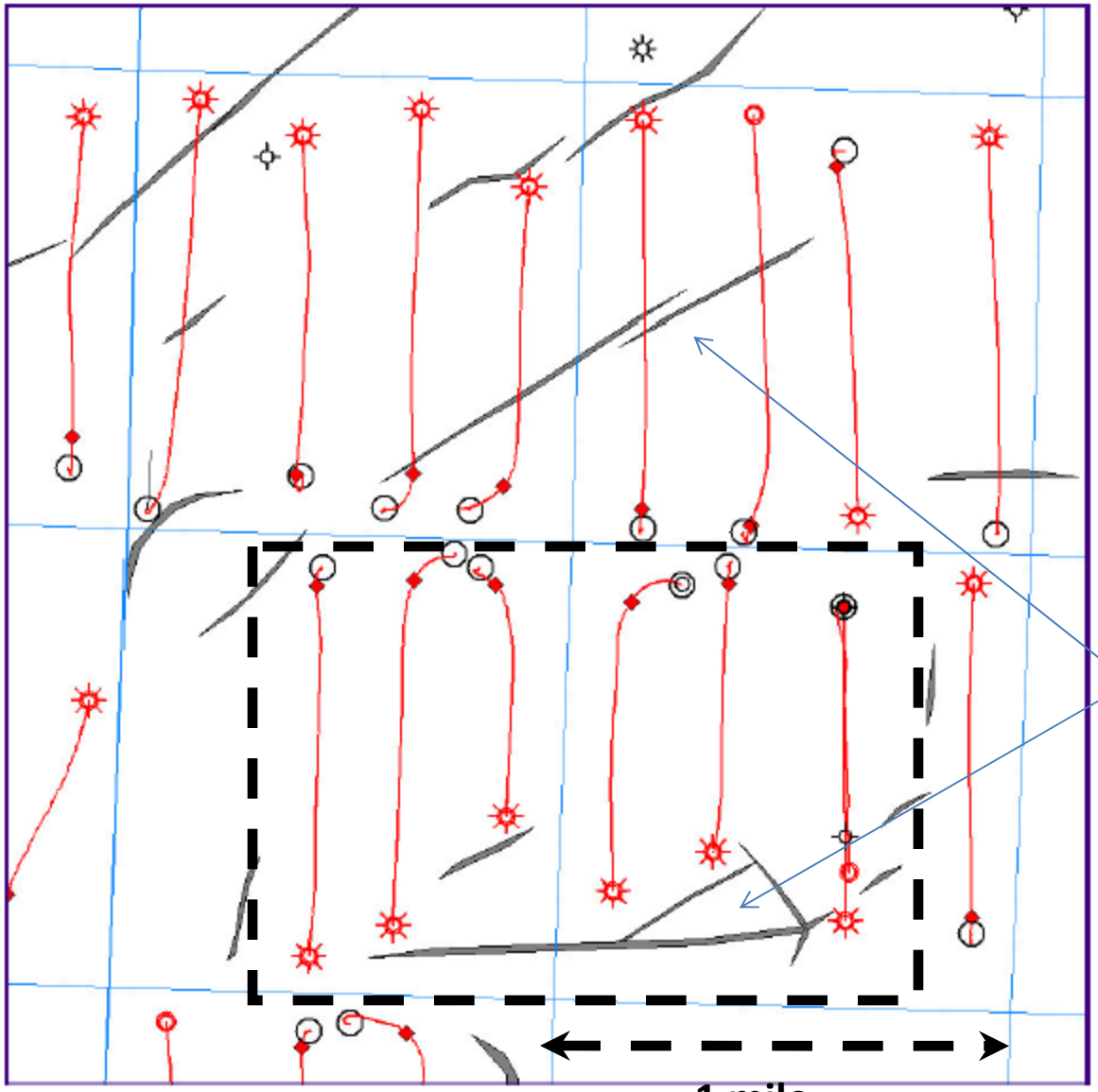


Lee Superpad Frac Sequence



Note: Order of surface location from left to right: #3, #4, #2 & #5

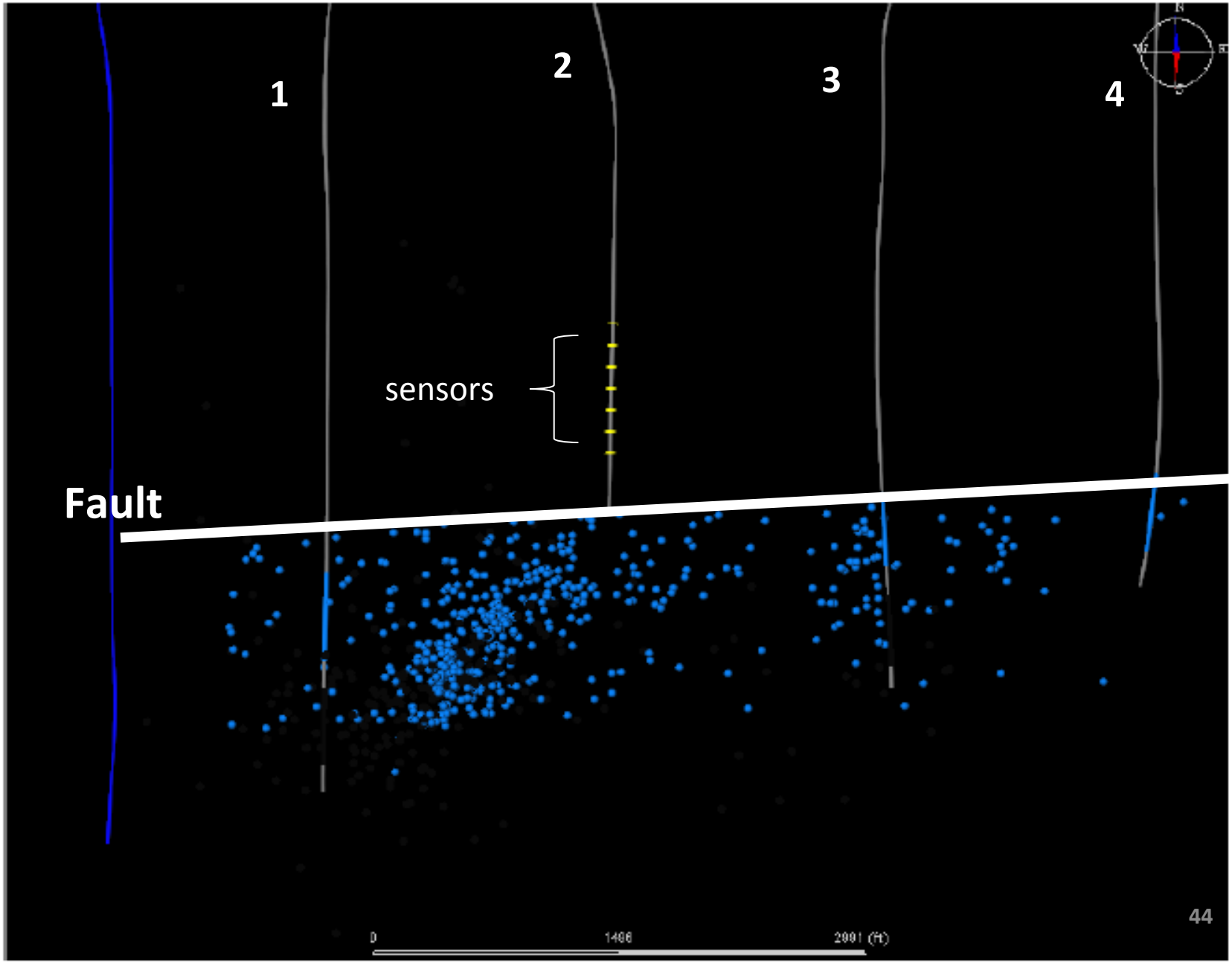
Continental Resources Complicated Multifrac Experiments in the Woodford



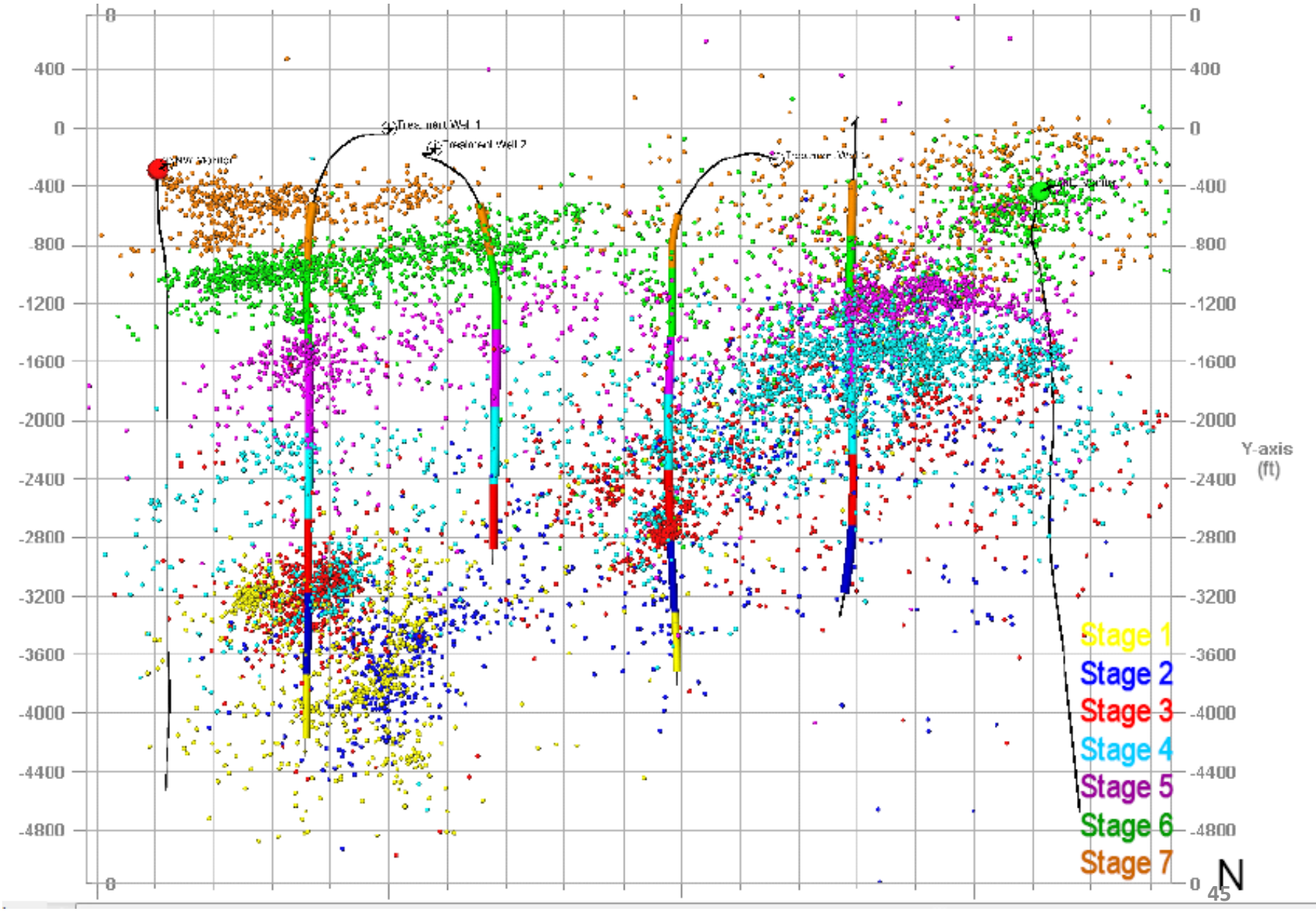
Z=6000-7700'
th= 160-180'

faults

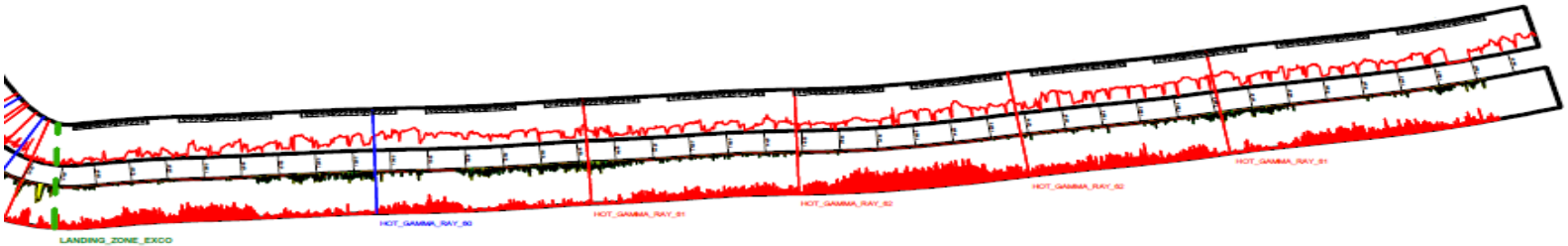
Initial stimulation 1,2 & 4 recorded at 2

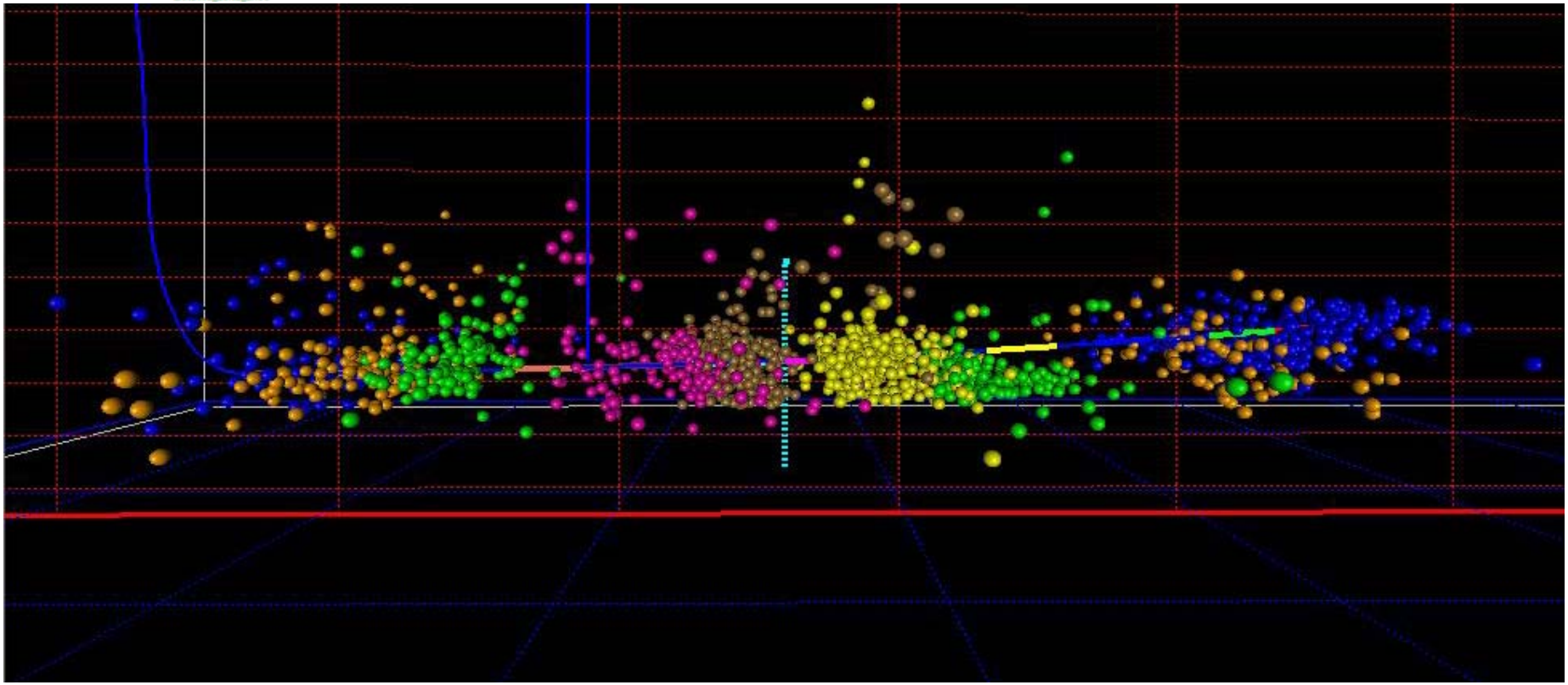


Time Evolution of Stimulation

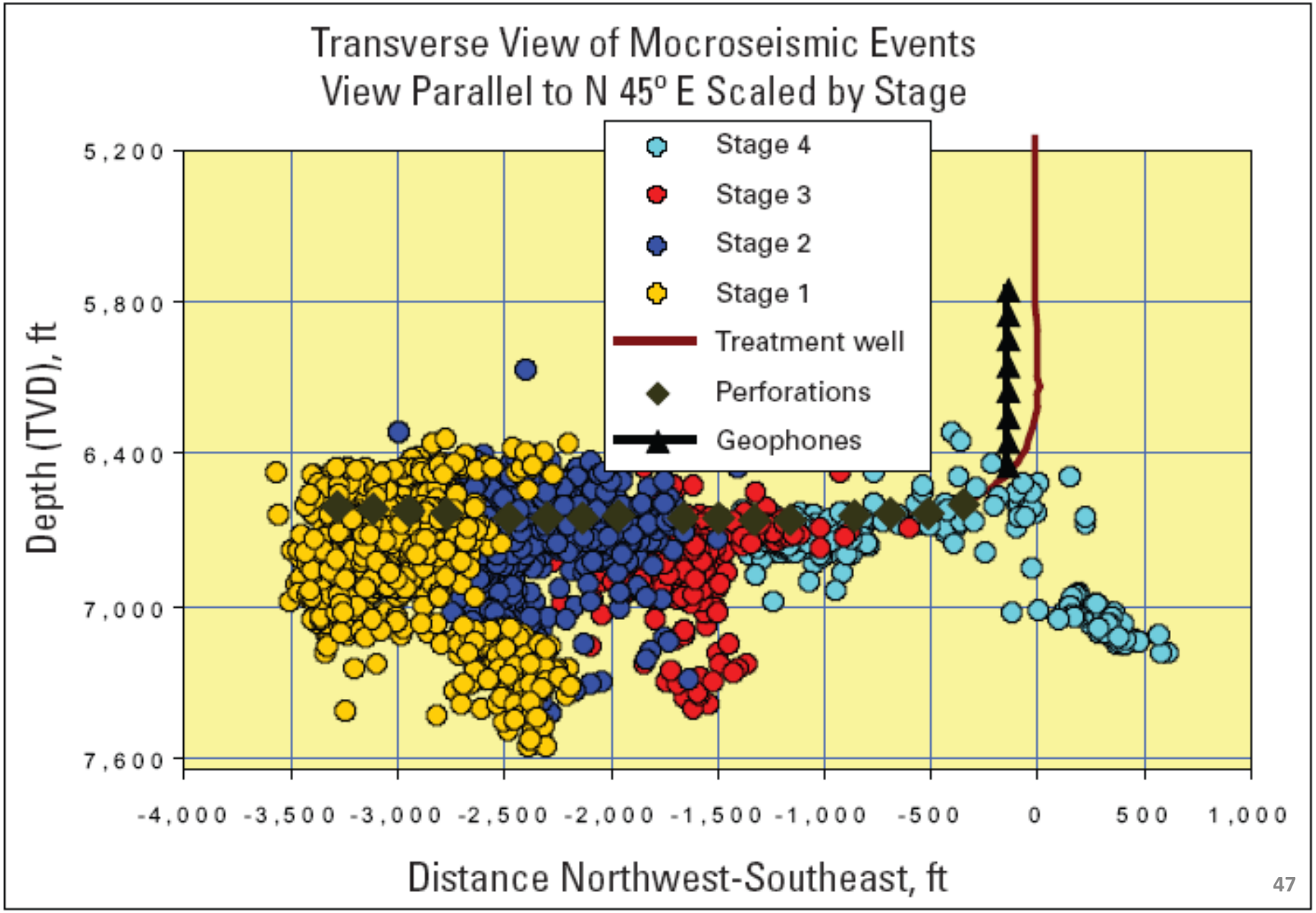


Evaluation of Frac Stages

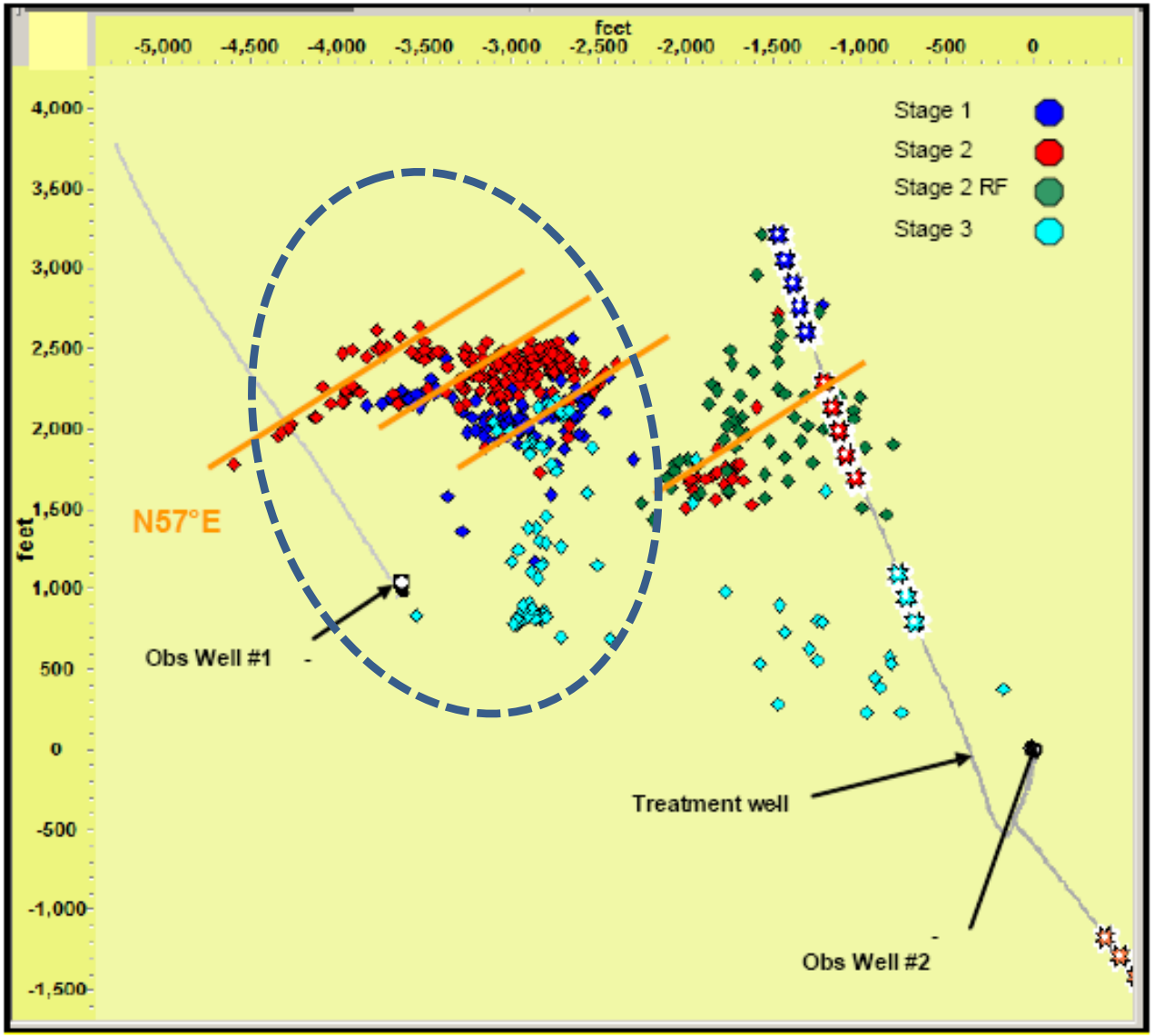




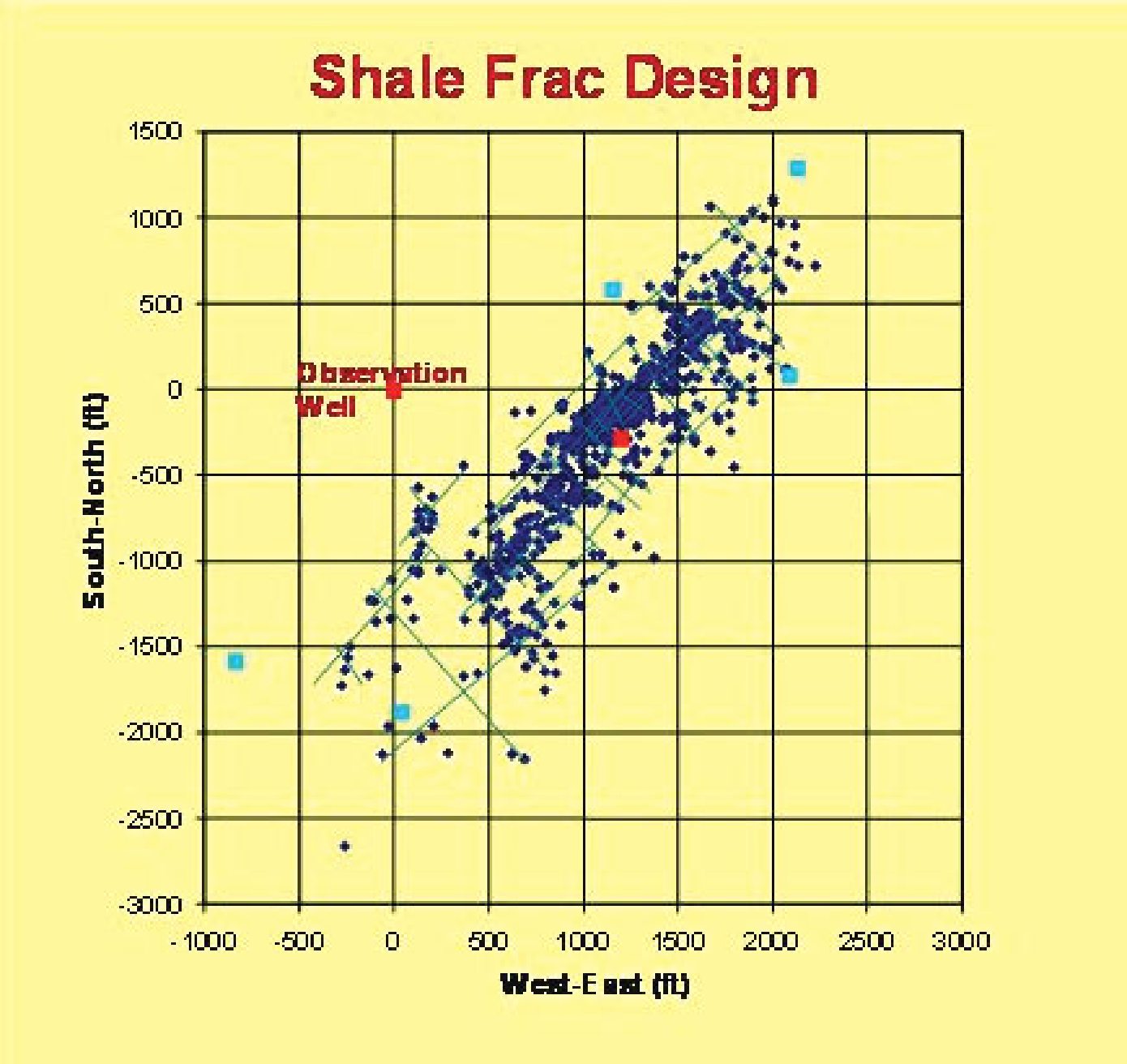
Barnett Well fracking down into the Ellenberger



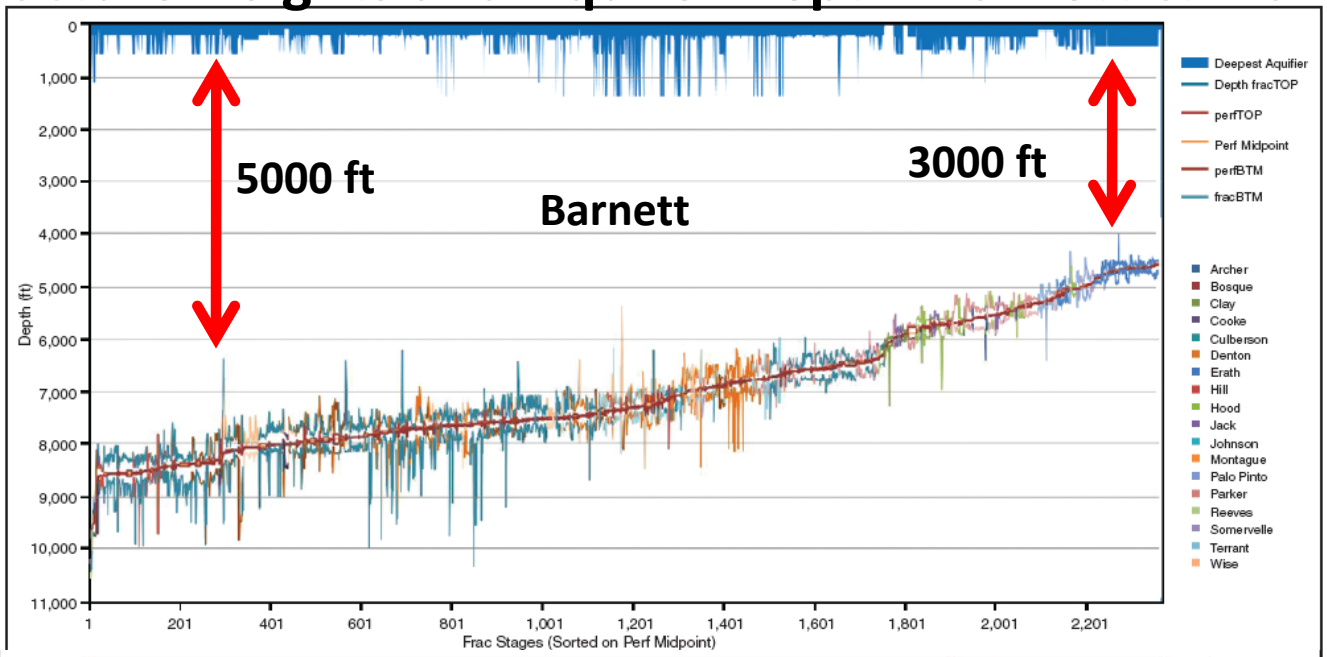
Note activity far away from treatment well but close to observation well.

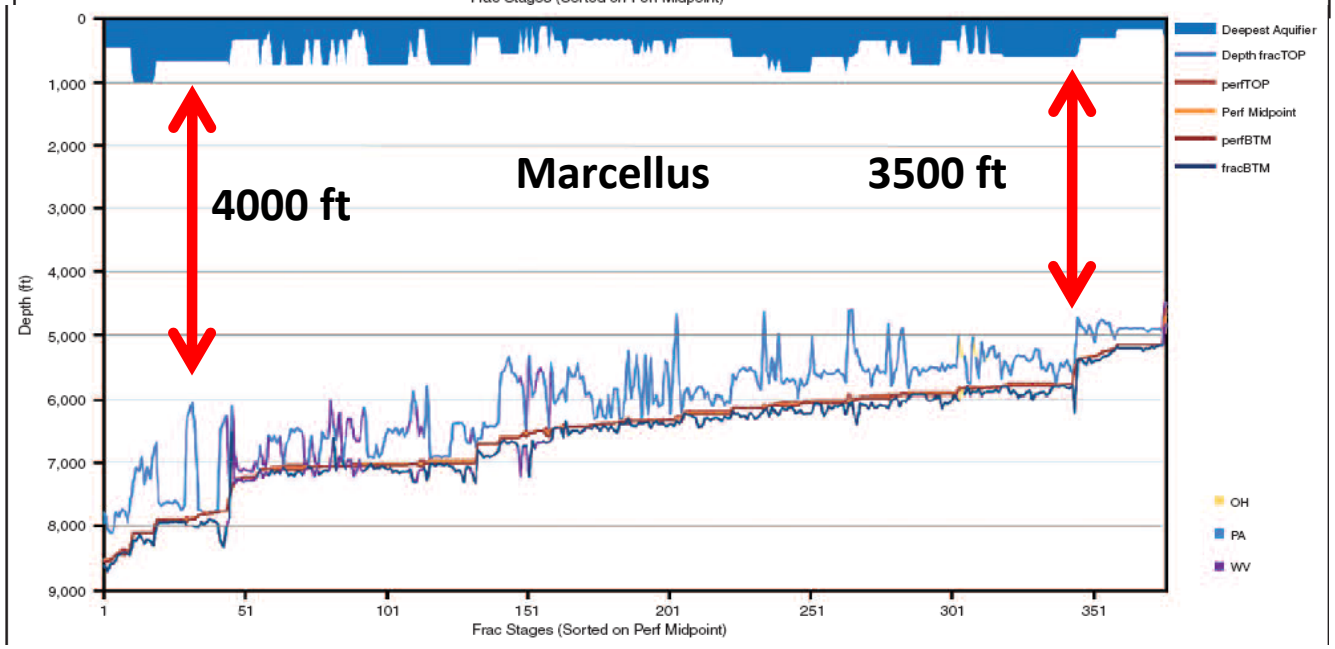


Microseismic Mapping of Stimulated Reservoir Volume



Hydraulic Fracture Heights and Aquifer Depth: Barnett & Marcellus





Hydraulic fractures do not communicate with aquifers!

OU-IC³

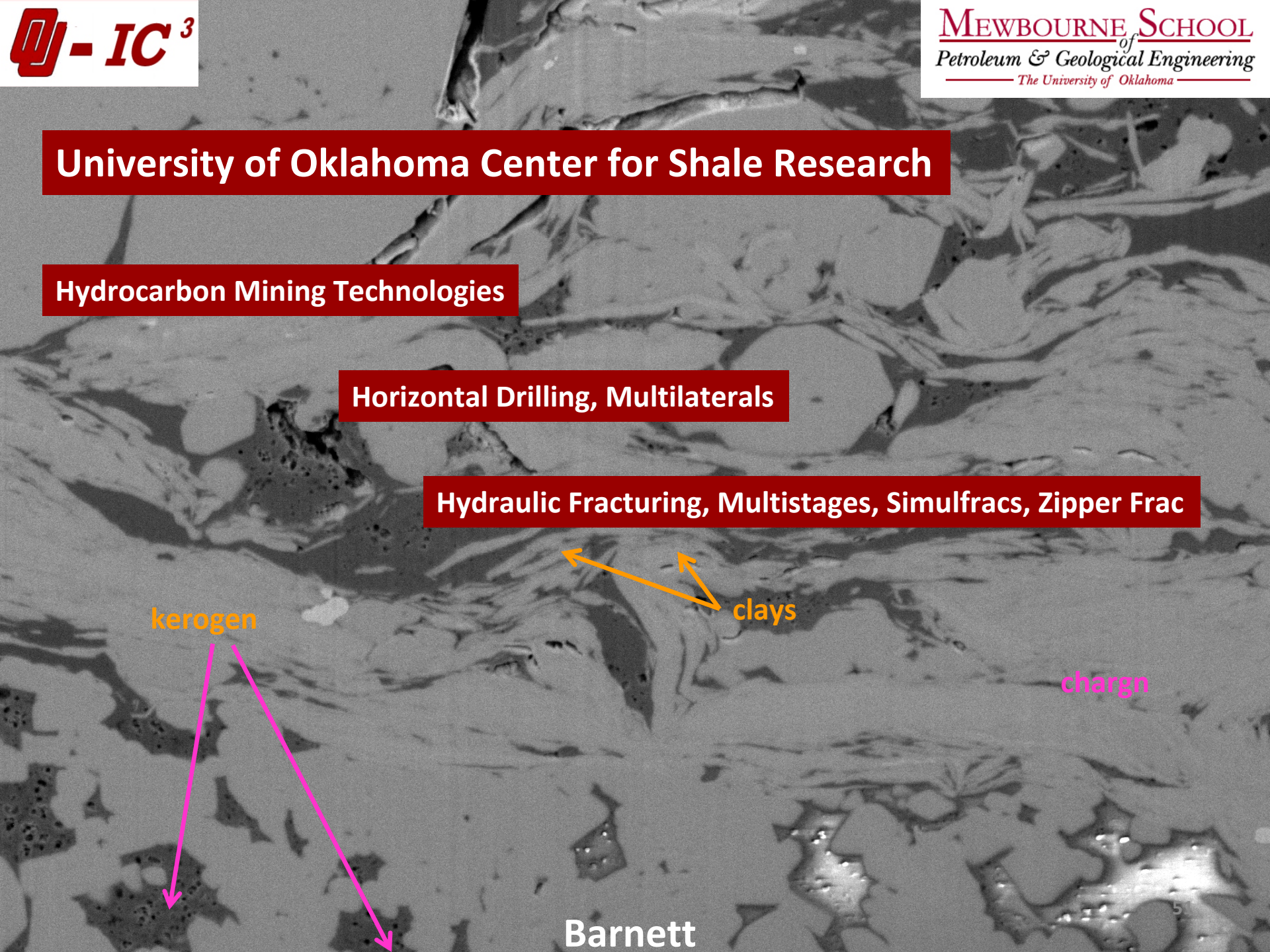
Mewbourne School of Petroleum & Geological Engineering
The University of Oklahoma

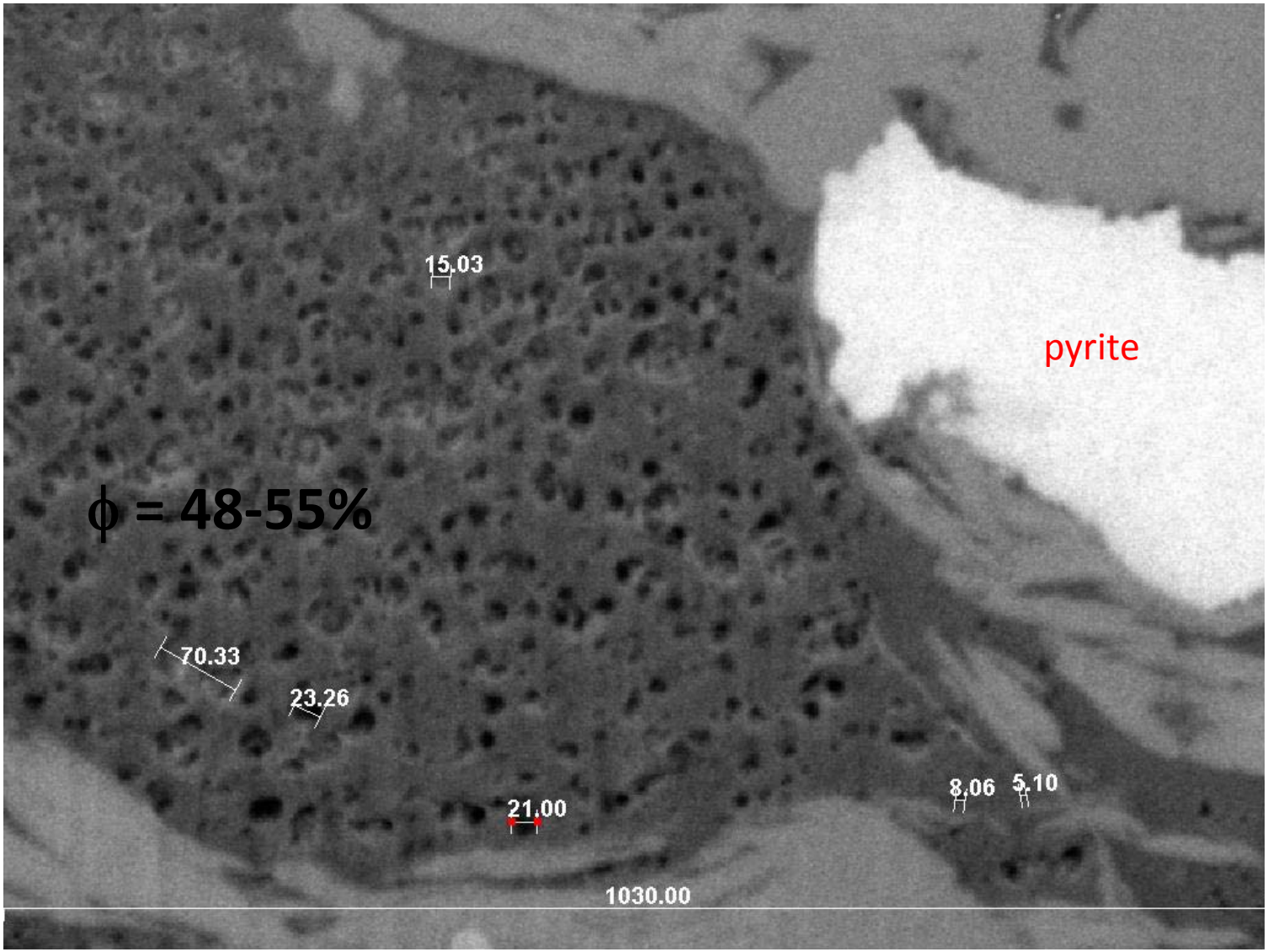
University of Oklahoma Center for Shale Research

Hydrocarbon Mining Technologies

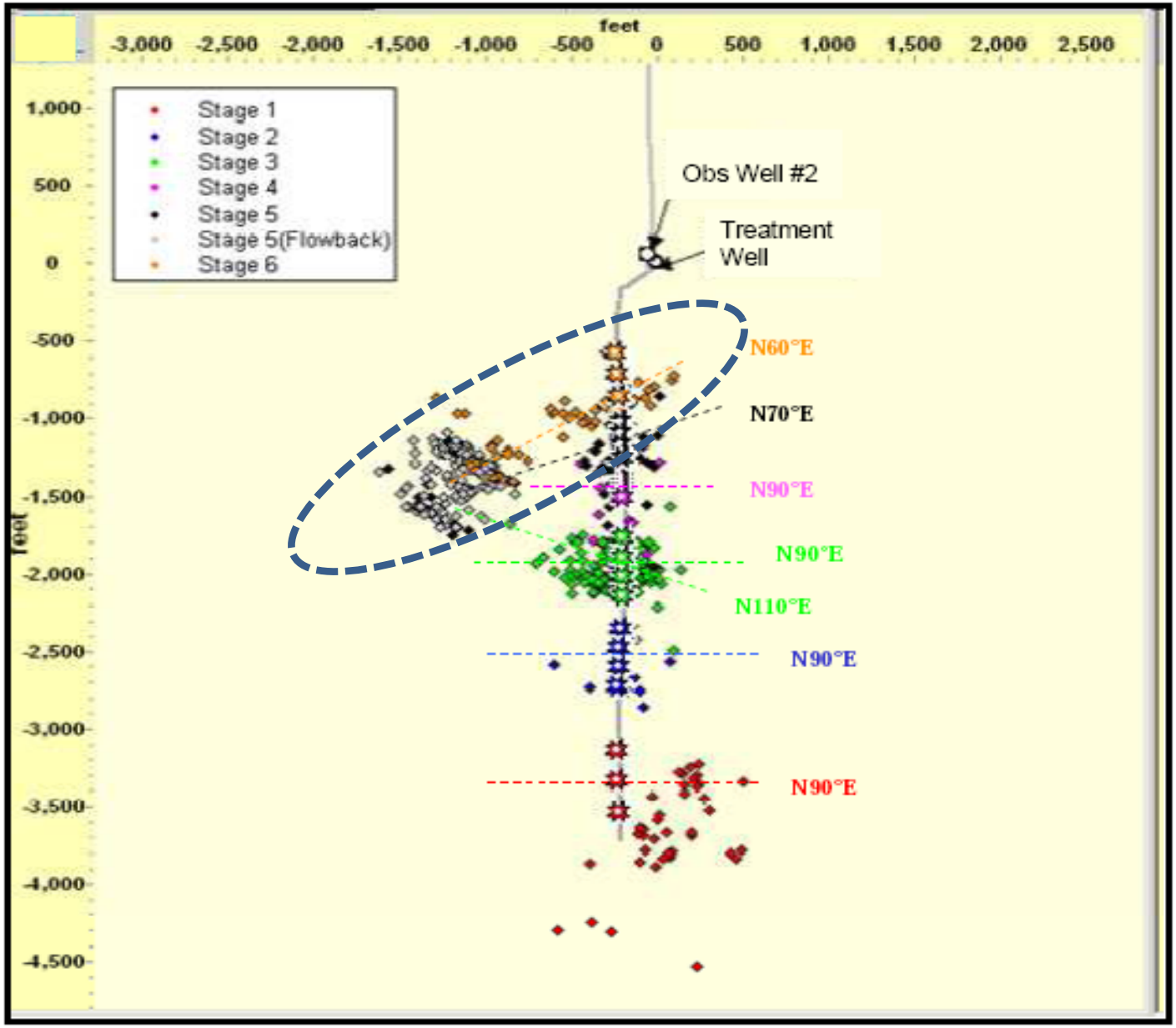
Horizontal Drilling, Multilaterals

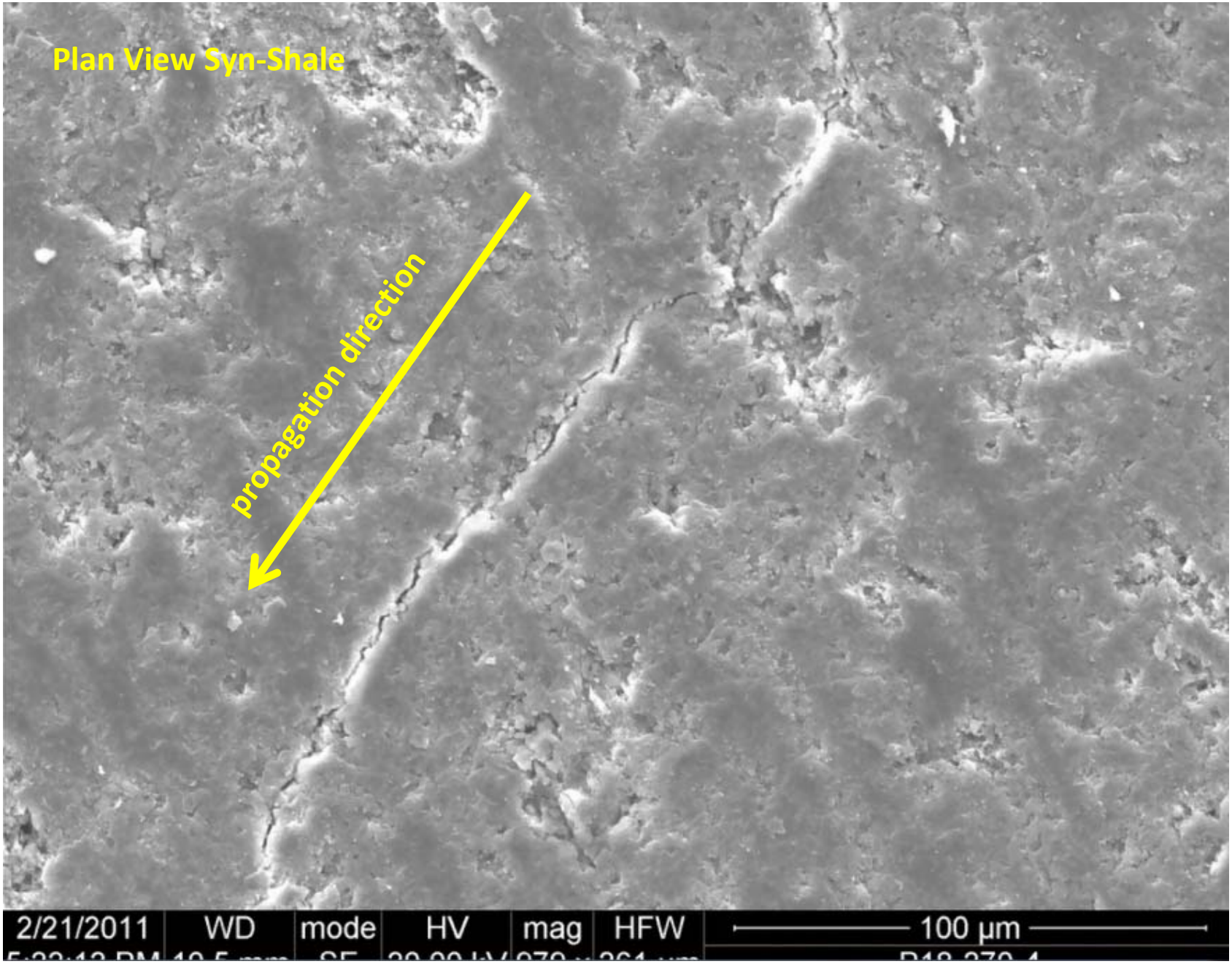
Hydraulic Fracturing, Multistages, Simulfracs, Zipper Frac




15.03
pyrite
ϕ = 48-55%
70.33
23.26
21.00
8.06
5.10
1030.00

Stages 2-6 mapped with OBS well #2 :stages 5 &6 intersect faults

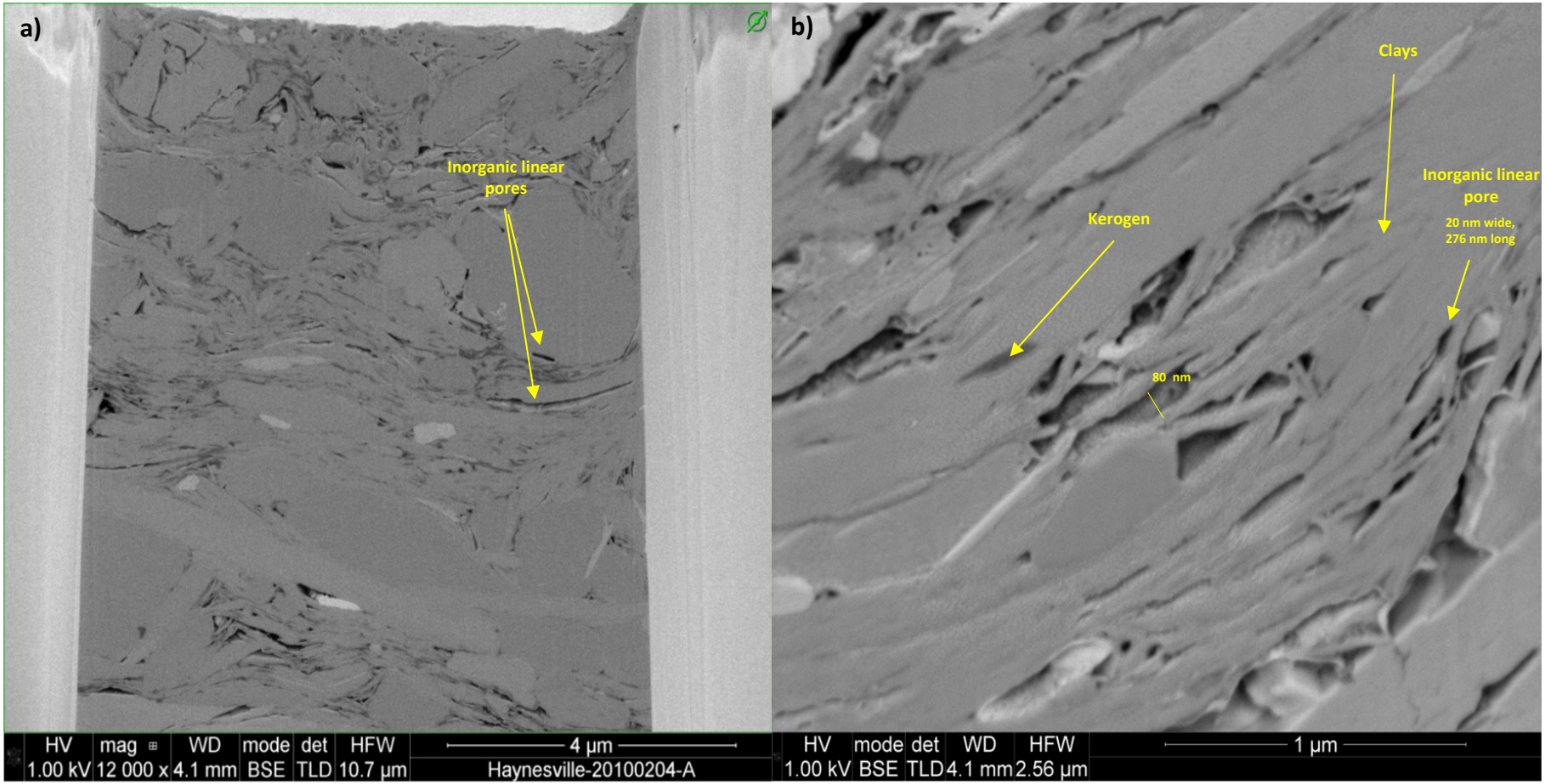



Plan View Syn-Shale
propagation direction
2/21/2011
WD
mode
HV
mag
HFW
100 µm

Ion Milled Scanning Electron Microscope Images:

Reveal microstructure in grains and kerogen which contains and delivers gas

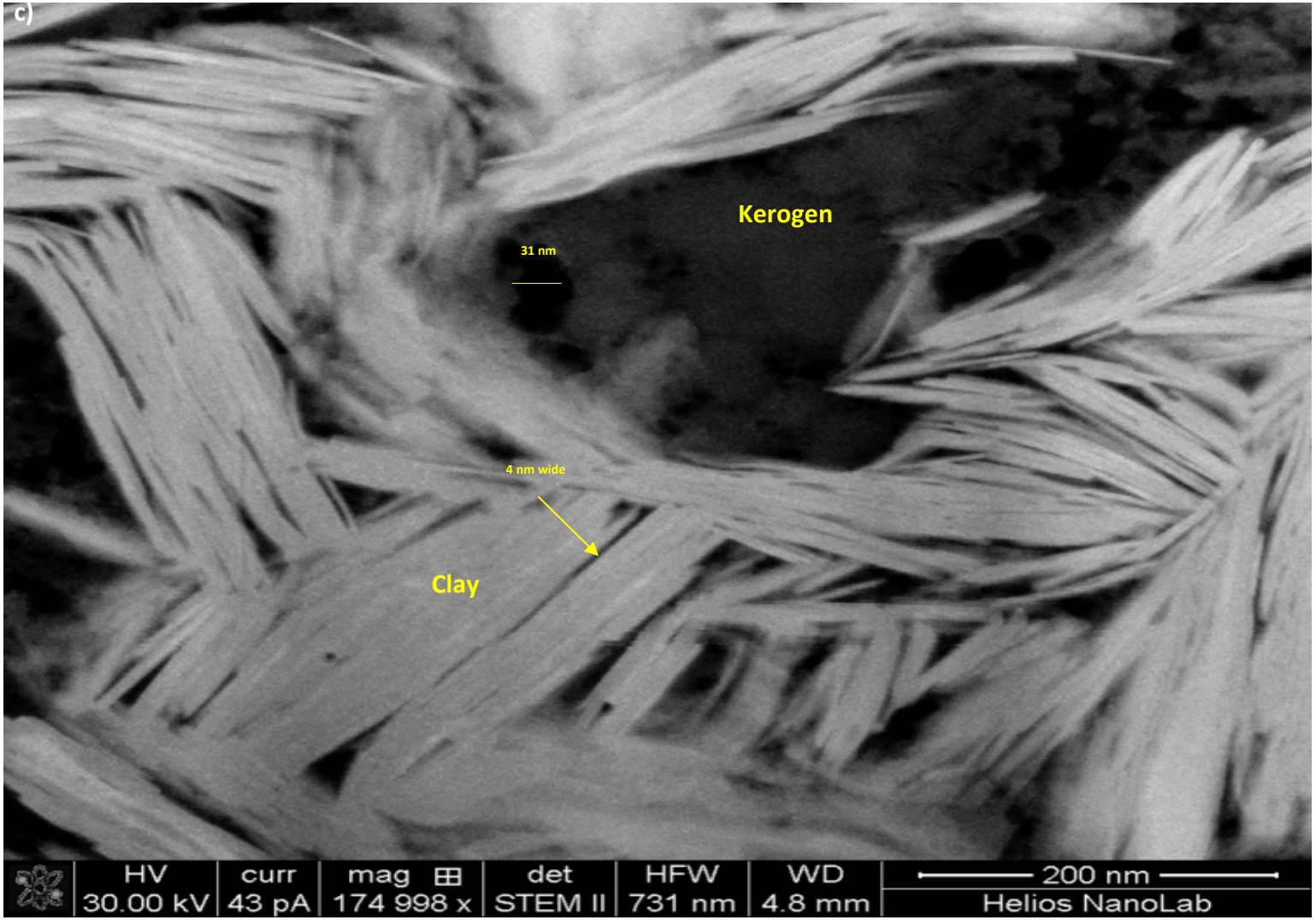
Kerogen estimation from logs, kerogen density?



Curtis, Sondergeld, Ambrose and Rai, 2010

Scanning Transmission Electron Microscopy:

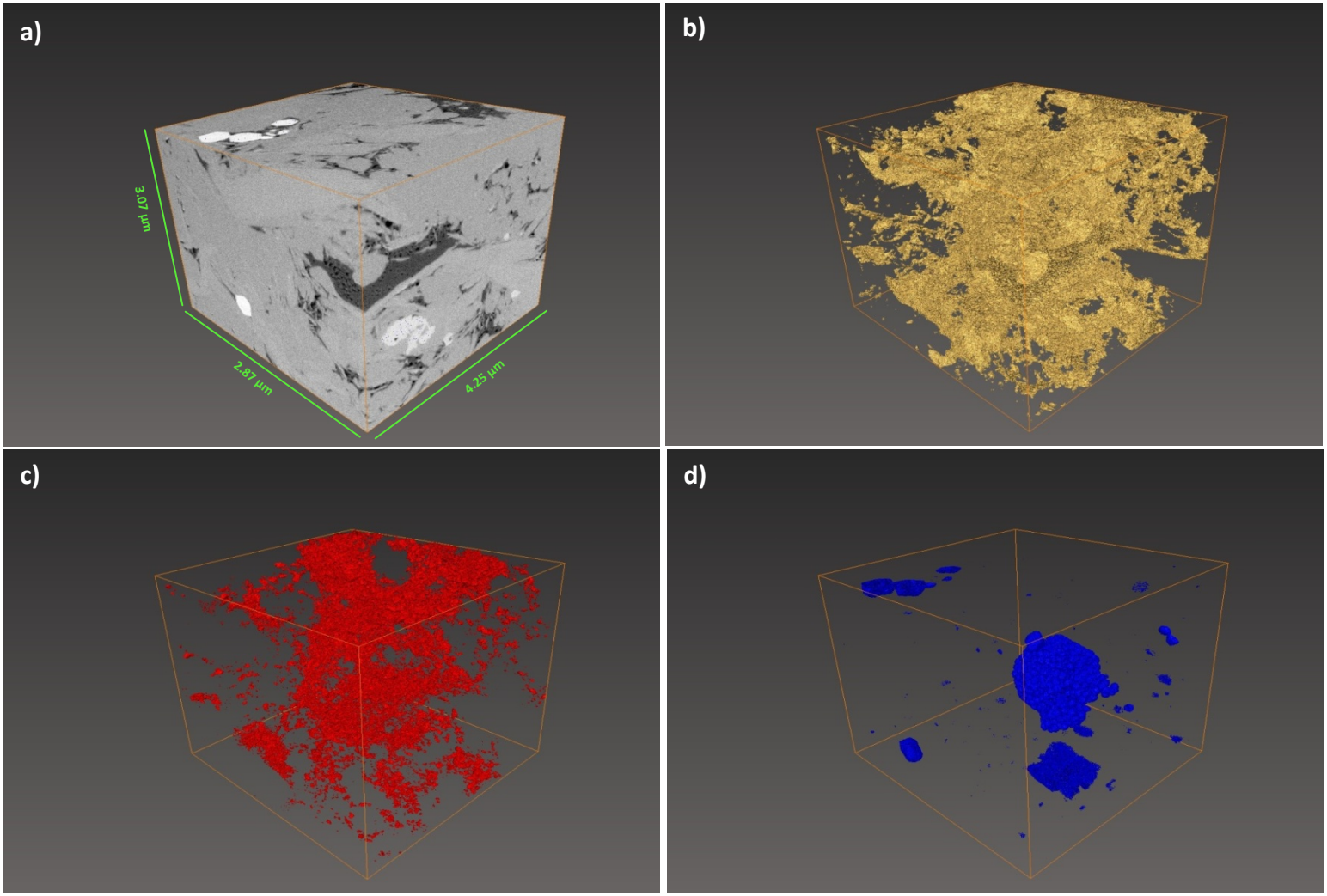
Reveals even finer details of phyllosilicate porosity



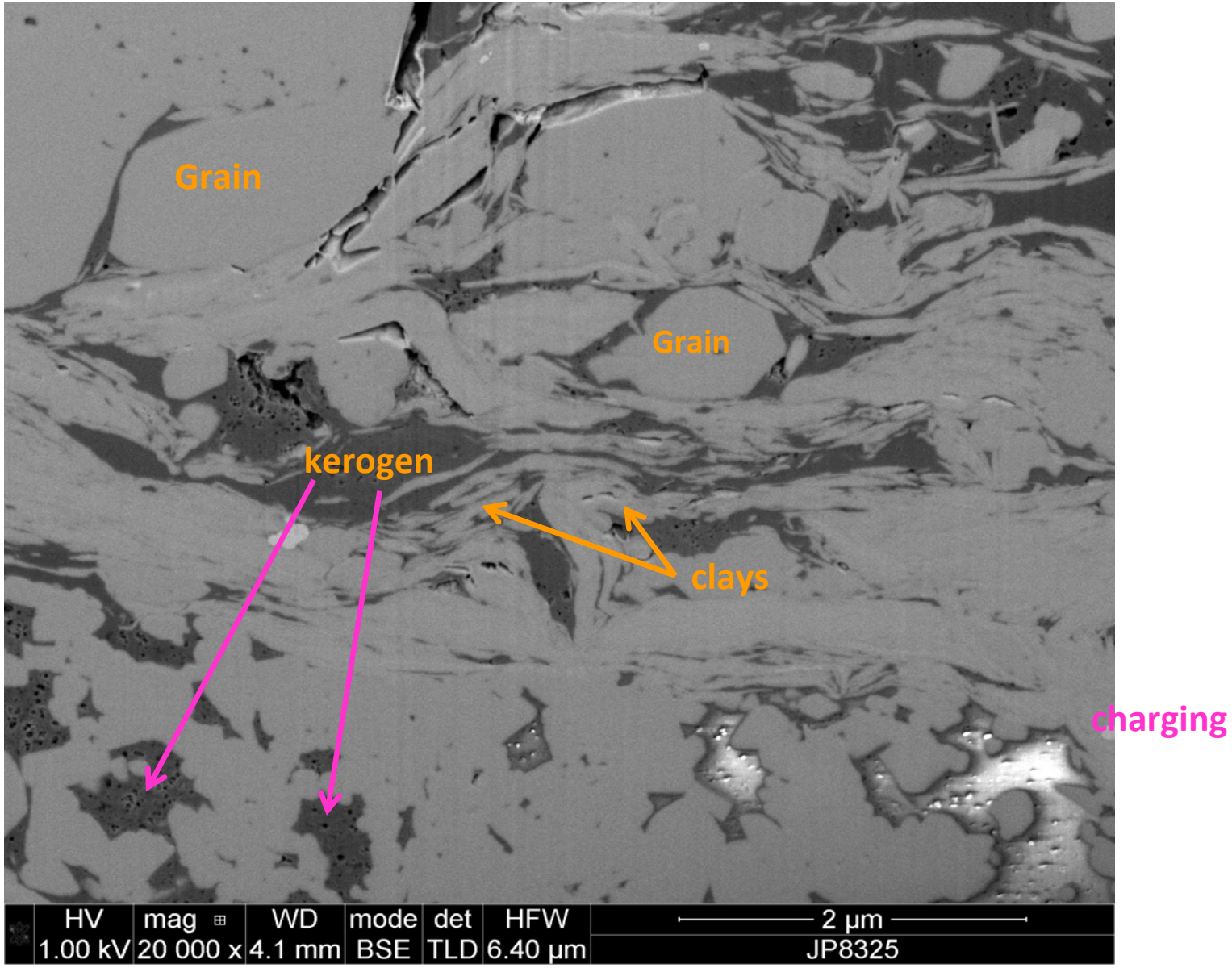
Curtis, Sondergeld, Ambrose and Rai, 2010

Slice and View Capabilities:

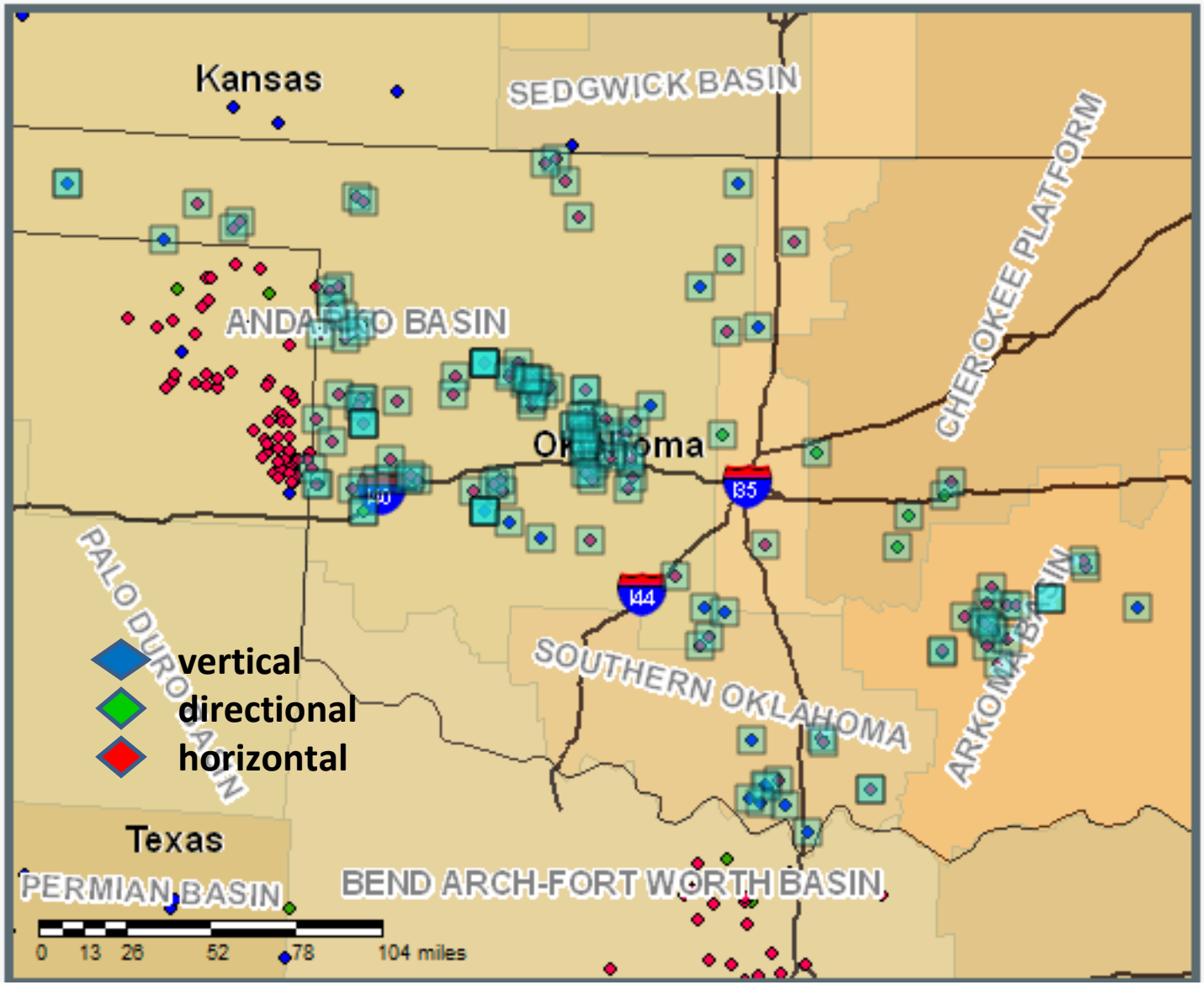
Renders volume from which organic and pore geometries can be extracted.



Curtis, Sondergeld, Ambrose and Rai, 2010

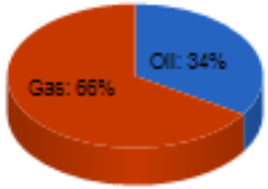

Grain
Grain
kerogen
clays
charging
HV
1.00 kV
mag
20 000 x
WD
4.1 mm
mode
BSE
det
TLD
HFW
6.40 µm
2 µm
JP8325

Wells drilled in OK-March-2011

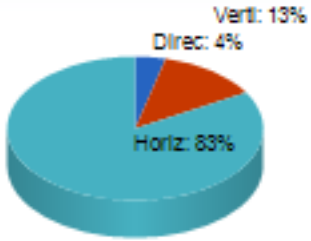


Rig Count: 1738
25-Mar-2011

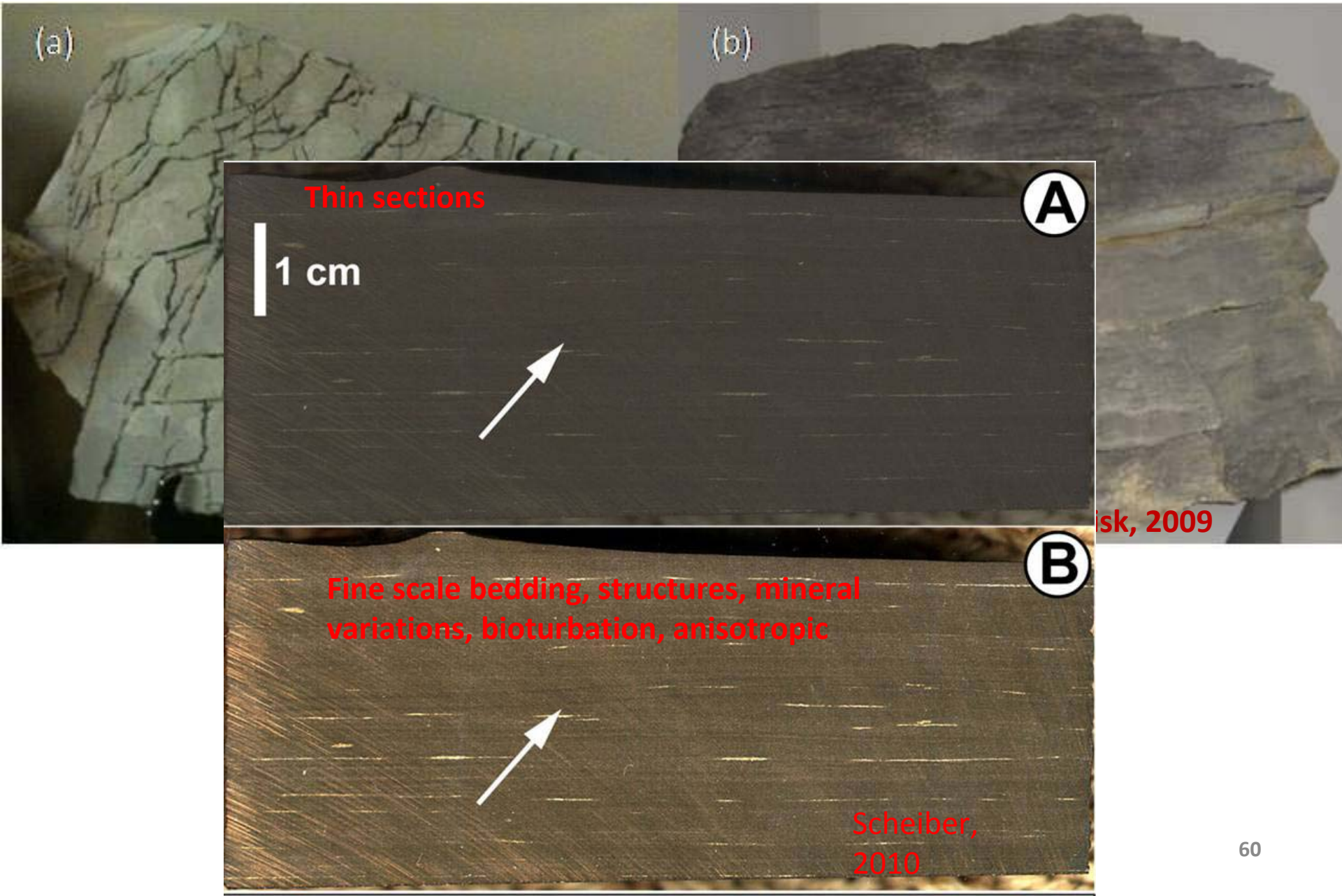
Drill For (Selection)



Trajectory (Selection)

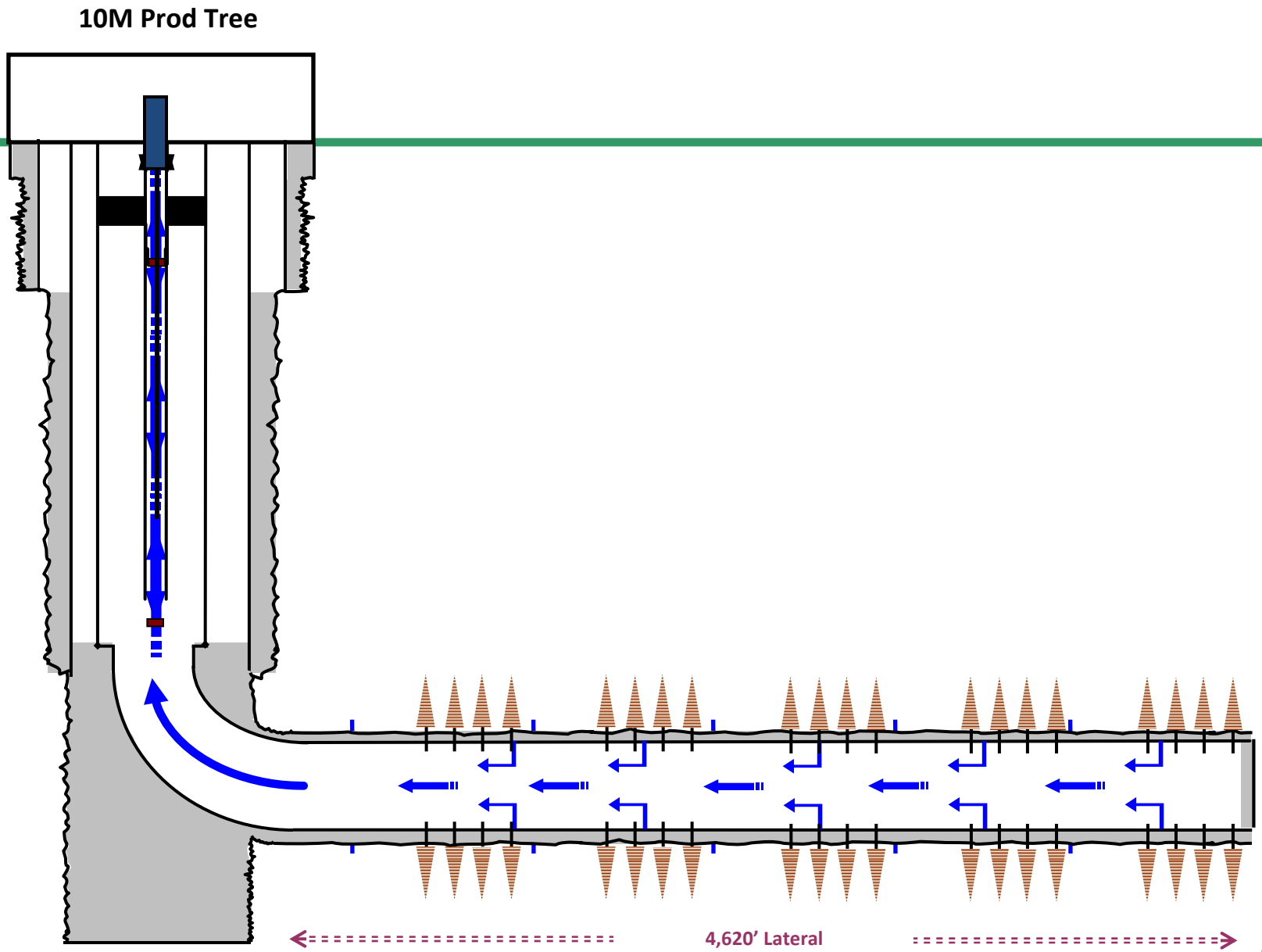


Hand Specimen: Woodford, pyrobitumen filled fractures

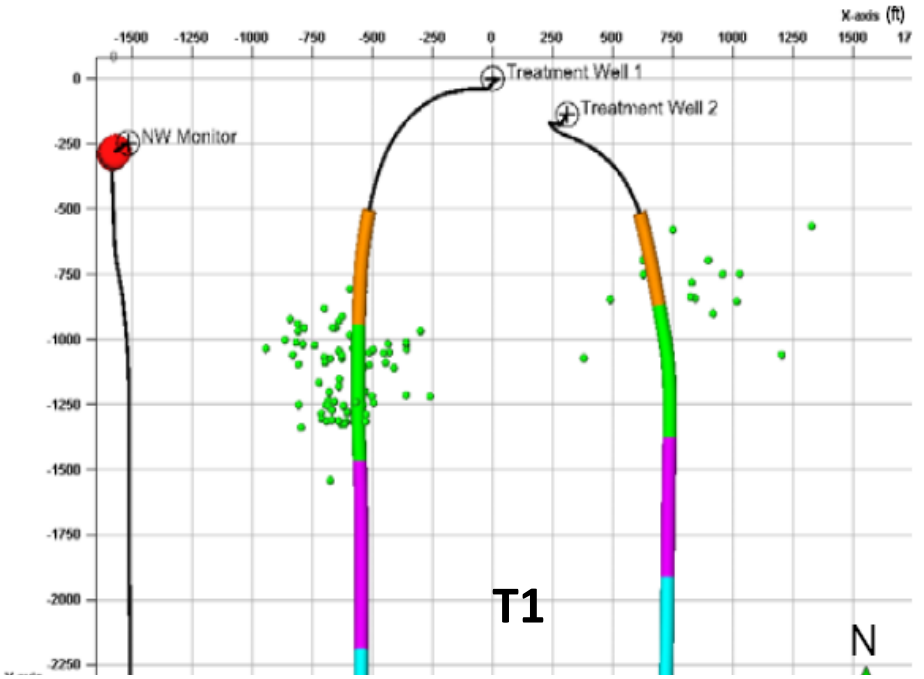


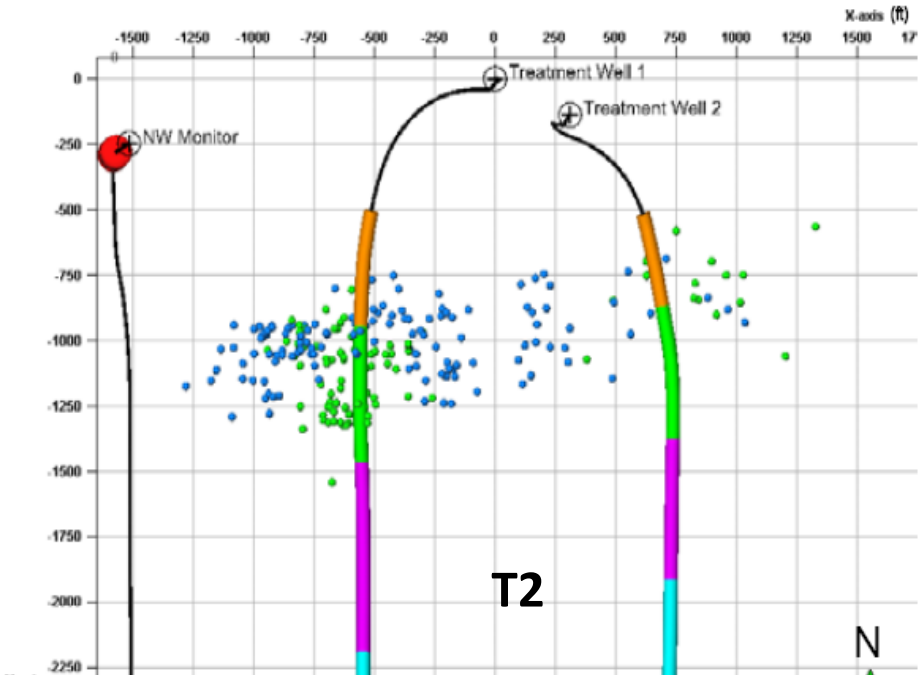
isk, 2009

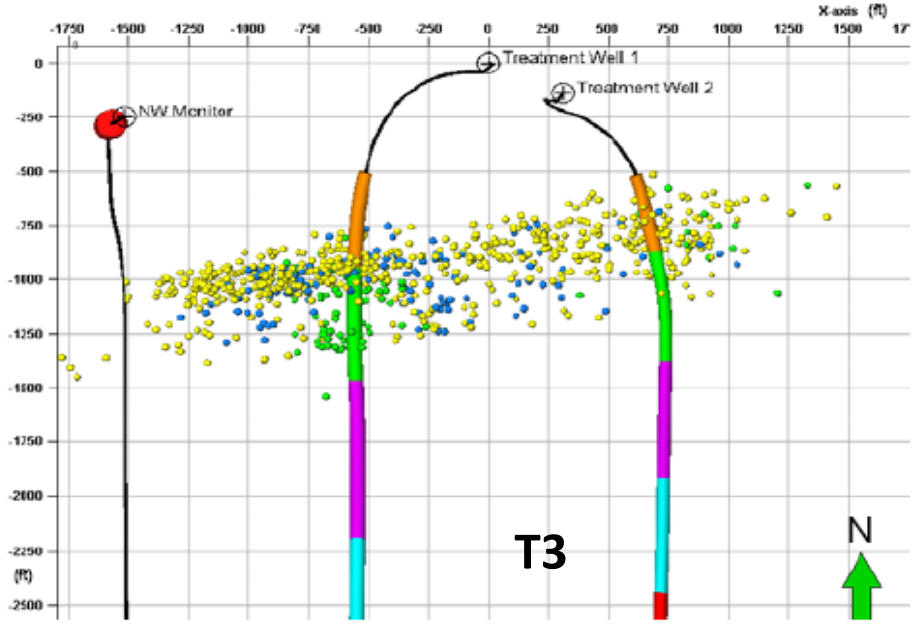
Haynesville Horizontal Well Plan

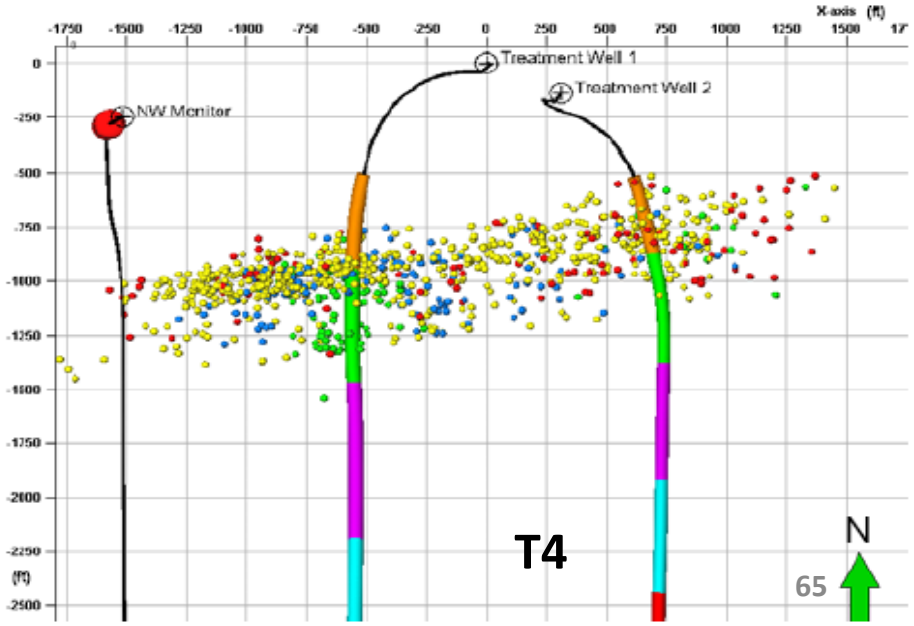


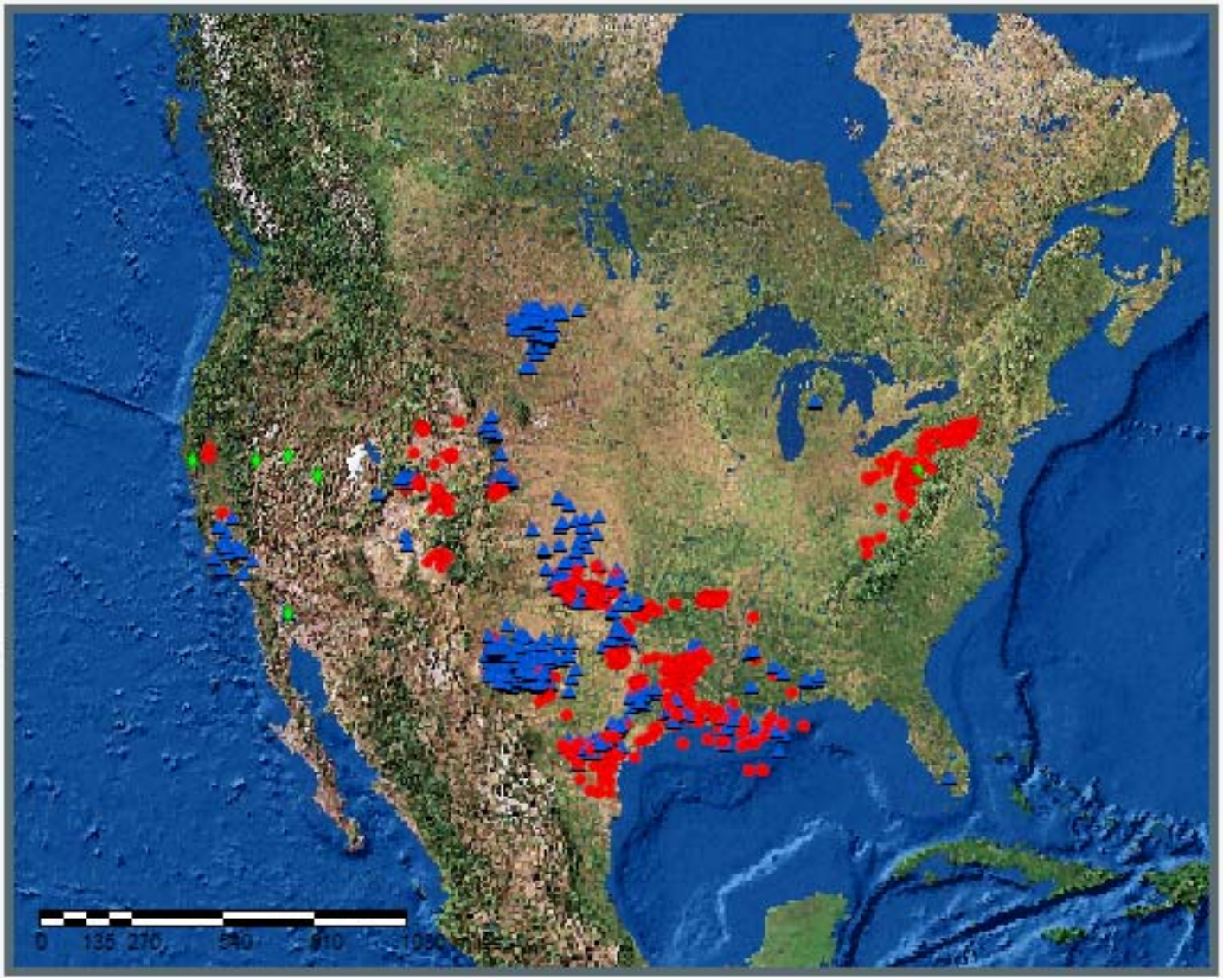
Connection of Hydraulic Fractures





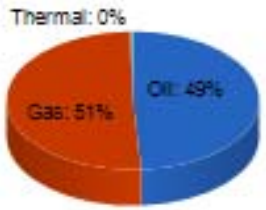






Rig Count: 1738
25-Mar-2011

Drill For (Week)



Trajectory (Week)

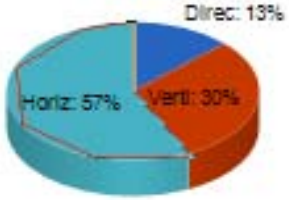


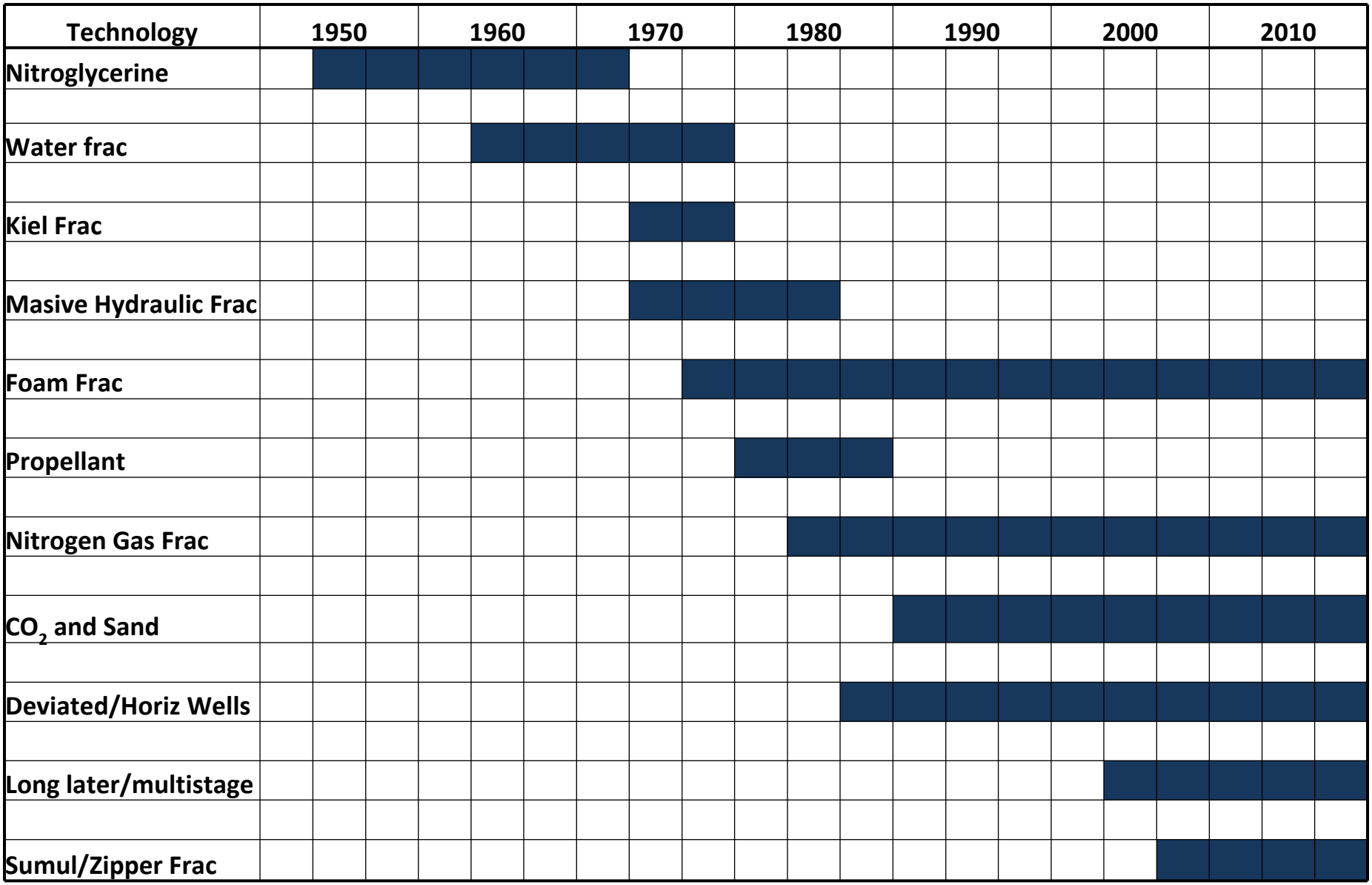
Table 3. Principal Shale Gas Plays: Natural Gas Production and Proved Reserves, 2008-2009

(billion cubic feet)

	2008		2009		Change 2009-2008	
Shale Play	**Production**	**Reserves**	**Production**	**Reserves**	**Production**	**Reserves**
Barnett	1,501	22,492	1,745	26,493	318	4,001
Haynesville/Bossier	25	1,031	321	10,468	296	9,437
Fayetteville	279	3,833	527	9,070	248	5,237
Woodford	168	3,845	249	6,389	81	2,544
Marcellus	2	102	76	4,478	74	4,376
Antrim	122	2,894	132	2,499	14	-395
Sub-total	**2,097**	**34,197**	**3,050**	**59,397**	**953**	**25,200**
Other Shale Plays	19	231	60	1,247	41	1,016
All U.S. Shale Plays	**2,116**	**34,428**	**3,110**	**60,644**	**994**	**26,216**

Note: The above table is based on shale gas proved reserves and production volumes as reported to the EIA on Form EIA-23. It does not include EIA-estimated volumes for non-surveyed operators. For this and other reasons (e.g., incorrect or incomplete respondent submissions, respondent misidentification of shale versus non-shale reservoirs) the actual proved reserves and production of natural gas from shale plays may differ. Official EIA shale gas production volumes are reported in Natural Gas Navigator.

Evolution of Hydraulic Fracturing

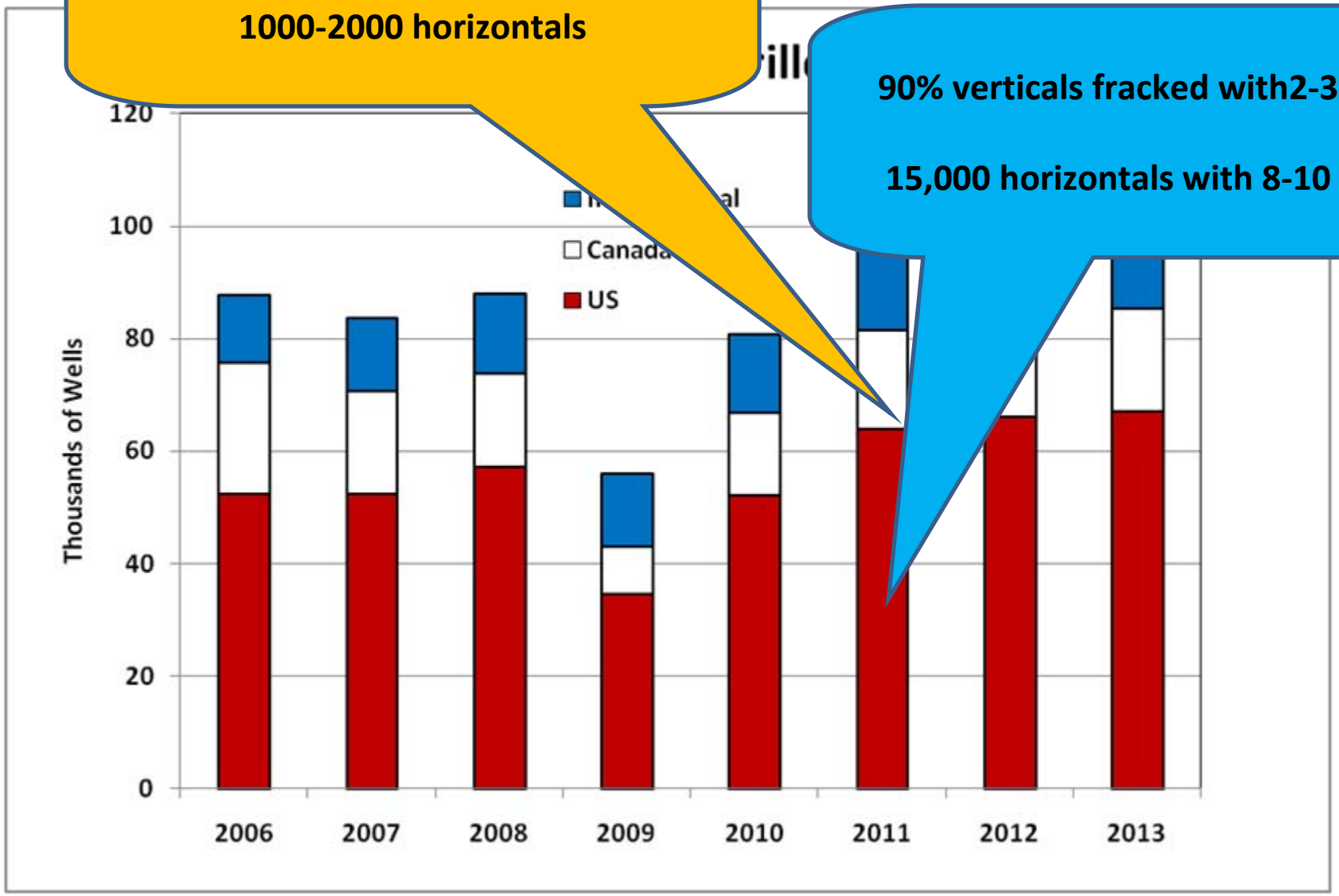


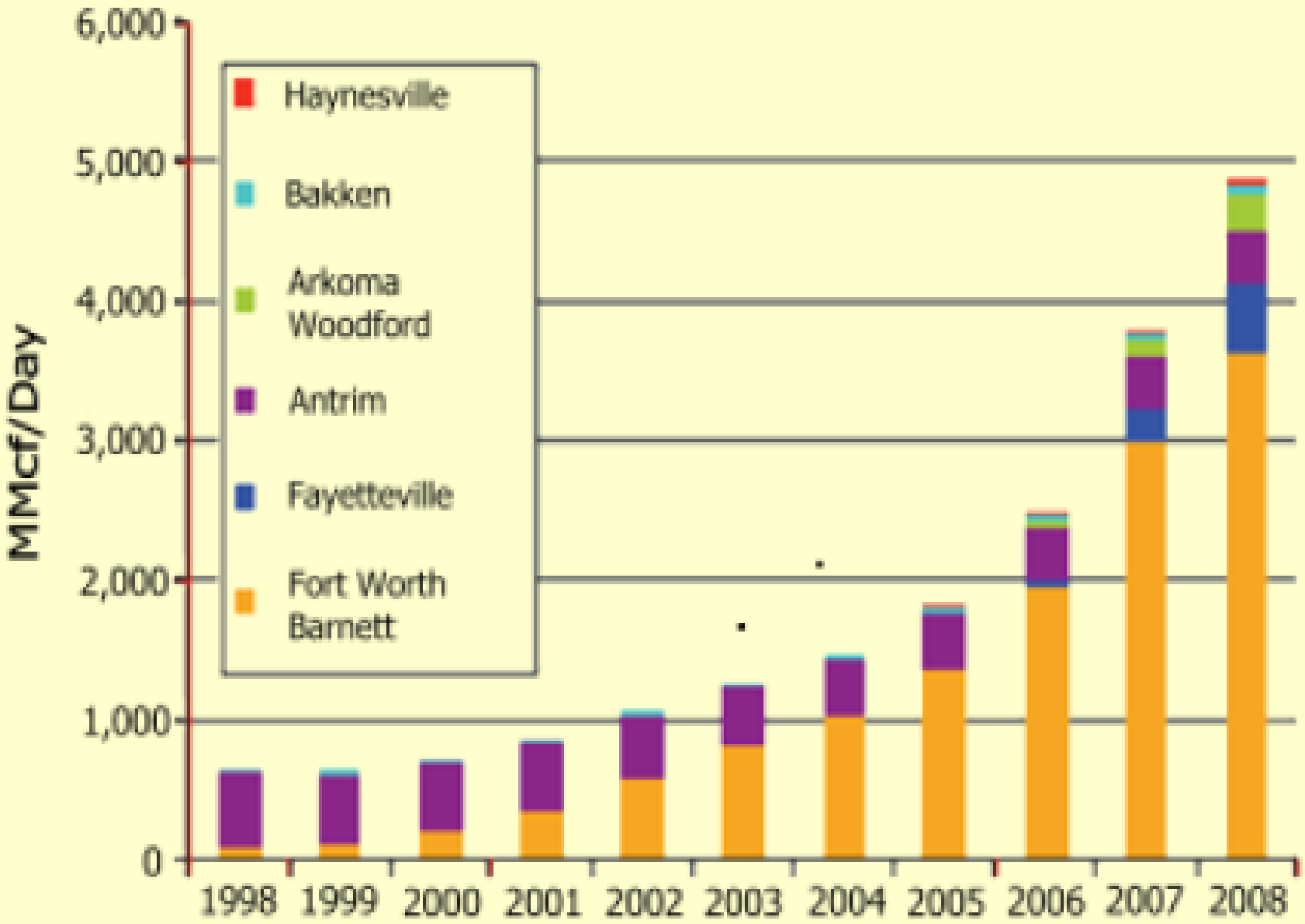
90% verticals fracked, 2-3 fracs

1000-2000 horizontals

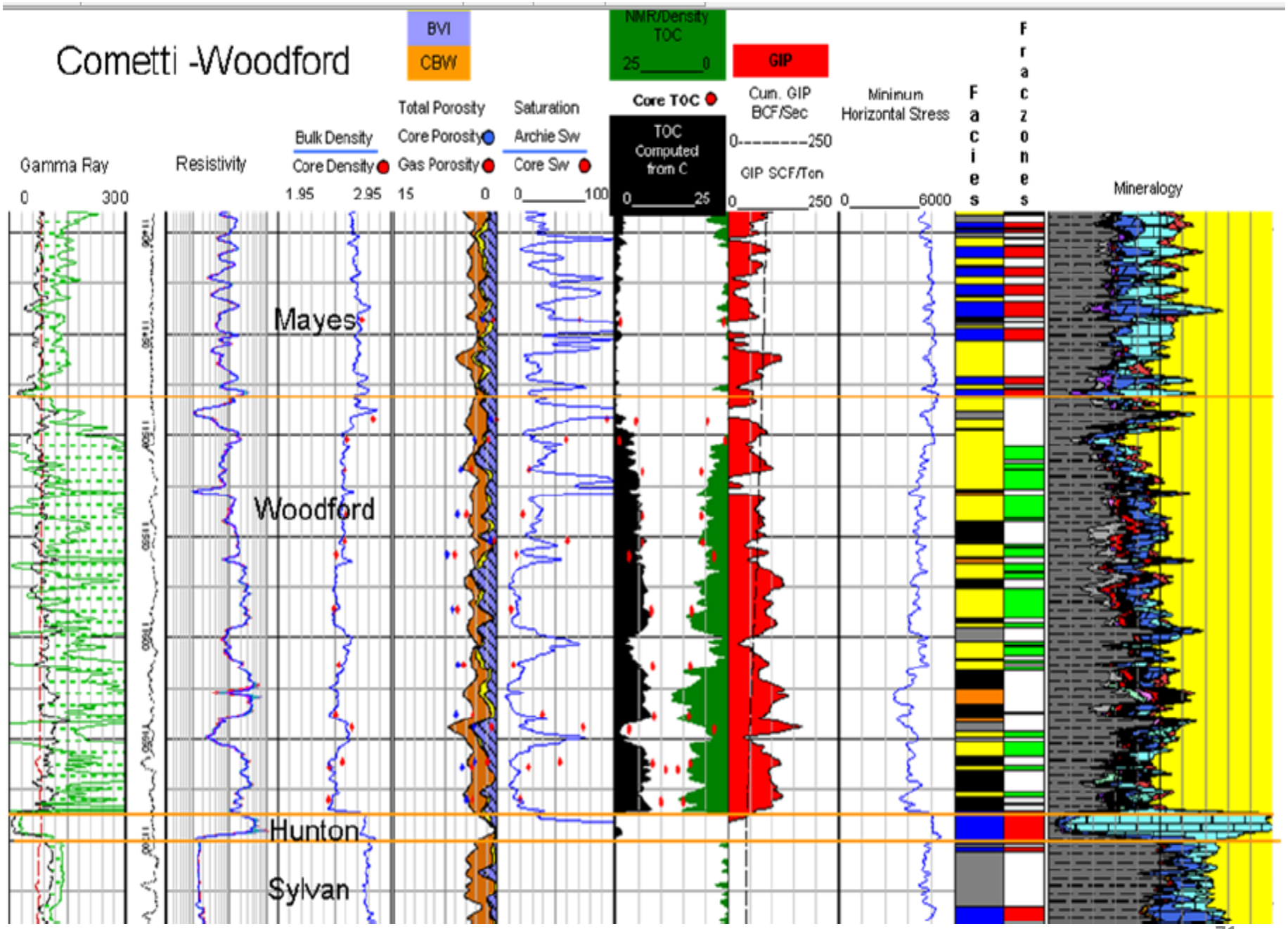
90% verticals fracked with2-3 fracs

15,000 horizontals with 8-10 fracs





Modified from Navigant 2008

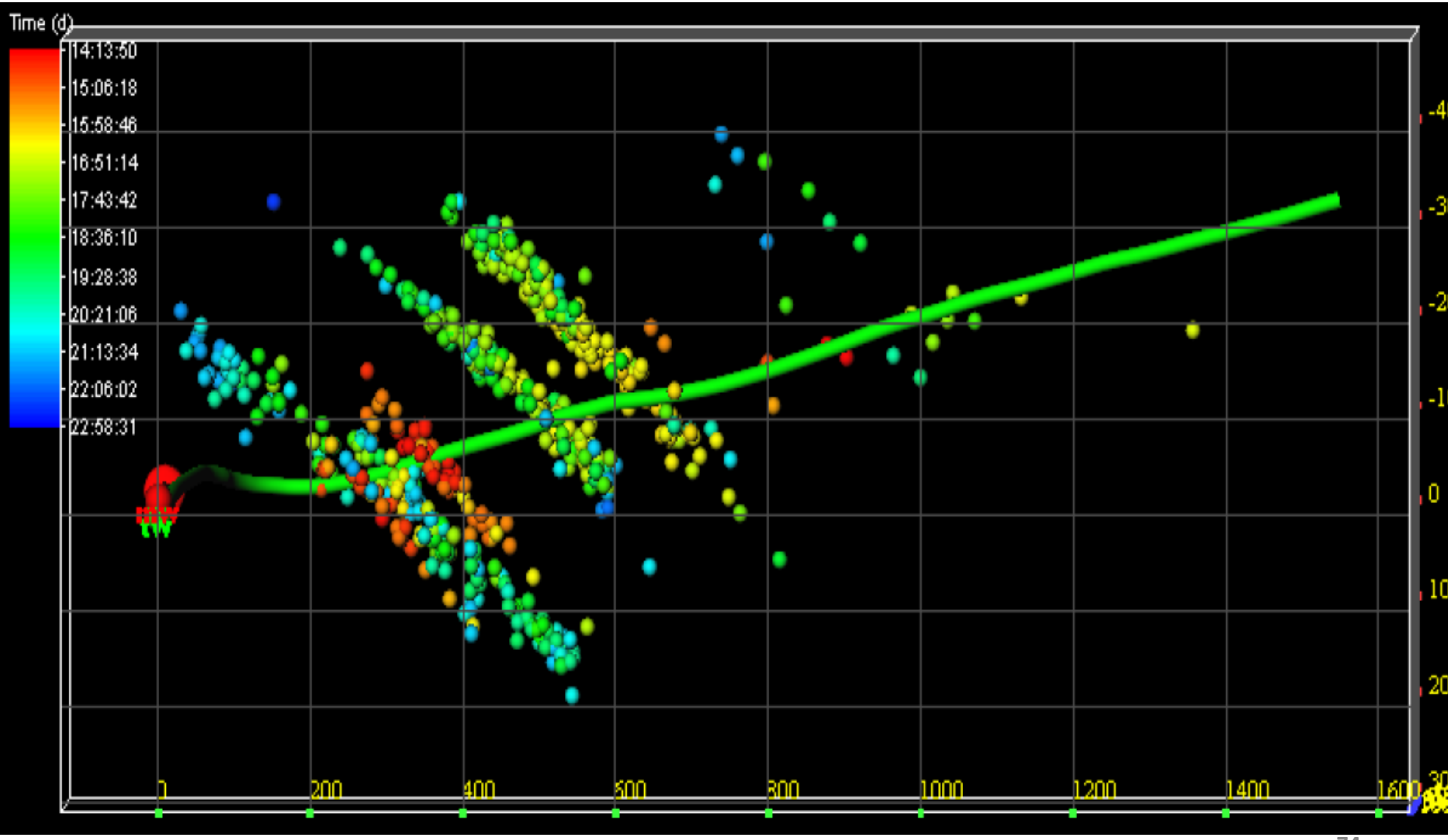

Cometti -Woodford
BVI
CBW
NMR/Density TOC
25 0
GIP
Gamma Ray
0 300
Resistivity
Bulk Density
Core Density
1.95 2.95
Total Porosity
Core Porosity
Gas Porosity
15 0
Saturation
Archie Sw
Core Sw
0 100
Core TOC
TOC Computed from C
0 25
Cum. GIP BCF/Sec
0 250
GIP SCF/Ton
0 250
Minimum Horizontal Stress
0 6000
Facies
Fracz ones
Mineralogy
Mayes
Woodford
Hunton
Sylvan

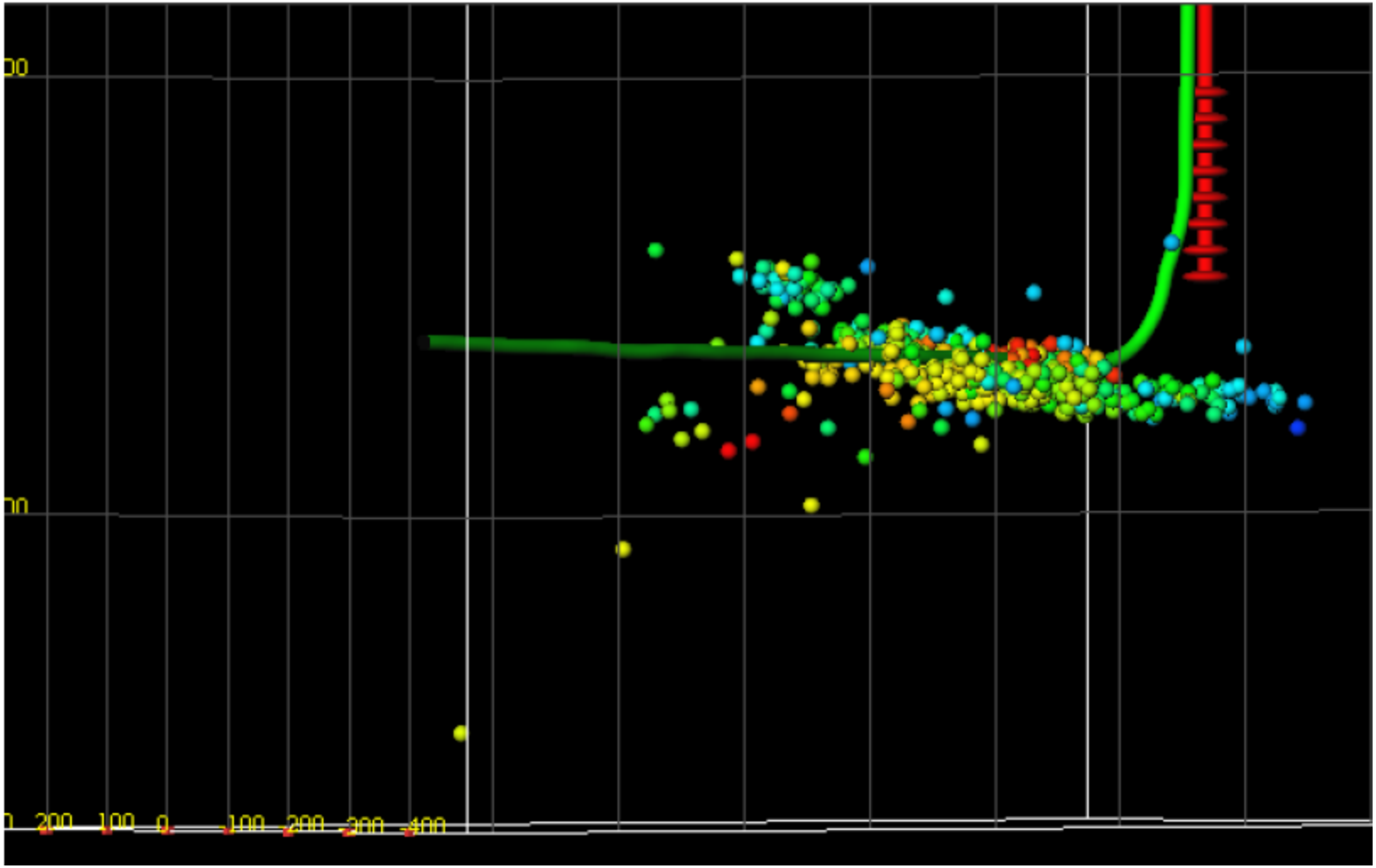
Section 29 Milestones

1980	—	Congress creates Section 29 Tax Credit
1982	—	Non-conventional gas production is 1.5 trillion cubic feet per year
1984	—	First significant Coalbed Methane production
1991	—	Devonian Shale production doubles from historic levels
1993	—	Non-conventional gas doubles from historic levels reaching 3 trillion cubic feet
1997	—	Coalbed Methane reaches 1 trillion cubic feet per year
1999	—	Non-conventional gas production totals 4.8 trillion cubic feet per year
1990 to 2000	—	The nation benefits from a decade of stable and fair priced gas supplies
2001	—	Non-conventional gas represents 30% of lower-48 gas well production
2002	—	**Credit will expire without action**
2015	—	The nation needs over 7 trillion cubic feet of non-conventional gas to meet demand

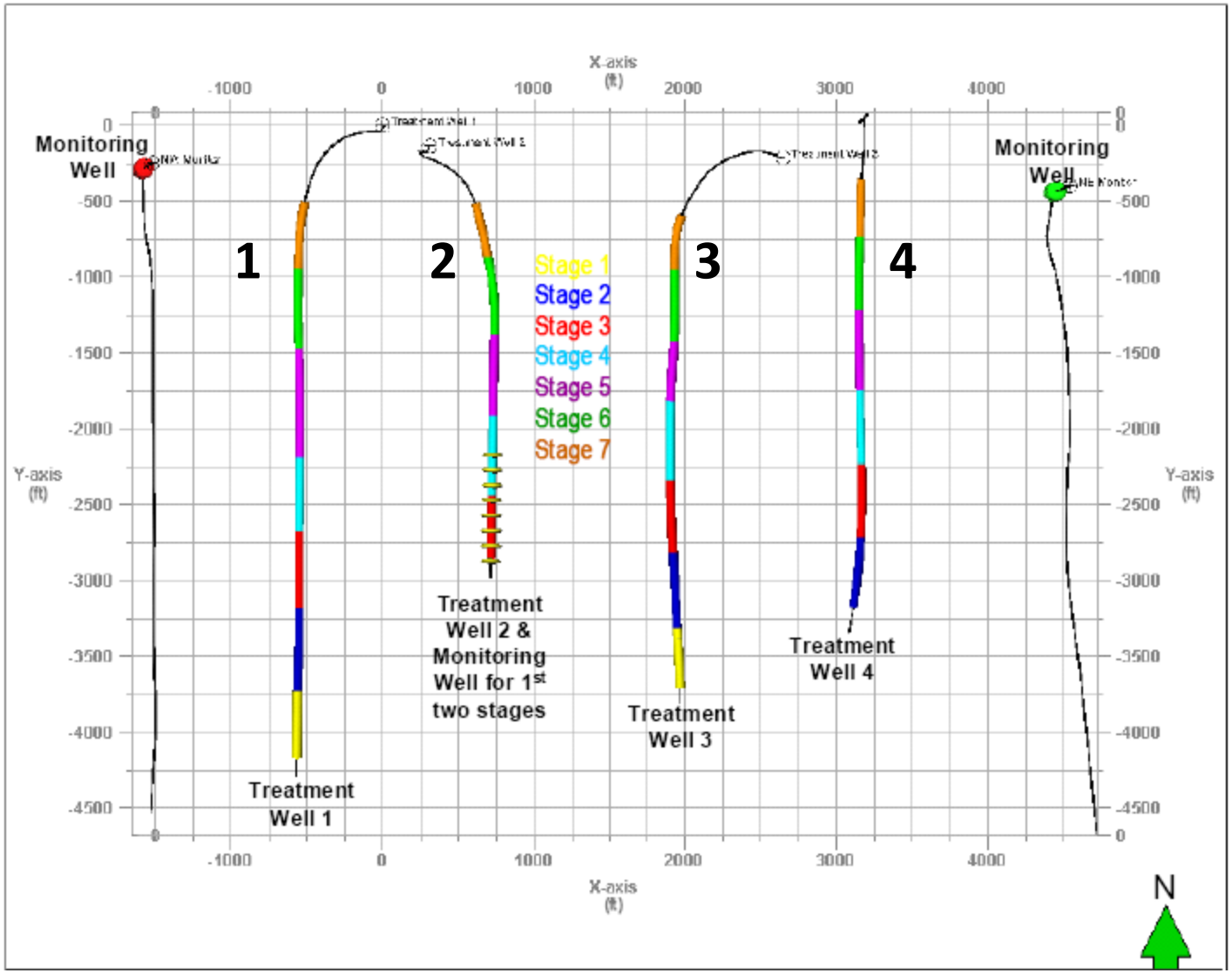
The tax credit provided a $0.50/Mcf incentive for gas produced from nonconventional gas resources (Tight Gas Sands, Coalbed Methane, Devonian Shale).

Mine Back of a Hydraulic Fracture


Time (d)
14:13:50
15:06:18
15:58:46
16:51:14
17:43:42
18:36:10
19:28:38
20:21:06
21:13:34
22:06:02
22:58:31
0
200
400
600
800
1000
1200
1400
1600
-4
-3
-2
-1
0
10
20
30


200 100 0 -100 -200 -300 -400

Woodford Multifrac---Continental Resources



Deja vu