Producing Natural Gas from Shale – Opportunities and Challenges of a Major New Energy Source

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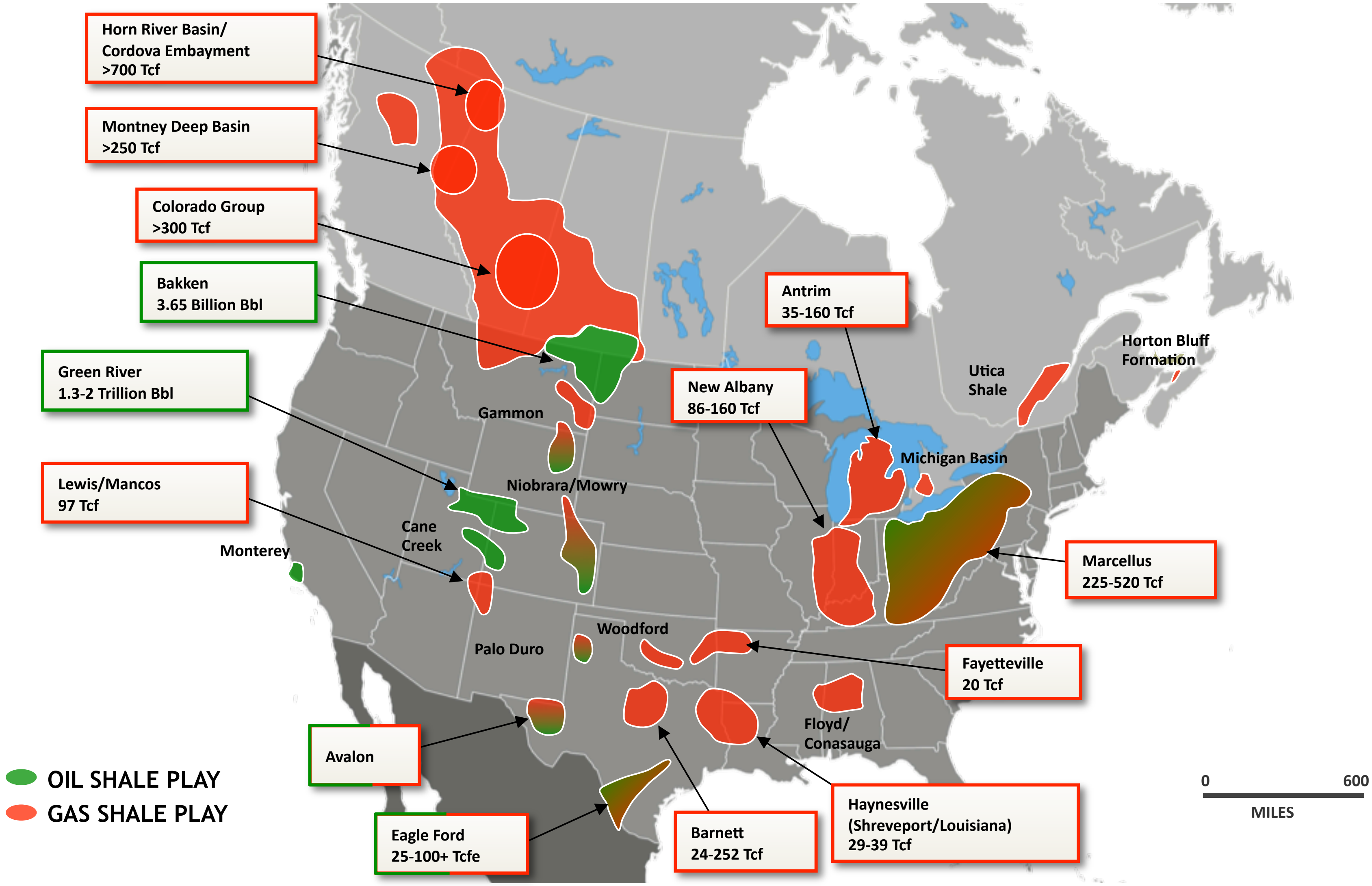
STANFORD UNIVERSITY

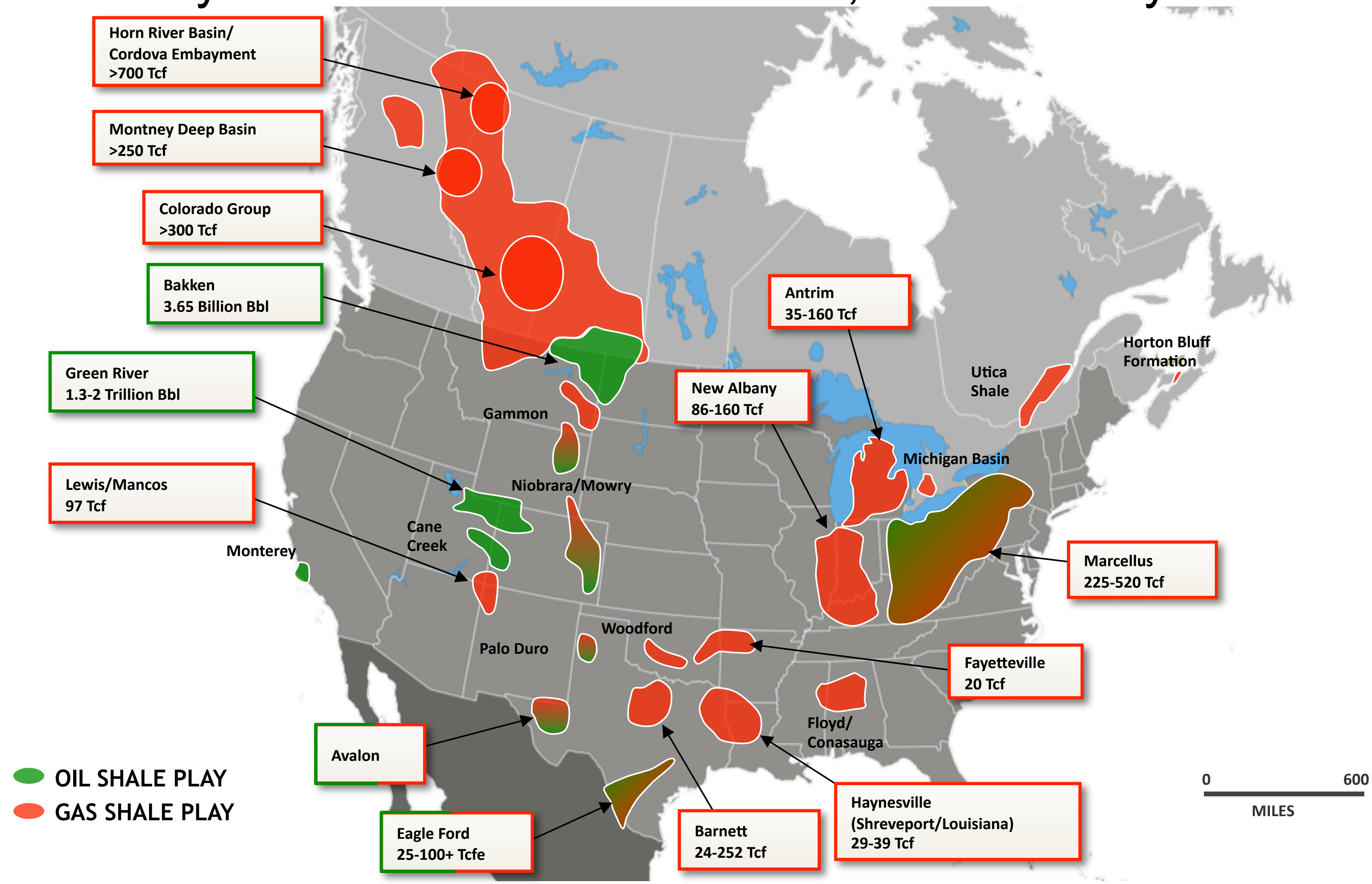
Opportunity: North American Shale Plays



~2300 TCF (85% Shale Gas)

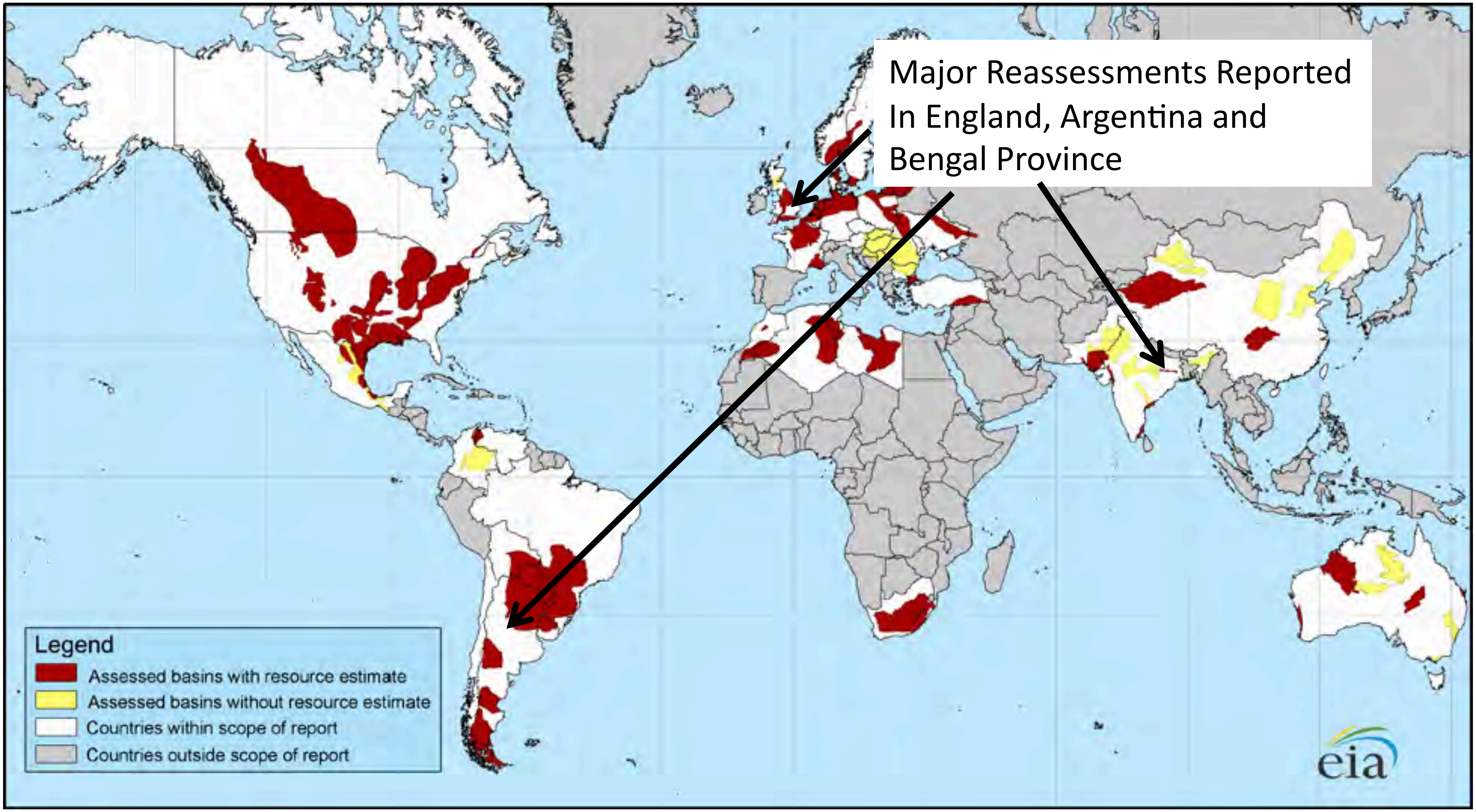
"100 years of Natural Gas" U.S. Consumption 23 TCF/y

The Challenge of Natural Gas - Next ~10 Years
Many 10's of Thousands of Wells, ~1 Million Hydrofracs



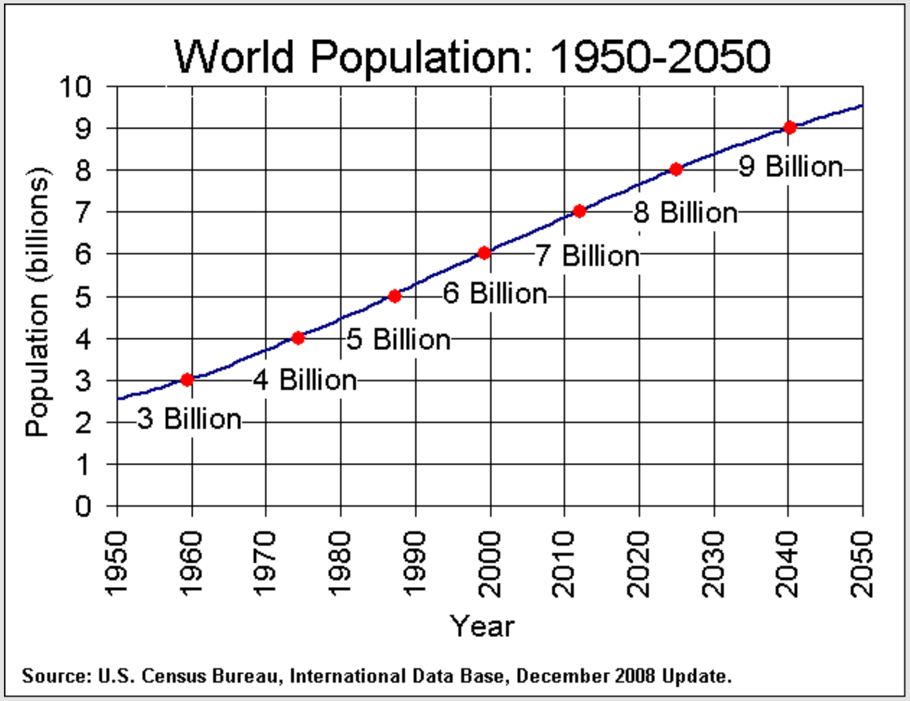
- How Do We Optimize Resource Development?
- How Do we Minimize the Environmental Impact?

Global Shale Plays



~22,600 TCF of Recoverable Reserves
6600 TCF from Shale (40%)
Current use ~160 TCF/year (140 years)

Global Energy and Environment Challenge



How Do We Provide Accessible, Affordable, and Secure Energy While Protecting the Planet (2x by 2050, 3-4x by 2100)?

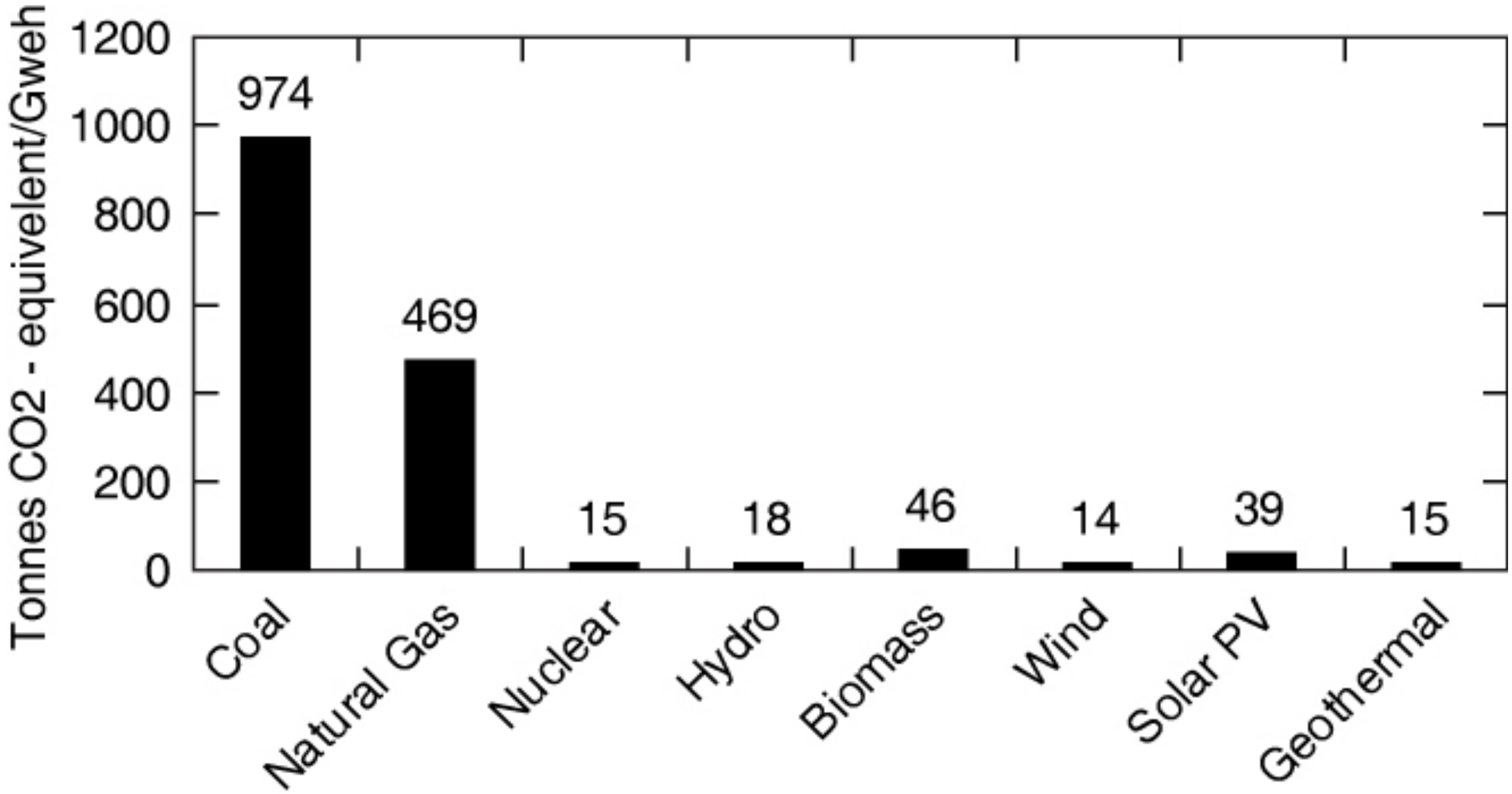
Air Pollution and Energy Source*

	CH_4	Oil	Coal
CO_2	117,000	164,000	208,000
CO	40	33	208
NO_x	92	448	457
SO_2	0.6	1,122	2,591
Particulates	7.0	84	2,744
Formaldehyde	0.75	0.22	0.221
Mercury	0	0.007	0.016

*Pounds/Billion BTU

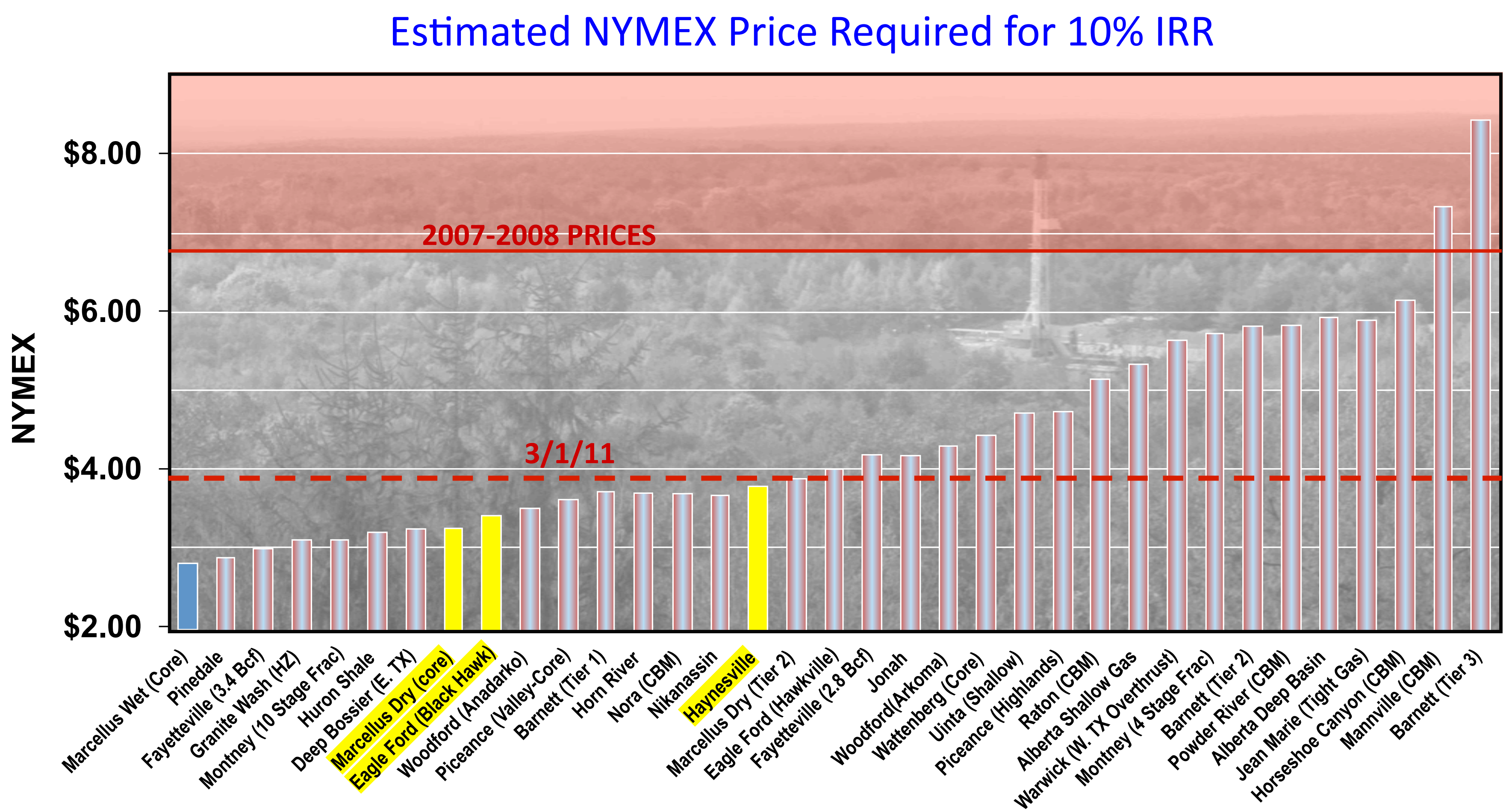
EIA, 1998

Lifecycle Emissions for Various Electricity Generation Technologies



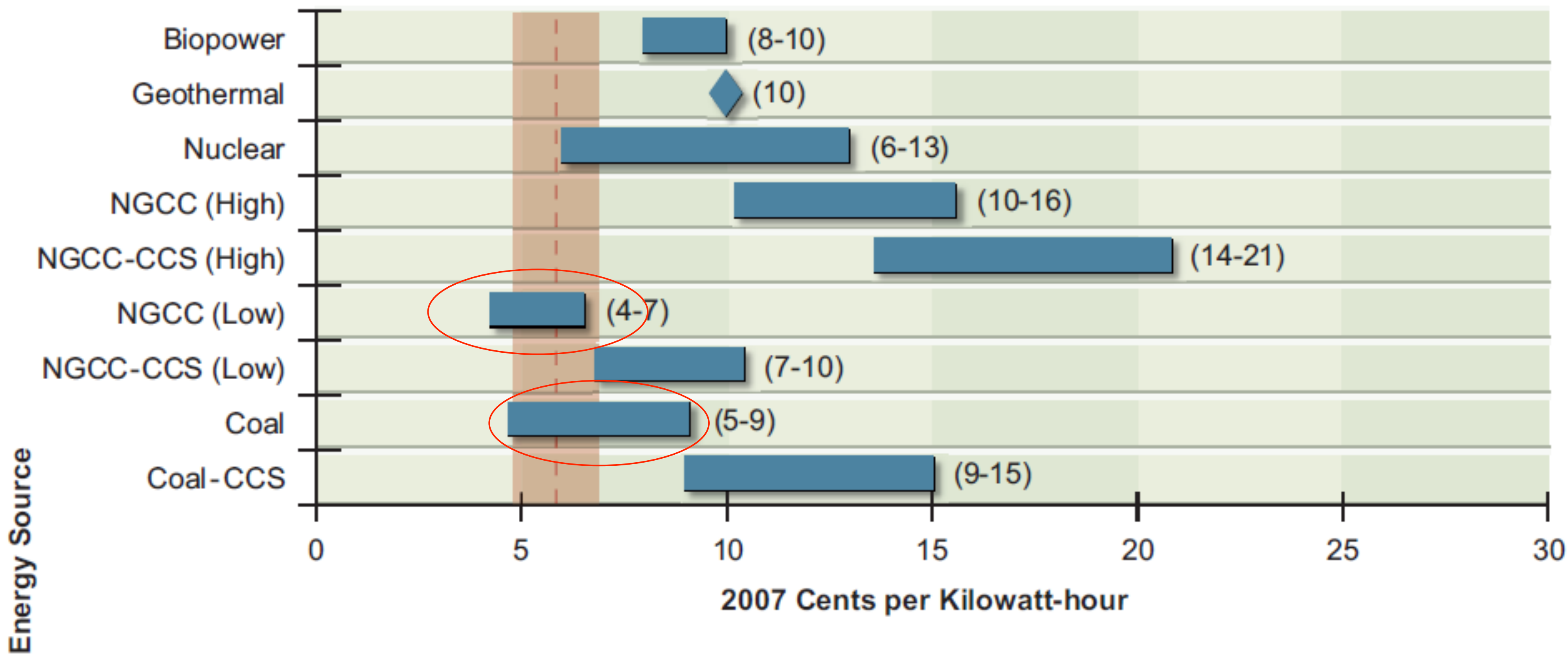
Comparison of Life Cycle Emissions in Metric Tonnes of CO_2e per GW-hour for various modes of Electricity Production; P.J. Meier, *Life-Cycle Assessment of electricity Generation Systems with Applications for Climate Change Policy Analysis,* Ph.D. dissertation, University of Wisconsin (2002); S. White, *Emissions form Helium-3, Fission and Wind Electrical Power plants,* Ph.D. Dissertation, University of Wisconsin (1998); M. K. Mann and P. L. Spath, *Life Cycle Assessment of a Biomass Gasification Combined-Cycle System*, (1997), www.nrel.gov/docs/legosti/fy98/23076.pdf *(ref 33).*

The Challenges of $4 Gas



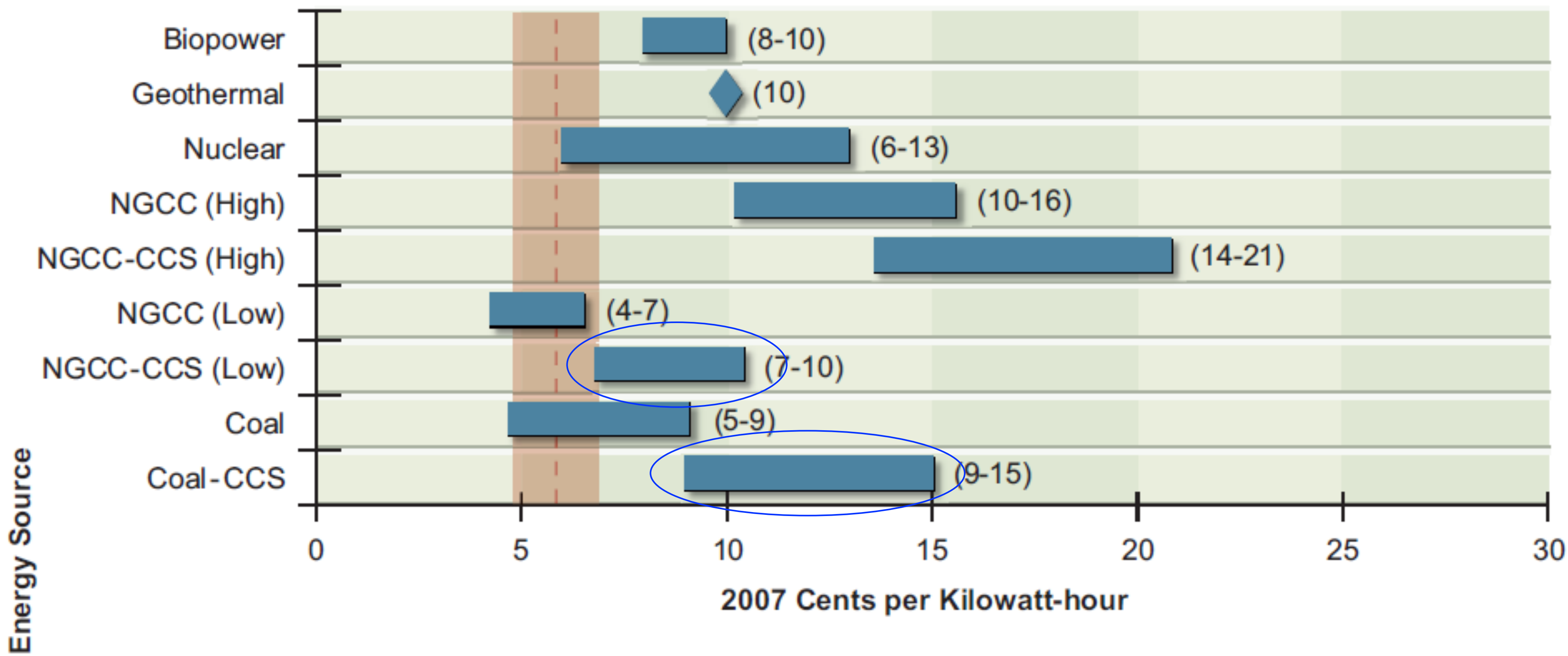
Source: Morgan Stanley Research Report

Gas And Coal Economics



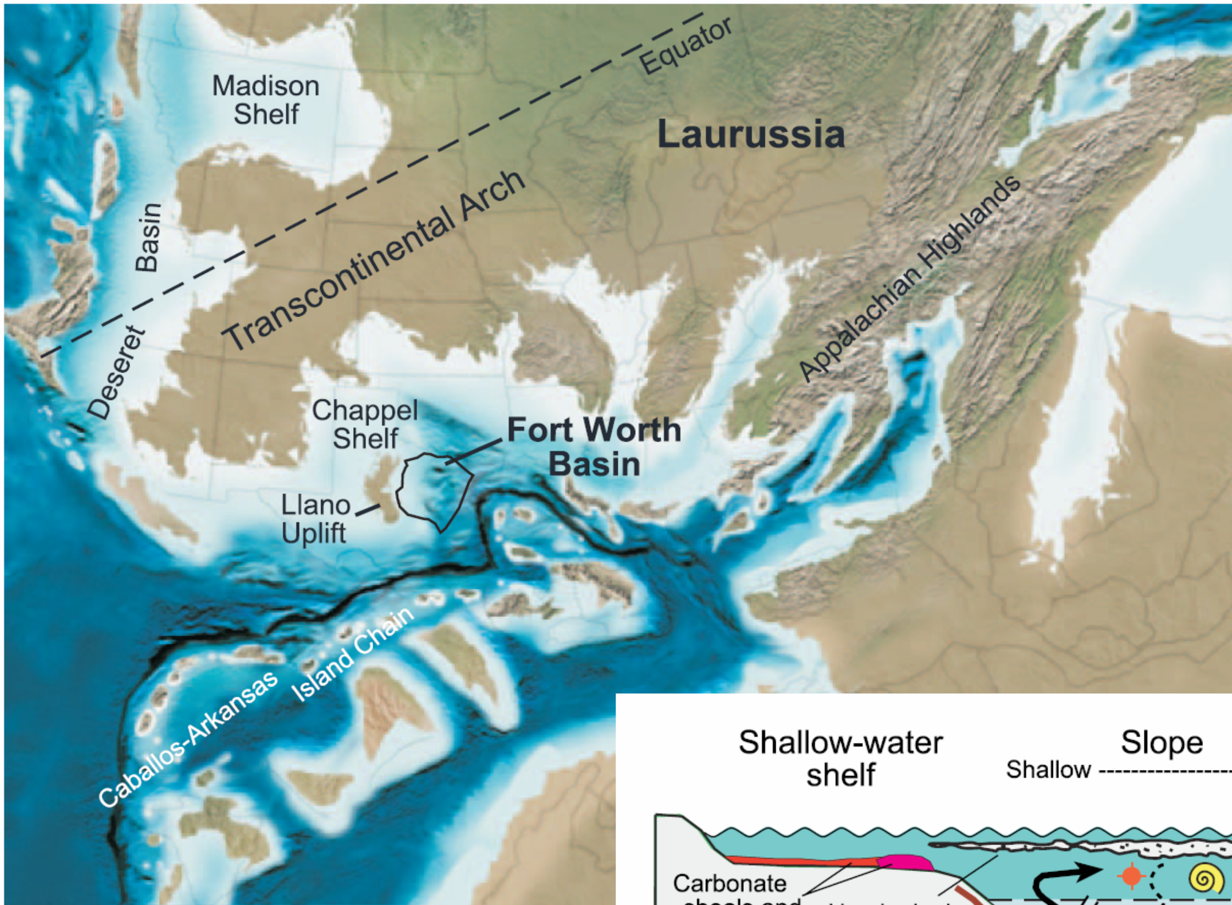
(from *America's Energy Future*) NAS - 2009

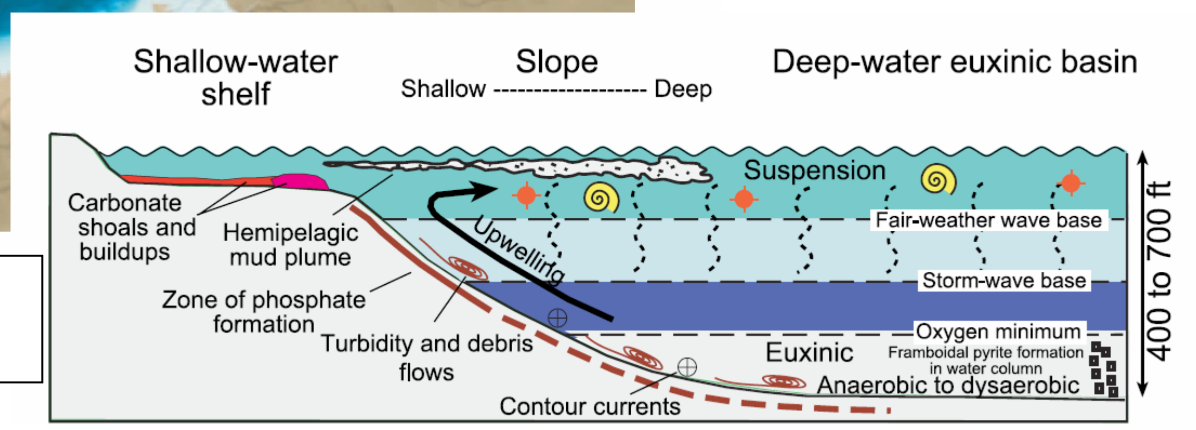
Gas And Coal Economics



(from *America's Energy Future*) NAS - 2009

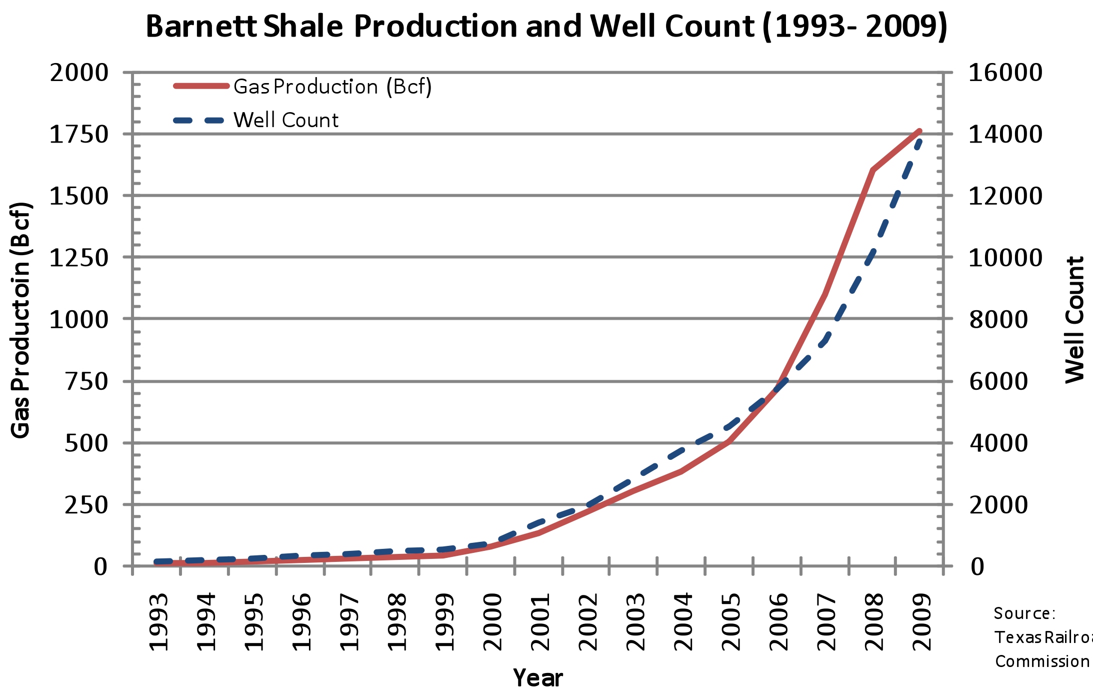
Organic Shales - Deep Water, Anaerobic /Clay Matrix



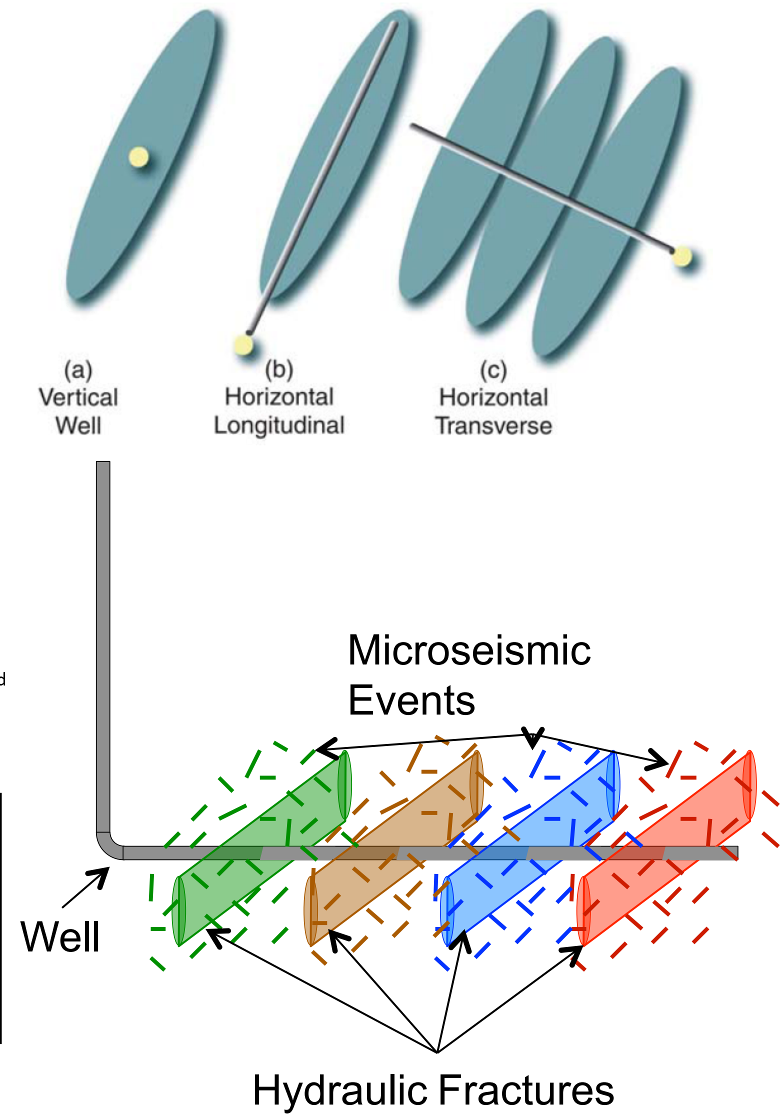


Organic Rich Source Rock
Extremely Low Permeability

Drilling/Completion Technology Key To Exploitation of Shale Gas

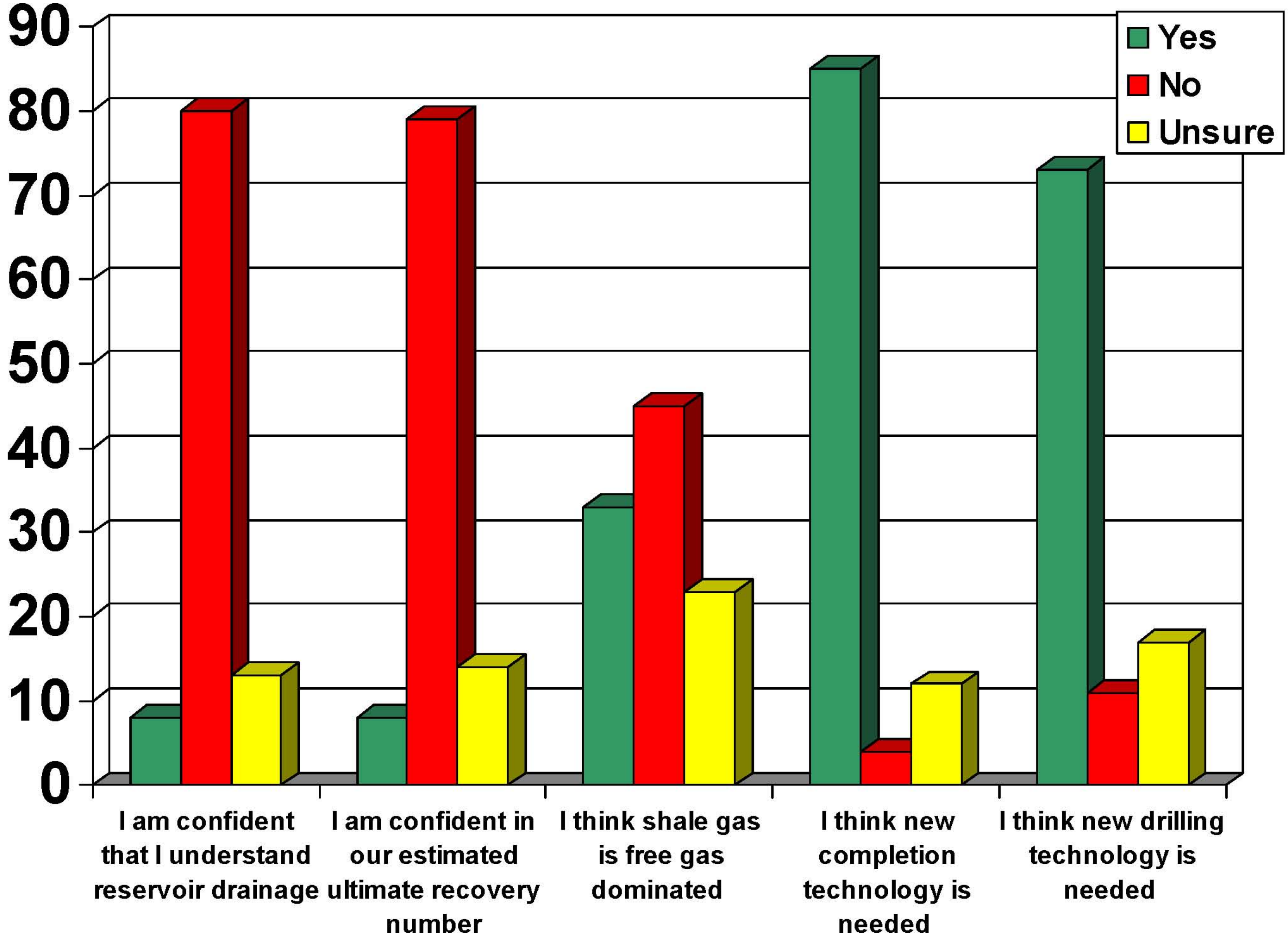


Source: Texas Railroad Commission



Horizontal Drilling and Multi-Stage
Slick-Water Hydraulic Fracturing
Induces Microearthquakes (M ~ -1 to M~ -3)
To Create a Permeable Fracture Network

Upstream Challenges

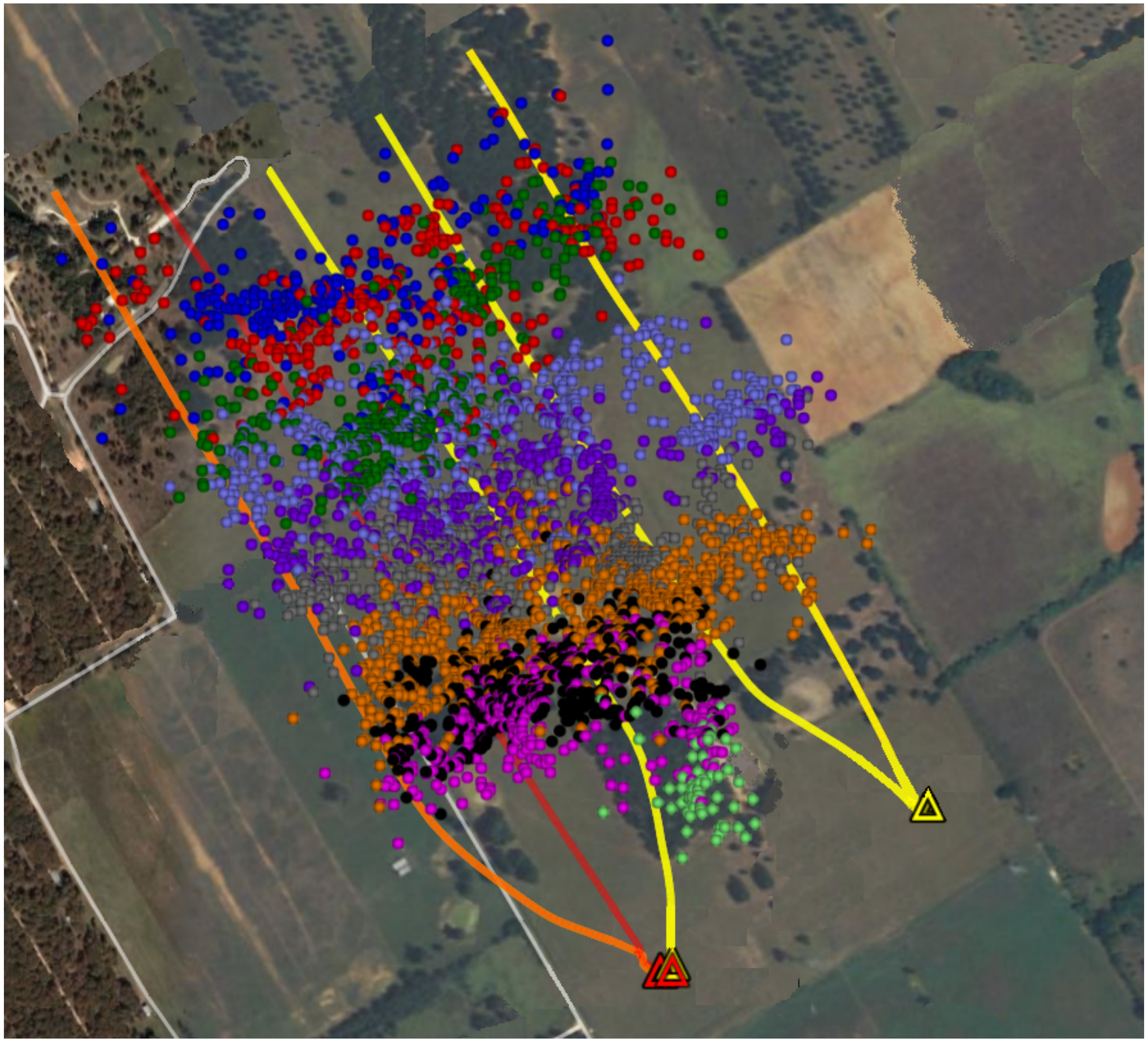


Briefly….

- How do rock properties affect the success of stimulation?
- How does hydraulic fracturing really stimulate production?
- What factors affecting ultimate recovery?
- How do we minimize the environmental impact of shale gas development?

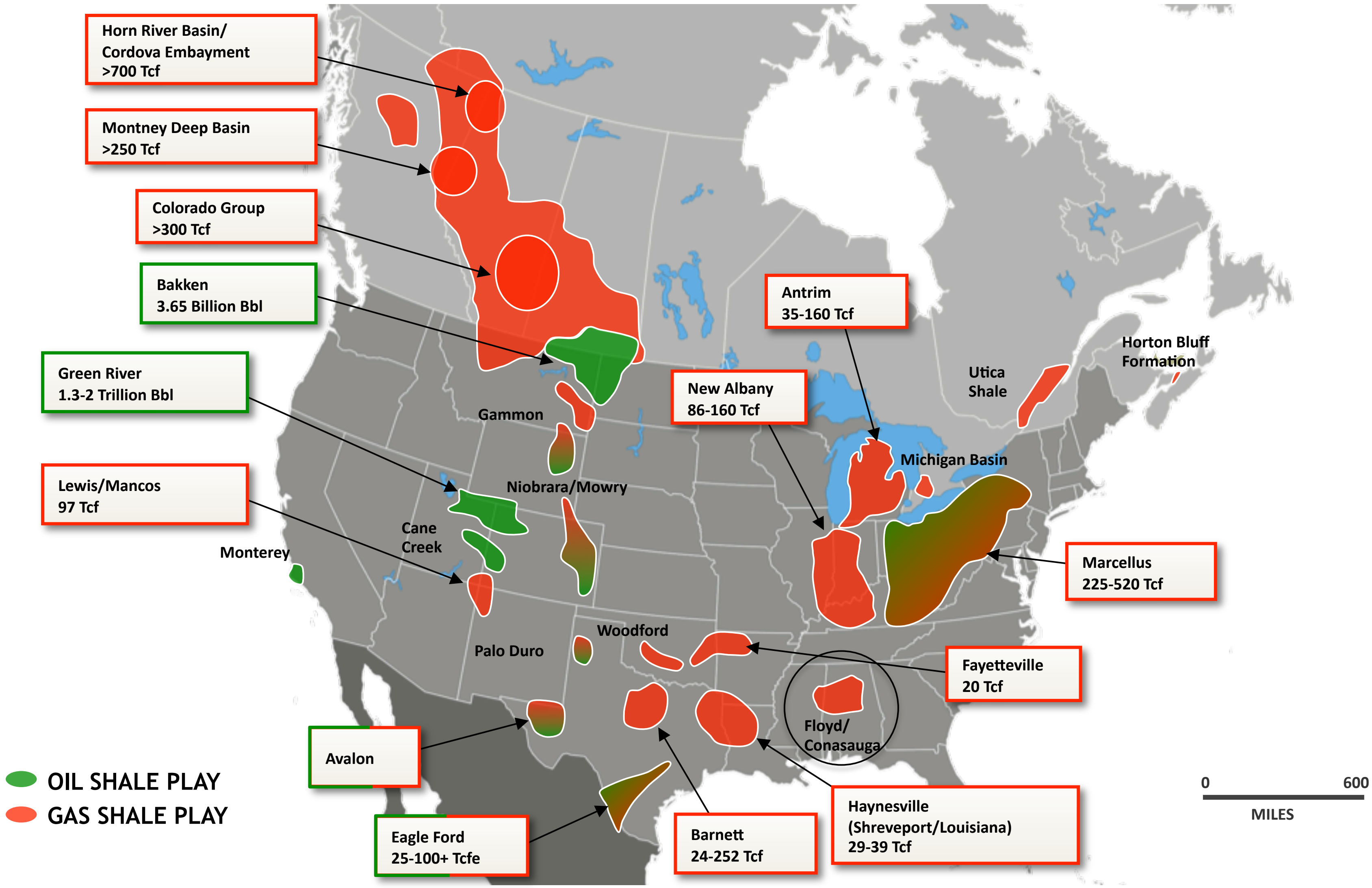
Physical and Chemical Properties of Organic Rich Shales

How Do the Properties of Shale Affect the Outcome of Hydraulic Fracturing Stimulation?



5 Wells, 40 Stages, ~4000 Microseismic Events

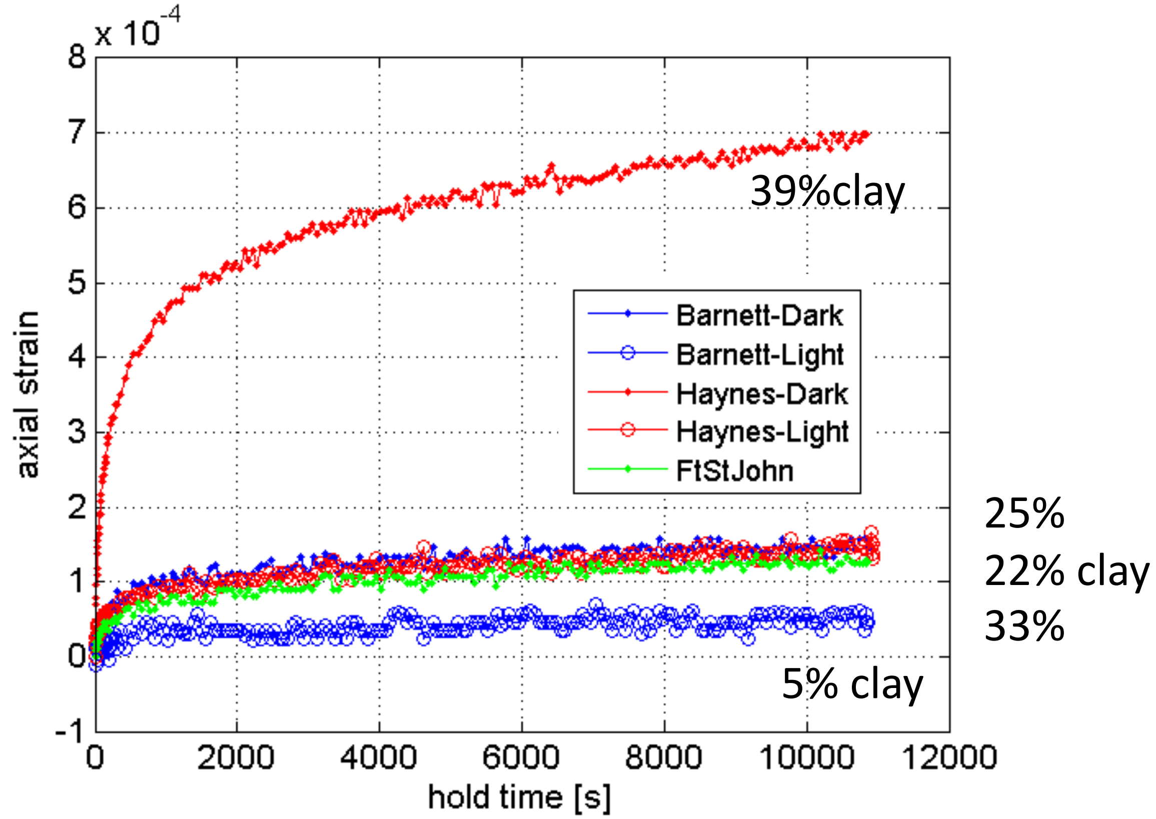
The Floyd Shale?

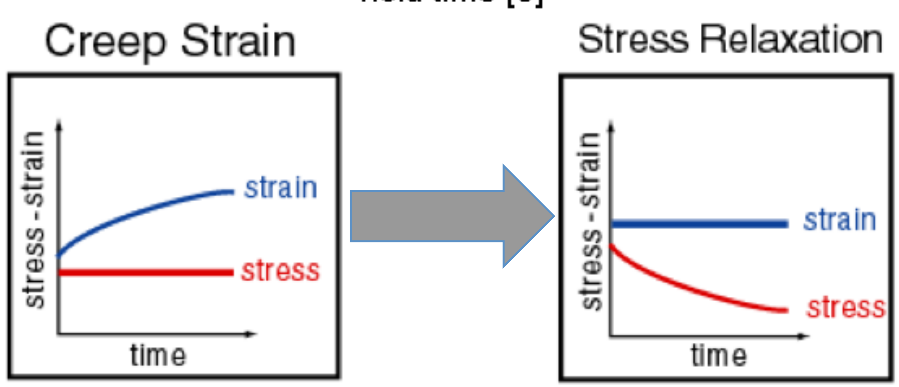


Organic Rich Shales are Viscoplastic

Sample group	Clay	Carbonate	QFP	TOC (wt%)
Barnett-dark	29-43	0-6	48-59	4.1-5.8
Barnett-light	2-7	37-81	16-53	0.4-1.3
Haynesville-dark	36-39	20-23	31-35	3.7-4.1
Haynesville-light	20-22	49-53	23-24	1.7-1.8
Fort St. John	32-39	3-5	54-60	1.6-2.2
Eagle Ford-dark	12-21	46-54	22-29	4.4-5.7
Eagle Ford-light	6-14	63-78	11-18	1.9-2.5

Is the Floyd Shale too Viscous to Stimulate?





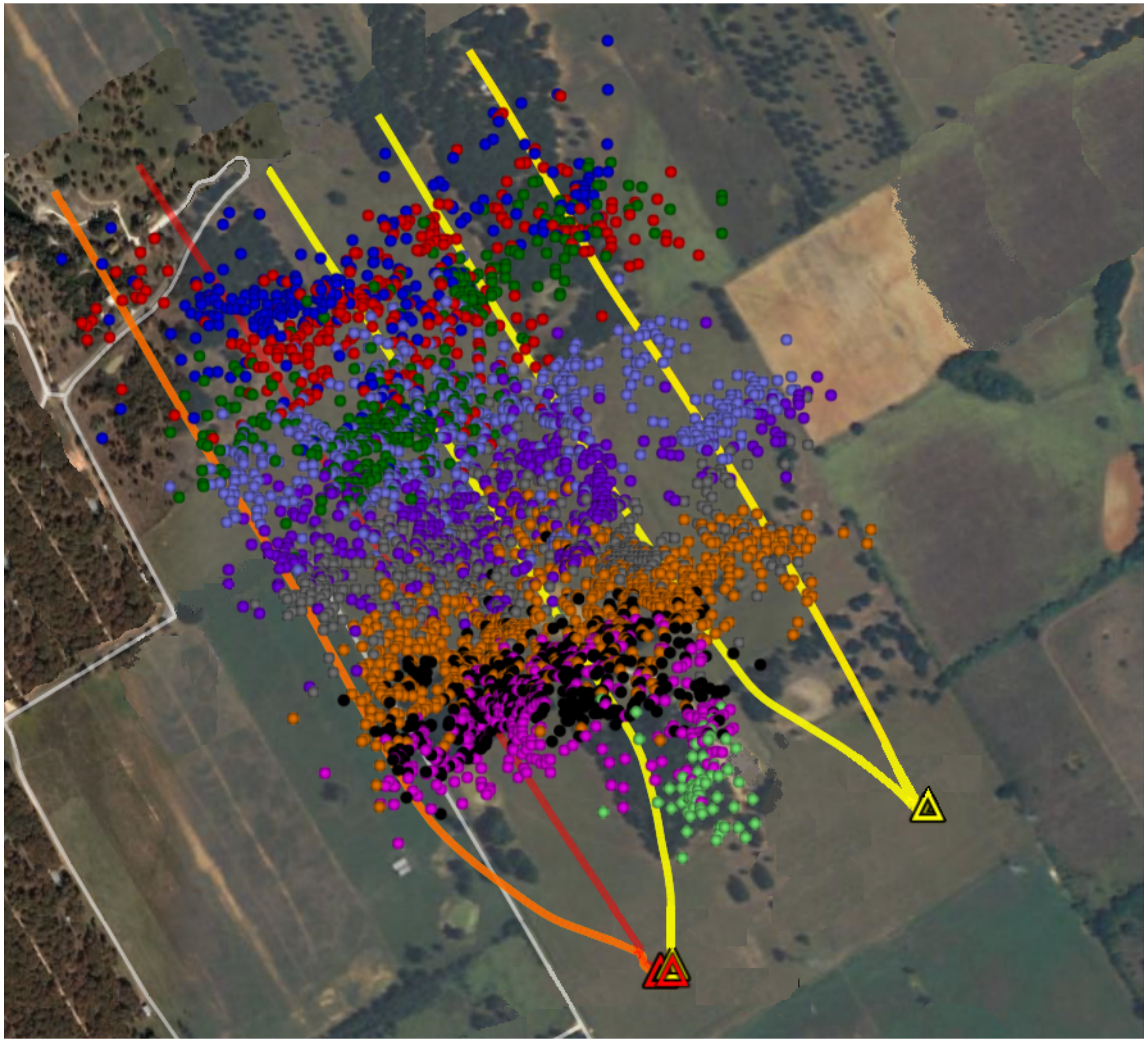
Average Shale Properties

	BARNETT	MARCELLUS	EAGLE FORD	FLOYD
Depth (ft)	3 - 9,000	2 - 9,500	4 - 13,500	6 - 13,000
TOC (%)	1 - 10	1 - 15	2 - 7	1 - 7
RO (%)	0.7 - 2.3	0.5 - 4+	0.5 - 1.7	0.7 - 2+
Porosity (%)	2 - 14	2 - 15	6 - 14	1 - 12
Qtz + Calcite (%)	40 - 50	40 - 60	50 - 80	20 - 30
Clay (%)	20 - 40	30 - 50	15 - 35	45 - 65
Areal Extent (mi^2)	22,000	60,000	15,000	6,000
Resource Size (Tcf)	25 - 250	50 - 500	10 - 100	<<1

How many Floyd Shales are Out There?

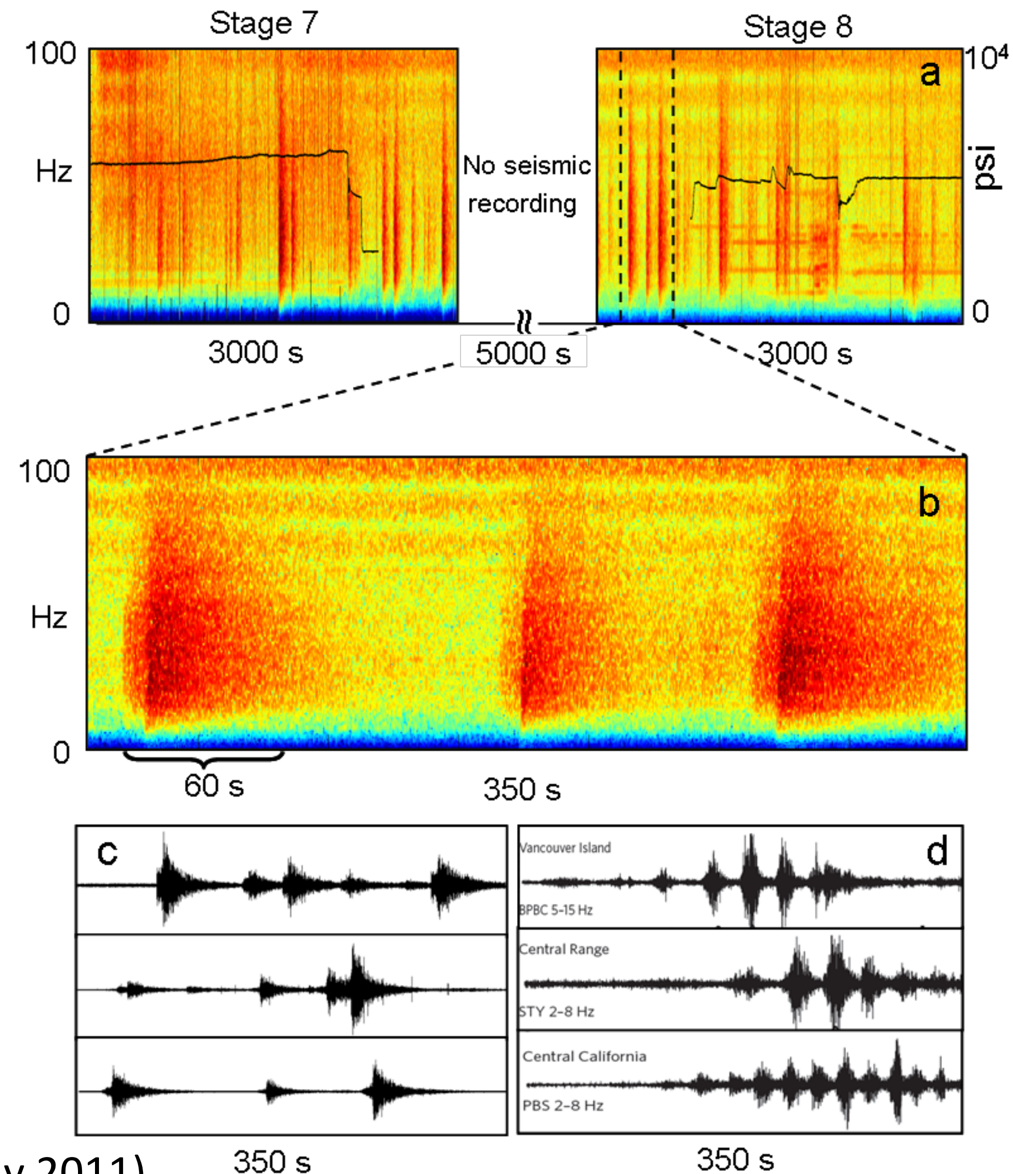
Stimulation Challenge - ???

Volume Affected by Microearthquakes Can Account for Less Than 1% of Gas Production in First 6 Months



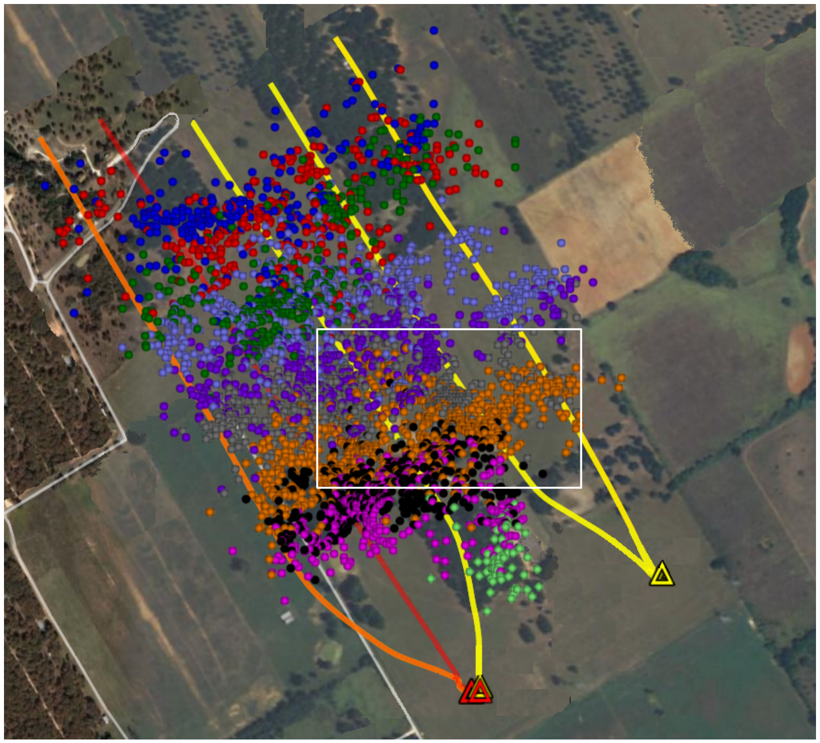
5 Wells, 40 Stages, ~4000 Microseismic Events

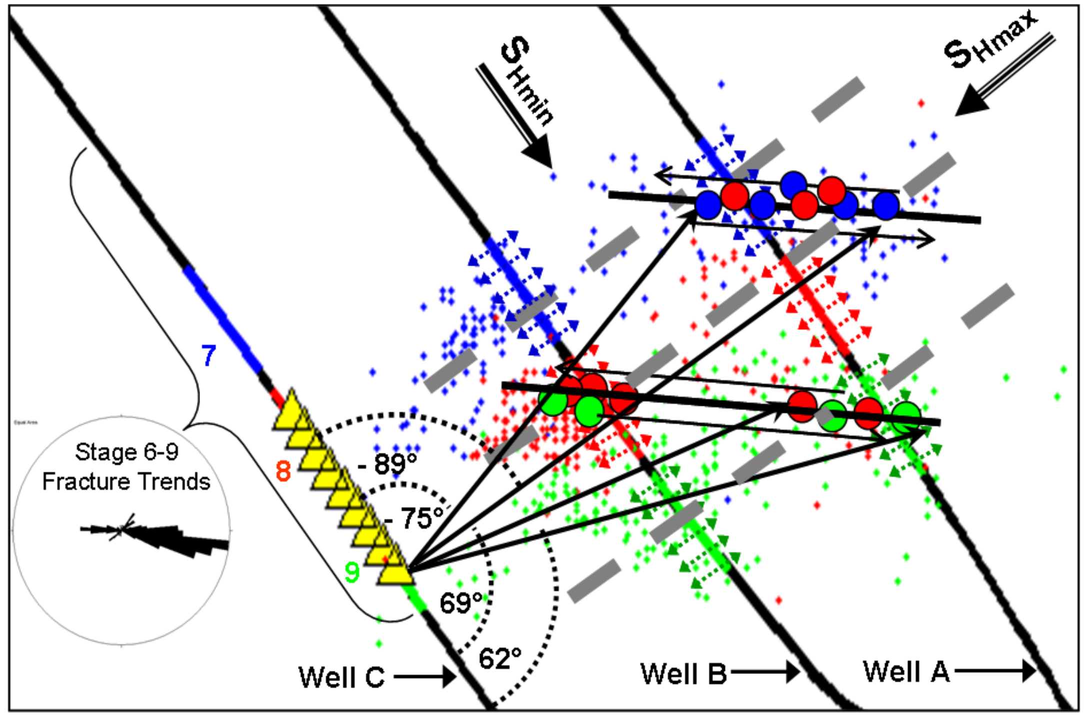
Long Period Long Duration Seismic Events



Das and Zoback,
The Leading Edge (July 2011)

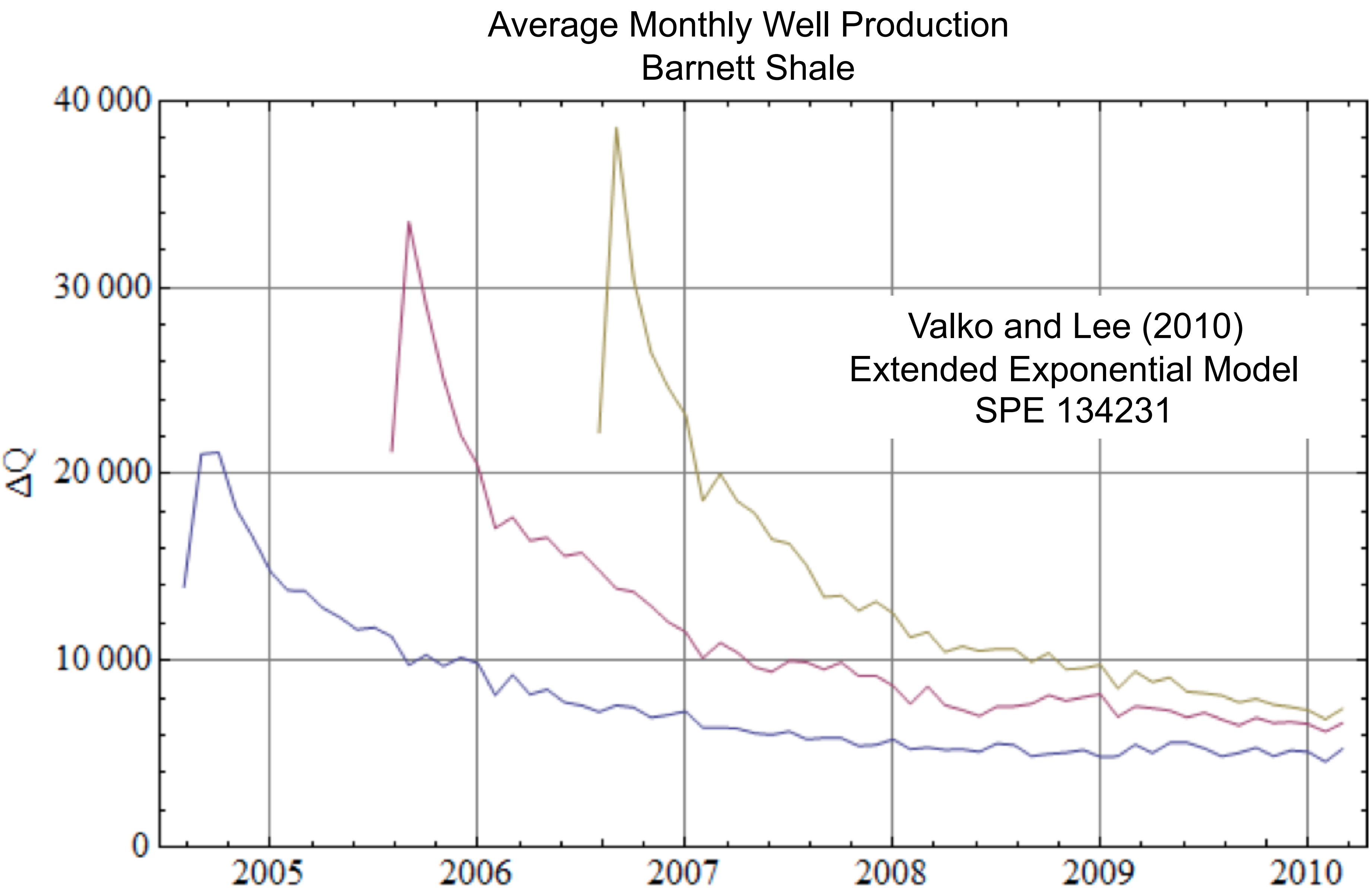
Most Deformation Within the Reservoir During Hydraulic Fracturing is Aseismic





Das and Zoback,
The Leading Edge (July 2011)

Production Challenge - EUR?

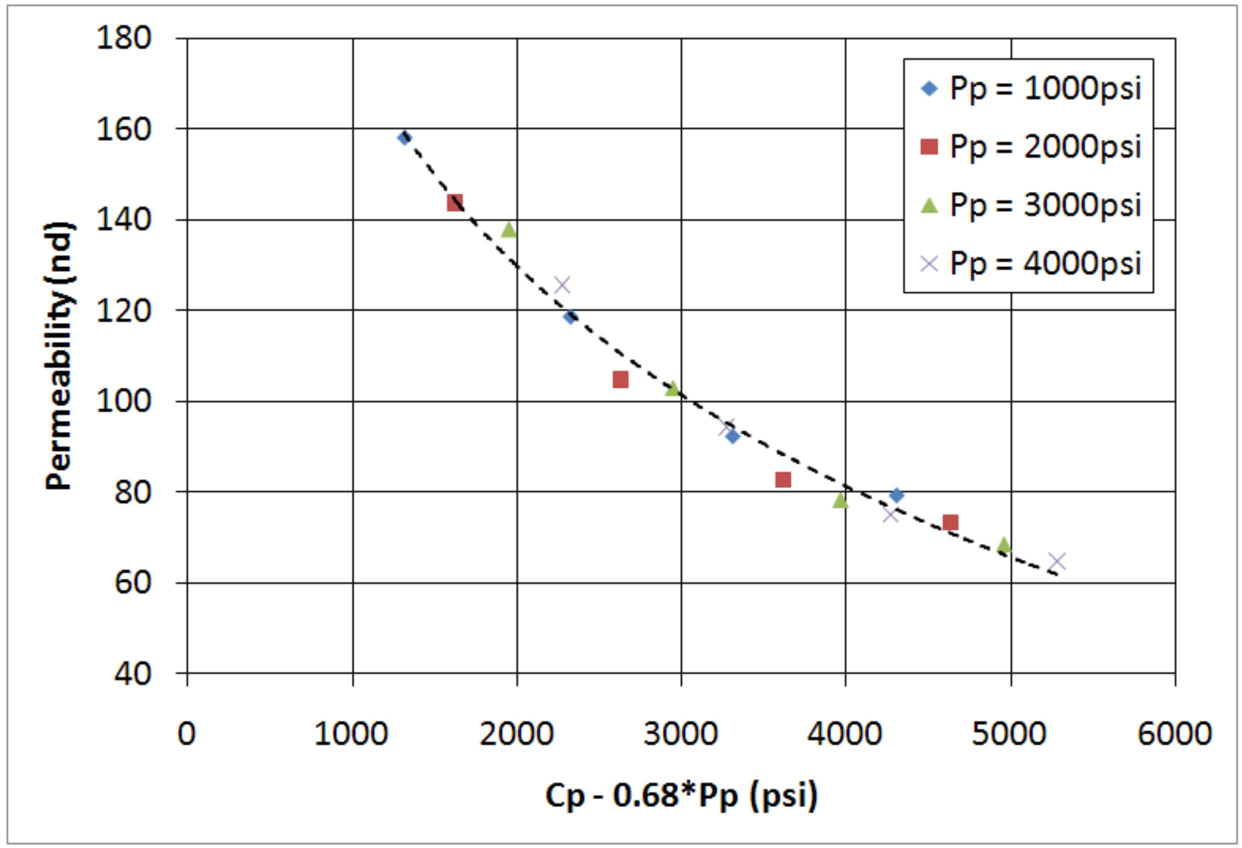


Barnett Shale Permeability

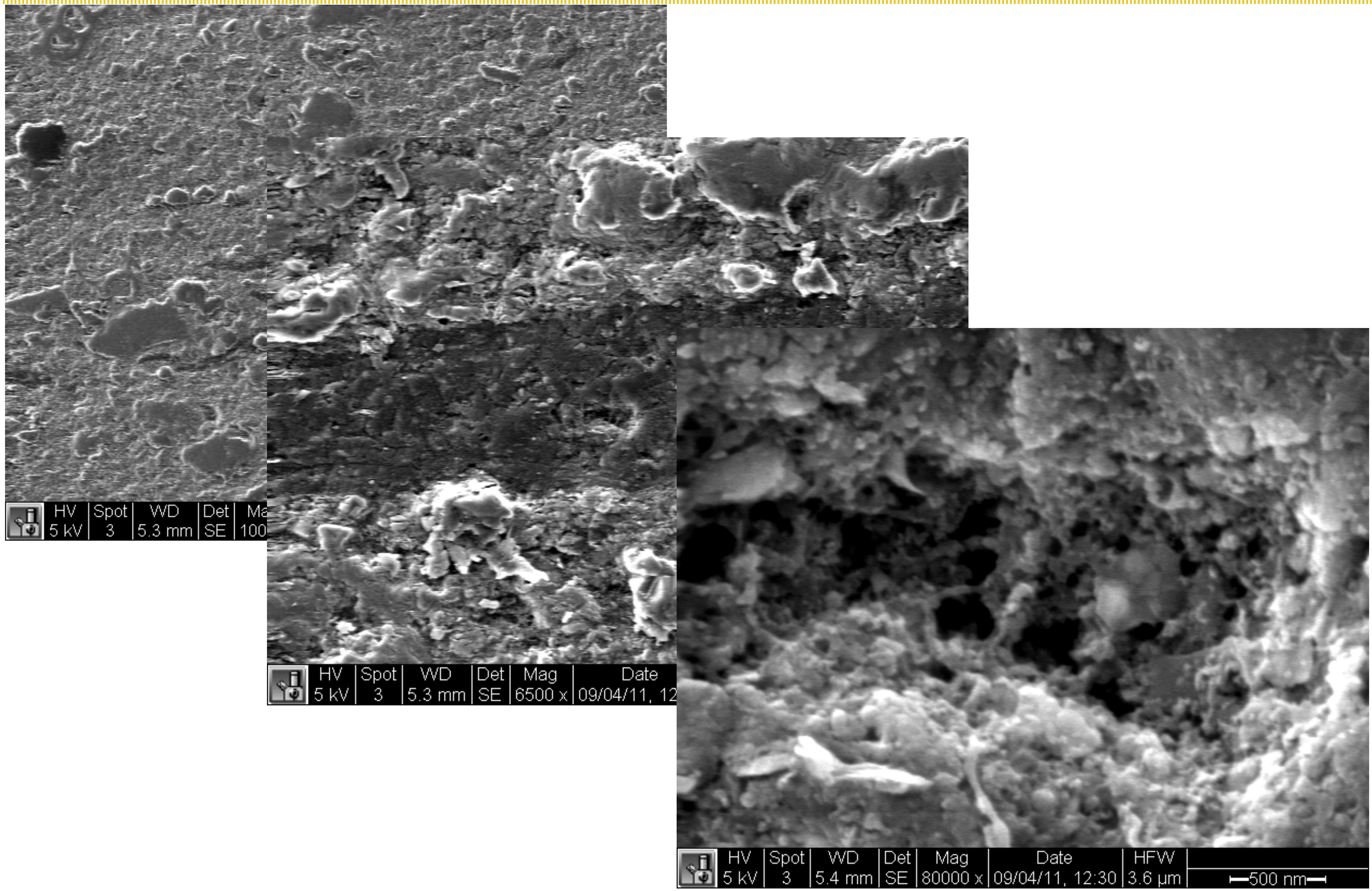
Barnett Shale 31Ha

- Typical dark, organic-rich sample
- 51.3% qtz, 0.4% carbonate, 37.4% clay, 5.3% TOC
- Density porosity: 10.7%

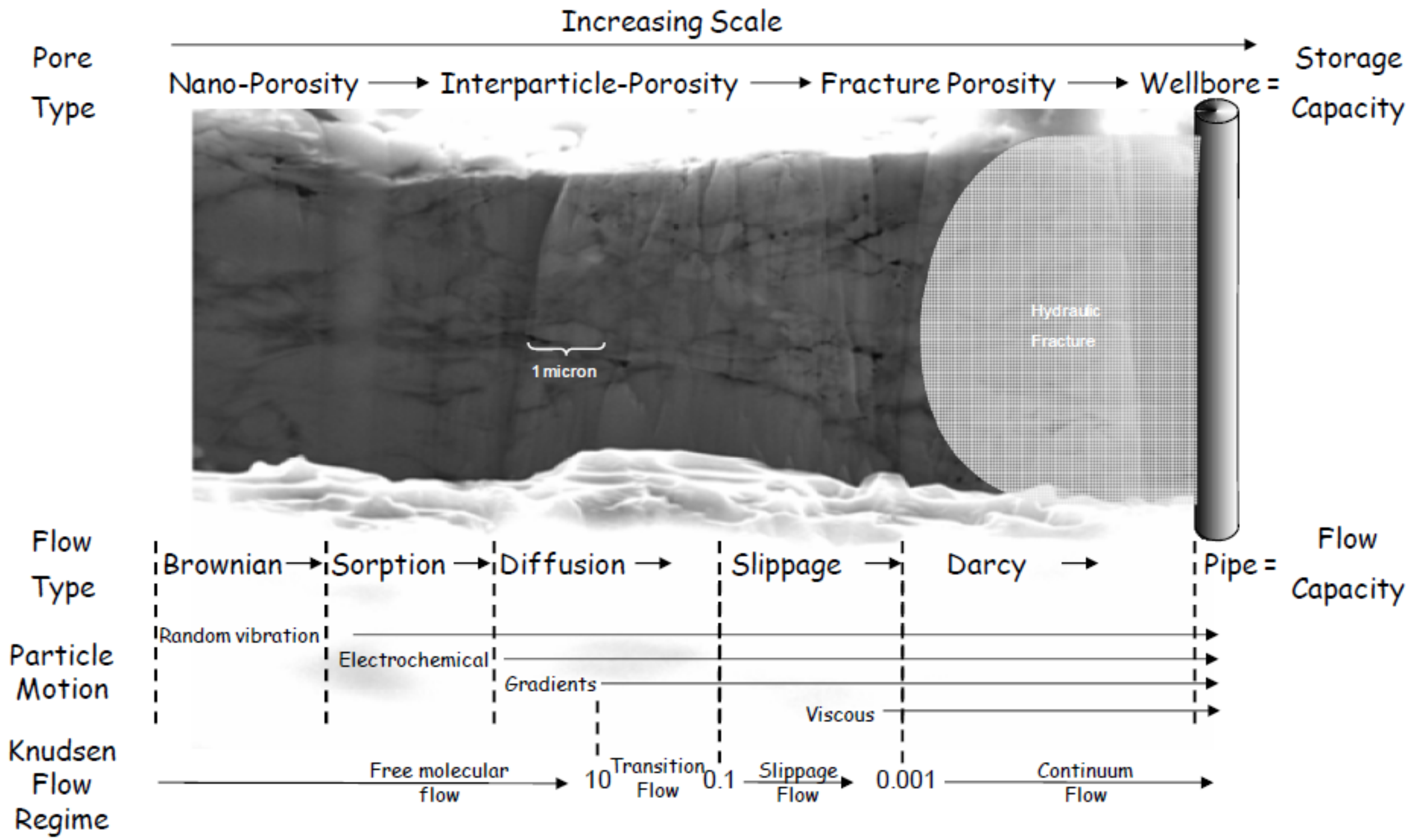
Best Fit Effective Stress Coefficient: χ = 0.68



Eagleford Shale Pore Structure

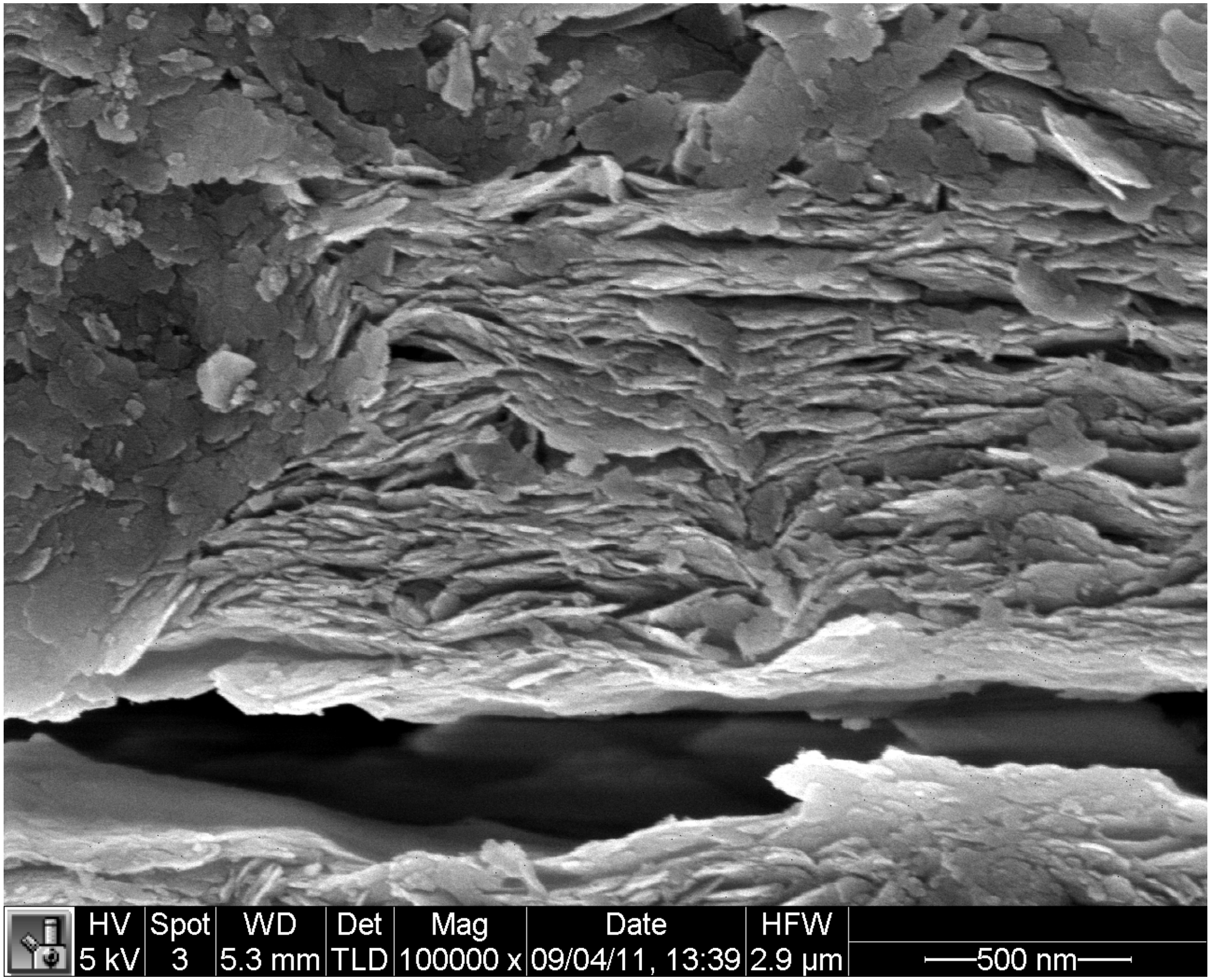


Scale Dependent Flow Mechanisms

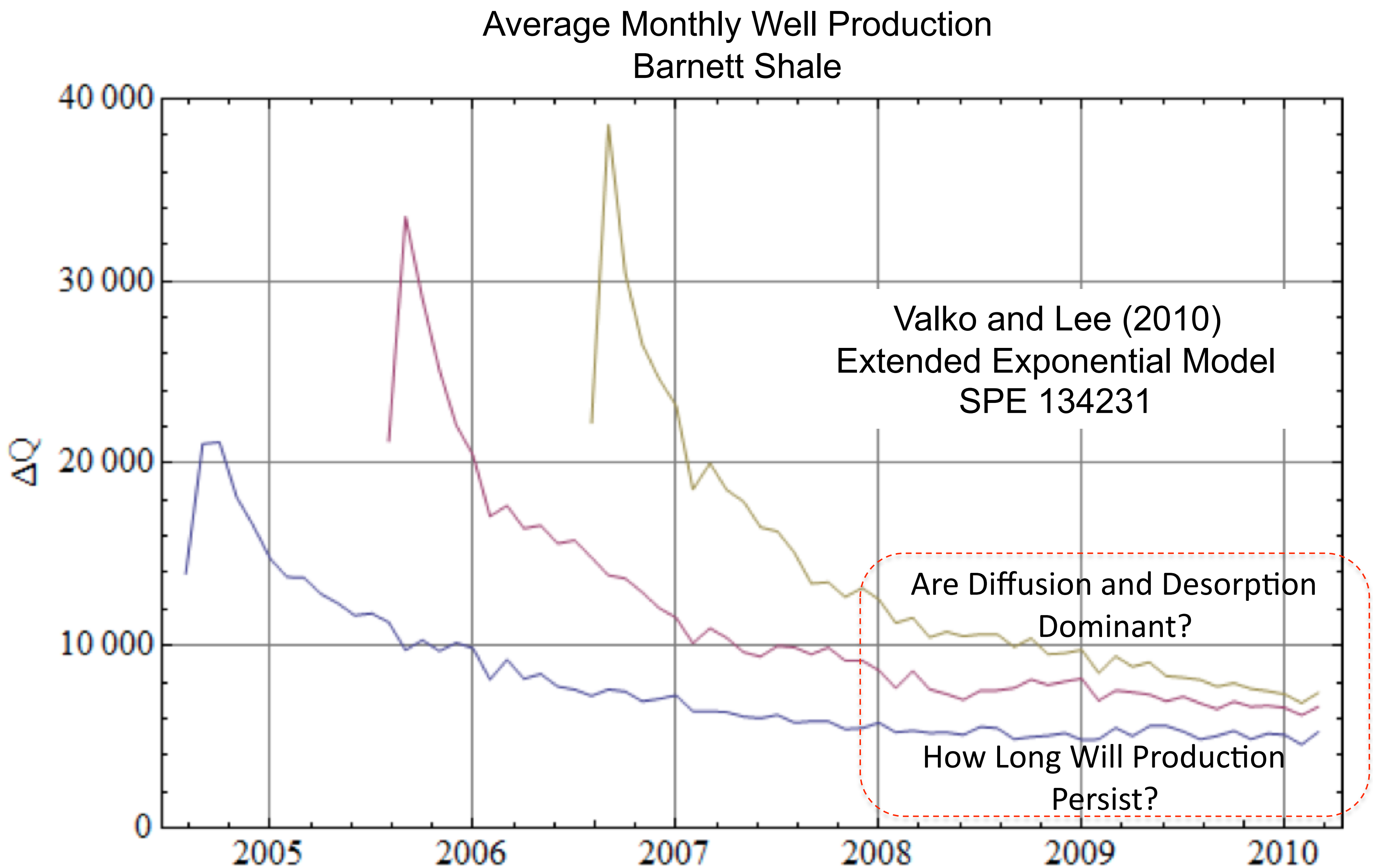


Sondergeld et al., 2010

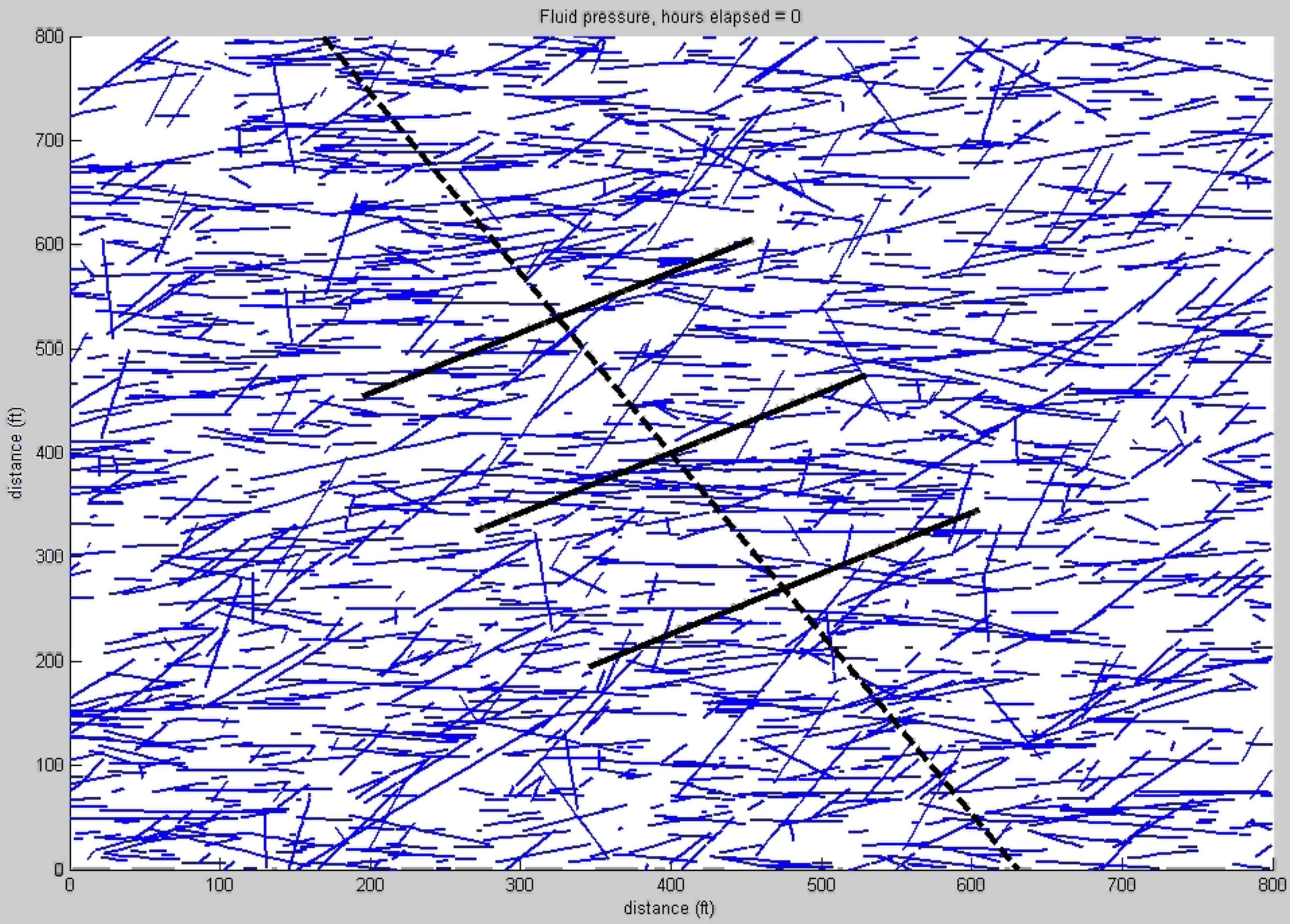
Eagleford Shale



Why Is Production Persistent?



Evolution of Aseismic Slip in Reservoirs



Environmental Issues

- Surface Contamination
- Gas Leakage From Wells
- Disposal of Flow-back Waters
- Hydraulic Fracturing Affecting Well Water
- Earthquake Triggering Associated with Injection of Flow-back Water
- Impacts on Residents and Land Use

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Secretary of Energy Advisory Board

Shale Gas Production Subcommittee 90-Day Report

August 18, 2011

U.S. DEPARTMENT OF ENERGY

Secretary of Energy Advisory Board

Shale Gas Production Subcommittee Second Ninety Day Report

November 18, 2011

U.S. DEPARTMENT OF ENERGY

DOE Shale Gas Subcommittee

- John Deutch – MIT
- Stephen Holditch – Texas A&M
- Fred Krupp – Environmental Defense Fund
- Katie McGinty – Pennsylvania DEP
- Sue Tierney – Massachusetts Energy
- Dan Yergin – Cambridge Energy Research
- Mark Zoback - Stanford

New DOE Committee

Secretary Chu Tasks Environmental, Industry and State Leaders to Recommend Best Practices for Safe, Responsible Development of America's Onshore Natural Gas Resources

President Obama directed Secretary Chu to convene this group as part of the President's "Blueprint for a Secure Energy Future"

"**Setting the Bar for Safety and Responsibility:** To provide recommendations from a range of independent experts, the Secretary of Energy, in consultation with the EPA Administrator and Secretary of Interior, should task the Secretary of Energy Advisory Board (SEAB) with establishing a subcommittee to examine fracking issues. The subcommittee will be supported by DOE, EPA and DOI, and its membership will extend beyond SEAB members to include leaders from industry, the environmental community, and states. The subcommittee will work to identify, within 90 days, any immediate steps that can be taken to improve the safety and environmental performance of fracking and to develop, within six months, consensus recommended advice to the agencies on practices for shale extraction to ensure the protection of public health and the environment."

90 Day Report Summary

- Shale gas is extremely important to the energy security of the United States
- Shale gas currently accounts for 30% of the total US natural gas production
- Shale gas development has a large positive economic impact on local communities and states
- Shale gas development creates jobs
- Shale gas can be developed in an environmentally responsible manner.

90 Day Report Summary

- Protection of water quality-1: The Subcommittee urges adoption of a systems disclosure of the flow and composition of water at every stage of the shale gas production process.

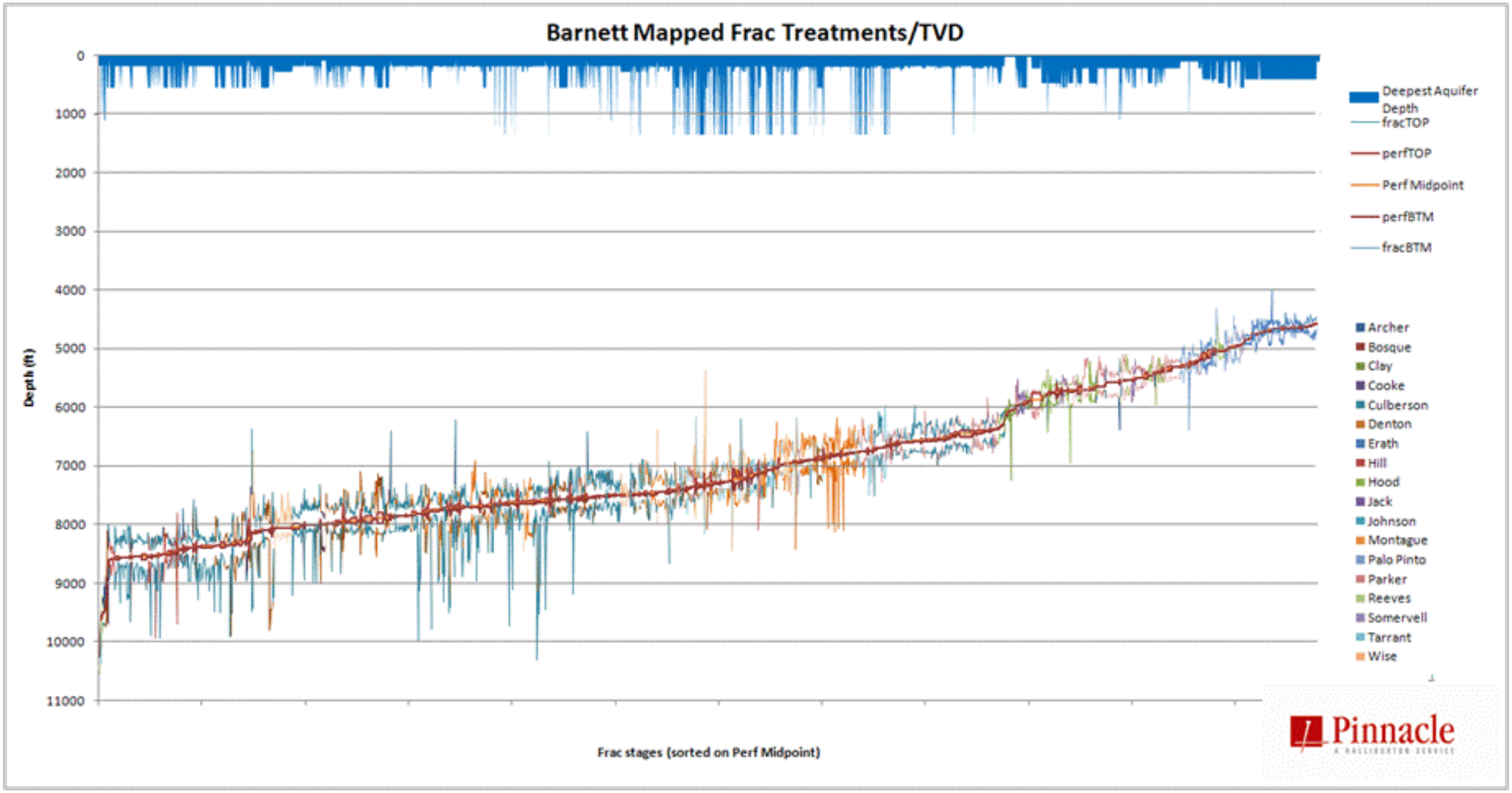
90 Day Report Summary

- Protection of water quality-2: Hydraulic Fracturing

Will Vertical Hydrofrac Growth Affect Water Supplies?

NO!
In nearly all active shale gas plays

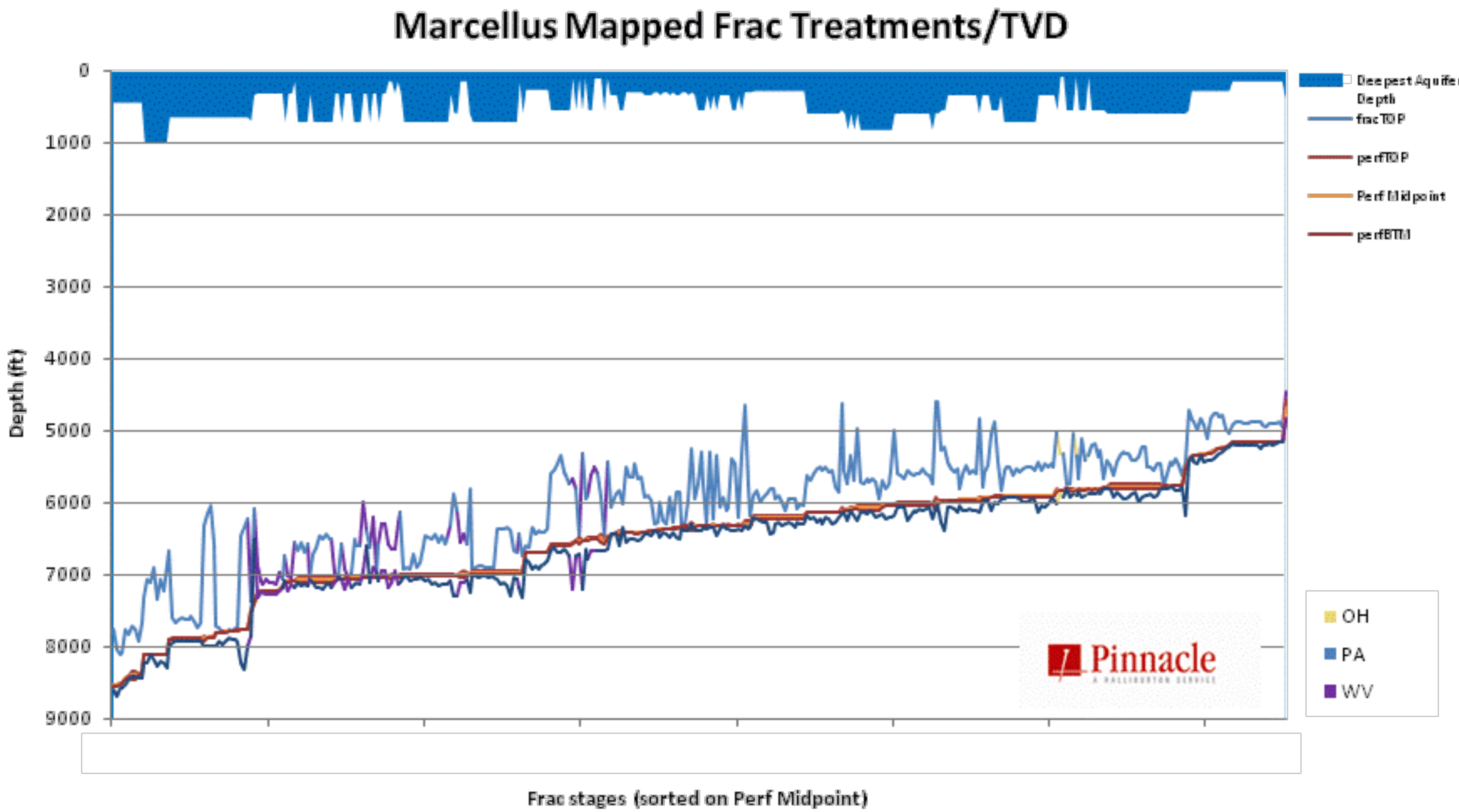
Depth of Affected Region Affected by Hydraulic Fracturing



Fisher (2010)

http://nwis.waterdata.usgs.gov/nwis/inventory

Depth of Affected Region Affected by Hydraulic Fracturing



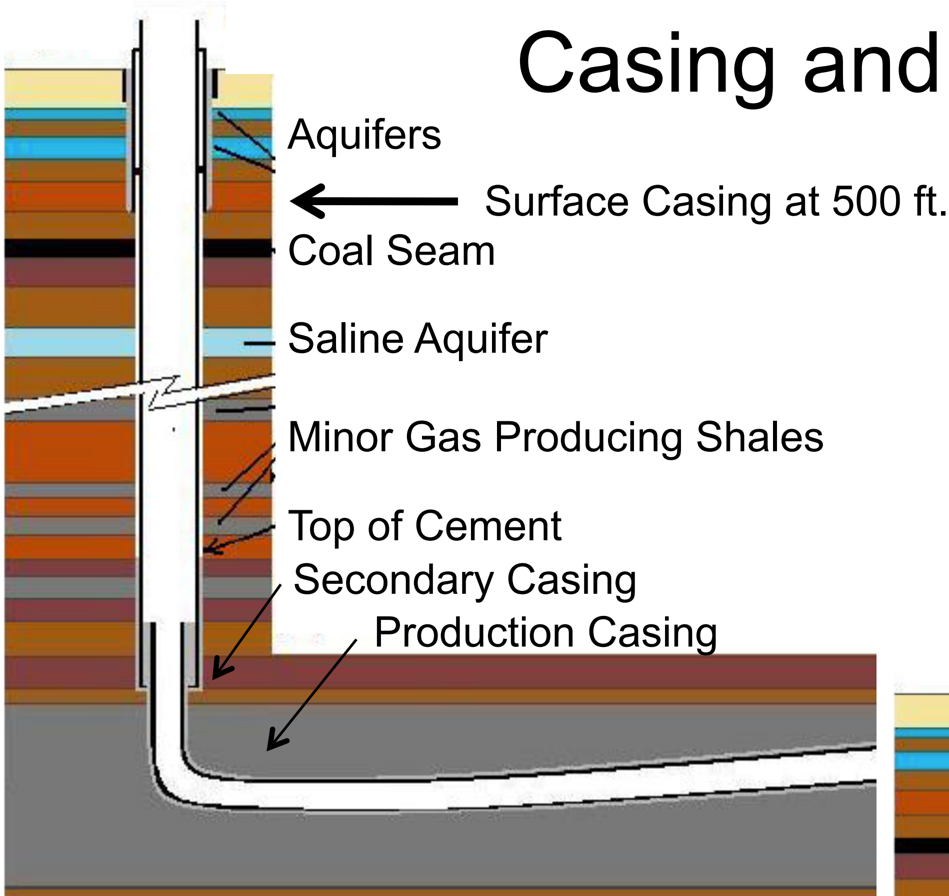
Fisher (2010) http://nwis.waterdata.usgs.gov/nwis/inventory

90 Day Report Summary

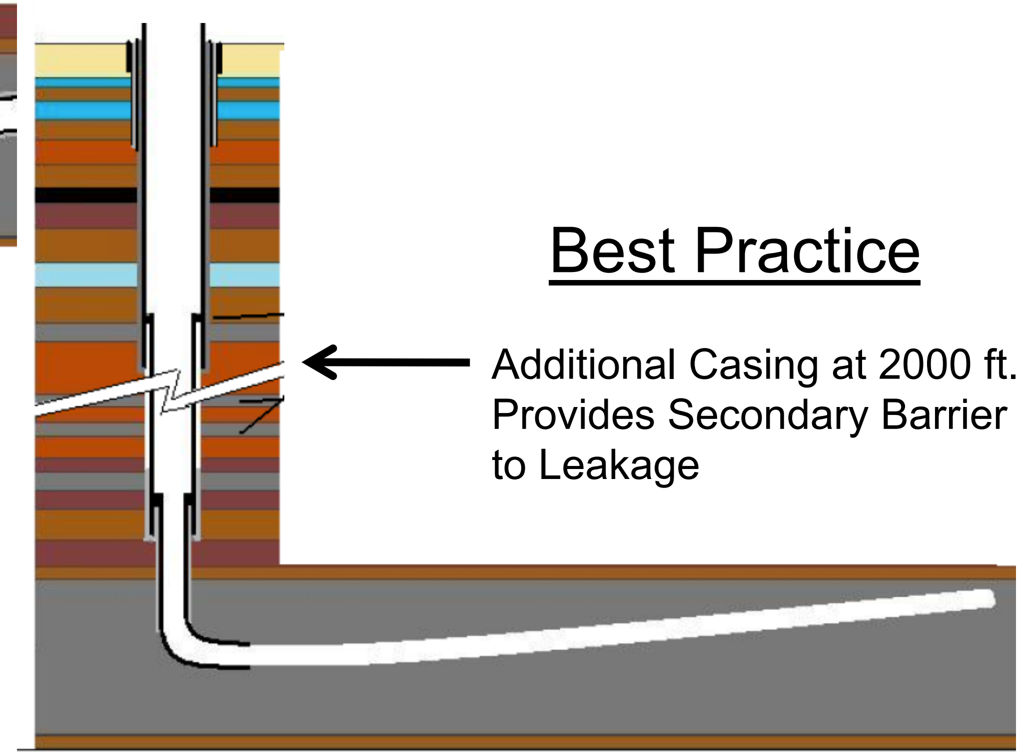
- Protection of water quality-3:
  - Adopt best practices in well development and construction, especially casing, cementing, and pressure management.

Casing and Cementing

API Recommended Practice



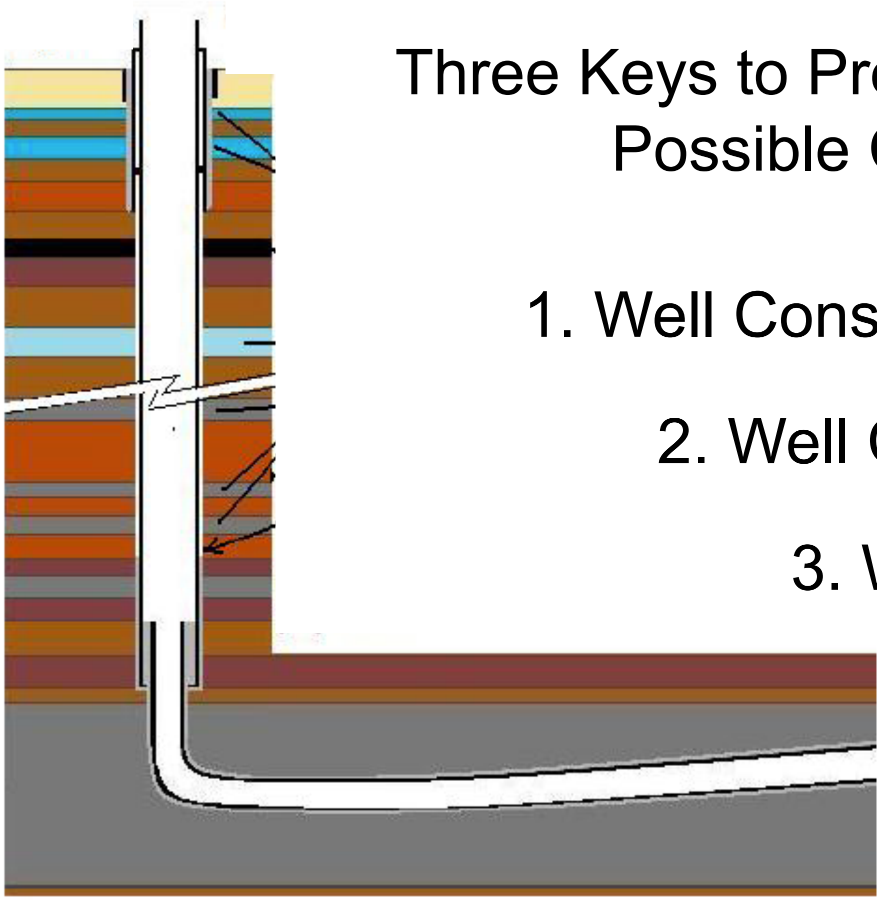
Best Practice



Courtesy George King, Apache Corp.

Range Resources
Washington County, Pennsylvania

Three Keys to Preventing Leakage and Possible Contamination



1. Well Construction

2. Well Construction

3. Well Construction

Best Practice and Regulation Must Reflect Local Conditions

Courtesy George King, Apache Corp.

90 Day Report Summary

- Protection of water quality-4:
  - Water use and water disposal issues are changing rapidly

Water Recycling – Western Pennsylvania

Utilization/Disposal of Saline Water

Figure 13. The Apache 34 pad in the Horn River Development of Northern British Colombia is a total of 6.3 acres where twelve multiple fractured horizontal wells recover gas from approximately 5000 acres.

Courtesy George King, Apache Corp.

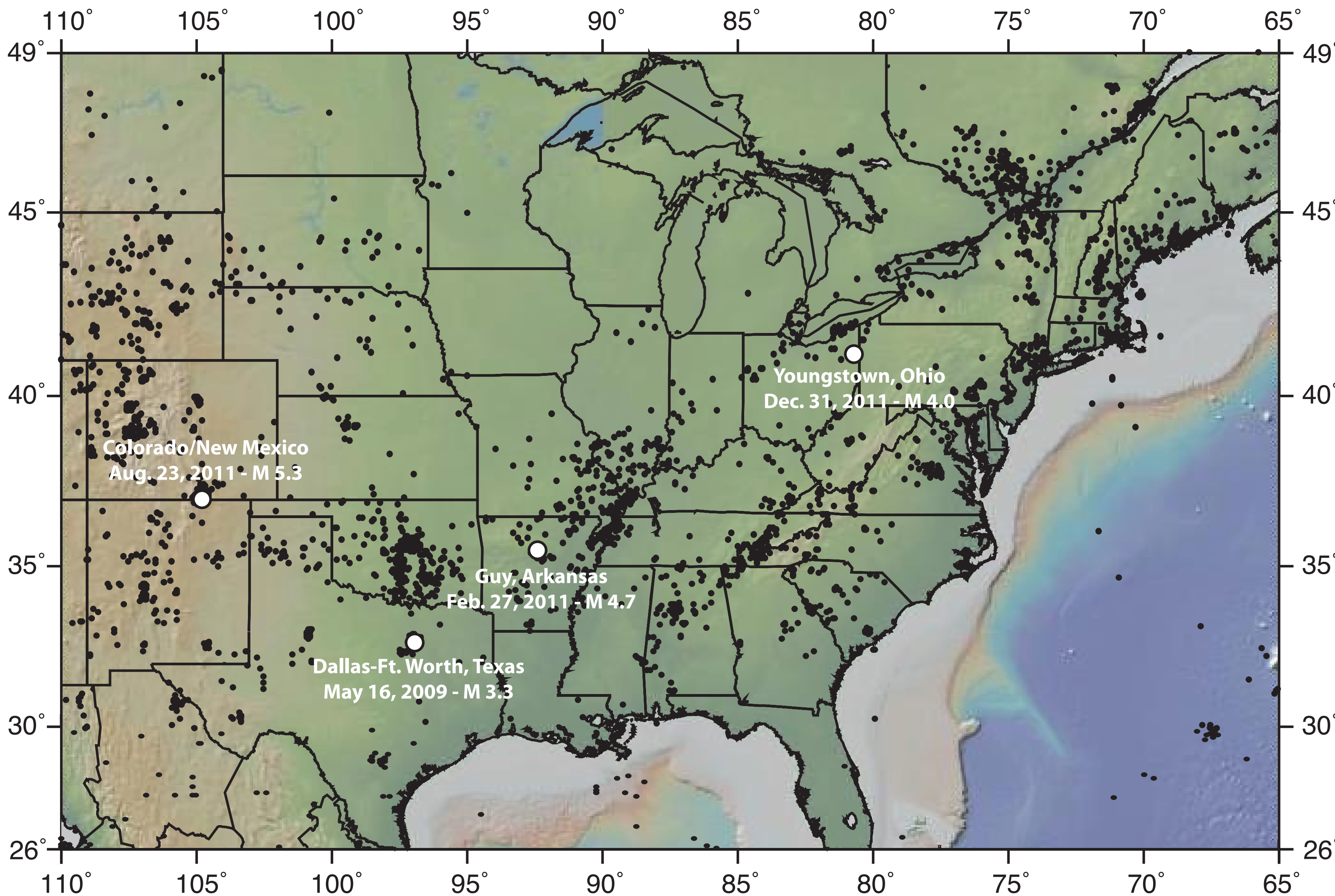
90 Day Report Summary

- Managing cumulative impacts on communities, land use, wildlife, and ecologies.

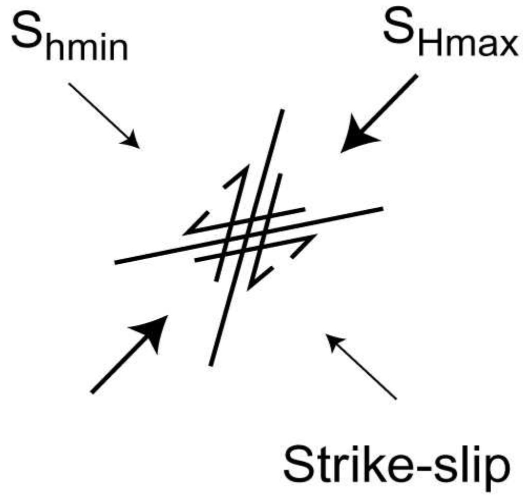
- Organizing for best practice: The Subcommittee recommends the creation of a shale gas industry production organization dedicated to continuous improvement of best practice

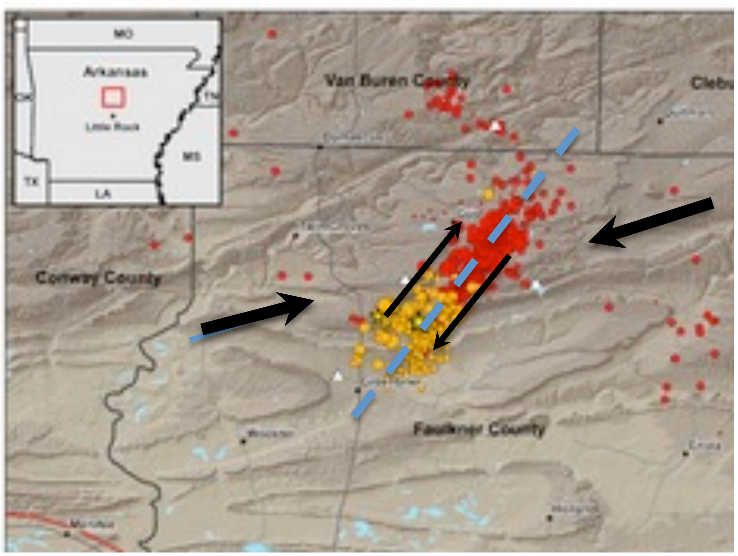
http://www.shalegas.energy.gov/

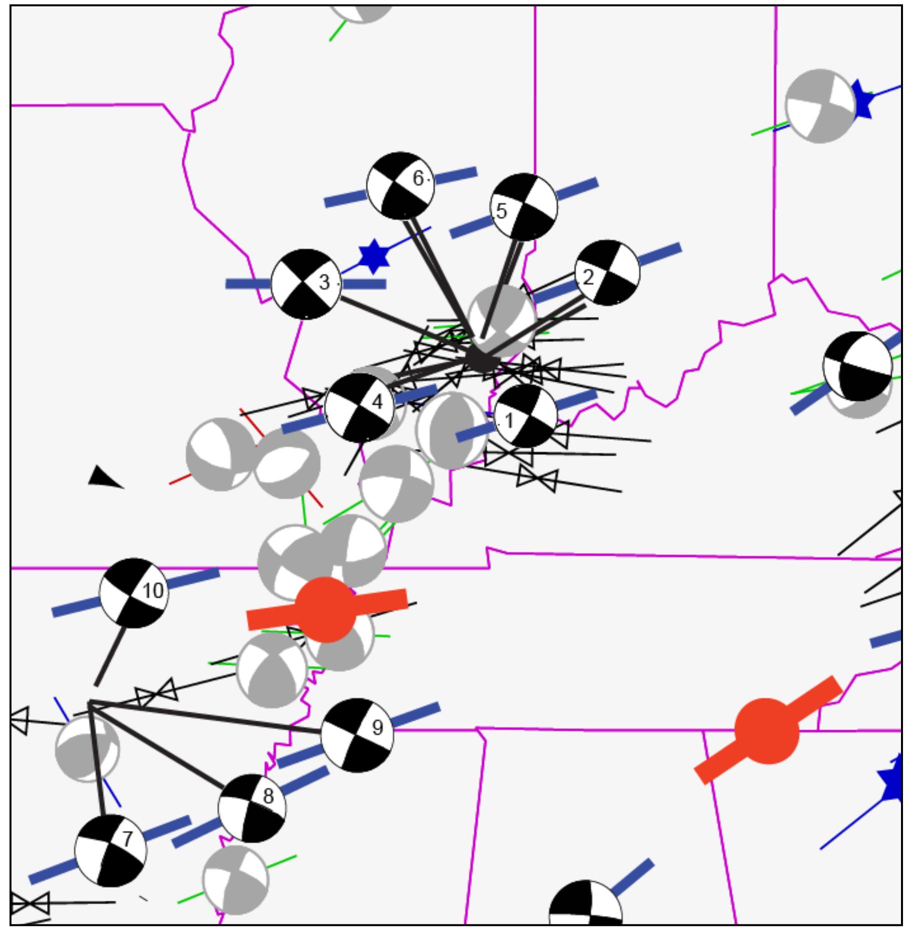
Earthquakes Triggered by Fluid Injection



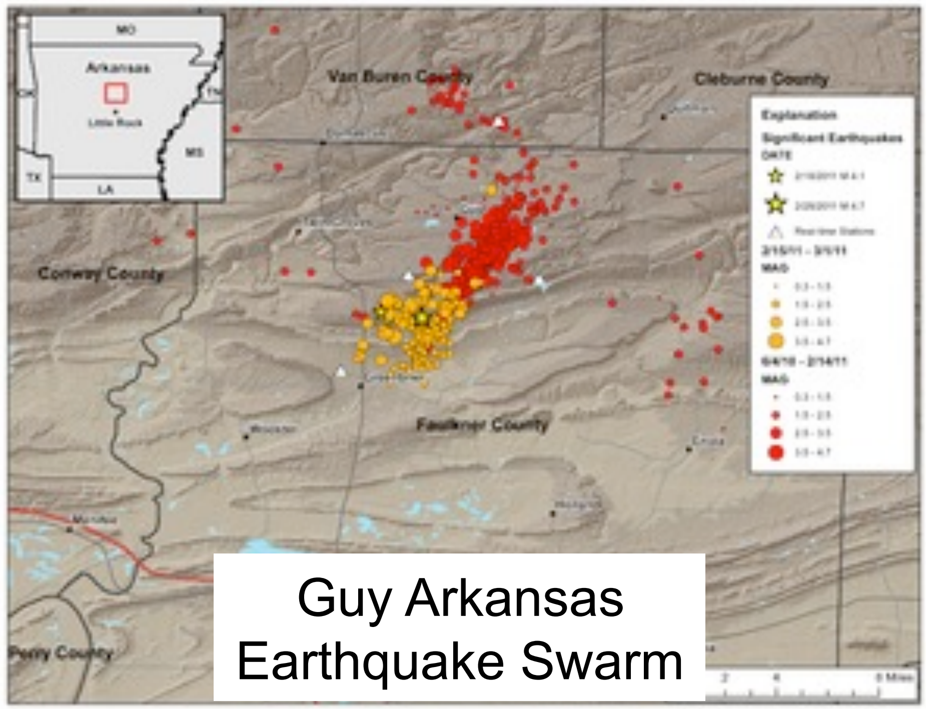
Triggered Earthquakes Guy, Arkansas





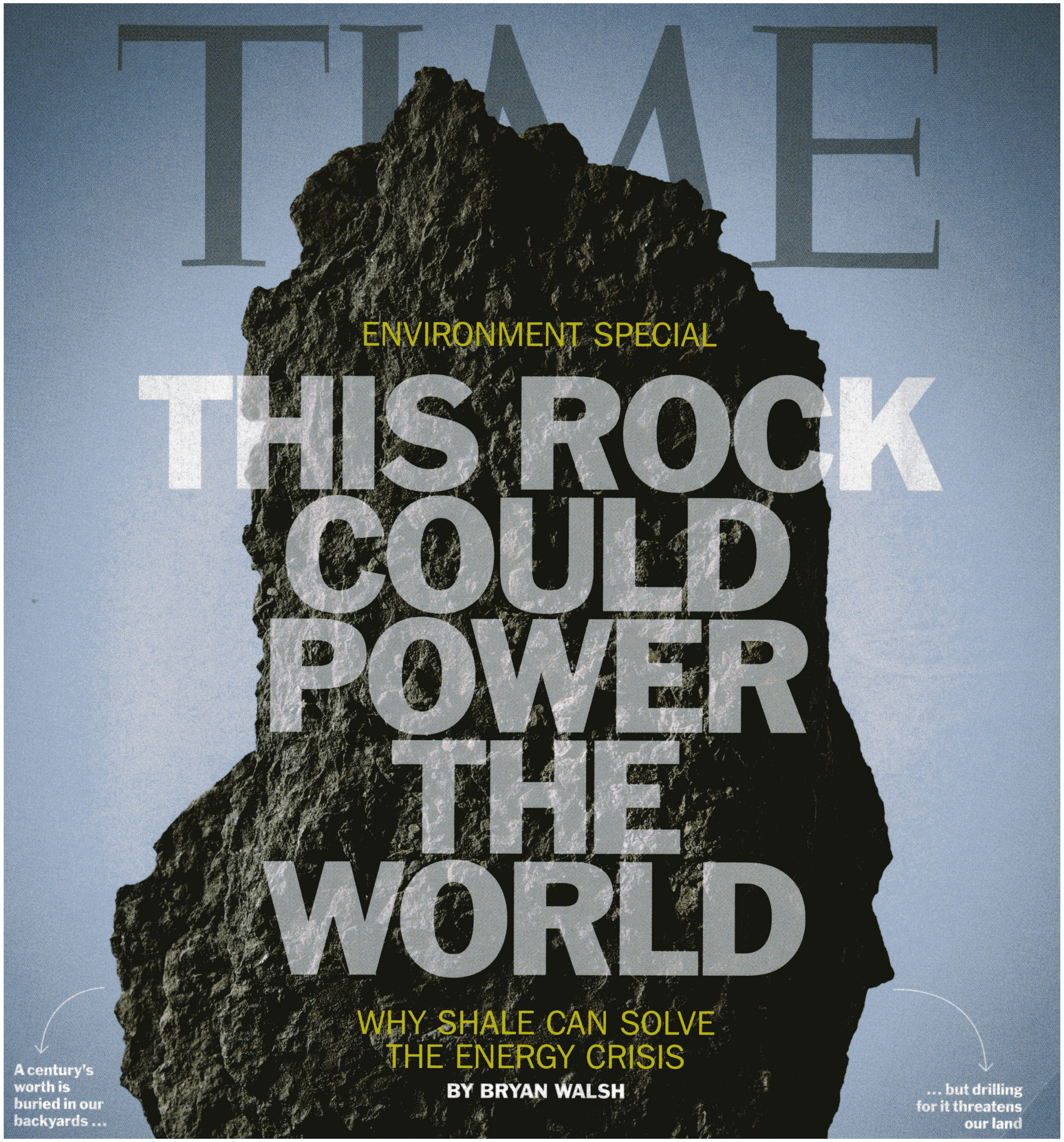


Managing Triggered Seismicity



Guy Arkansas
Earthquake Swarm

- Avoid Injection into Potentially Active Faults,
- Limit Injection Rates (Pressure) Increases,
- Monitor Seismicity (When Appropriate)
- Be Prepared to Abandon Some Injection Wells


TIME
ENVIRONMENT SPECIAL
THIS ROCK COULD POWER THE WORLD
WHY SHALE CAN SOLVE THE ENERGY CRISIS
BY BRYAN WALSH
A century's worth is buried in our backyards ...
... but drilling for it threatens our land

But we still have a lot of work to do!