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

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The Shale Gas Miracle
A Tribute to George P. Mitchell

The Academy of Medicine, Engineering and Science of Texas
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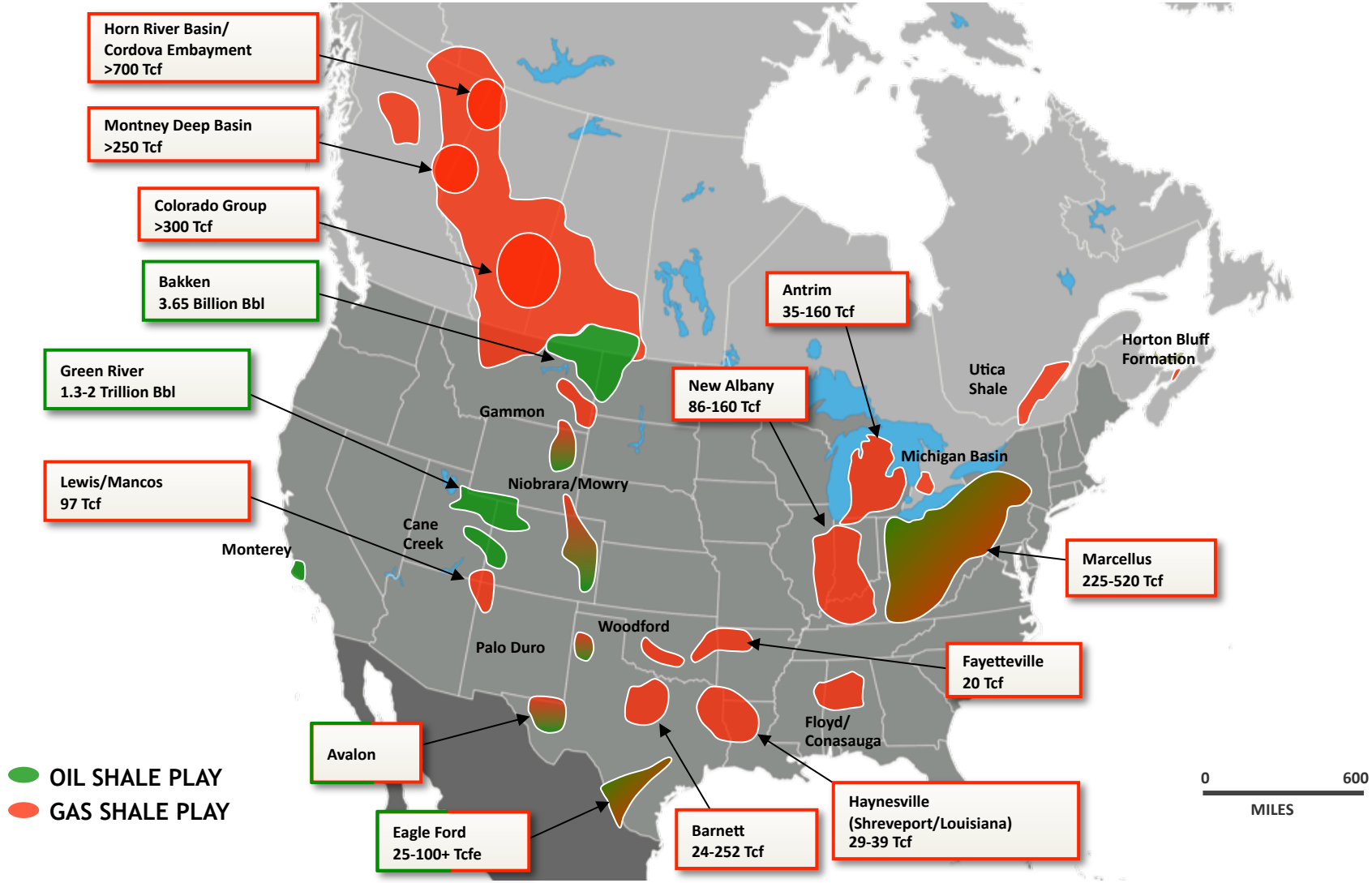
STANFORD UNIVERSITY

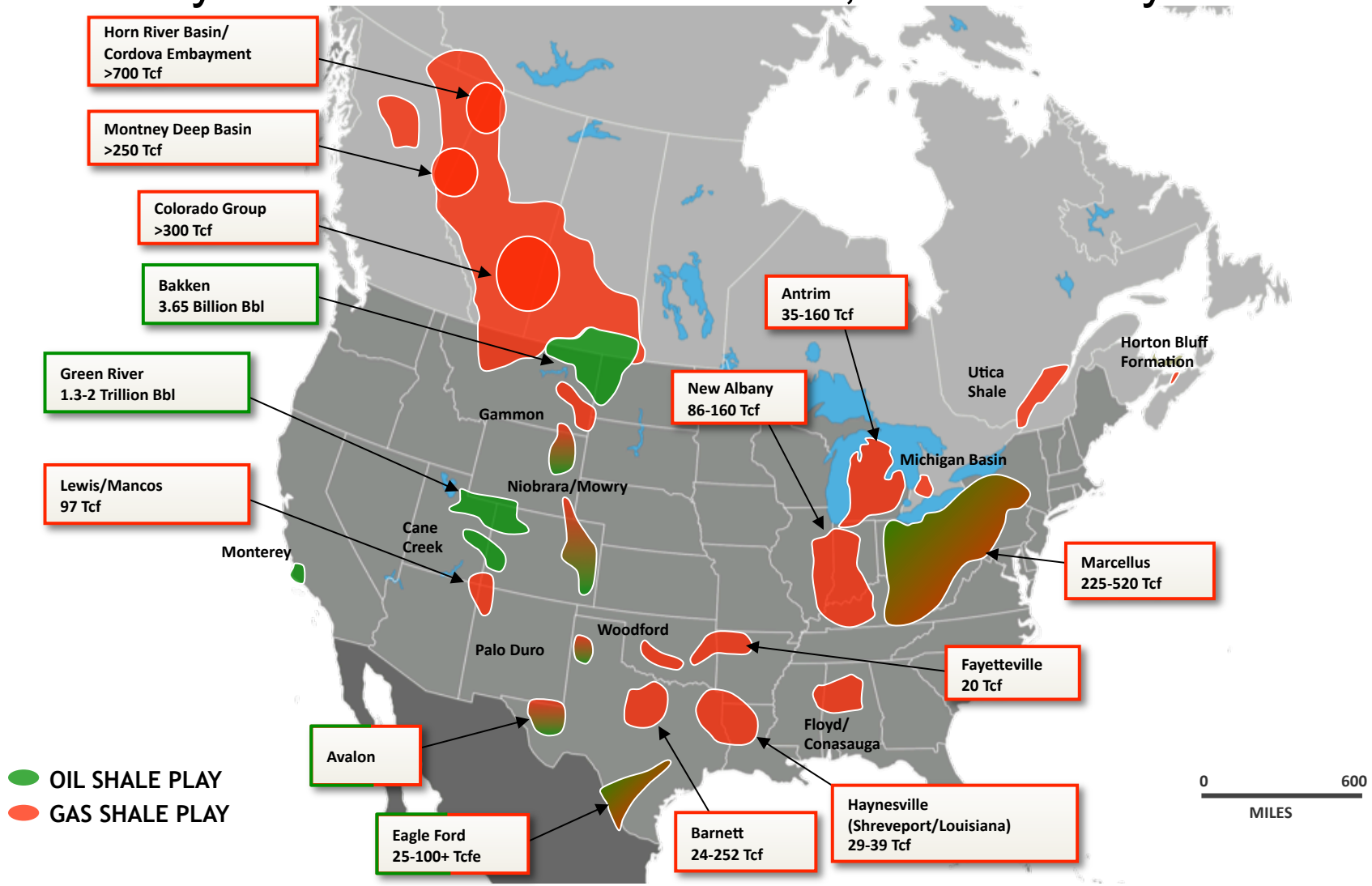
Opportunity: North American Shale Plays



~2300 TCF (85% Shale Gas)

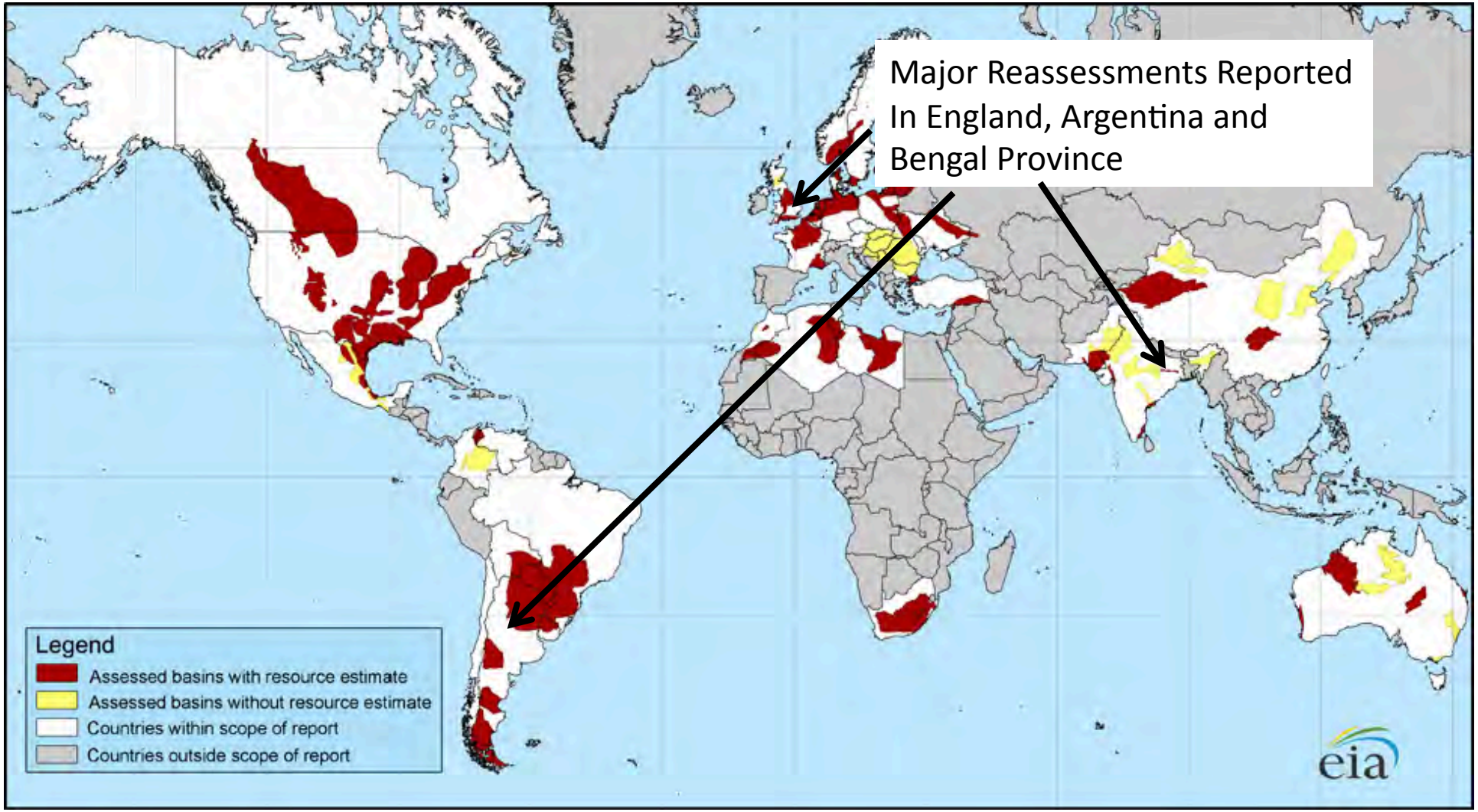
"100 years of Natural Gas" U.S. Consumption 23 TCF/y

The Next ~10 Years
Many 10's of Thousands of Wells, ~1 Million Hydrofracs



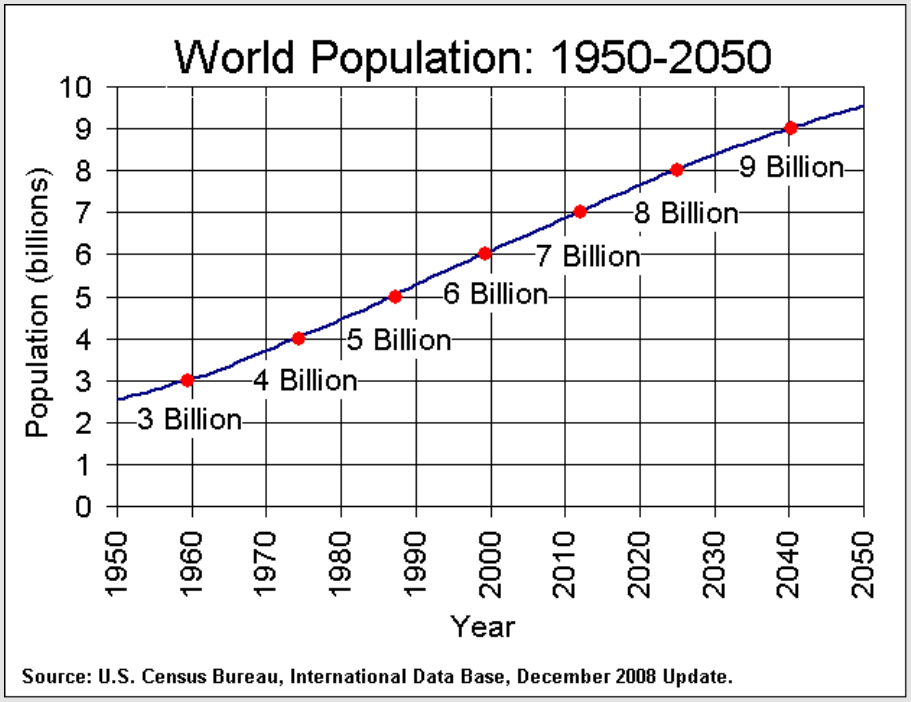
- How Do We Optimize Resource Development?
- How Do we Minimize the Environmental Impact?

Global Shale Plays



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

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)?

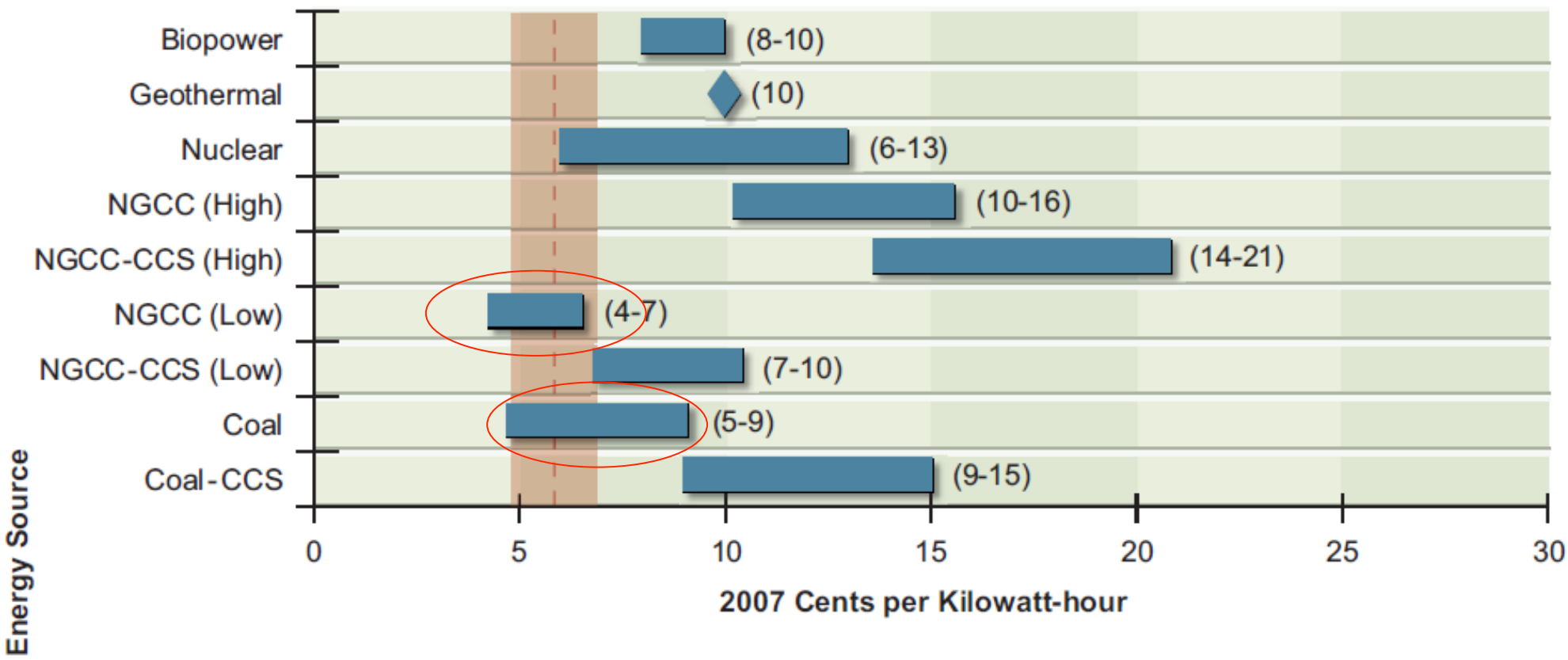
Air Pollution and Energy Source*

	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

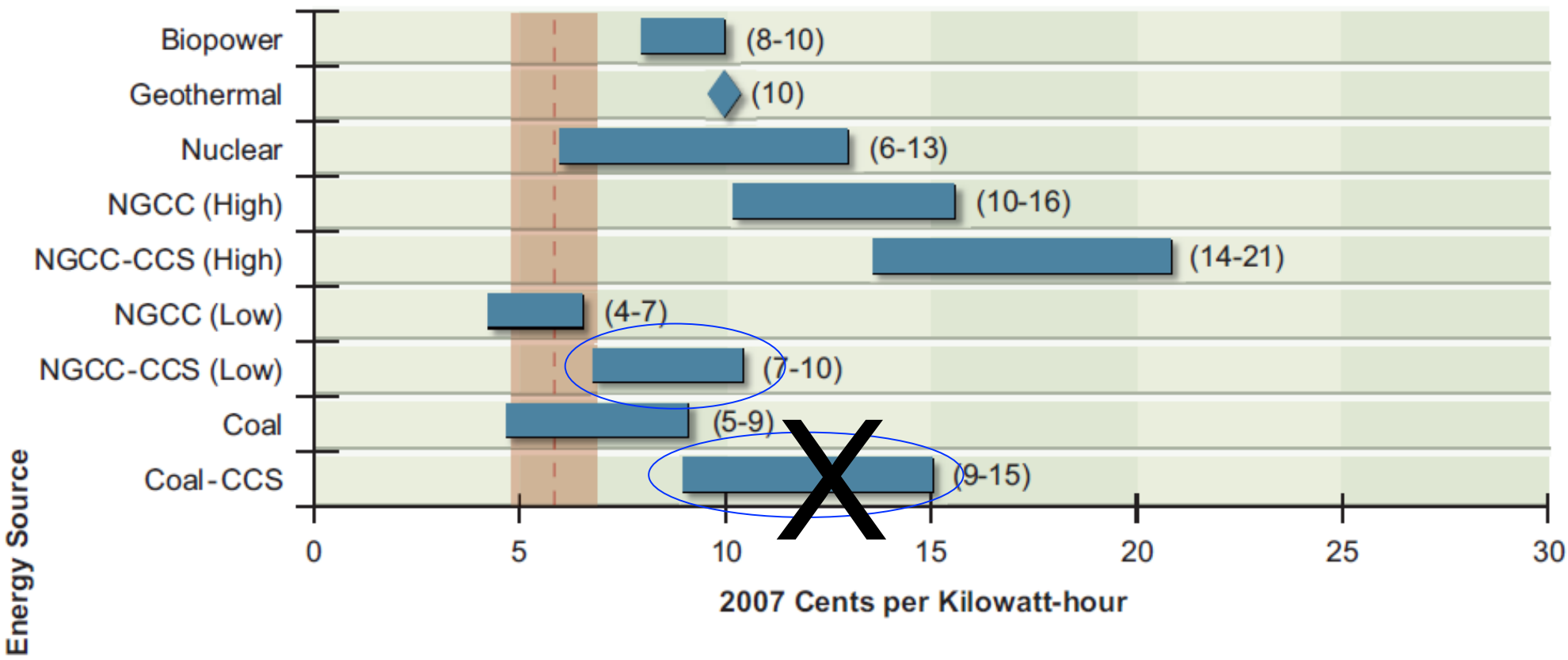
EIA, 1998

Gas And Coal Economics



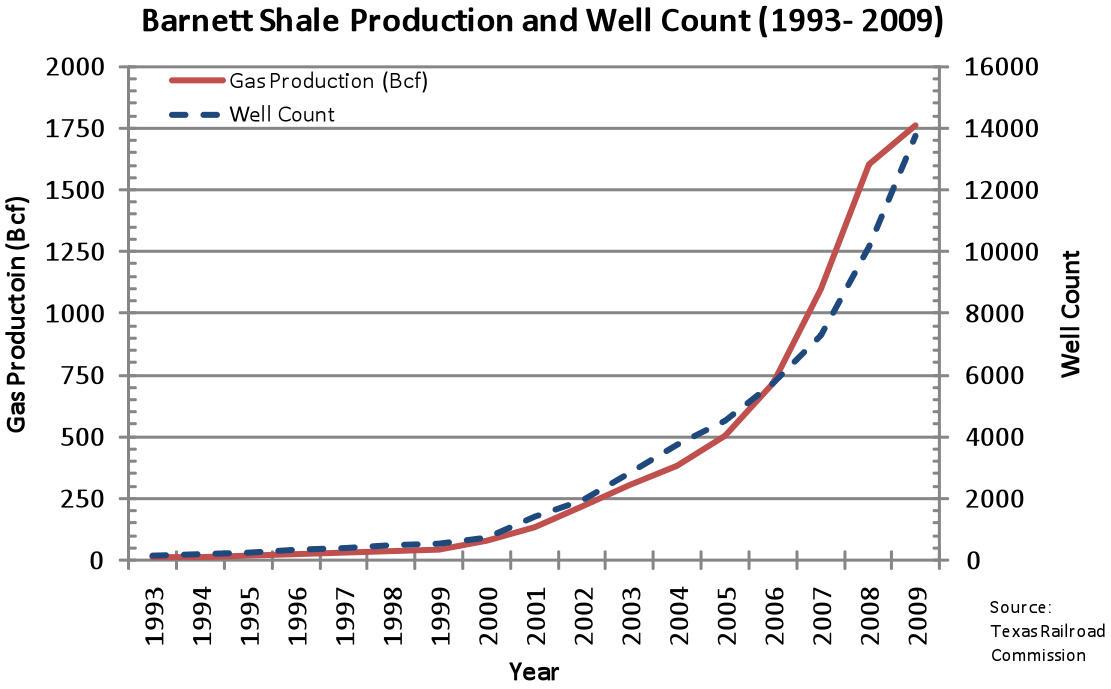
(from *America's Energy Future*) NAS - 2009

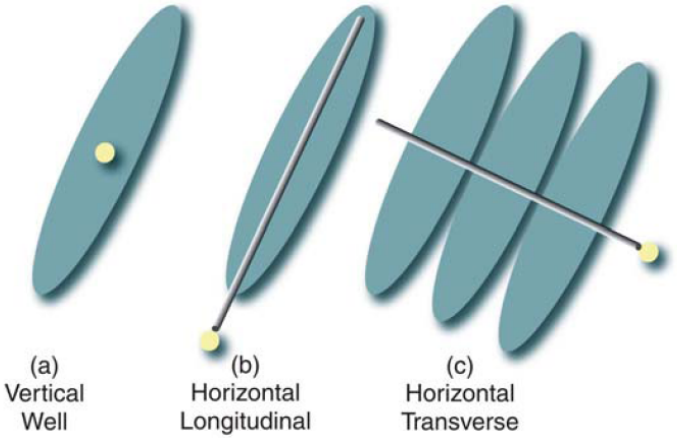
Gas And Coal Economics



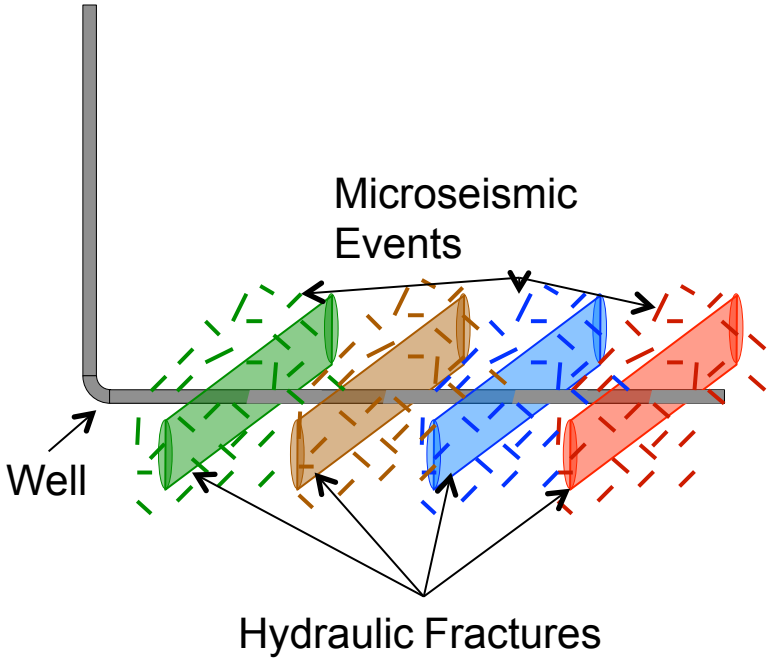
(from *America's Energy Future*) NAS - 2009

Drilling/Completion Technology Key To Exploitation of Shale Gas

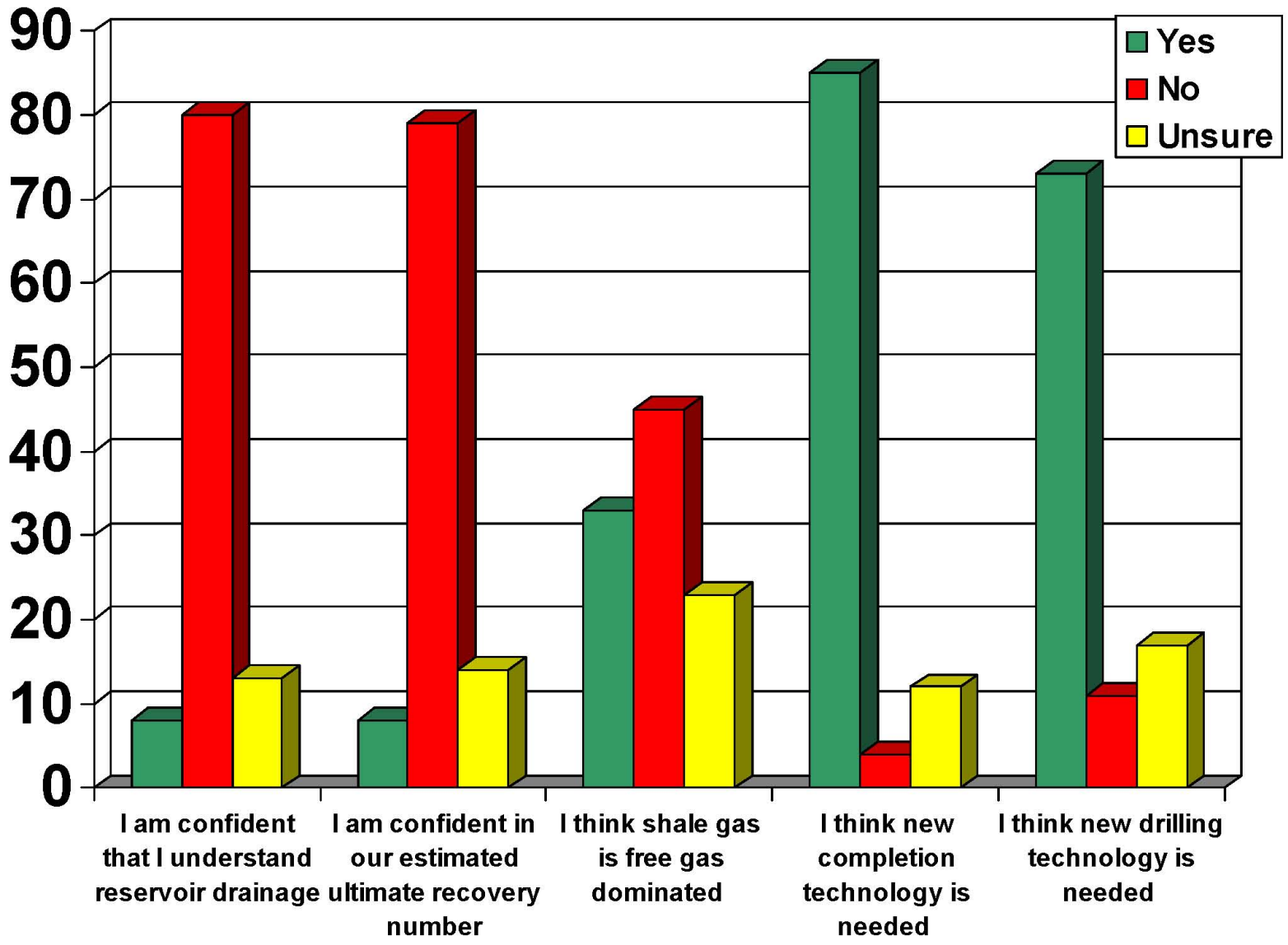




Horizontal Drilling and Multi-Stage
Slick-Water Hydraulic Fracturing
Induces Microearthquakes (M ~ -1 to M~ -3)
To Create a Permeable Fracture Network



SPE Shale Gas Production Conference - Survey



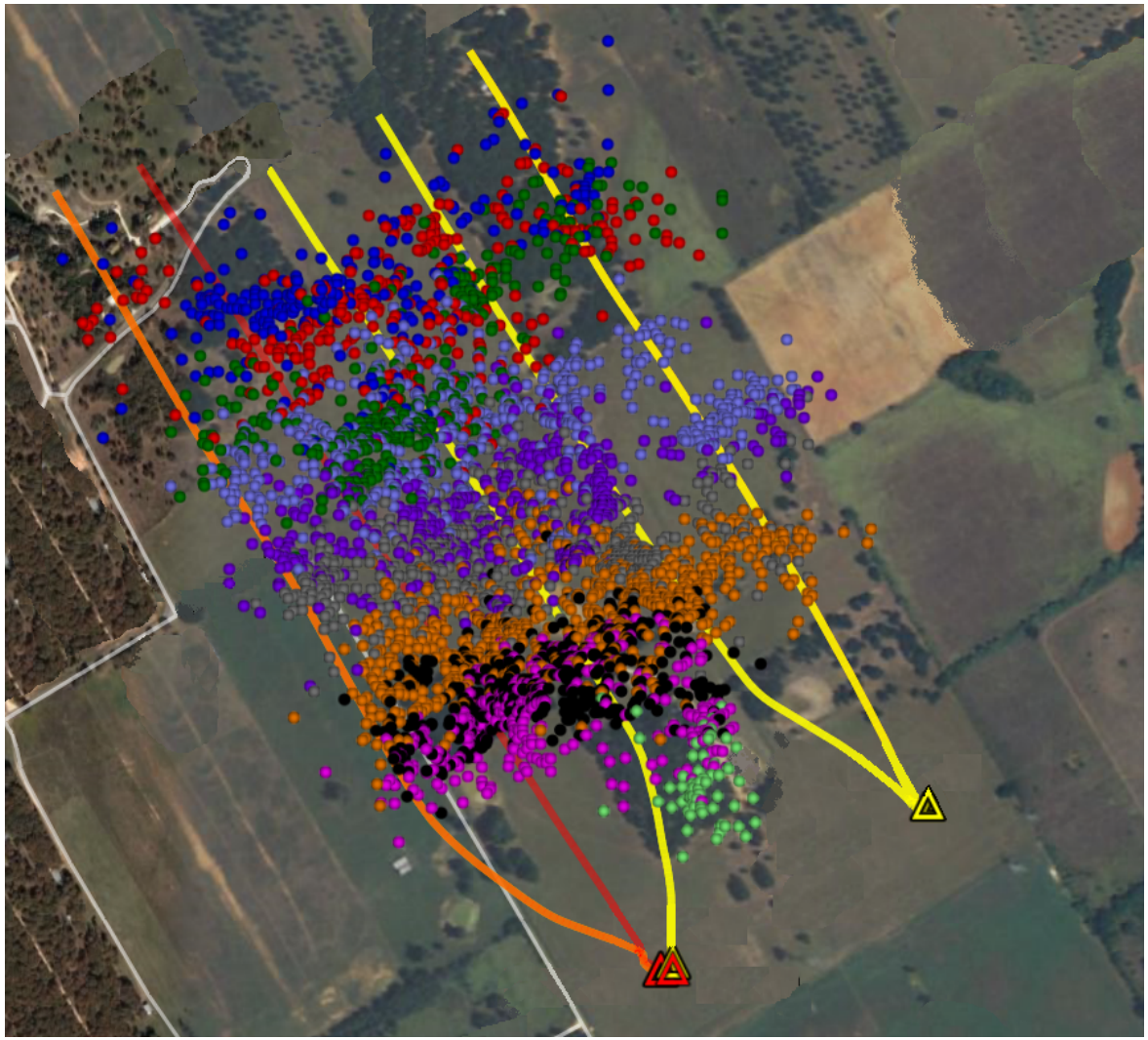
Reservoir Geomechanics Research

Briefly….

- How do rock properties affect the success of stimulation?
- What is the importance of aseismic deformation mechanisms during reservoir stimulation?
- What factors affecting ultimate recovery?
- How do we minimize the environmental impact of shale gas development?

Physical and Chemical Properties of Organic Rich Shales

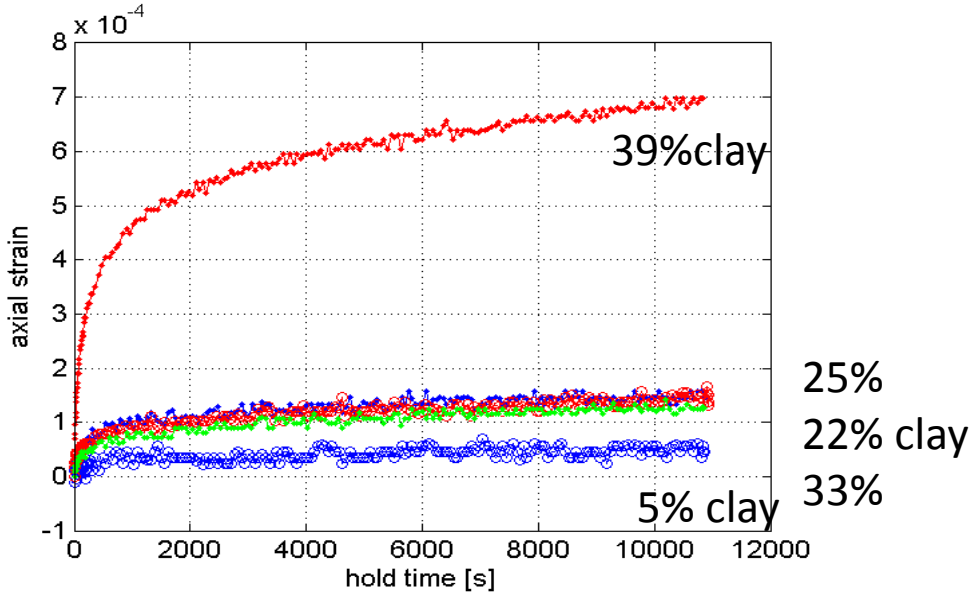
How Do the Properties of Shale Affect the Outcome of Hydraulic Fracturing Stimulation?



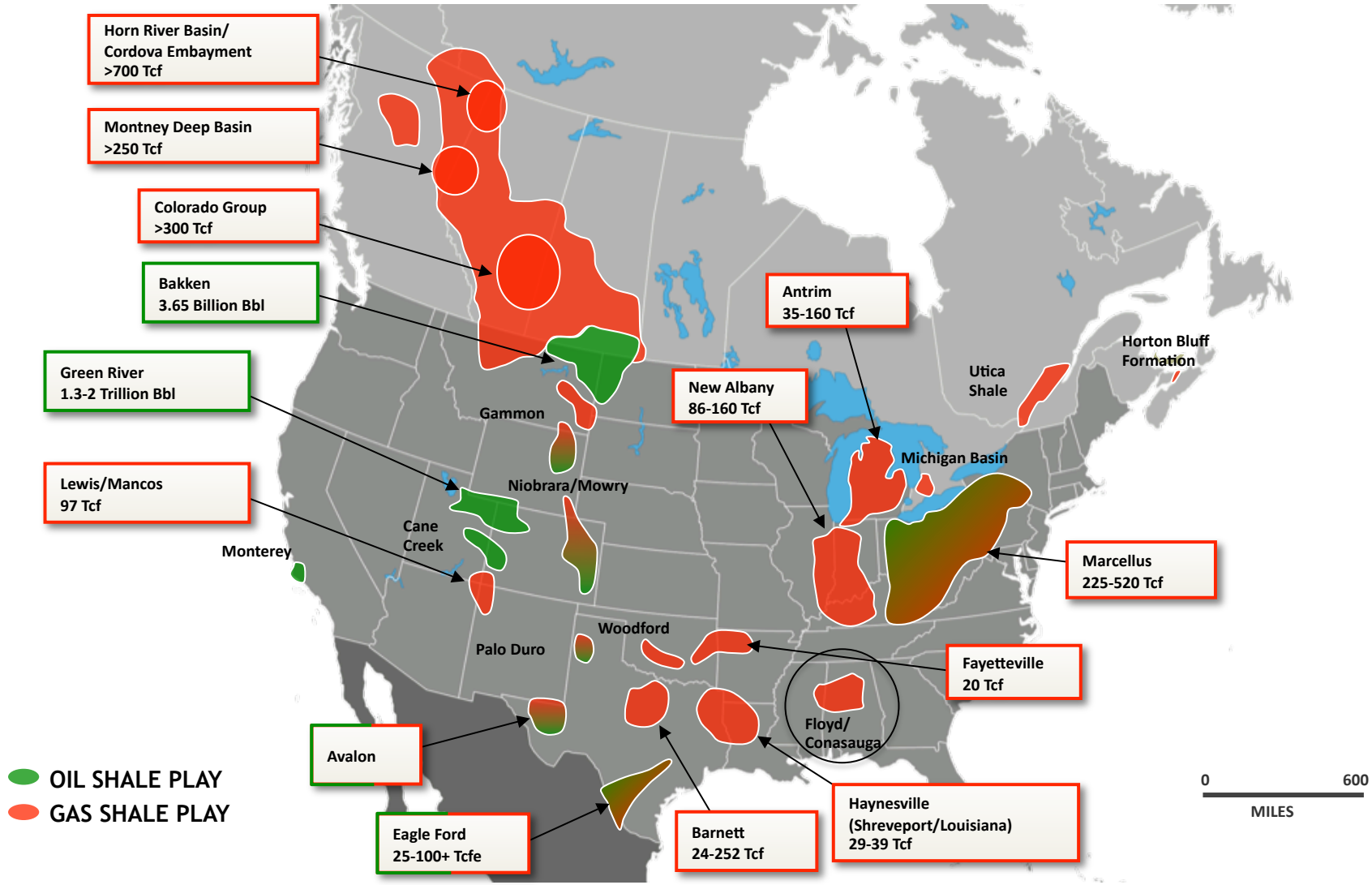
5 Wells, 40 Stages, ~4000 Microseismic Events

Organic Rich Shales are Viscoplastic

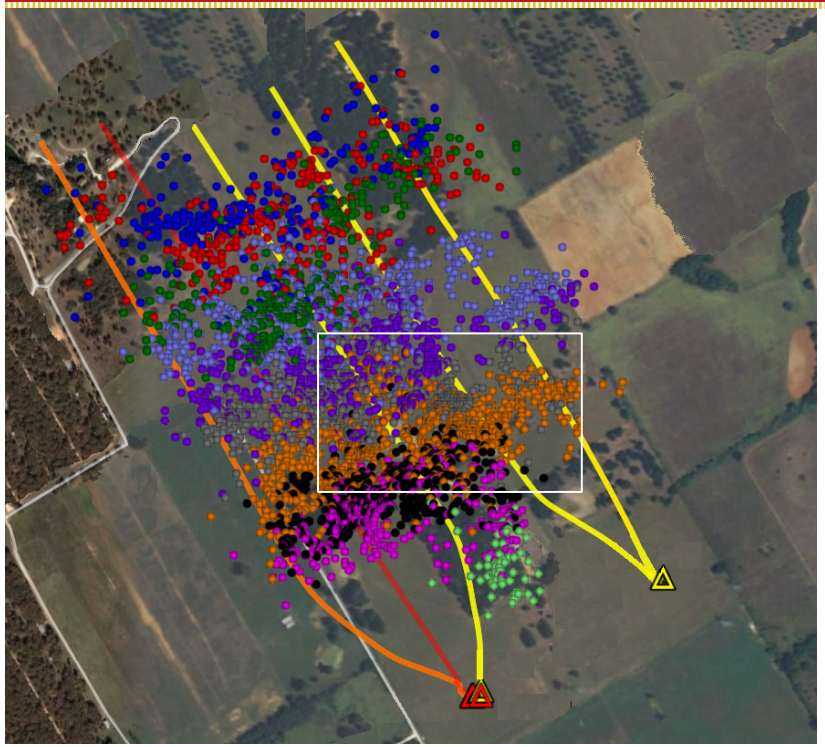
Sample group	Clay	Carbonate	QFP	TOC (wt%)
Barnett-dark	29-43	0-6	48-59	4.1-5.8
Barnett-light	2-7	37-81	16-53	0.4-1.3
Haynesville-dark	36-39	20-23	31-35	3.7-4.1
Haynesville-light	20-22	49-53	23-24	1.7-1.8
Fort St. John	32-39	3-5	54-60	1.6-2.2
Eagle Ford-dark	12-21	46-54	22-29	4.4-5.7
Eagle Ford-light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

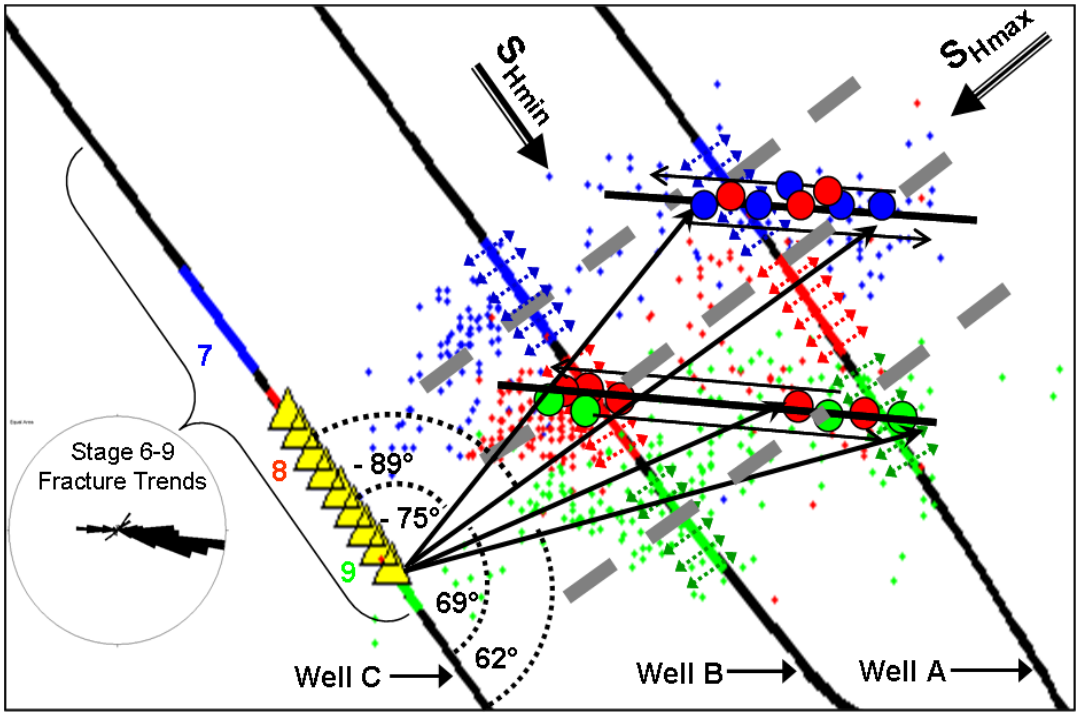


The Floyd Shale?



Most Deformation Within the Reservoir During Hydraulic Fracturing is Aseismic

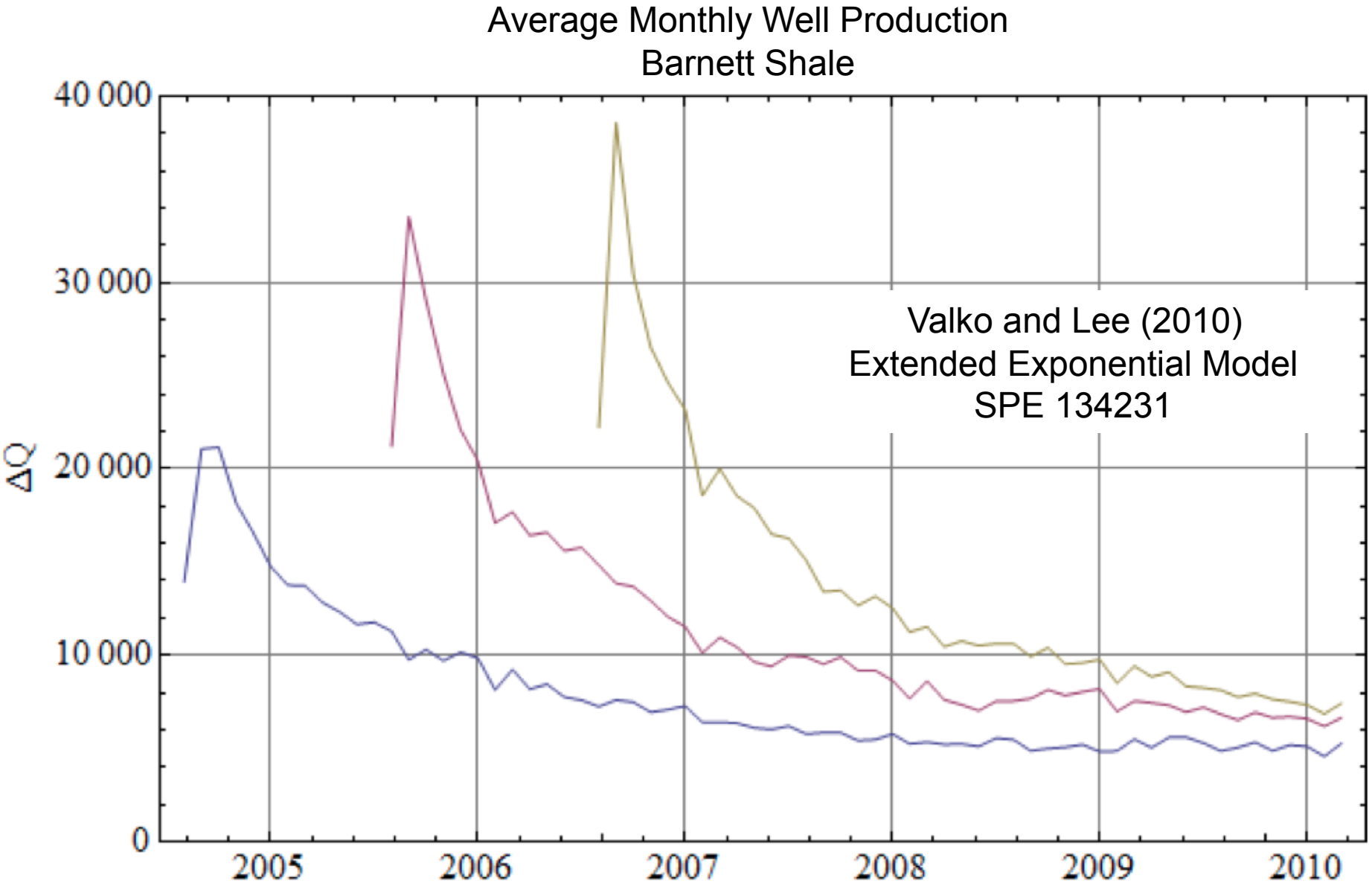




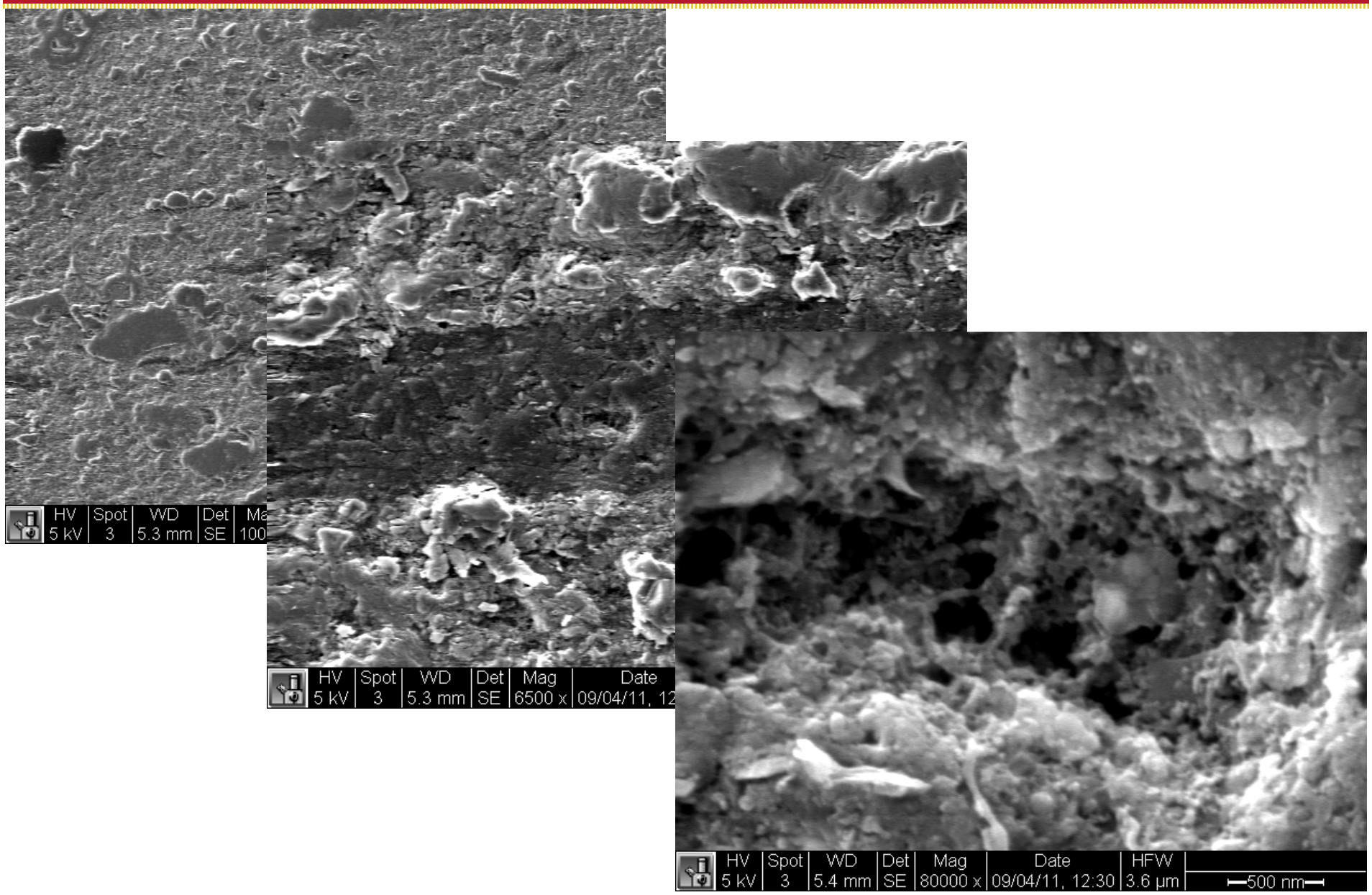
Das and Zoback (2011)

Volume Affected by 4000 Microearthquakes Can Account for Less Than 1% of Gas Production in First 6 Months

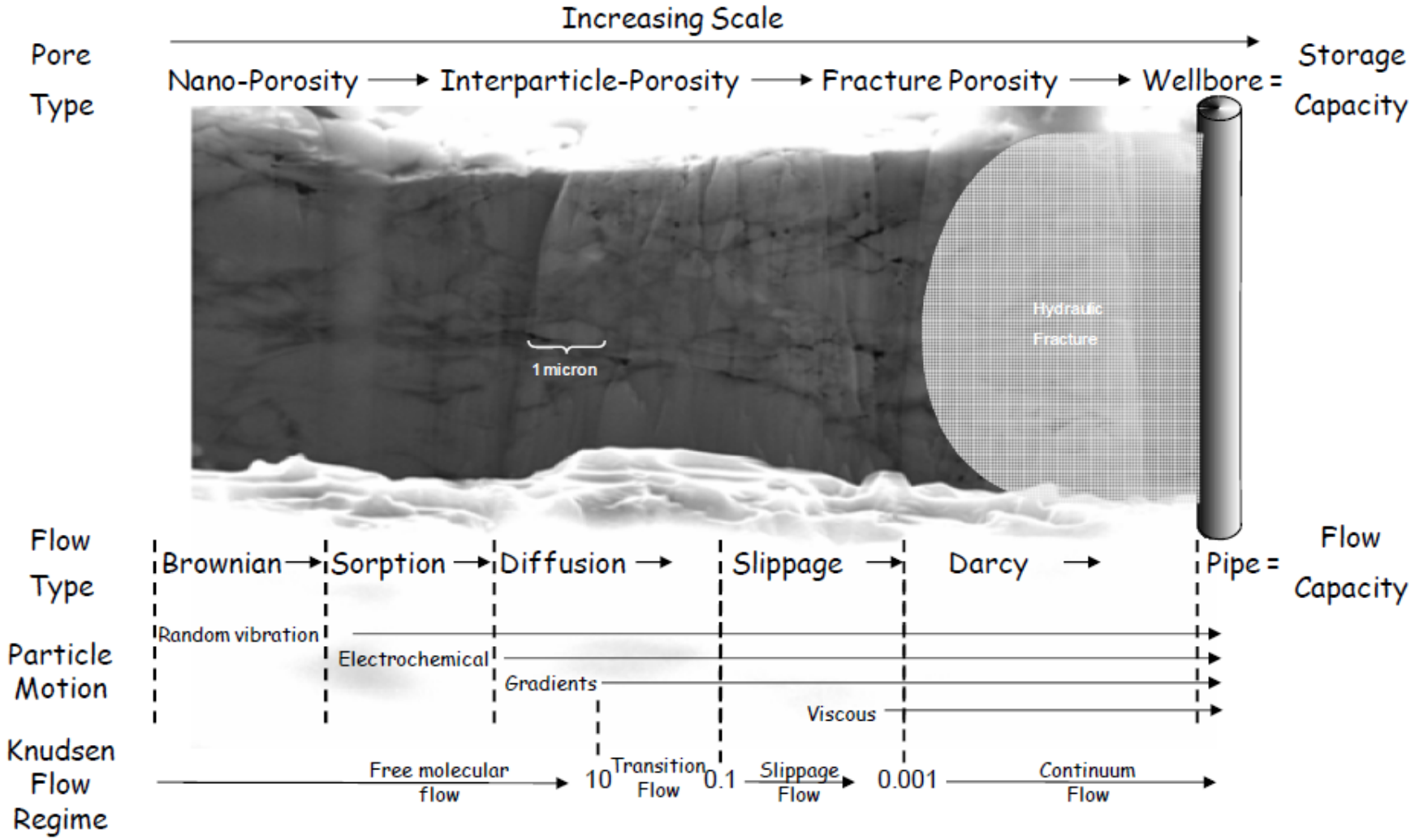
Why Is Production So Persistent?



Eagleford Shale Pore Structure

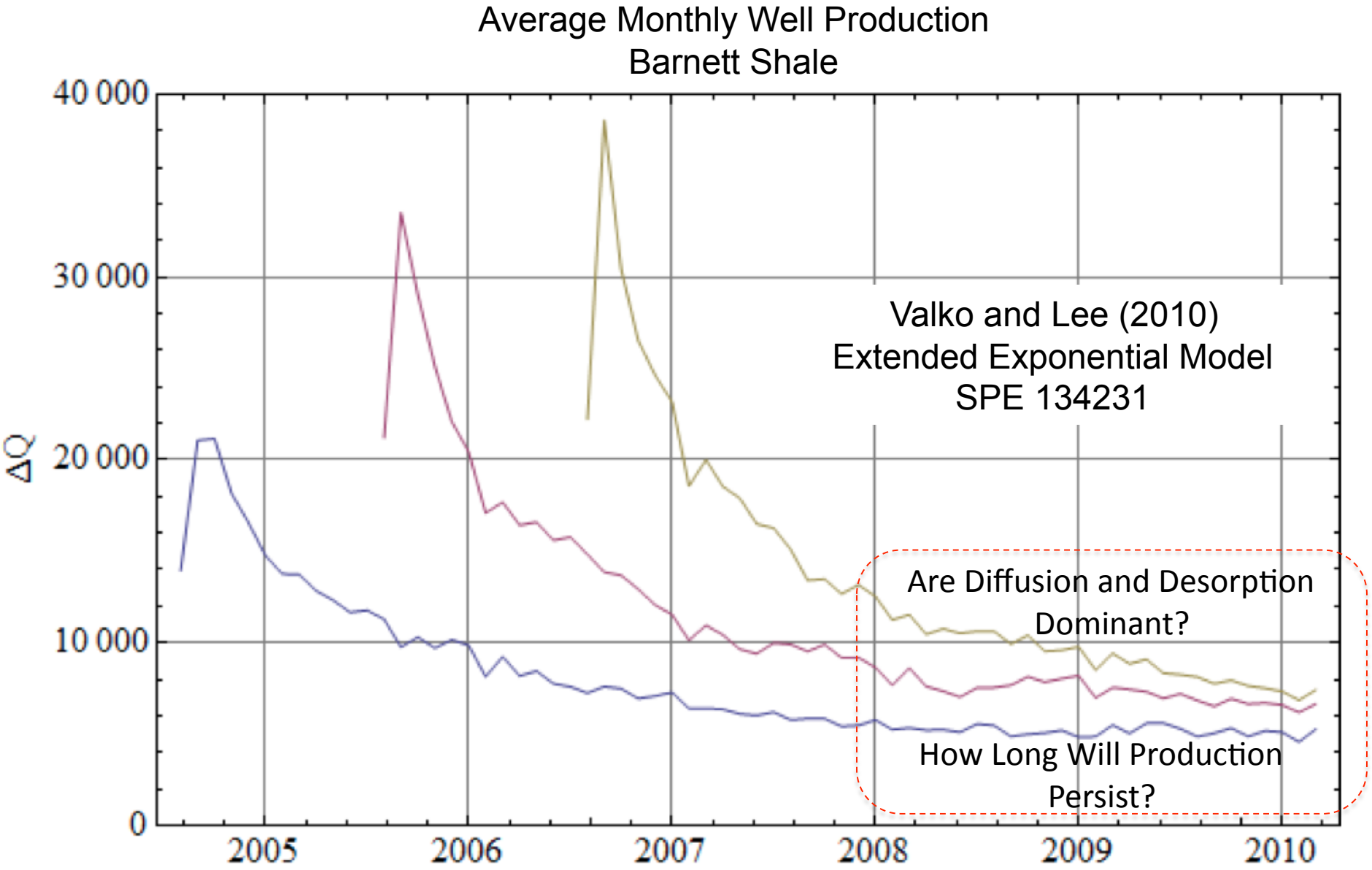


Scale Dependent Flow Mechanisms



Sondergeld et al., 2010

Why Is Production Persistent?



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

Environmental Issues

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Secretary of Energy Advisory Board

Shale Gas Production Subcommittee 90-Day Report

August 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.

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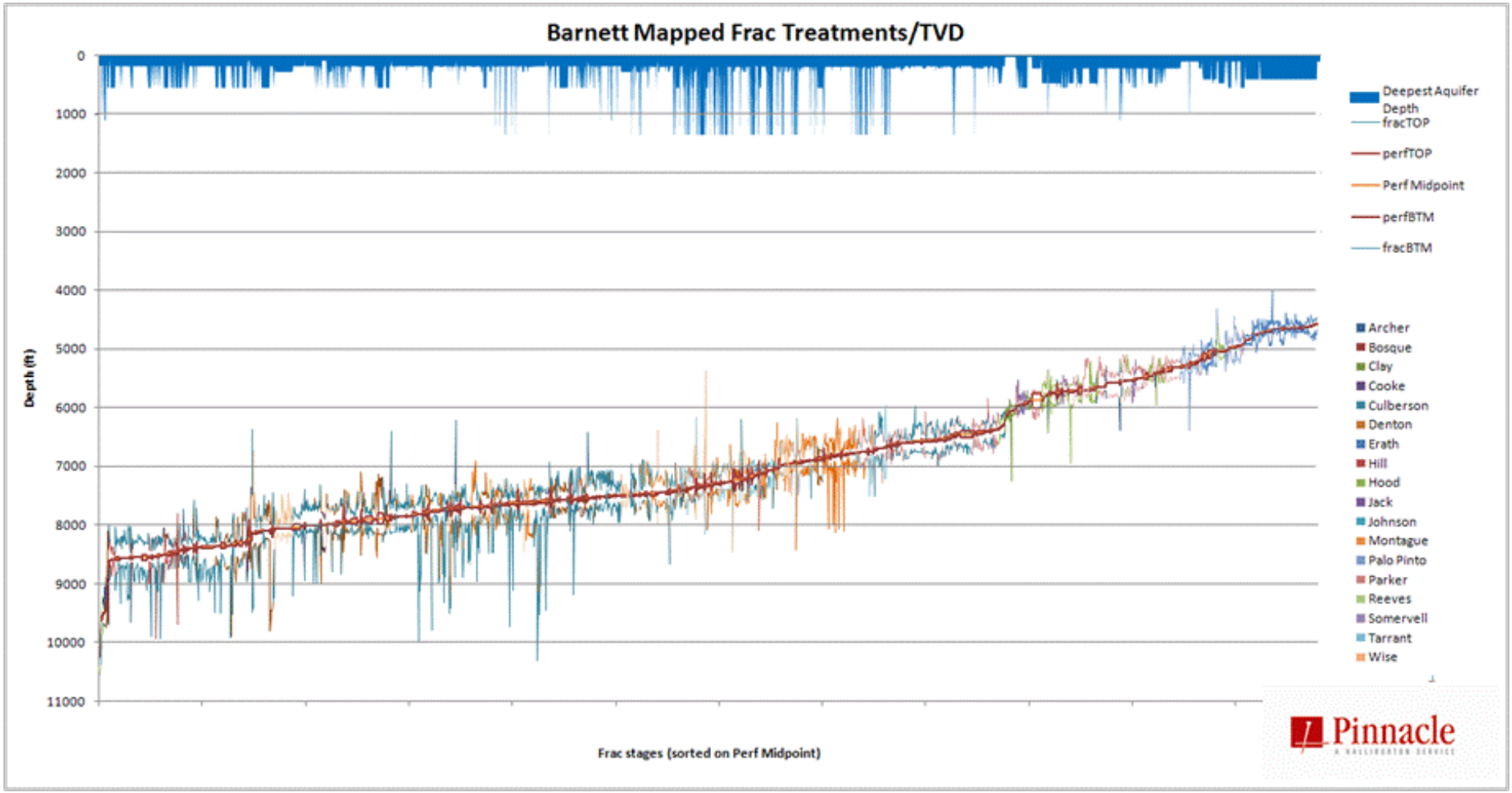
90 Day Report Summary

- Protection of water quality-2: Hydraulic Fracturing

Will Vertical Hydrofrac Growth Affect Water Supplies?

NO!
In nearly all active shale gas plays

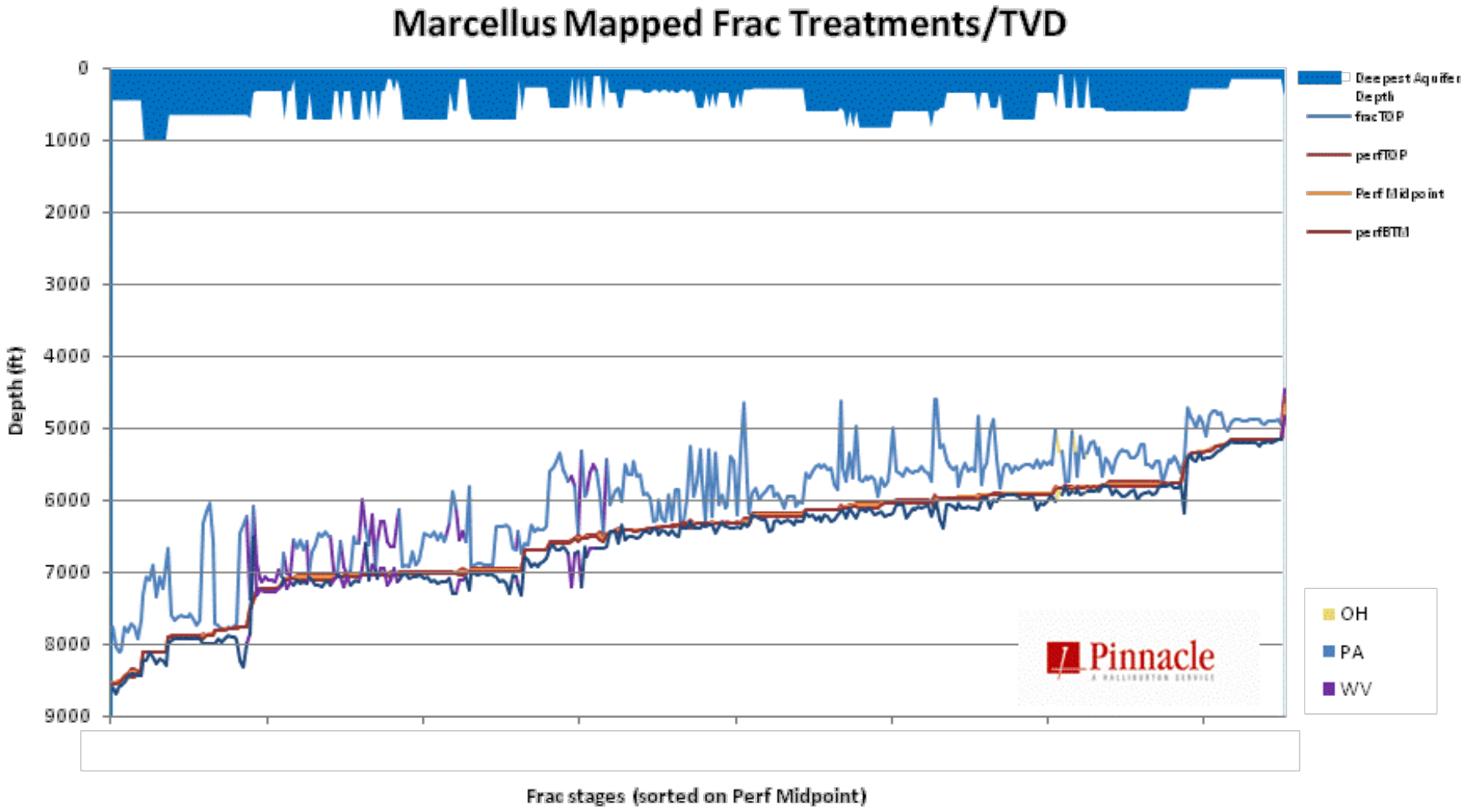
Depth of Affected Region Affected by Hydraulic Fracturing



Fisher (2010)

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

Depth of Affected Region Affected by Hydraulic Fracturing

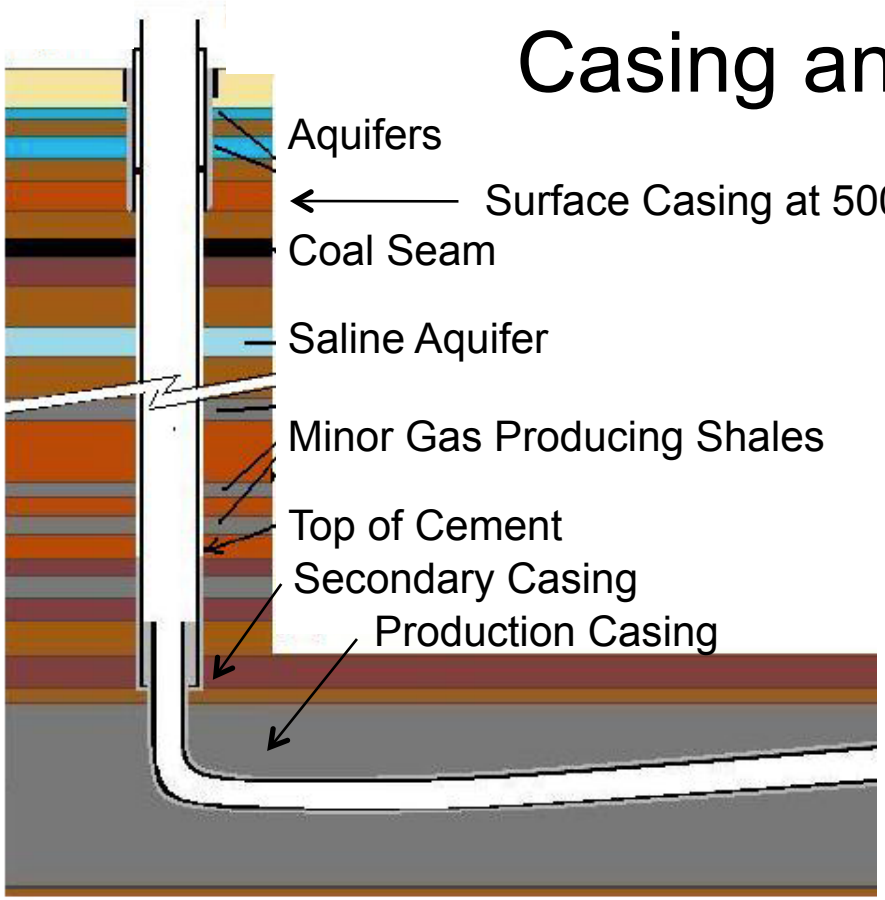


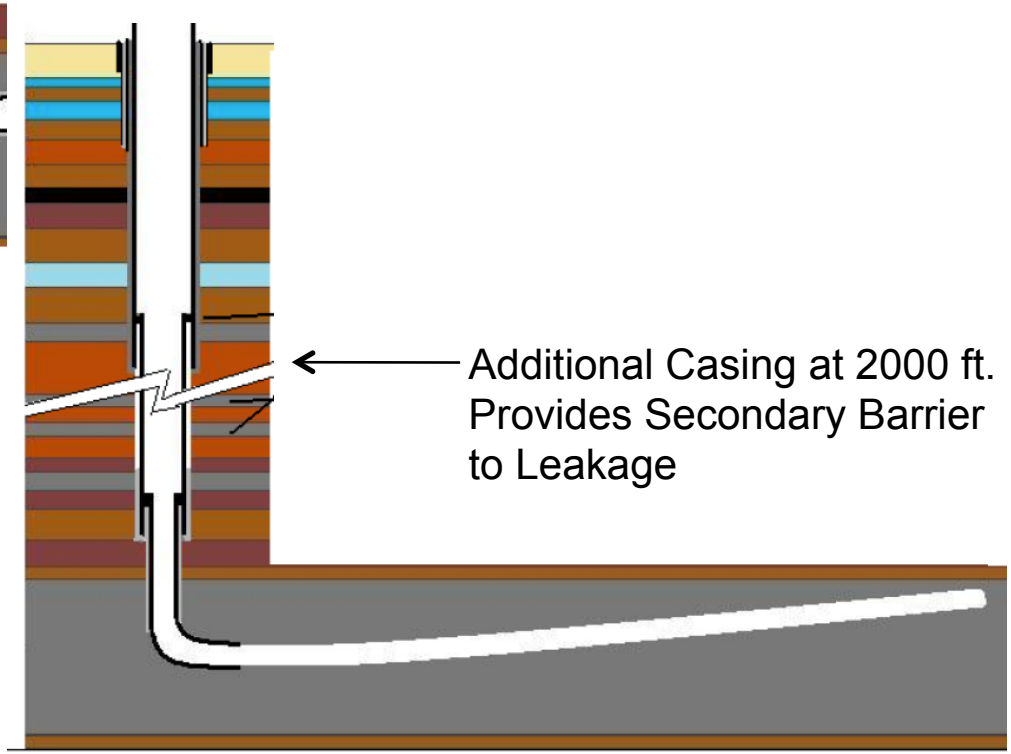
Fisher (2010) http://nwis.waterdata.usgs.gov/nwis/inventory

90 Day Report Summary

- Protection of water quality-3:
  - Adopt best practices in well development and construction, especially casing, cementing, and pressure management. Pressure testing of cemented casing and state-of-the-art cement bond logs should be used to confirm formation isolation.

Casing and Cementing





Courtesy George King, Apache Corp.

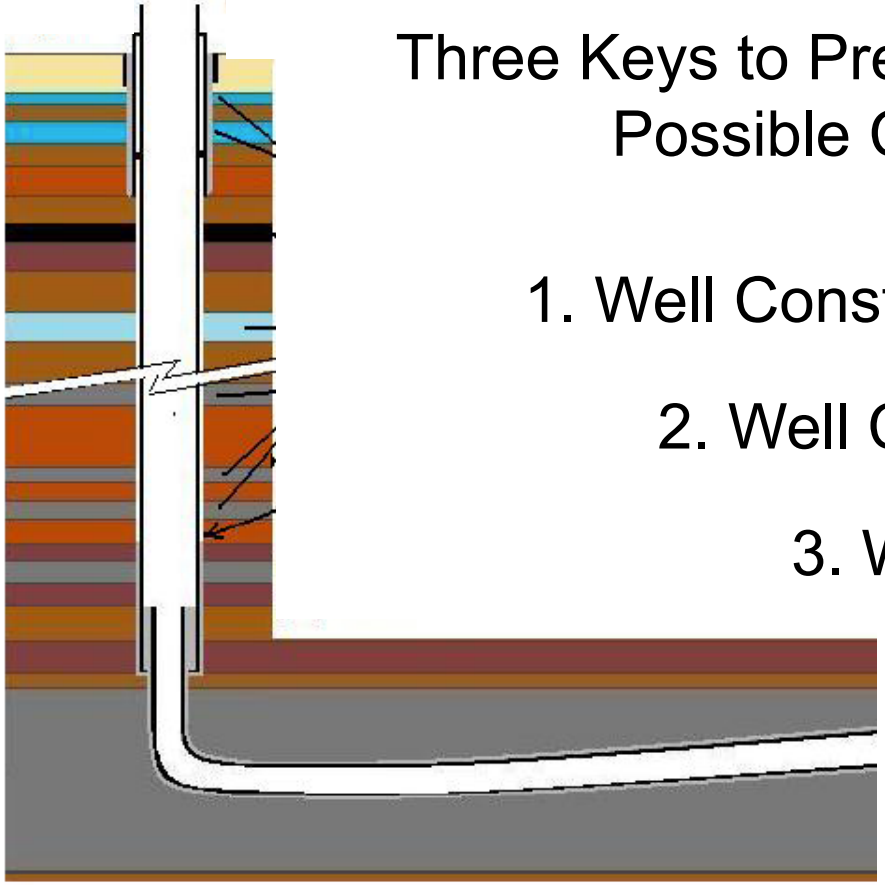
Range Resources
Washington County, Pennsylvania

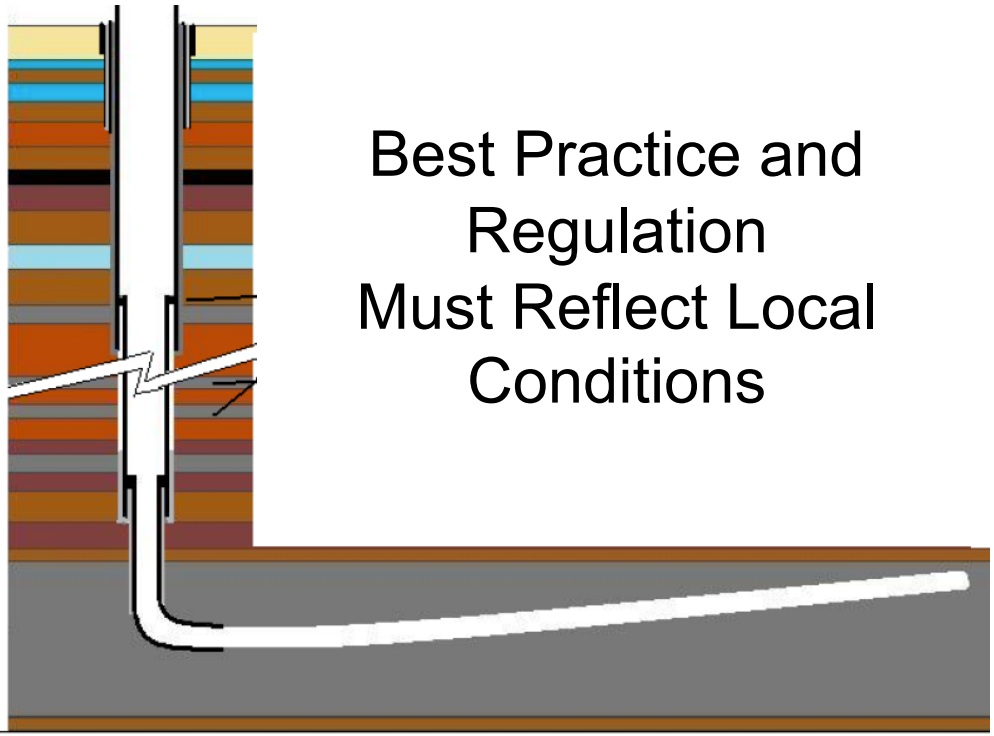
Three Keys to Preventing Leakage and Possible Contamination

1. Well Construction

2. Well Construction

3. Well Construction





Best Practice and Regulation Must Reflect Local Conditions

Courtesy George King, Apache Corp.

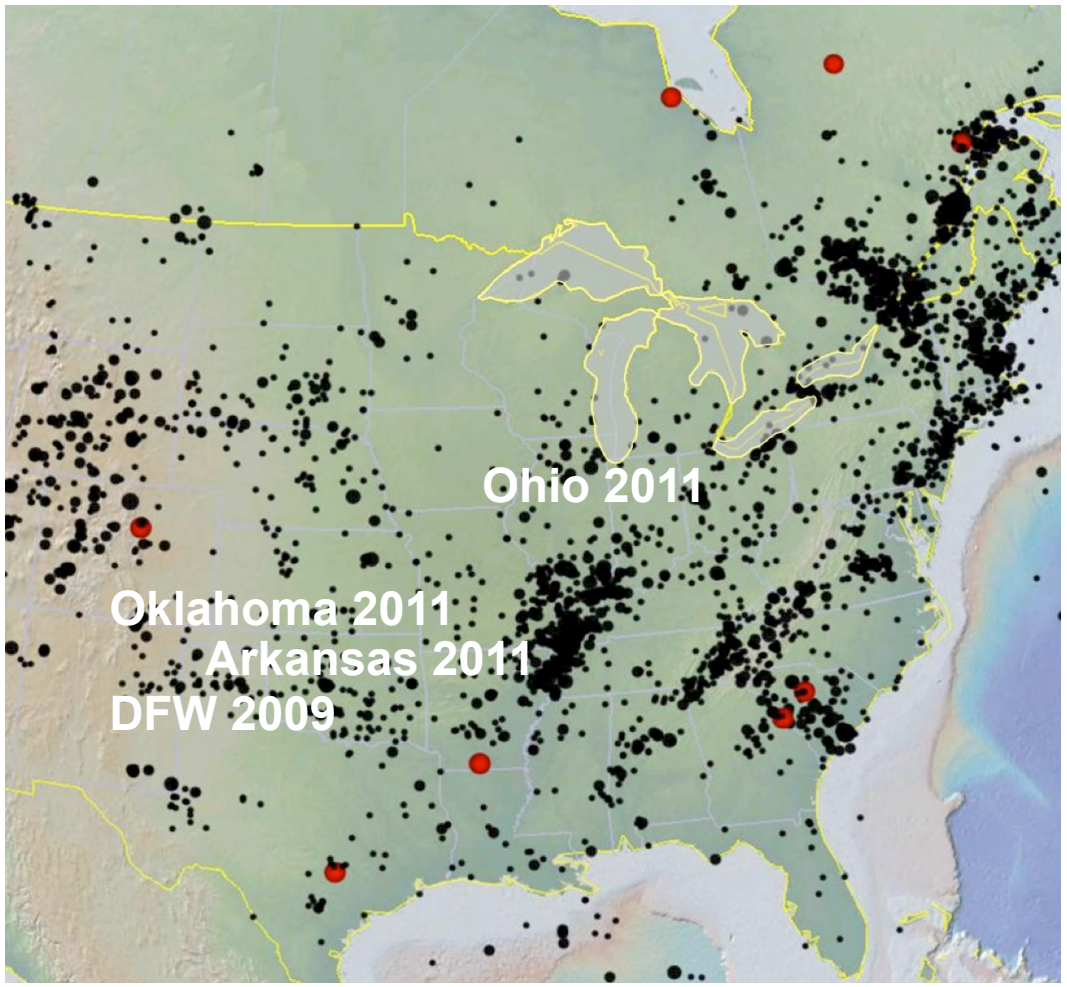
90 Day Report Summary

- 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

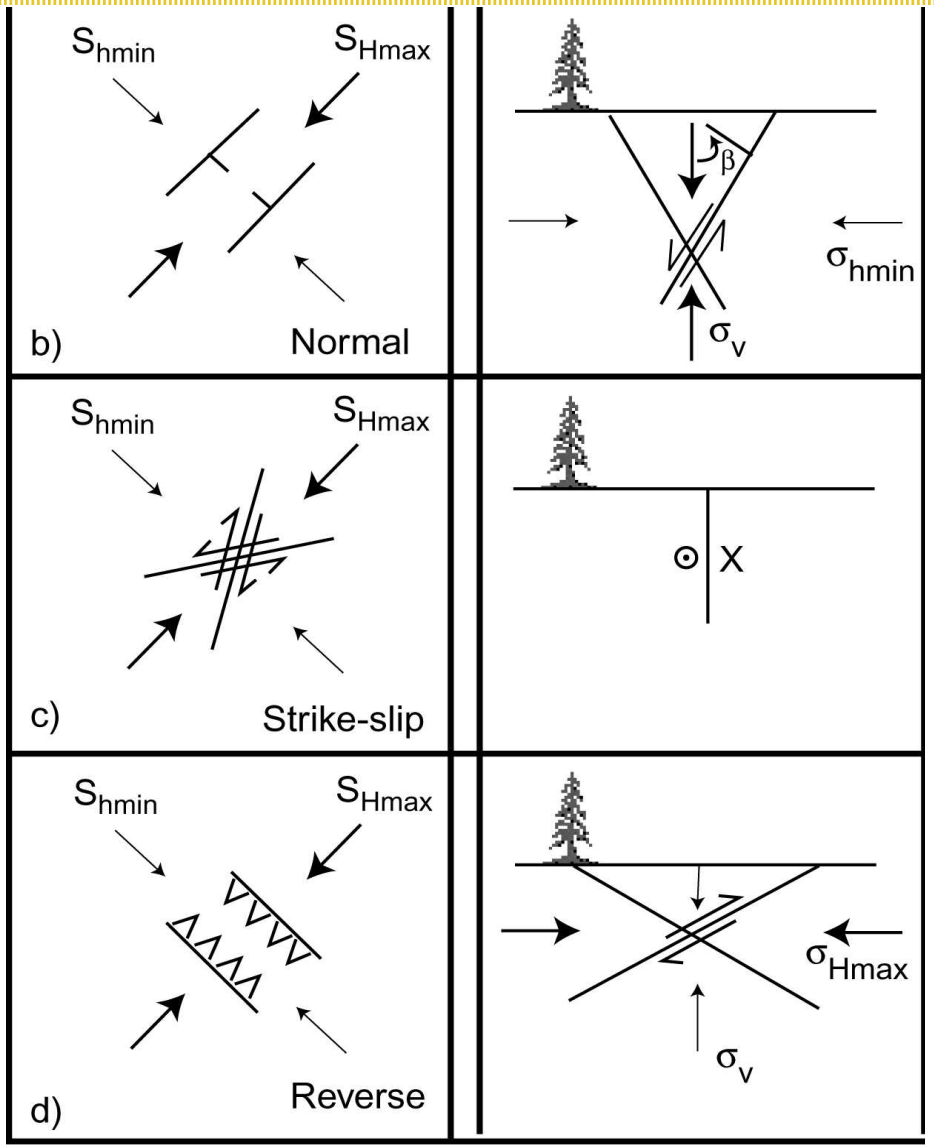


Stress and Faulting

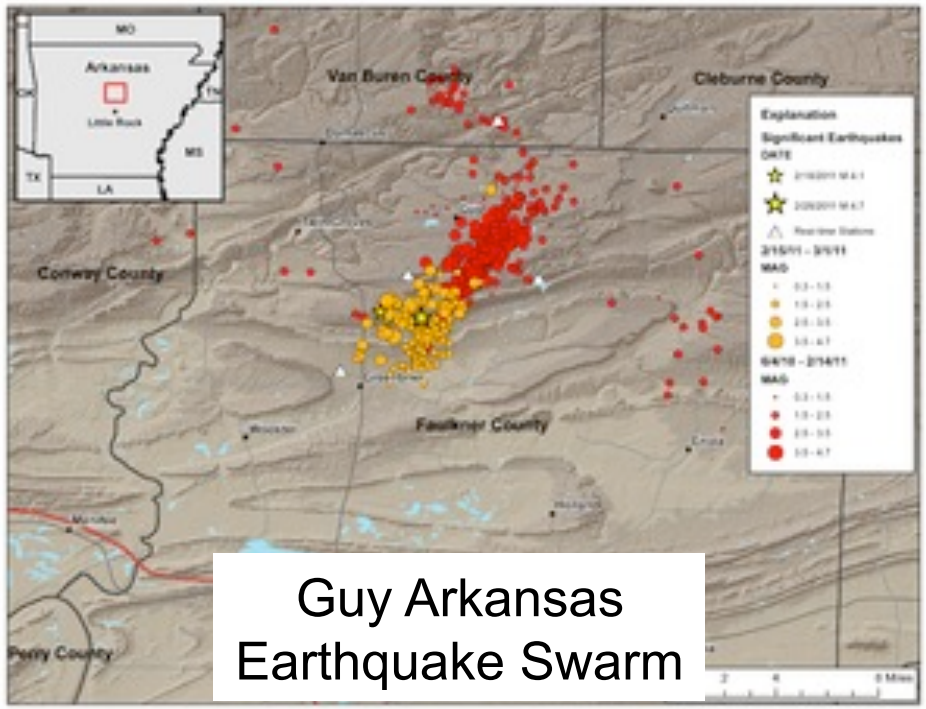
Normal

Strike-Slip

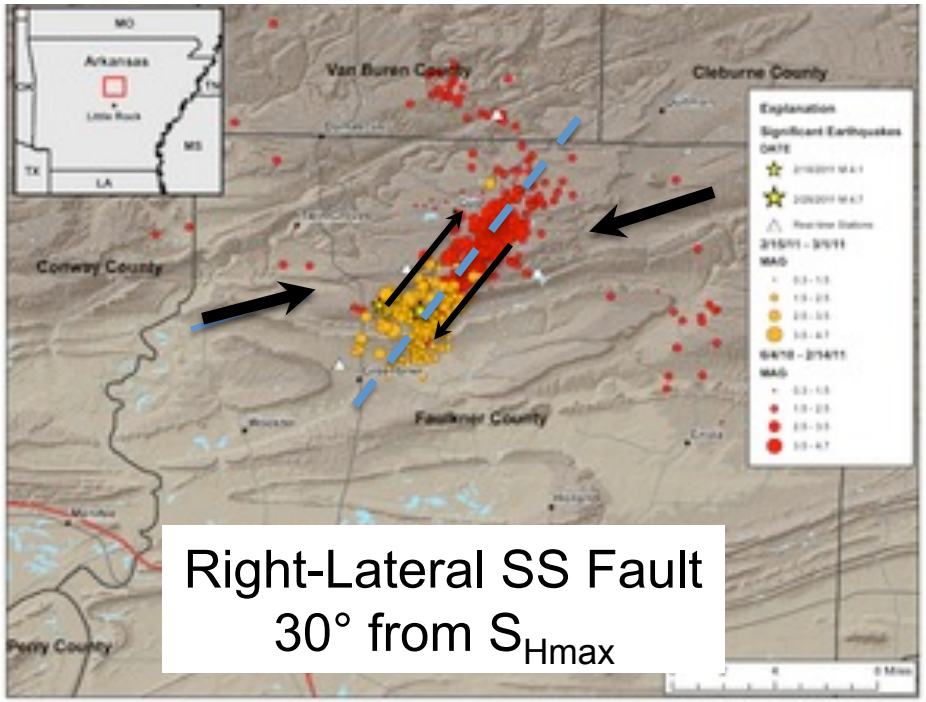
Reverse



Map View Cross-section

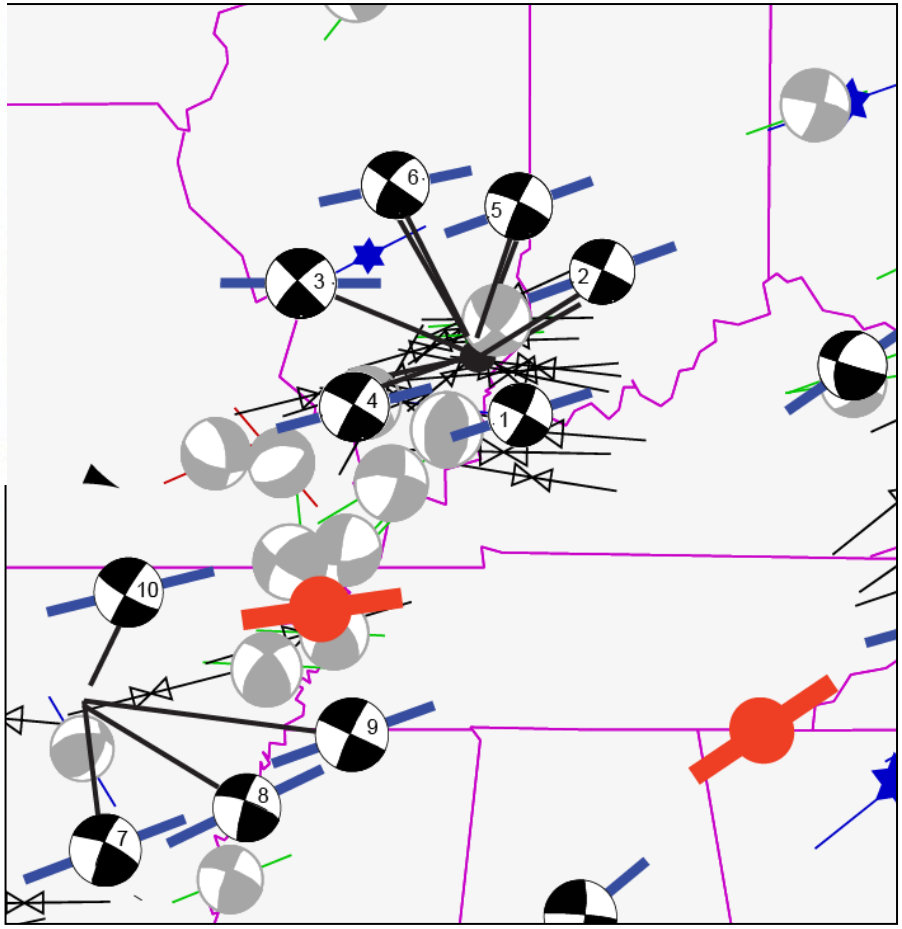


Guy Arkansas
Earthquake Swarm



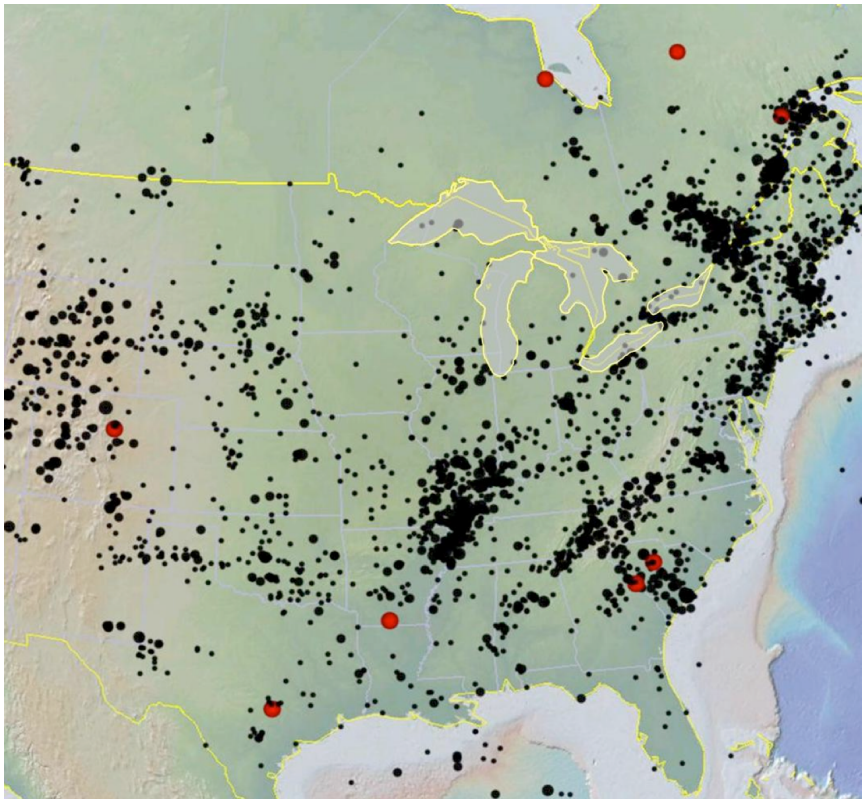
Right-Lateral SS Fault
30° from S_{Hmax}

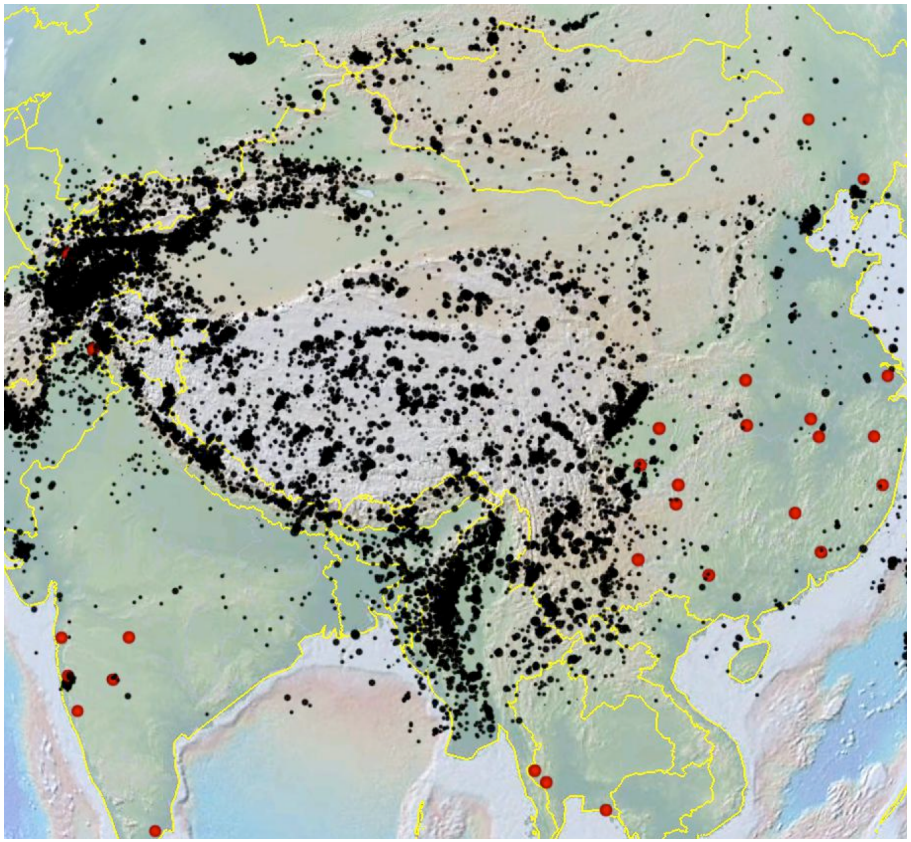
Stress Map
New Madrid Area



Hurd and Zoback (in press)

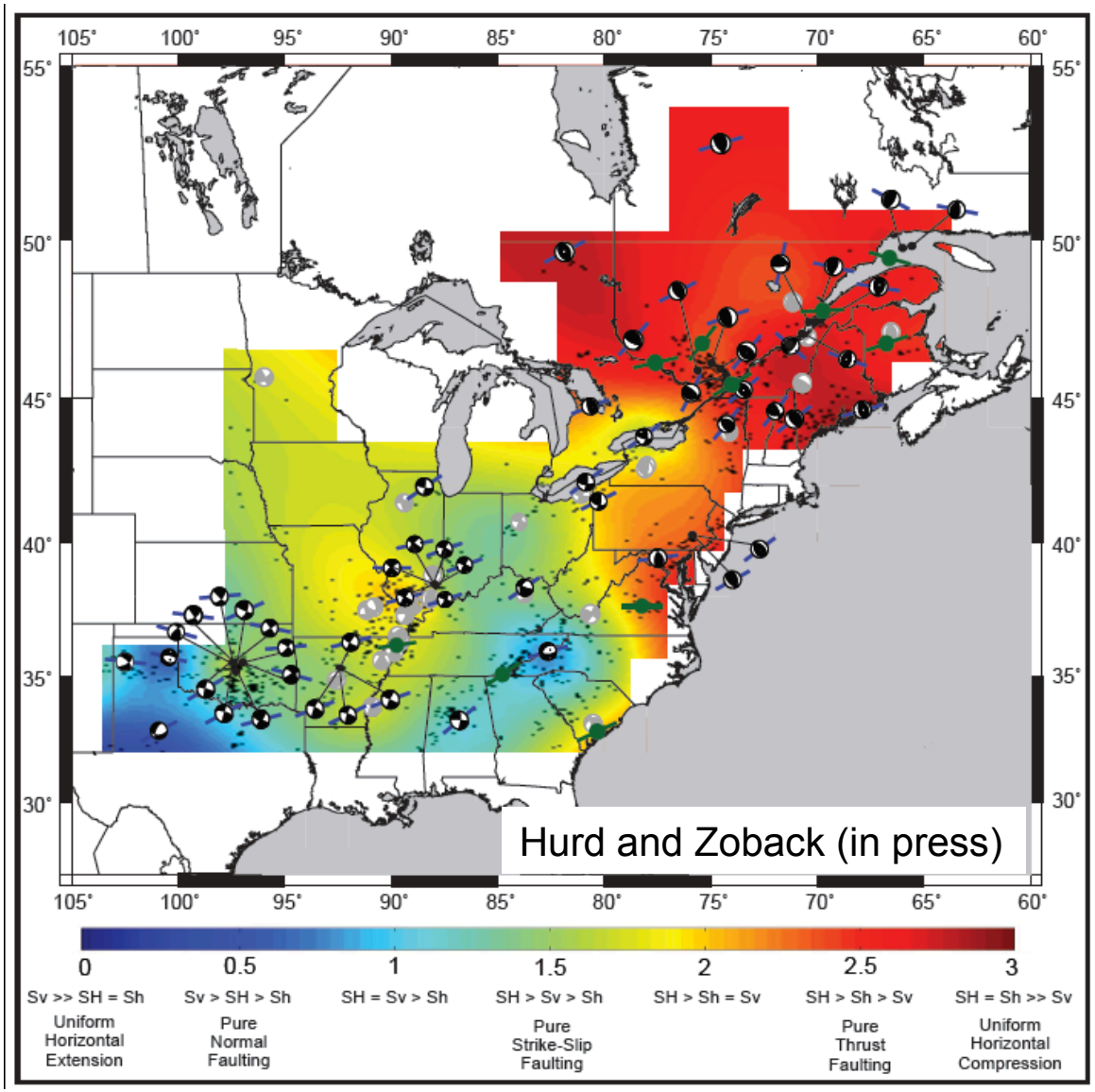
Seismicity Occurs Almost Everywhere
The Earth's Crust is *Critically-Stressed*





- EarthquakesTriggered by Reservoir Impoundment

Stress in Central and Eastern America



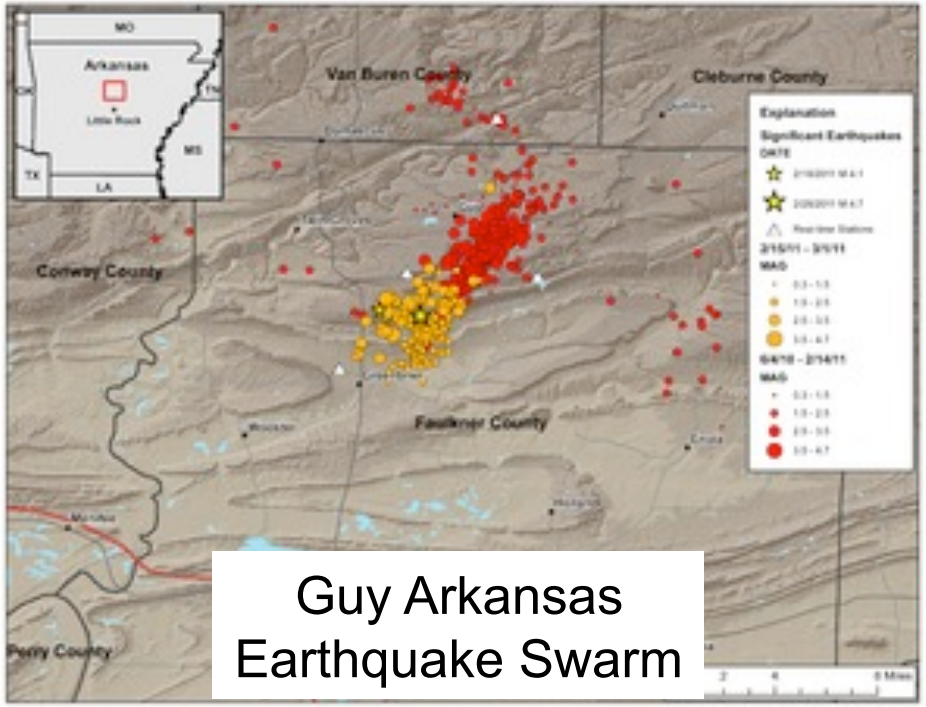
Barnett Shale – 1.5 km laterals
Few Wellbore Stability Problems

Bakken Shale – 3.0 km laterals
Few Wellbore Stability Problems

Marcellus Shale – 1.0 km laterals
Wellbore Stability Problems

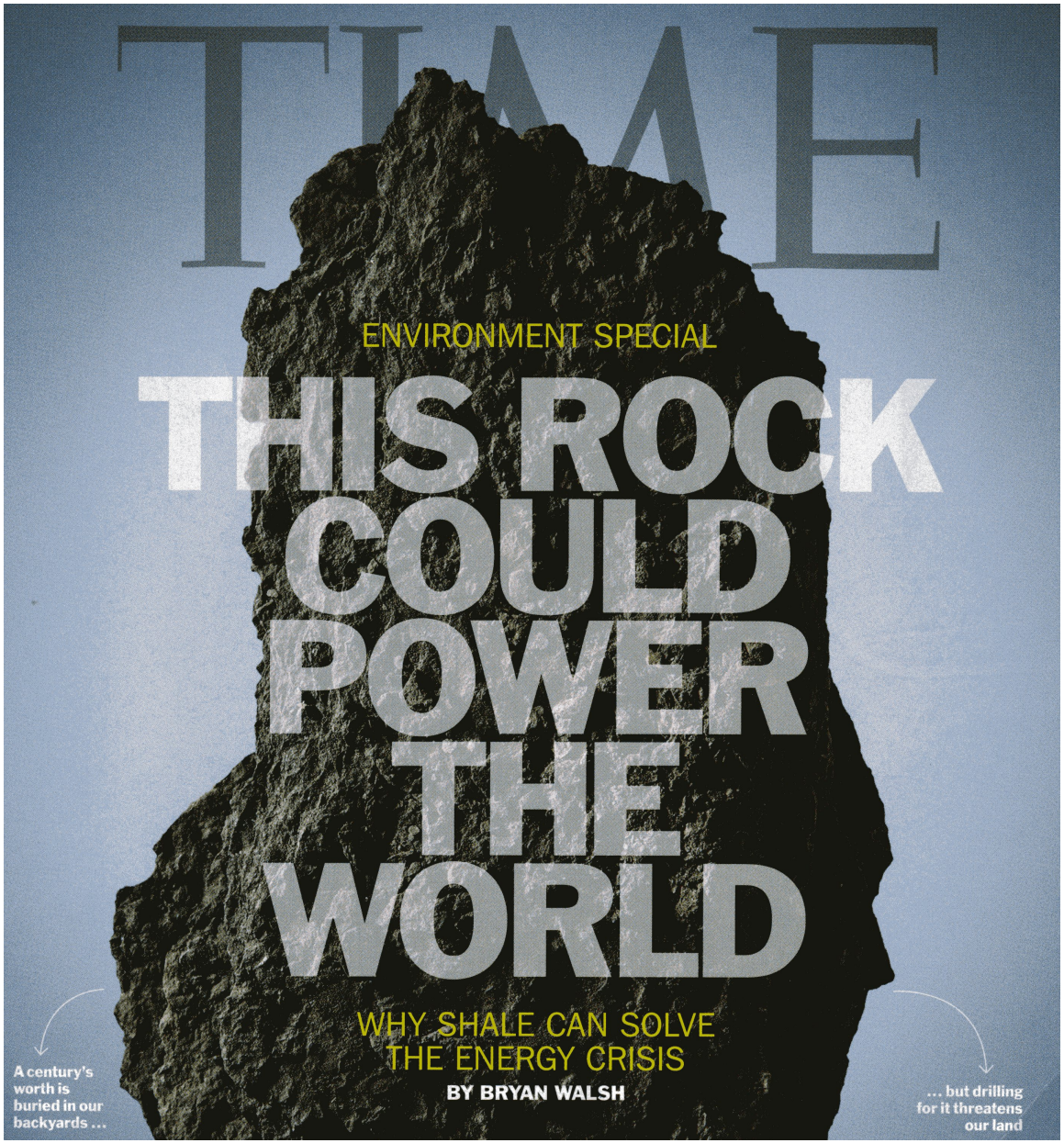
Different Faults are Activated
During Stimulation

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!