Hydraulic Fracture Growth: Real Data*

Kevin Fisher[1]

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Abstract

Much public discourse has taken place regarding hydraulic-fracture growth in unconventional reservoirs and whether fractures could potentially grow up to the surface and create communication pathways for fracture fluids or produced hydrocarbons to pollute groundwater supplies. Real fracture-growth data mapped during thousands of fracturing treatments in unconventional reservoirs are presented along with the reported aquifer depths near the fractured wells. These data are supplemented with an in-depth discussion of fracture-growth limiting mechanisms augmented by mineback tests and other studies performed to visually examine hydraulic fractures. These height-growth limiting mechanisms, which are supported by the mapping data, provide insight into why hydraulic fractures are longer laterally and more constrained vertically. This information can be used to improve models, optimize fracturing, and provide definitive data for regulators and interest groups. Additional information regarding toxicity of fracturing chemicals in the event of a spill or fracture intersection with aquifers will be presented.

Selected References

Bruner, K.R., and R. Smosna, 2011, A Comparative Study of the Mississippian Barnett Shale, Fort Worth Basin and Devonian Marcellus Shale, Appalachian Basin: DOE/NET l- 2011/1478, Web accessed May 9, 2014. http://www.netl.doe.gov/File%20Library/Research/Oil-Gas/publications/brochures/DOE-NETL-2011-1478-Marcellus-Barnett.pdf

Curry, M., T. Maloney, R. Woodroof, and R. Leonard, 2010, Less Sand May Not be Enough: SPE Unconventional Gas Conference, Pittsburg, PA, USA, February 23-25, 2010, SPE 131783.

Donze, T., 2012, Climate Realism: Xulon Press, 166 p.

O'Brien, N., G.D. Thyne, and R.M. Slatt, 1996, Morphology of hydrocarbon droplets during migration: visual example from the Monterey Formation (Miocene), California: AAPG Bulletin., v. 80, p. 1710-1718.

Slatt, R.M., P. Singh, R.P. Philp, K.J. Marfurt, Y. Abousleiman, N.R. O'Brien, and E.V. Eslinger, 2009, Workflow for stratigraphic characterization of unconventional gas shales: Gulf Coast Association of Geological Societies Transactions, v. 59, p. 699-710.

Hydraulic Fracture Growth: Real Data

AAPG Eagle Ford Workshop

Kevin Fisher
Flotek Industries

March 17, 1949

Outline

- Media and Public Scrutiny of Hydraulic Fracturing

- Hydraulic Fracturing Issues
  - Aquifer Contamination
  - Earthquakes
  - Frac Chemicals
  - Water Usage

Some "Fracking" Facts

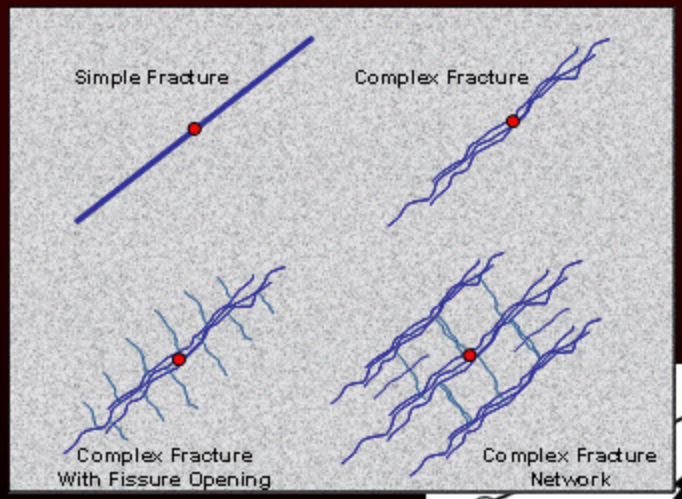
- Ethanol --- The U.N says that 500 lbs of corn can produce ethanol to fill a 13 gallon fuel tank OR feed a child for a year
  - It takes 9100 liters of water to make 1 liter of biodiesel
  - Carbon to hydrogen ration of methane CH_4 is 1:4; Biomass fuels average 40:4 – burning biofuels releases more carbon than methane, gasoline (2:4), jet fuel (2:4) AND coal (8:4)
  - Greenhouse Gases*
    - CO2 is 3.6% of non-water vapor greenhouse gases in atmosphere
      - Attributed manmade amounts is 0.12%
    - Methane, Nitrogen Dioxide and Chlorofluorocarbons, et al are 1.4%
      - Attributed Manmade amounts are 0.066%, 0.047%, 0.046% respectively
- CO2 levels today are about 390ppm*, average for last 5 million years has been 2500ppm. Below 200ppm plant growth slows appreciably.

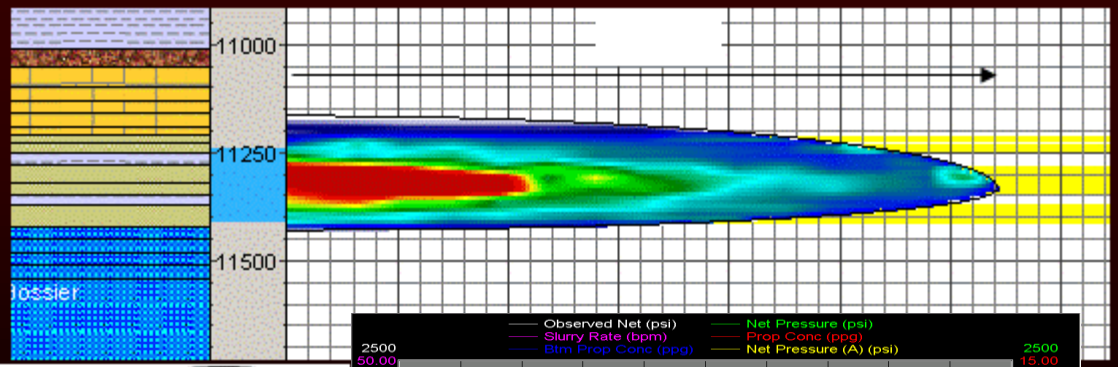
*Source "Climate Realism", Terry Donze

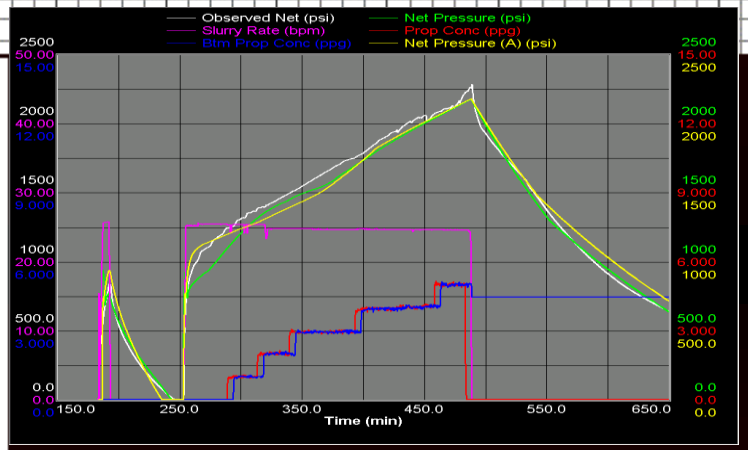
“Fracking” Facts continued…

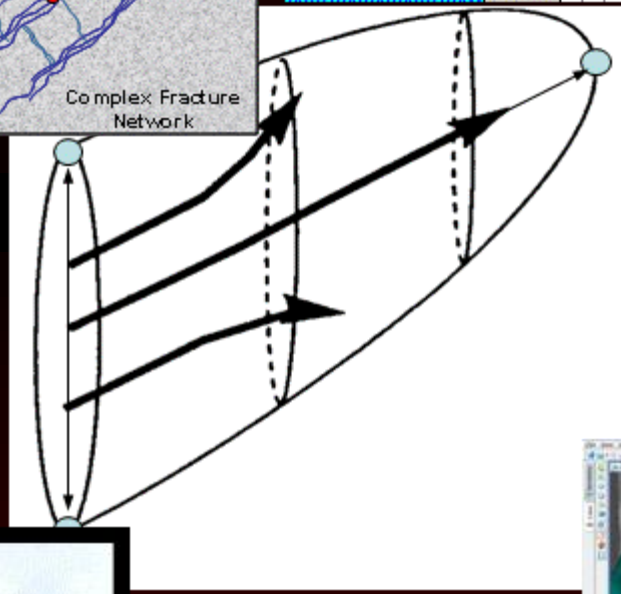
- US imported 60% of our oil in 2005; est <40% this year
- Oil Production ND exceeds two OPEC nations (Qatar and Ecuador) as well as that of the UK
- In 2006, ND per capita income was ranked 39th in US; in 2012, it was 7th
- A typical Bakken pad contains 16 wells and uses 10 acres of land to produce oil from 2560 acres (four square miles) – 0.5% of the land used for O&G activity
- Avg Marcellus well EUR ~10BCF. Converted to thermal energy = 3 TWh. A 10 well pad = 30 TWh. At 60% thermal efficiency of a combined cycle gas turbine = ~18TWh from a 1 acre pad in PA. This is about the output of the entire British wind industry in 2012 (19TWh)!

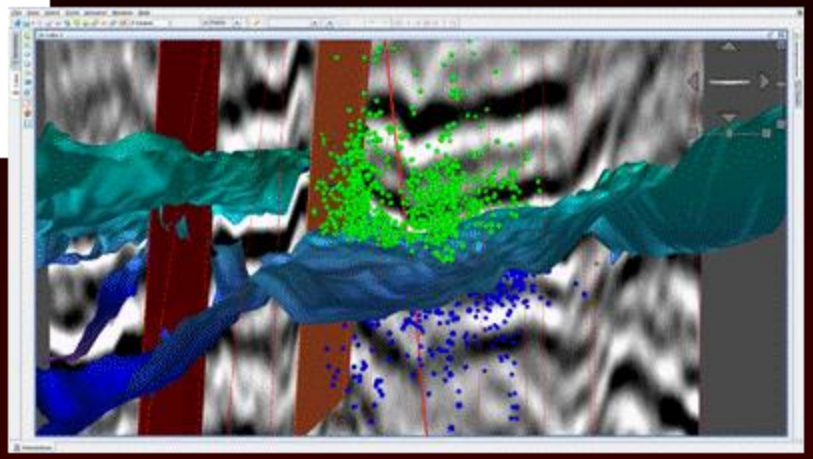
How Industry Experts Perceive Fracturing



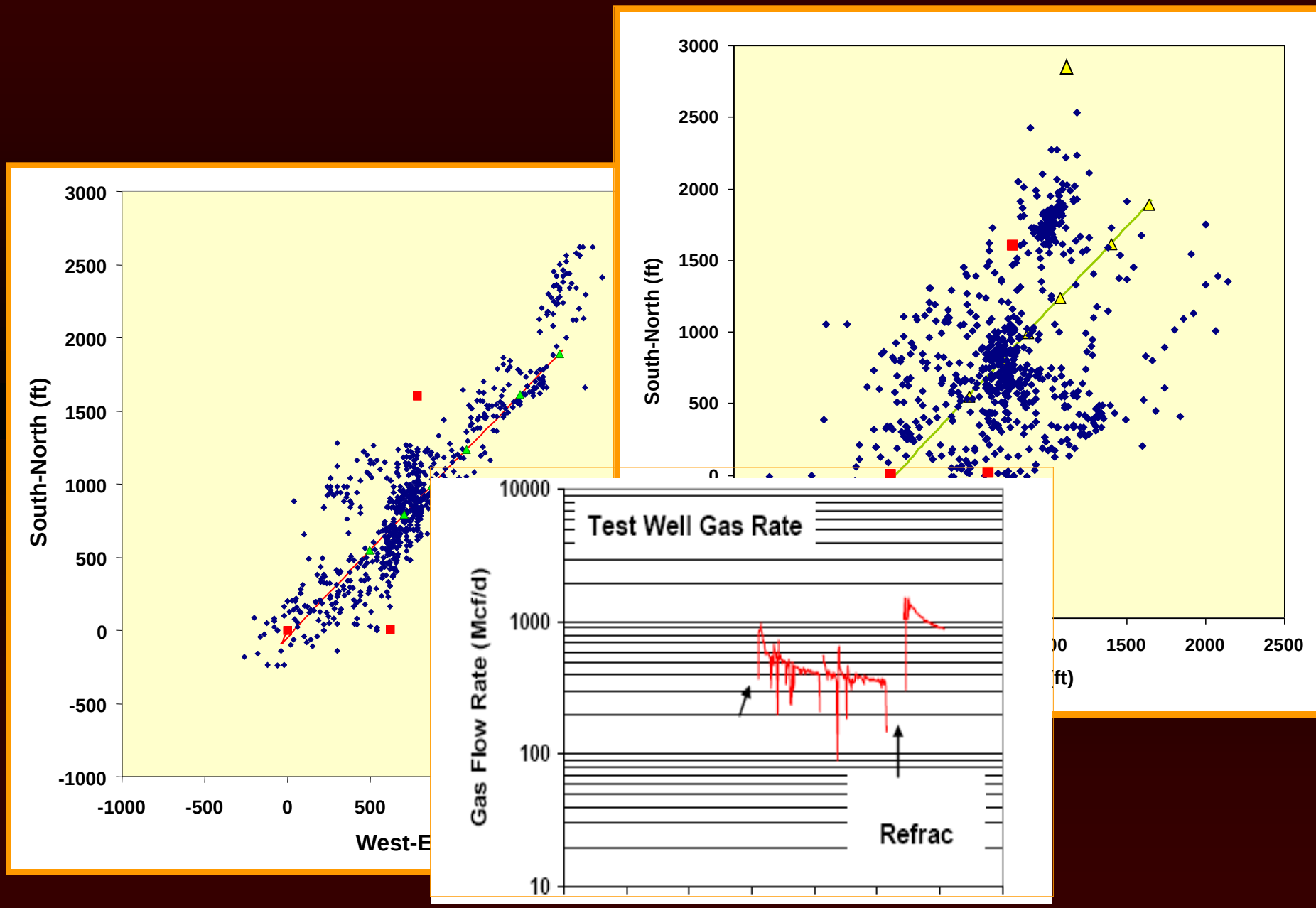






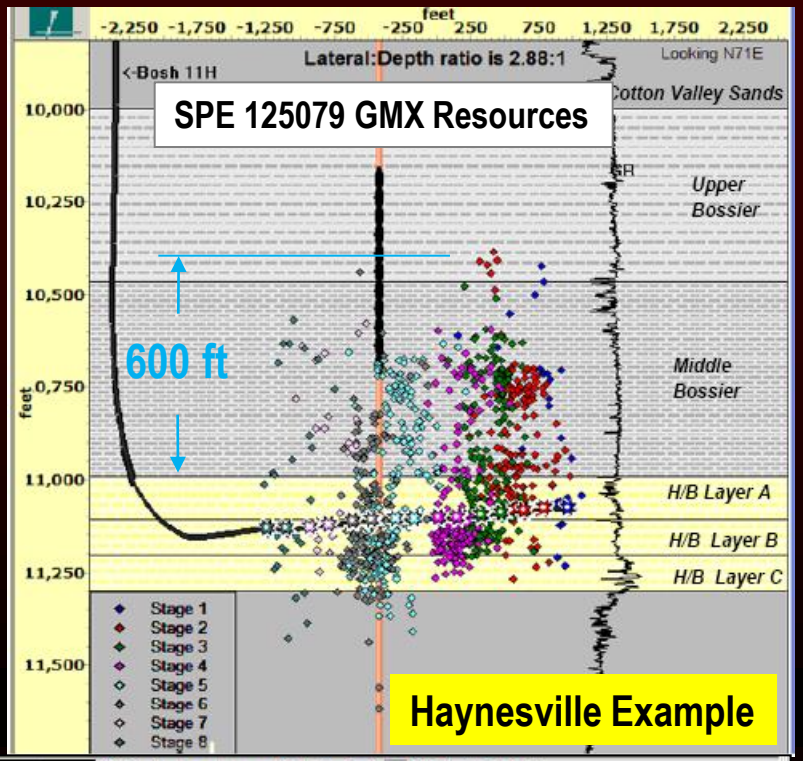


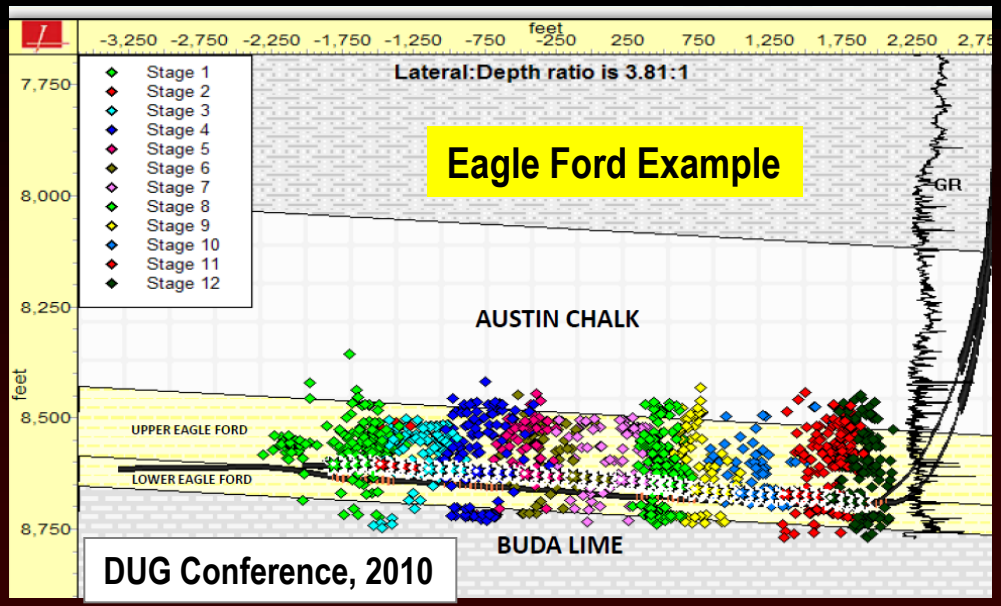
In Low-Perm Contact Area is Everything

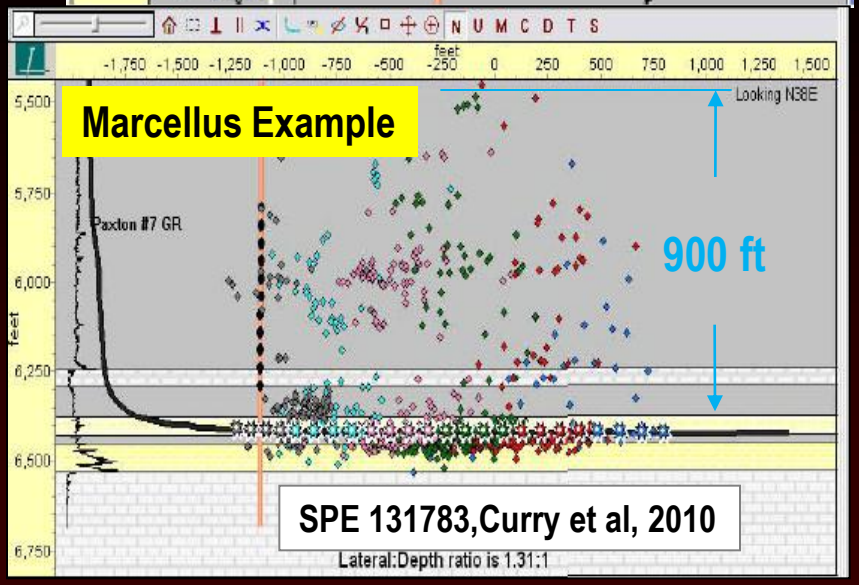


Fracture height growth

- Variable containment in shales
  - Containment (e.g., Eagle Ford & Barnett)
    - Bounded by carbonates
  - Upward growth (e.g., Marcellus & Haynesville
    - Relatively continuous shale
- Faulting
  - Common and bi-directional

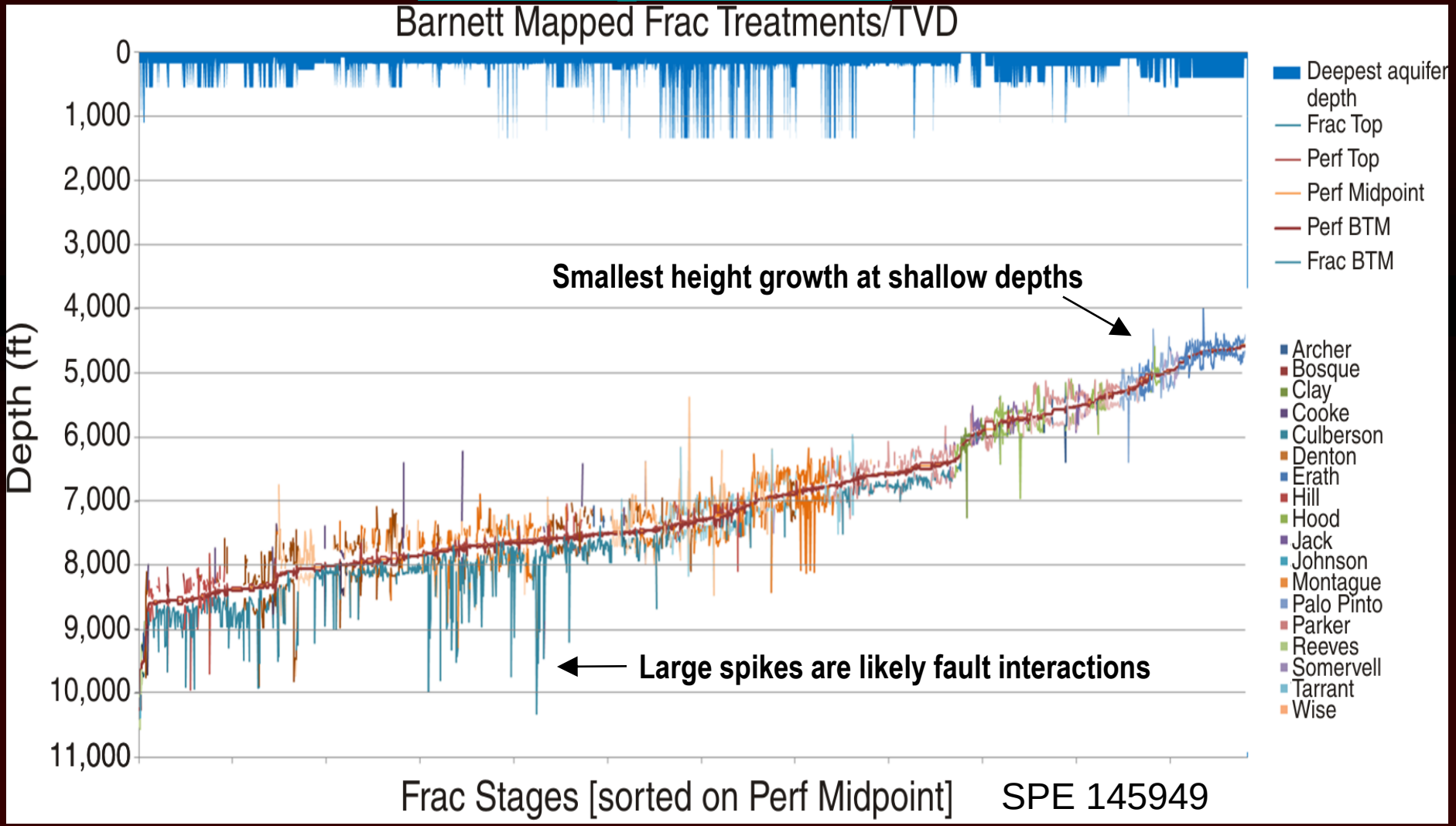




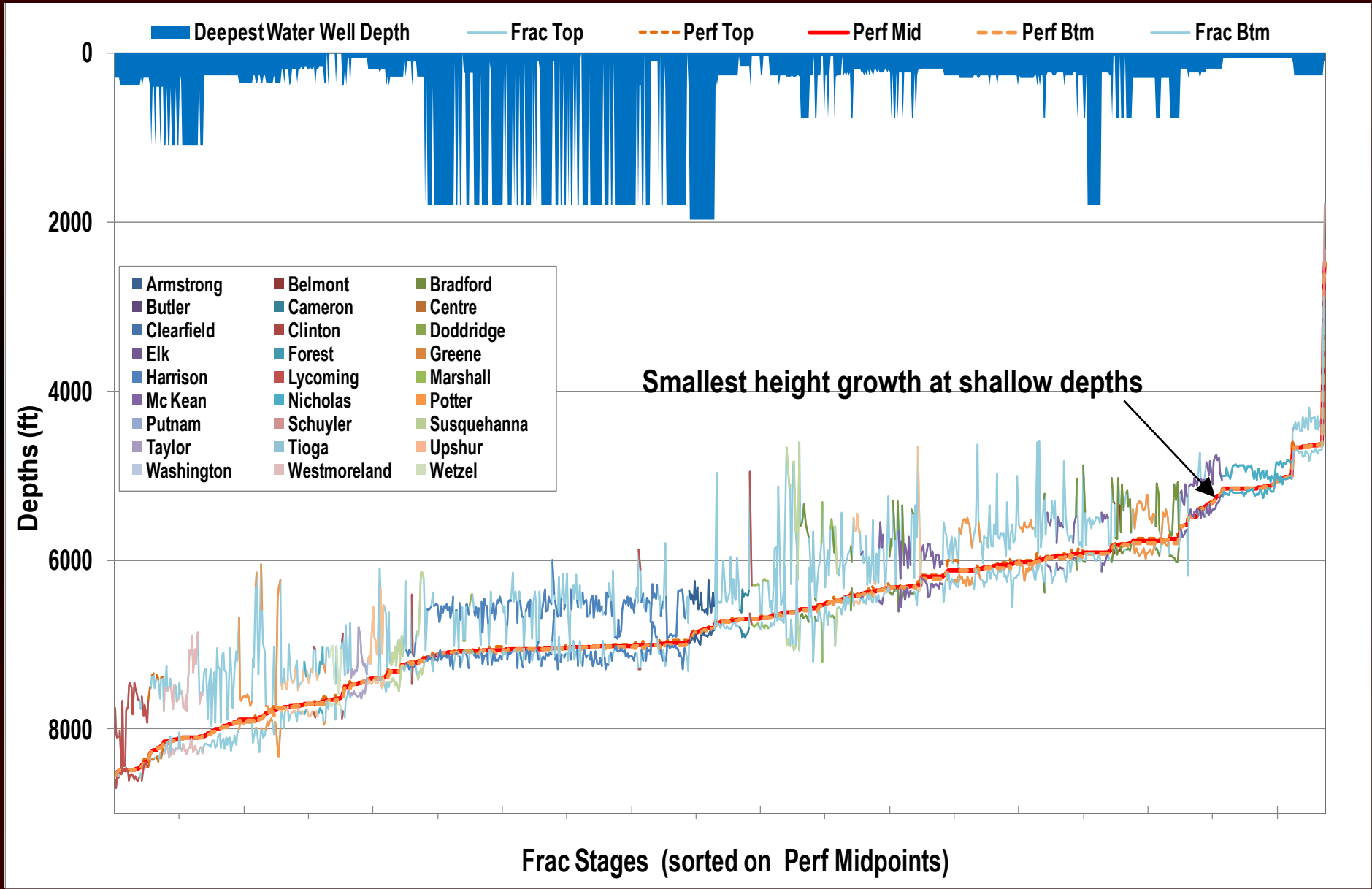


Mapped microseismic height for Barnett shale

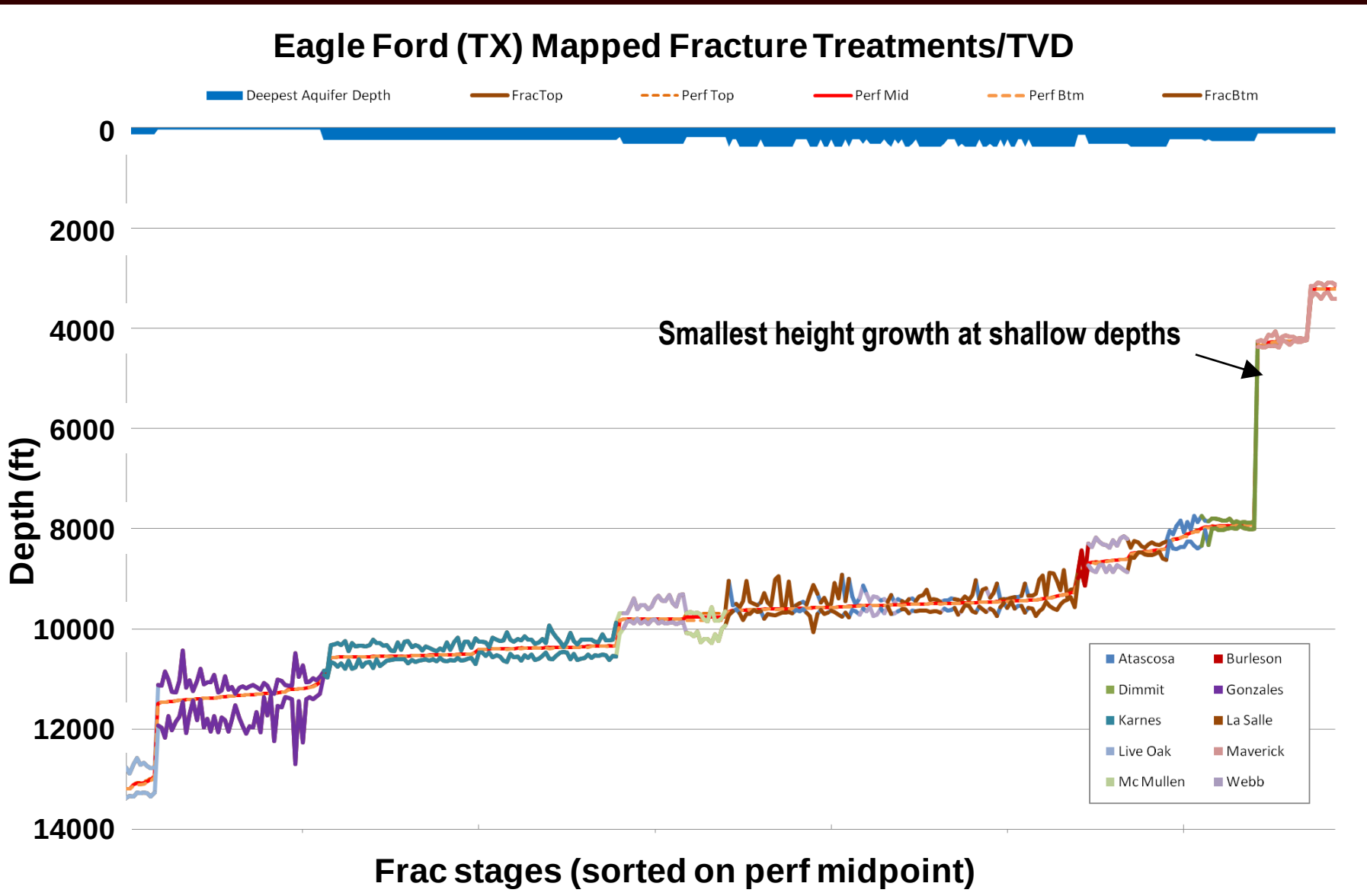
- Top: shallowest microseism; Bottom: deepest microseism
- Aquifers: USGS http://nwis.waterdata.usgs.gov/nwis/inventory?search_criteria=state_cd&submitted_form=introduction



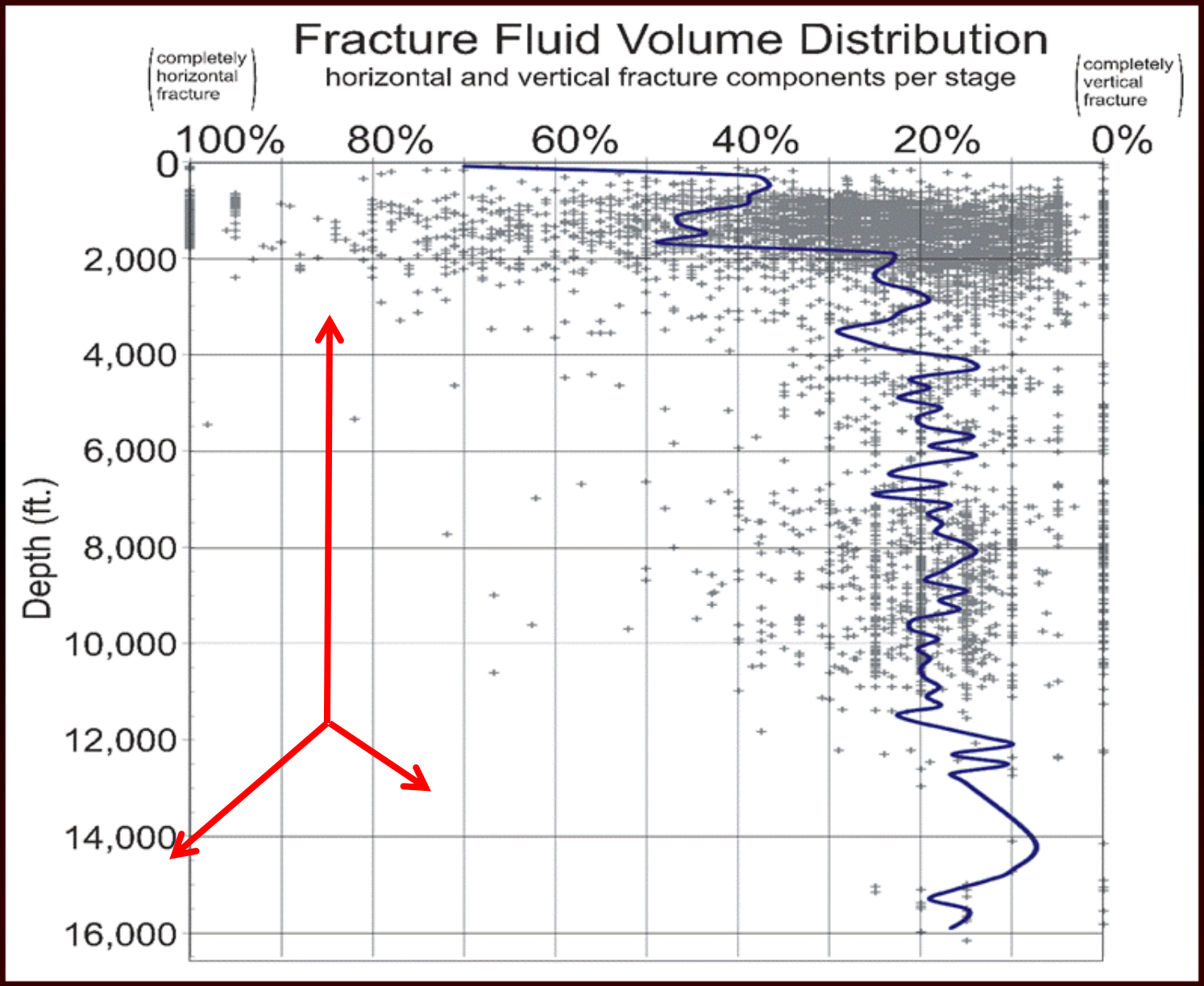
Mapped microseismic height for Marcellus shale



Mapped microseismic height for Eagle Ford shale

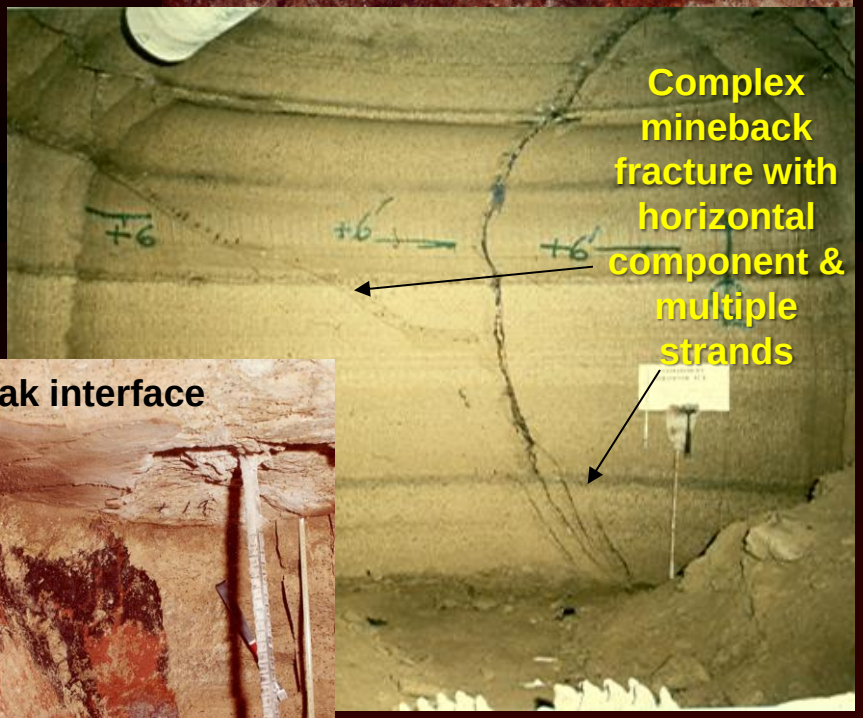


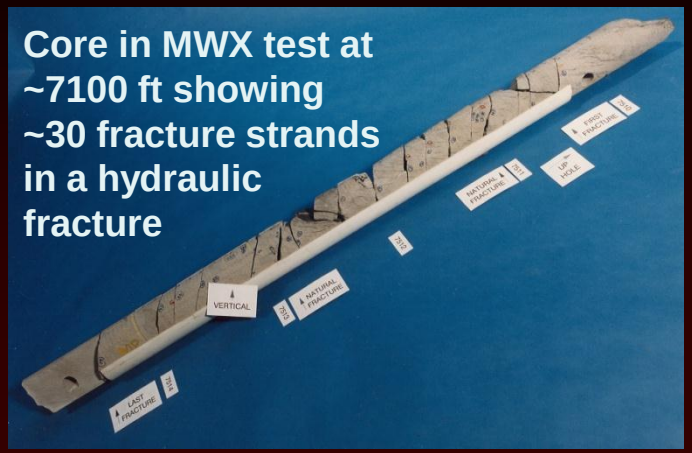
Tiltmeter Fracture Orientation vs Depth

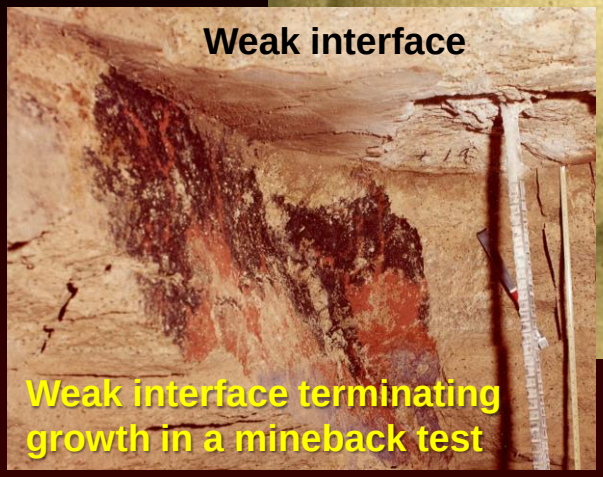


Direct Observations: Minebacks & Core

- Hydraulic fractures are complicated features
  - What we see:
    - Multiple strands
    - Offsets at discontinuities
    - Kinking, branching & turning







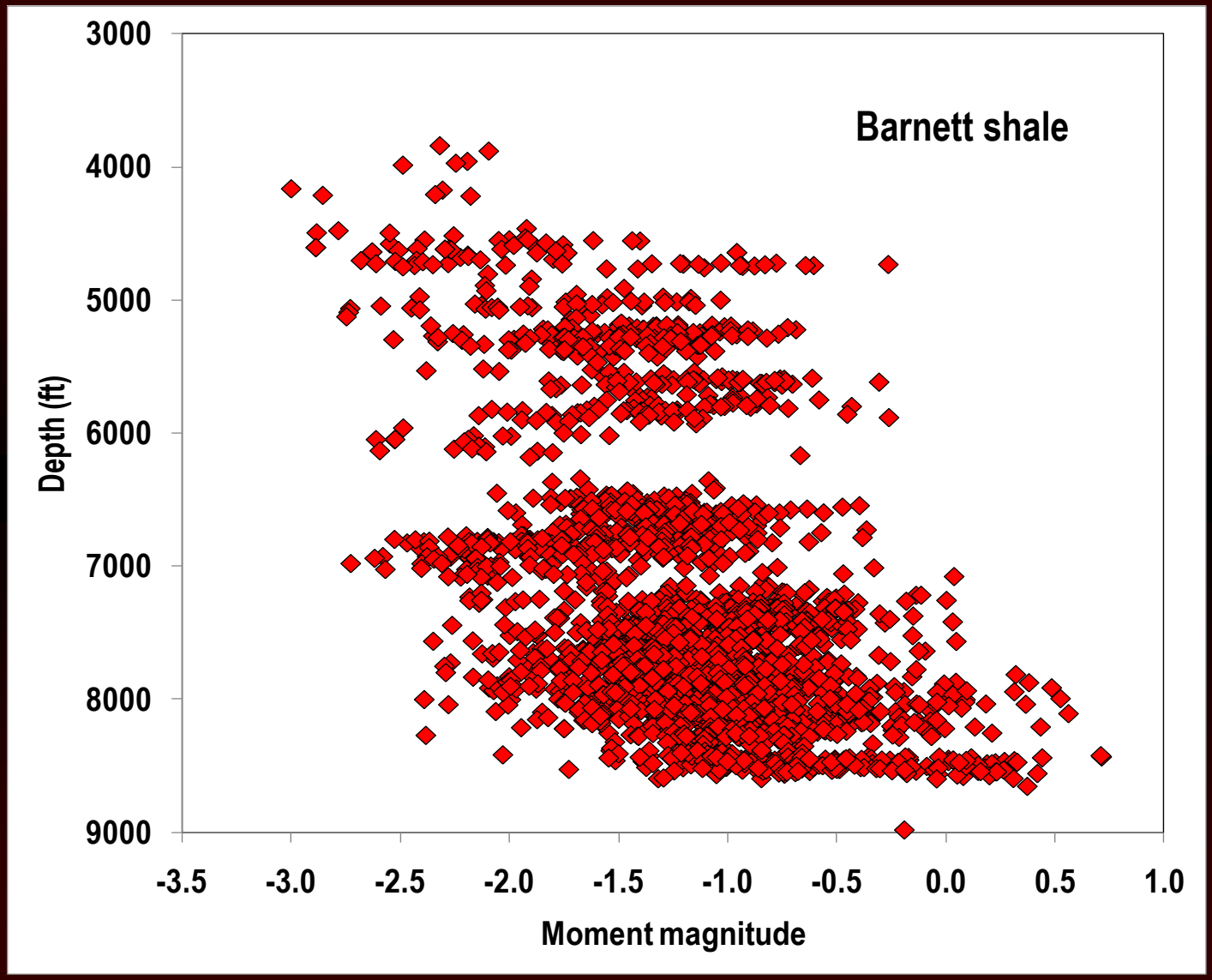
Source: DOE mineback, Multiwell Experiment & Slant Hole Completion Tests

Fracture Growth Summary

- Decades of study and monitoring of thousands of fracture treatments have demonstrated:
  - Fracture treatments in shales do not grow into aquifers
    - Microseismic data, tiltmeter data, tracer data, frac models
  - Vertical fracture growth is inhibited by layering & interfaces
    - Mineback, laboratory, numerical, and field studies
  - Except in cases of very unique tectonics, Fracturing does not generate even moderate magnitude earthquakes; disposal and long term injection can be problematic
  - Faults can influence fracture growth, but do not provide pathways for fracture fluid to reach the surface

- Always ensure that the casing strings are properly designed and cemented to prevent fluid/gas movement up the casing annulus

Does Fracturing Cause Earthquakes?



a -0.5 magnitude earthquake is about 180,000X less energy than a +3.0

Frac Chemicals: What About Spills?

- *"The Dose makes the Poison" - Paracelsus, 16th Century Chemist*

1gpt = 5.376 oz/bbl

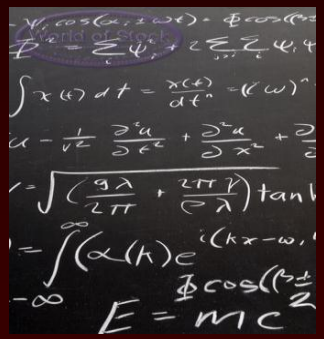
- **Any substance can be bad to human health in the right dosage. Examples:**

  Water and Vitamin C can kill humans if concentrations are high enough in the stomach or blood stream.

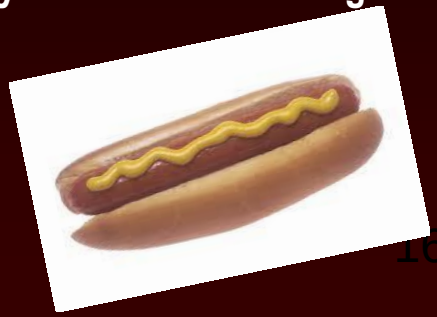
  Acrylamide (a common oilfield chemical) is contained in over 750 common foods including ketchup, olives, breakfast cereal and coffee. Acrylamide is also a carcinogen

- **Food Grade: Food grade is simply a way to communicate with the public in terms they understand. It doesn't mean that it cannot cause harm to human's. Food grade concept may not consider "dosage"**

- **Many may not understand this**



But ALL understand this



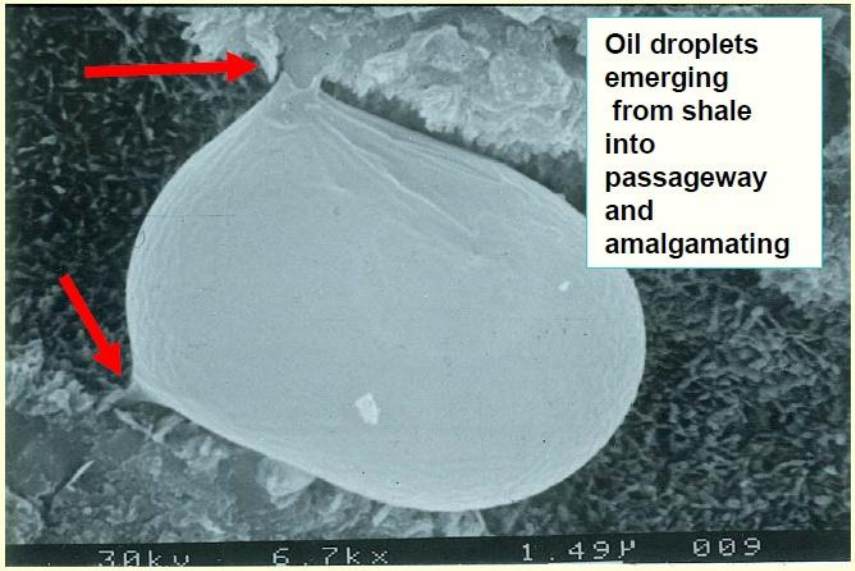
Common Frac Chemicals 1gpt = 5.376 oz/bbl

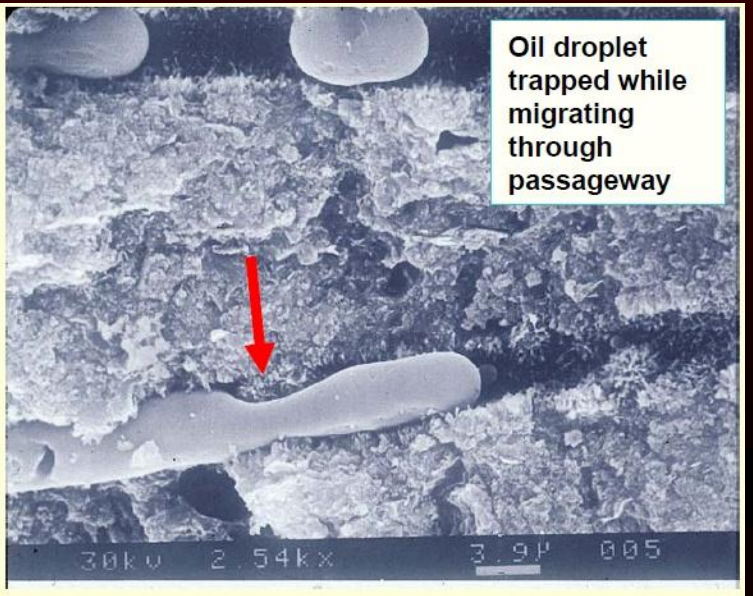
Most Common Slick Water Frac Additives	Composition	CAS Number	Alternate Use
Friction Reducer	Polyacrylamide	9003-05-8	Adsorbent in baby diapers, flocculent in drinking water preparation
Biocide	Glutaraldehyde	111-30-8	Medical disinfectant
Alternate Biocide	Ozone, Chlorine dioxide UV,	10028-15-6 10049-04-4	Disinfectant in municipal water supplies
Scale Inhibitor	Phosphonate & polymers	6419-19-8 and others	Detergents and medical treatment for bone problems.
Surfactant	various	various	Dish soaps, cleaners

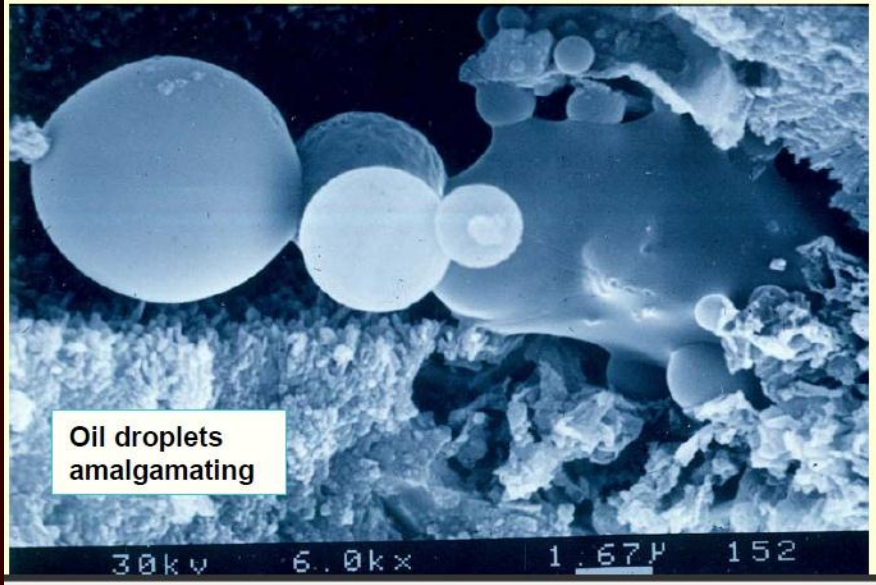
Post those fracs in www.fracfocus.com

SPE 152596 courtesy of George King/Apache

How Does Oil Move Through Shale?







O'Brien, N., G.D. Thyne, and R.M. Slatt, 1996, Morphology of hydrocarbon droplets during migration: visual example from the Monterey Formation (Miocene), California, AAPG Bull., v. 80, p. 1710-1718

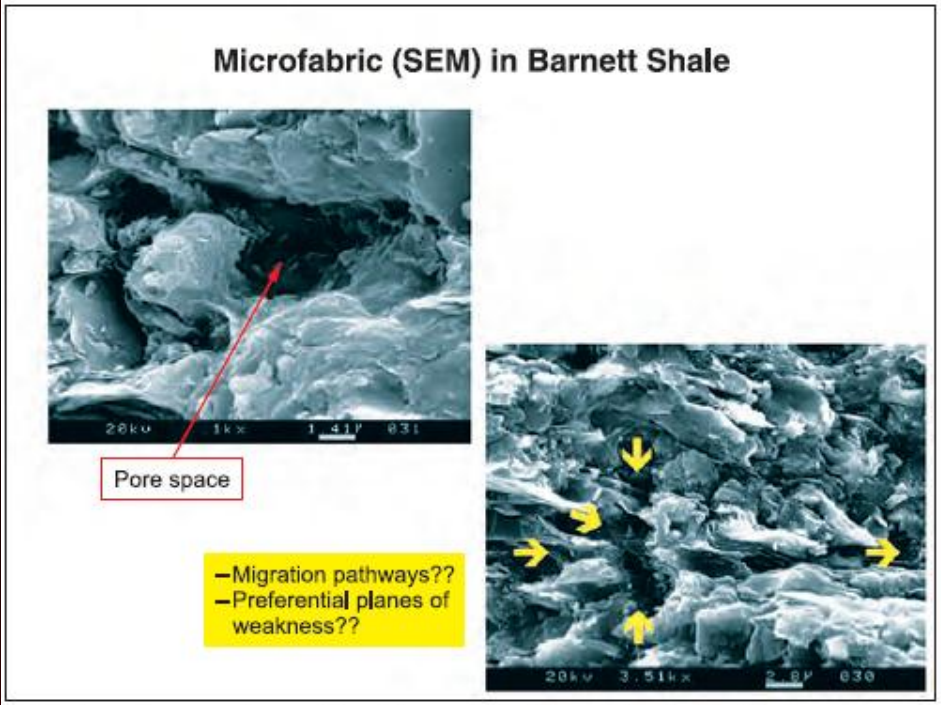
Source: Conoco-Phillips Slide

Courtesy of George King/Apache

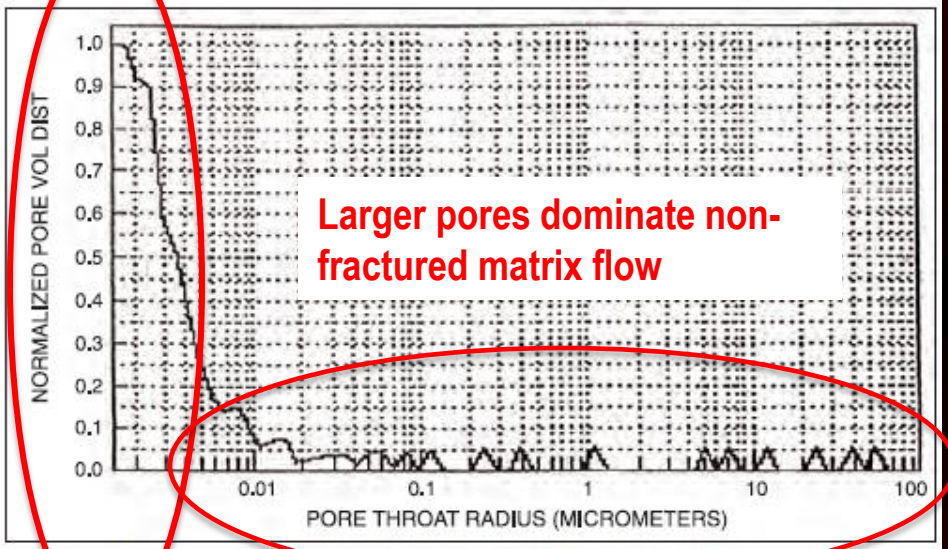
Roger M. Slatt, Prerna Singh, R. Paul Philp, K.J. Marfurt, *and* ***Y. Abousleiman,*** *ConocoPhillips School of Geology and Geophysics, University of Oklahoma, and* ***N.R. O'Brien,*** *Department of Geology, State University of New York*

Porosity vs. Flow Passages

Smaller pores dominate pore numbers



SEM view of pores and porosity pathways in the Barnett Shale. Modified from Slatt and others, 2009.



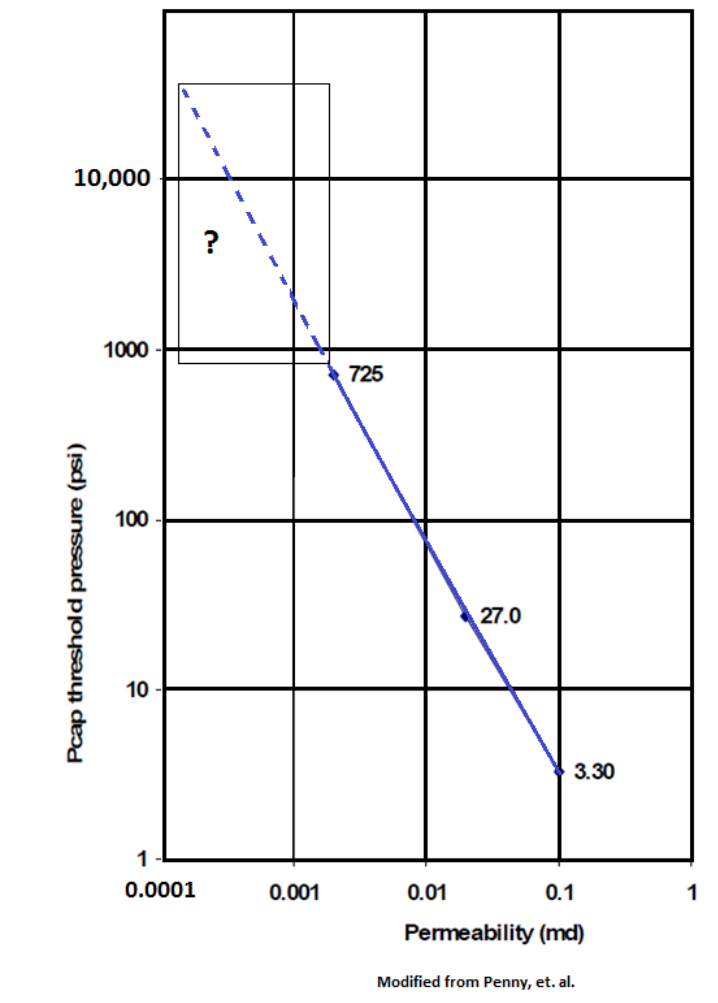
Results of mercury-porosimetery analysis of the Barnett Shale. Eighty percent of the pore throats have a radius of less than 0.005 micrometer. Sample from 8,094 ft in Enre Corporation (Chevron), Mildred Atlas #1, Johnson County. Modified from Bowker, 2007b.

Bruner, K.R., Smosna, R.: "A Comparative Study of the Mississippian Barnett Shale, Fort Worth Basin, and Devonian Marcellus Shale, Apalachian Basin," DOE/NETL - 2011/1478, April 2011

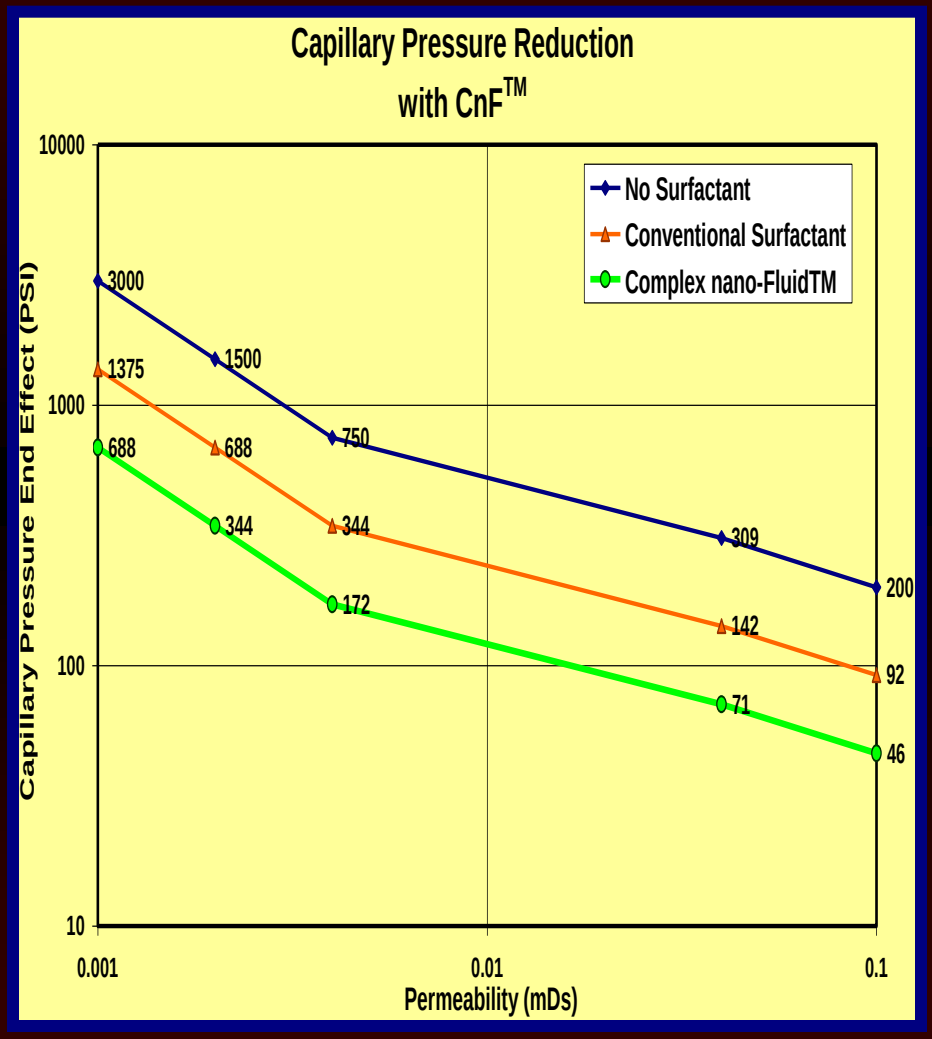
Courtesy of George King/Apache

Issues Impacting Flow in Low Permeability Reservoirs

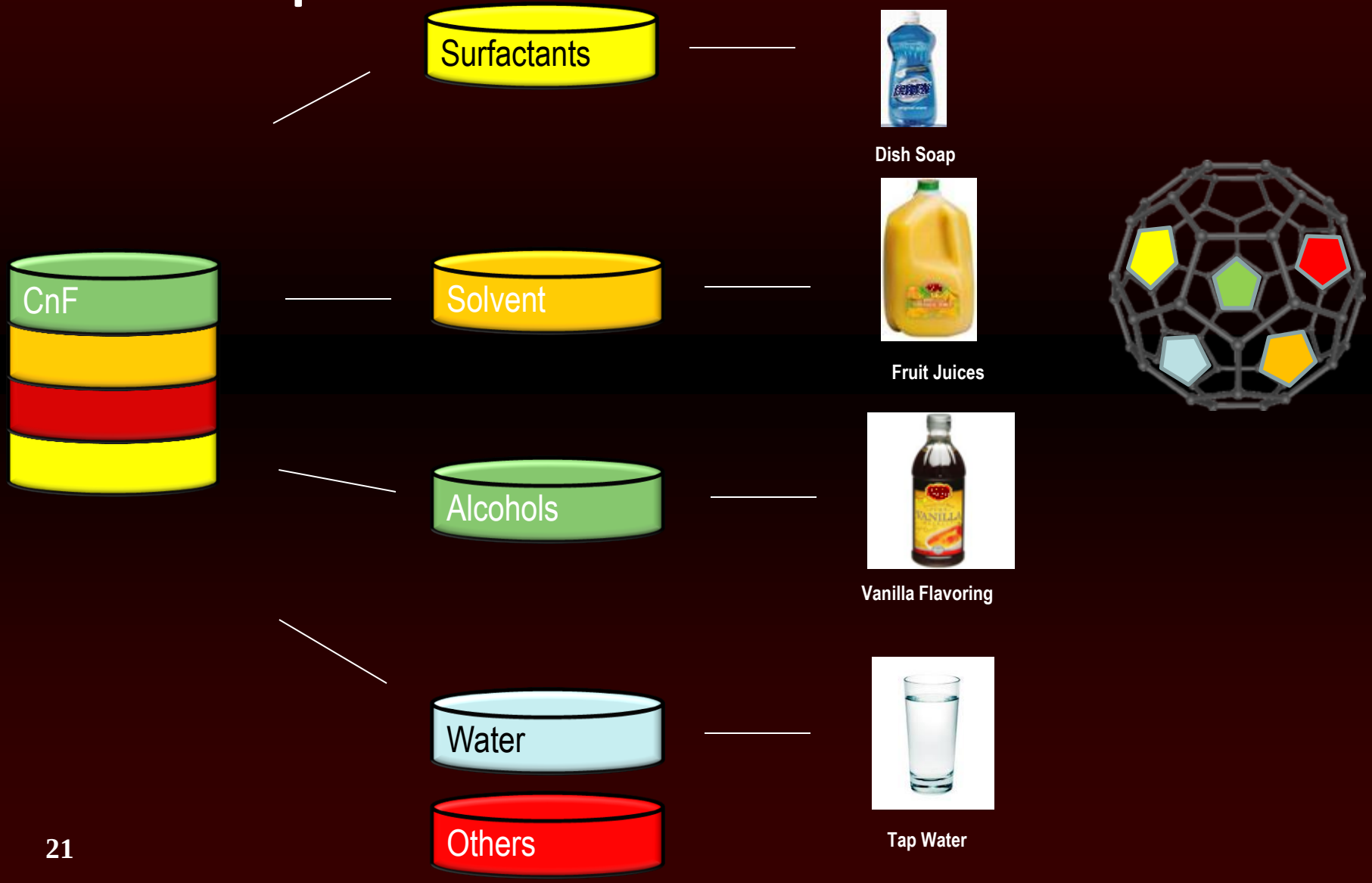
Threshold Pressure to Flow in lower Permeability Formations



Capillary pressures or “blocking pressure”



Made From the Best Stuff on Earth-- Complex Nano Fluid™ Additives

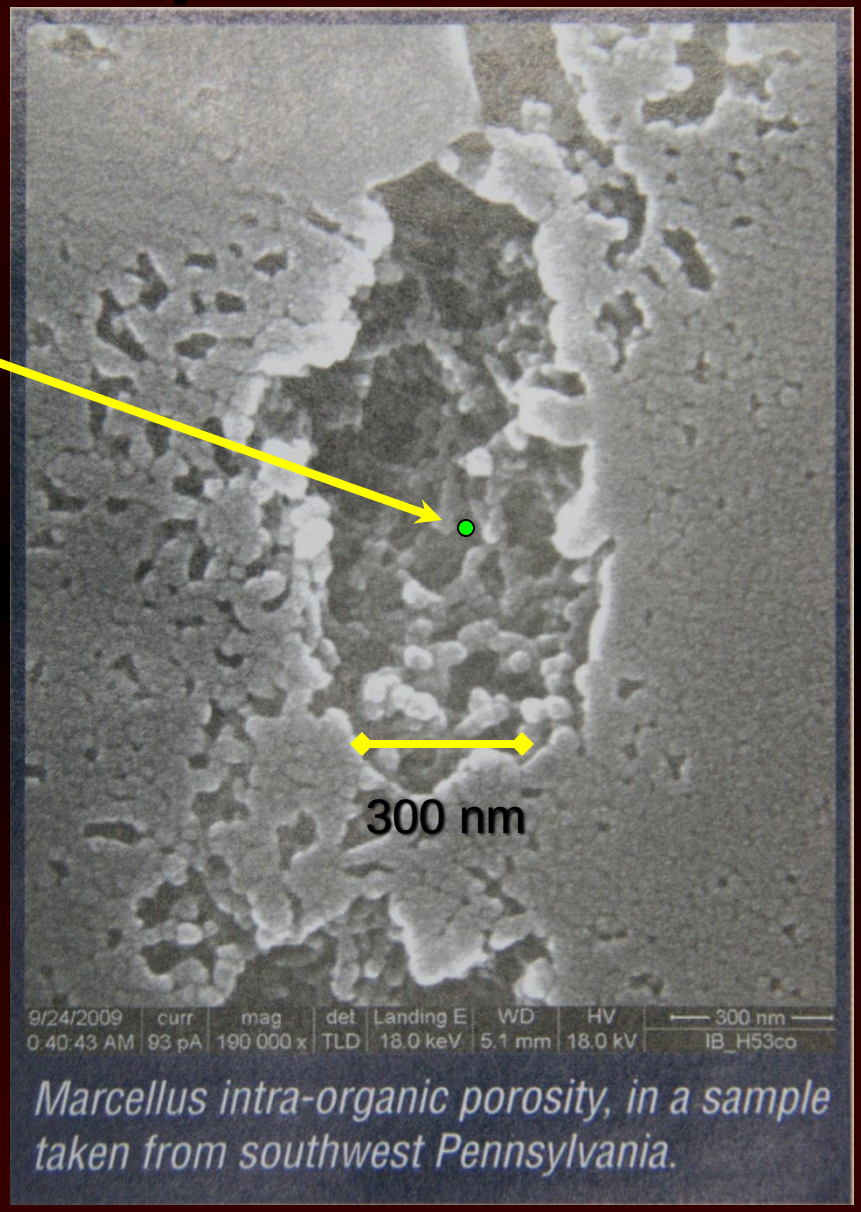


CnF® Droplets in Your Reservoir

A CnF® nano droplet

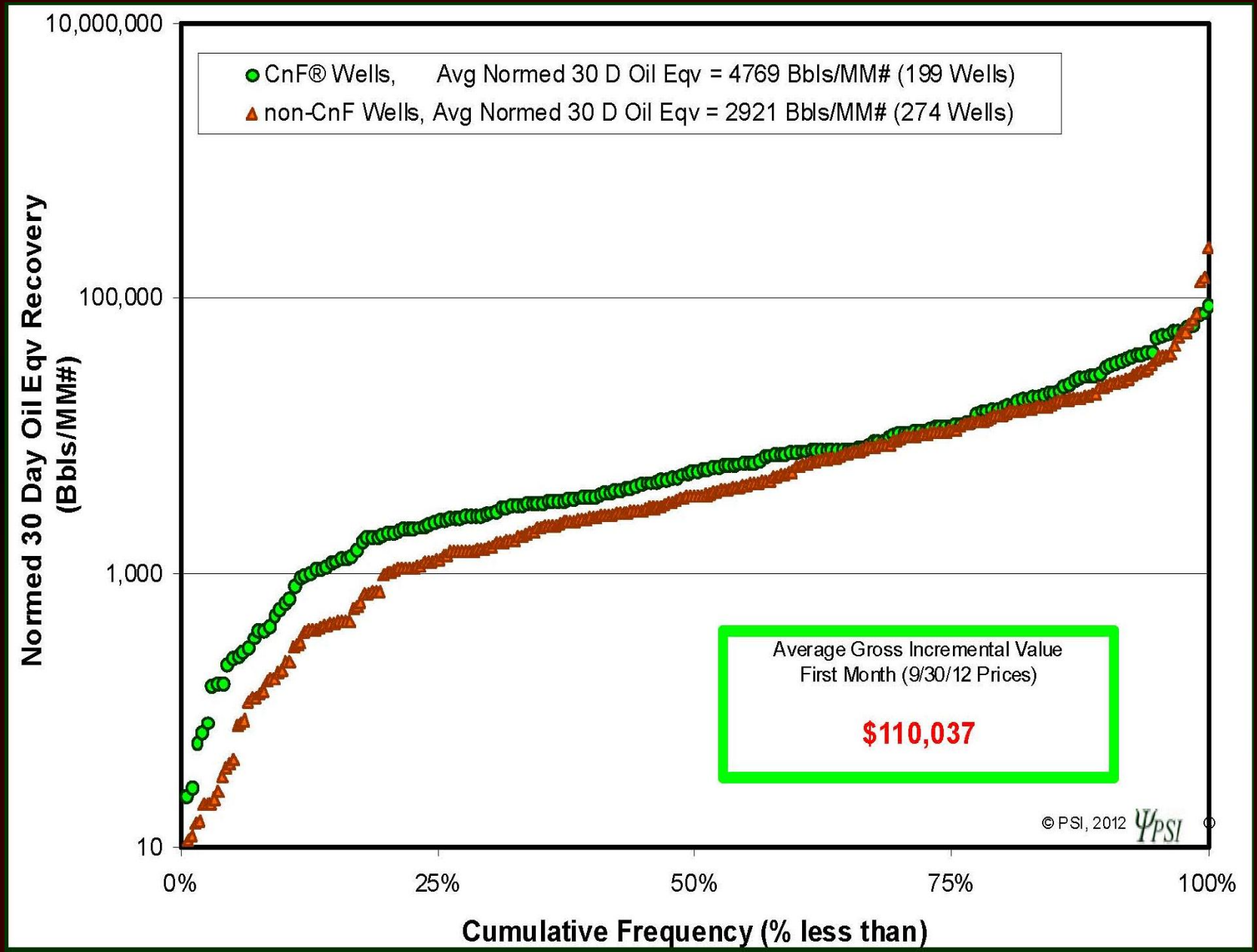
CnF effectiveness derived from:

- Advanced chemistry
- Physics and mobility of nanoparticle carrier



Courtesy of Range Resources

Can “Green” Outperform?



Can We Do Better? BTEX Issues

- At the heart the exploration and production debate is the chemical makeup of the drilling, completion and production fluids, which can pose a threat to soil and groundwater. There is concern in both the industry and the general public regarding many additives used by the oil and gas industry; here we are specifically referring to the toxic “Terrible Quadrilateral” of benzene, toluene, ethylbenzene, and xylene, or BTEX.

- Benzene, Toluene, Ethylbenzene and Xylene, commonly referred to as BTEX, are hazardous, toxic compounds used in the drilling, completion and production process. BTEX compounds are listed as hazardous air pollutants in the Clean Air Act. They are also listed as regulated contaminants in the Safe Drinking Water Act.

    - Benzene is a common component of crude oil, gasoline and cigarette smoke, and the Department of Health and Human Services has determined that benzene is a known carcinogen.

    - Toluene is a naturally occurring component of many petroleum products and is a suspected carcinogen. Chronic exposure can lead to problems in the nervous system, kidneys and liver.

    - Ethylbenzene is a known carcinogen, and is used primarily as an additive to gasoline and aviation fuel.

    - Xylene is a suspected carcinogen, and has harmful effects on the human body, including the central nervous system. Xylene is one of the top 30 chemicals produced in the United States by volume.

Citrus Based Solvent

- Through research and innovation, Florida Chemical and Flotek have developed effective substitutes for xylene that provide similar results while at the same time mitigate the environmental impact of harmful toxins.

- Florida Chemical's FC-PRO operating company provides a suite of renewable and sustainable oilfield production chemistries that are **GREAT and GREEN!**

Product Comparison Chart	Citrus Terpene Solvents	Toluene/ Xylene
Teratogen (reproductive hazard)	**No**	**Yes**
Suspected Carcinogen	**No**	**Yes**
SARA Title III (Section 313)	**Not Subject**	**Subject**
GRAS (Generally Regarded As Safe)	**Yes**	**No**
Regulated Drinking Water Contaminant	**No**	**Yes**
Federal Biobased Products Preferred Procurement Program	**100% compliant**	**Not compliant**
Flashpoint (ºF)	**> 100**	**< 100**

WATER USAGE

Water availability is a local challenge – Chesapeake Bay example

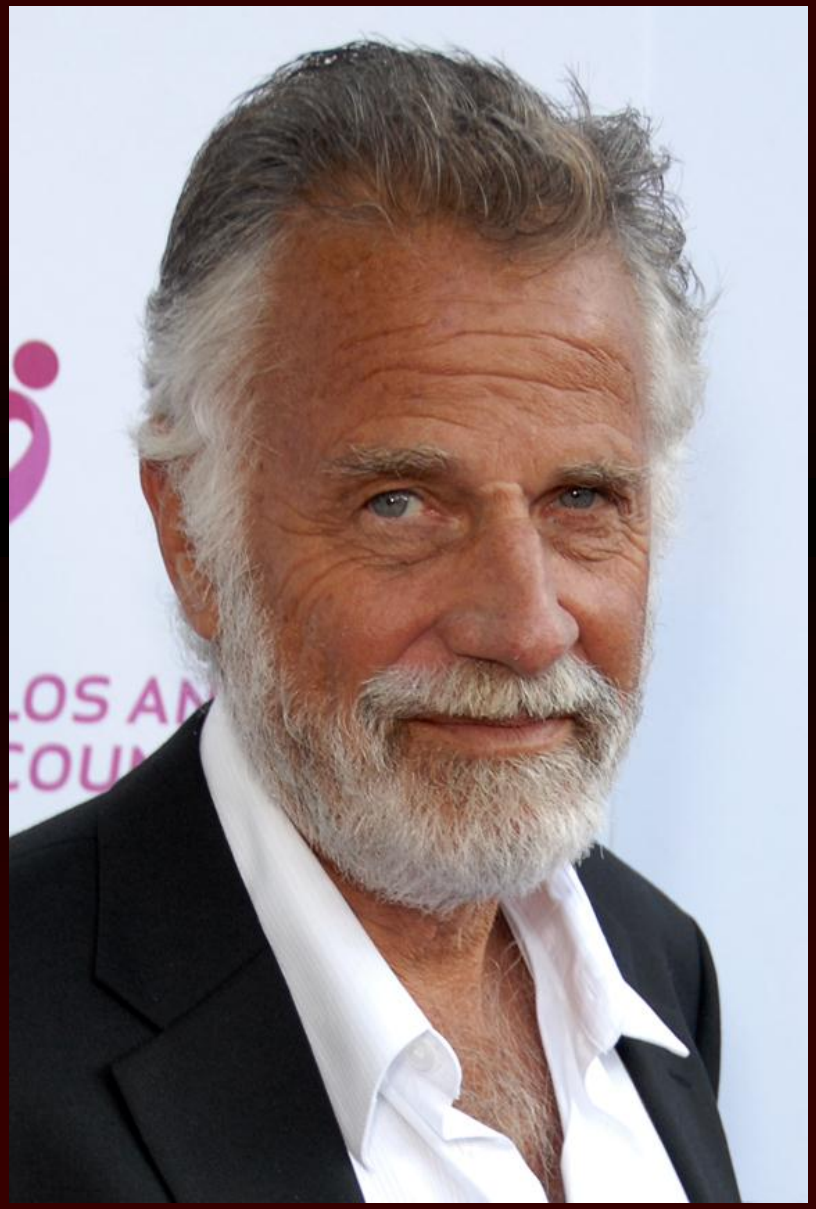
TX 1% of water use goes to oil and gas; Eagle Ford used about 19 billion gals for fracturing in 2013. City of Houston LOST about 22 billion gals to leaks in 2013.

TX has 19 coal fired power plants. Just two of them used more water than all Eagle Ford frac jobs last year. Water used in natl gas operations produces 25 to 50X more kwh per gallon of water than coal fired power plants

CO 0.13% of water for fracturing for 7% of CO economy so water usage effectiveness of fracturing about 50X greater than all other sources

“Oil Companies” manage far more water than oil or gas

Stay Productive, My Friends



He doesn't always frac his wells, but when he does, he uses environmentally friendly frac fluids. He is the world's most informed fracker!

FLOTEK