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An Industry View on Shale Gas Developments and Hydraulic ~~Fracking~~ Fraccing

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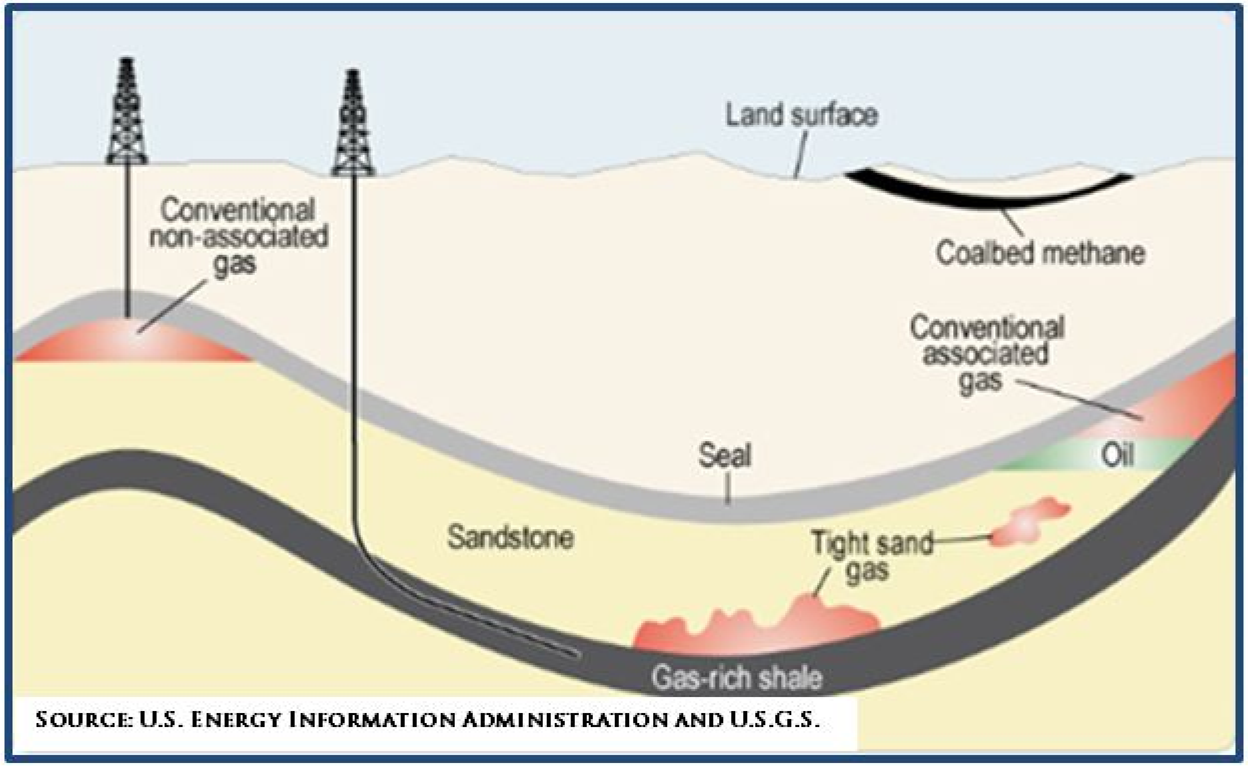
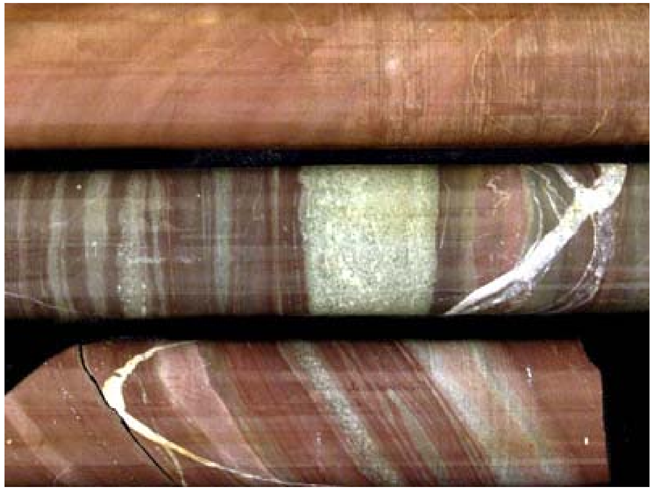
Agenda

- Oil and Gas introduction
- Hydraulic Fracturing
- Shale gas
- Media/Politics
- The Future
- Questions (but you can interrupt me at any point!!)

- Nomenclature: conventional vs. unconventional (e.g. shale gas)



Conventional Vs. Unconventional Oil & Natural Gas



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Hydraulic Fracturing

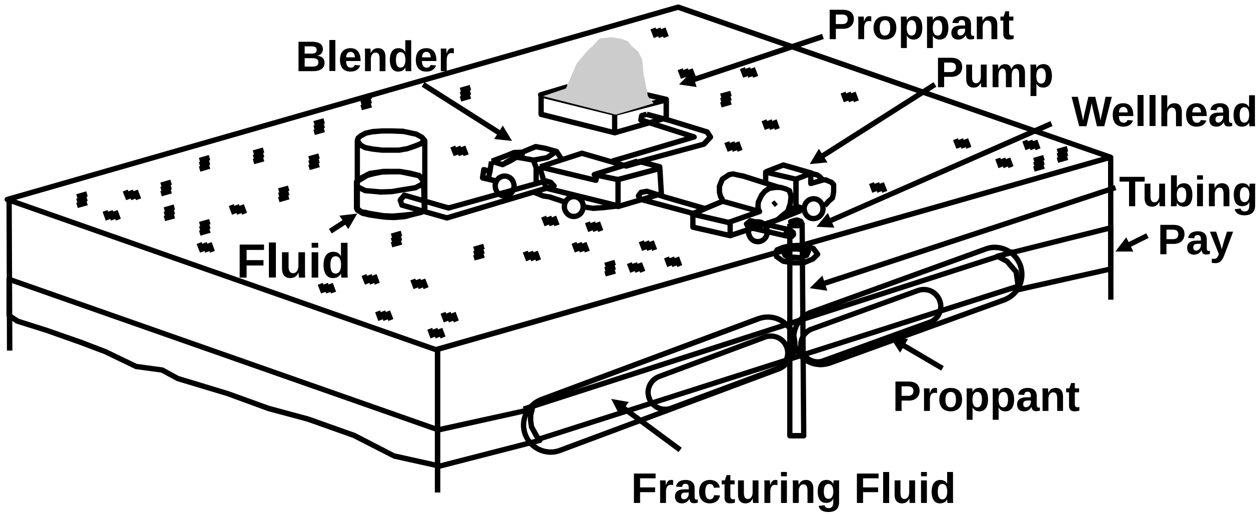
- Topics:
  - What is it?
  - Objectives
  - Physics
  - Practice: fluids & proppants
  - History
  - But first ....

Ice Age- Trailer 1 (2002) (1).mp4

Ice Age 4- Scrat Continental Crack Up HD.mp4

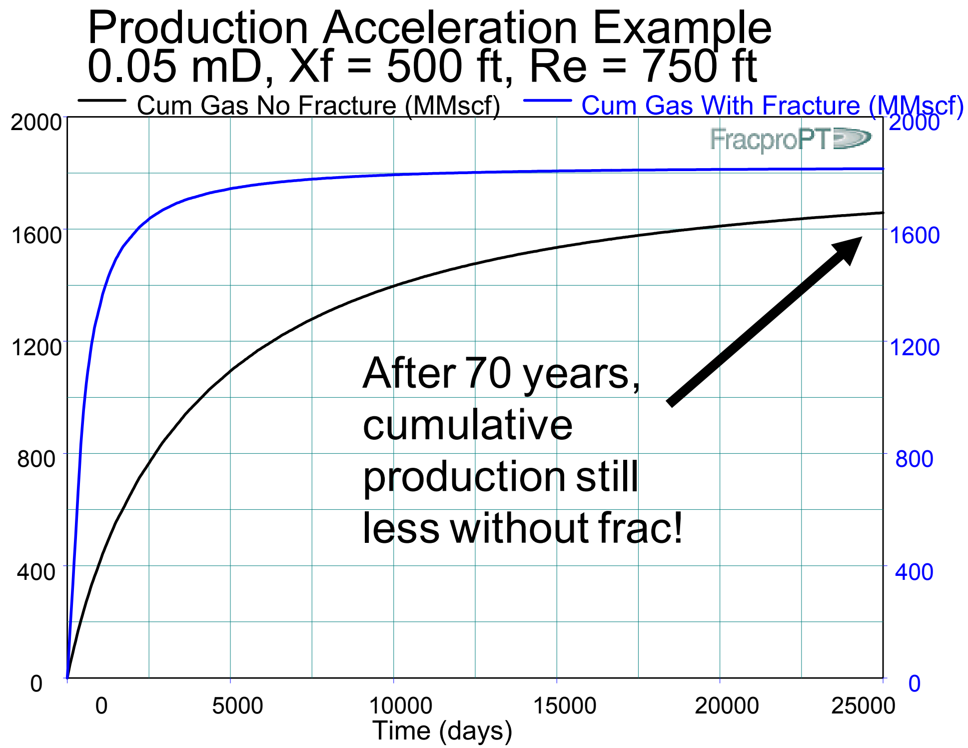
What is Hydraulic Fracturing?

- Hydraulic fracturing is the process of using hydraulic pressure to create an artificial fracture in a reservoir
- The fracture grows in length, height and width by pumping a mixture of fluid and proppant or acid
- The proppant keeps the fracture open after pumping stops
- For acid fracturing, an etched width and wormholes are created that remain open for some time (Carbonates only)



How does it look down there?

Why Frac?



- Increase NPV
  - Accelerate production
- Increase contacted *kh*
  - In layered reservoirs
- Increase recovery
  - More uniform depletion in layered reservoirs
  - Reduce drawdown: Avoid condensate banking, scaling, salting, fines
  - High perm: Bypass skin, avoid non-Darcy flow in matrix
- Improve field development economics: Reduce well count

When to frac?

- In general: To optimize production
  - Lower permeability (borderline depending on economics)
  - High permeability wells (best economics)
  - Bypass skin (initial skin from drilling & avoid during production)
    - Frac & Pack
  - Minimize wells
  - Layered reservoirs

What are the objectives?

- Enhance production/recovery as efficient as possible
  - Low investment: well technology, completion technology, stimulation cost
  - High return: right fracture geometry, right conductivity

- The right fracture. What is it?

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What are the rewards?

- Great economics in most cases:
  - Payback time of days is normal for medium to high perm
  - Payback time of weeks to months for low permeability
- Great potential to limit the # of wells
- Only way to make field economics work for low permeability
  - NPV & recovery

Where is Hydraulic Fracturing Performed?

- Across all type of environments
  - 90% of all wells onshore in the USA are hydraulically fractured
  - High permeability Gulf of Mexico, North Sea, Alaska, etc.
  - 600 ft deep coal seams to 18,000 ft deep sandstones
  - Carbonates, shales, sands, diatomite, coal, volcanic, etc.
  - Hard rock & soft rock
  - Offshore & onshore
  - All six continents

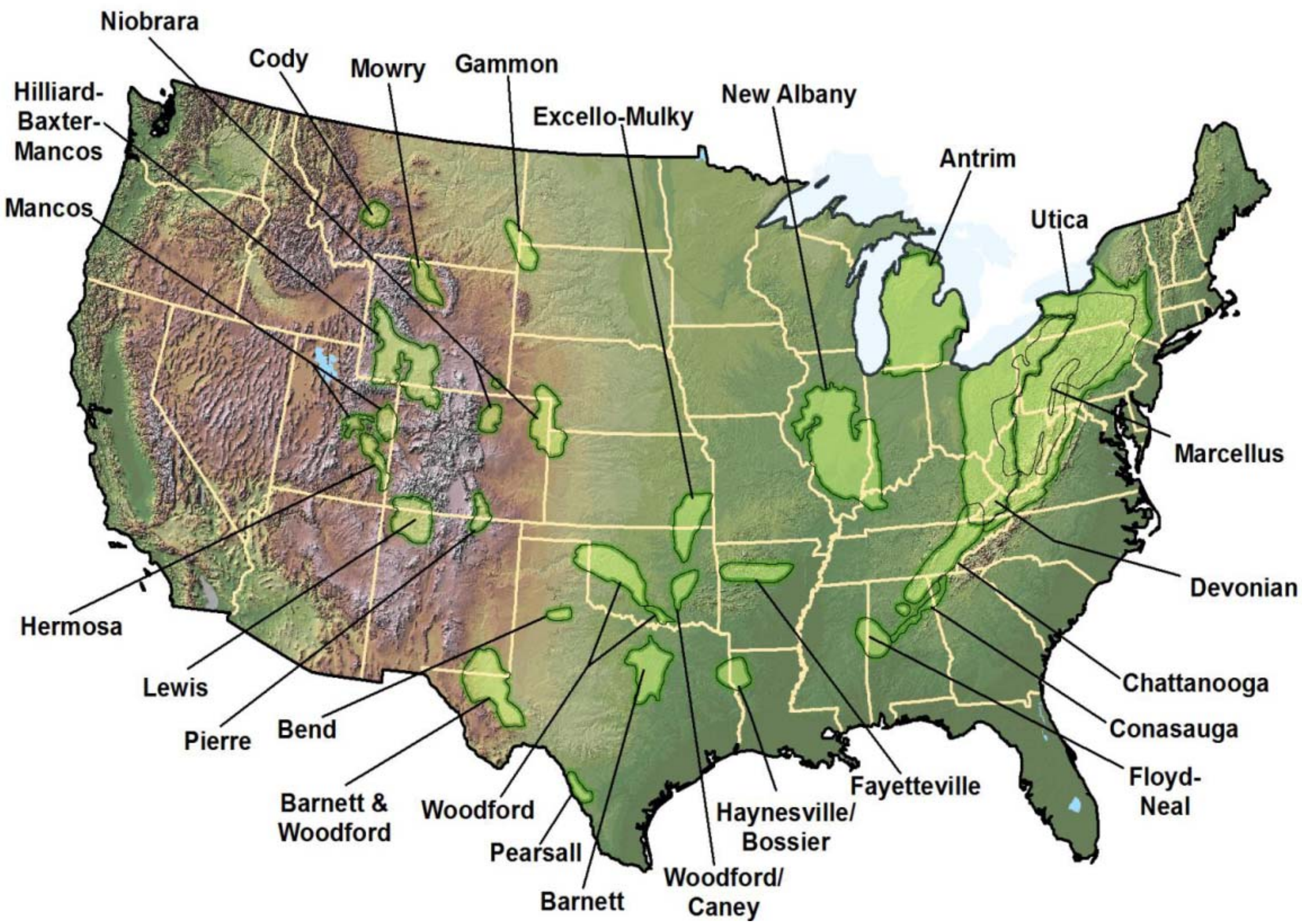
Hydraulic Fracturing History

- First performed in 1949 by Stanolind oil (later Amoco)
  - Previous forms of fracturing (incl. nitroglycerin, guns, etc.) are traced back to 1860s
  - Early fracs with gelled oil and (river) sand
  - First water-based fracturing fluid in 1953
  - Guar crosslinked by borate & borate gel breaker arrived in the 1960's
- Large increase in size of treatments in early 1980s
- Today ~ 50,000 fracture treatments are performed every year in all type of reservoirs
  - 10% outside North America
- Today ~ 60% of all wells drilled globally are fracced
  - >90% of wells onshore North America
  - Since start added 9 billion bbls oil & 700 Tscf in reserves in the US alone

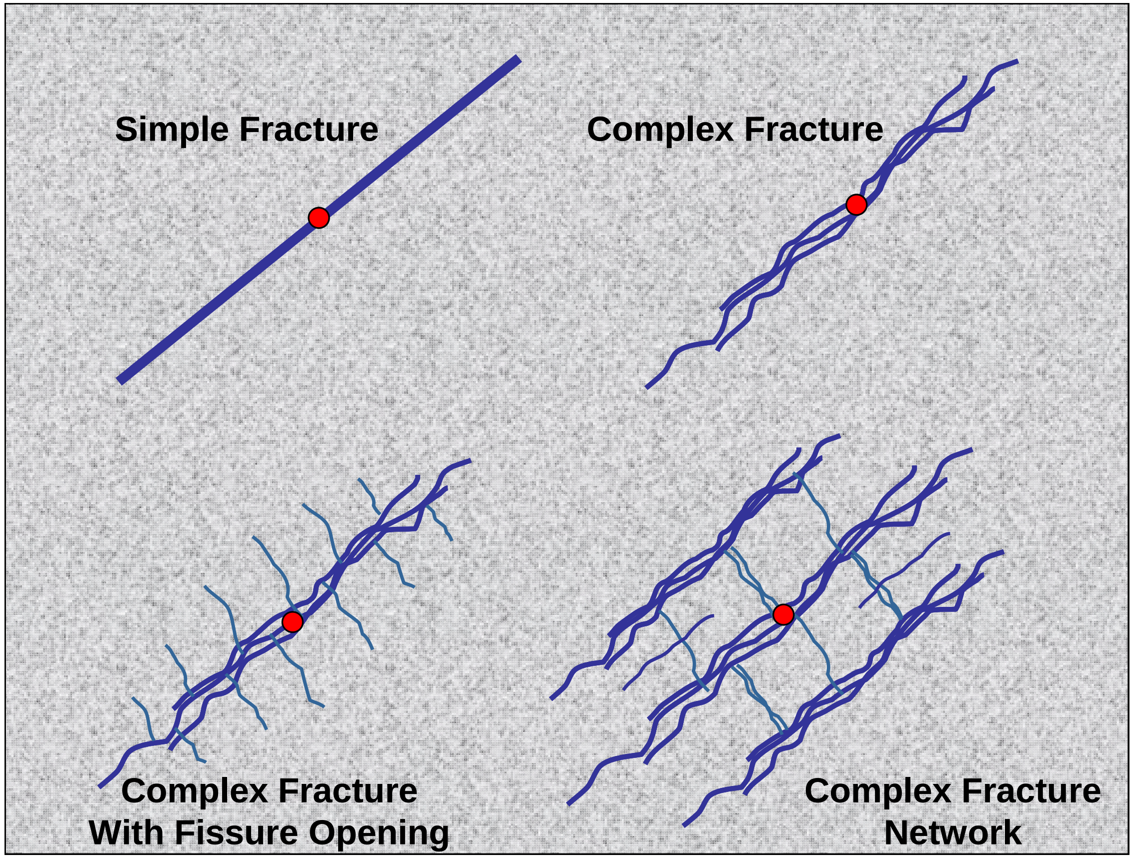
Shale gas

- Unconventional: Source is Reservoir
- Shale gas: lumped name for very tight (<0.001 mD) reservoirs

US Shale Plays



Fracture Complexity



Fracture Complexity in Shales

A complex fracture network is preferable, as it provides the maximum amount of reservoir contact. More contact area = more gas. However, this is not always possible

A simple or bi-planar fracture system will access the least amount of reservoir rock. Multiple perforation clusters and multiple parallel fractures will be required to contact the same reservoir volume. (if successful)

Microseismic is very valuable in (horizontal) shale completions

- Identifies Fracture Complexity
- Identifies Reservoir Coverage Issues

Rock Brittleness

Ductile Shale

Natural and induced fractures will tend to heal

High degree of proppant embedment

Brittle Shale

Tends to be naturally fractured

Easily fractured

Natural fractures increase hydrocarbon storage and flow capacity

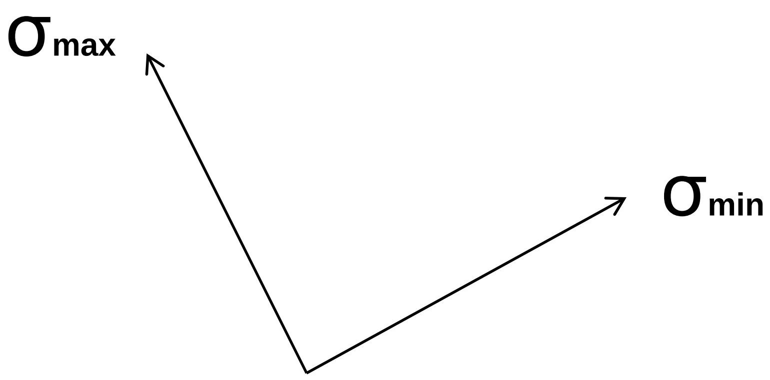
Aids to get a complex fracture network (together with stress anisotropy)

Maximum SRV

Stress Distribution

ISOTROPY - A Physical Property is Homogeneous in all Directions

ANISOTROPY - A Difference in a Physical Property When Measured Along Different Axis



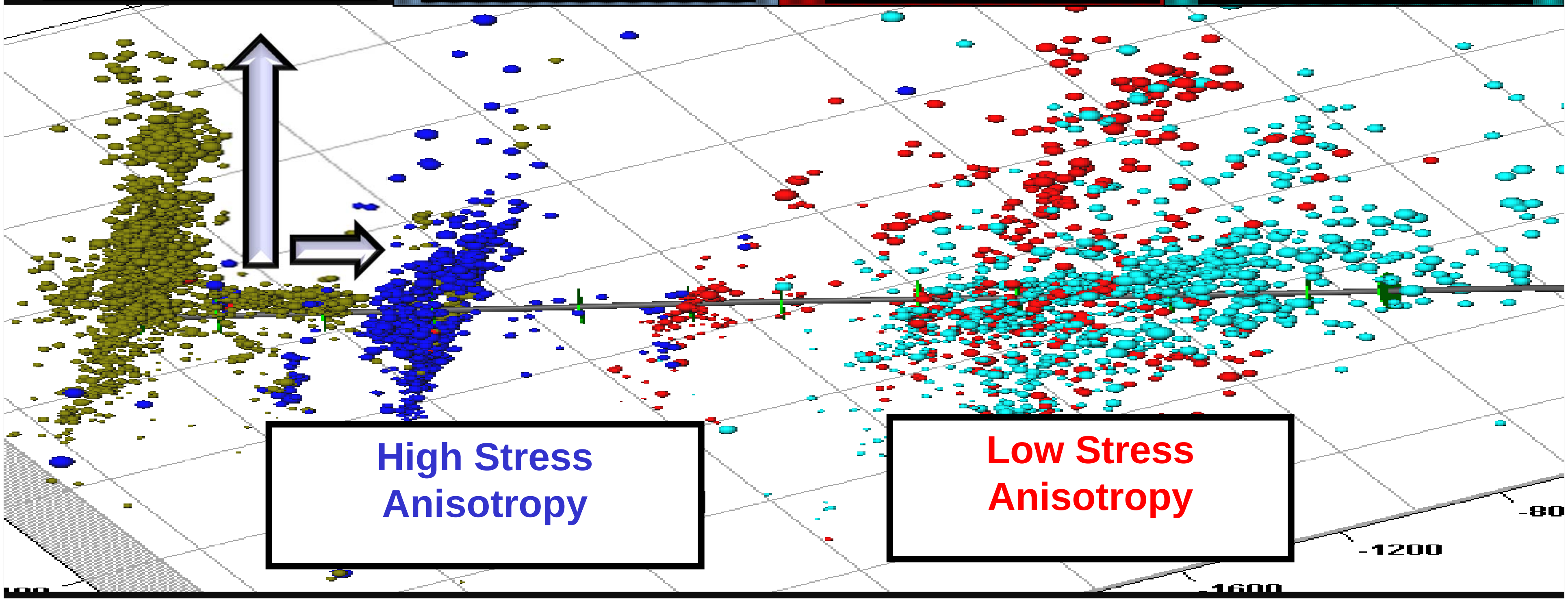
Stress Anisotropy

0 ——— 5% ——— 10% ———→

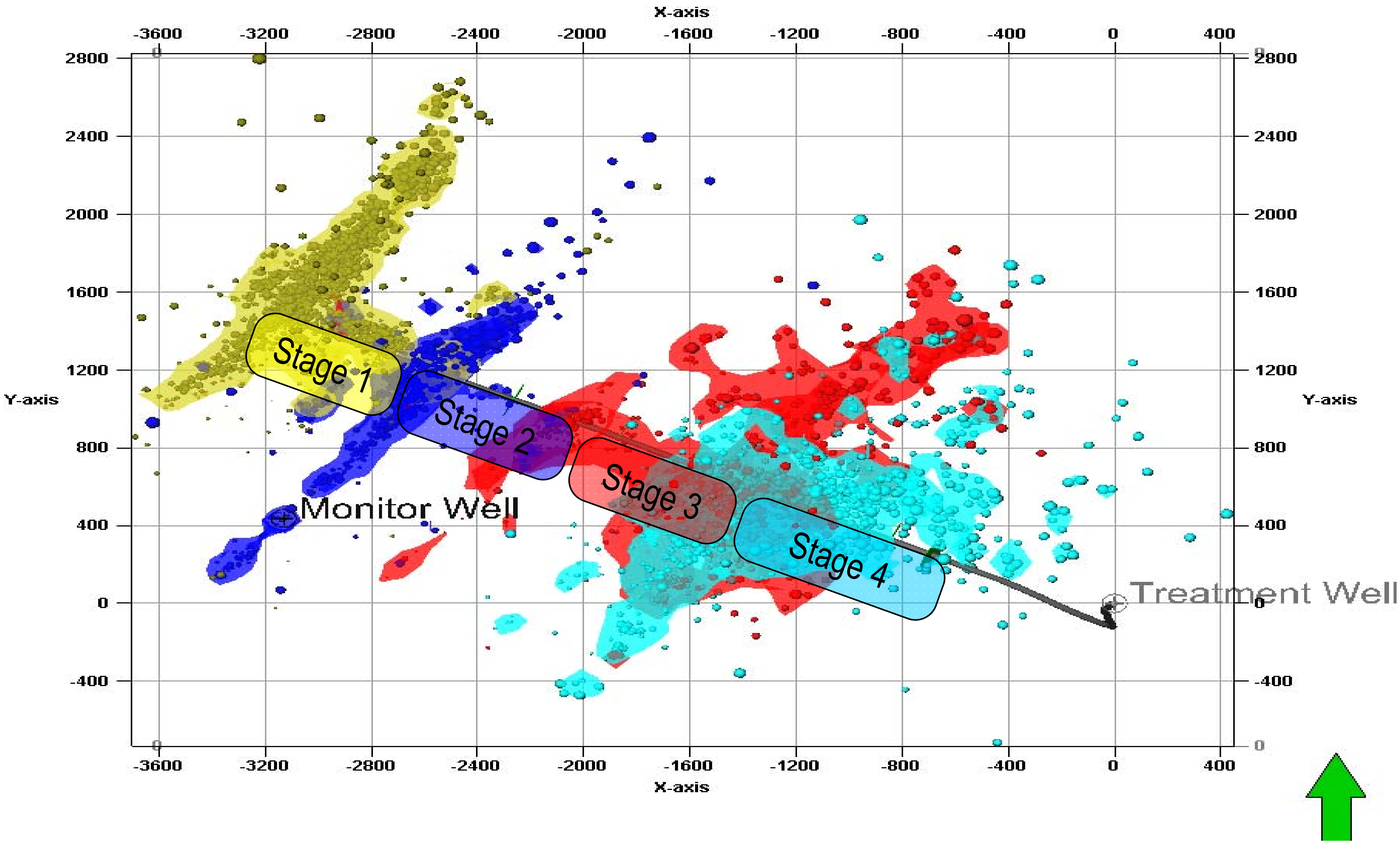
0 – 5%	5% – 10%	10% →
Multiple Fractures	Extensive Fracture Network	Bi-Planar Fractures
Tortuosity		Tortuosity
Delaware Basin	Barnett Fayetteville Bakken Marcellus (most)	Haynesville Eagleford

Barnett Shale Microseismic

Stage 1	Stage 2	Stage 3	Stage 4
σmax avg = **.77**	σmax avg = **.74**	σmax avg = **.69**	σmax avg = **.65**
σmin ISIP = **.70**	σmin ISIP = **.64**	σmin ISIP = **.65**	σmin ISIP = **.62**
σM- σm = **.07**	σM- σm = **.10**	σM- σm = **.04**	σM- σm =**.03**



Barnett Shale Microseismic



The Perfect Shale

- Depth < 3,000 mTVD
- BHST < 135°C
- Stress Anisotropy 4% - 8%
- TOC > 3%
- Poisson's Ratio < 0.18
- Young's Modulus > 4.0E06 psi
- Brinell Hardness > 30
- Quartz ≥ 45%
- Calcite/Dolomite ≤ 20%
- Clay ≤ 25%
- Naturally Fractured

Differences between Conventional vs. Unconventional (hydraulic fracturing)

- In short: The differences are minimal
- Below is a listing of current day industry typical numbers per hydraulic fracture (perforation interval) to compare. Be aware that several numbers are changing as the industry learns and evolves, as well as that certain outlyers are not included.

Typical values	Normal gas: > 1mD	Tight Gas: 0.01-0.1 mD	Unconventional: < 0.001 mD
Fluid system	XL (high viscosity)	XL (high viscosity)	Slickgel/water (low viscosity)
Pad fraction	5-15%	5-25%	20-50% (pad/slurry switching)
Total volumes	100-2000 m^3	100-1000 m^3	500-3000 m^3
Proppant mass	100-500 ton	50-400 ton	50-300 ton
Proppant Max. Conc.	12 ppg (1440kg/m^3)	8 ppg (960kg/m^3)	2 ppg (240kg/m^3)
Rates	30-40 BPM (5-6 m^3/min)	20-30 BPM (3-5 m^3/min)	40-60 BPM (6-10 m^3/min)
# stages	1-3	3-10	10-30
Additives	• Gelling agent: e.g. Guar • Biocides: e.g. Bleach (NaClO) or Glutaraldehyde • Surfactants • Clay swelling inhibitors: salts like KCl • X-linkers: e.g. Borate, Zirconium • XL-control: PH-control/PH-buffers • Breakers: e.g. oxidizers / enzymes		• Gelling agent: e.g. Guar • Biocides (not always used) • Surfactants (not always used) • Clay swelling inhibitors: salts like KCl (not always used)

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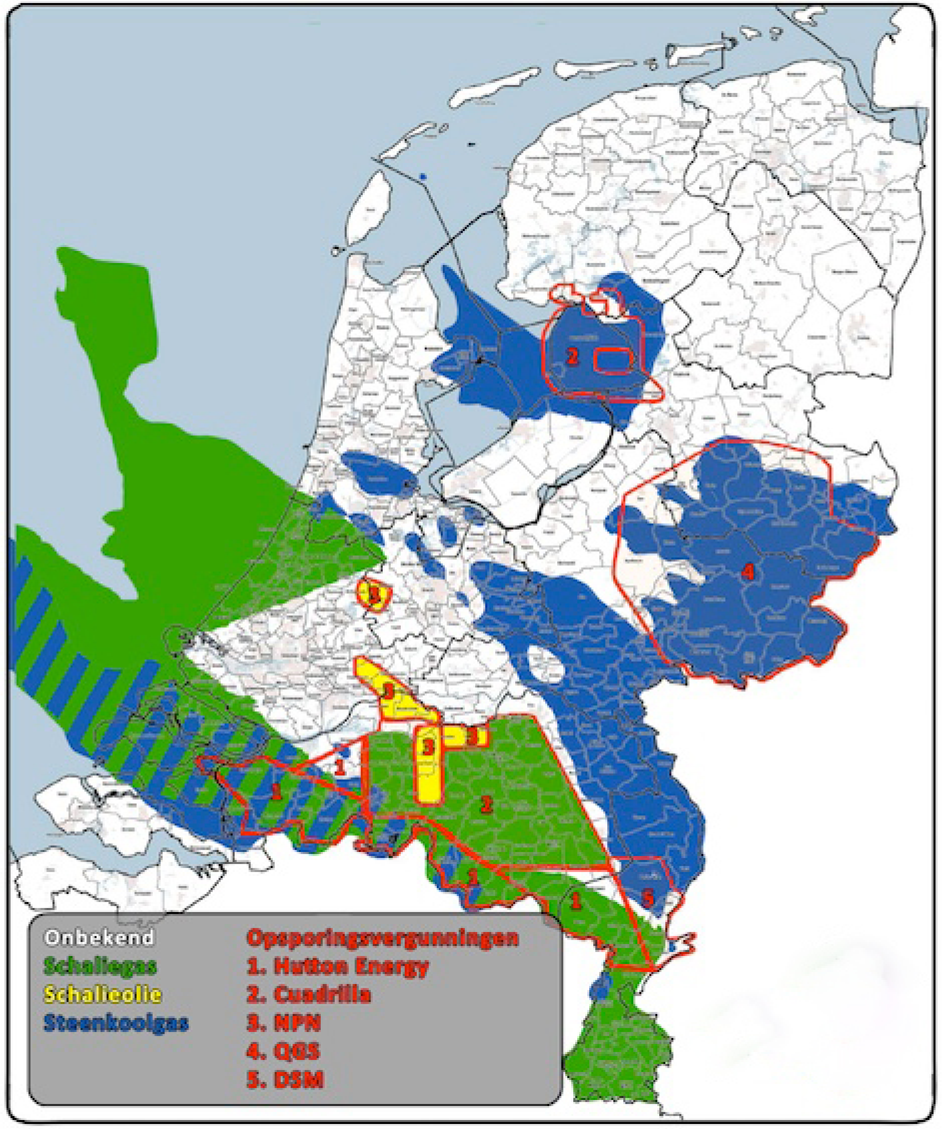
Shale Gas prospects in NL



Media & Politics

- Why suddenly an issue??
- Drink water reservoirs
  - Industry is busy with 5-10m height growth more or less. Why worry about 2000-3000 m?
  - 60 years of fully regulated history
    - NL: ~350 fracs (~1 out of 10 wells)
    - D: ~500 fracs
    - DK: ~500 fracs
    - UK: ~100 fracs
    - Any incidents and disasters over past 60 years?
    - US has ~1,000,000 fracs over past 60 years. Incidents?
- Earthquake in Blackpool (UK)

Media & Politics

- Vested interests:
  - Difficult for politics.
    - The knowledge lies with vested interests
    - But so do the accusations
  - Russians (Germany)
  - Nuclear (France)
  - “Green” lobby (Europe)

Future

- Does shale gas stand a chance in Europe?
  - Economics are difficult (wells too expensive)
  - ..,but things can change rapidly (see Europe depending below)
  - Logistics are challenging
    - 50 rigs & 6 frac spreads/crews

- Geopolitics?
  - US not interested in the ME? Nonsense
  - More a geopolitical economic issue (energy price in Europe)
  - Europe depending on Algeria, Russia and Norway?
    - LNG?

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Final comment about flaming taps (from the Zuiderzee museum)

EN Methane gas boilers from Andijk have been installed next to this house from Grootebroek. Such boilers were a familiar feature in West-Friesland because in some parts of the province the groundwater contained methane. The colourless and odourless marsh gas was extremely suitable as a fuel for lighting and for cooking appliances.

But how did one extract the methane from the groundwater? A gas fitter would drive a pipe down into the ground until it reached the water level and the water began to flow from it. A copper sprinkler placed on the nozzle of the installation degassed the water. The gas was piped from the small boiler to the large storage boiler, where it was ready for use.

A sizeable levy had to be paid to the polder authority for such an installation, because of the amount of salt water it brought into the polder water. For this reason many people switched over to cheaper natural gas after the Second World War.

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Questions?