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Primary funding is provided by

The SPE Foundation through member donations and a contribution from Offshore Europe

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Distinguished Lecturer Program

Releasing Shale-Gas Potential with Fractured Horizontal Wells

Erdal Ozkan
COLORADO SCHOOL OF MINES

Society of Petroleum Engineers
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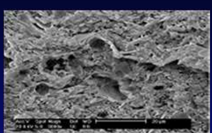
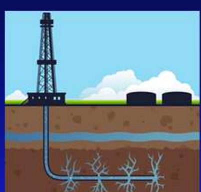
Unconventional Reservoirs

In the last decade, production from ultra-tight formations has been viable

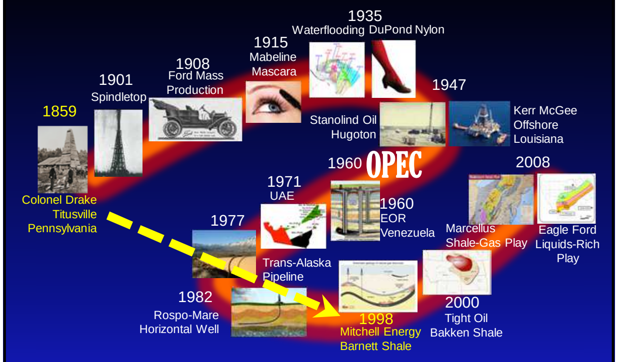


Today, we produce hydrocarbons from the nano-pores of source rocks



This development came about at the intersection of the persistent entrepreneurship of the industry with the technological advances in the areas of horizontal drilling, completions, and stimulation.

Technology and the Oil & Gas Industry



Colonel Drake did not discover oil; he developed and proved the technology to produce it in large quantities and economically (NPC, 2007) 4

The Impact of Technology on "Shale-Gas Revolution"

In 1859, Colonel Drake produced 10 bbl oil per day from 71 feet

Today, we drill thousands of feet vertically and then horizontally

As a result of technological innovations, we produce hydrocarbons from geological structures unimaginable only a couple of decades ago

"The technology used to access natural gas from shales is as complex and sophisticated as that used in the Apollo Space Programme."

(Financial Times, 2010)

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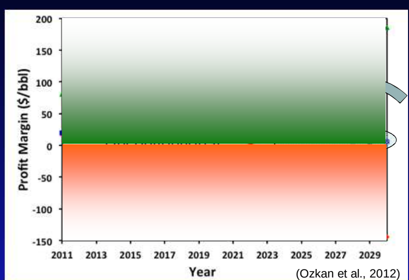
Why Do We Go Unconventional?

Reserve Replacement
Conventional vs. Unconventional



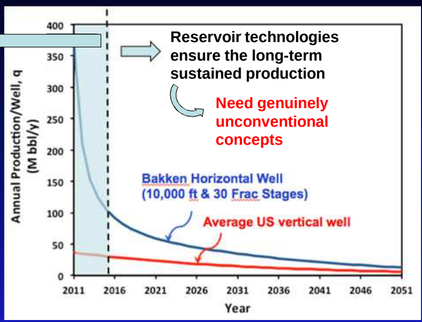
Can the industry operate with this kind of profit margin?

Price being exogenous, the only viable solution is to reduce the cost of exploration and production 6

The Impact of Technology on "Shale-Gas Revolution"

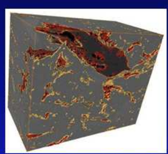
Drilling & completion technologies provide the early return of the investment

No new breakthroug h recently



Key Characteristics of Shale-Gas Plays

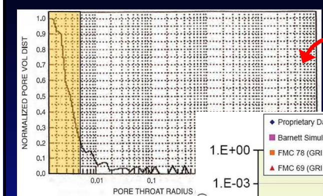
- Small pore sizes (nanoscale) 10^{-9} m $\leq d_{pore} \leq 10^{-6}$ m
- Ultra tight formation 10^{-9} md $\leq k \leq 10^{-3}$ md
- Involvement of source rock
- Natural fractures
- Hydraulically fractured horizontal wells
- …
- …



Sample size:
4 μm high,
5 μm wide,
2.5 μm deep

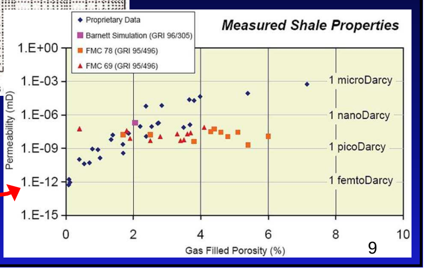
Pore network in shale sample *(Ambrose et al.,2010)*

Pore size distribution and permeability of siliceous mudstones



Mercury porosimeter analysis

80% of the pores have a pore size less than 5 nanometers



Why bother with characterizing nano-Darcy permeability?

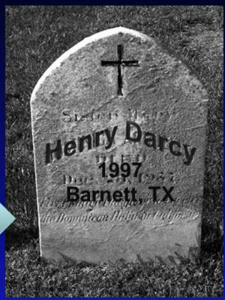
Characterization implies significance!

The Myth of “Production from Nano-Darcy Formation”

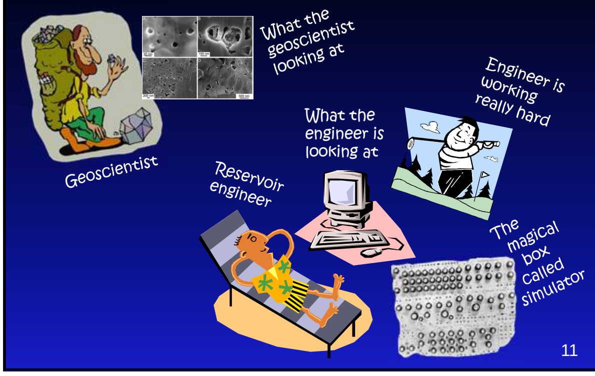
Permeability of Barnett shale is in nano-darcies as opposed to milli-darcies in conventional formations.

Darcy’s law precludes commercial flow at these low levels of permeability

In 1997, Mitchell Energy proved that economic production was possible from Barnett shale by horizontal well and "slickwater" fracturing.



The Myth of “Production from Nano-Darcy Formation”



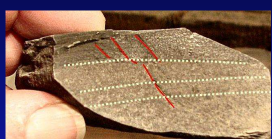
Fluid flow in Nano-Darcy Shale

“… numerical modeling requires gas permeabilities 2 to 4 orders of magnitude greater than observed to match flow rates and ultimate recoveries … Some other, higher permeability pathway through shale seems necessary.”

Cliff, Shanley, and Miller, AAPG 2007

Field Scale (m)

Core Scale (cm)

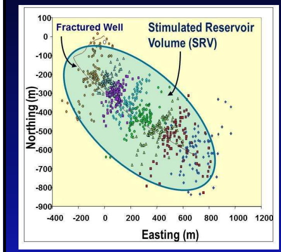


Micro Scale (mm)

FRACTURES IN SHALE

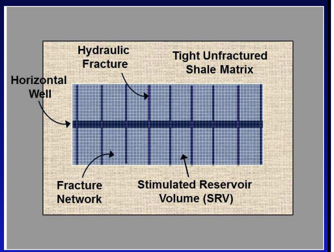
Hydraulic Fracturing Induces and Rejuvenates Fractures in Shale

Microseismic Record of Fracturing Events



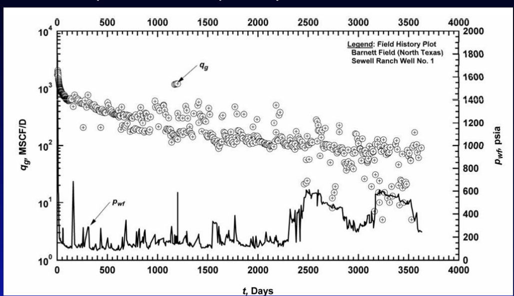
From Rimrock Energy, SPE 119896

Stimulated Reservoir Volume (SRV) Representation



Production from fracture network

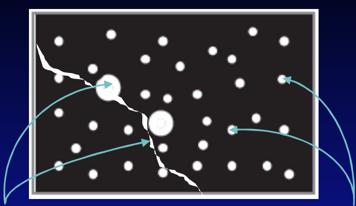
Barnett (North Texas) well production



10 years of production without support of matrix?

After T. Blasingame

Combined Flows in Shale



Micropores and Fractures

$(d_{pore} \geq 10^{-1}\ \mu m)$

Darcy Flow

He is not completely dead

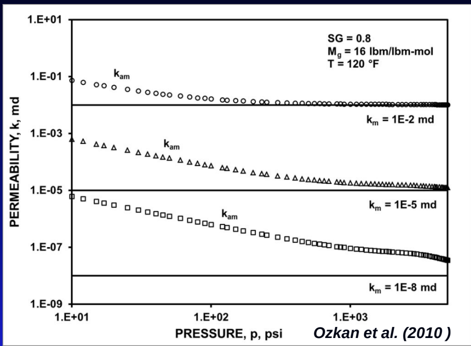
Nanopores

$(10^{-1}\ \mu m \geq d_{pore} \geq 10^{-3}\ \mu m)$

Slip Flow

Mixed Flow in Shale Matrix

Contribution of slip flow to apparent shale permeability



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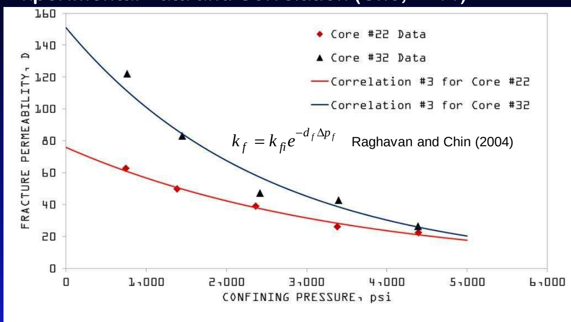
What happens when the fractures close? Pressure-Dependent Fracture Permeability

Experimental Data and Correlation (Cho, 2011)



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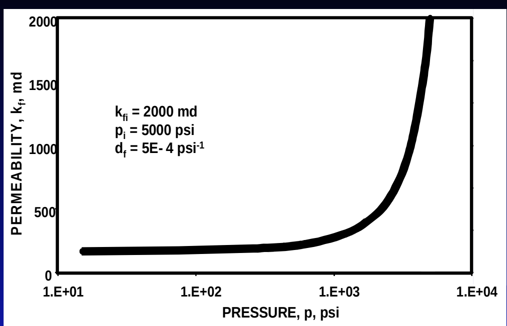
Pressure-Dependent Natural-Fracture Permeability



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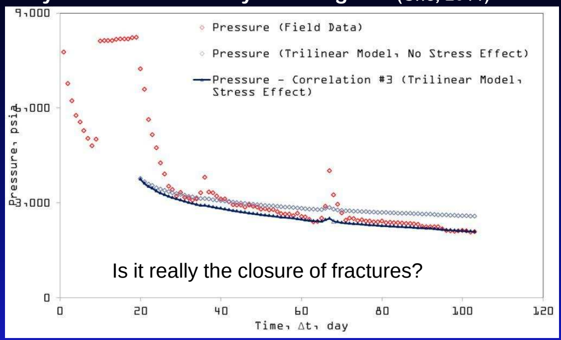
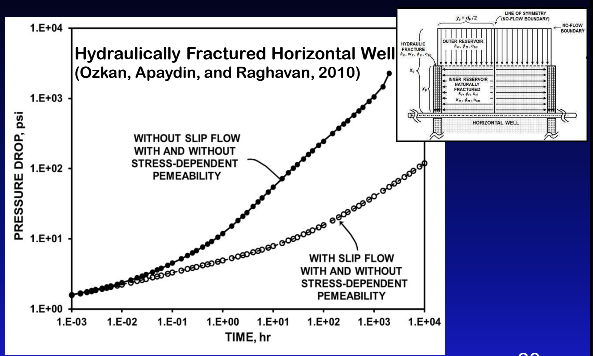
What happens when the fractures close?
Pressure-Dependent Fracture Permeability

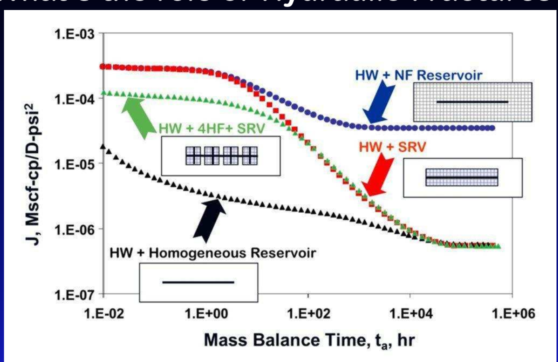
Haynesville Well History Matching (Cho, 2011)



What happens when the fractures close?
Pressure-Dependent Fracture Permeability



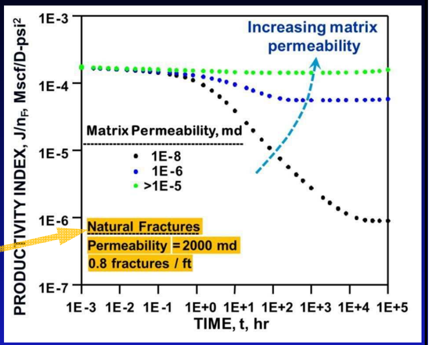
What's the role of Hydraulic Fractures?



Effect of Matrix Permeability

Productivity increases with increasing matrix permeability for $k_m \leq 10^{-5}$

When flow capacity of natural fractures is reached, no additional productivity is possible



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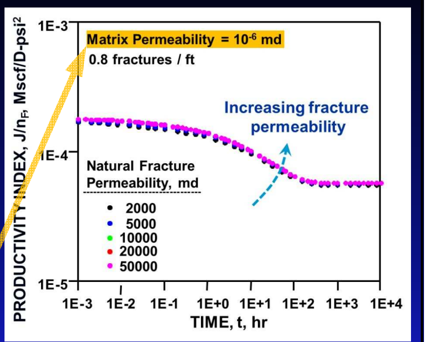
Effect of Natural Fracture Permeability

No difference in productivity with increasing natural fracture permeability

Natural fracture permeability has little effect on productivity

Flow capacity of the matrix is the limiting factor



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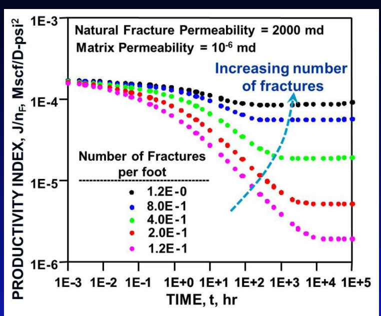
Effect of Natural Fracture Density



Natural fracture density has significant effect on flow capacity of matrix.

Greater surface area for flow allows for a greater volume of fluid to be moved

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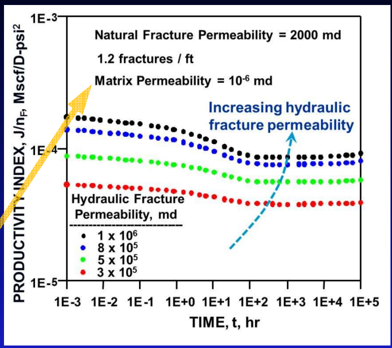
Effect of Hydraulic Fracture Conductivity

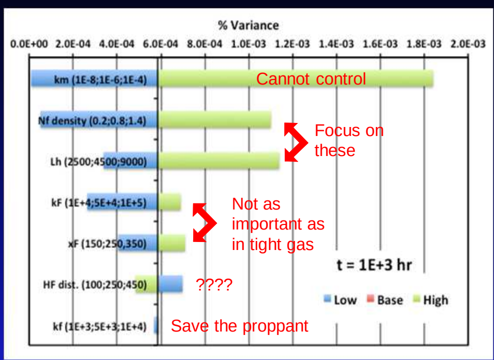
Incremental productivity decreases as conductivity increases.

Volume of fluid available to flow is limiting factor



Well Construction and Stimulation Considerations

Sensitivity of productivity to various parameters



Conclusions

Our potential to recover gas from shale has been increasing due to

- new technologies to fracture horizontal wells
- better understanding of flow and production mechanisms

Marginal economics of shale-gas projects requires more improvements in

- characterization and modeling capabilities
- analysis and prediction tools and techniques