Let's put Engineering back into Fracture Stimulation!

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Pinnacle – a Halliburton Service

Oklahoma Geological Society – Shales Moving Forward

Norman, Oklahoma; 21 July 2011

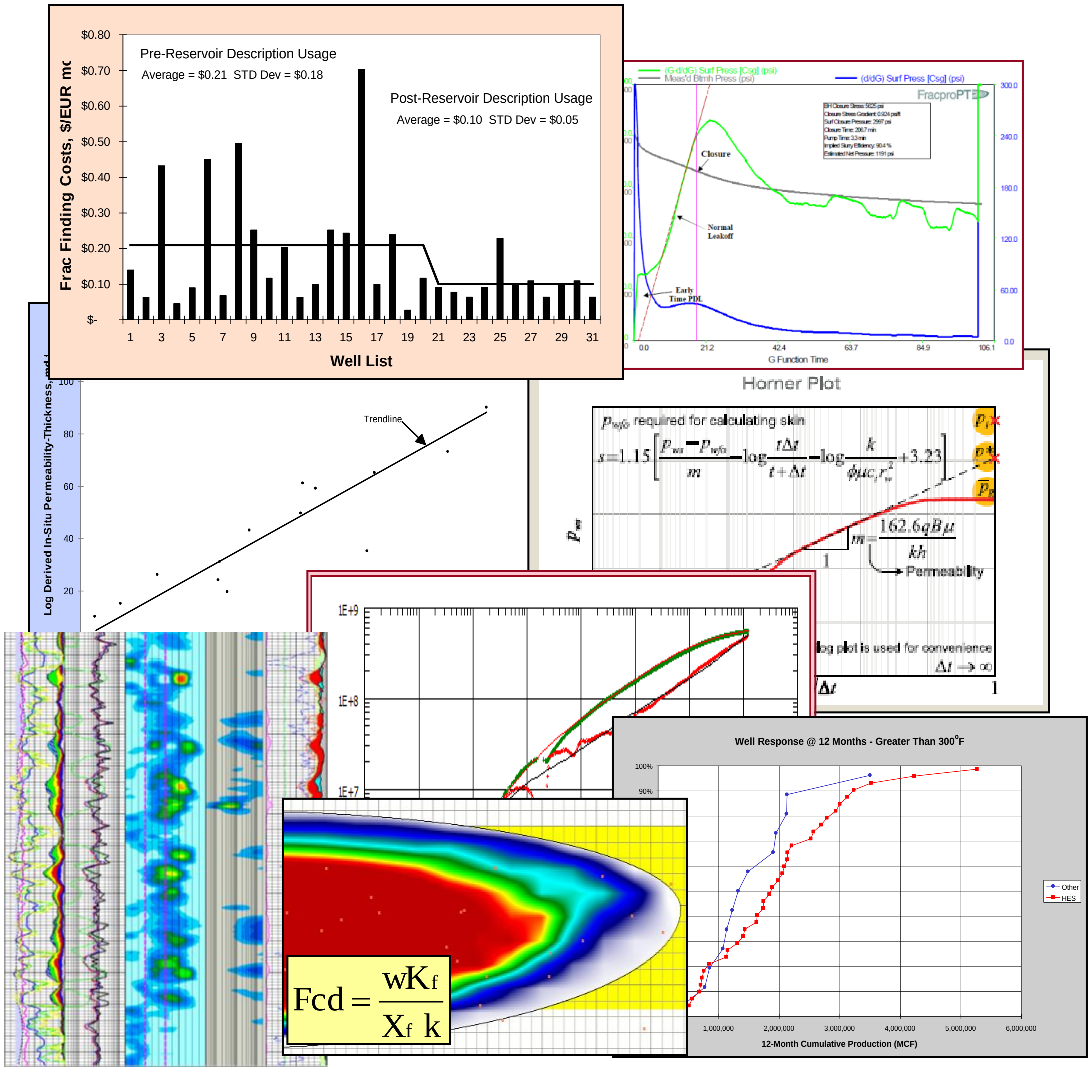
HALLIBURTON

The Company President asking his staff ....

.... How are we going to “Frac” this well?

- What are the other Operators doing on their wells?
- How much is it going to cost?
- HOW MUCH!!!!!
- Why’s it cost so much?
- Do we really need to do all that stuff?
- What stuff can we leave out?
- Do you think it will work if we don’t do all that stuff?
- Who’s going to figure it out if it doesn’t work?

Engineered Completions



Un-Engineered Completions

Schedule:

1) Perforate
2) Pump
3) Repeat

- Horsepower
- Fluid
- Proppant

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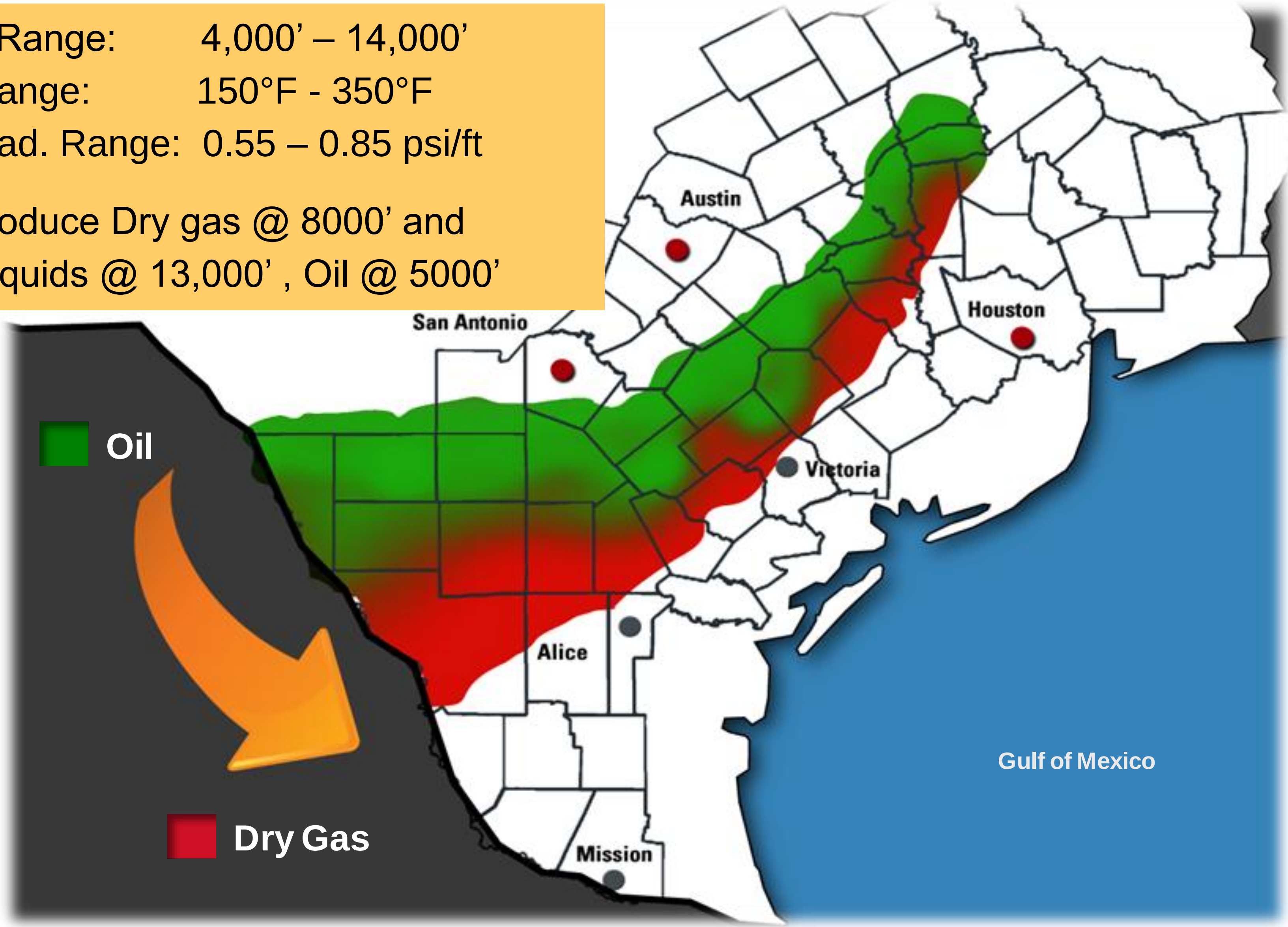
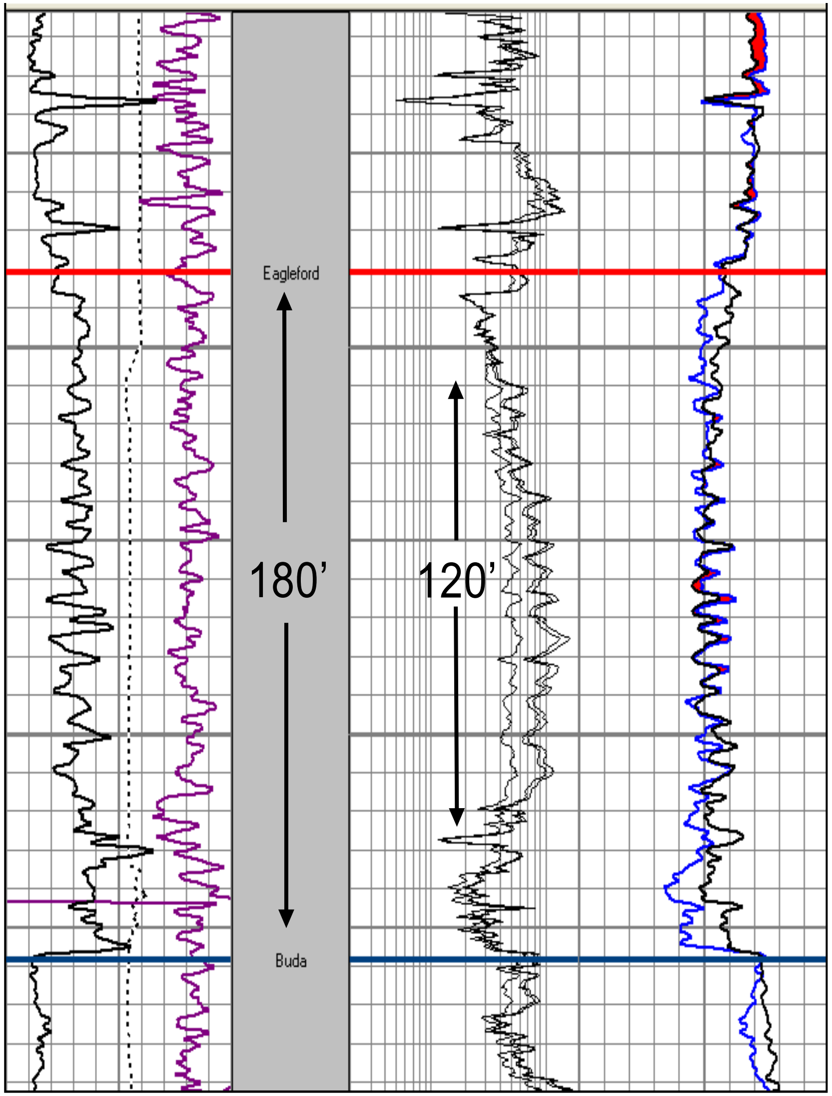
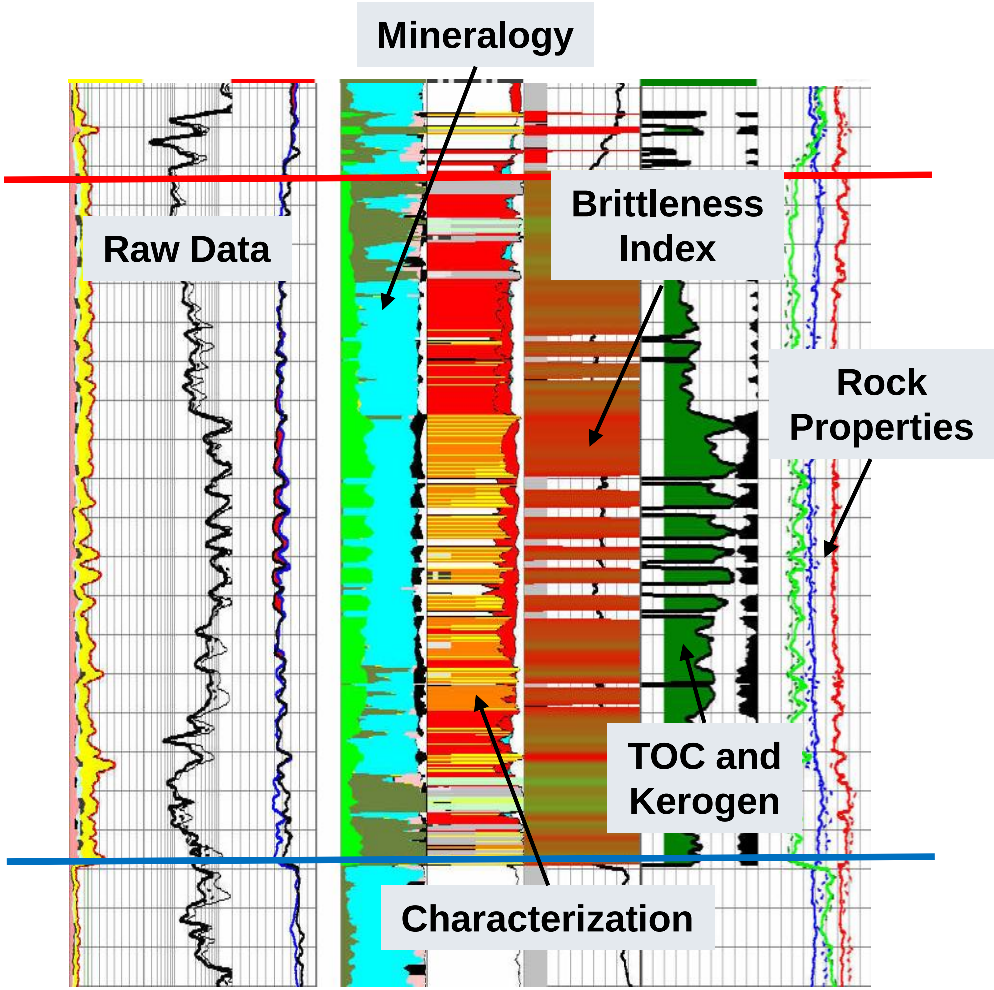
Eagle Ford Shale - Background

- Depth Range: 4,000' – 14,000'
- BHT Range: 150°F - 350°F
- P_{res} Grad. Range: 0.55 – 0.85 psi/ft
- Can produce Dry gas @ 8000' and High Liquids @ 13,000' , Oil @ 5000'



Eagle Ford Shale - Petrophysics

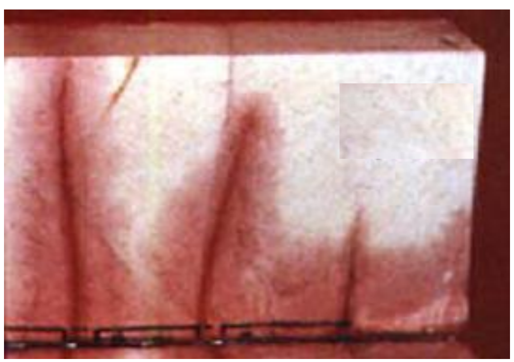


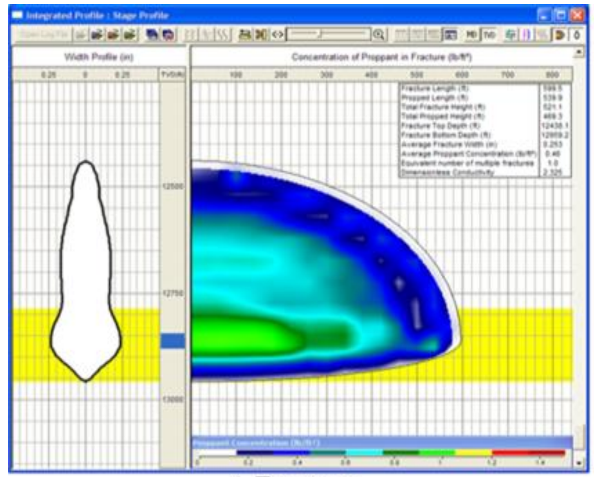


SPE 136183

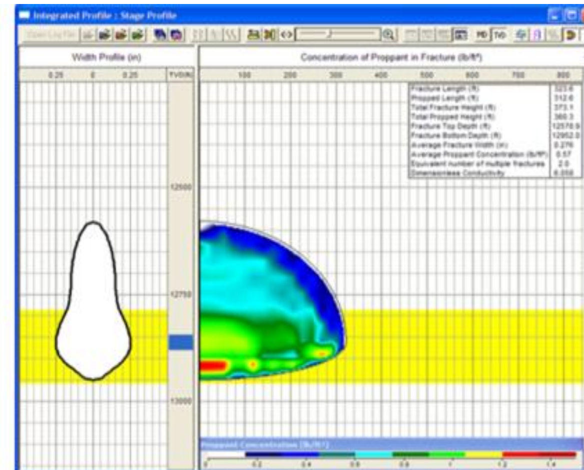
Frac Design in Horizontal: Run Sensitivities

- Injection Rate
- Fluid Volumes
- Fluid Viscosity
- Prop Volume
- Prop Concentration
- Prop Mesh Size
- Others

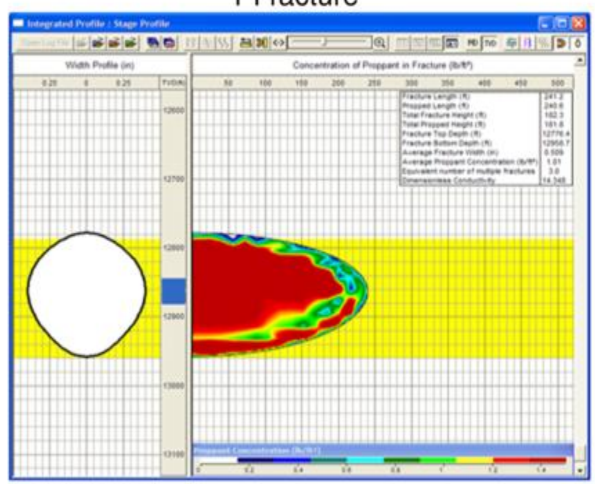




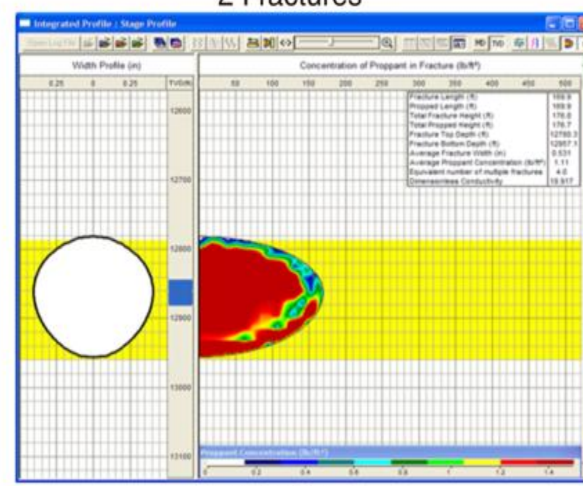
1 Fracture



2 Fractures



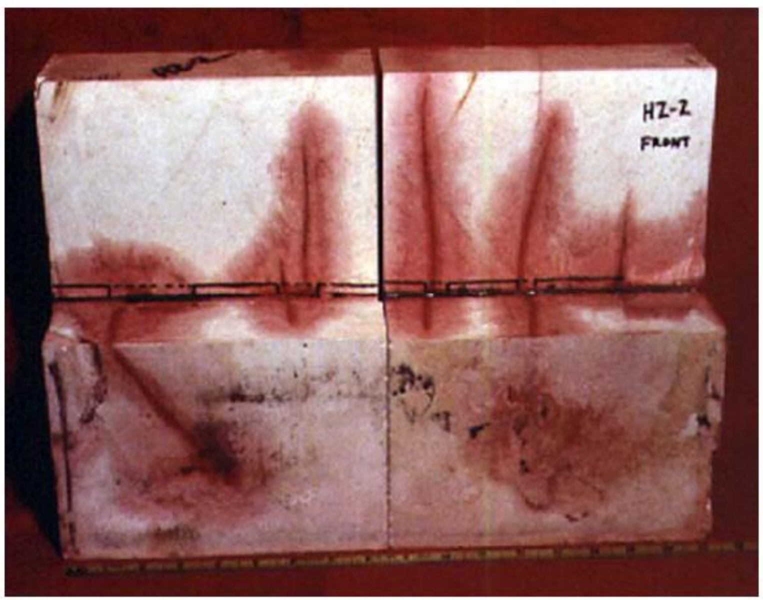
3 Fractures



4 Fractures

Near Wellbore Restriction (tortuosity)
Issues with Proppant Placement

- Transverse fracture initiation in perf cluster that is to long can create multiple fractures (SPE 19720).
- Multiple fractures can create tortuosity (SPE 35194).
- Limit perf interval to 4 times the ID of the casing (SPE 86992)
- Use Acid Soluble Cement in Horizontal (SPE 137441)



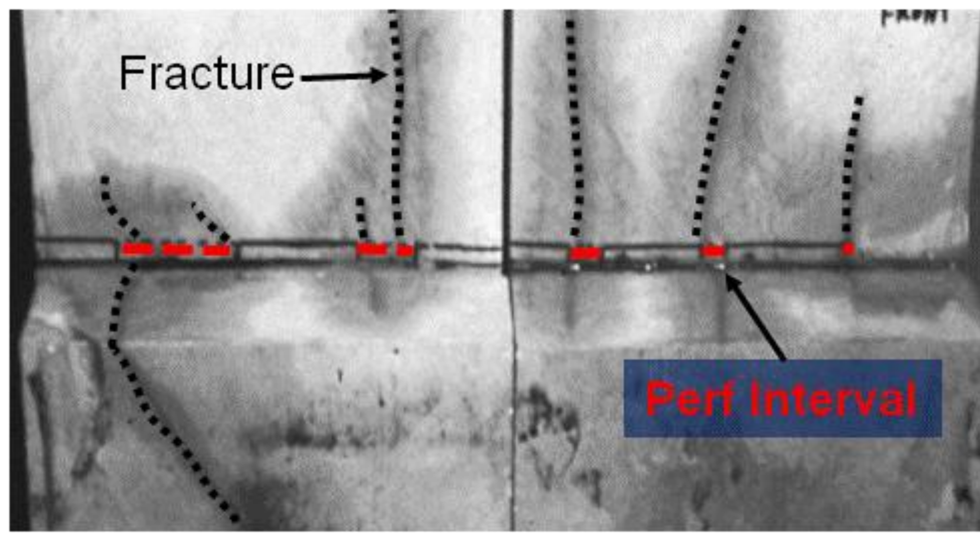
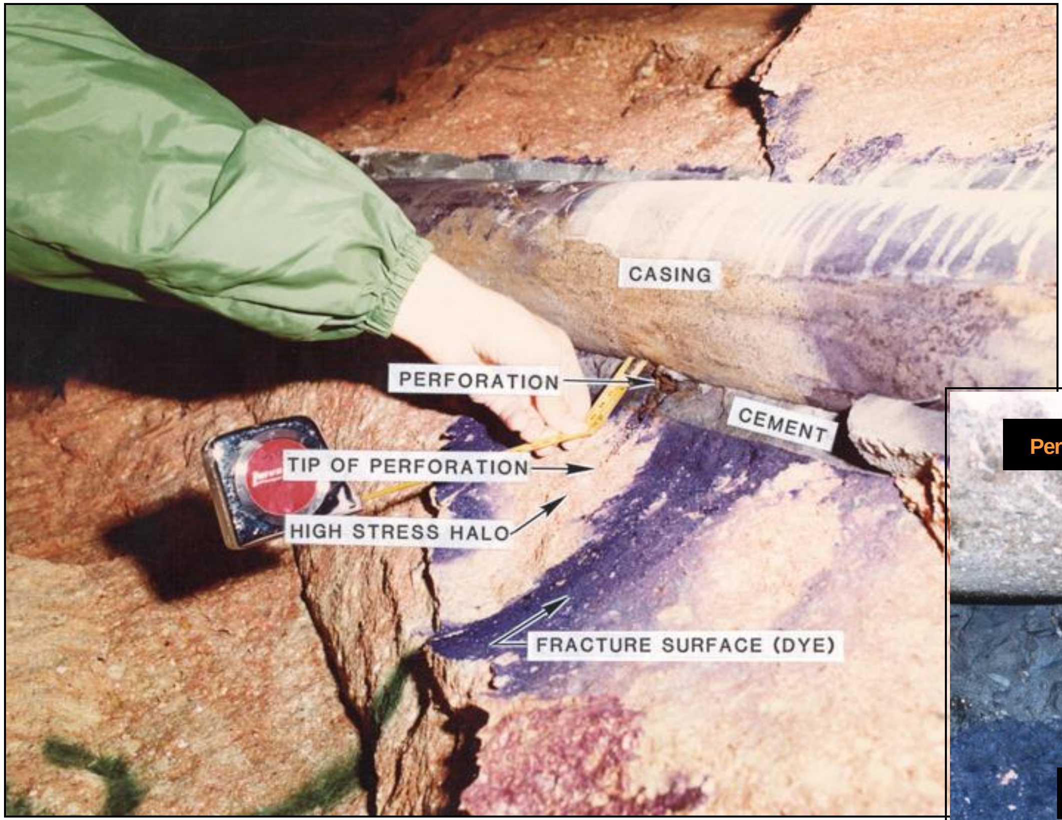
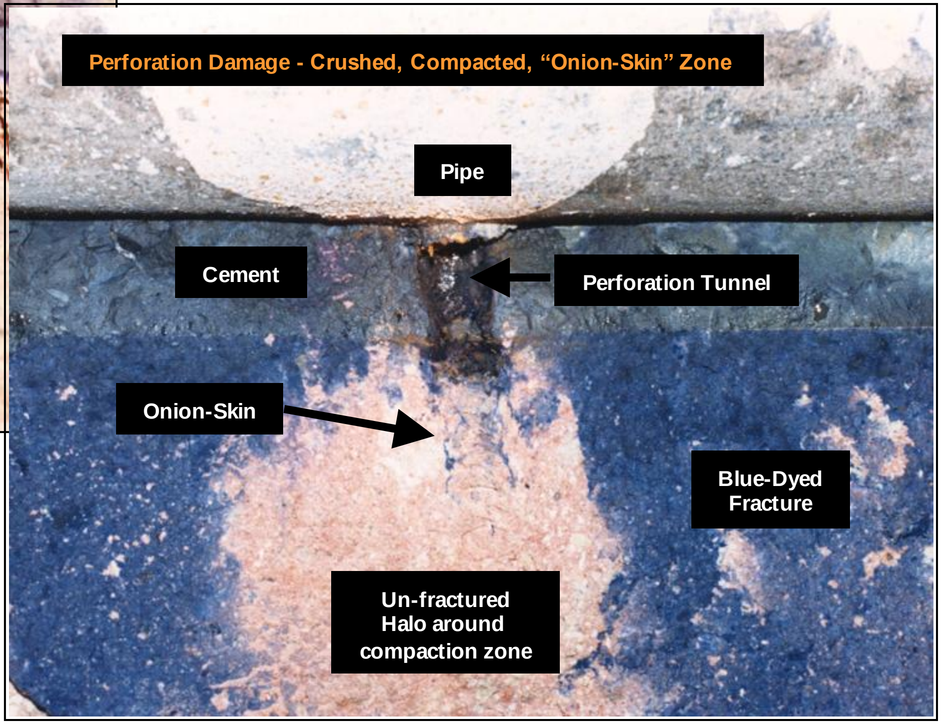


Image from SPE 19720 by El Rabaa, 1998 and SPE 102616 by Soliman, 2006

Impact of Perforation on the Formation:

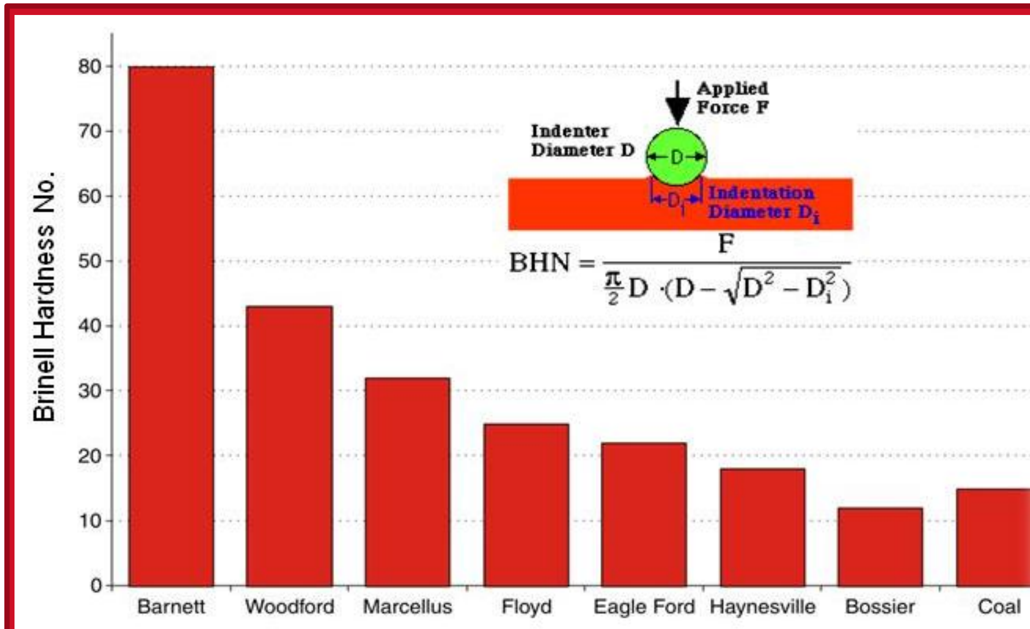


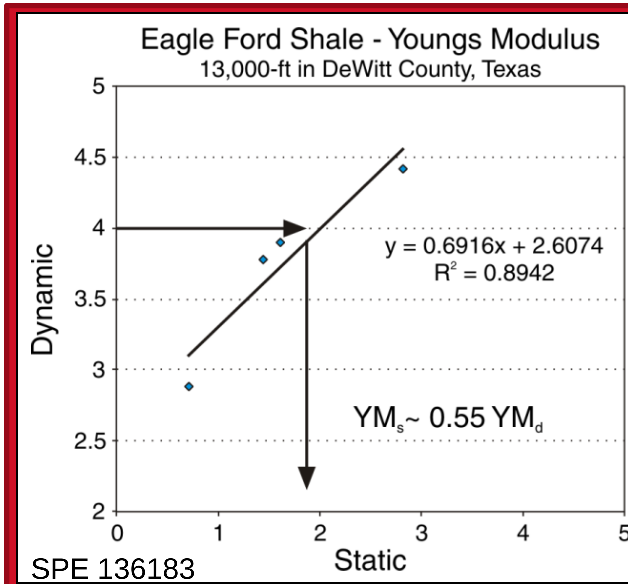
Formation Compaction Zone (Halo)

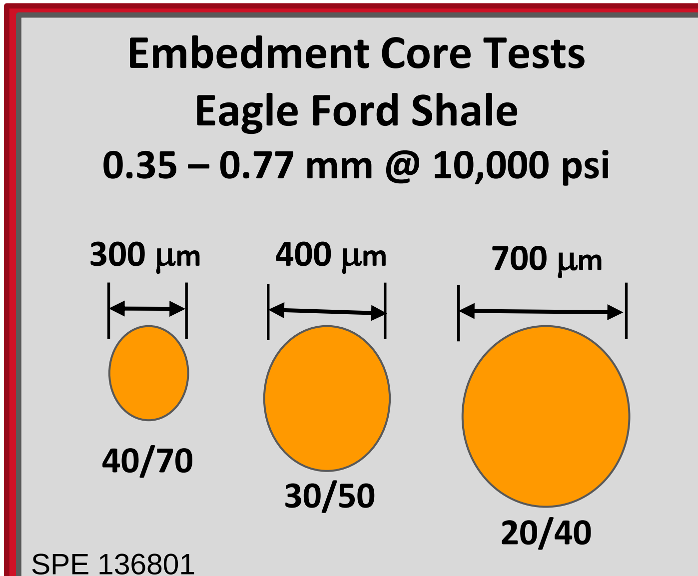


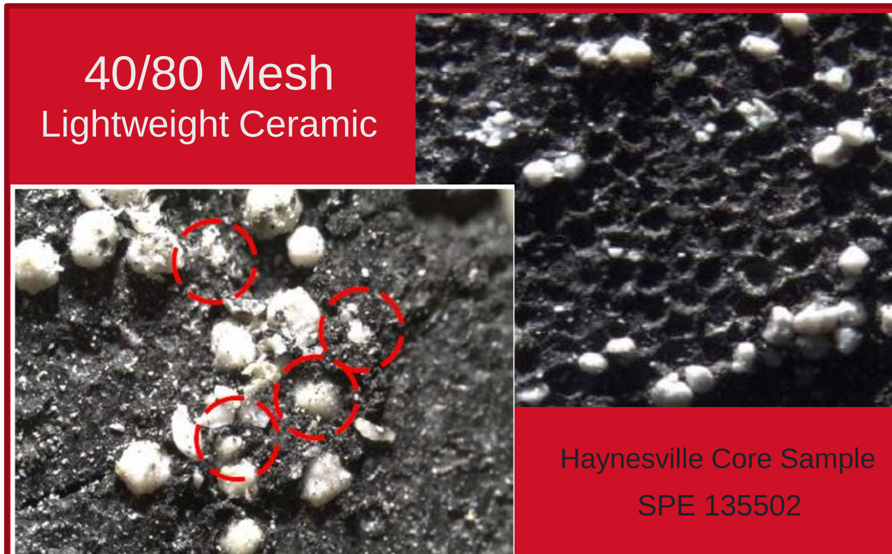
Work by Norm Warpinski, 1983

Frac Design Considerations

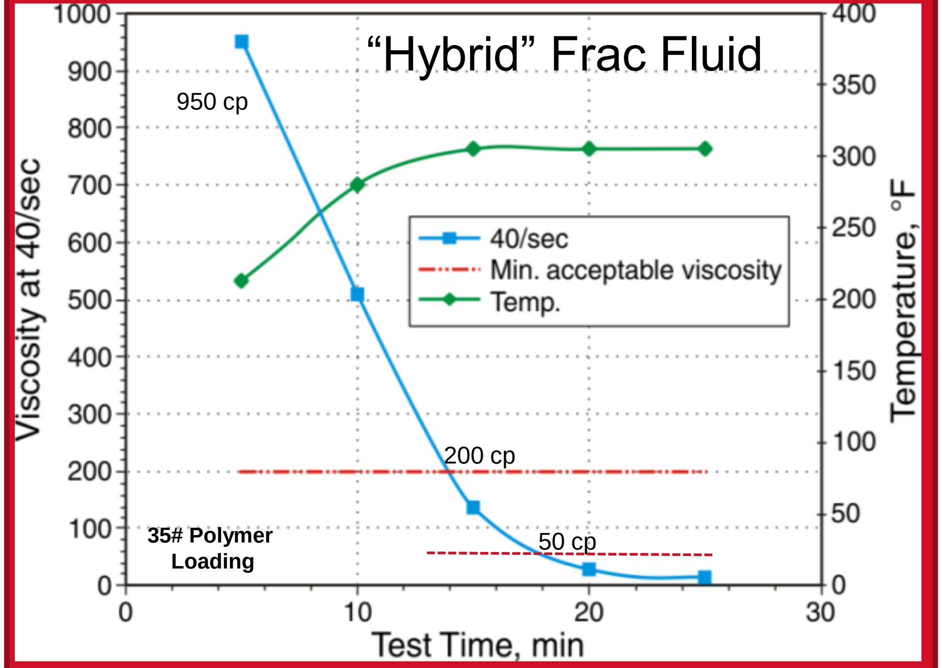








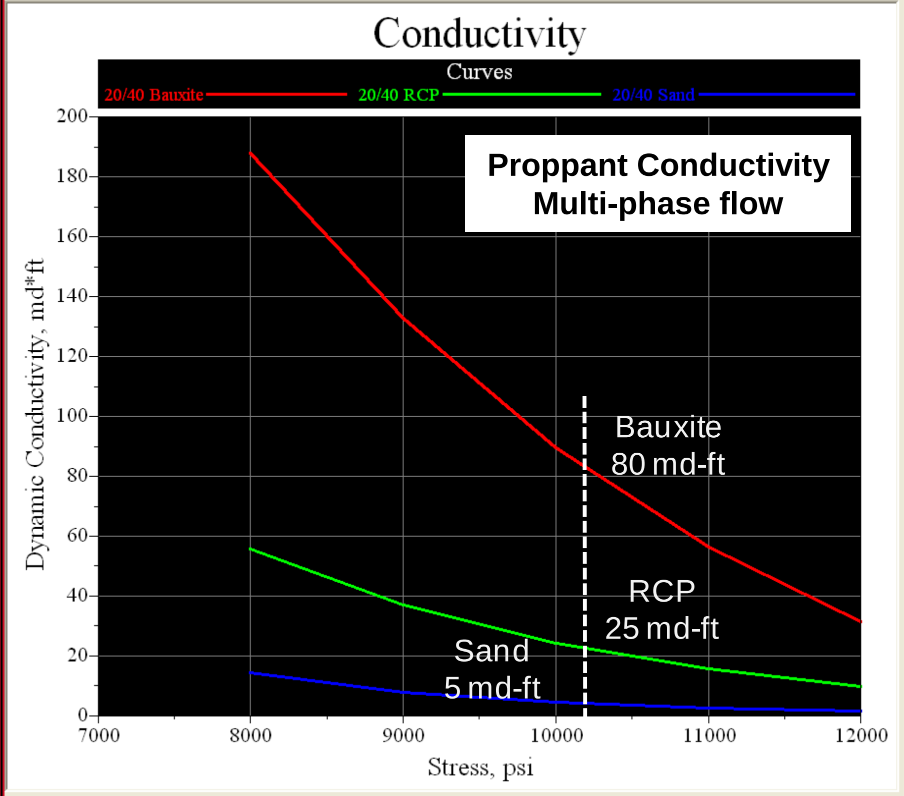
Frac Design Considerations



Dimensionless Conductivity (F_{cd})

$$F_{cd} = \frac{w_f K_f}{X_f\ k}$$

$$\frac{25\,\text{md-ft}}{500\,\text{ft} * 0.001\,\text{md}} = 50$$



Frac Design Considerations:

Basic Definitions (SPE 136183)

Water Frac or Slick Water Frac:

• Frac fluid is very low viscosity
• Chemicals or gelling agents are used for friction reduction, not prop transport
• Velocity (not viscosity) used to place proppant
• Injection rates tend to be high
• Typically have alternating stages of proppant followed by fluid “sweeps”

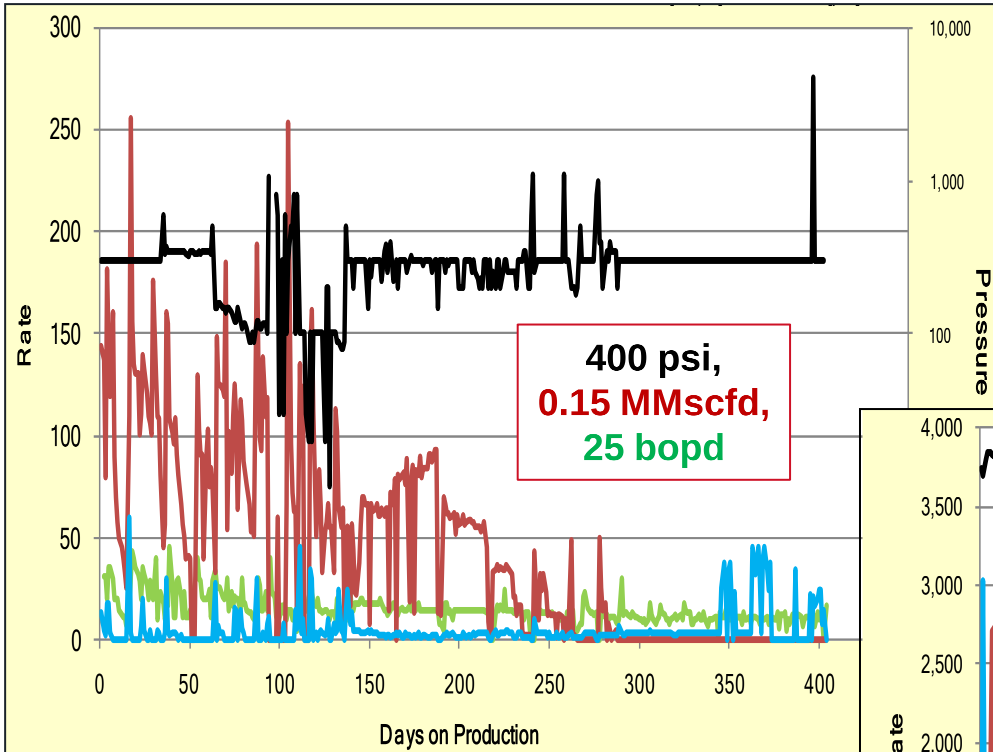
Conventional Frac:

• Frac fluid is high viscosity (from foams to crosslinked fluids)
• Chemicals used to generate viscosity for proppant transport
• Viscosity (not velocity) used to place proppant
• Injection rates can vary greatly (not depending on velocity to place prop).
• Typically have “pad” fluid followed by continuous proppant-laden fluid.

Hybrid Frac:

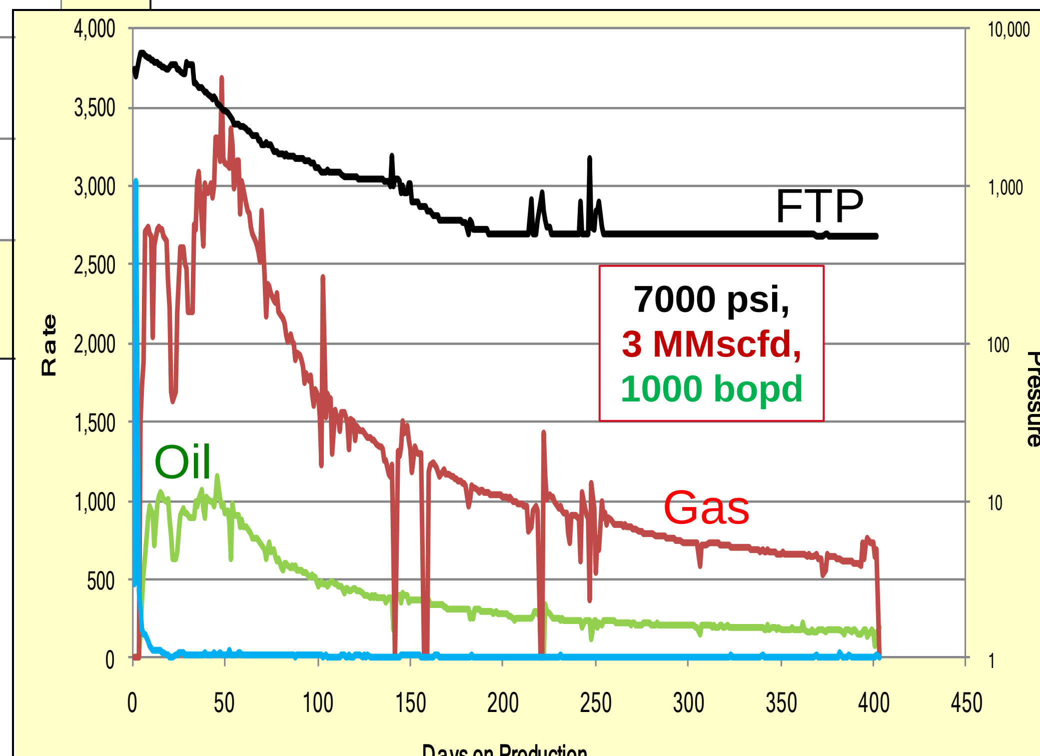
• Anything in-between a water frac and a conventional frac.
• Typically, a hybrid frac is a combination of the two.
• They tend to begin with a low-viscosity fluid (at a high rate)
• May have alternating proppant volumes with fluid “sweeps”
• Tail-in (sometimes at a lower injection rate) with proppant high-viscosity fluid.
• Large part of job may be crosslinked or just Tail-in fluid may be crosslinked.

Production Comparison: Slick Water vs. Hybrid/Conventional



Oil Rate [bopd]
Gas Rate [mcfpd]
Water Rate [bwpd]
FTP [psi]

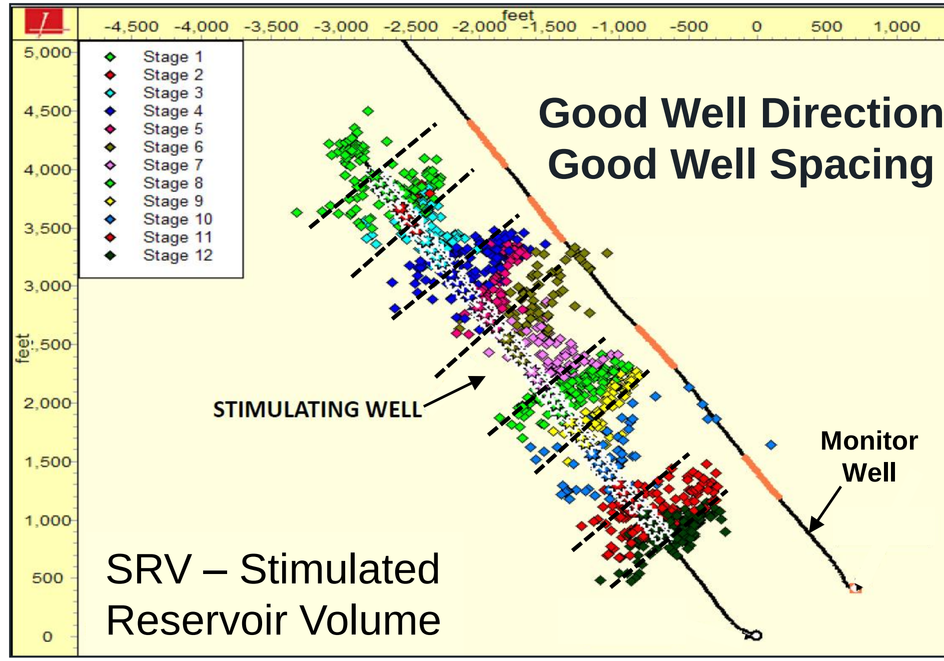
1st year production
150,000 bbls oil 1st year
518,000 mscf (0.5 bcf)
(Hybrid Frac/Conventional)

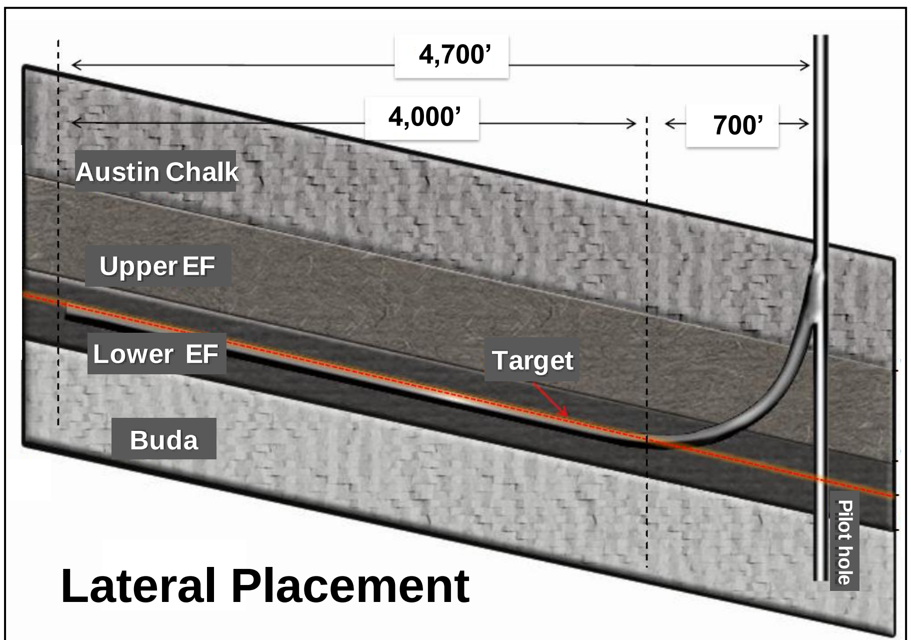


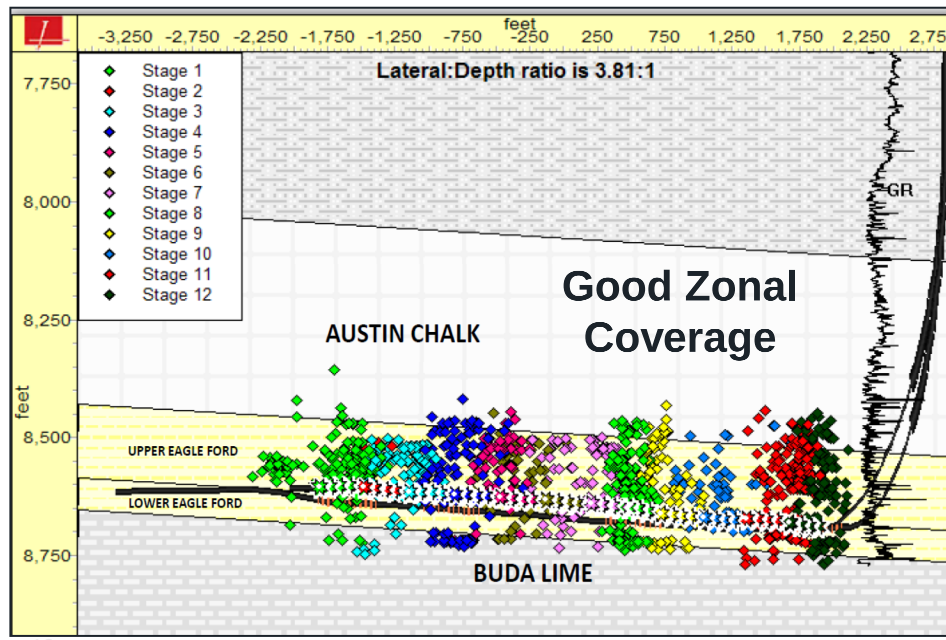
Choke Sizes: 10-20 first 140 days

1st year production
5,500 bbls oil 1st year
16,900 mscf (0.017 bcf)
(Slick Water Frac)

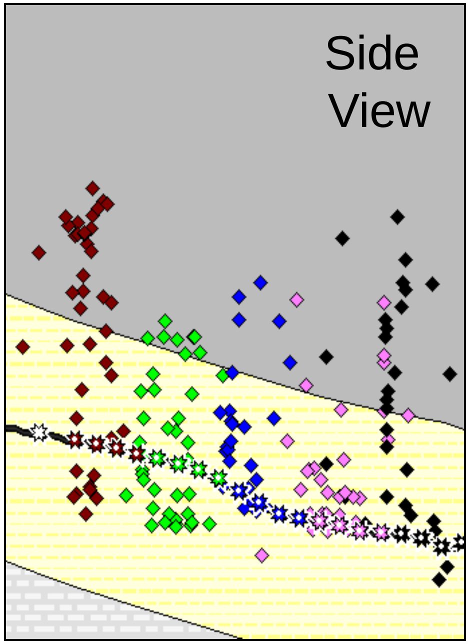
Frac Mapping:

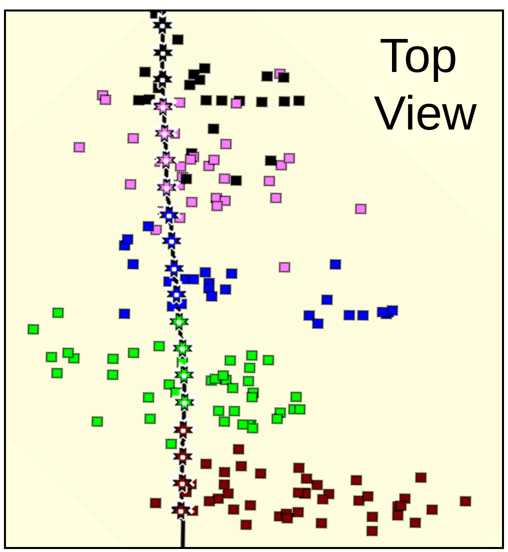




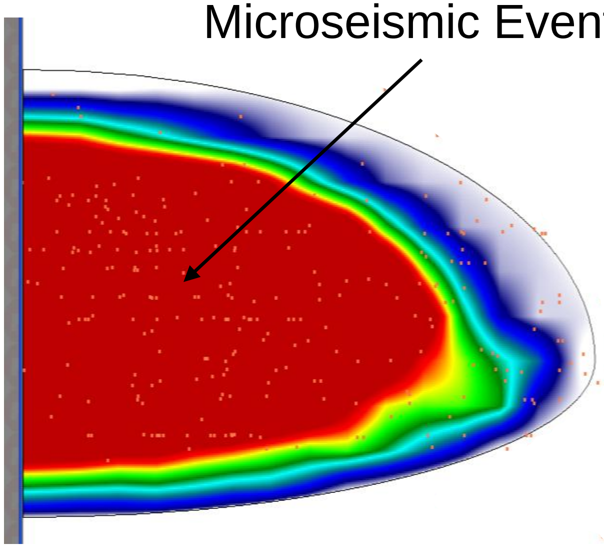


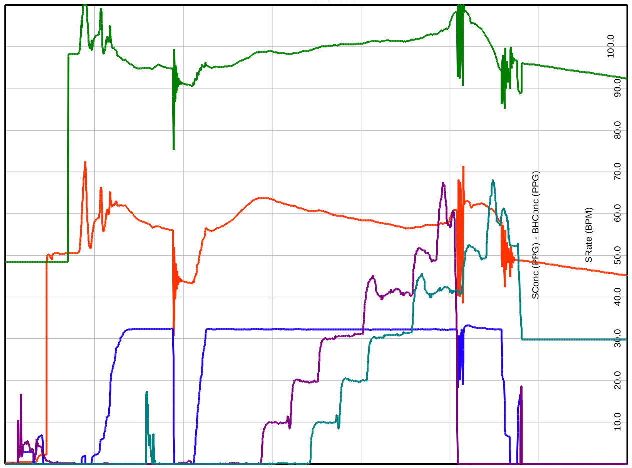
Frac Mapping for Frac Model Calibration:



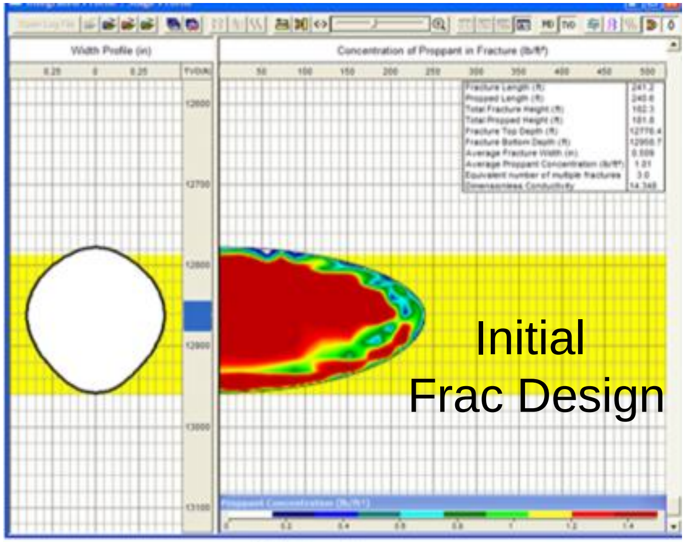


Frac Match with
Microseismic Events





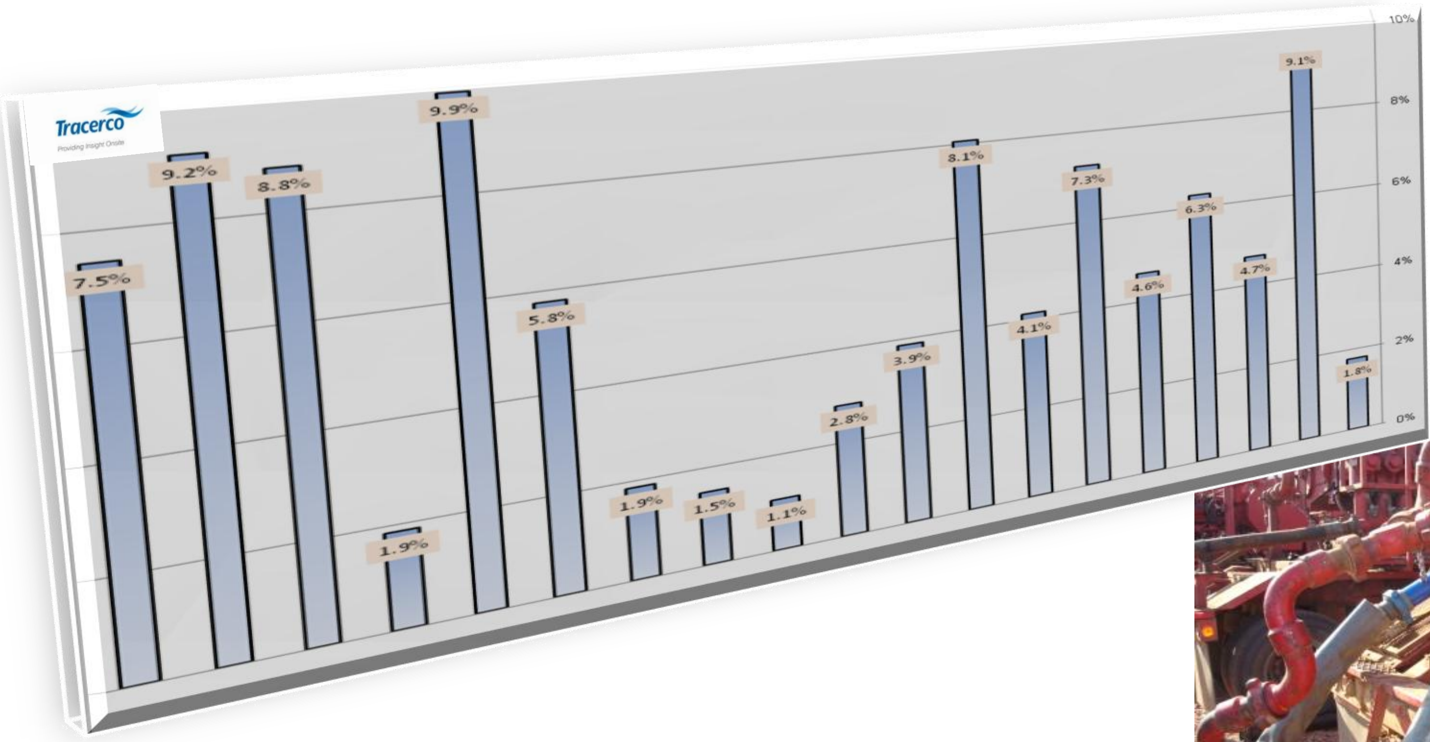
Time (min)	Volume Factor	Leakoff Factor	Opening Factor
0.00	2.0	2.0	1.5
30.00	3.0	2.0	2.5
40.00	3.0	3.0	3.0
60.00	3.0	3.0	3.0
90.00	3.0	3.0	3.0
0.00	0.0	0.0	0.0



3 Fractures

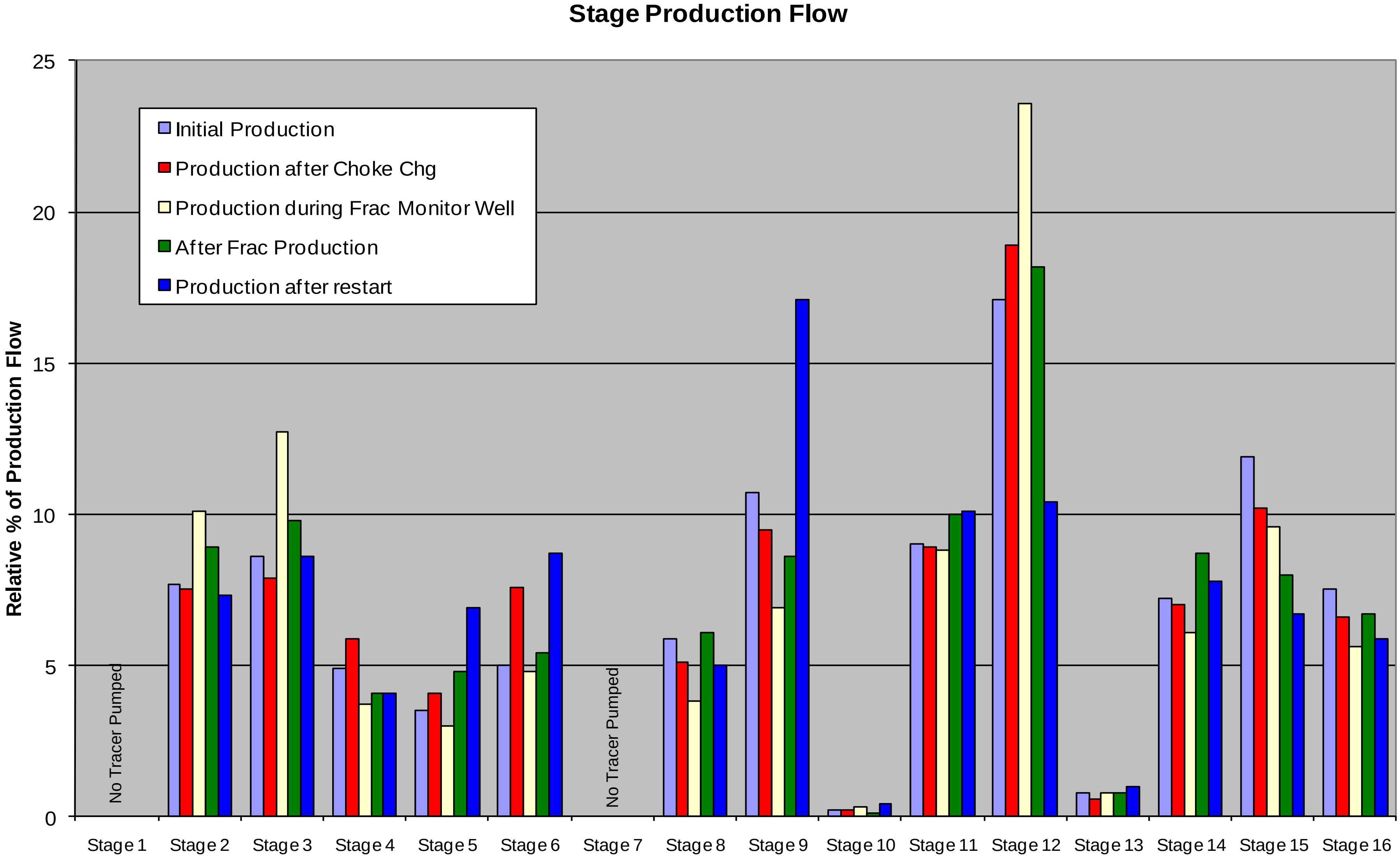
Post Frac Hydrocarbon Flow Profiling

- A **hydrophobic tracer** is added to each frac stage.
- Each of the hydrophobic tracers **dissolves within reservoir hydrocarbons**.
- Surface **flowback samples are analyzed** for the different tracers.
- Analysis verification of stage flow and its **relative contribution to production**.

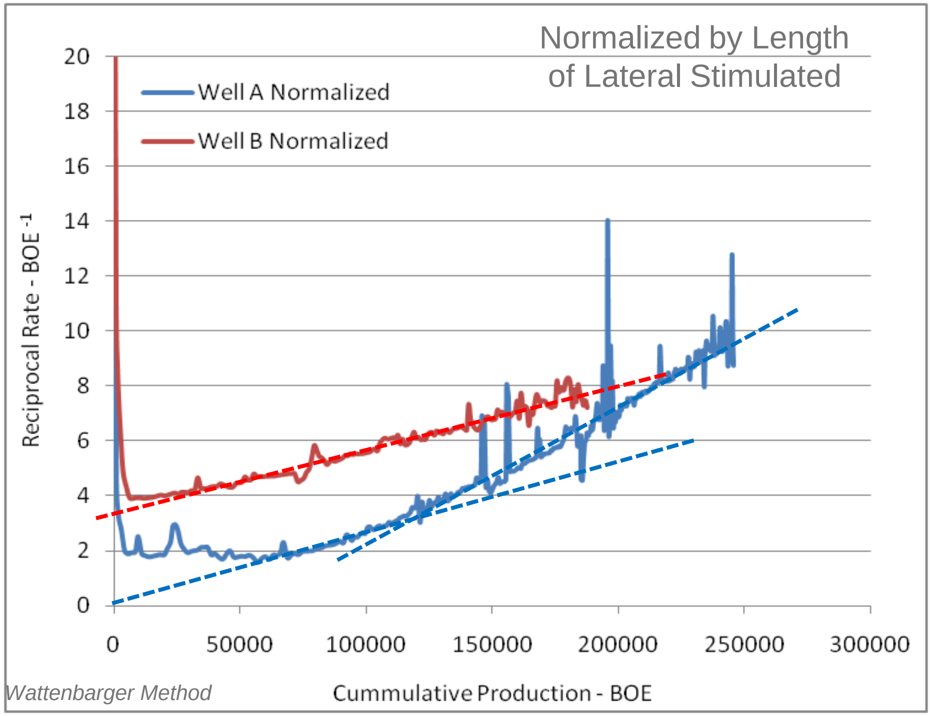


Information provided by TracerCo

Post Frac Hydrocarbon Flow



Production Analysis - 1/Rate vs. Cum Prod



2500 ft Lateral with
11 frac stages
300, 000 lbs per stage

5000 ft Lateral with
14 frac stages
300,000 lbs per stage

- The slope is proportional to the system perm and fracture length
- A constant slope indicates “stabilized” fracture conductivity (after clean-up)
- First trend: must have a ***non-negative intercept***
  - Intercept is a qualitative measurement of conductivity of the fracture network
  - Zero intercept = infinite conductivity   Positive intercept = finite conductivity
- Second trend: influenced by boundaries
  - Either drainage boundaries or interference between fractures

Dr Jeff Callard,
University of Oklahoma

SPE 139981 & 142382

The Company President asking his staff ....

.... How are we going to “Frac” this well?

- What are the other Operators doing on their wells?
- How much is it going to cost?

You Are!

And you can because you have Data!

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- What stuff can we leave out?
- Do you think it will work if we don’t do all that stuff?
- Who’s going to figure it out if it doesn’t work?

Thank You

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