# *Stimulation 101*


Dallas YP Luncheon

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CARBO CERAMICS

SPE International

Society of Petroleum Engineers

# *Terry Palisch*

## *Sr. Staff Petroleum Engineer*
## *CARBO Ceramics*

- After completing his BS in Petroleum Engineering at the University of Missouri-Rolla, **Terry Palisch** worked as a petroleum engineer for 10 years with ARCO in Alaska and for four years with ARCO in Algeria, North Africa. During a portion of his tenure in Alaska, Terry supervised the fracture stimulation program at ARCO's Kuparuk River Field. In 2004 Terry joined CARBO Ceramics as a Sr. Staff Petroleum Engineer. His current work primarily focuses upon helping clients improve fracture designs by accurately predicting production under realistic conditions. He has authored numerous technical papers and currently manages CARBO's "Ask Fracdog™!" program and personally provides guidance and analysis on all field trials run by CARBO's customer base. Terry is currently a member of the Dallas section and serves on the ATCE Well Stimulation Subcommittee and the Completions Operations Technology Award Committee.

# *Why is Stimulation Important?*

- Ranks 2nd only to reservoir description and evaluation as a topic of research or publication
  - SPELibrary search – 11451 hits for "stimulation" (10%)
    - 9345 Hydraulic Fracturing, 4324 Acidizing
- Numerous books written entirely on the subject
- Stimulation programs typically weather tough economic times (capital $'s shift to expense)
- Multi-billion $ industry
- Without stimulation the Unconventional Plays are uneconomic

"…*this facet of the (well) construction process actively and positively affects a reservoir's productivity, whereas most of the other operations in this process are aimed at minimizing reservoir damage or eliminating production problems*…." - Economides "Petroleum Well Construction"

# *Outline*

Why do we Stimulate Wells?

How do we Stimulate Wells?

Acidizing Basics

Hydraulic Fracturing Basics

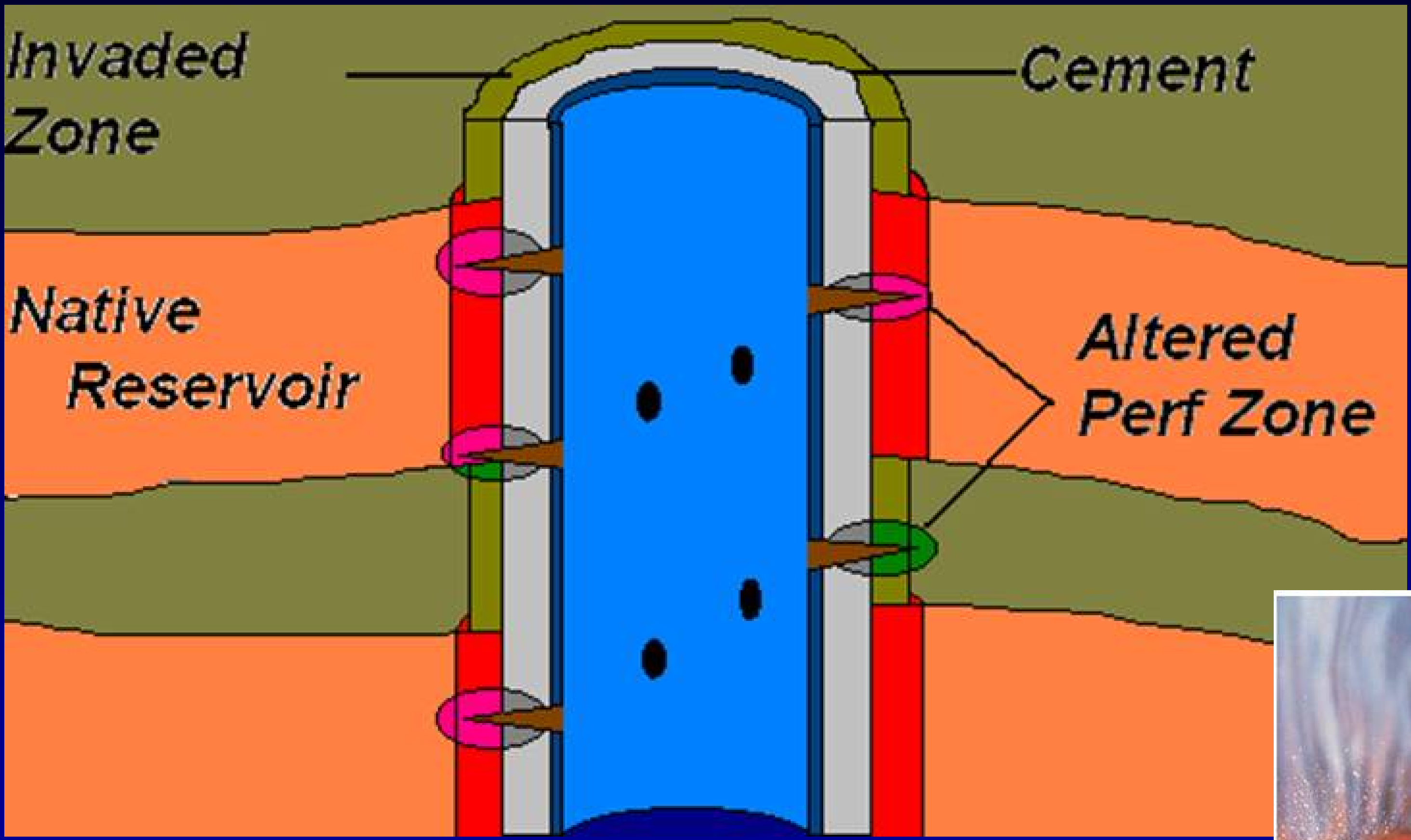
Summary

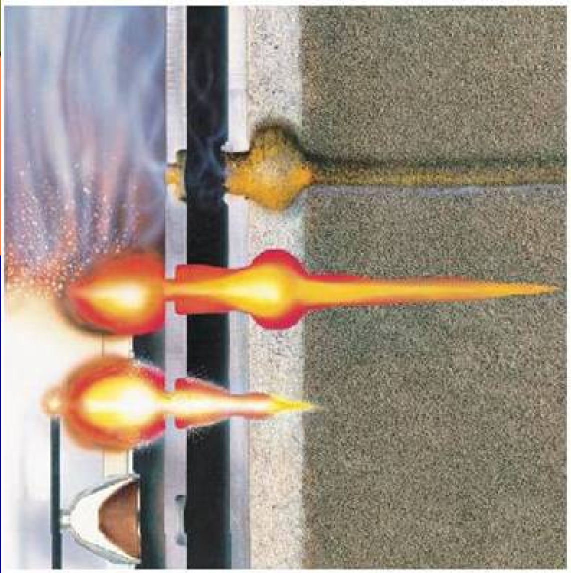
**Informal Presentation**

**Please ask questions!**

# *Why Stimulate a Well?*

When we drill and complete the well…

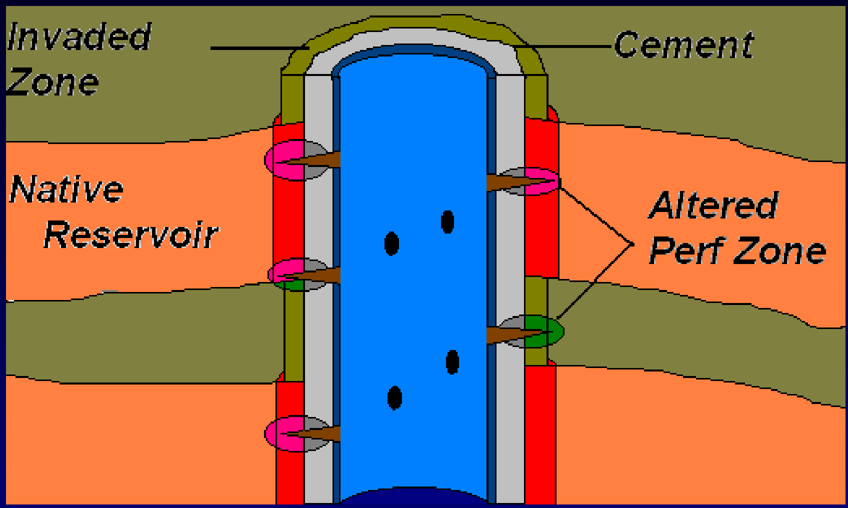


# *Why Stimulate a Well?*

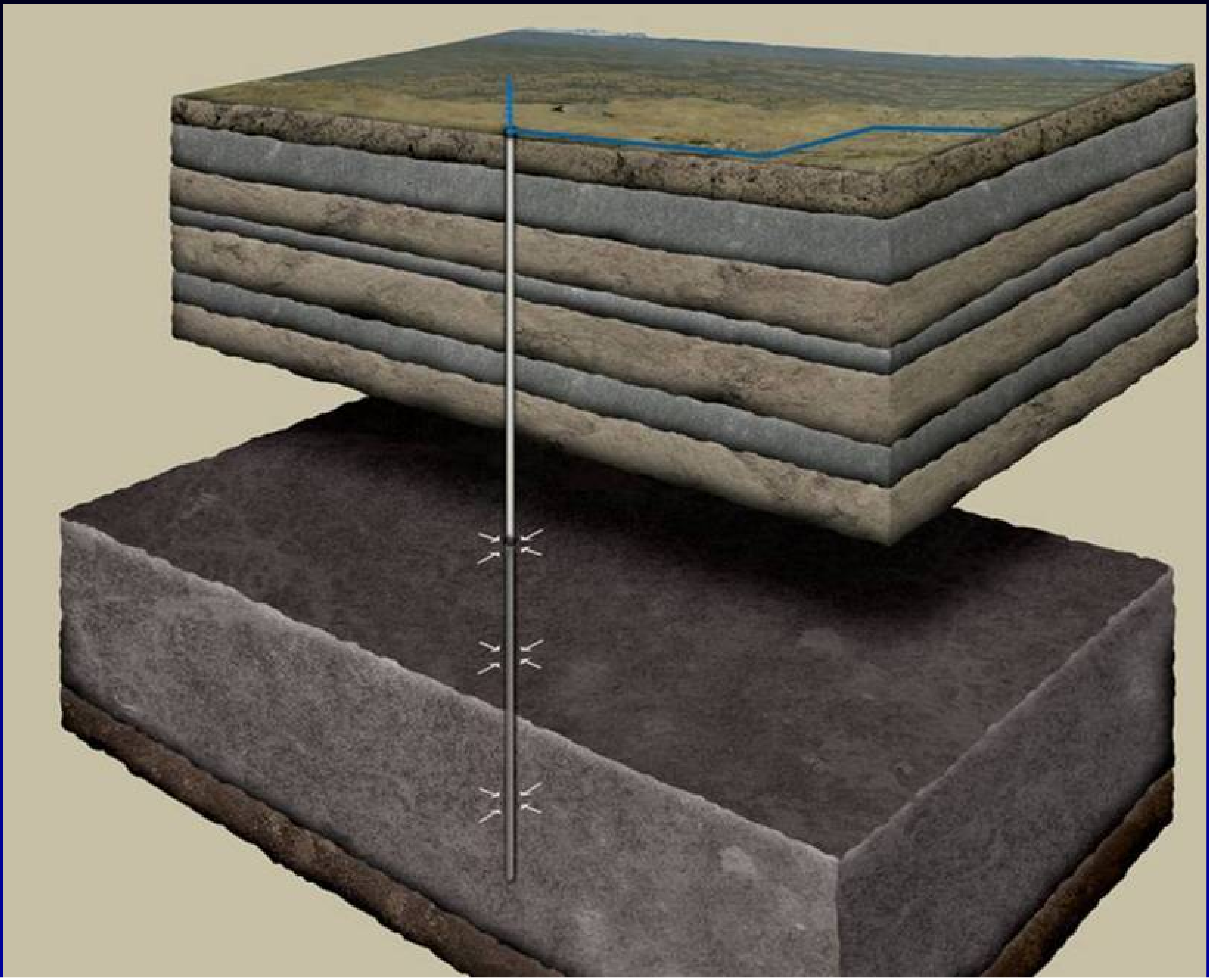
1) Overcome completion damage

- Drilling mud, cement, perforation damage, fluid loss additives, etc.
- Production damage (paraffin, scale, gas/water block, etc,)

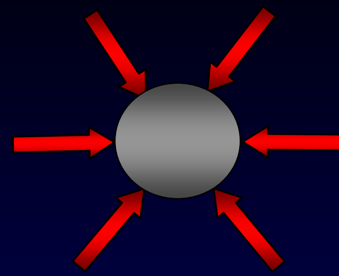



- More "remedial" than "stimulation" - merely removes damage
  - If successful, results in final skin of "0" or flow efficiency of 100%
  - Injection well stimulation *generally* fits this category

# Vertical Well Flow Regimes

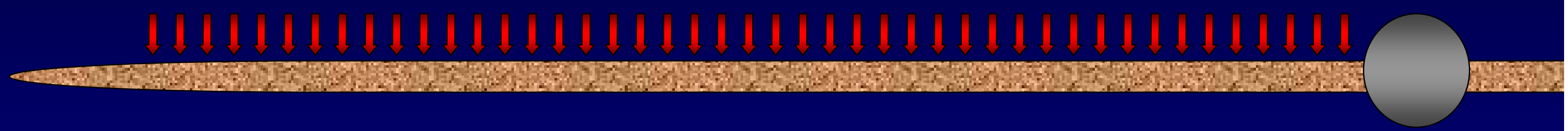


# *Why Stimulate a Well?*



2) Enhance Productivity

– Expand the "effective wellbore radius" of the well



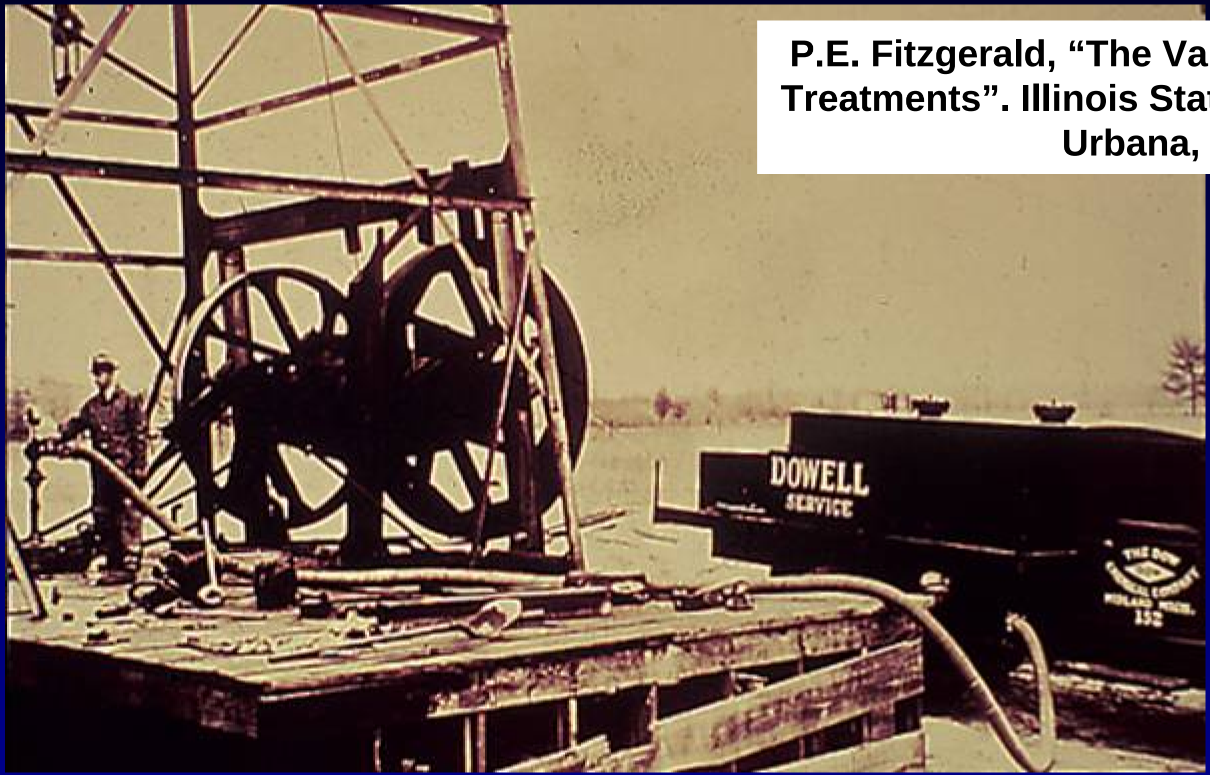
- Stimulates the well beyond radial production
  - Can potentially obtain wells with apparent skins of -10 and flow efficiency of 300%
  - In HZ wells can effectively drain many equivalent wellbores, effectively replacing several wells
  - In Unconventional wells it may be the difference between development and abandonment

# *What are the Methods for Well Stimulation?*

- Acidizing
- Hydraulic Fracturing
- Other
  - Reperforation
    - High Energy “R.O.P.E” treatments
  - Explosives (old) & Propellants (new)
  - Abrasive Jet Cutting
  - Chemical treatments (excluding acid)
    - Mud, paraffin, scale, water/gas block, etc
  - Steam Injection (“huff n’ puff”)

Rapid Overpressure Perforating Extension

# *Acidizing Basics**




**P.E. Fitzgerald, “The Value of Repeated Acid Treatments”. Illinois State Geological Survey, Urbana, 1934.**

*This is an extremely mature technology and there are numerous books, procedures, rules of thumb and experts on the subject, that will not be presented here.

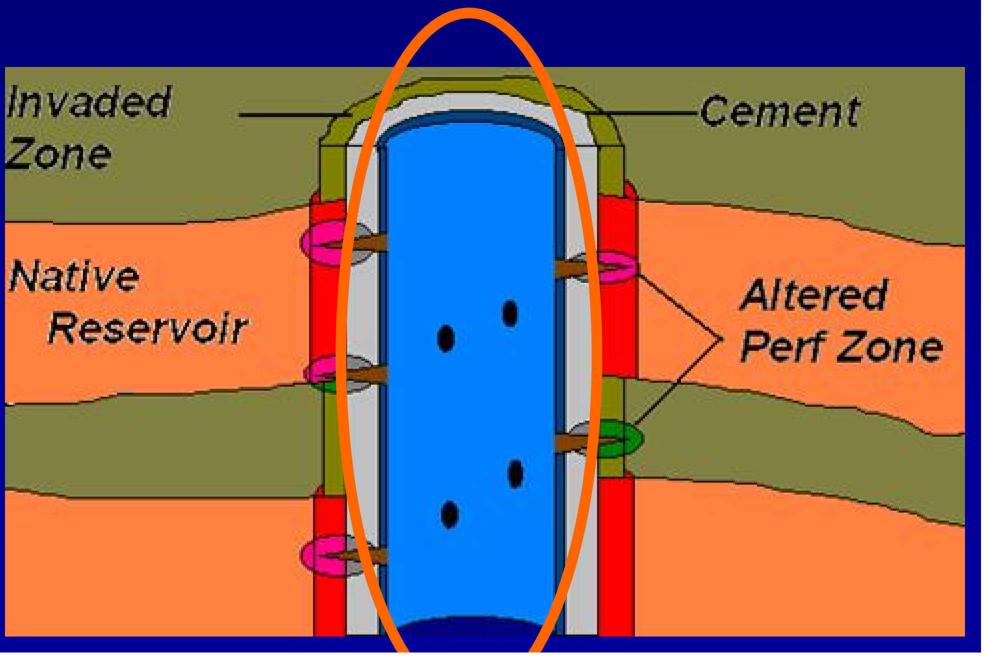
# *Brief History of Acidizing*

- First use of acids to stimulate or improve production from carbonate reservoir in 1895. Severe corrosion.
- In 1925-1930, used to dissolve scale in Glenpool Field in OK. Unsuccessful.
- Pure Oil and Dow Chemical developed inhibitors, and in 1932 the first successful acid stimulation occurred in Isabella County, MI.
- Over the years one fundamental rule….

...the first step in any stimulaton process is to assess the damage, and determine the goal or reason for the treatment….

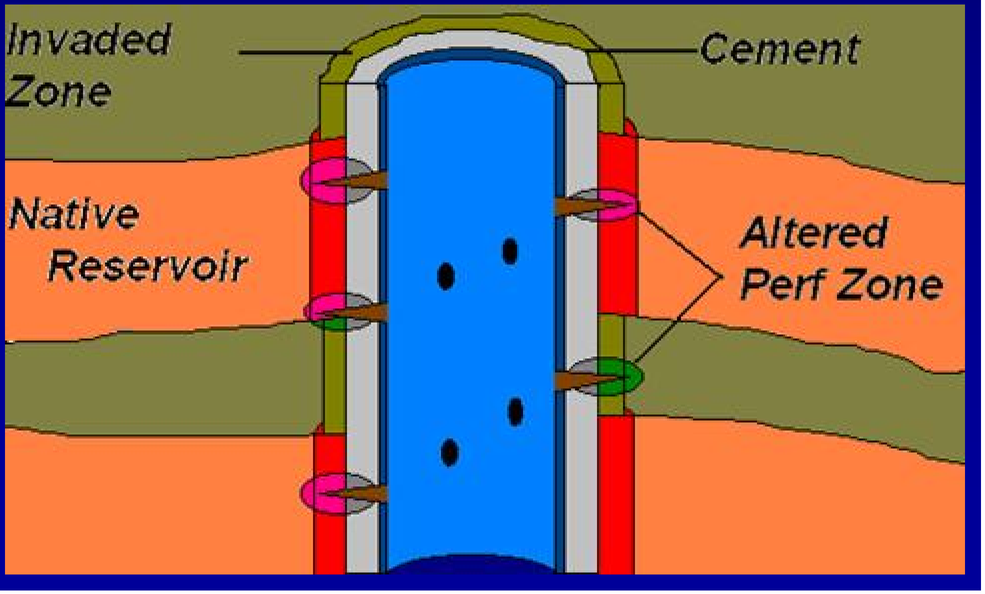
# *Acid Techniques*

- <u>Wellbore clean-up</u>
  – Clean up mill/corrosion/$CaC0_3$ scale, perf debris, pipe dope and other acid soluble buildups in the tubulars
  – Displace (bullhead/dump/spot) wellbore to acid and let soak
  – Typically minimal mechanical agitation



# *Acid Techniques*

- <u>Matrix Acidizing</u>
  - Primarily used for damage removal in the near wellbore, caused by scale, drilling/completion, perforating, or to dissolve formation
  - Typically applied in high perm formations
  - Inject acid formulation into the matrix below the frac/parting pressure
  - Radial flow pattern, using existing permeabilty and porosity.



# *Acid Techniques*

- Acid Fracturing
  - Used to "enlarge the effective wellbore" by creating an acid-etched fracture deep into the formation.
  - Typically applied in low perm formations.
  - Inject acid formulation into the matrix above the frac/parting pressure
  - Operational/design issues similar to conventional fracturing

SPE 104203

Core picture of acid etched fracture conductivity test

# *Acidizing "Materials" - Acids*

- Hydrochloric (HCl)
  - Most common – economy & no insoluble "leftover"

$$2HCl + CaCO_3 \rightarrow H_2O + CO_2 + CaCl_2$$

  - 1000 gals 15% HCl will dissolve ~11 $ft^3$ (>1800 lb) limestone, and liberate 7000 scf $CO_2$ and 2000 lb $CaCl_2$ dissolved in 40 gals $H_2O$.
  - Typically 15% concentration, up to 20% and 28%

# *Acidizing "Materials" - Acids*

- <u>Acetic/Formic</u>
  - Weakly ionized, slowly reacting, organic

$$2HOrg + CaCO_3 \rightarrow H_2O + CO_2 + CaOrg_2$$

  - Less common than HCl, used when long reaction times are desired, or with high BH temperature.
  - Acetic typically limited to 15% concentration, and Formic 10% to avoid insoluble precipitates

# *Acidizing "Materials" - Acids*

- Hydrofluoric (HF)
  - High intensity; removes mud, clays and silicas, typically insoluble in HCl

$$4HF + SiO_2 \rightarrow 2H_2O + SiF_4$$

and

$$2HF + SiF_4 \rightarrow H_2SiF_6$$

  - Usually must be combined with HCl to be effective; used as a complement
  - Concentrations must be carefully studied to avoid adverse (or over) reactions, or damaging precipitates

# *Acidizing "Materials" - Additives*

- Corrosion Inhibitors
  - Retard reaction rates to protect tubulars
- Surfactants & Alcohols
  - Improves treating efficiency (matrix) and return of spent acid
- Silica and Iron Control Agents
  - Reduces unwanted precipitates and blocks
- Retarders
  - To provide deeper penetration into matrix
- Gelling agents (for Acid Fracs)
- Liquefied Gases ($N_2$ and $CO_2$)

# *Carbonates*

- Most Acidizing (matrix and fracturing) is performed on Carbonate formations
- Typically HCl, but Acetic/Formic should be considered at temperatures over 250°F.
- Matrix treatments used to dissolve damaging material, or to dissolve the rock located in the damaged area.
  - In many cases "wormholes" are developed

# *Carbonates cont.*

- Acid Fracturing is more popular in Carbonates
  - Used in low perm or ineffective perm structure
  - Relies on "etching" of the fracture faces
  - Requires competent rock to retain etched frac

- In all Carbonate acidizing, it is important to understand what happens to the formation structure after the introduction of acid, and after the well is placed back on production.
  - It is possible to collapse the structure and actually damage the flow paths

# *Sandstones*

- Sandstone Acidizing is almost always carried out as a matrix treatment.

- Typically a mixture of HCl and HF – aka mud acid. Usually 2-6% HCl, followed by 8-12% HF.

- Matrix treatments used to dissolve damaging clay-like minerals or other acid soluble material.
  - HCl pumped first, followed by HF

# *Sandstones cont.*

- Core work and caution must be employed to ensure that acid treatments in Sandstones don’t in fact reduce the perm.

- Secondary reactions are possible, so HF/HCl in Sandstones should be returned as soon as possible.

- Sandstones are typically stimulated using Hydraulic Fracturing.

# Success of Matrix Acid Treatments

*SPE 63179, Nitters, Roodhart et al. (Shell + HES)*

- 60-70% of all matrix acidizing treatments fail to produce more oil or gas.
  - Poor candidate selection
  - Poor treatment design
- Despite acidizing being a “mature” science – there remains a lot to learn!

# *Hydraulic Fracturing Basics*

# *How important is Hydraulic Fracturing?*

## ConocoPhillips Fracturing Activity

| *COP Fracture Stimulation Job Count for 2006 and 2007* | | |
|---|---|---|
| ***Location*** | ***2006 Job Count*** | ***2007 Job Count*** |
| North Sea | 105 | 129 |
| UAE | 132 | 69 |
| Indonesia | 1 | 7 |
| Libya | 73 | 36 |
| China | 8 | 5 |
| Alaska | 156 | 202 |
| **Canada** | **1296 (40%)** | **2215 (46%)** |
| Gulf Coast | 9 | 14 |
| **US Land (ex. Alaska)** | **1443 (45%)** | **2114 (44%)** |
| **Global Total** | **3223** | **4791** |

| *COP Fracture Stimulation Spend for 2006 and 2007* | | |
|---|---|---|
| ***Location*** | ***2006 Spend*** | ***2007 Spend*** |
| **Canada** | **$79.1 MM (31%)** | **$139.5 MM (36%)** |
| **US Land (ex. Alaska)** | **$133.5 MM (52%)** | **$194.4 MM (51%)** |
| **Global Total** | **$ 256.2 MM** | **$ 383.4 MM** |

- Currently ~80% of COP US Land and Canada production from hydraulically fractured wells
- 95% US Land and Canada fractures are tight gas or unconventional resource wells
- Tight gas totals:
  - 2006: 2600 fractures (81%)
  - 2007: 4110 fractures (86%)

**Current Total Industry spend ~$3.7 BILLION**

**Courtesy COP, Hydraulic Fracturing Conference, Jan 2009**

# *Brief History of Hyd. Fracturing*

## Keppler No. 1
## First Hydraulic Fracturing Operations (1947)

- Formation Cracking
- First Treatment
  - Hugoton Gas Field - June, 1947
  - 4 Limestone Gas Pay Zones (2340 to 2580 ft)
  - BHTP = 420 psi
  - Fluid = 1000 gal of Napalm + 2000 gals of Gasoline
  - Proppant = Arkansas River Sand (2000 lbs)

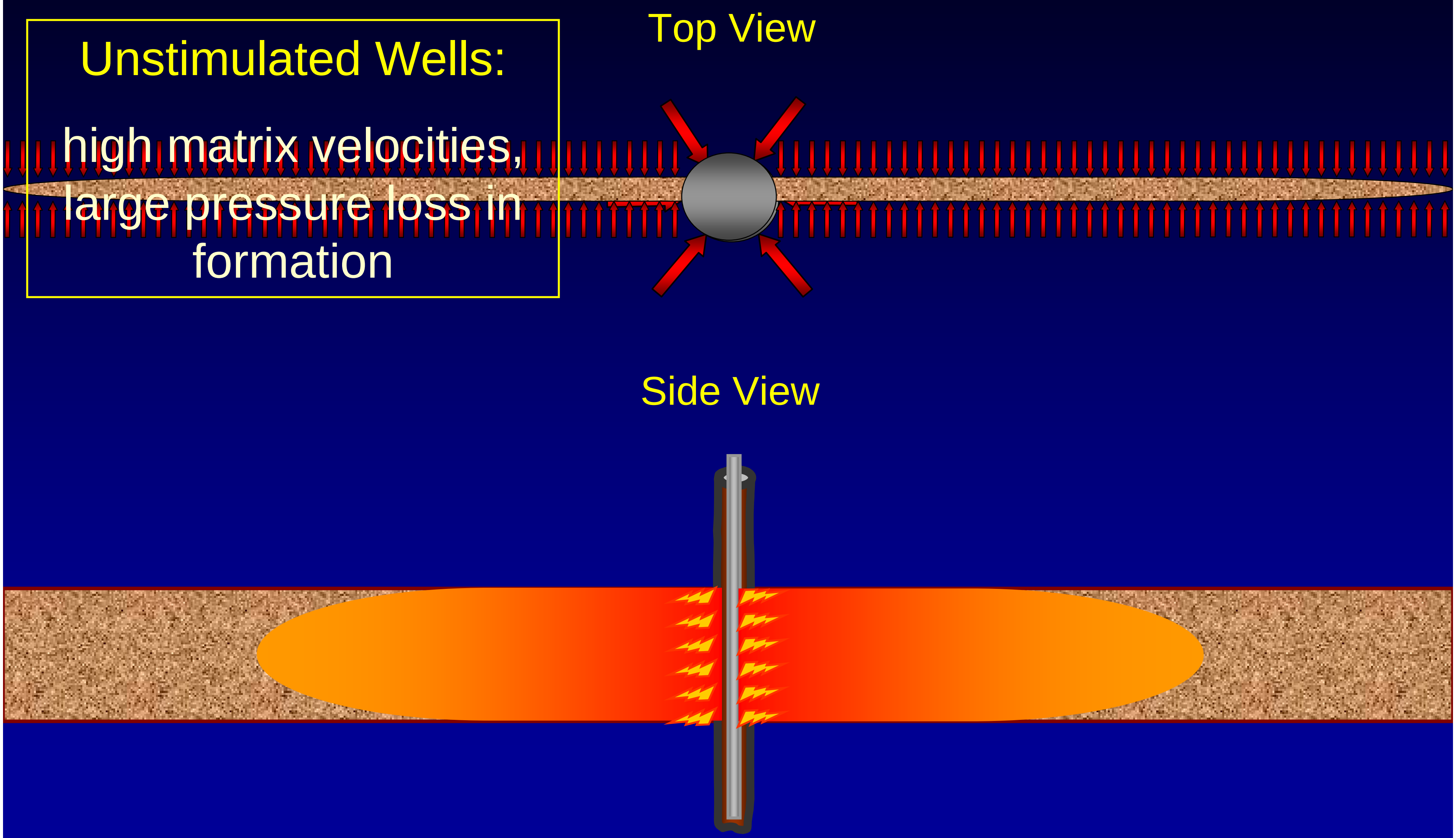
# *Brief History of Hyd. Fracturing*

- The first commercial frac in 1949.
- So successful that only a few years later 1000's of fracs were being performed.
- 60's Analytical techniques developed to estimate negative skin
- 80's Mini-frac analysis converted fracturing from an art to a science
- 90's Tip Screen outs opened up fracturing to medium and high perm reservoirs
- 2000 reservoir/fracture numeric modeling introduced for fracture optimization and design

# Why Fracture Stimulate?

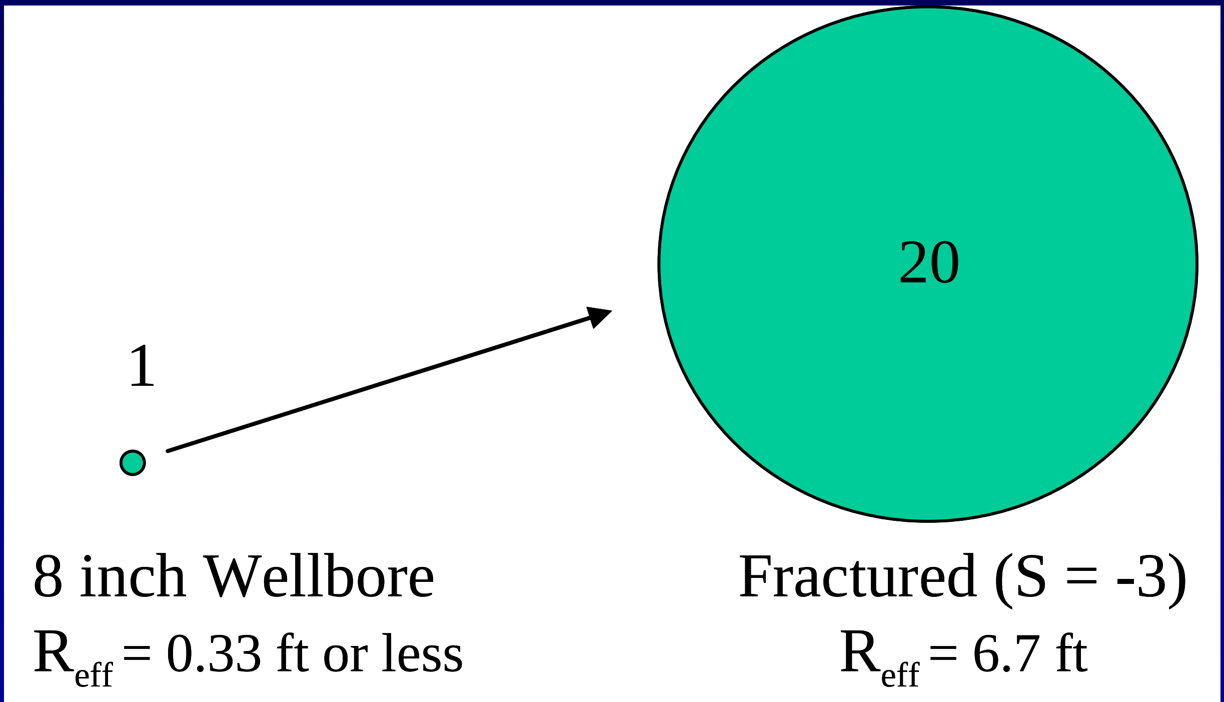
Unstimulated Wells:

high matrix velocities, large pressure loss in formation



# Why Fracture Stimulate?

**Goal: create large effective wellbore diameter, reduce matrix velocities, reduce pressure losses, while producing more oil/gas**



# Fracture Orientation

**Frac orientation and complexity depend on the in-situ stresses**

**In real life, fracs are MUCH MORE complex than what we envision and model**

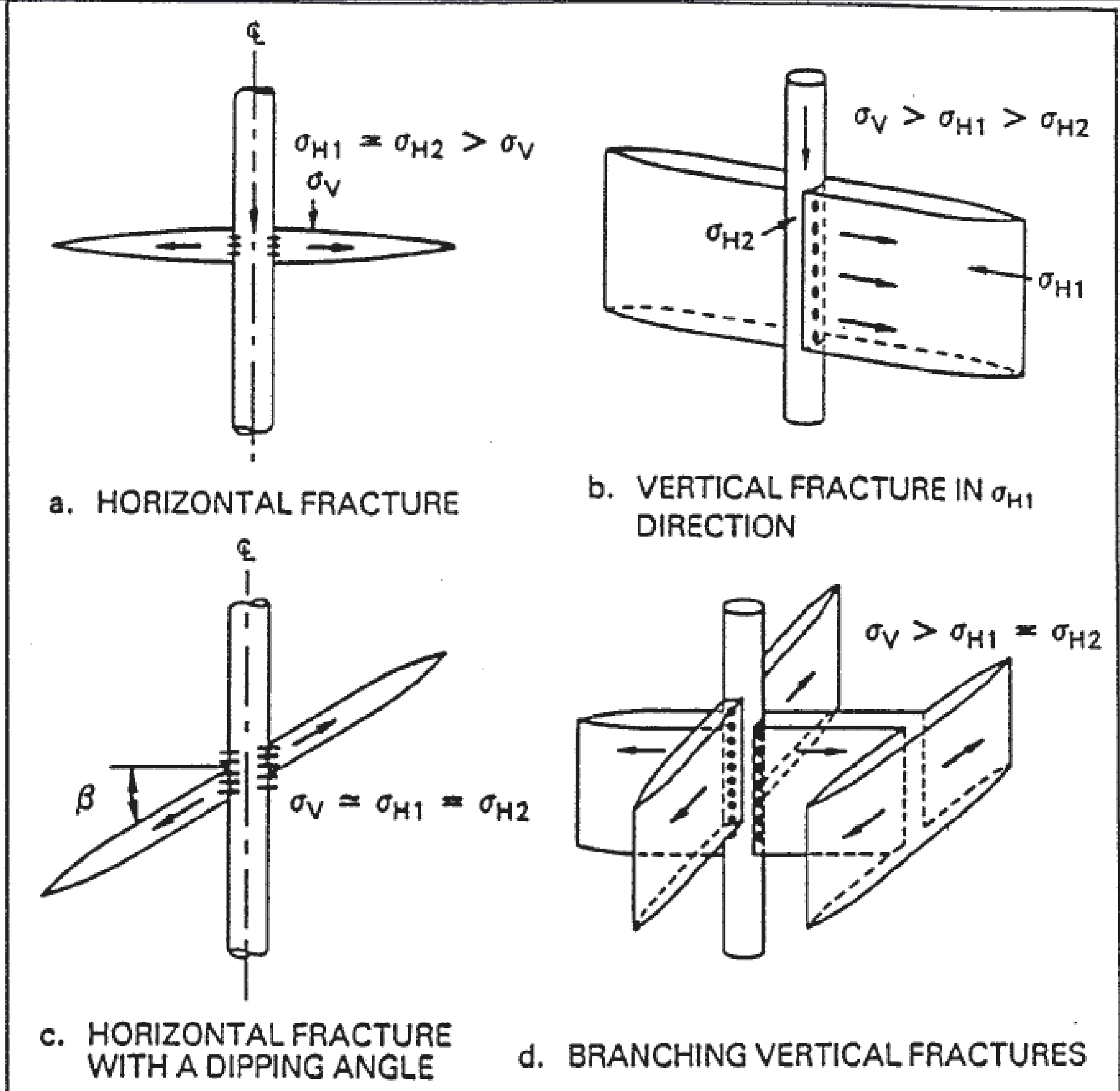
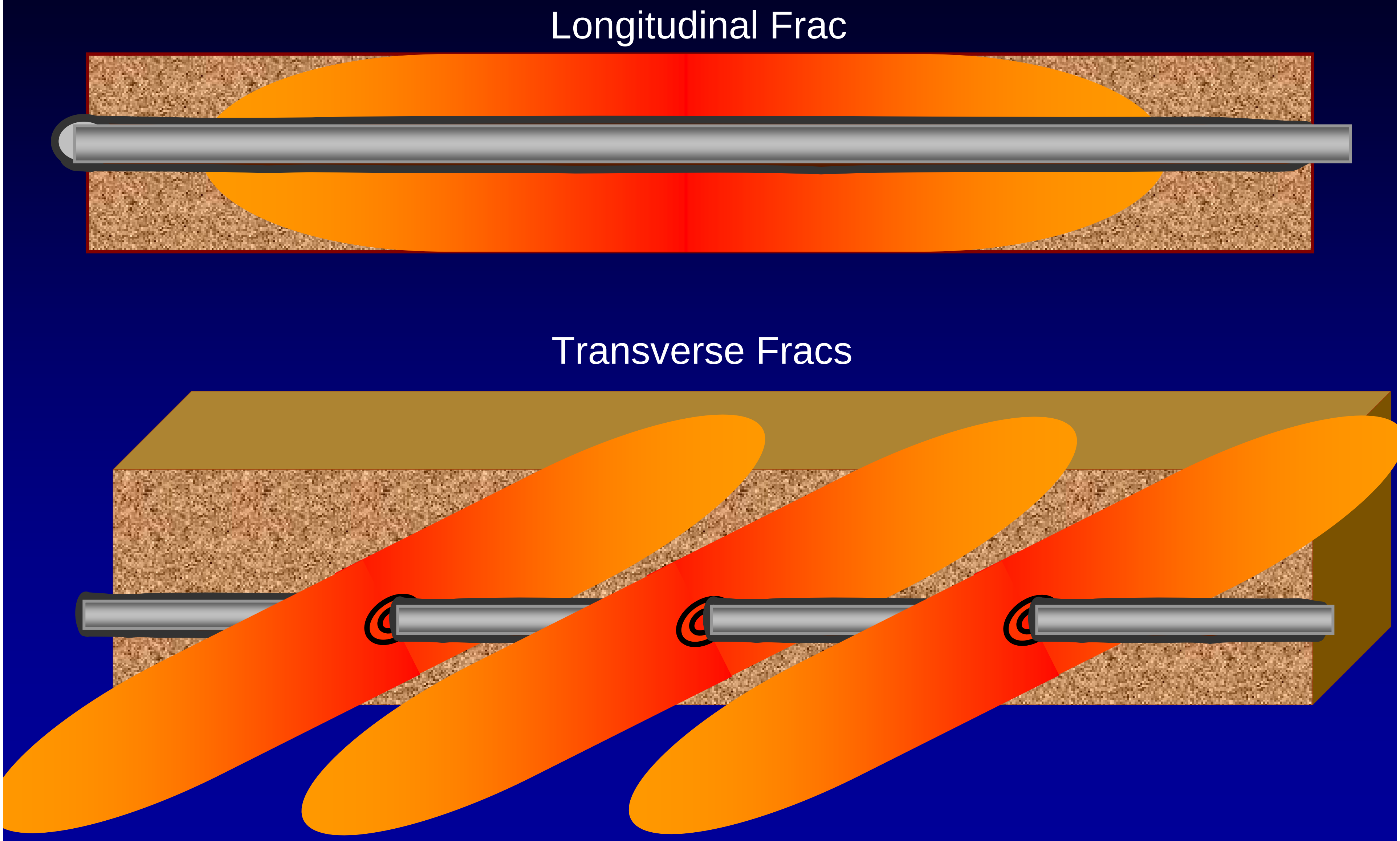


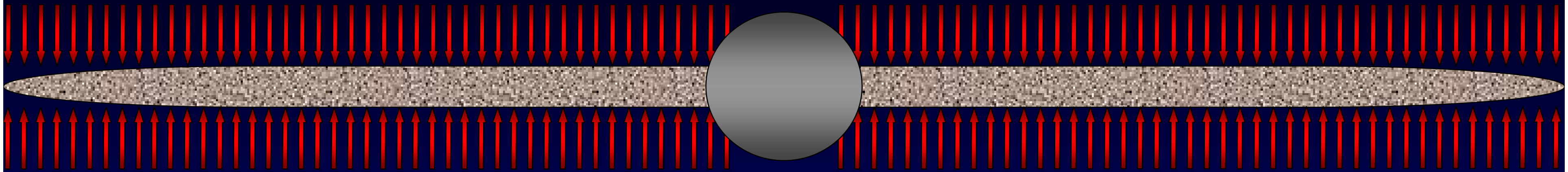

Fig. 16.3—Geometry and orientation of hydraulic fractures depend on the principal formation stresses.

**[Courtesy Hydraulic Fracturing Monograph]**

# What happens in Horizontal Wells?

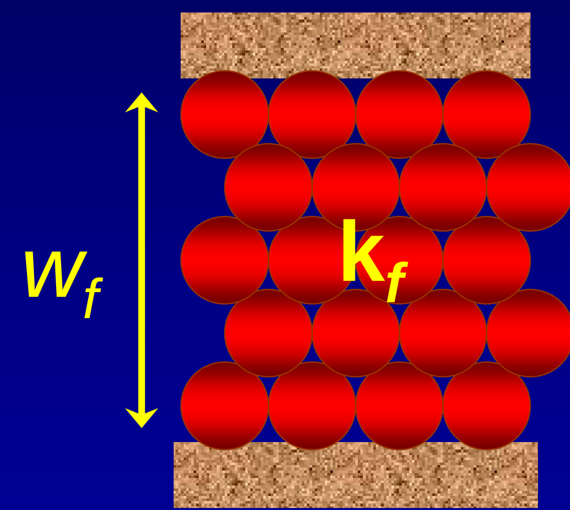


# *Fracture Conductivity*

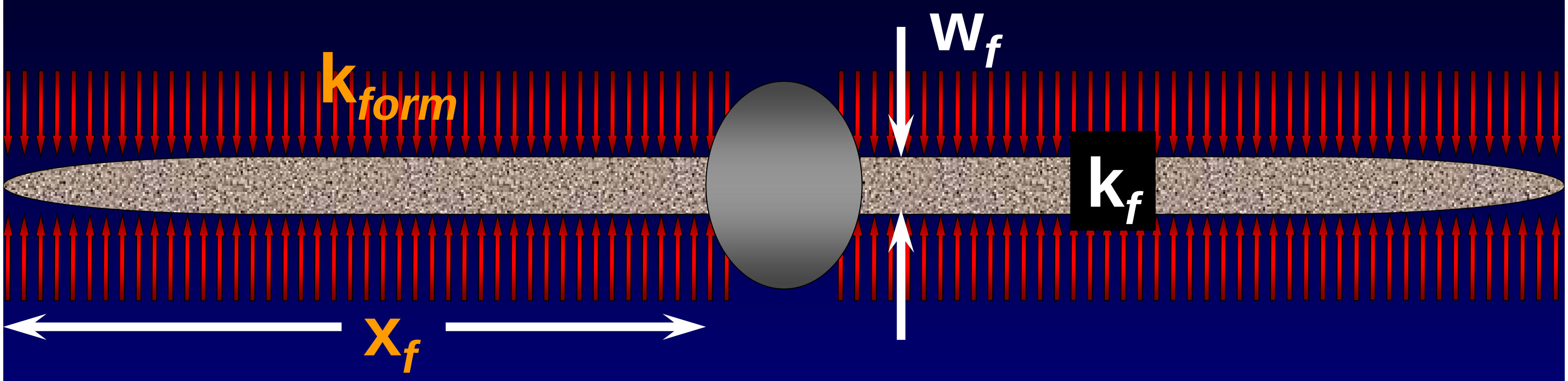


$$c_f = k_f * w_f$$

***Conductivity ($C_f$) is a measure of the fracture's ability to transmit fluids***



# *Why is Conductivity Important?*




$$F_{CD} = \frac{k_f * w_f}{k_{form} * x_f}$$

***Dimensionless Fracture Conductivity ($F_{CD}$) is a measure of the contrast between the flow capacity of the fracture and the formation***

# *Materials - Proppants*

- Sand
  - “Brown” & “White
- Resin Coated Sand
  - Precured and Curable
- Ceramics
  - Lightweight (LDC)
  - Intermediate Density (IDC)
  - High Strength (Bauxite)
- Resin Coated Ceramics
- Other
  - Walnut Hulls, glass beads, thermoplastics, ultra-lightweight

# *Materials - Frac Fluids*

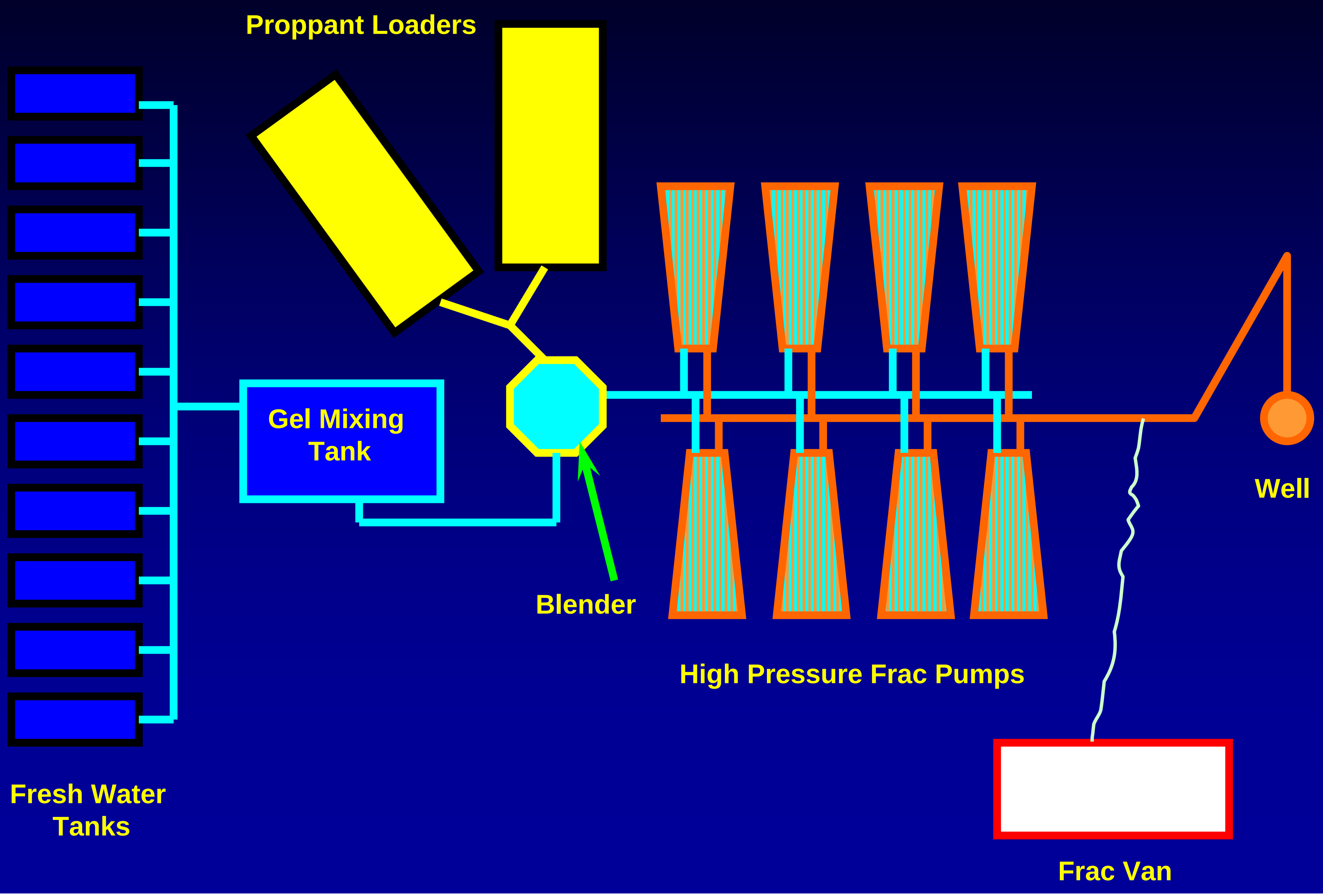

- Water Based
- Oil Based
- Emulsions
- Foams ($N_2$ & $CO_2$)

- Crosslinked
- Linear
- Slickwater

# *Basic Frac Fluid Composition*

- Conventional Water Based
  - Polymer
  - Crosslinker
  - pH Buffer
  - Clay Control
  - Gel Stabilizer
  - Breaker
  - Surfactant
  - Biocide
  - Fluid Loss Control
- Slickwater
  - Polymer or PA
  - Clay Control - maybe
  - Surfactant - maybe

# Typical Frac Layout



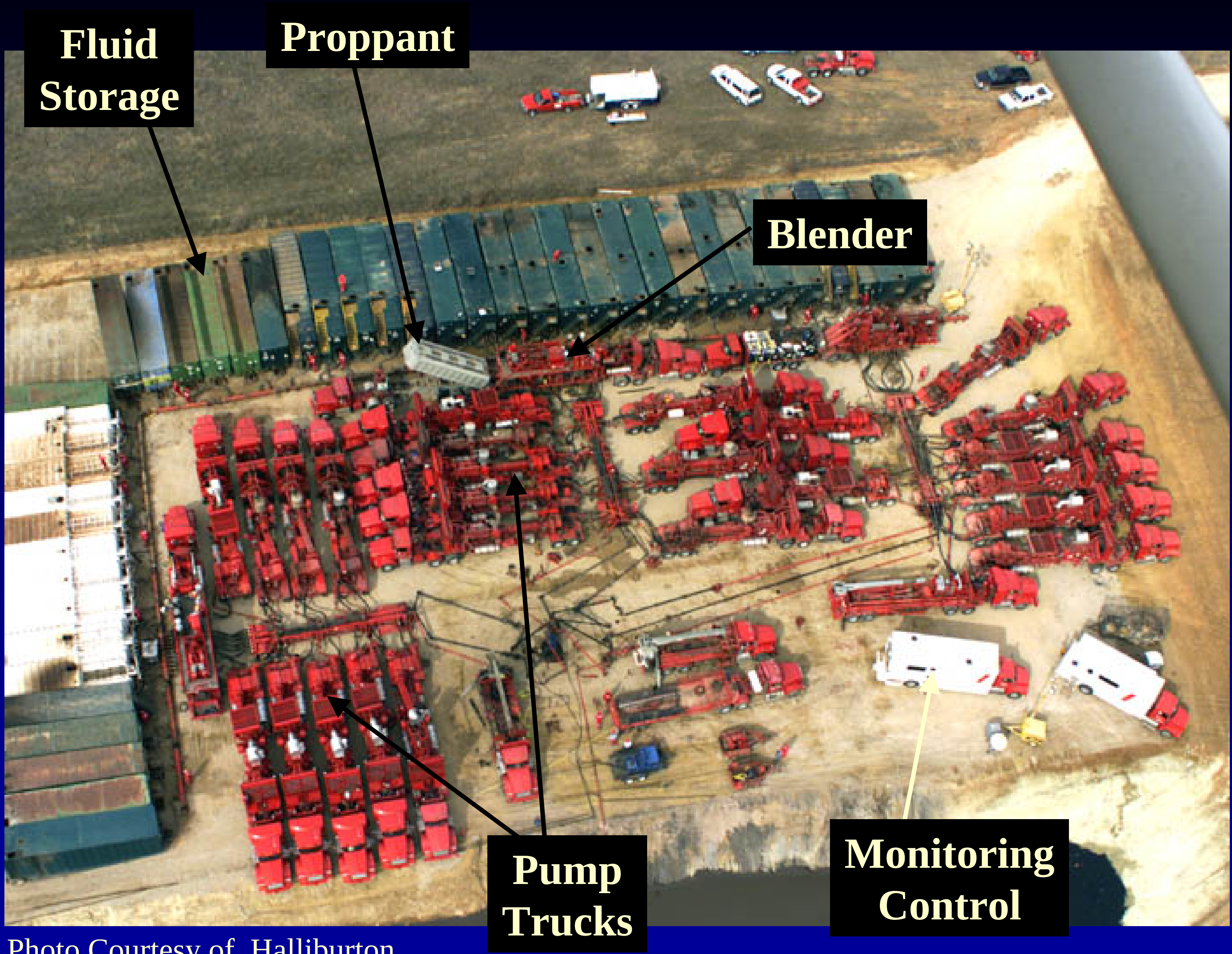
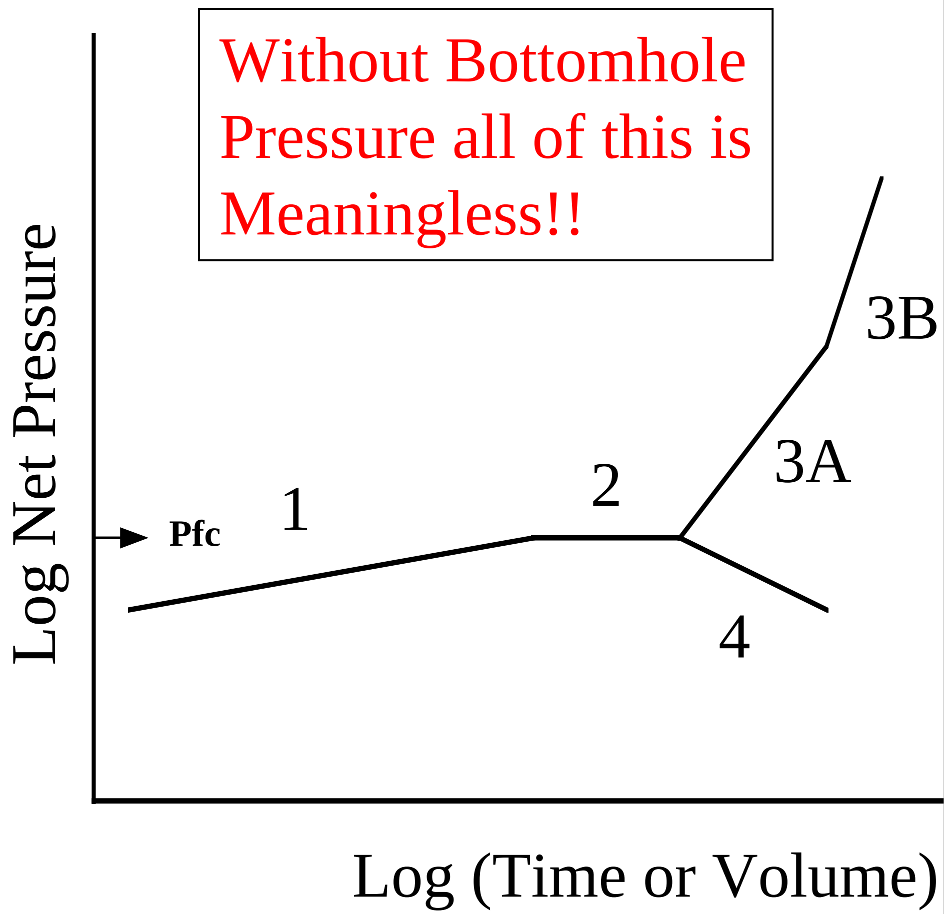


Photo Courtesy of Halliburton

# *“High Tech” Operation*

- Sophisticated modeling used for design
- Datafrac/Minifrac gathers fluid efficiency, perm and other data prior to frac
- Sophisticated monitoring and analysis during the frac
- Most fracs are run from a fully integrated and automated “command center” on location
- Post frac pressure analysis and history match for use in future fracs
- Diagnostics – tracers, mapping, logging, etc.

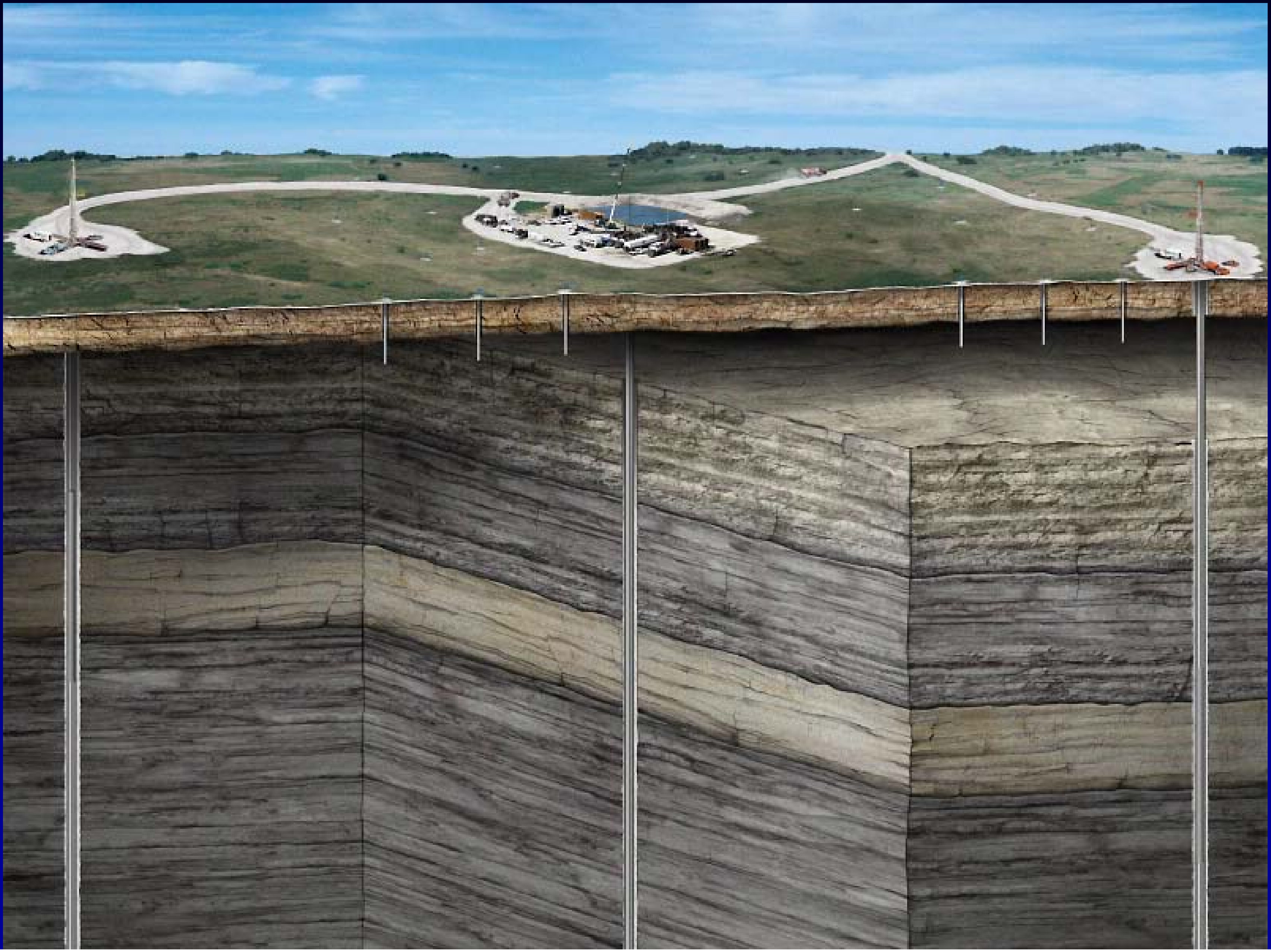
# Net Pressure Plot
# Slope Interpretation



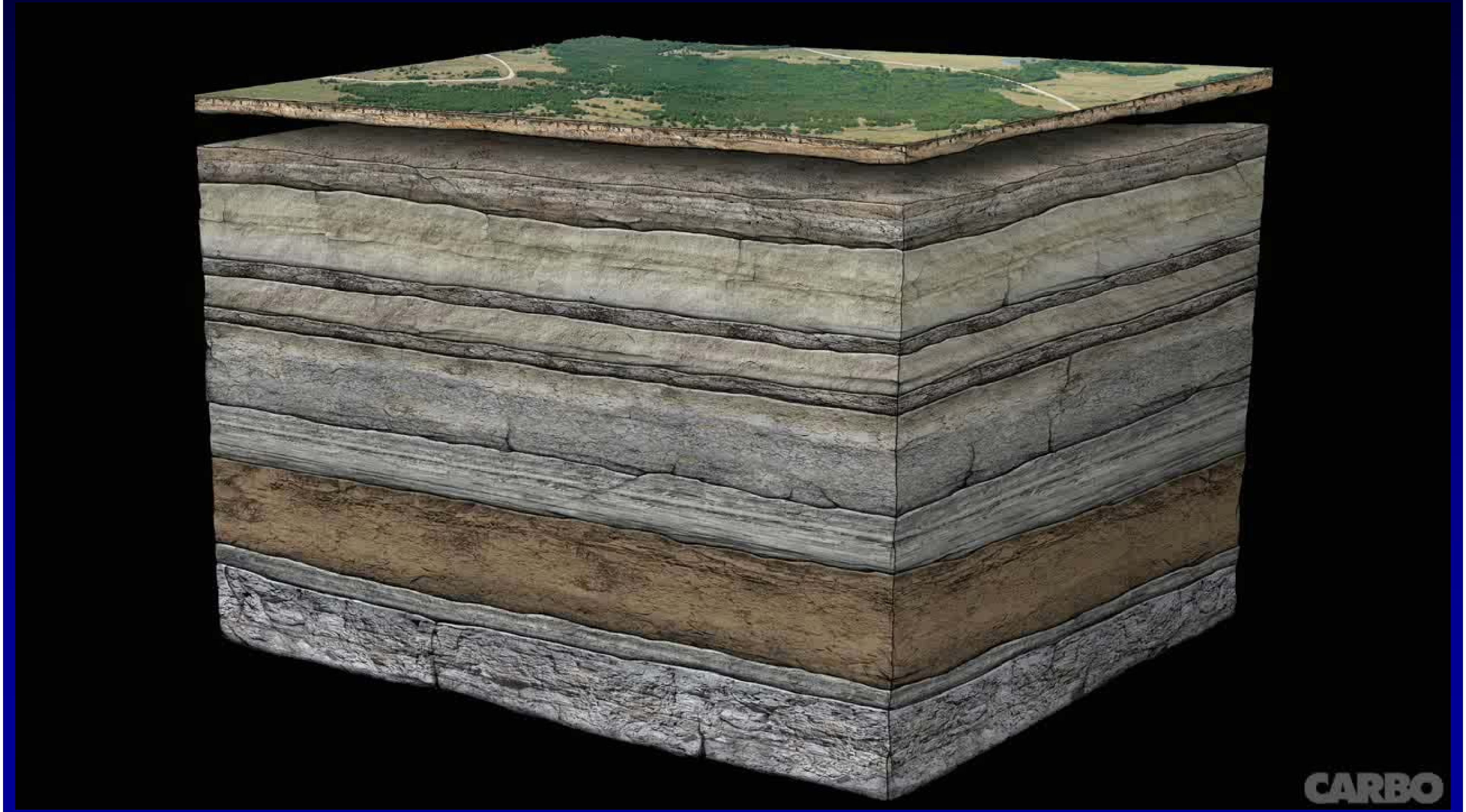

**Slopes of Fracturing Pressures and Their Interpretation**

| Type | Approximate log-log Slope Value | Interpretation |
|---|---|---|
| 1 | 1/8 to ¼ | Restricted Height and Unrestricted Extension |
| 2 | 0 | a) Height Growth<br>b) Fissure Opening |
| 3A | 1 | Restricted Extension (Two Active Wings) |
| 3B | 2 | Restricted Extension (One Active Wing) |
| 4 | Negative | Unrestricted Height Growth |

# Hydraulic Fracturing Diagnostics



# *Why has HF opened up the Unconventional Plays?*



# Which Formations are Hydraulically Fractured

- All formations!!! – Sandstone, Carbonates, Coal, Shales, etc.
- All permeabilities!! – low, medium and high
- As technologies have changed, many wells are now refractured/restimulated

# *Summary*

- Stimulation technology, techniques and operations are extremely leveraging
- Two reasons to Stimulate a well – overcome damage and increase effective WB radius
- Numerous stimulation technologies, but primary are Hydraulic Fracturing and Acidizing
- Hydraulic Fracturing has been the key to unlocking most of the unconventional plays
- Candidate selection and design are the key to successful stimulation treatments

# *Questions?*

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Carl Montgomery (COP)
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