SHAPED CHARGE PENETRATION INTO GAS SATURATED SANDSTONE

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Overview

- Introduction / Background
- Recent Experiments
- Conclusions & Future Work

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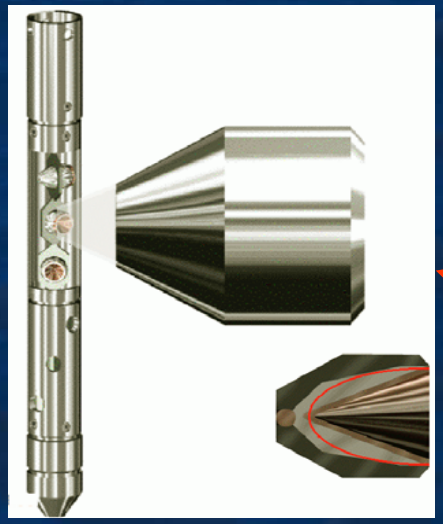
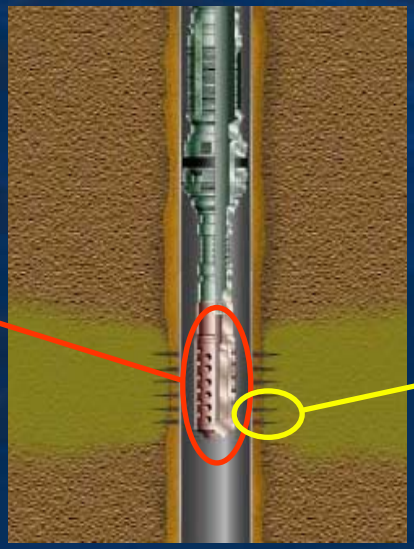
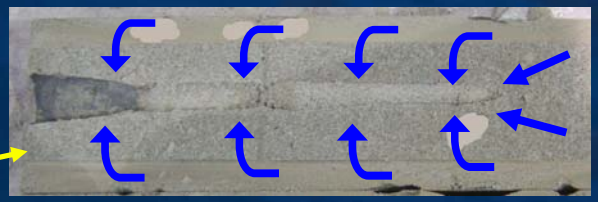
Introduction

- Oilwell perforators
  - small caliber shaped charges
  - create the pathway for oil or gas to flow from the reservoir rock into the wellbore
- Deep, clean perforations required for well productivity







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Introduction

- Reservoir properties influencing perforation depth:
  - Rock strength
  - In-situ stresses (overburden, tectonic)
  - Pore fluid pressure
  - Pore fluid type (liquid vs. gas)

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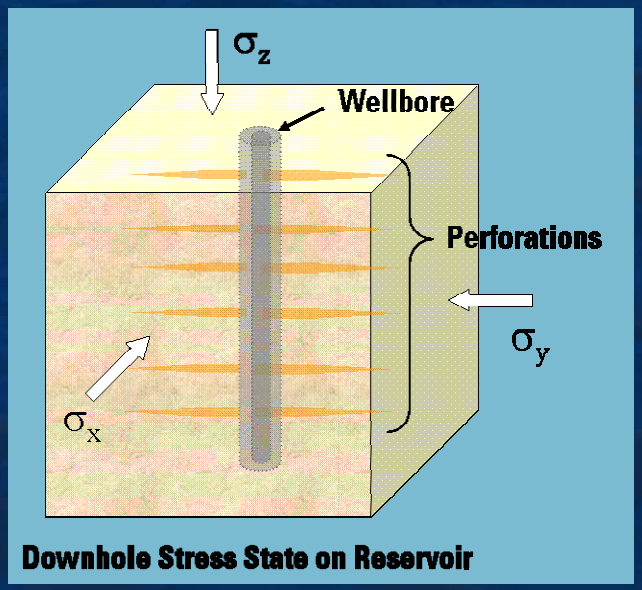
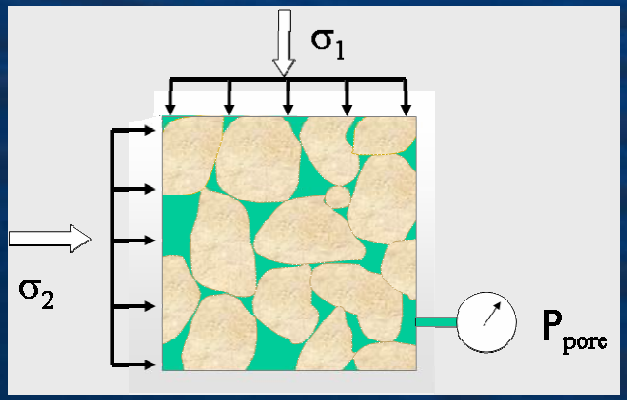
Background

- Geomechanics considerations:
  - In-situ stresses ("total" stress)
  - Pore fluid pressure

Effective stress

$$\sigma_{eff} = (\sigma_{mean} - a * P_p)$$





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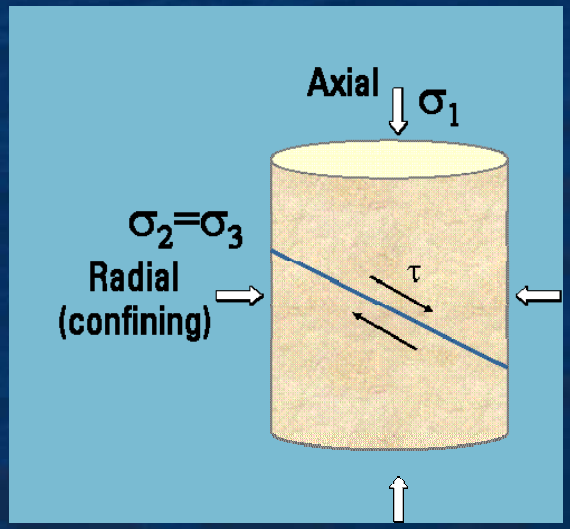
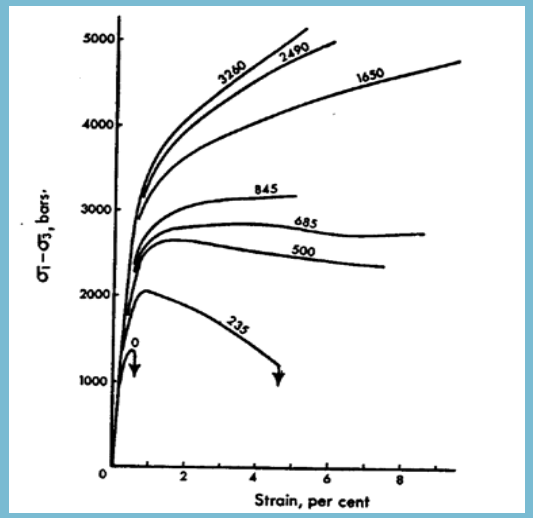
Background

- Why is in-situ stress important to SC penetration?
  - Rocks are stronger under increasing applied stress





$$\tau = f(\sigma_{mean})$$

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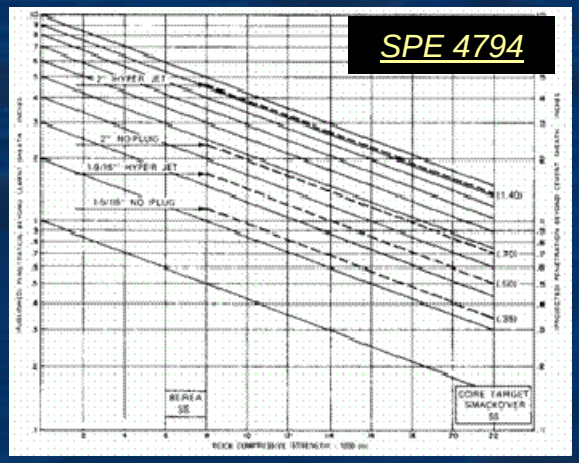
Background

a = "ballistic pore pressure coefficient"

Perforation depth depends on:

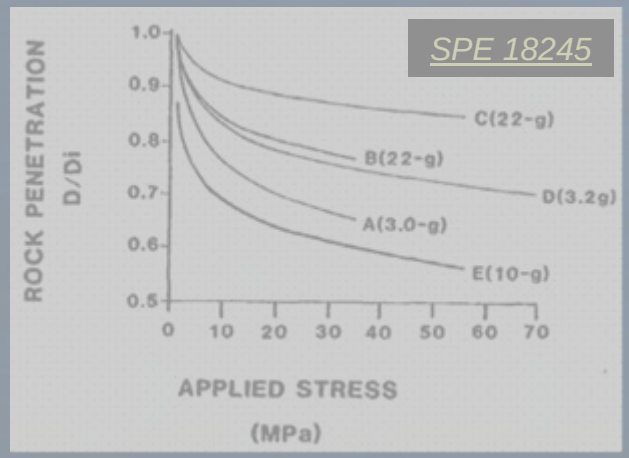
$$\sigma_{eff} = (\sigma_{mean} - a * P_p)$$

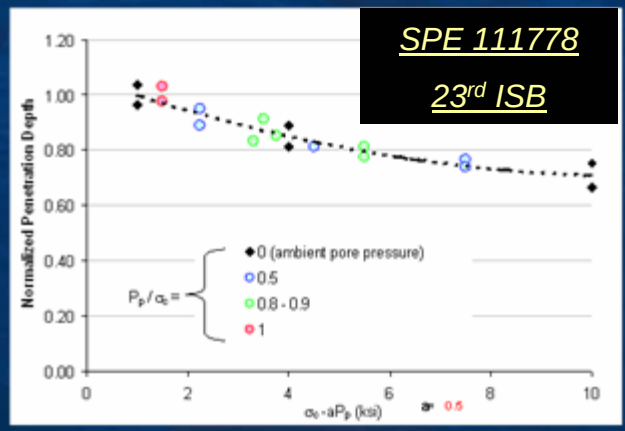
$$a \sim 0.5$$



Formation Strength (UCS)

$$\sigma_{eff} = (\sigma_{mean} - P_p)$$





Formation Effective Stress

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Background

- Historical and recent laboratory work consistently demonstrated that perforation depth decreases with…
  - increasing rock strength
  - increasing effective stress
- Recent laboratory work demonstrated
  - pore pressure's influence is less significant than previously thought (i.e. a<1)
  - a new definition of effective stress*

** for purposes of SC penetration depth*

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Background

- Motivation for current work
  - All previous laboratory work (especially into stressed targets) addressed liquid-filled rock
  - Reasonably valid for oil reservoirs, but not necessarily for gas reservoirs
- Focus on perforation depth; tunnel diameter is another variable not addressed here

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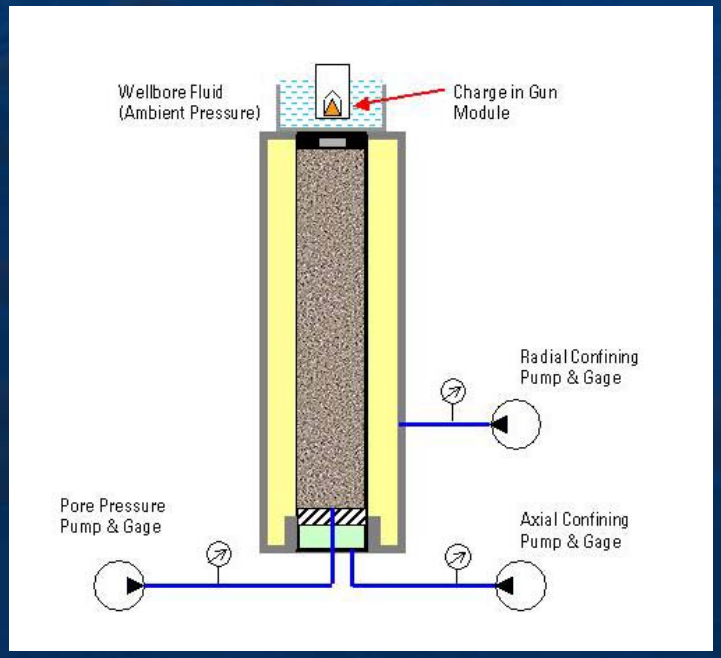
Current Work

- Penetration experiments into stressed rock targets
  - independent confining and pore pressures, up to 10,000 psi
  - simulates stress levels representative of depths up to 10,000'
  - does not mimic downhole temperature or wellbore fluid pressure
- Berea sandstone
- Pore fluid is dry N_2



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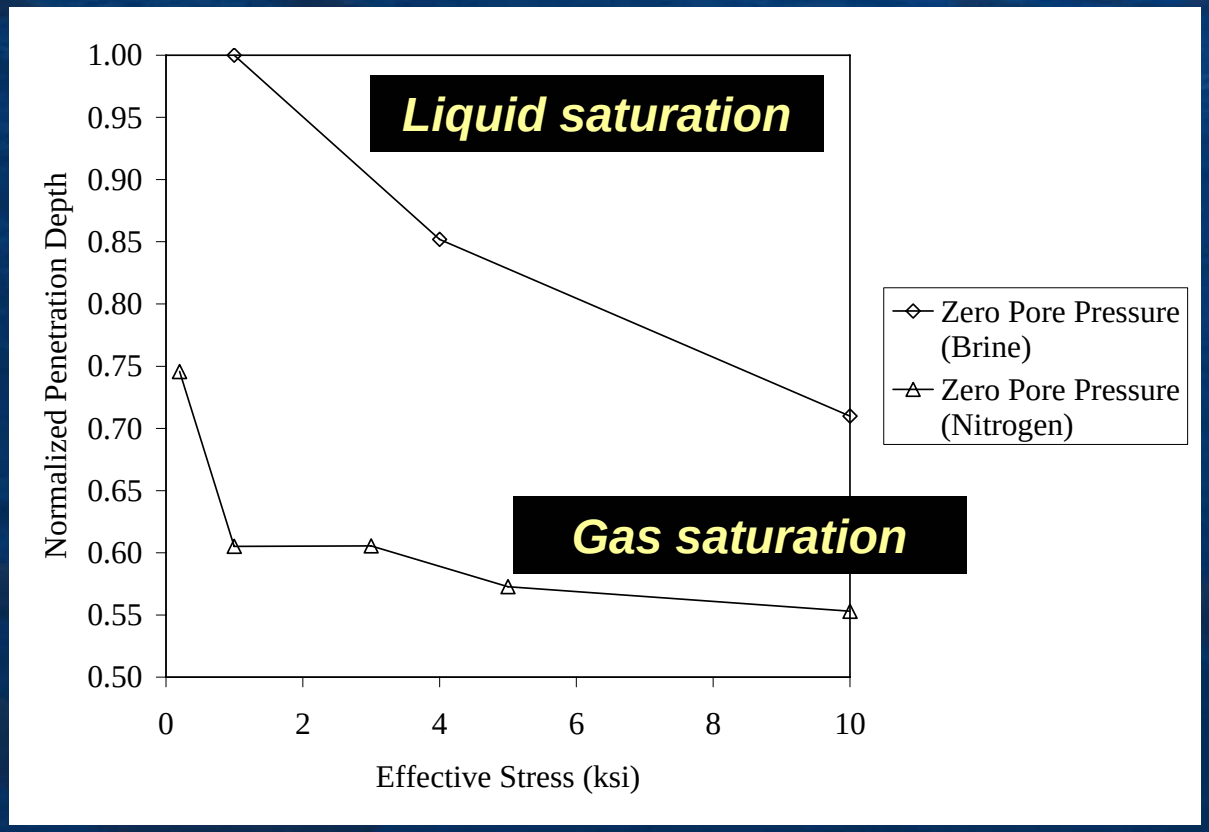
Results: Ambient Pore Pressure

- Perforation depth vs. confining stress
  - for both liquid- and gas-saturated sandstone



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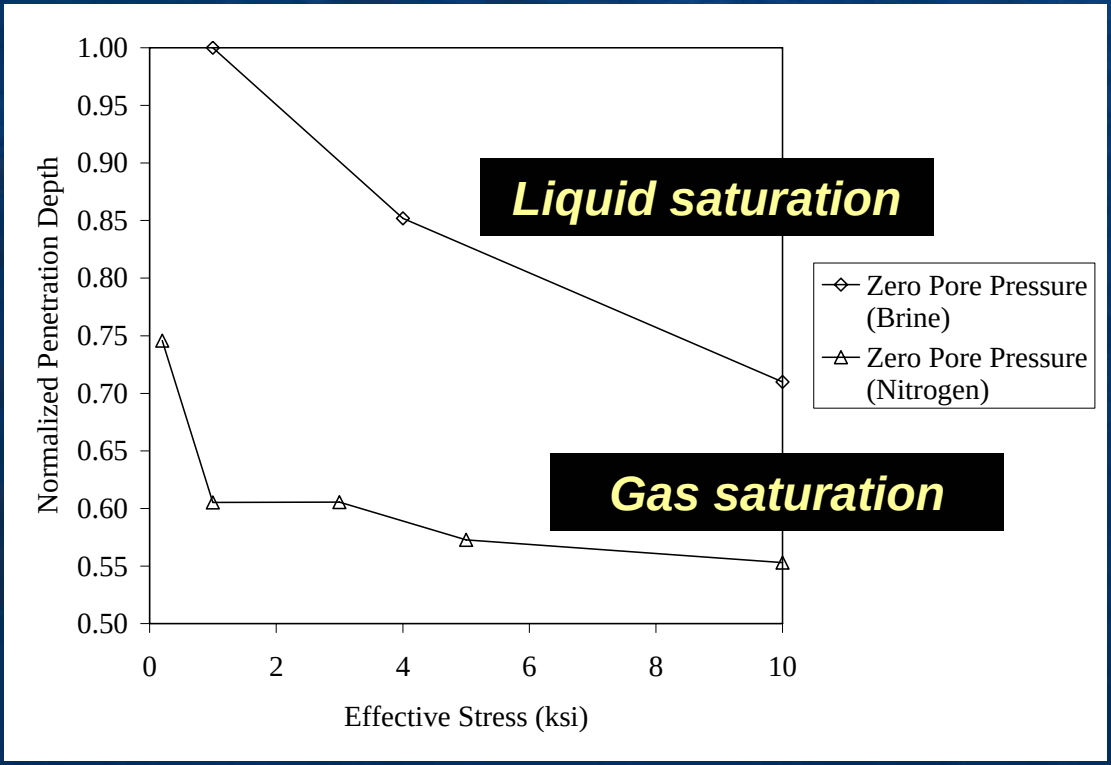
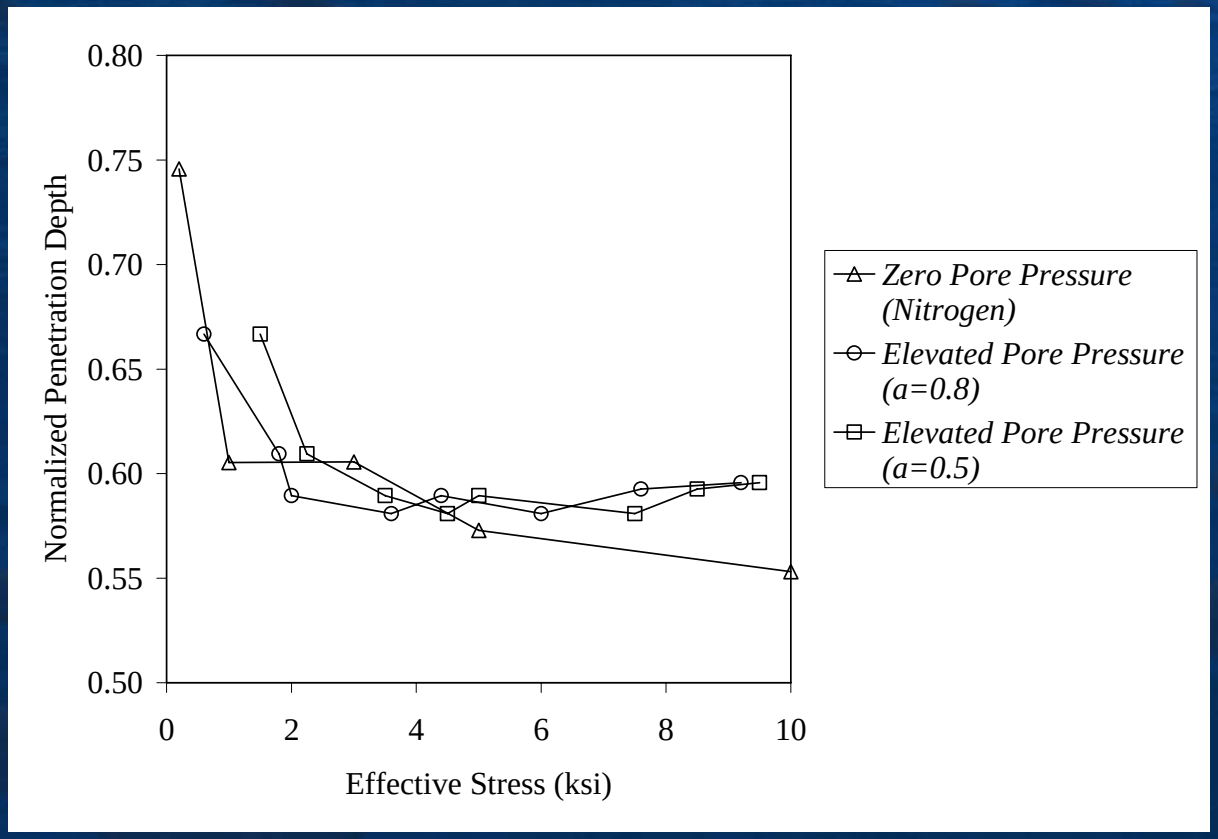
Results: Ambient Pore Pressure

- Two primary observations
  - PD significantly reduced in gas saturated target
  - Stress influence on PD
    - high for liquid
    - minimal for gas
      (above ~1 ksi)



Results: Elevated Pore Pressure

- Perforation depth vs. effective stress $\sigma_{eff} = (\sigma_{mean} - a * P_p)$
  - gas saturation only; both elevated and ambient pore pressure



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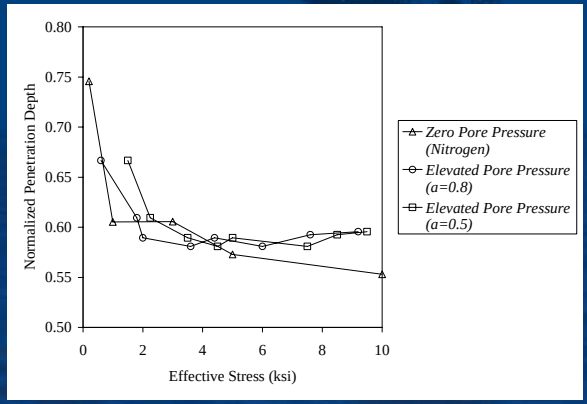
Results: Elevated Pore Pressure



- Primary observations
  - Pore pressure influence
    - For stress>2ksi, a=0.5 gives reasonable fit
    - For stress<2ksi, fit is improved with a=0.8
  - Strictly speaking, BPC is not a constant rock property, but *f(stress, pore fluid)*
  - For elevated pore pressure, penetration into gas saturated rock is even less stress dependant

Practically speaking, both stress and pore pressure may be irrelevant to perforation depth for dry gas saturated rock (above some threshold stress value)

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Summary

- Laboratory experiments were conducted
  - shaped charge penetration
  - dry nitrogen-saturated sandstone targets
  - stressed to simulate downhole conditions
- Results:
  - penetration depth into dry gas saturated sandstone is…
    - considerably shallower than into liquid-saturated sandstone
    - essentially independent of effective stress (above 2 ksi)
  - confining stress (and also pore pressure): only important at very low stress levels

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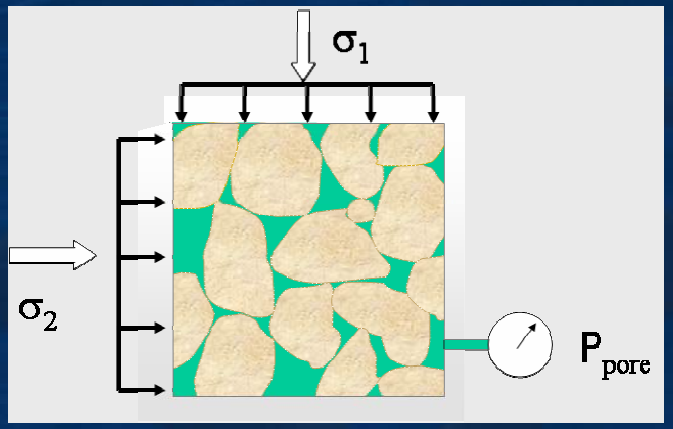
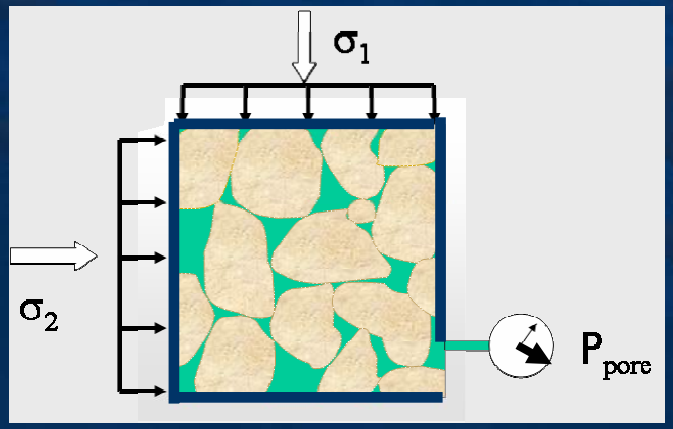
Possible Mechanisms

- reduced penetration depth
  - dry sandstone is stronger than brine-saturated (surface tension and cementation weakening)
  - energy absorption of pore collapse in target
  - “active target” effect (Aseltine, 1985)
- stress independence
  - shallow penetration = high jet cutoff velocity ~ hydrodynamic penetration
  - for liquid saturation, rapid “undrained” loading may limit the increase in the target’s “dynamic effective stress” (and, therefore, strength)



drained



Undrained, or rapid loading

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Future Work

- Future Work
  - Understand the mechanisms responsible for these fundamental differences in ballistic response of liquid and gas saturated sandstones
  - Design of shaped charges optimized for gas saturated reservoirs

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Thank You

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