Enhanced Compaction of Porous Sandstone Deformed Under High Confining and Pore Fluid Pressures

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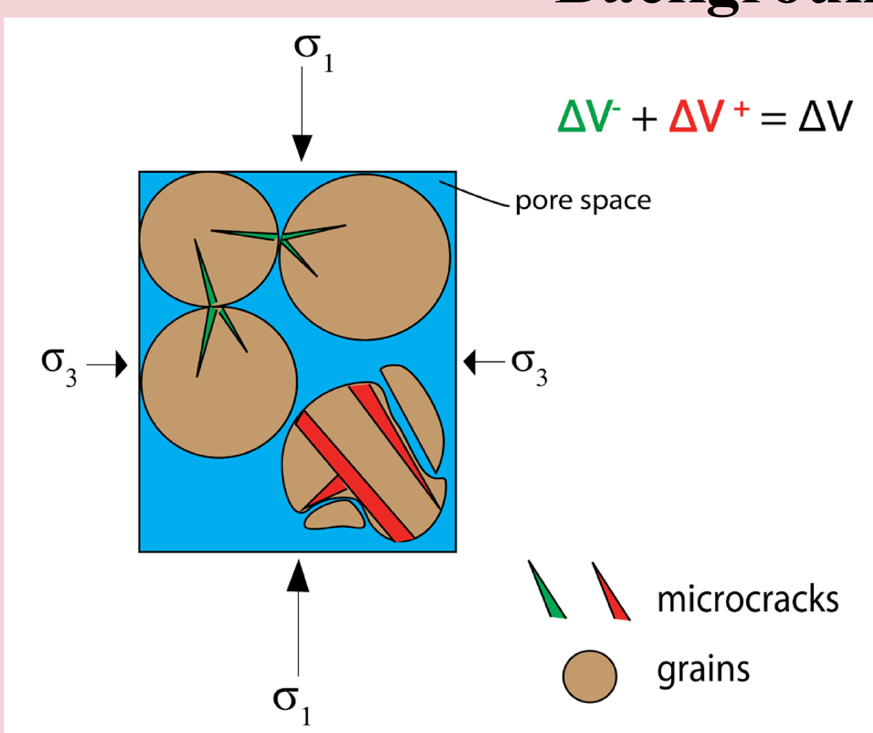
Introduction: Sandstone reservoirs have important uses for oil and gas deposits, carbon sequestration, waste disposal, and other fluid related extracation or injection. Therefore, the deformation of sandstone is necessary to use these reservoirs effectively. These sandstones are often fluid-saturated and under upper-crustal pressures, which can be achieved in a laboratory setting with confining and pore fluid pressures. Deformation of porous sandstones results in dilatant and compactant behavior, changing the volume of the sample and available pore space. Understanding the mechanisms that lead to volume change is vital for sandstone reservoir quality.

Background



Brittle deformation

- Dilatancy (ΔV^-)
  - microcracks
- Compaction (ΔV^+)
  - pore collapse
  - grain crushing

Variables

σ_{eff}: effective stress
σ_n: normal stress
P_{dif}: differential pressure
P_f: pore fluid pressure
P_c: confining pressure
ΔV: change in volume
Vt: total volume
εv: volumetric strain
Δσ: differential stress
σ1, σ3: principal stresses

- Effective stress law models inelastic behavior during deformation:

$$\sigma_{eff} = \sigma_n - P_f$$

- Differential pressure during experiment relates to effective stress:

$$P_{dif} = P_c - P_f$$

Hypotheses

Null hypothesis

Varying pore fluid pressure at constant P_{dif} **has no effect** on effective stress law behavior during deformation

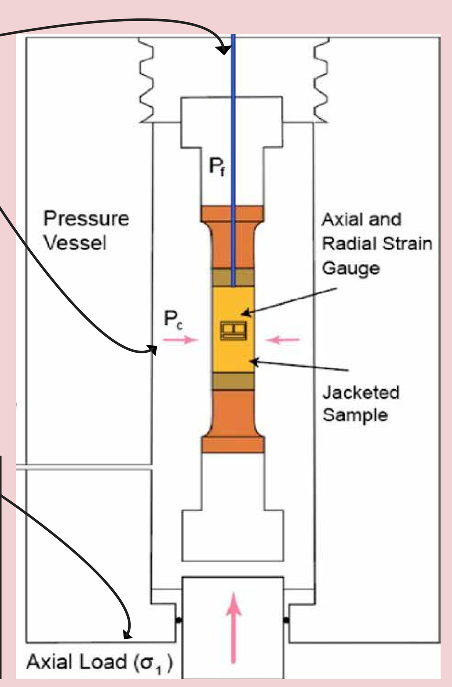
Alternative hypothesis

Varying pore fluid pressure at constant P_{dif} **has an effect** (e.g. enhanced compaction) on effective stress law behavior during deformation

Methods

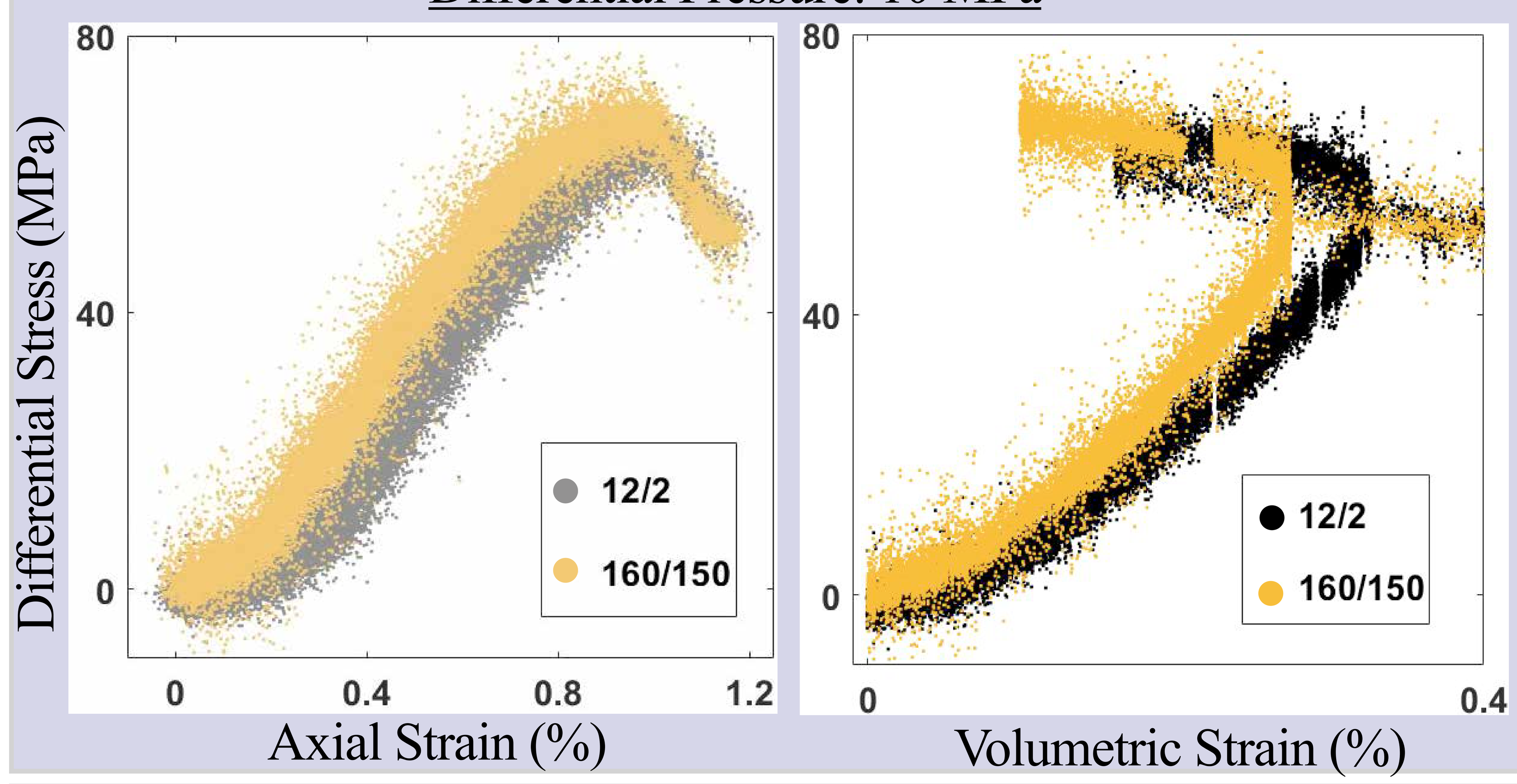
P_c and P_f set for constant P_{dif}

axial load (σ1) increased to deform sample

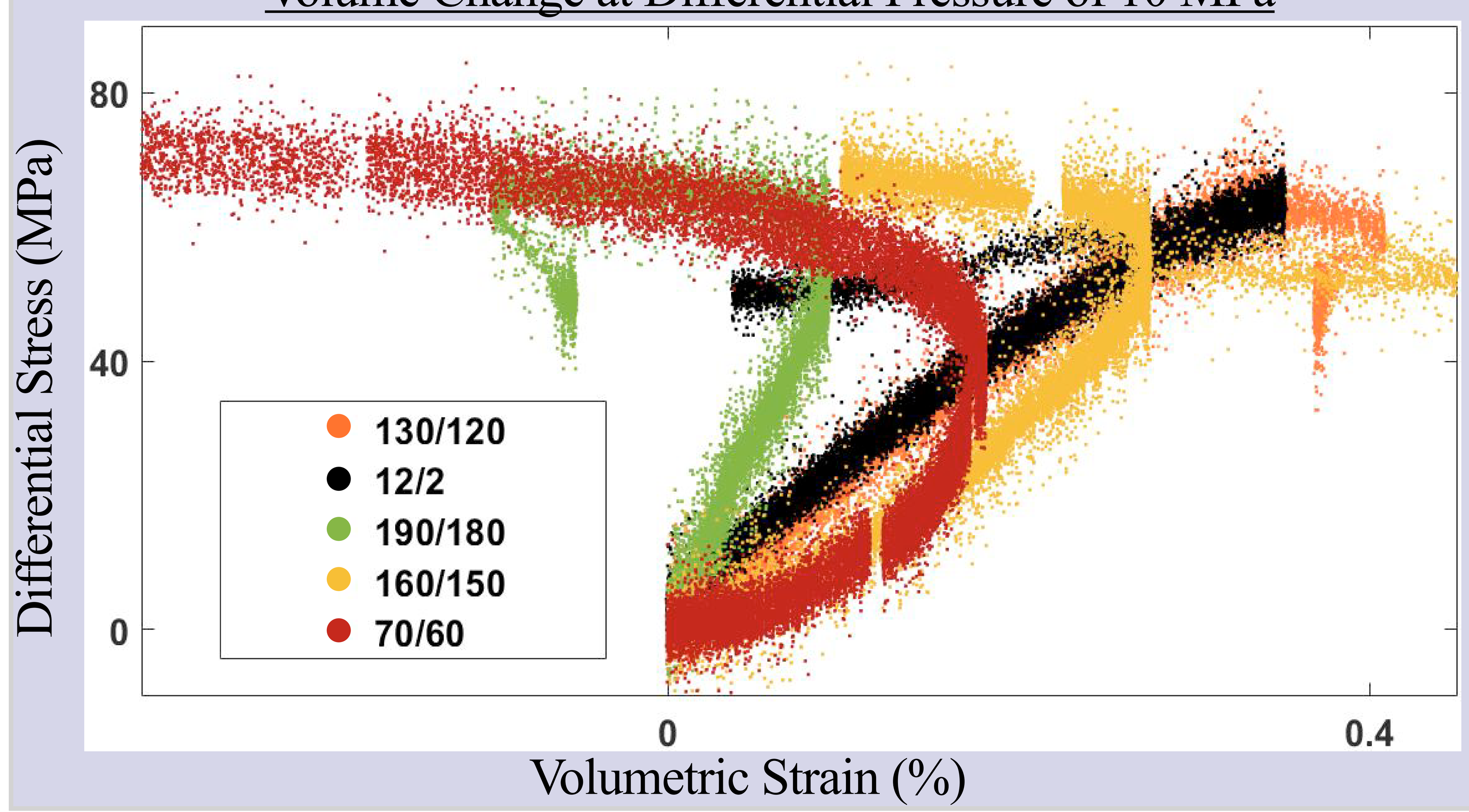


Axial deformation strain rate: 10^{-6} s^{-1}

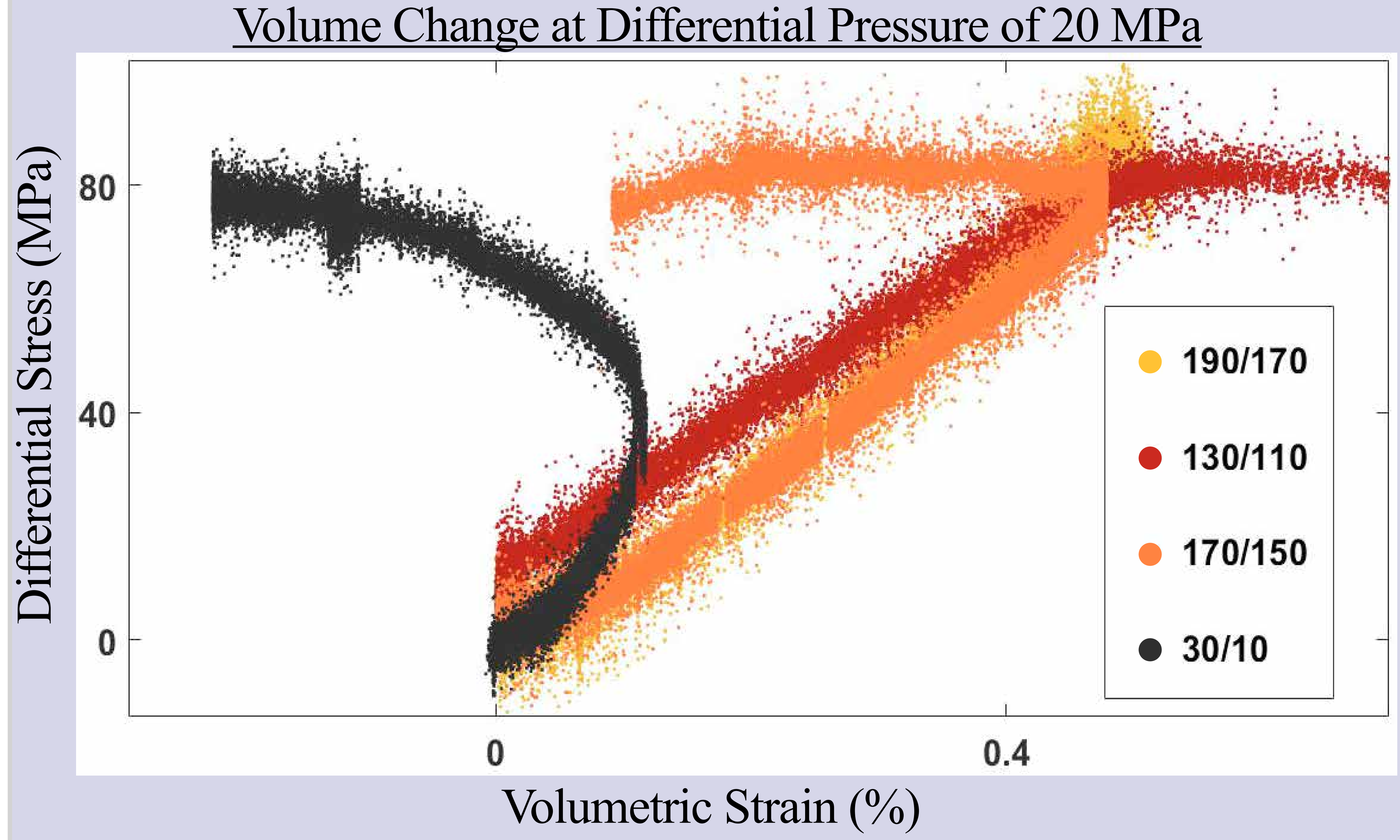
Differential Pressure: 10 MPa



Volume Change at Differential Pressure of 10 MPa



Volume Change at Differential Pressure of 20 MPa



Results

- Volumetric and axial strain plots for experiments performed at differential pressures of 10 and 20 MPa
- **Enhanced compaction** of high pore fluid pressure experiments at P_{dif} **= 20 MPa**
- More damage in low pore fluid pressure microstructure than high pore fluid pressure

Graph axes

Volumetric strain: εv = ΔV/Vt

Axial strain*: εx = ΔL/L
*measured via LVDT

Differential stress: Δσ = σ1 - σ3

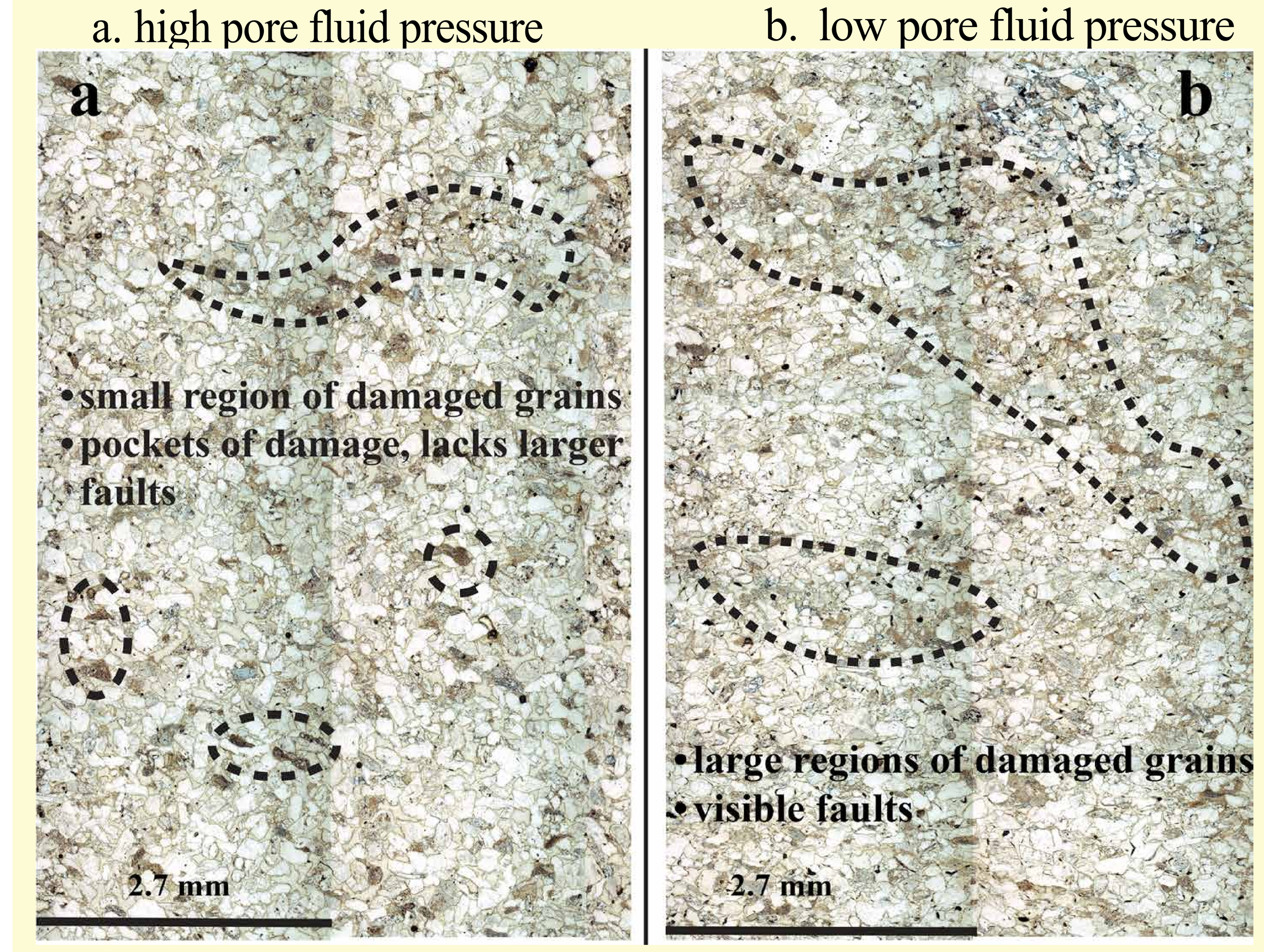
Experiment #	Pc (MPa)	Pf (MPa)	Differential Pressure (MPa)	Initial porosity (%)
H167-A7b	130	120	10	--
H168-A8b	12	2	10	25
H169-A2a	190	180	10	25
H171-A3a	190	180	10	26
H172-A4a	190	180	10	24
H173-A5a	12	2	10	24
H174-A6a	160	150	10	24
H175-A7a	70	60	10	24
H177-A9a	130	120	10	24
H179-A11a	40	10	30	24
H180-A12a	30	10	20	24
H181-A14a	190	170	20	25
H182-A15a	130	110	20	24
H183-A16a	130	110	20	25
H184-A17a	170	150	20	24
H185-A18a	30	10	20	23
H186-A19a	30	10	20	23

thin section sample

reproducible experiments

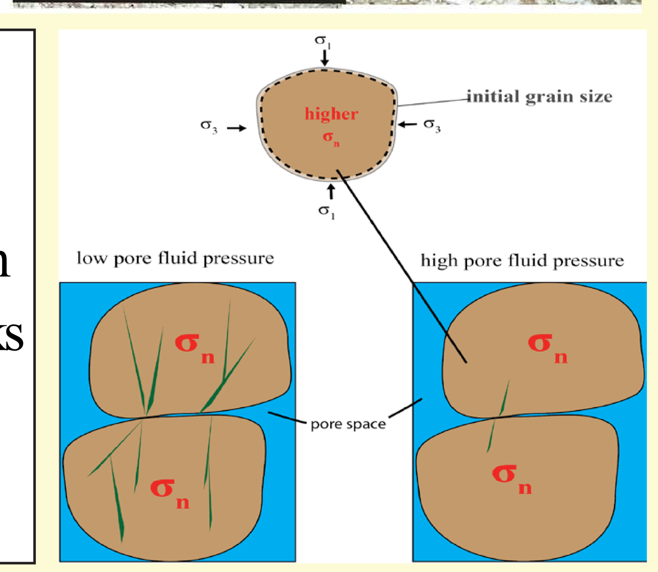
Discussion

a. high pore fluid pressure b. low pore fluid pressure



Understanding:

- High P_c and P_f could increase normal stress within the grain
  - harder to nucleate microcracks than at low P_c and P_f



Implications

- Sandstone reservoir quality depends on permeability of sandstone
- Permeability and fluid flow is affected by compaction
  - enhanced compaction is important for extraction

Conclusions

- Enhanced compaction at P_{dif} of 20 MPa
- P_{dif} of 10 MPa followed behavior expected by effective stress law
- Microstructures for high pore fluid pressure show less damage throughout sample
  - result of higher normal stress within grain due to higher confining pressures

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