The Role of Fluid Chemistry, Pressure, and Temperature on Deformation Microstructures in Limestone

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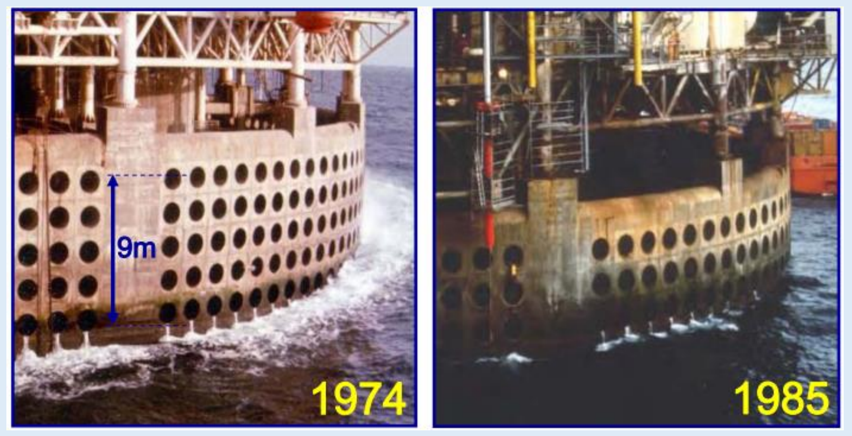
Senior Thesis Geology 394

Introduction

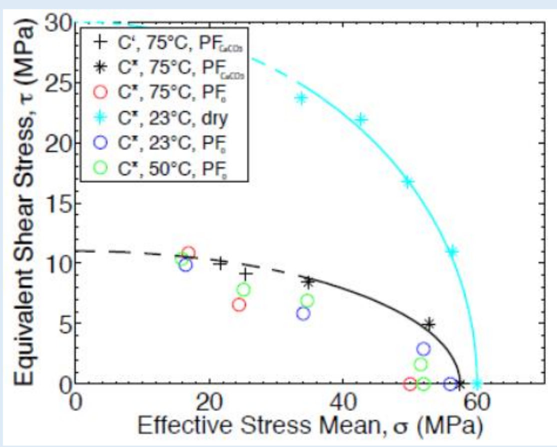


Sindre Sorensen (2011)

Interstitial pore fluids have been shown to influence yield strength and deformation processes in porous rocks. Calcium carbonate rocks in particular are strongly influenced by pore fluid, due to the high solubility of calcite. Weakening in these rocks due to pore fluid can lead to increased compaction and deformation, as seen at the Ekofisk oil field. Introduction of water into a chalk layer caused increased compaction, leading to dramatic subsidence of the oil platform. A better understanding is needed of how pore fluid exerts control on deformation processes in these rocks.

Background

A recent study by Lisabeth and Zhu (2015) concluded yield strength in Indiana Limestone can be reduced up to 60% in the presence of pore fluid. Coupling of mechanical and chemical loads may influence deformation microstructures within these rocks.



Lisabeth and Zhu (2015)

Hypotheses

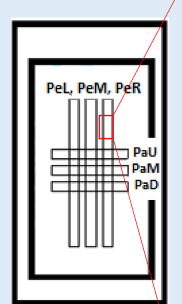
(1) Fluid chemistry does affect the deformation microstructures in limestones.

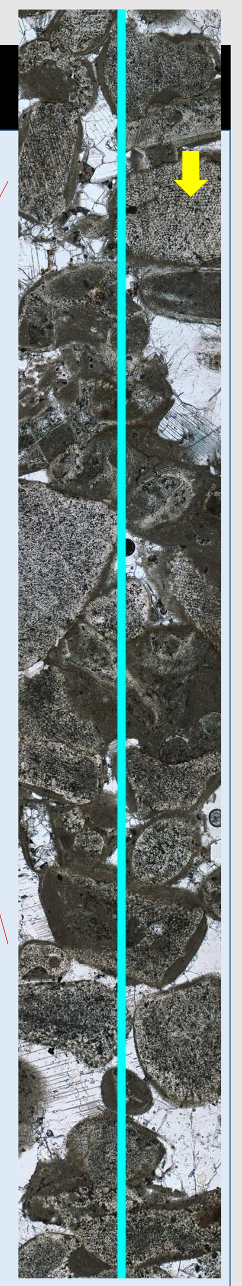
(2) Fluid chemistry will affect the intensity of twinning.

(3) Coupling of mechanical and chemical loads will enhance dissolution.

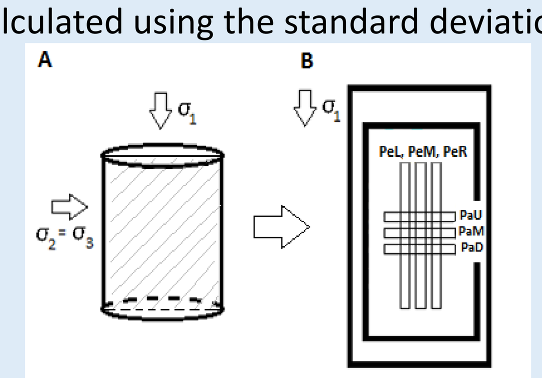
Methods

Sample Name	Fluid	Temperature °C	Pressure MPa
IndLs3-8	PF_0	75	10
IndLs3-17	PF_0	75	50
IndLs5-3	PF_{CaCO_3}	75	10
IndLs5-8	PF_{CaCO_3}	75	50

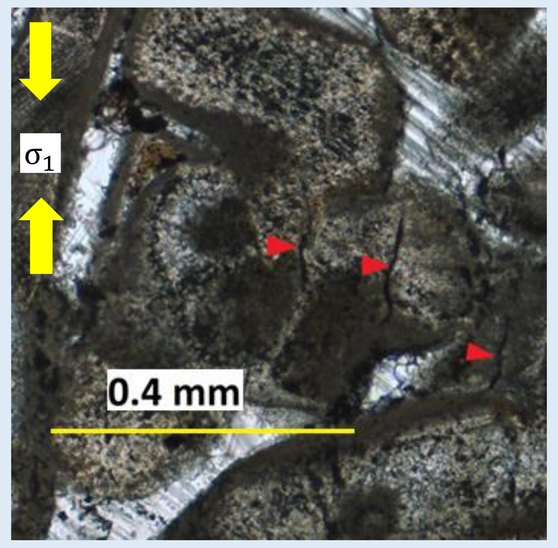




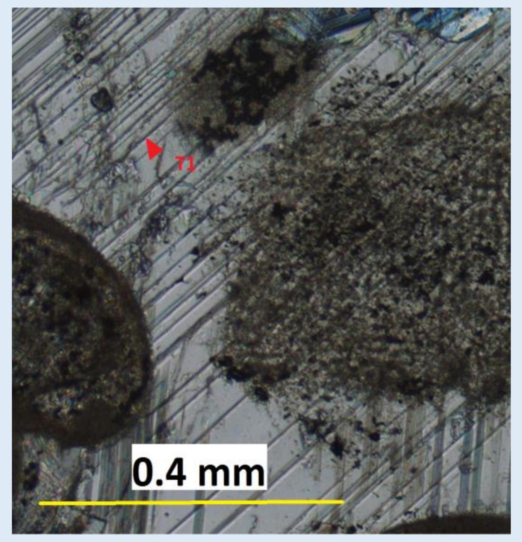
- Thin sections of triaxially deformed Indiana Limestone samples deformed over a range of temperature, pressure, and fluid chemistry conditions (Lisabeth and Zhu, 2015)
- Measurements of microcrack density, calcite twin density, and indentation density performed using linear density analyses.
- 5 linear density analyses performed both parallel and perpendicular to σ_1 on 5 thin sections
- Uncertainty calculated using the standard deviation of the mean



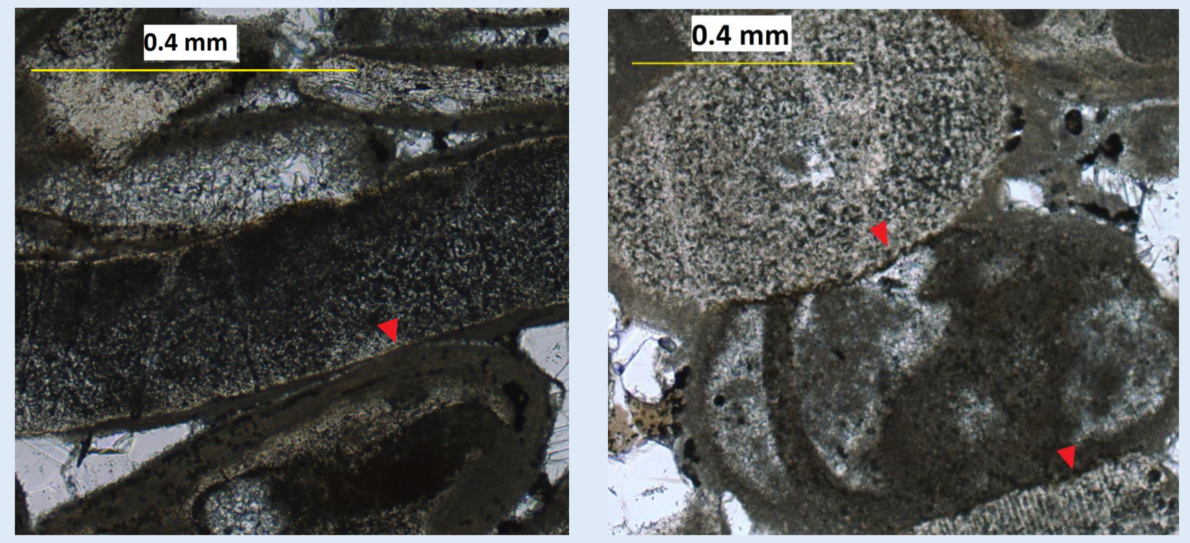
Microcracks



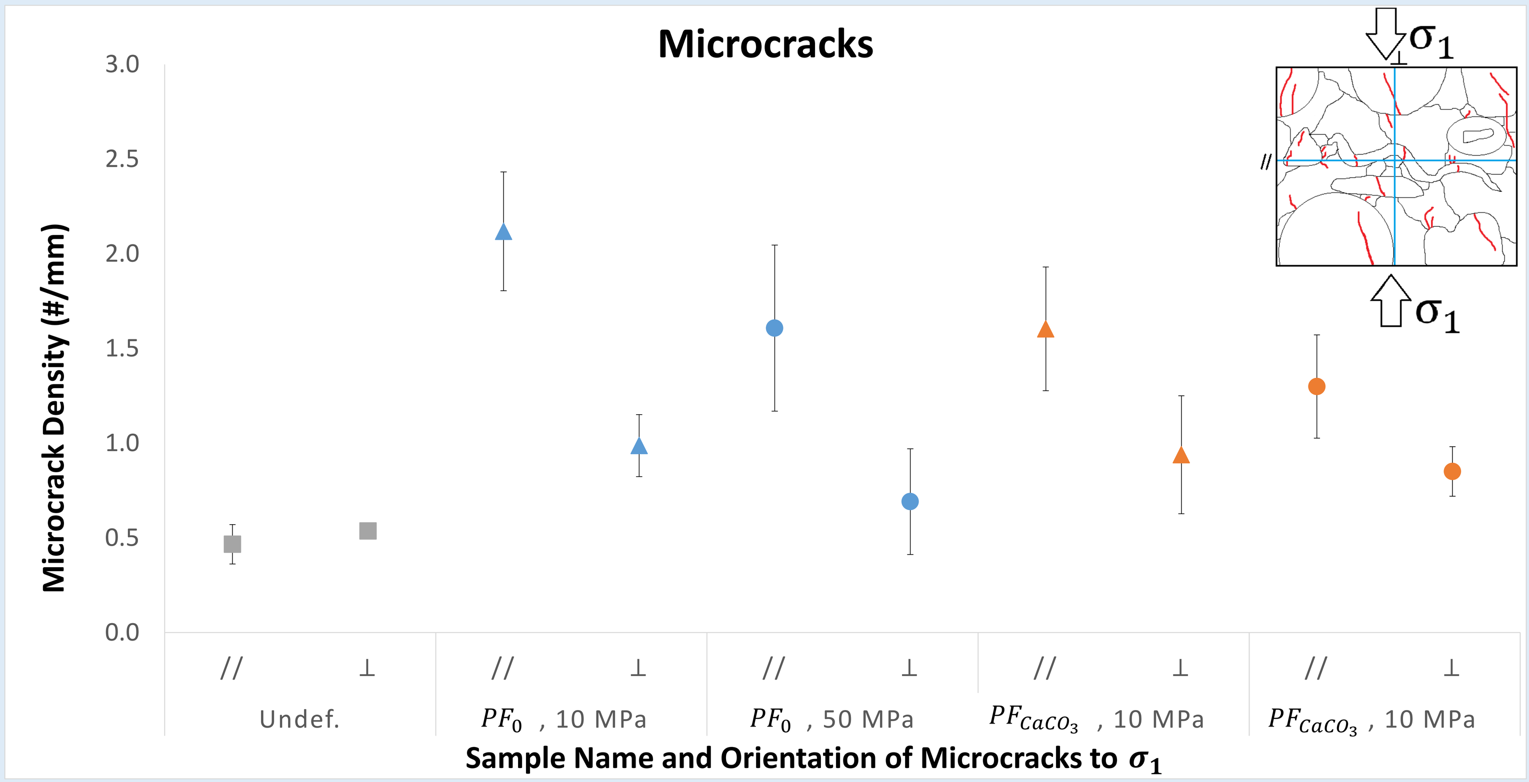
Calcite Twins



Indentations



Results

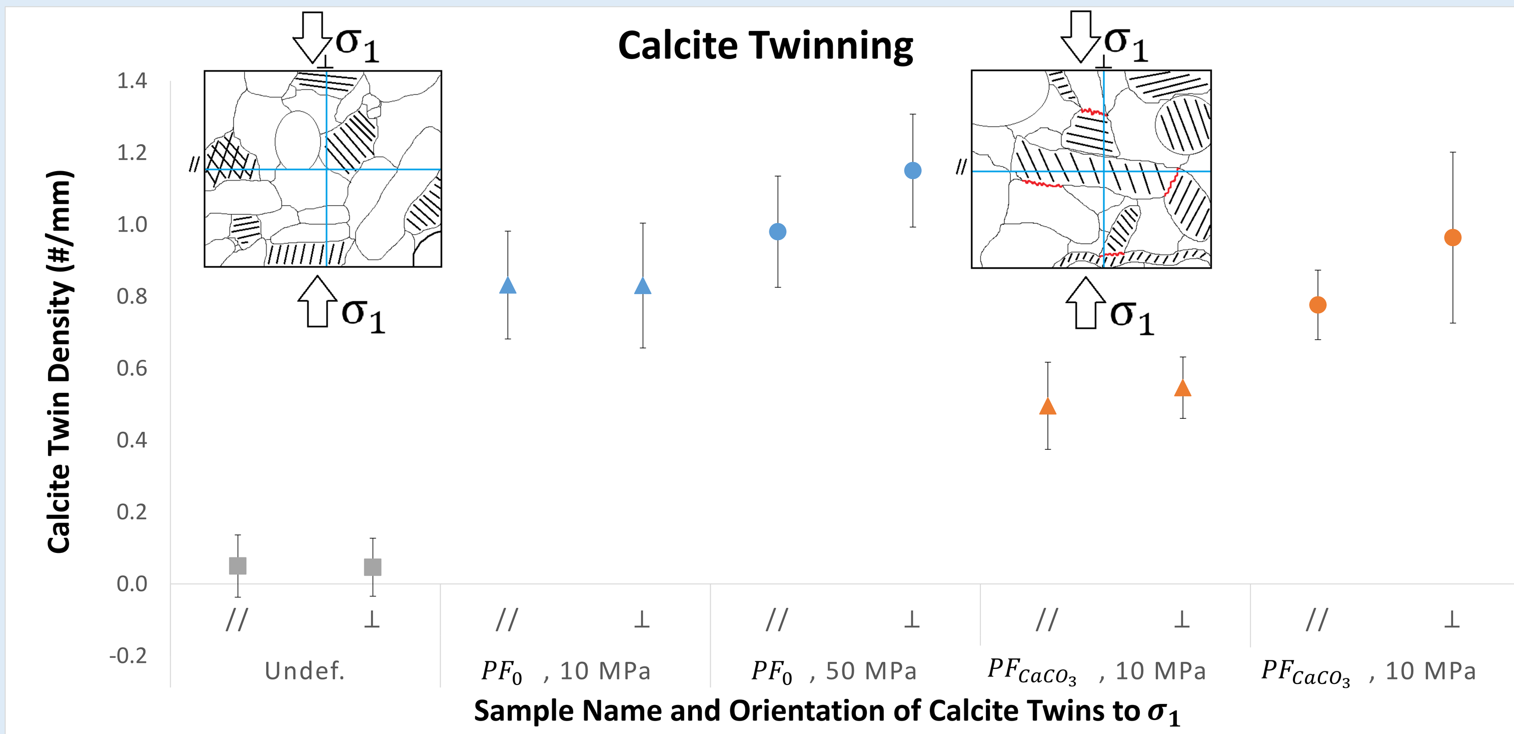


Legend

- ▲/● - PF_0 at 10 MPa/50MPa
- ▲/● - PF_{CaCO_3} at 10 MPa/50 MPa
- ■ - Undeformed
- * All samples deformed at 75°C

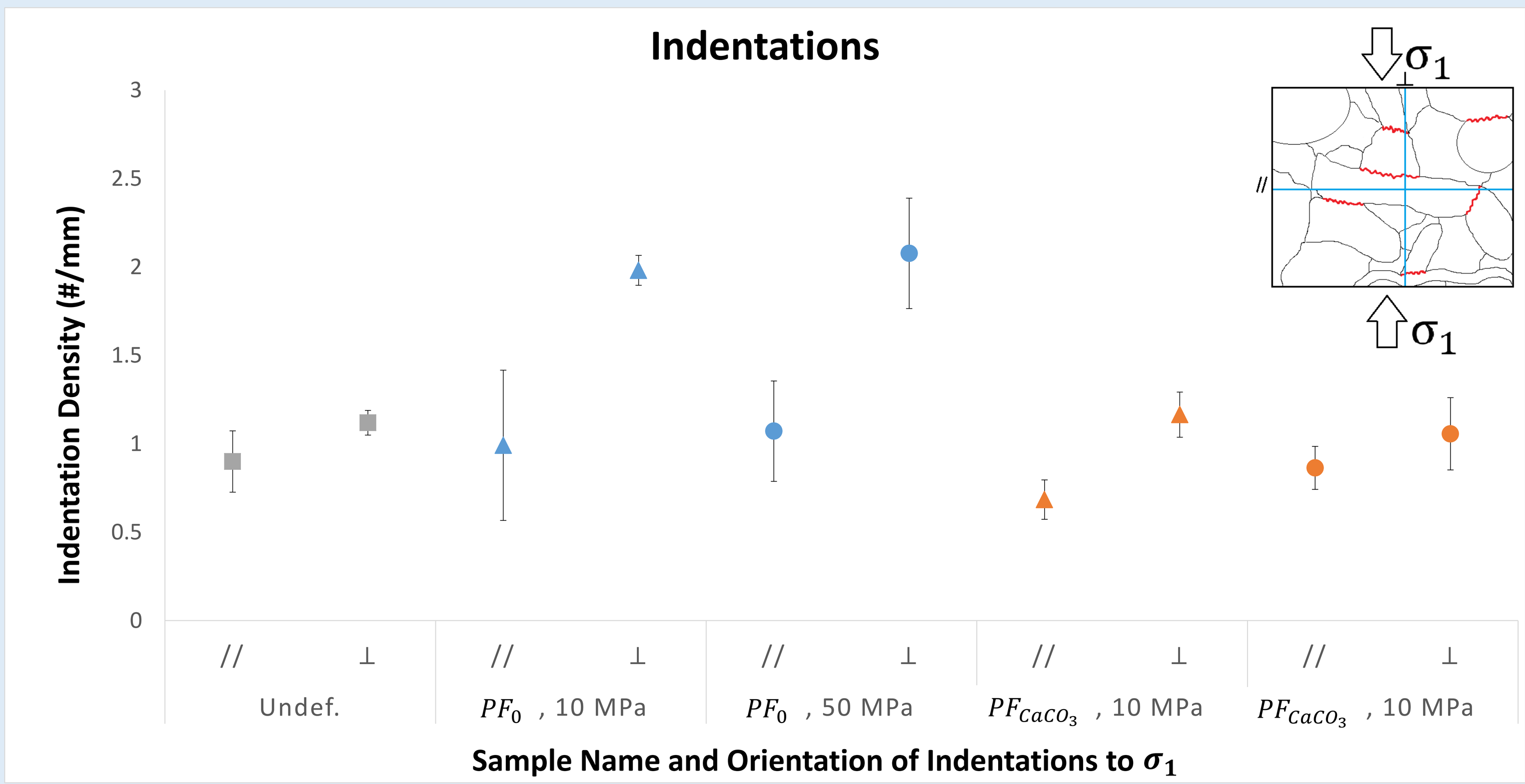
Graph 1

- Greater density of microcracks // to σ_1
- Microcrack density is greater in PF_0 than in PF_{CaCO_3} samples
- Microcrack density is greater at lower pressure (10 MPa) than at higher pressure (50 Mpa)



Graph 2

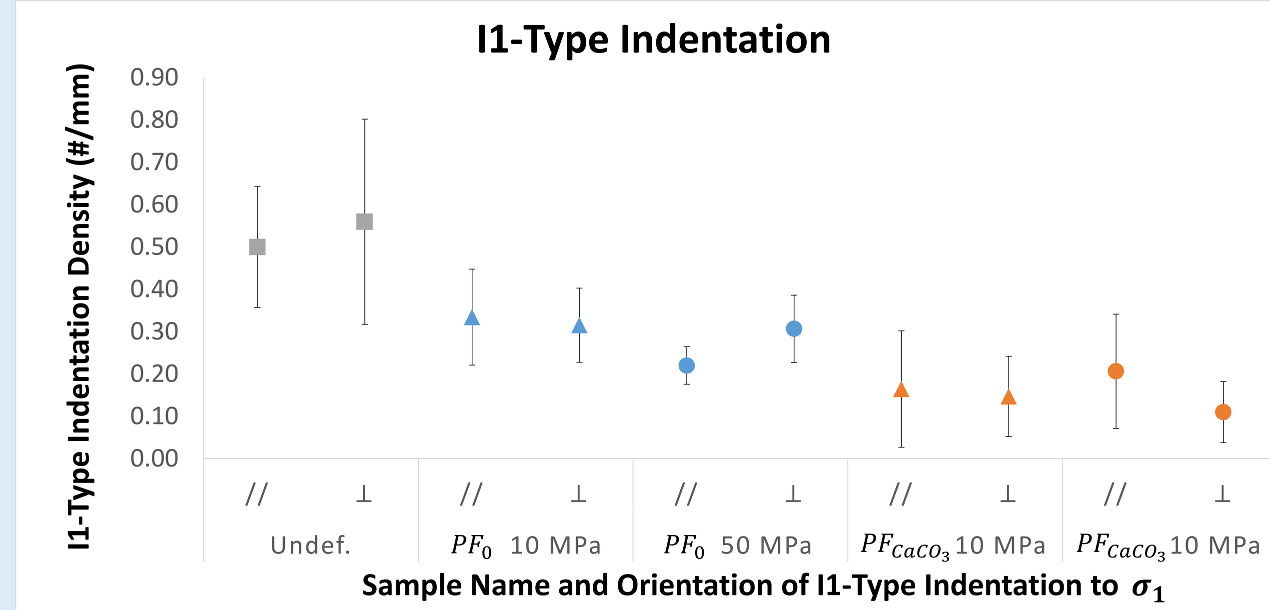
- Calcite twin density is equal at low pressure, but exhibits greater density ⊥ to σ_1 at high pressure
- Calcite twin density is greater in PF_0 than in PF_{CaCO_3} samples
- Calcite twin density is greater at higher pressure than at lower pressure

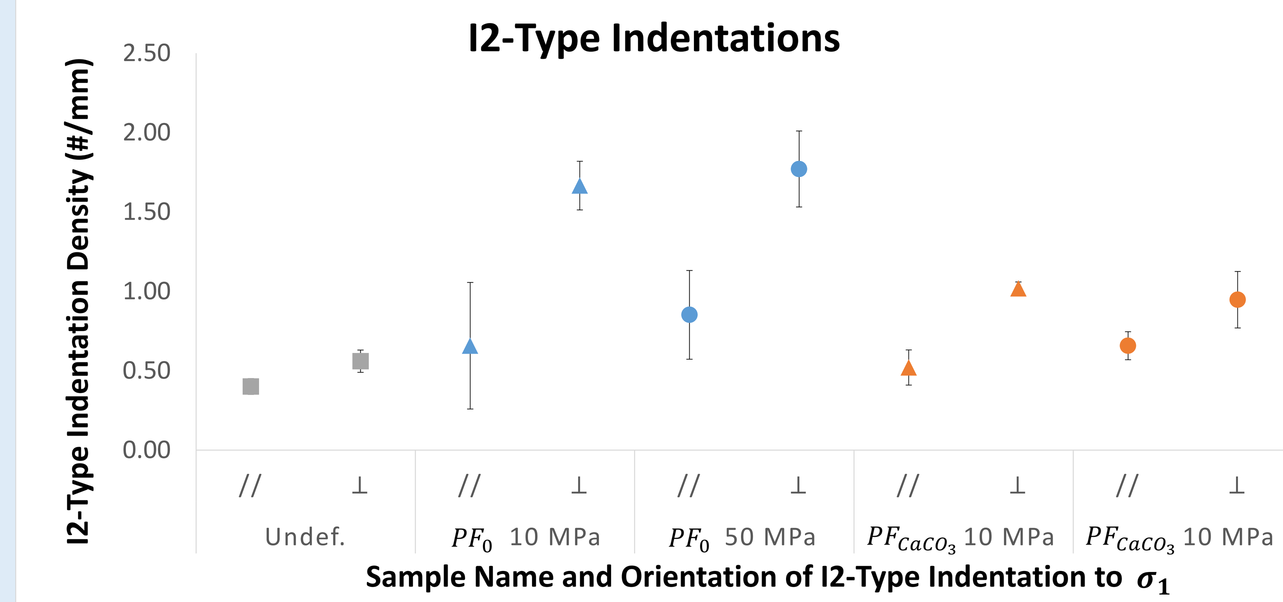


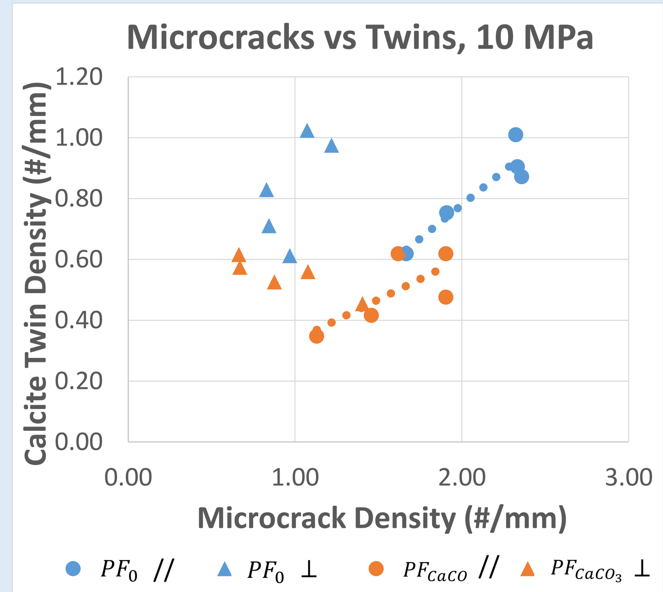
Graph 3

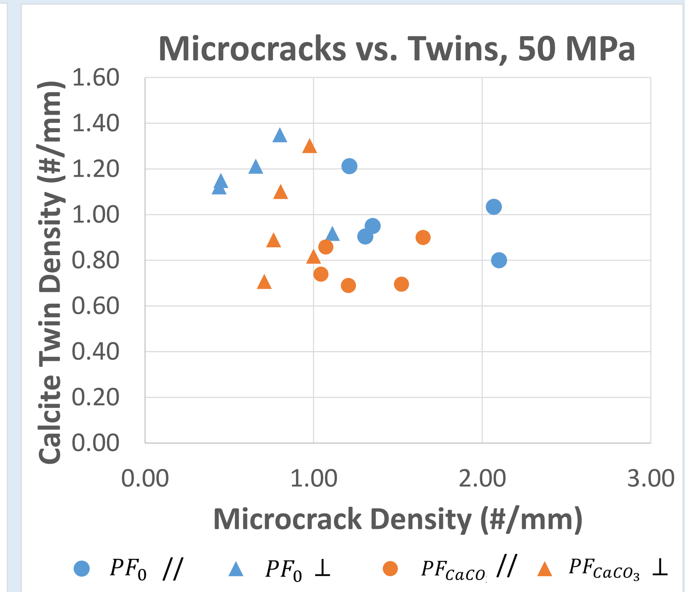
- Greater density of indentations ⊥ to σ_1
- Indentation density // to σ_1 in deformed samples is similar to indentation density in undeformed sample
- Indentation density is greater in PF_0 than in PF_{CaCO_3} samples
- Indentation density is similar for low and high pressure samples

Results Cont.









Conclusions

1. **There are clear differences between samples deformed with different pore fluids. Samples saturated with distilled water (PF_0) exhibit a greater density of microcracks, calcite twins, and indentations compared to samples saturated with fluid equilibrated with the rock (PF_{CaCO_3}). PF_0 samples may experience enhanced solubility due to continuous dissolution, leading to the increased formation of deformation microstructures.**
2. **Samples deformed at higher pressure (50 MPa) have less microcracks and more calcite twins than samples deformed at lower pressure (10 MPa), indicating a transition from brittle to ductile deformation with increasing pressure.**
3. **At low pressure (10 MPa) coupled formation of calcite twins and microcracks may occur. Corrosion may help initiate calcite twin formation. These twins can lower the local stress required for microcrack formation, leading to coupled formation. High pressure (50 MPa) may inhibit coupled calcite twin and microcrack formation.**
4. **No change in indentation density was observed with increasing pressure.**

References

Lisabeth, H.P., Zhu, W. (2015) Effect of temperature and pore fluid on the strength of porous limestone. *American Geophysical Union*, doi: 10.1002/2015JB012152