Towards image-based compaction forecasting: Comparison between laboratory experiments and X-ray CT images

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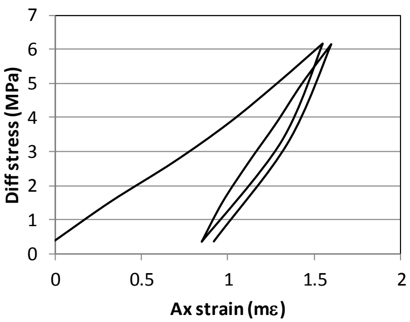
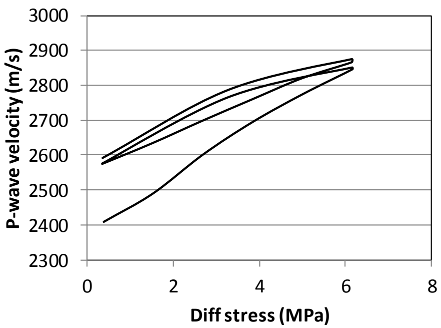
Outline

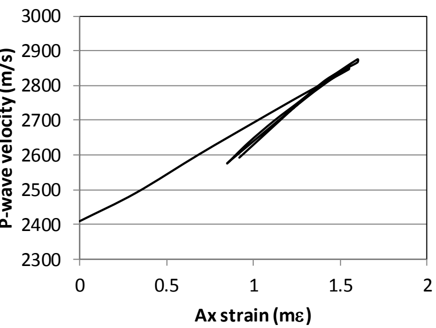
- Introduction
- Description of the study
- Testing apparatus and methods
- Tests results
- Image analysis
- Summary

Introduction

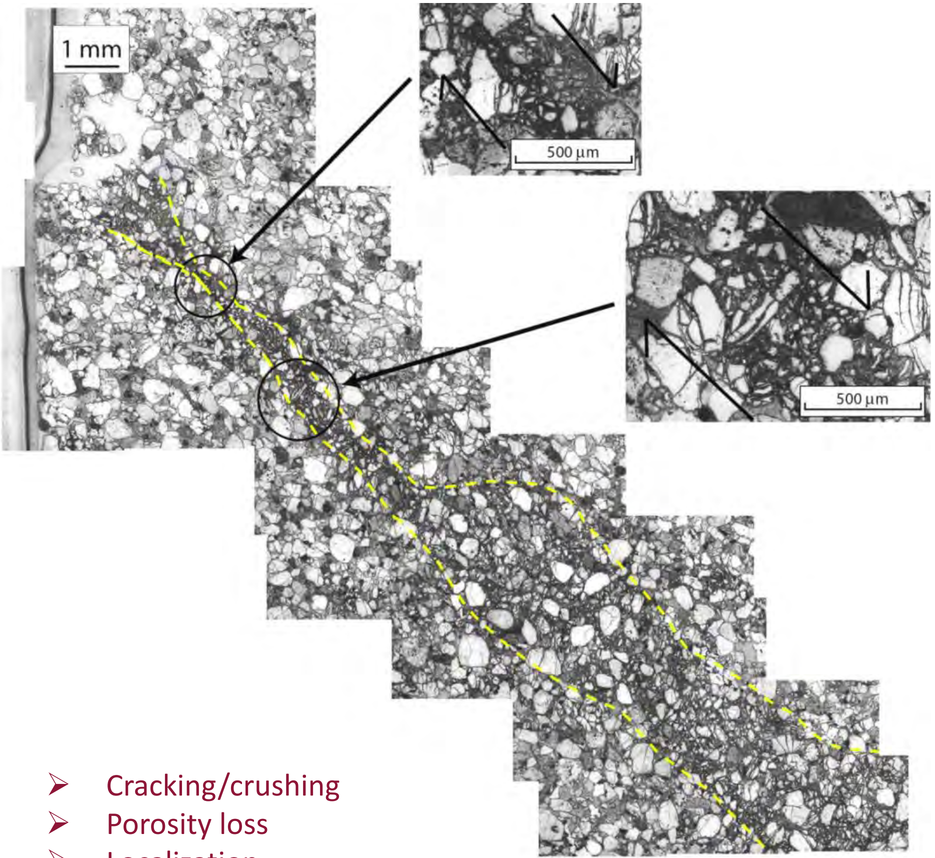
DRP as applied to rock mechanics







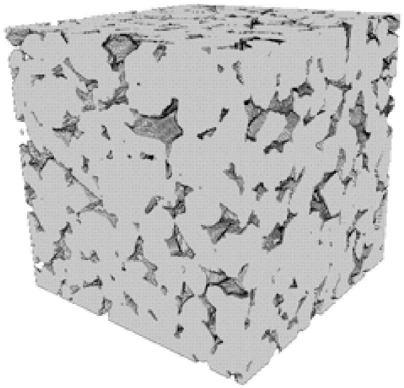
- ➢ Non linear response
- ➢ Hysteresis
- ➢ Significance?
- ➢ Stat/Dyn transform
- ➢ Behavior at grain contacts
- ➢ …



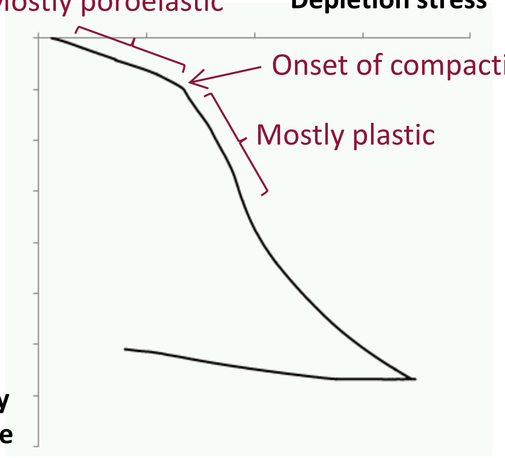
- ➢ Cracking/crushing
- ➢ Porosity loss
- ➢ Localization
- ➢ Transport (compaction & fines)
- ➢ Effect on wave propagation (4D)

Introduction

Compaction



?



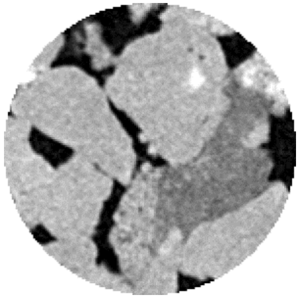
A set of measurable parameters ⟷ A model

- What constitutive law? exp, log, power, erf, elastoplastic, ..?
- Domains potentially impacted: Geomechanical forecasting, PP prediction, basin modeling, reservoir quality, ..
- Most complex for DRP right now (brittle behavior at contacts, resolution, large strains, ..)
- Can we leverage the CT data in the mean time?

Description of the study

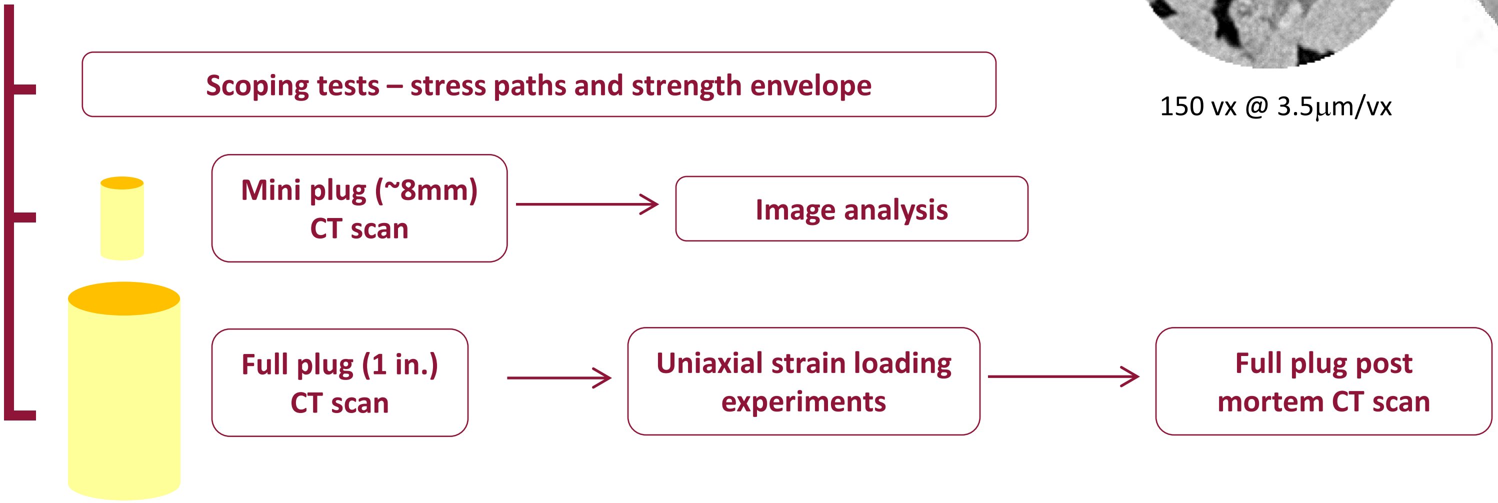
- ❑ Castlegate and Boise sandstones
- ❑ Experimental evaluation of compactive strength
- ❑ ~ 10 μm and ~4 μm CT scanning pre/post tests
- ❑ Parameter extraction from images and comparison with mechanical data

	Castlegate	Boise
Porosity (%)	25-27	28-30
Mineralogy (%)	Qz (85) Cal+Dol (~10) Clay (~5)	Qz (45) F (45) Bio(5) Clay (~3)



150 vx @ 3.5μm/vx

150 vx @ 4.3μm/vx

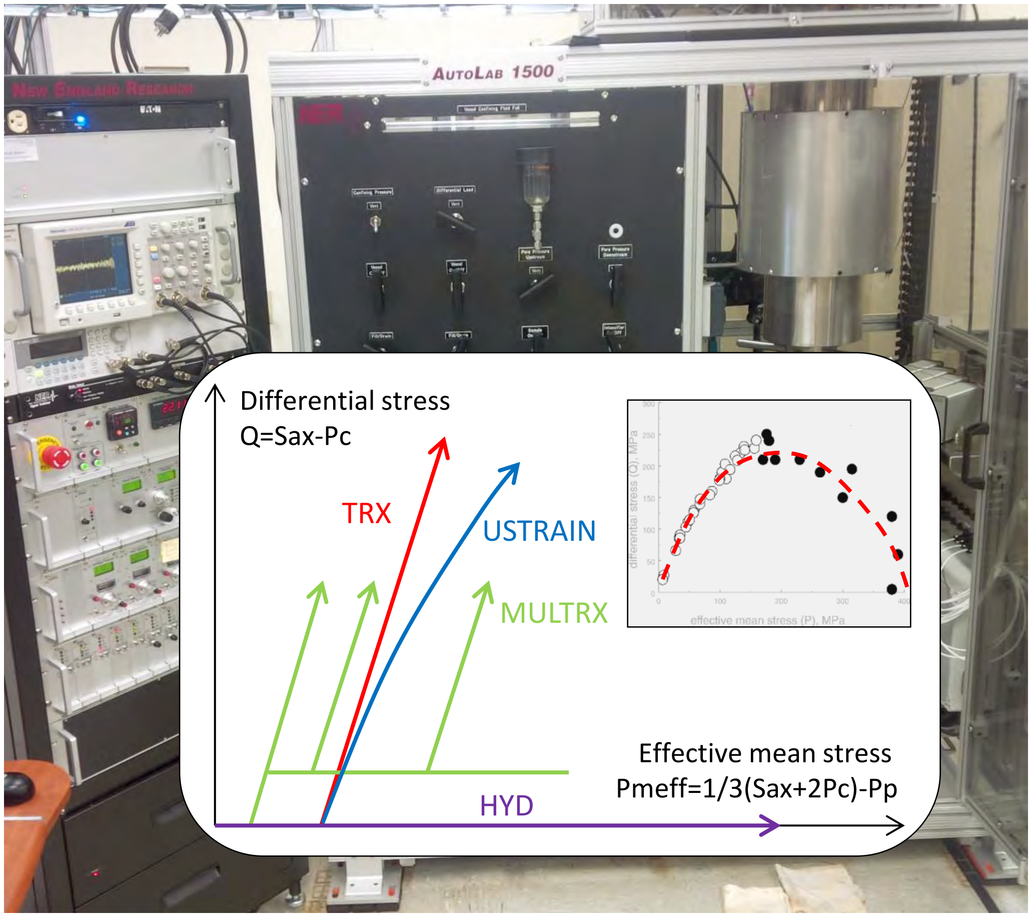


Testing apparatus and methods

Tests conditions:

- 1in x 2in samples
- Water sat and measure of expelled pore fluid
- Axial ultrasonics (not shown)
- Pp of 5MPa throughout and Pc up to 45000 Psi
- Scoping with both strain gages and LVDT setups
- Triax, uniax strain and hydrostatic

Testing apparatus and methods



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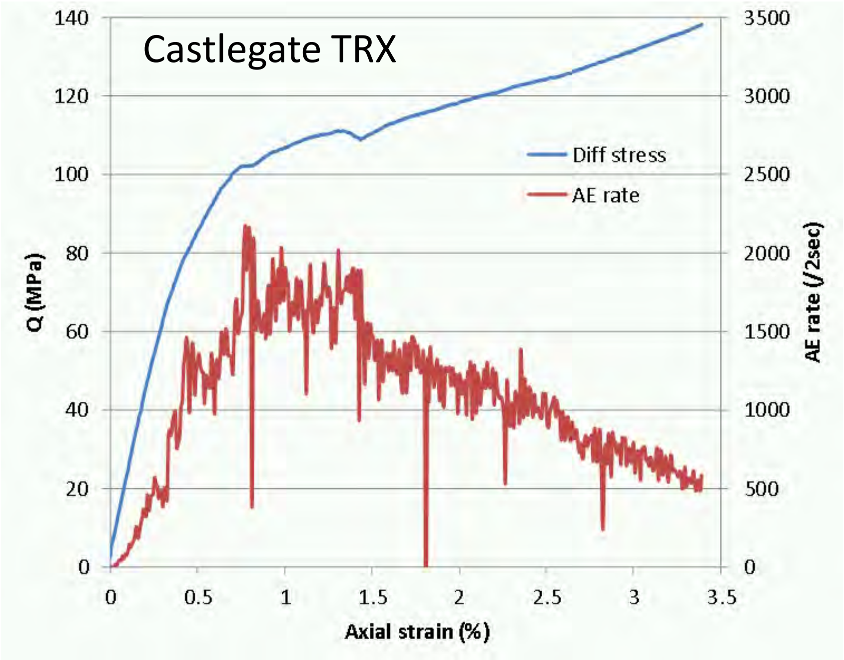
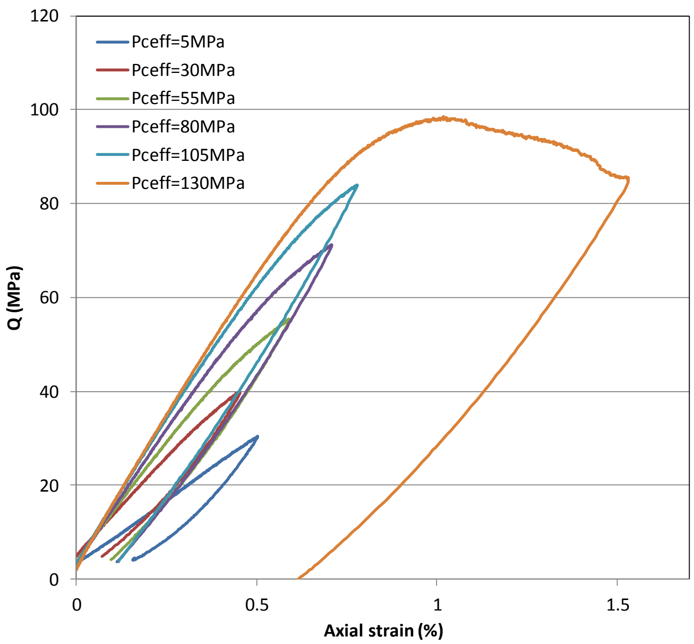
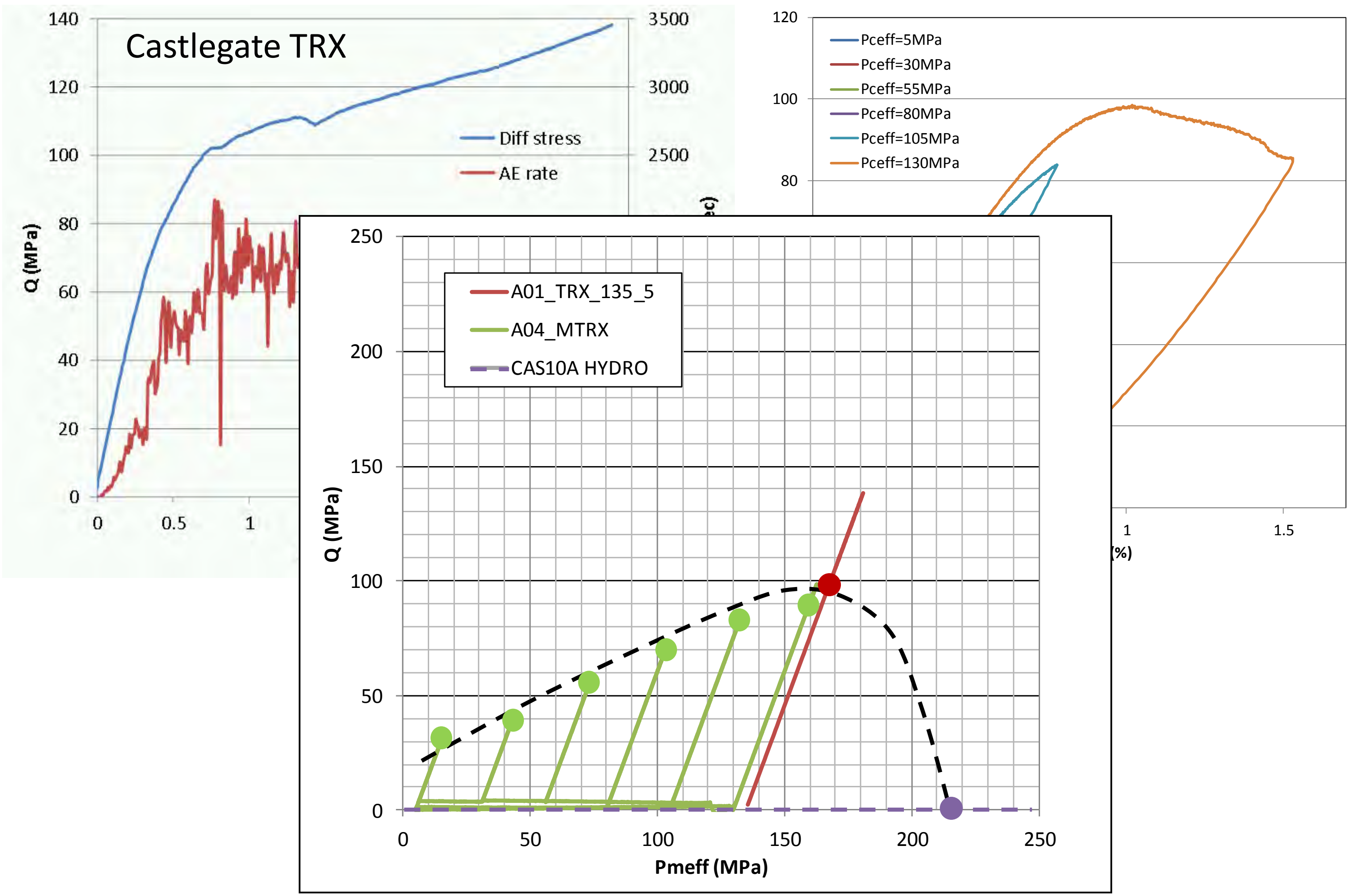
Results


Castlegate TRX
Diff stress
AE rate
Q (MPa)
AE rate (/2sec)
Axial strain (%)
140
120
100
80
60
40
20
0
3500
3000
2500
2000
1500
1000
500
0
0
0.5
1
1.5
2
2.5
3
3.5

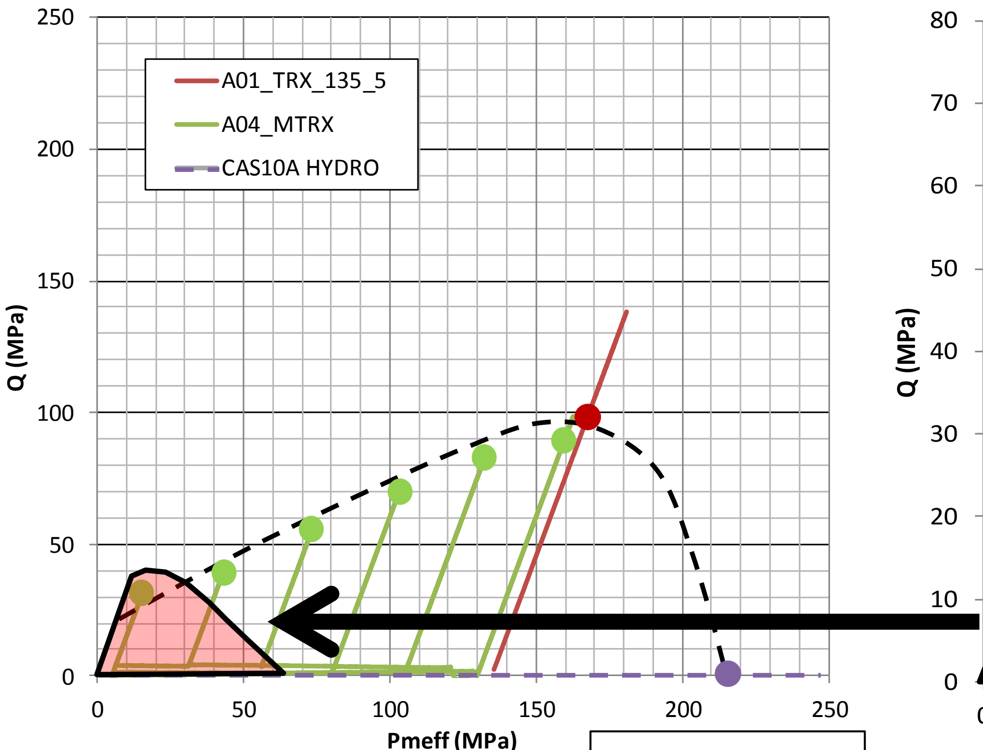

Pceff=5MPa
Pceff=30MPa
Pceff=55MPa
Pceff=80MPa
Pceff=105MPa
Pceff=130MPa
Q (MPa)
Axial strain (%)
120
100
80
60
40
20
0
0
0.5
1
1.5

Results


Castlegate TRX
Diff stress
AE rate
Q (MPa)
Pceff=5MPa
Pceff=30MPa
Pceff=55MPa
Pceff=80MPa
Pceff=105MPa
Pceff=130MPa
A01_TRX_135_5
A04_MTRX
CAS10A HYDRO
Pmeff (MPa)

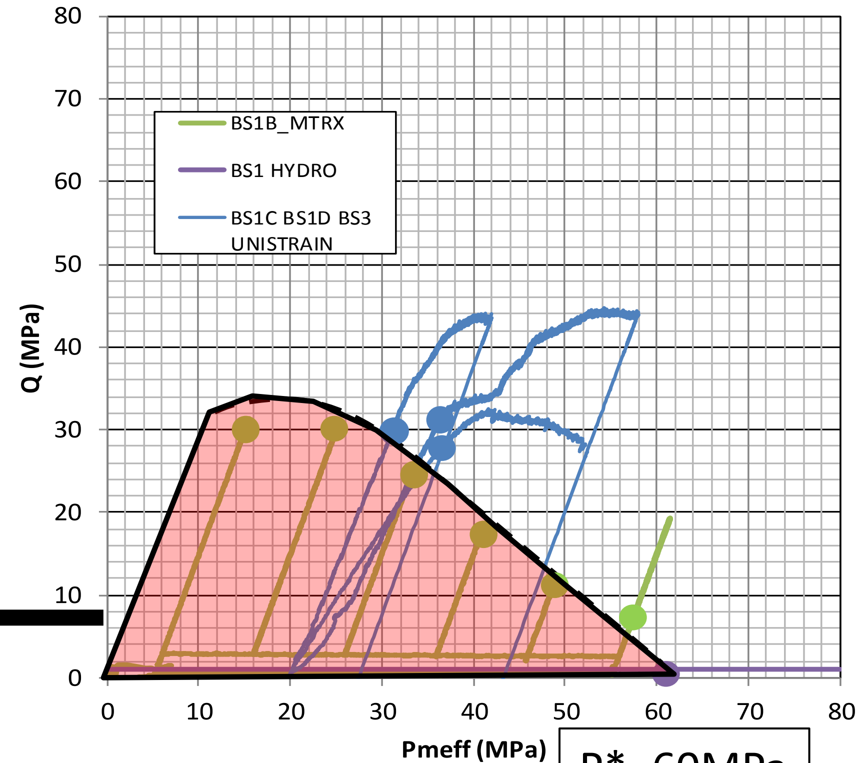
Results

Castlegate phi=25-27%



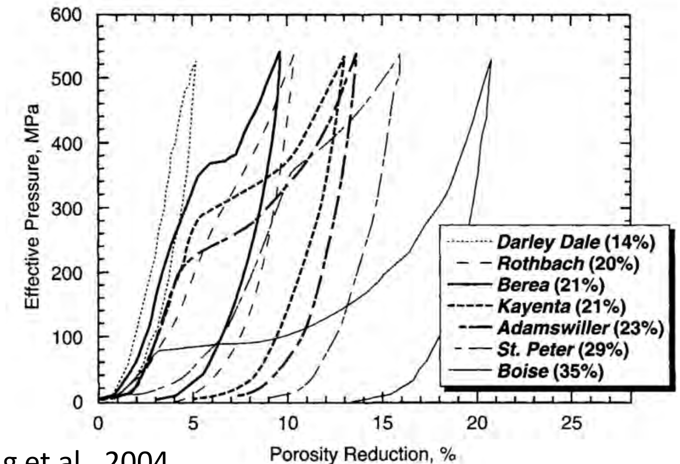
P*=215MPa

Boise phi=28-30%

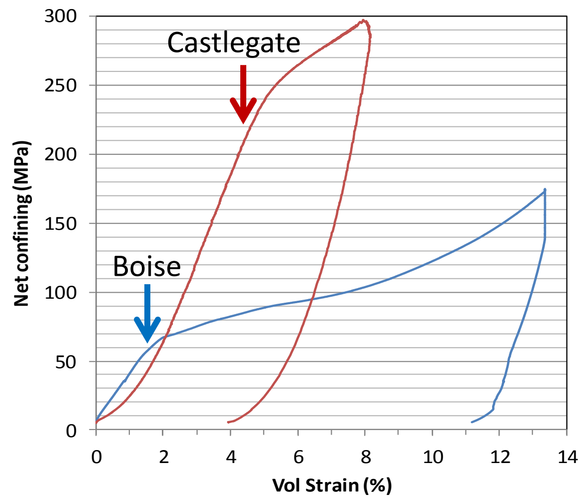


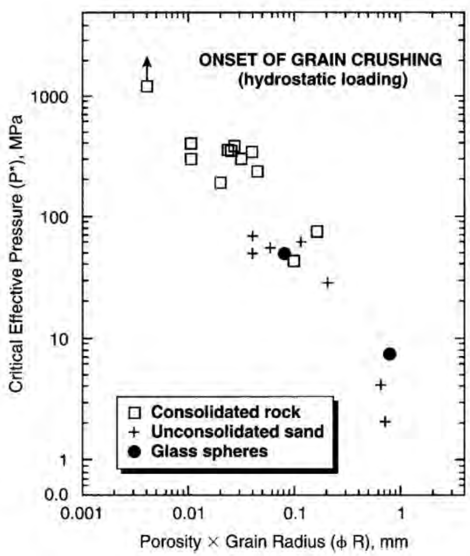
P*=60MPa

Results



Wong et al., 2004





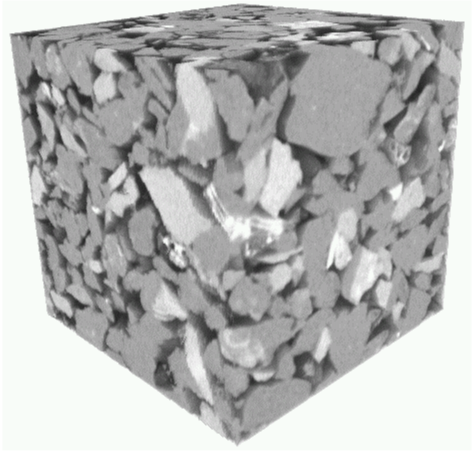
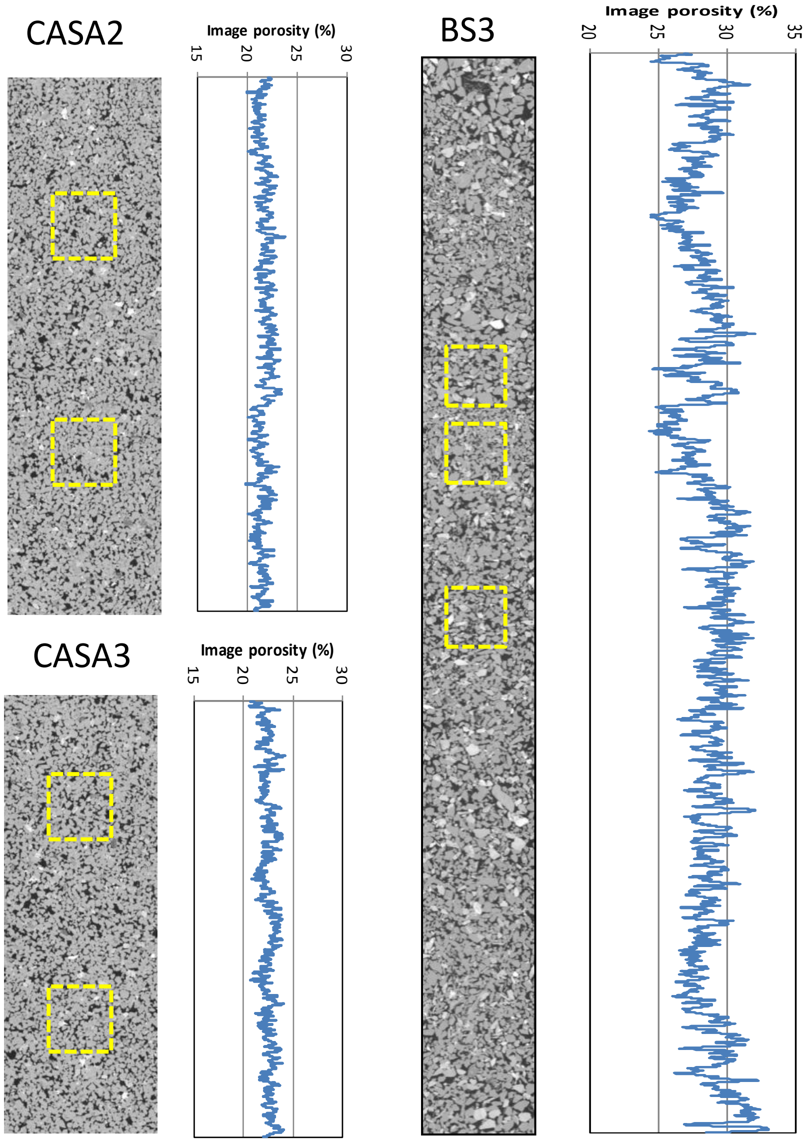
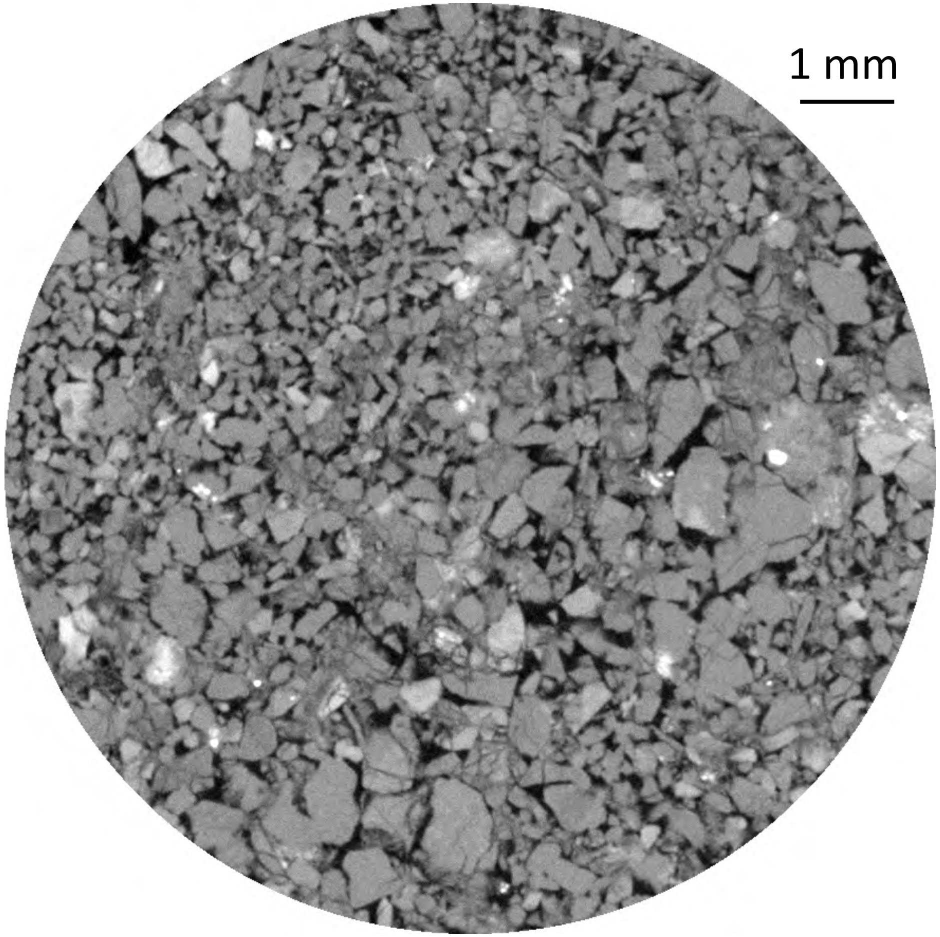


Image analysis





Boise uniaxial strain (BS3)

Image analysis

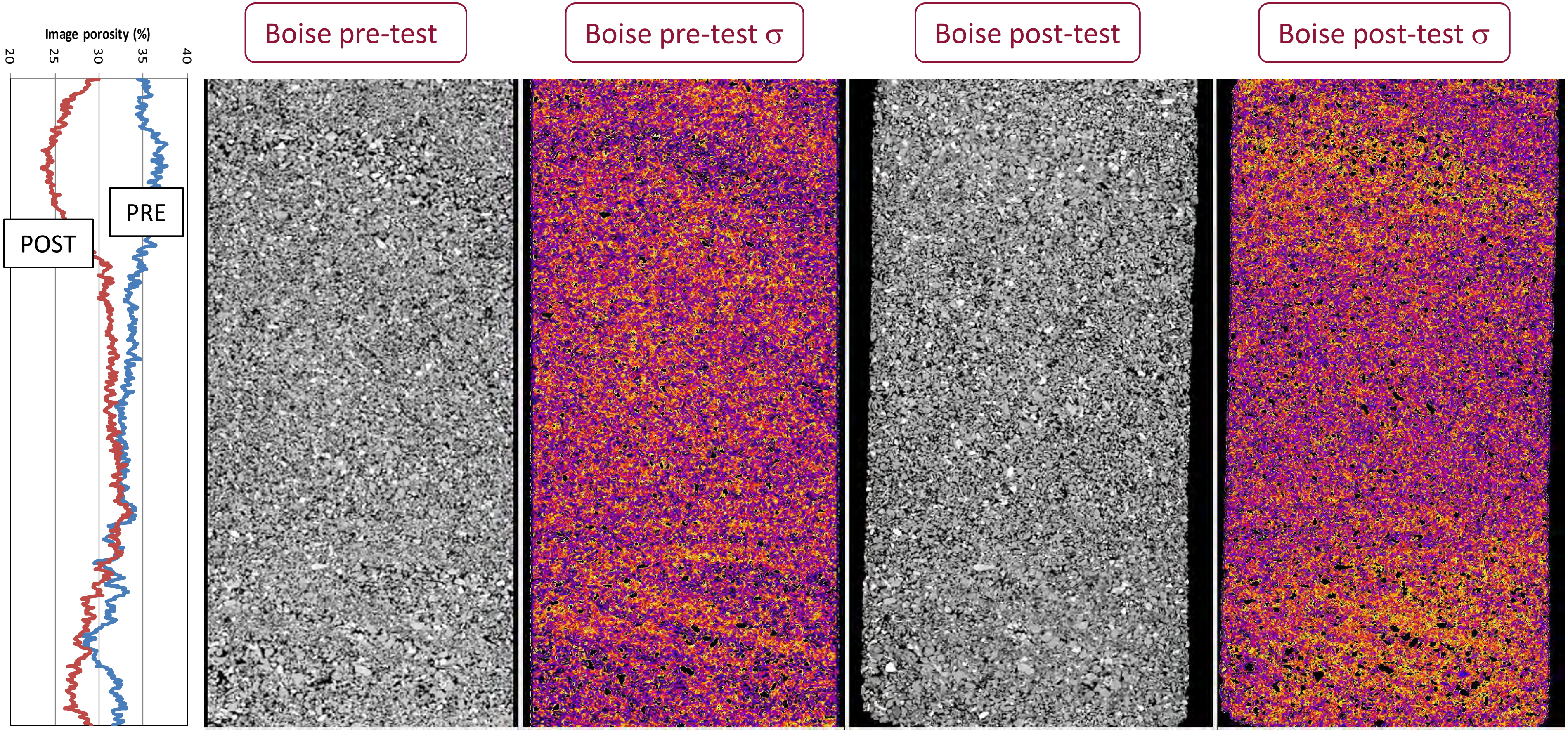
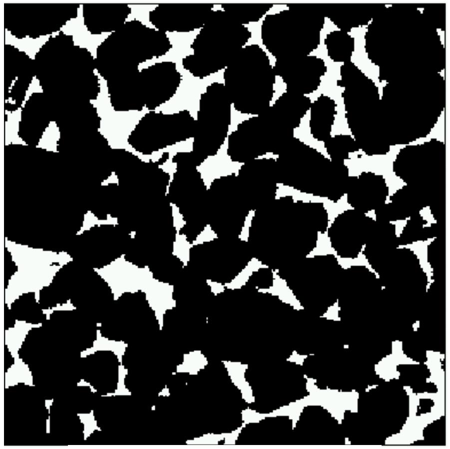
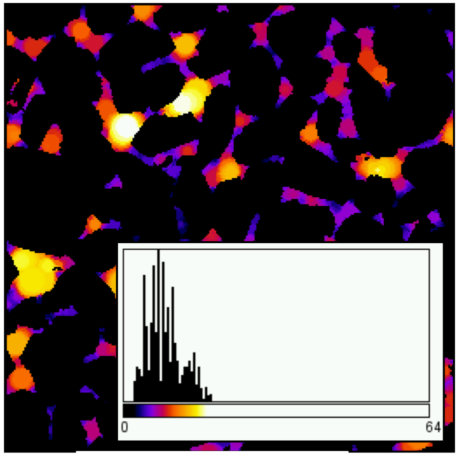


Image analysis

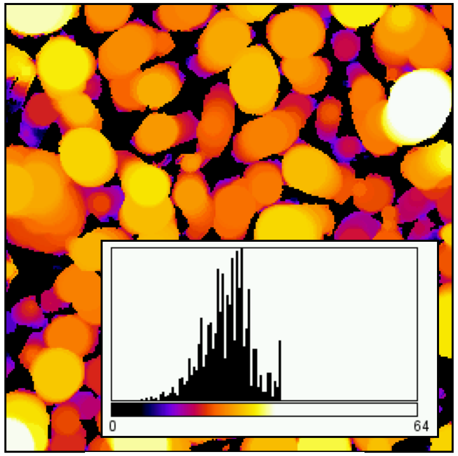
Maximal inscribed sphere (MIS) algorithm



Segmented image



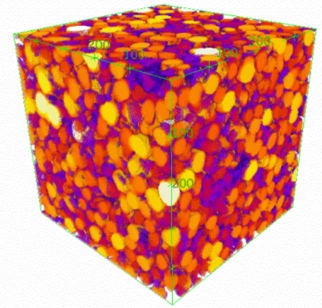
Pore space MIS



Framework MIS

- Fast characterization without grain separation
- Grain and contact radius
- Demonstrate stress intensification

Castlegate



Boise

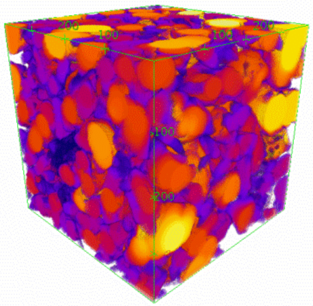


Image analysis

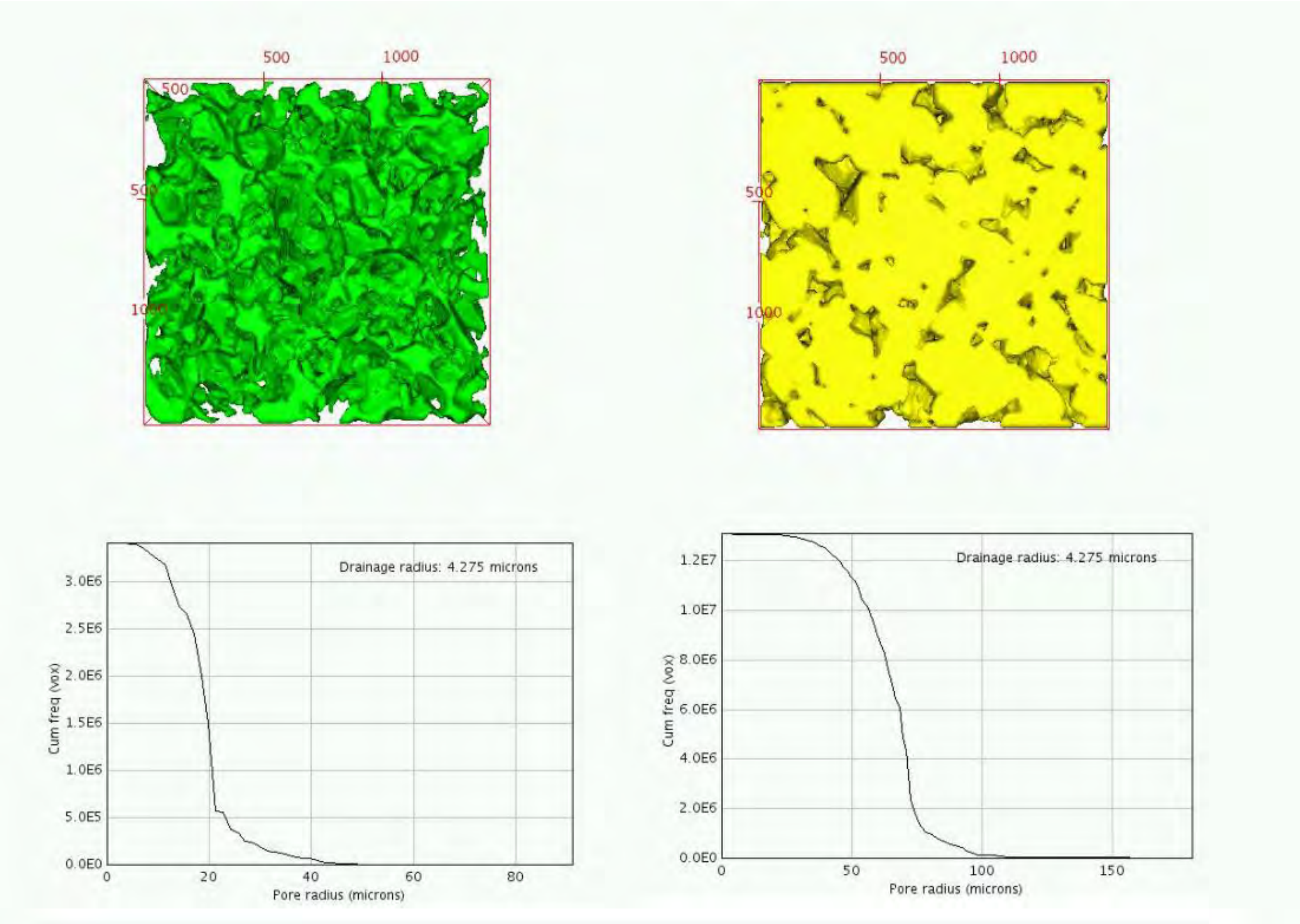
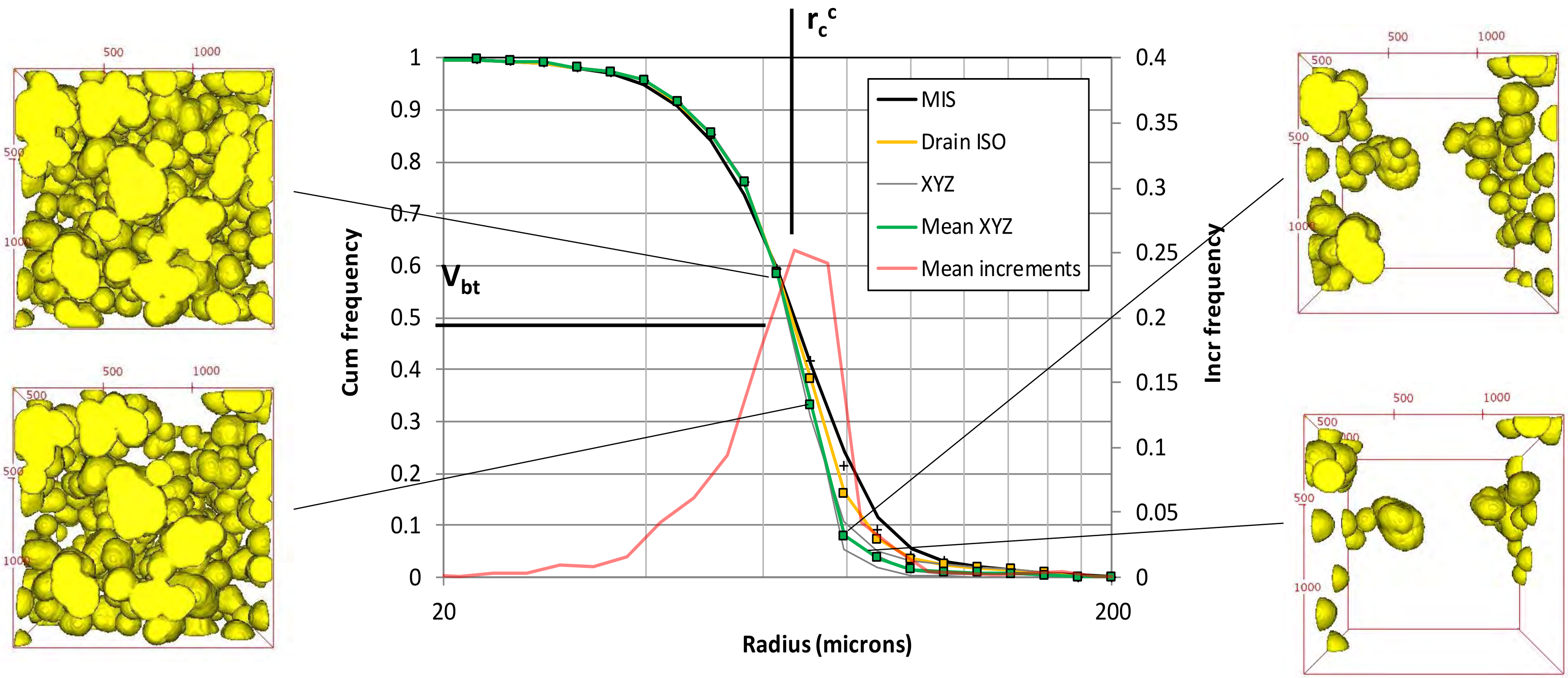
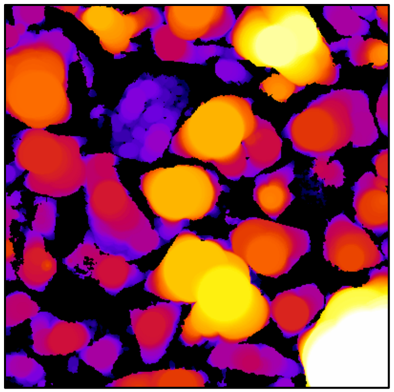


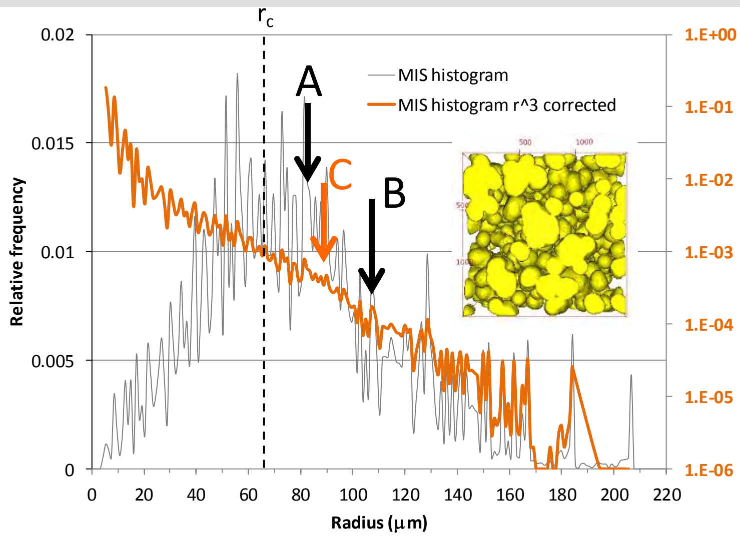
Image analysis

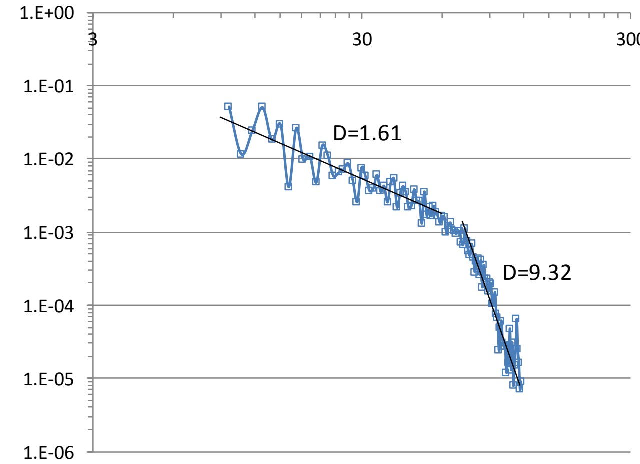


- Role of this 'characteristic' contact radius for elastic and mechanical properties? Similar to what pore entry radius is to flow?

Image analysis



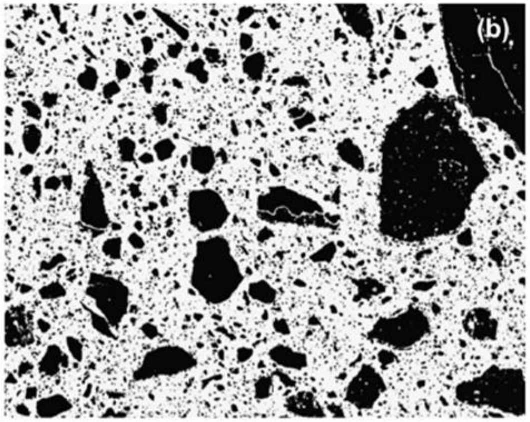




A: average of MIS

B: average of MIS at BT

C: average of r^3 norm dist. at BT



Keulen et al., 2007 – Nojima Fault Zone

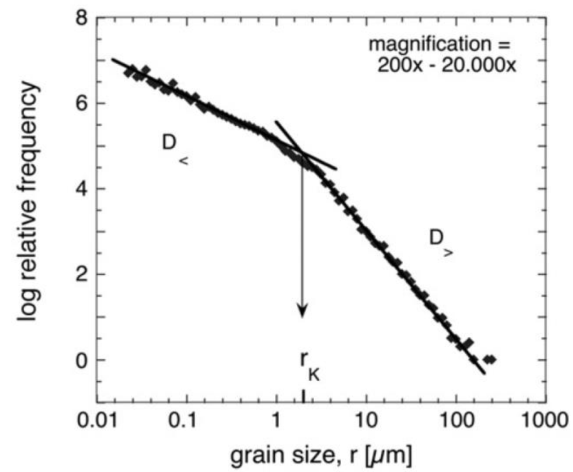
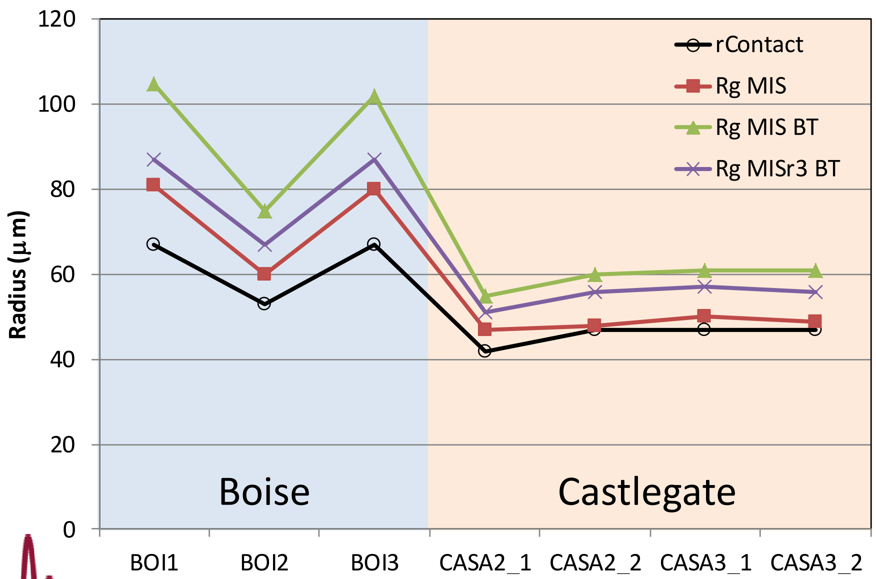
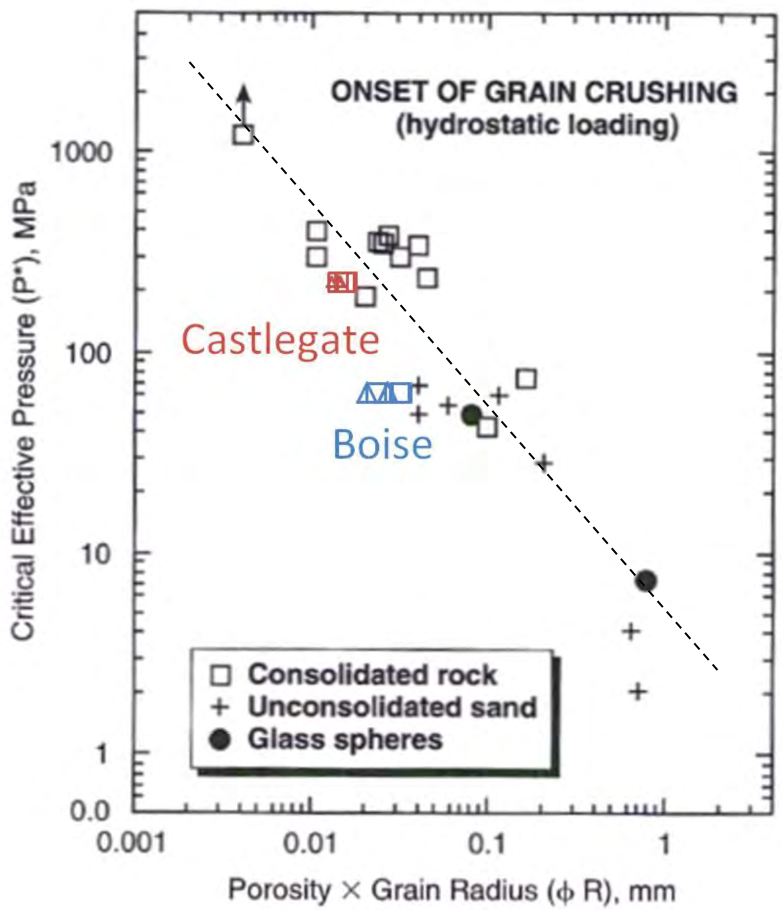


Image analysis

Sample	r_C (+-4)	Rg MISmean	Rg MISmeanBT	Rg r3 meanBT
BOI1	67	81	105	87
BOI2	53	60	75	67
BOI3	67	80	102	87
CASA2_1	42	47	55	51
CASA2_2	47	48	60	56
CASA3_1	47	50	61	57
CASA3_2	47	49	61	56



Zhang-Wong model: Rg only



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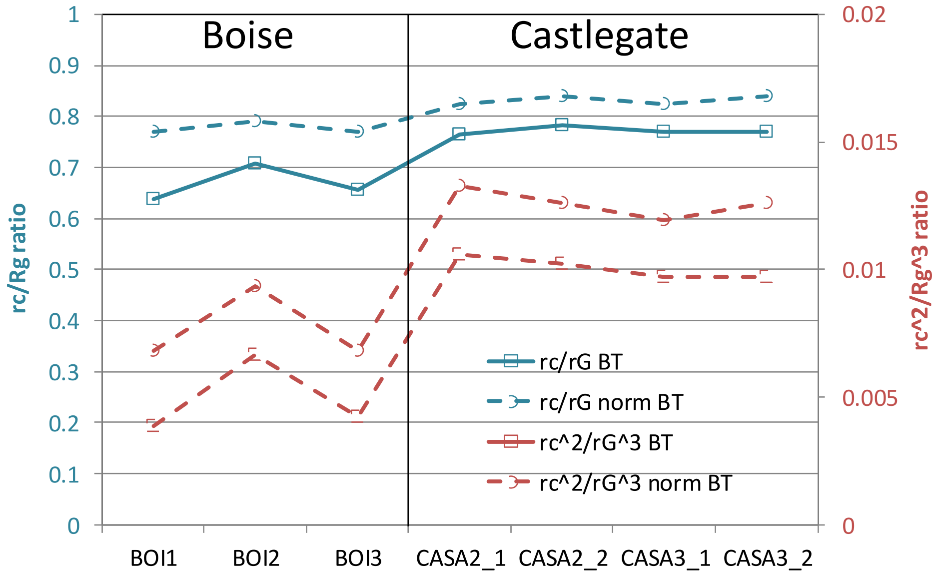
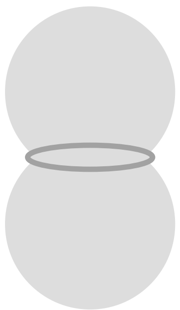


P^*_{Boise}~60MPa
$P^*_{Castlegate}$~215MPa
Assume similar porosities and mineralogy - **Target a 3.5 factor**…

Compute rc/Rg ratio and rc^2/Rg^3 ratio to estimate potential contribution to strength

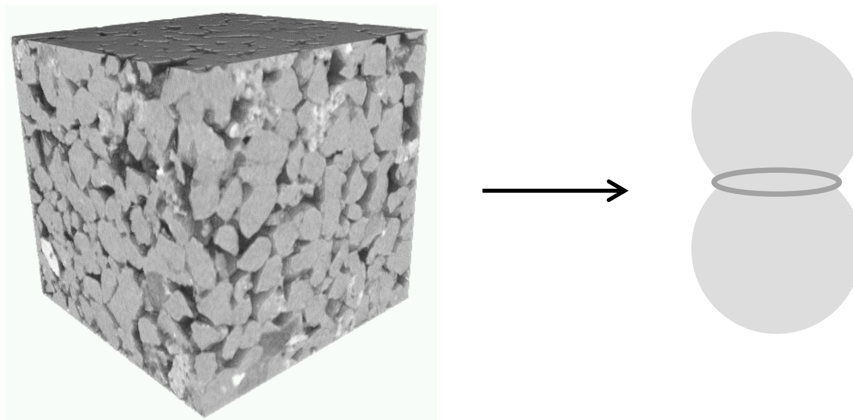


r_c^2/R_g^3 leads to a substantial difference between Boise and Castlegate while keeping the scale sensitivity through L^{-1}

$$P^* \propto \frac{r_C^2}{\phi R_g^3}$$

Taking the 'weakest' Boise volume: $\frac{P^*_{CAS}}{P^*_{BOI}} \sim 3.2$

Summary



- Ratio of grain contact surface area to grain volume helped accounting for strong differences in strength between Castlegate and Boise sandstones – Augmented the approach based on grain radius only
- Relatively fast process for screening and detection of REV strength heterogeneities incl. anisotropy
- Compaction modeling could be based on such distribution
- The availability of the grain contact surface area allows incorporating shear at contacts for (1) further the modeling of the entire yield surface (2) connecting to elastic properties (compression and shear) – e.g. HS bounds

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