Evolution of Permeability and Porosity during Brittle Faulting

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Geology Senior Thesis

BACKGROUND

- Transport properties in rocks include-
  Porosity ϕ – percentage of pore volume to total volume.

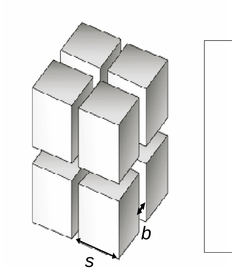
Permeability, k - The measure of the ability of fluid-flow through a rock.

$k = C\,d^2$: C = dimensionless constant
d = mean pore diameter

Dilatancy is an inelastic pore volume increase due to deformation

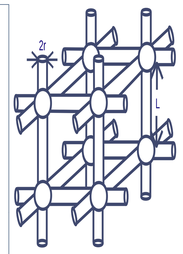
- Dilatancy is generally observed prior to brittle faulting

- Porosity and Permeability are **positively correlated** in **Westerly granite** during dilatancy
- Porosity and Permeability are **negatively correlated** in **Berea sandstone** during dilatancy

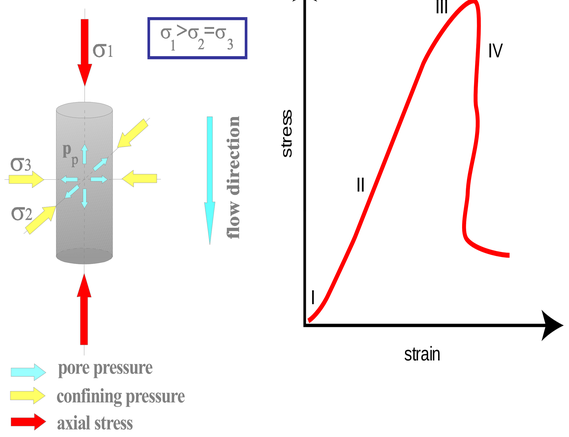


Fracture aperture, b

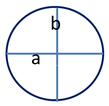
Fracture spacing, s
permeability
$k=b^3/12s$
Total porosity $\phi=b/s$



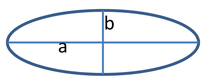
- Cross-section radius, *r*
- Length, l
  - Intrinsic permeability $k=r^2/8$
  - porosity $\phi = (\pi r^2 l)$



- Aspect ratio (α) = b/a
- For pores : a ~ b
  α = 0.1 – 1.0



- For cracks : a>>b
  α = .0001 - 0.1



- Deformed **Westerly granite** consists of pre-existing, as well as, induced high aspect ratio cracks

- Deformed **Berea Sandstone** consists of equidistant pre-existing pores and high aspect ratio cracks

Westerly granite, the net **permeability enhancement** during dilatancy is due to induced microcracking

- It results in the net **permeability decrease** during dilatancy in Berea sandstone, however, an **enhancement** in **Westerly granite** is observed

HYPOTHESIS

- In **Berea sandstone**, permeability **decrease** due to pre-existing pore reduction is more effective than permeability enhancement due to microcracking.

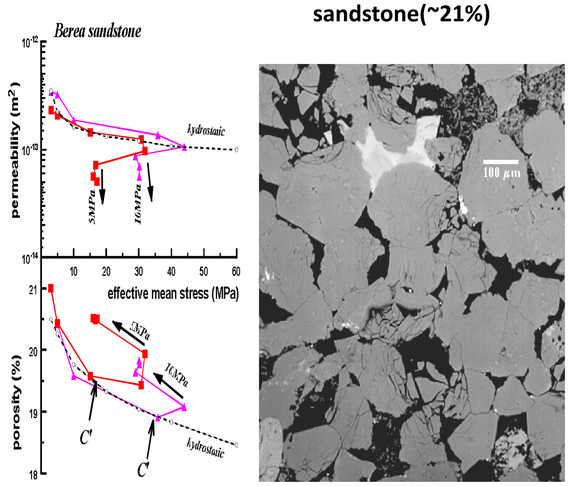
METHOD- EXPERIMENTAL

Stage I: Crack closure

Stage II: Linear elasticity (Young's modulus)

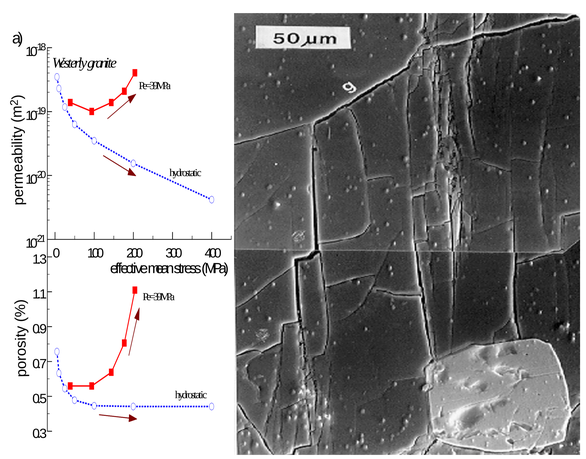
Stage III: Dilatancy

Stage IV: Coalescence of microcracks; formation of macroscopic fracture



Deformed Berea sandstone(~21%)

Deformed Westerly granite (~0.7%)



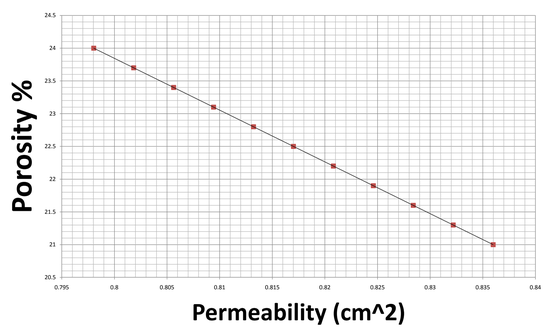
Preliminary Results- Berea sandstone

$K_{initial}$ (cm^2)	$\Delta\phi_{p,\%}$	$\Delta\phi_c$ %	Φ_{pore}	Φ_{crack}	Φ_{total}	Radius p(cm)	K_p (cm^2)	K_c (cm^2)	S (10^{-4})	b (10^{-4})	K_{total}
0.84	0.00	0.00	21.00	0.00	21.00	2.59	0.84	0.00	10.00	1.00	0.84
	-0.20	0.50	20.80	0.50	21.30	2.57	0.83	0.00	10.00	1.00	0.83
	-0.40	1.00	20.60	1.00	21.60	2.56	0.82	0.01	10.00	1.00	0.83
	-0.60	1.50	20.40	1.50	21.90	2.55	0.81	0.01	10.00	1.00	0.82
	-0.80	2.00	20.20	2.00	22.20	2.54	0.80	0.02	10.00	1.00	0.82
	-1.00	2.50	20.00	2.50	22.50	2.52	0.80	0.02	10.00	1.00	0.82
	-1.20	3.00	19.80	3.00	22.80	2.51	0.79	0.03	10.00	1.00	0.81
	-1.40	3.50	19.60	3.50	23.10	2.50	0.78	0.03	10.00	1.00	0.81
	-1.60	4.00	19.40	4.00	23.40	2.49	0.77	0.03	10.00	1.00	0.81
	-1.80	4.50	19.20	4.50	23.70	2.47	0.76	0.04	10.00	1.00	0.80
	-2.00	5.00	19.00	5.00	24.00	2.46	0.76	0.04	10.00	1.00	0.80

Westerly granite

$\Phi_{crack\ initial}$	$K_{initial}$ (cm^2)	$\Delta\phi_c$ %	Φ_{crack}	K_c (cm^2)	s(10^{-4})	b(10^{-4})
0.1	0.00	0.10	0.20	0.00	10.00	1
		0.20	0.30	0.00	10.00	1
		0.30	0.40	0.00	10.00	1
		0.40	0.50	0.00	10.00	1
		0.50	0.60	0.01	10.00	1

Net Porosity change vs Net permeability change in Berea sandstone



APPLICATIONS/ IMPORTANCE

Understanding of Permeability and Porosity is Critical in:

- **Earthquake and Faulting-** Pore fluid pressure reduces the effective stress: Total Stress (σ_t) – Pore pressure(P_p)
- **Fold and thrust belts-** deformation of thick crustal lithologies
- **Oil and Gas Industry-** Ease of extracting hydrocarbons / Oil through high permeable rocks