Porosity & Transport Property Relationships in Fractured Yates Amphibolite

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GEOL 394

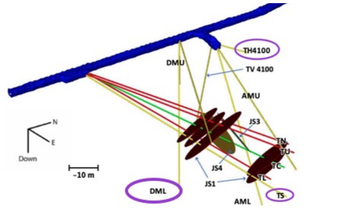
Introduction and Background

Enhanced Geothermal Systems (EGS) hold potential in mass production of low-carbon energy by engineering fracture networks in Earth's subsurface.

→ Efficient heat extraction in EGS relies heavily on controlled fracture induction and stable, permeable pathways.

Power law relationships for permeability (k)-porosity (φ) and conductivity (e)-porosity are constrained in this project.

→ Conductivity is measured in situ; however permeability data is difficult to collect, so this relationship is investigated from lab simulated fluid flow through fractured



Map of the Sanford Underground Research Facility where the samples were sourced from: DML1, TS4, and TH41004

Permeability Simulation[1]

$$\frac{Q}{S} = -\frac{k}{\mu}\frac{P_{in} - P_{out}}{L}$$

μ : viscosity [Pa s^{-1}] k : permeability [m^2]
P : pressure [Pa] L : subvolume length [m]
S : cross section [m^2] Q : Darcy velocity [m s^{-1}]

Electrical Conductivity Simulation[2]

$$\vec{j} = -e\vec{\nabla}v$$

$$\frac{j_{total}}{S} = e\frac{v_{in} - v_{out}}{L}$$

$$j_{total} = \int S - e_{solution}\frac{v_{in} - v_{out}}{L}$$

j : current density [A m^{-2}]
e : electrical conductivity [S m^{-1}]
v: electrical potential [volts]
S : cross section [m^2]
R : sample resistivity
R_f : fluid resistivity
F: formation factor

Hypothesis

H_a: The permeability exponent (n) and conductivity exponent (m) relationships with porosity are affected by fracture geometry type.

H_0: The permeability exponent (n) and conductivity exponent (m) relationships with porosity are not affected by differences in the fracture geometry.

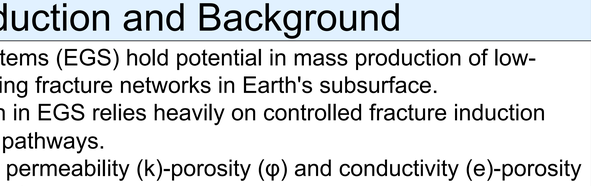
Data Preparation

I. Core samples sustained deformation in the Rock Physics Lab at UMD

Pressure Conditions

DML1, TS4, TH41004

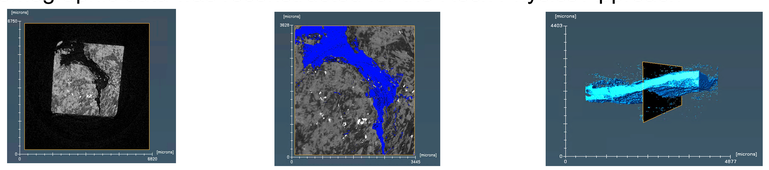
P_f: 10 MPa P_c: 35 MPa



DML1 TS4 TH41004

II. X-Ray Microtomography was performed at the Advanced Photon Source Synchrotron

III. Tomographic data was reconstructed for the Rock Physics Approach



Simulations and Fracture Geometry

Power Law Relationships

→ Permeability[3]

$$k \propto \varphi^n$$

- For a well-connected uniform pore network, n = 2
- For well-connected uniform fracture network, n = 3

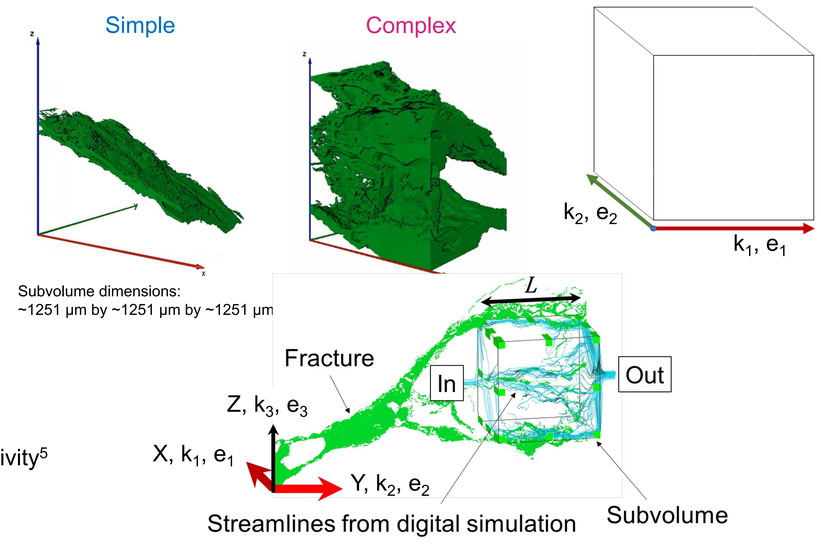
→ Electrical Conductivity[4]

$$\mathrm{F} = \frac{R}{R_f} = \varphi^{-m}$$

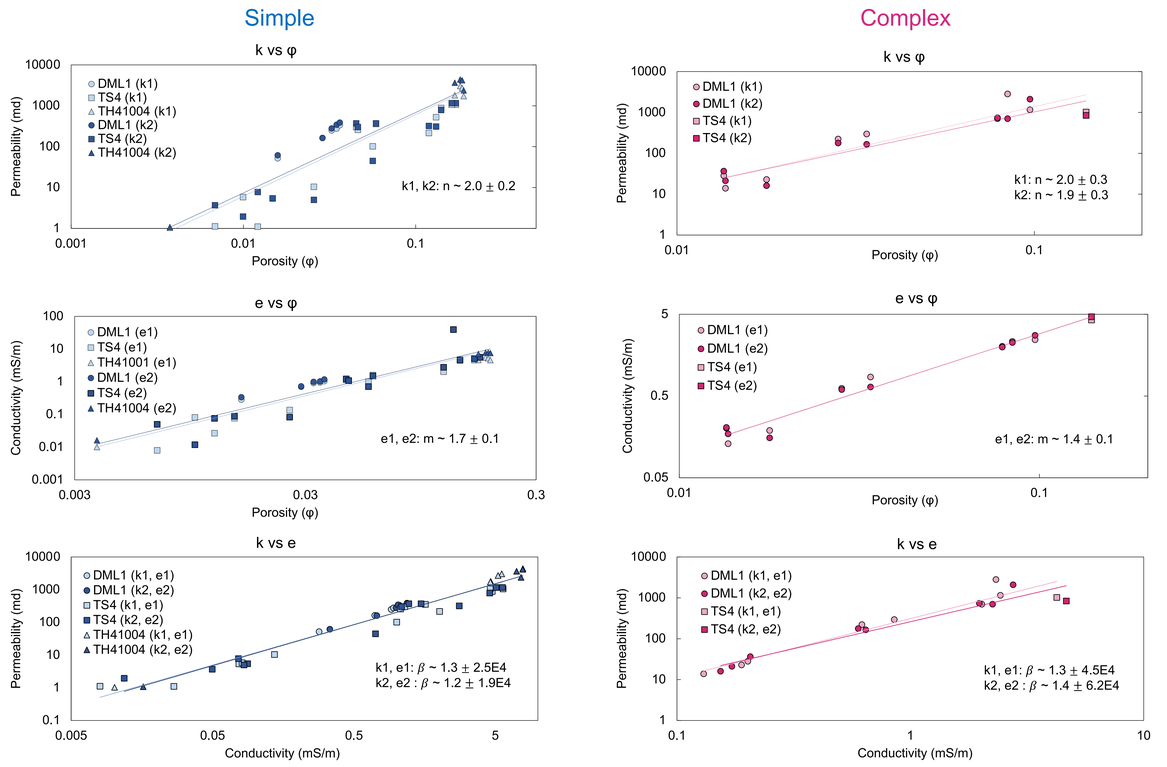
→ Permeability-Electrical Conductivity[5]

$$\mathrm{k} = e^{\beta}$$

Fracture Geometry



Transport Property Data



Results

Permeability–Porosity (n):

Simple fractures

- Midrange of n values, n ~ 2.0 (k1), 2.0 (k2)

Complex fractures

- Lowest n value, n ~ 1.9 (k2)
- Comparable to simple, n ~ 2.0 (k1)

Electrical Conductivity–Porosity (m):

Simple fractures

- Higher values m ~ 1.7 (e2), 1.7 (e1)

Complex fractures

- Lowest m values, m ~ 1.4 (e1), 1.4 (e2)
- Closest to theoretical[6] m ~ 1.5

Permeability-Electrical Conductivity:

Simple fractures

- Higer value β ~ 1.3 (k1, e1), comparable to the complex (k1, e1) exponent
- Lowest of all fracture types in the (k2, e2) direction, β ~ 1.2

Complex fractures

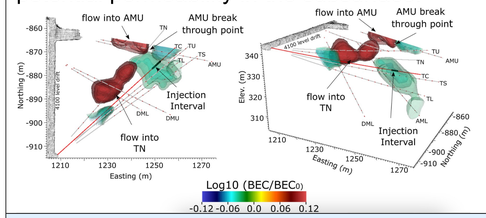
- Highest exponent value in the (k2, e2) direction, β ~ 1.4

Conclusions

The electrical conductivity-porosity exponent differs regarding fracture geometry. The permeability-porosity exponent remains consistent between the two fracture types. Lower than expected n values likely due to fracture roughness and tortuous pore networks

Furthering this research involves investigating the effect of subvolume size on the exponent.

Conductivity measurements, which can be collected in situ, can be used as indicators of potential permeability in the subsurface.[7]



References

1 (Darcy, 1856)
2 (Ohm, 1827)
3 (David et al., 1994)
4 (Revil & Glover, 1997)
5 (Ghanbarian & Male, 2021)
6 (Sen et al.,1981)
7 (Johnson et al., 2024)