The role of stress-dependent wallrock permeability in Minewater Geothermal Energy

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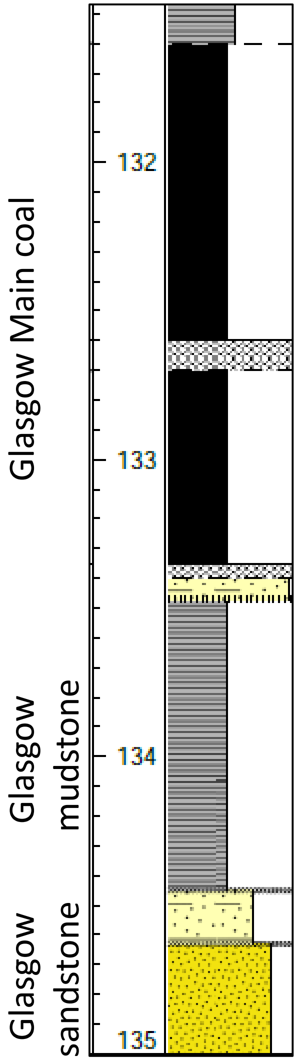
EGU2020-1225

Minewater Geothermal Energy – UKGEOS Glasgow



- Samples of Glasgow Main coal and the underlying mudstone and sandstone were taken from depths around 135m in the GGC01 borehole at the Glasgow UKGEOS research site.

- $T \simeq 13\ ^{o}\mathrm{C}$

- $\sigma_1 \simeq 4\ \mathrm{MPa}$

Figures reproduced from *Monaghan et al., (2018)*

Heat transfer through a saturated porous medium

- Heat is transported through a saturated porous body by a combination of conduction through the matrix and fluid, as well as convection of moving liquid.
- Through conservation of Energy in a control volume, heat transfer can be expressed as

$$\rho c\frac{\partial T}{\partial t} + \rho_f c_f q_x \frac{\partial T}{\partial x} = \nabla.(\lambda \nabla T)$$

- λ, ρ, c were calculated from a combination of the XRD mineralogies, porosity and density measurements for each material.

- In a traditional geothermal situation, fluid flow effects are very small, but in minewater geothermal, permeability is relatively high (due to depths < 500m), and thermal conductivity of the matrix is relatively low.

Sample	90	92	93
Material	Glasgow Main coal	Glasgow mudstone	Glasgow sandstone
ϕ (%)	2.37	7.27	9.64
ρ_m $(\mathrm{kg.m^{-3}})$	1194	2812	2938
λ_{eff} $(\mathrm{W.m^{-1}.K^{-1}})$	4.84	2.80	3.29
ρc $(\mathrm{kJ.m^{-3}.K^{-1}})$	1027	2526	2488

Darcy’s Law and the groundwater head gradient

- For 1d groundwater flow, $q\ (\mathrm{m.s^{-1}})$, head gradient, $\frac{\partial h}{\partial x}$, can be related though Darcy’s law expressed as:

$$q_x = \frac{-k\rho g}{\mu}\frac{\partial h}{\partial x}$$

where k, ρ, g, μ are the permeability, fluid density, acceleration due to gravity and dynamic fluid viscosity respectively. $\frac{\partial h}{\partial x}$ is the groundwater head gradient.

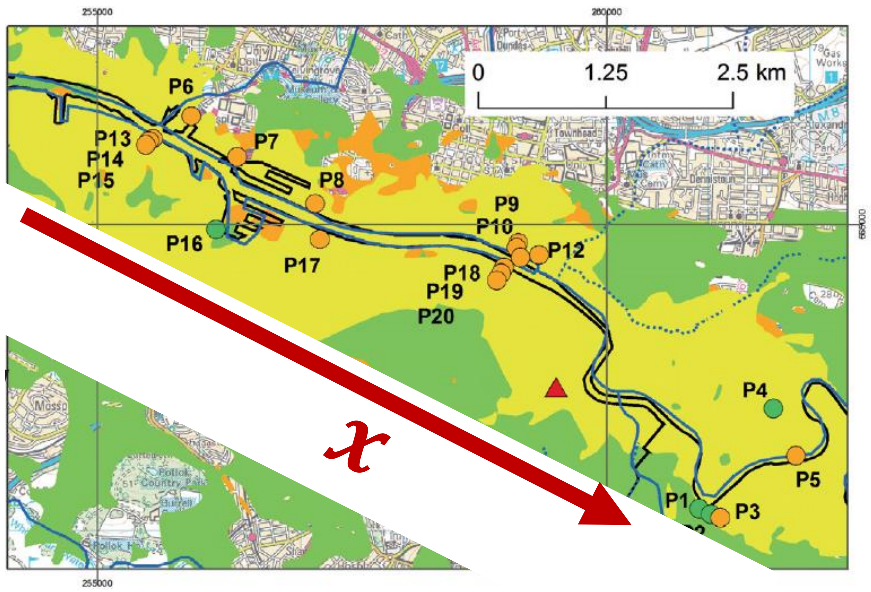
- *O’Dochartaigh et al., (2019)* measured the minimum groundwater head in a range of boreholes along the River Clyde. Fitting a linear regression gives an approximate value of

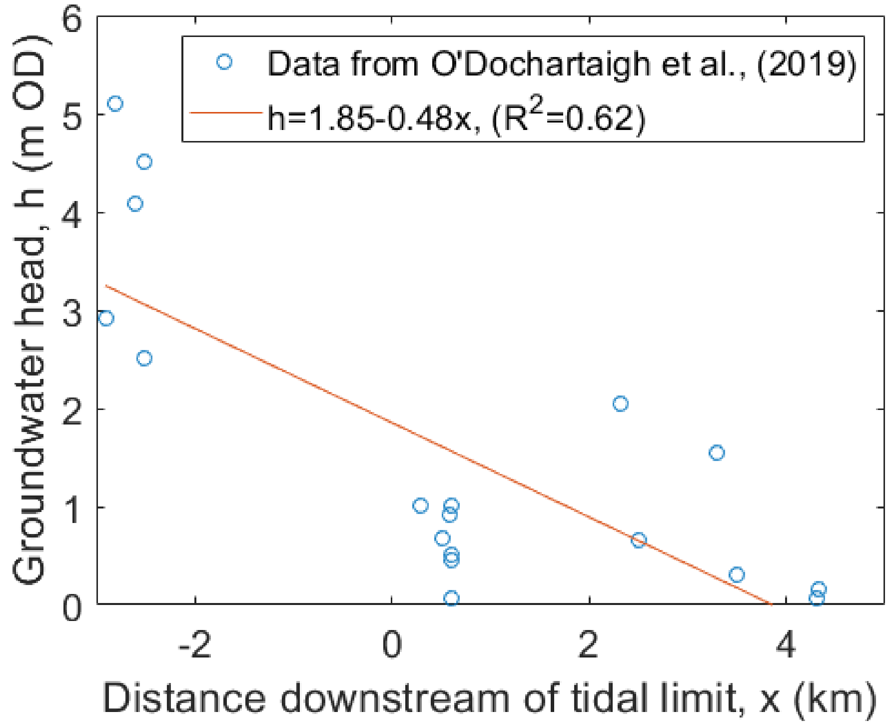
$$\frac{dh}{dx} \simeq 0.48\mathrm{m.km^{-1}}$$

- Using values corresponding to water, then

$$\boldsymbol{q_x \simeq (5.3 \times 10^3)k}$$

for groundwater flow in the Cuningar Loop area.

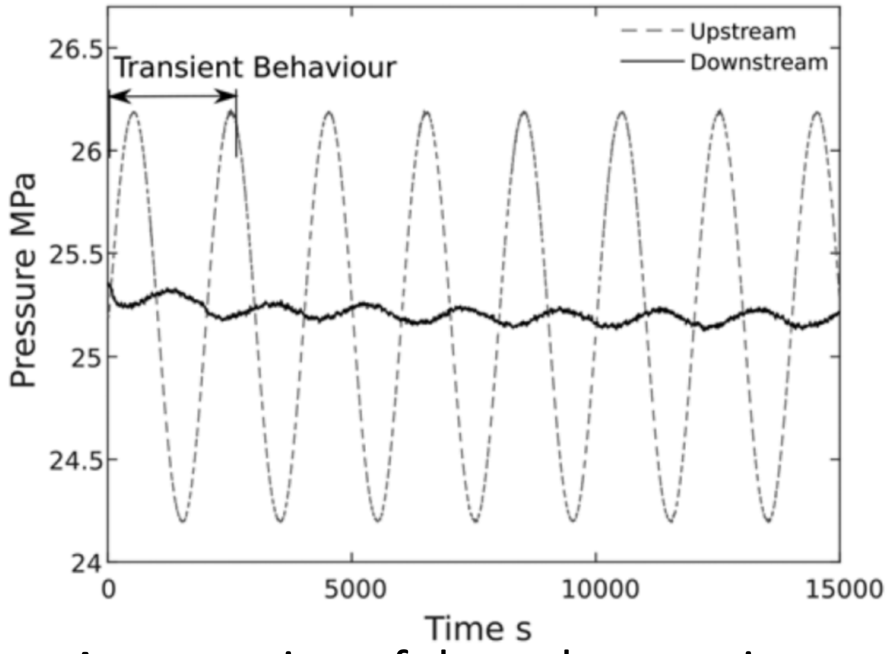




Figures modified after *O’Dochartaigh et al., (2019)*

Stress-dependent Permeability measurement using Oscillating Pore Pressure

- Stress-dependent k was measured using the oscillating pore-pressure technique.



- An extension of the pulse transient permeability technique, appropriate for measuring very low k.
- $P_{\mathrm{eff}} = P_{\mathrm{C}} - \overline{P_{\mathrm{P}}}$

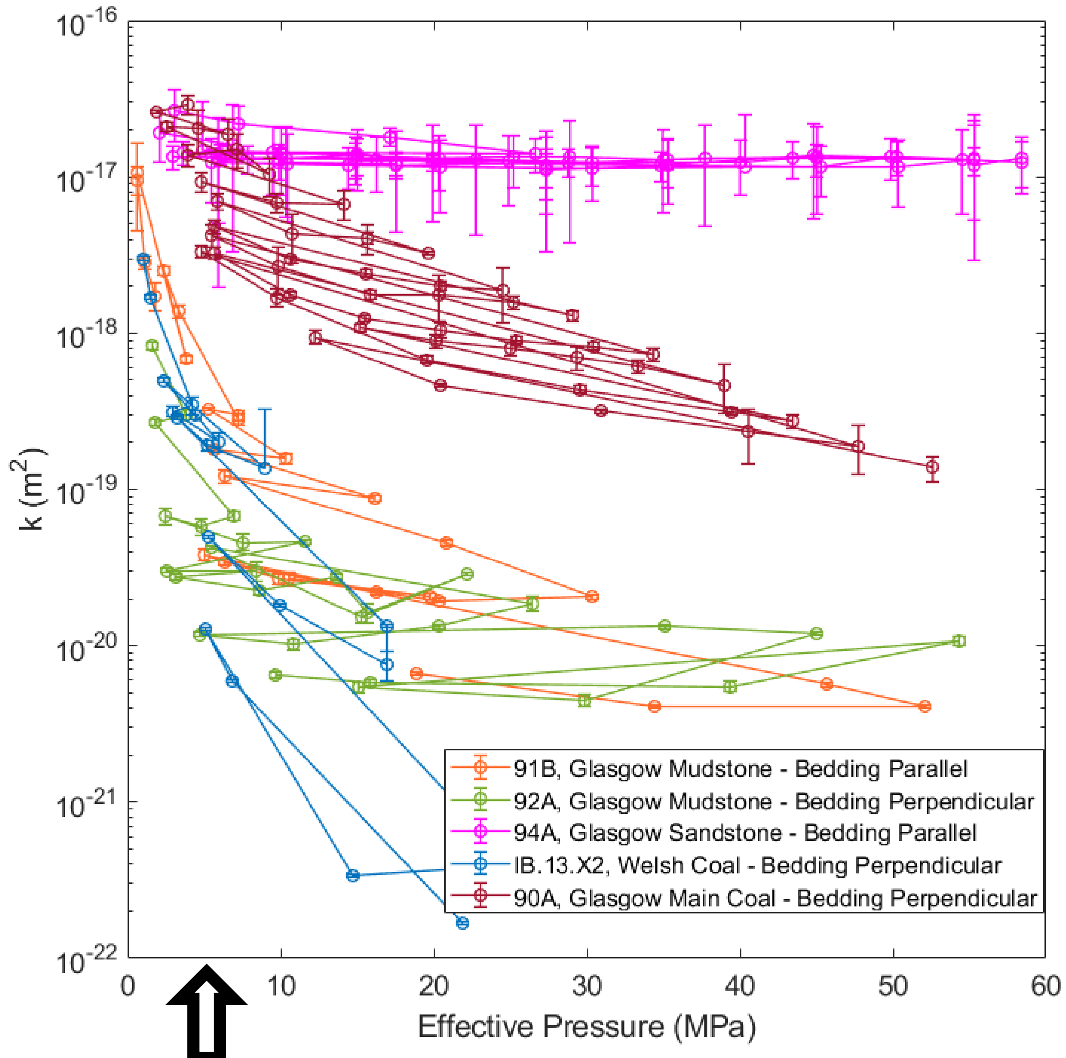
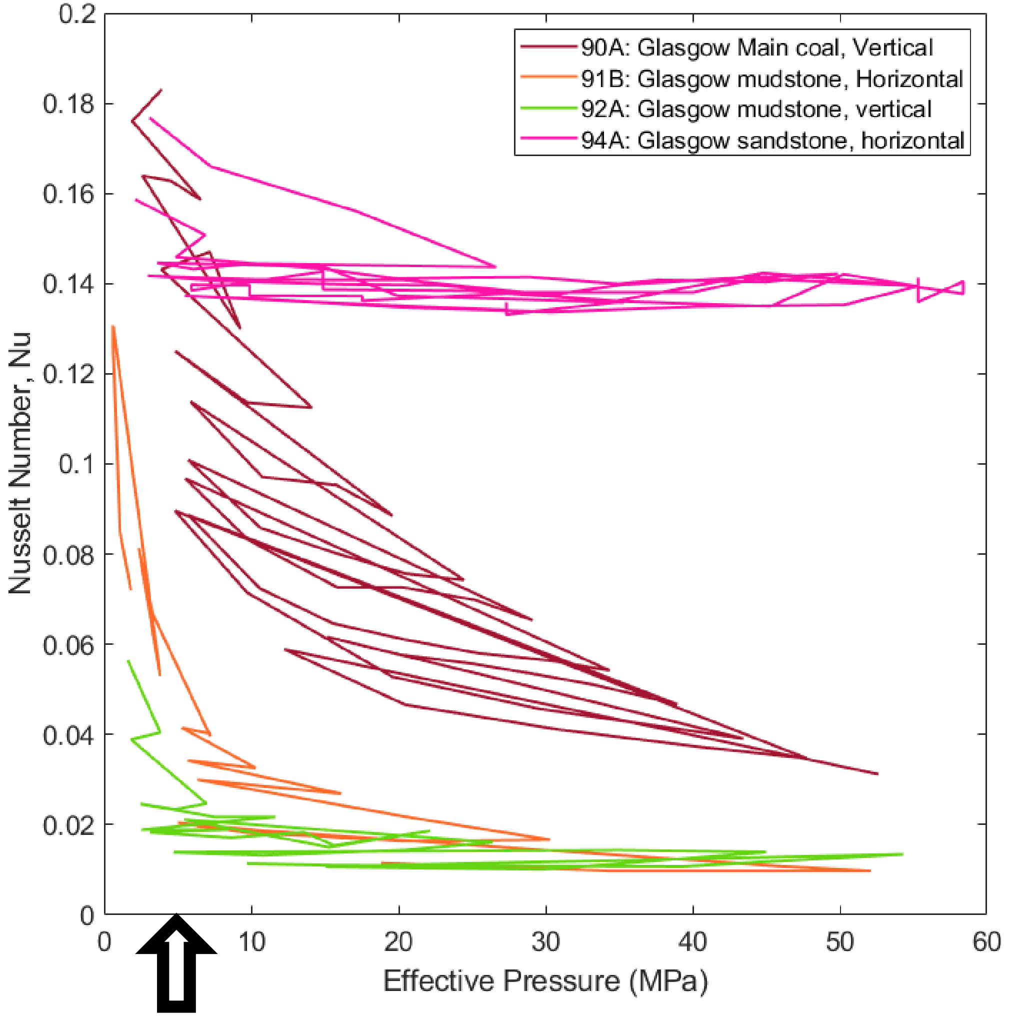


Figure reproduced from *Mckernan et al., (2017)*

The Nusselt number, Nu



- Nu is the ratio of convective to conductive heat transfer across a boundary.

$$Nu_L = \frac{h}{\lambda_{eff}/L}$$

- For external flow alongside a cylinder:
  $Nu_L = CRe^m Pr^{\frac{1}{3}}$ *(Hilpert, 1933)*
- Where

  Re is the Reynolds number:

$$Re = \frac{\rho q L}{\mu}$$

  Pr is the Prandtl number:

$$Pr = \frac{c_f \mu}{\lambda_f}$$

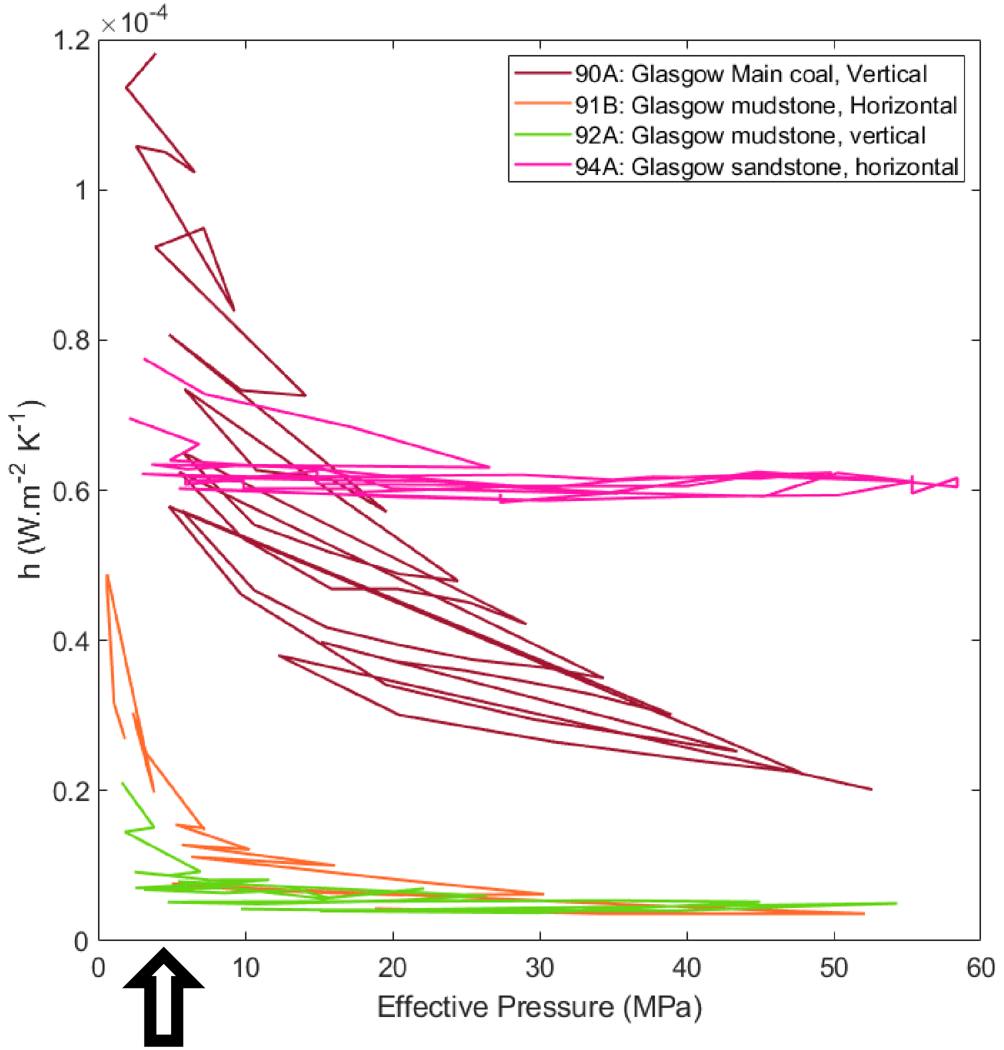
  C, m are constants

The heat transfer coefficient, h

- The heat transfer coefficient, h $(\mathrm{W.m^{-2}K^{-1}})$, is the proportionality constant between the heat flux and the temperature difference.

- Heat transfer in the coal is very pressure sensitive in comparison to the surrounding materials.

- *Watson et al., (2020)* estimate regional heat flow as $60\ \mathrm{mW.m^{-2}}$.



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Thanks for listening

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EGU2020-1225