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Thermal and Fluid Flows in Reservoirs

- A key component of the puzzle is an improved understanding of the thermal properties of igneous, metamorphic and sedimentary rocks and their potential for heat exchange, fluid flow and heat capacity at different scales.

- In particular, it has been shown that heat capacity and thermal conductivity are functions of temperature pressure and saturation, but these physics remain poorly understood for subsurface formations.

- Core and pore scale imaging and experiments will provide data on nano- and micro-scale flow and thermal diffusivity and will be scaled to core, well and reservoir scale using a variety of upscaling and machine learning methods.

- Once understood, an optimal heat recovery process must be designed which takes into consideration the aforementioned science.

- Work do date demonstrates that unless the pore level heat transfer (conduction and convection) is not well understood, we will always rely on empirical correlations to predict thermal behavior.

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- The equation for heat transfer is shown below.
- Based on this the effective thermal conductivity should fit the "parallel model".
- But if you look at the literature you will find numerous correlations.

$$(\rho c C_p)_m \frac{\partial (T)}{\partial t} + (\rho C_p)_f \mathbb{v} \cdot \nabla T = \nabla \cdot (k_m \nabla T) + q_m^m$$

$$(\rho C_p)\_m = (1-\varphi)(\rho C_p)_s + (\varphi)(\rho c)_f$$

$$k_m = (1-\varphi)k_s + (\varphi)k_f$$

$$q_m^m = (1-\varphi)q_s^m + (\varphi)q_f^m$$

The thermal conductivity of the pure solid is a "mystery". Here it is assumed to be quartz

- Some of these correlations are plotted for reference purposes.
- There is absolutely no rational in the choice of the correlation.
- These are for single phase system and ambient conditions.

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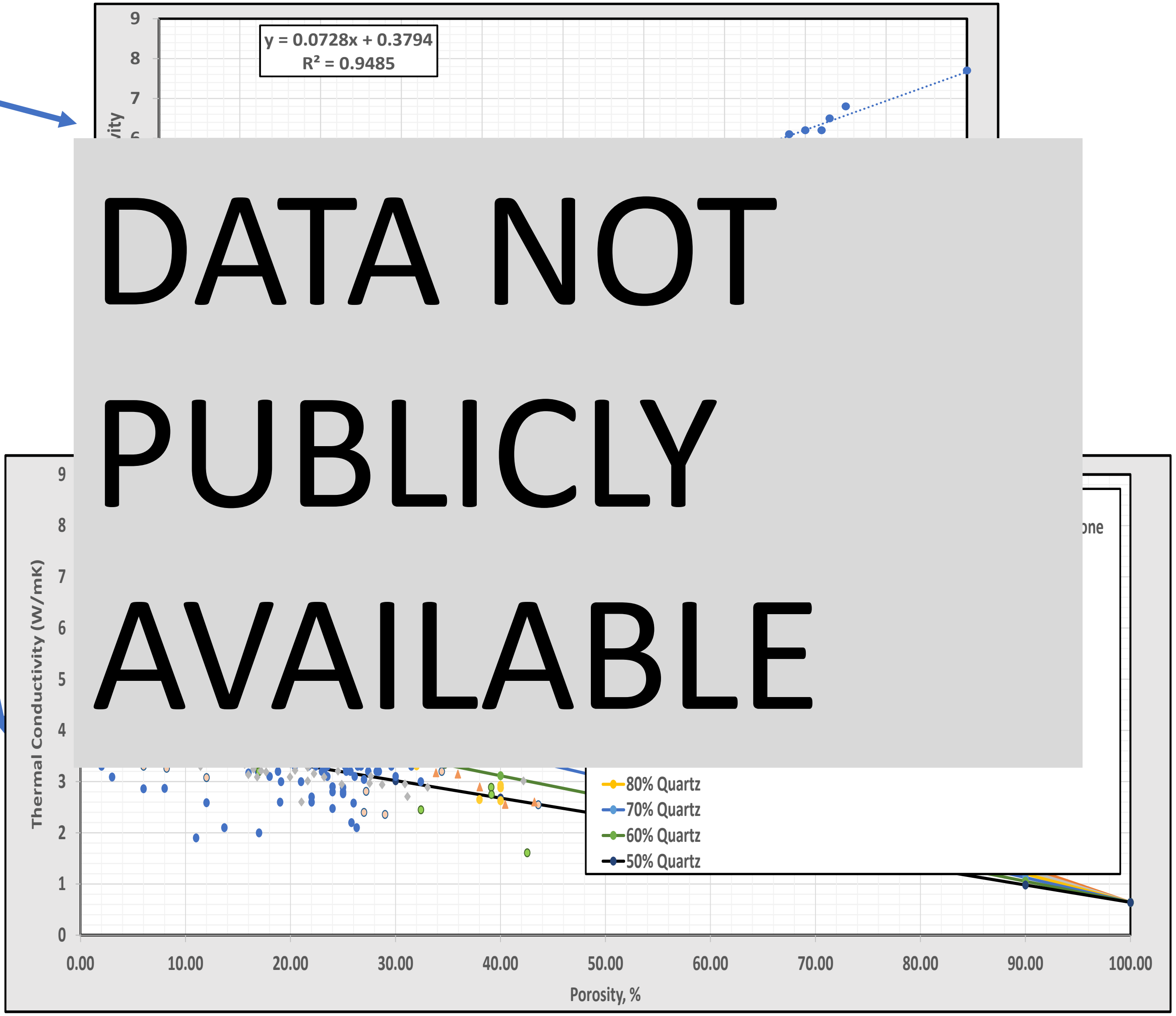
- The value of the solid thermal conductivity is a strong function of mineralogy and in high quartz content it can be linear with quartz fraction.

- If the parallel model is true one can extrapolate for the solid thermal conductivity.
- Also, we can develop compositional models based on the thermal conductivities of the minerals, say via x-ray diffraction.

- But then why should the choice of fluids affect the thermal conductivity selection model?
- Also, as porosity increases, we transition from a consolidated medium to a packing to a slurry, to a suspension.
- Should the same correlations apply for all porosities?
- Some correlations explicitly claim validity for narrow porosity ranges. Why?



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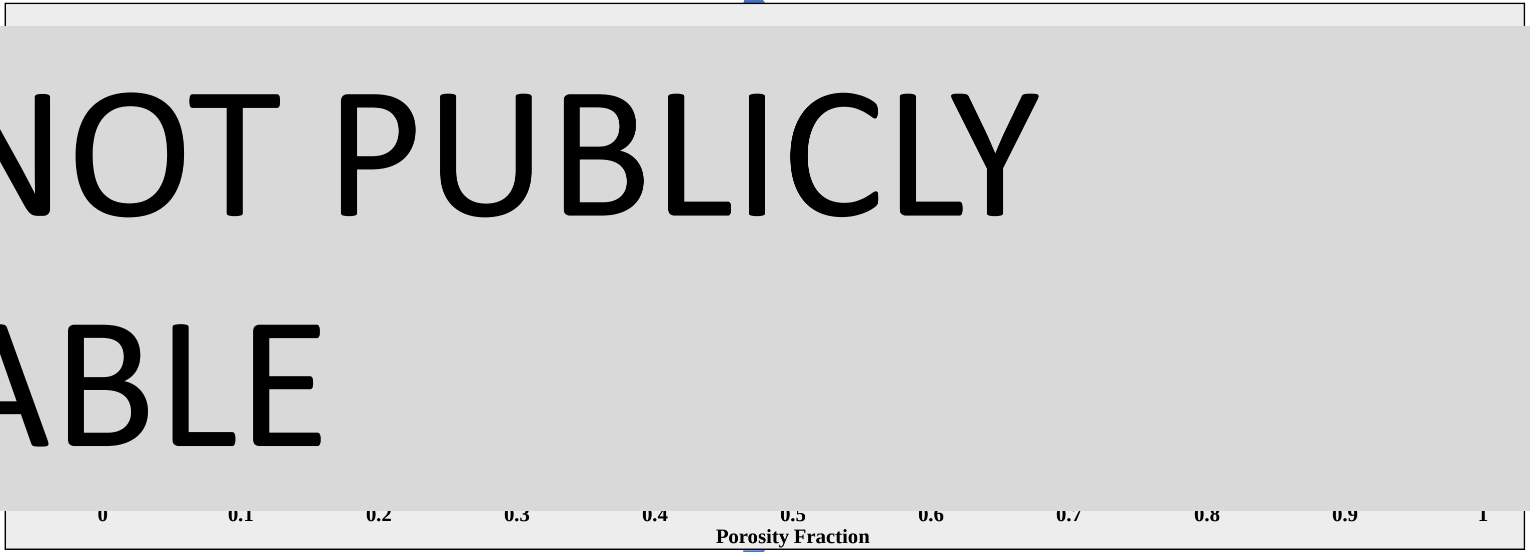
Thermal and Fluid Flows in Reservoirs

- Is there a correlation between dry and saturated core sample effective thermal conductivities?

DATA NOT PUBLICLY AVAILABLE



- In this data set the relative effective thermal conductivity is equal to the square root of porosity.
- There is no reason for this to happen.
- And, of course, there is considerable scattering of the data.
- This implies that the experimental error bars may be high.

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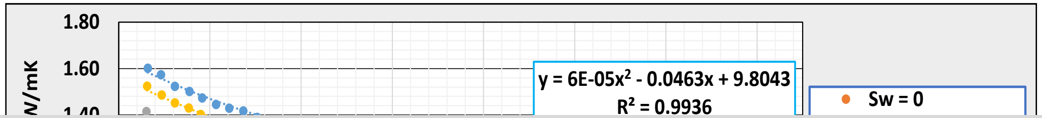
- Effects of saturation and temperature are also fairly complex.



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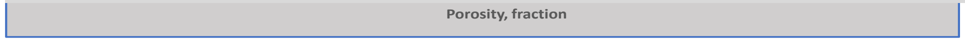
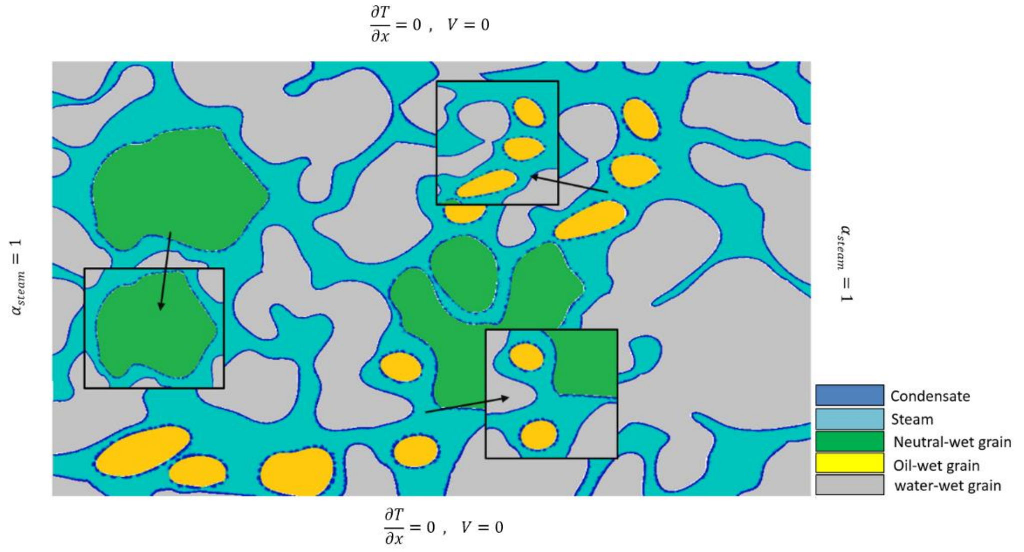


- The Nikolaev et al. correlation can be used to match a number of different experimental data.
- But it has 10 coefficients that need to be determined for EACH sample under testing.
- Generic coefficients for some data groups can be used as starting points.
- So experimental measurements are a must, but they are highly contested in the literature.

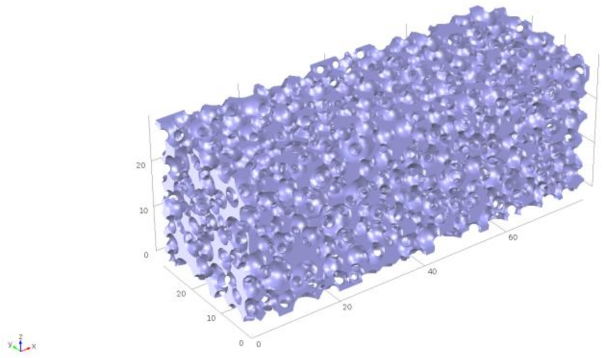
$$Ke\,(S_r, T) = \frac{a_1 + a_2 S_r + a_3 S_r^2 + a_4 S_r^3 + a_5 T}{1 + a_6 S_r + a_7 S_r^2 + a_8 T + a_9 T^2 + a_{10} T^3}$$

Thermal and Fluid Flows in Reservoirs

- Macroscopic modelling is not able to explain what are the possible contributors in the discrepancies in effective thermal conductivity predictions.
- The answer lies with pore level modelling.



- In pore level models we can specify the mineralogy, wettability and thermal conductivity of each pore and each grain.
- We can also build artificial media of specified geometries.
- What is not clear is whether a 2-D model can properly predict low porosity systems where both fluid and solid must be continuous.
- In suspensions this might not be a problem.



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- Preliminary modelling shows that for water saturated media the parallel model does not work (contrary to earlier work from our group).
- The geometric mean model seems to work better.
- Computational Multiphysics models are used.

DATA NOT PUBLICLY AVAILABLE

- Please note there are 2-D and 3-D models in the graph, and they do not perfectly align.
- There are several issues of how the solid grains touch, how the fluid wets the grains.
- Also meshing has become a major pain in properly generating realistic representations of grain-to-grain contacts.

Thermal and Fluid Flows in Reservoirs

- Looking at dry media, the models are at least consistent, and the geometric model predicts both water and air saturated media.

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- When we are looking for relative effective thermal conductivity the models a qualitatively matching experimental data.

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Thermal and Fluid Flows in Reservoirs

- In summary, there is a lot of work that needs to be done to quantify measurement s and modelling of effective thermal conductivity.
- We have also identified other areas where we can make contributions in the geothermal field.
- We propose an extensive research program focusing around this area.
- We already have the first two partners, and we are looking for more.

Research Areas

- Thermal energy flow at the reservoir, well and pore scale to understand thermal conductivity of heterogenous materials and the role of convection.
- Effects of scaling and corrosion on equipment and reservoir performance.
- The geochemistry of hot fluid transfer.
- Nanofluids and nano-conducting materials.
- CO_2 capture and geothermal utilization.
- Pore level modelling of heat transfer.
- New experimental techniques for heat transfer measurements.