The scale dependence of permeability: Effects of pore-throat size distribution and pore connectivity

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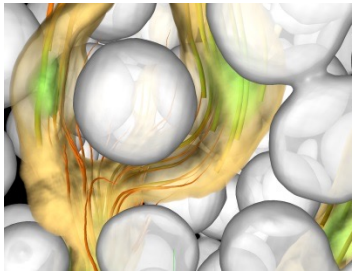
2021 AGU Fall Meeting

Introduction

Scaling: A long-standing issue in subsurface hydrology

Pore



http://subsurface.pnl.gov

nanometers

Core

http://physics.aps.org

centimeters

Lysimeter

http://www.gfz-potsdam.de

meters

Field

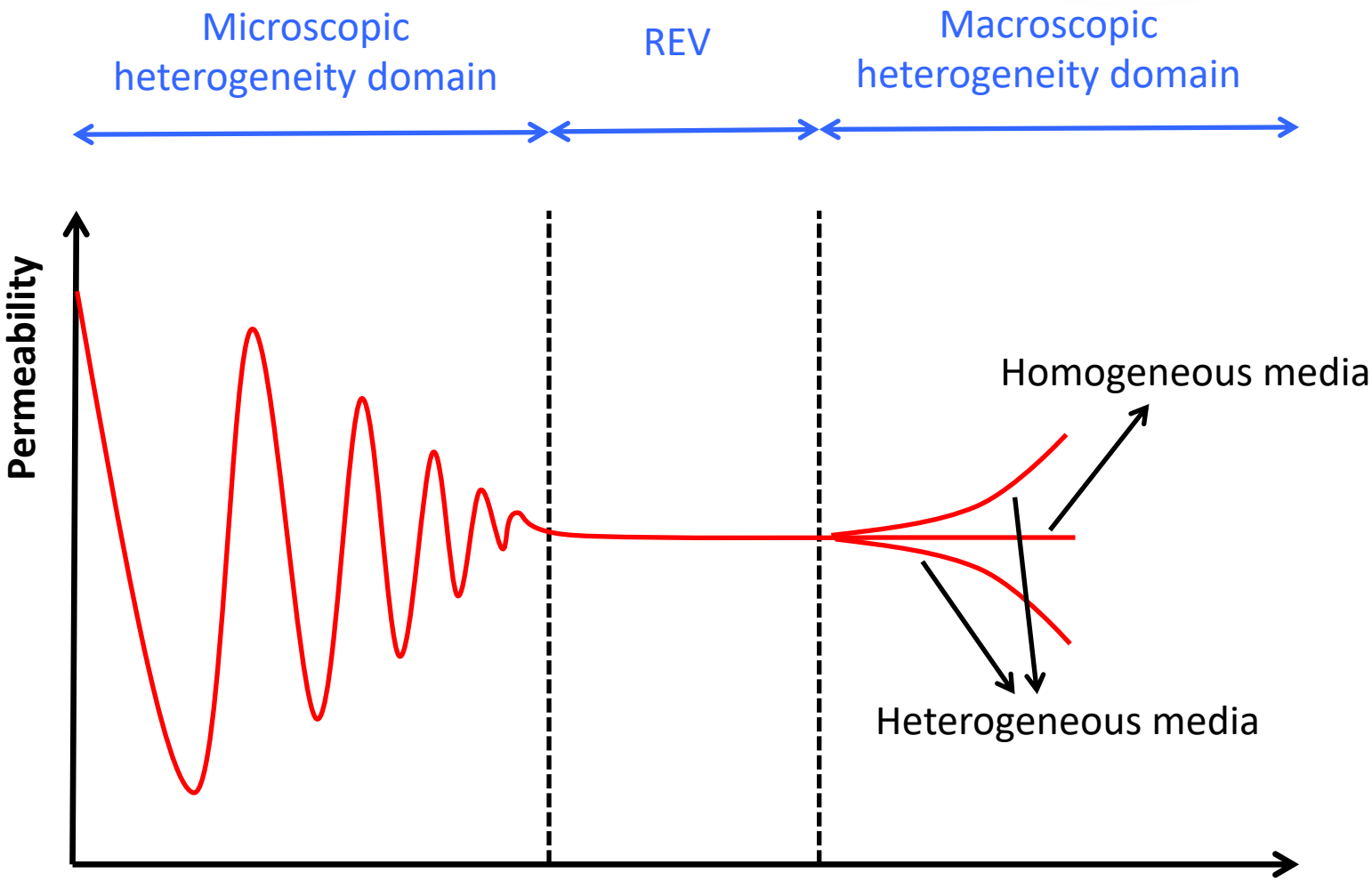
http://www.siliconinvestor.com

kilometers

7 orders of magnitude

5 orders of magnitude

Introduction



Bear (1972)

Objectives

(1) Investigating the effect of small-scale heterogeneity on scale-dependent permeability

(2) Providing a rigorous theoretical foundation for the interpretation of the scale dependence of permeability

(3) Investigating the increasing or decreasing trend of permeability with scale

Pore-network simulations

Generating pore networks

We used regular cubic lattices with coordination number Z = 1.5, 1.65, 1.75, 2, 3, 3.25, 3.5, 4, 5, and 6.

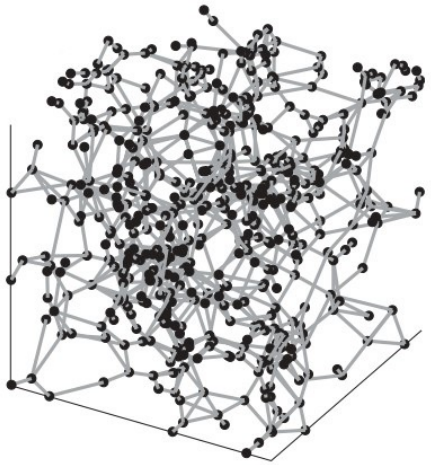
- **Networks 1.1 – 1.4**
  Pore-throat radius: 0.1-10 μm

- **Networks 2.1 – 2.4**
  Pore-throat radius: 1-50 μm

- **Networks 3.1 – 3.4**
  Pore-throat radius: 10-75 μm

In networks 1-3, pore-throat length l_t = 100 μm.

- **Fontainebleau sandstone networks**
  (Lindquist et al., 2000)



A 3D pore-network composed of pore throats and pore bodies (after Valvatne, 2004)

Pore-network simulations

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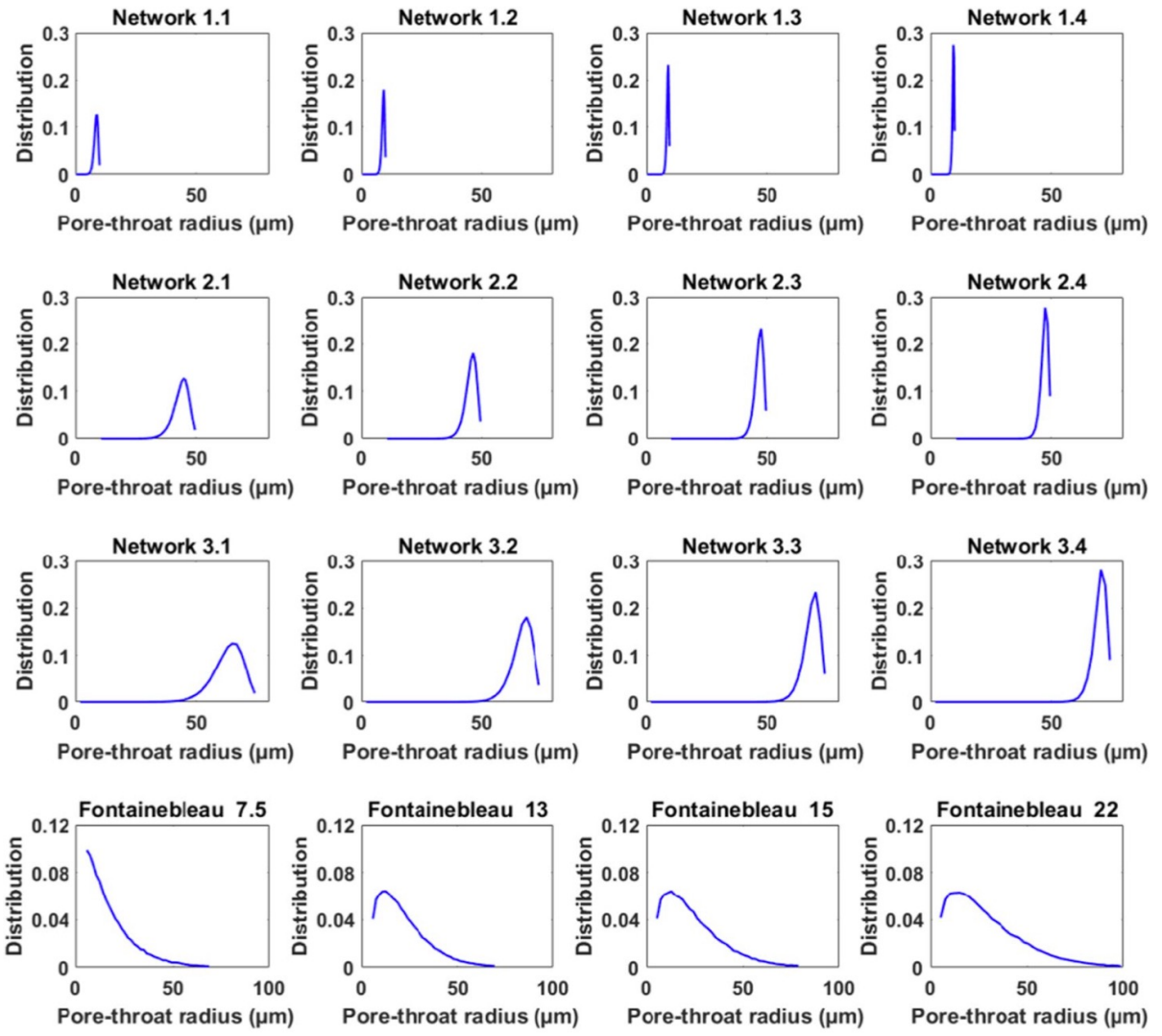
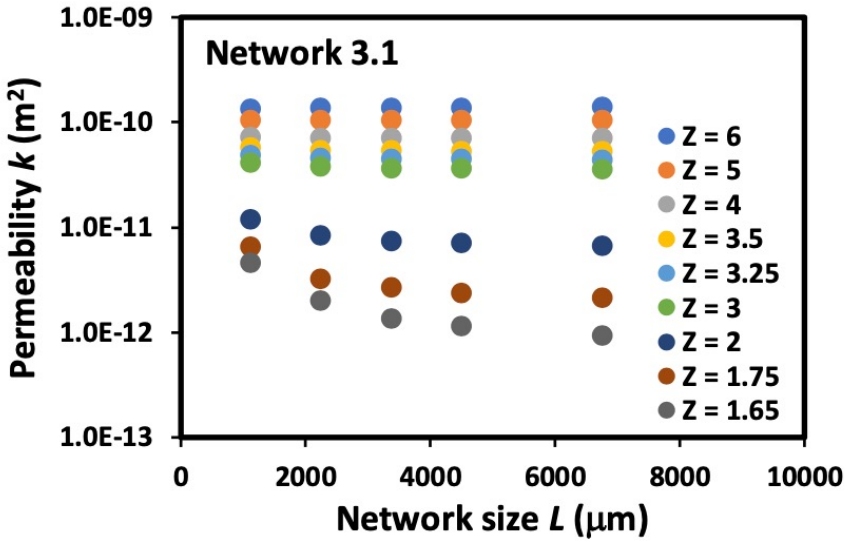
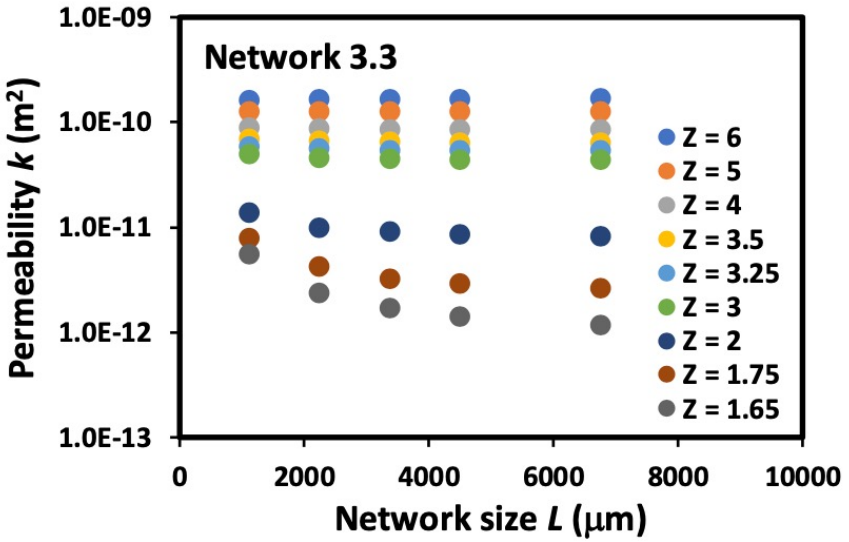
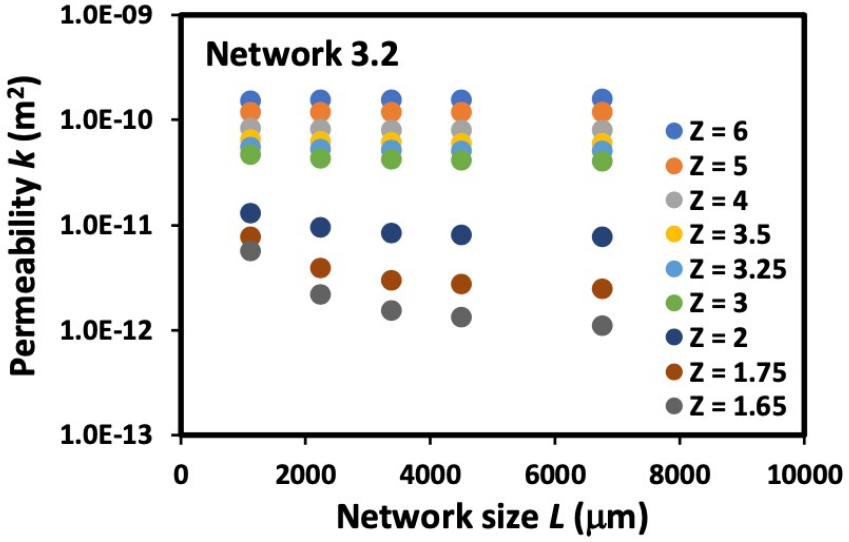
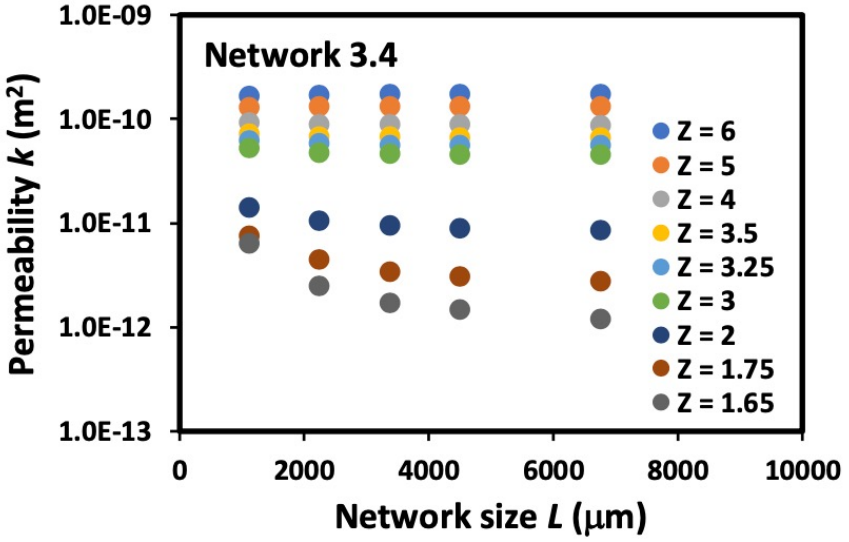


Results: Pore-network simulations





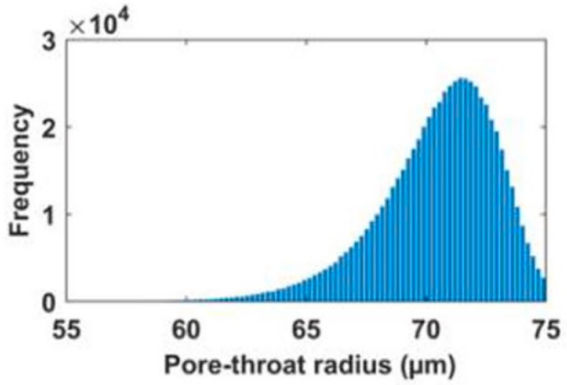


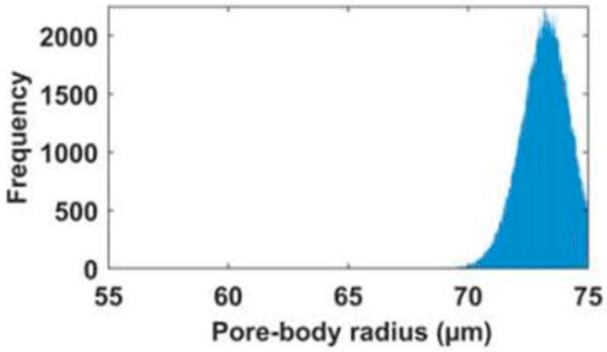


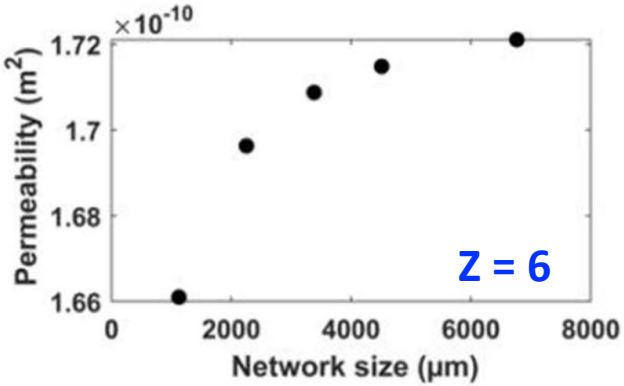
Results: Pore-network simulations

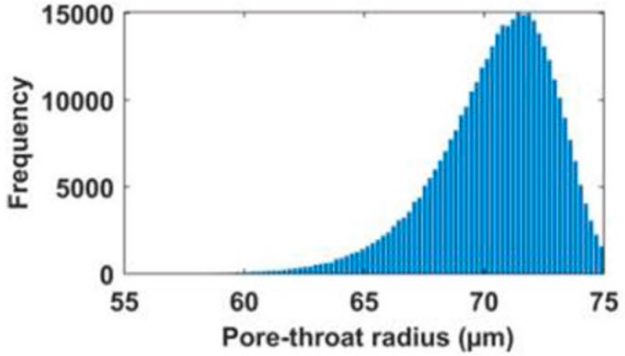
For the synthetic pore networks, we find a transition in the scale dependence of the permeability, with our results indicating that the permeability increases with the scale for larger pore coordination numbers, whereas the opposite is true for smaller *Z*.

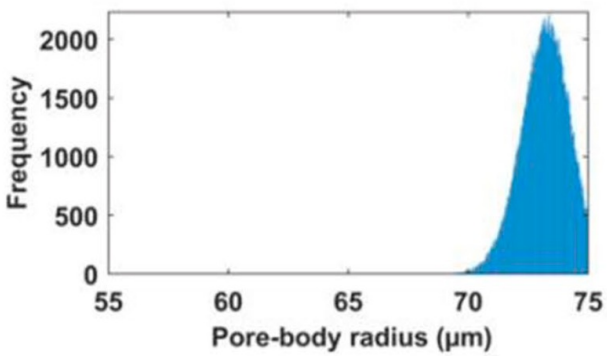
Network 3.4

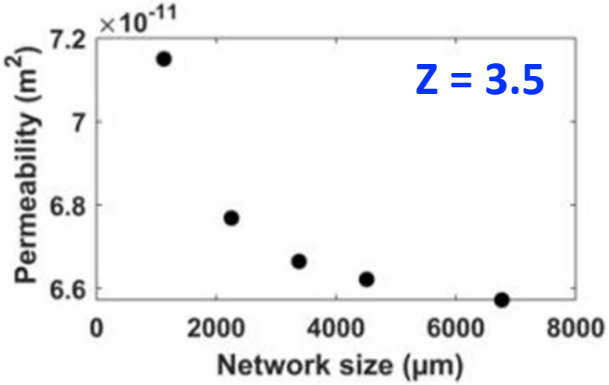






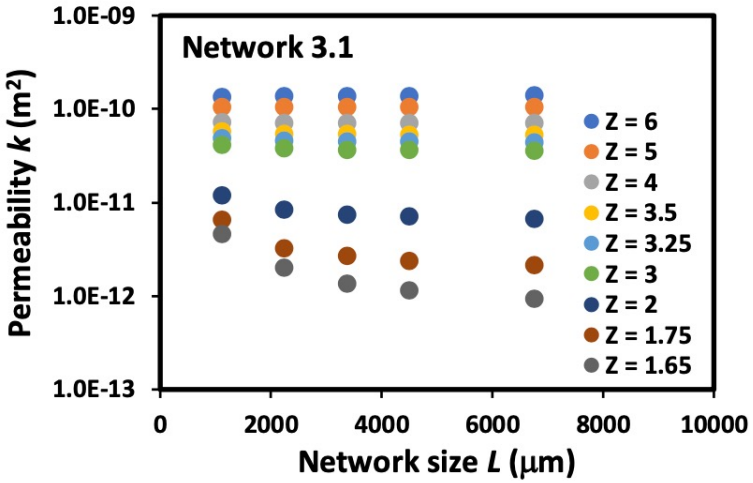


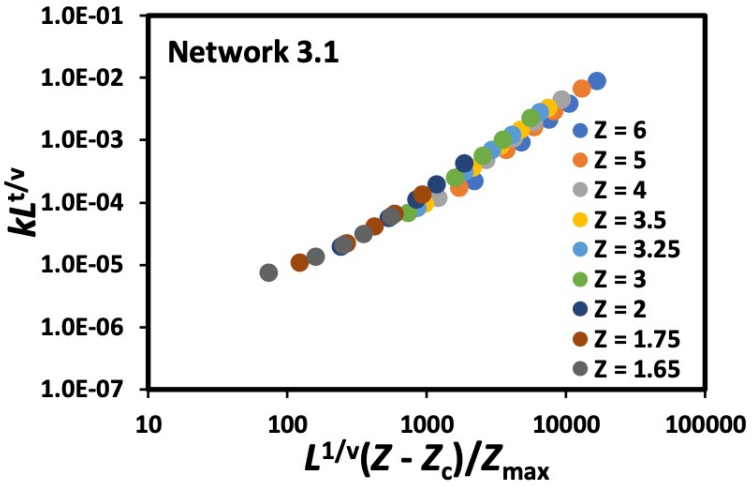


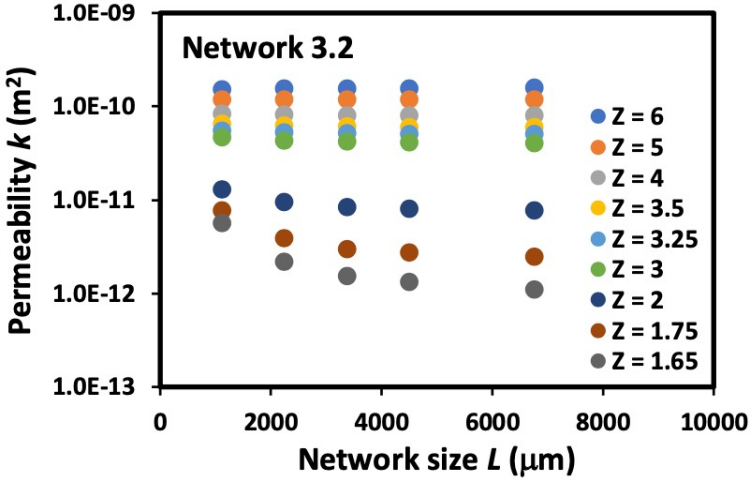


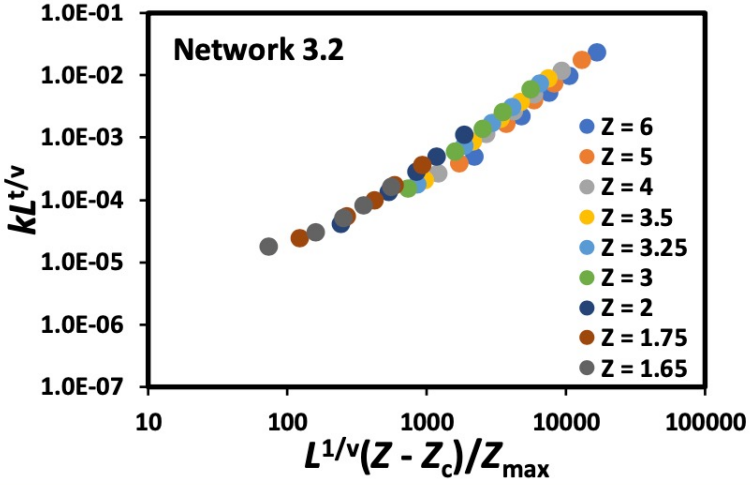
Results: Finite-size scaling analysis

$$k = L^{-\frac{t}{\nu}} f\left[L^{\frac{1}{\nu}}(p - p_c)\right] \quad \Rightarrow \quad k = L^{-\frac{t}{\nu}} f\left[L^{\frac{1}{\nu}}(Z - Z_c)/Z_{max}\right]$$









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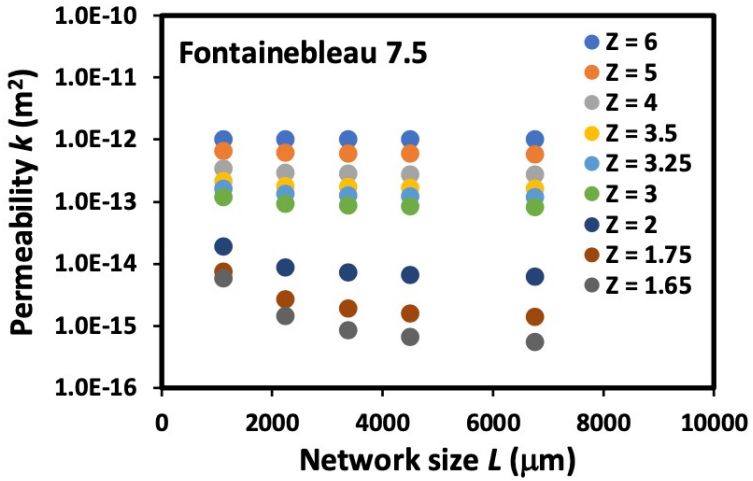

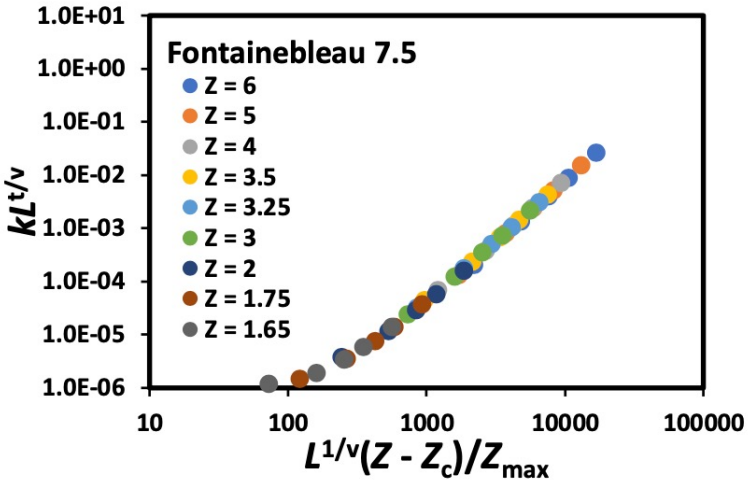

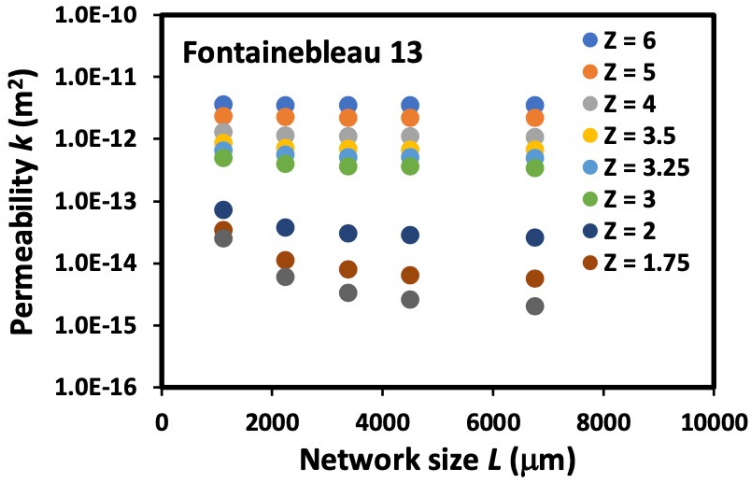

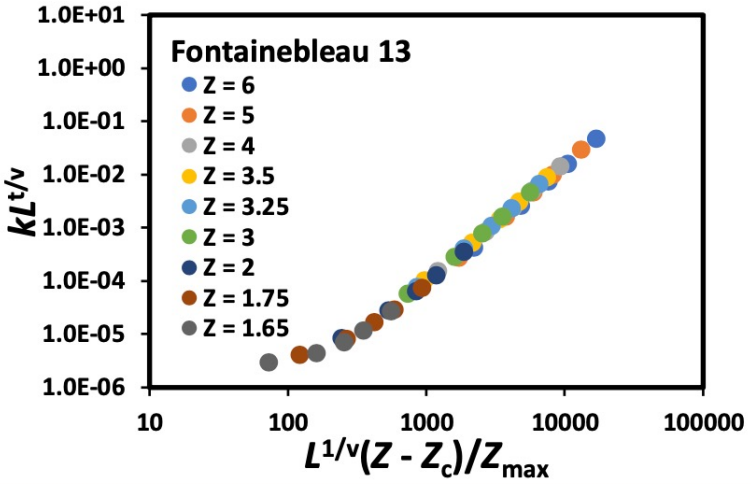

Conclusion

- **We found a transition in the scale dependence of the permeability.**

- **Depending on pore-throat radius distribution broadness, permeability may increase or decrease with scale.**

- **The modified finite-size scaling analysis results in perfect collapse in data indicating a quasi-universal trend.**

Questions?