Wormholing in anisotropic media: Pore orientation effect on large-scale patterns

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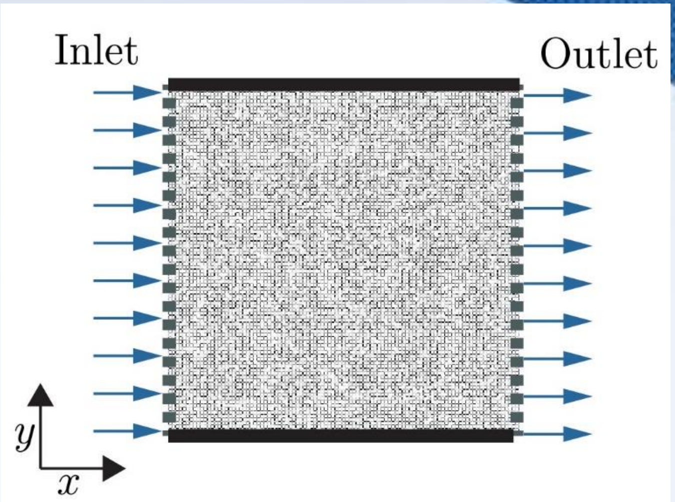
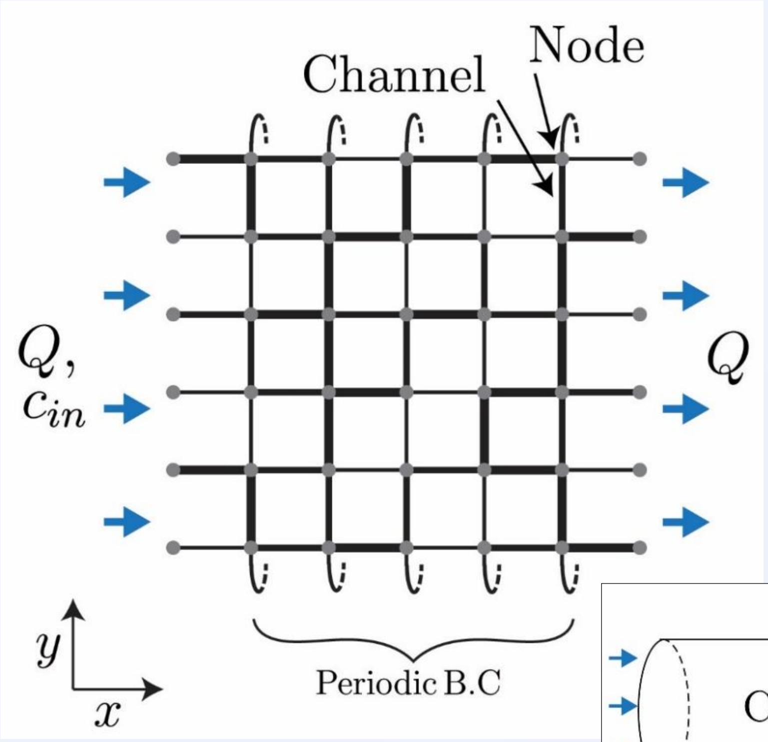
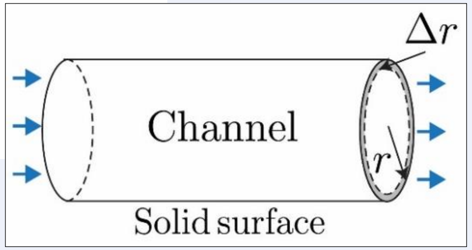
The network model



- Reactive flow is studied using analog model of network of cylindrical channels (Hoefner and Fogler, 1988; Roded et al., 2018)



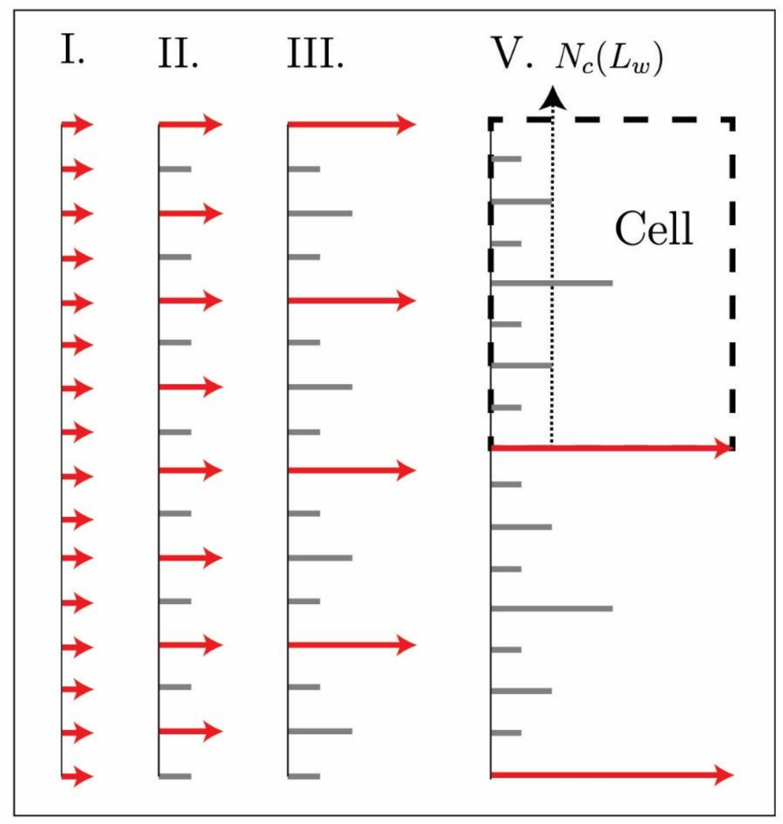


- Fluid fluxes resolved from mass conservation of fluid
- Solute concentrations and solid dissolved from solute conservation equations
- Solute transport by advection and diffusion, and 1st-order reaction

Wormhole competition

- Positive feedback between reaction and transport

- Longer wormholes increase their flow on the expanse of shorter ones and screens them off



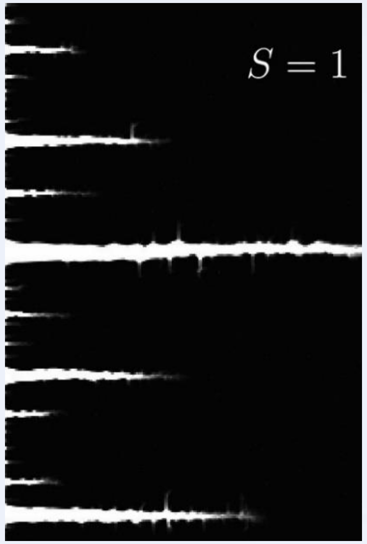
- Hierarchical scale-invariant distribution of wormhole lengths (Szymczak & Ladd, 2006)

$$N(L_w) \sim L_w^{-\alpha} \quad where \quad \alpha \approx 1$$

- Shared dynamics and patterns to other unstable growth processes, e.g. viscous fingering

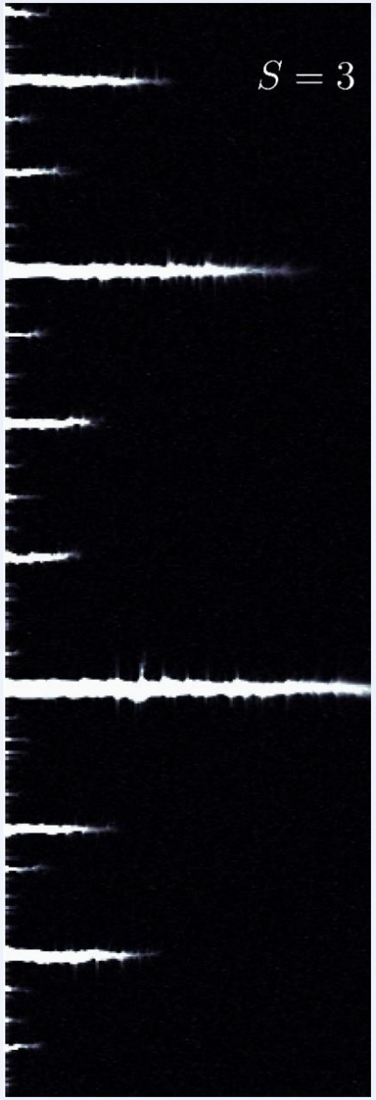
Wormholing in anisotropic media

Isotropic



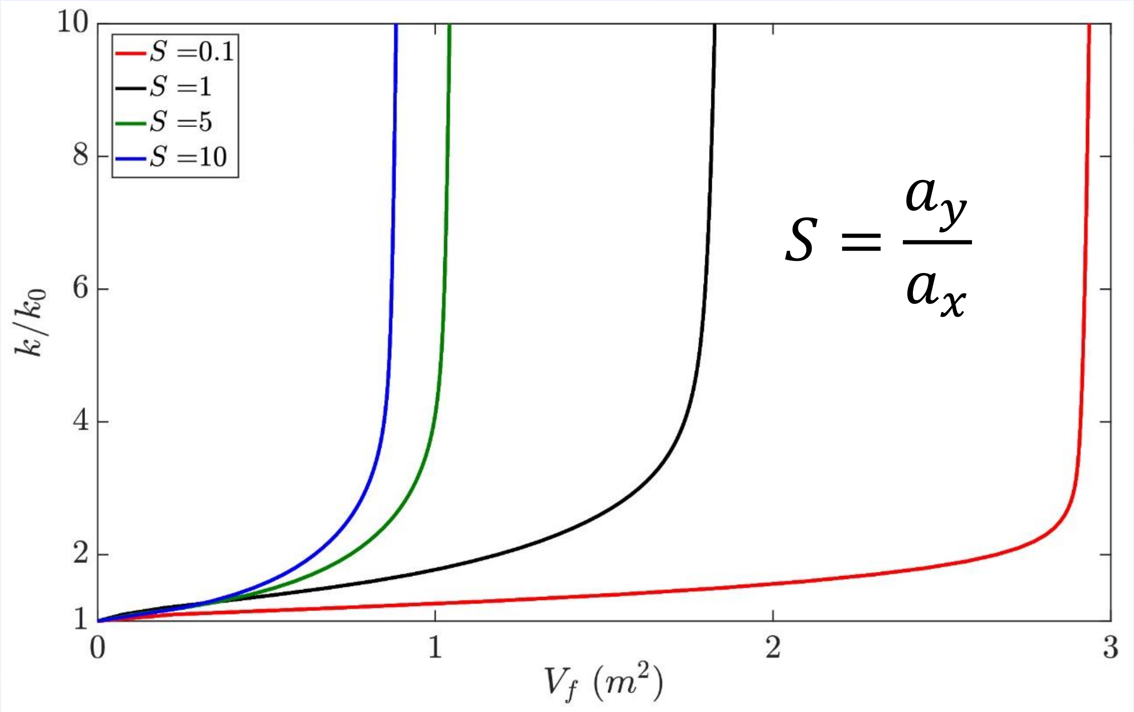
Small transverse channels

Large transverse channels



- Anisotropy alter wormholing pattern and permeability evolution

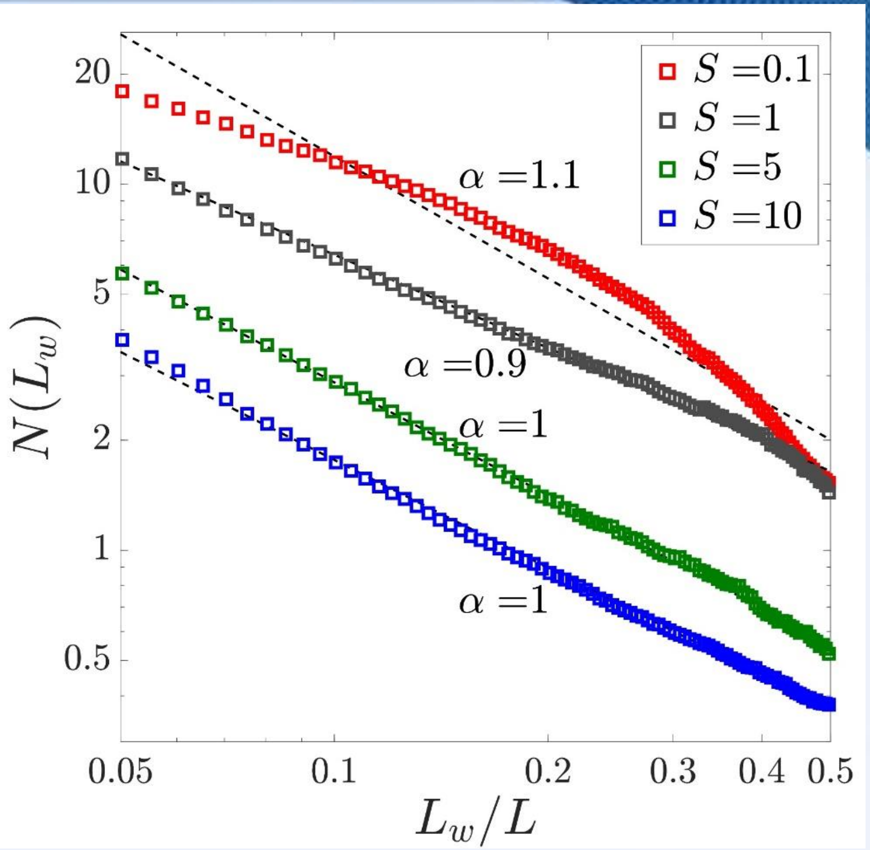
- For large *S*, enhanced interaction via the pressure field results in stronger competition

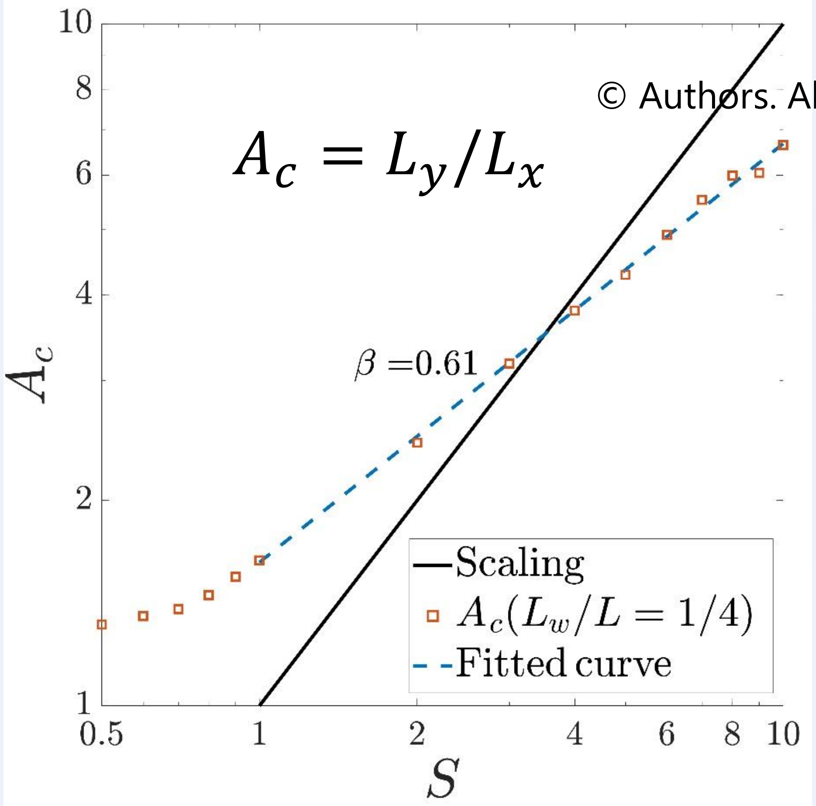


Wormhole distribution

- For larger *S* the power-law distribution with $\alpha \approx 1$ is kept, however not for $S<1$

- Consistent with recent experiments of viscous fingering in a microfluidic networks (Budek et al., 2015)

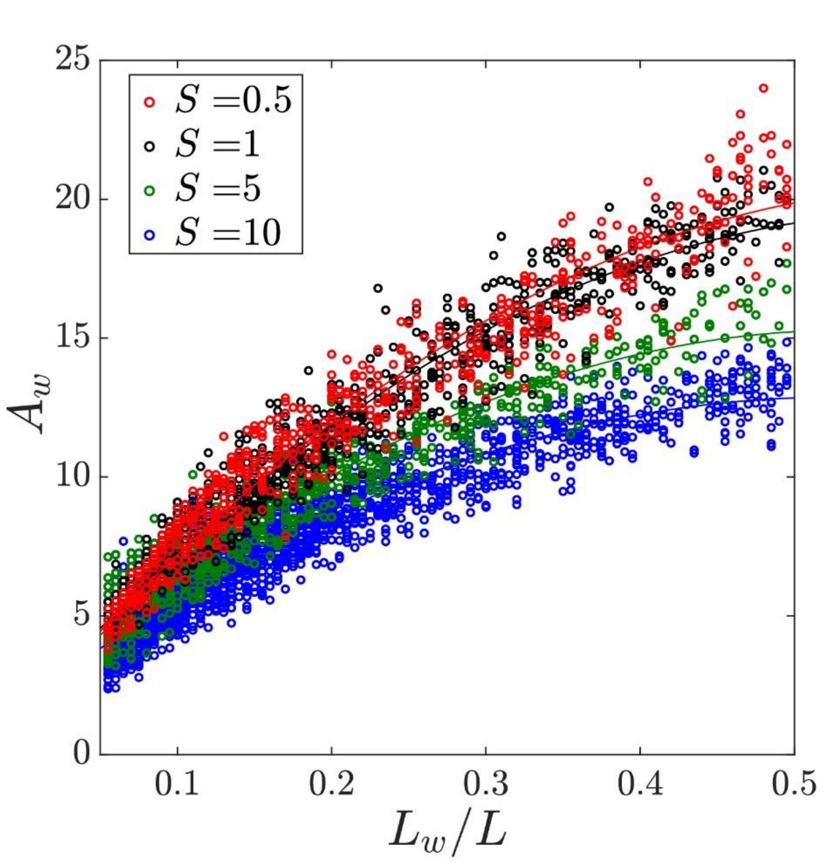




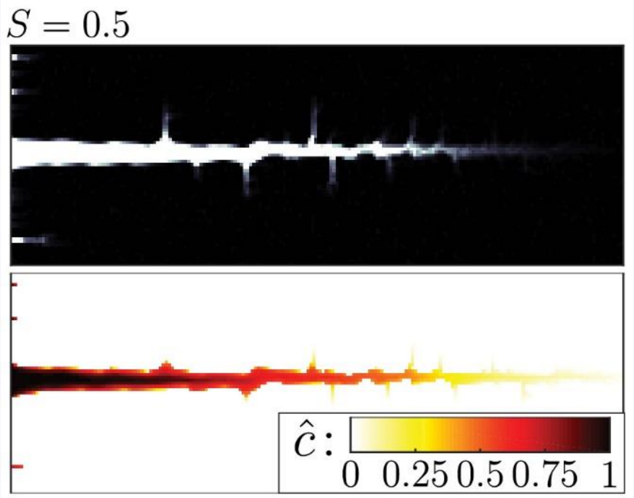
- Accordingly, spacing and aspect ratio scales linearly with *S*, $A_c \sim S$

- Here, while A_c increases with *S* it does not follow a linear trend but shows a fit to power-law, $A_c \sim S^{\beta}$

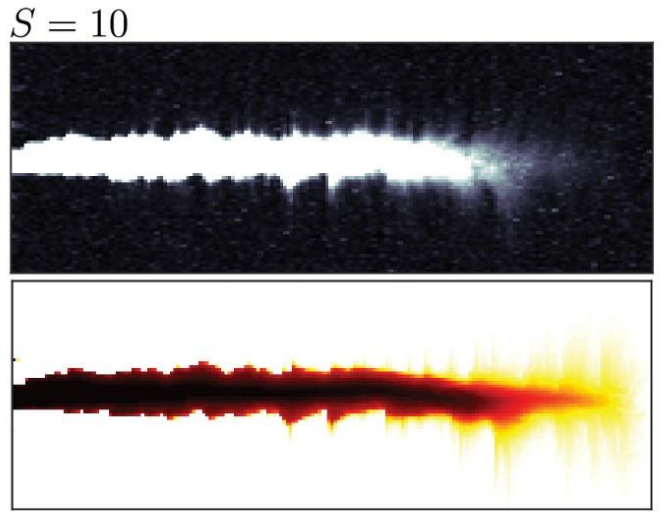
Wormhole shape



- Smaller S associated with larger wormhole aspect ratio, $A_w = L_w/b$



- Smaller S and spacing lead to reactivity decay and conical wormholes



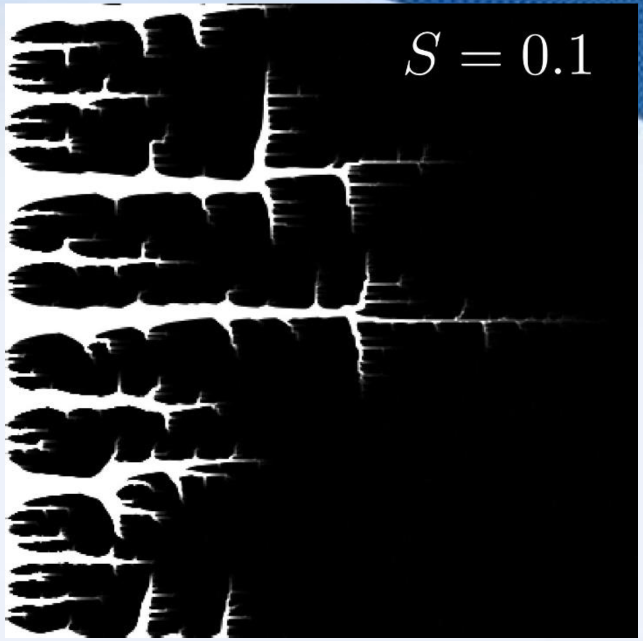
- For large S wormhole widen downstream as flow governs

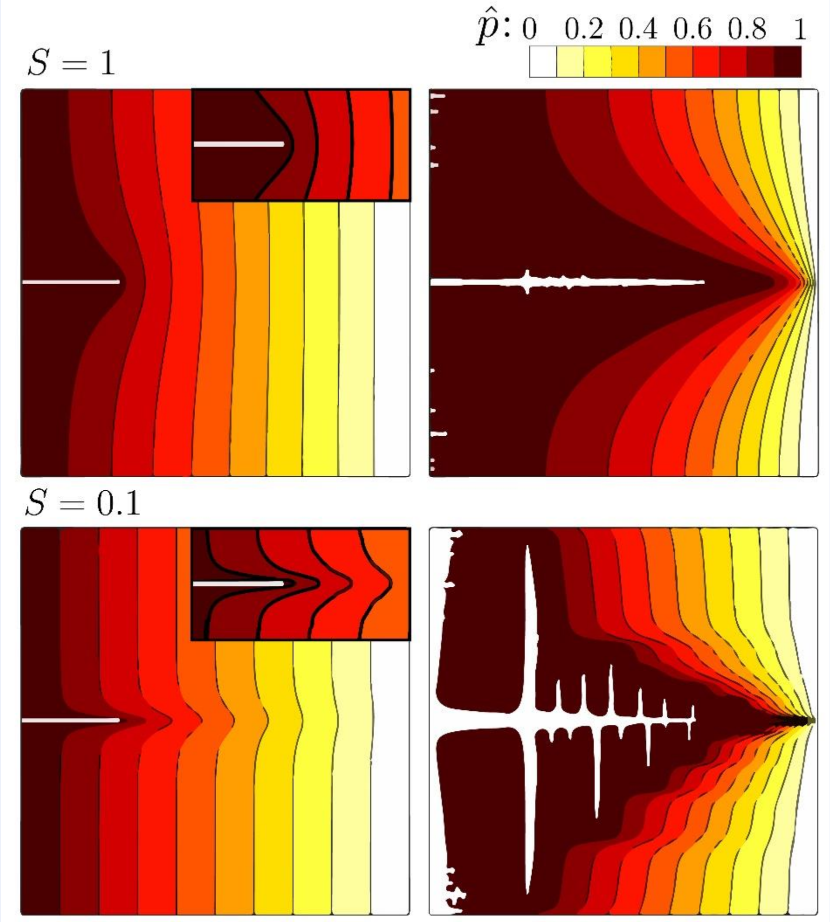
- A_w tends to level-off

Low *S* conditions

- Competing side-branches

- We use a simple system with a central preexisting channel





- For *S*=0.1 pressure perturbation induced by the channel, decays sharply in the transverse direction

- Promote sideways directed flow and development of branches

Conclusions

- Anisotropy alter wormholing pattern and permeability evolution, including:
    i. Wormhole competition and the characteristic separation
    ii. Wormhole shape and tendency to develop side-branches
- Findings are comparable with results of similar process– viscous fingering
- However, while in viscous fingering for $S \gtrsim 1$ spacing scales linearly with S, the increase is non-linear for wormholing
- This could be attributed to the effect of anisotropy on wormhole shape and advancement velocity, and remains the subject for future investigation

References

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- Roded, R., Paredes, X. and Holtzman, R., 2018. Reactive transport under stress: Permeability evolution in deformable porous media. *Earth and Planetary Science Letters*, *493*, pp.198-207.
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- Szymczak, P. and Ladd, A.J.C., 2006. A network model of channel competition in fracture dissolution. *Geophysical Research Letters*, *33*(5).