Jackson School of Geosciences

Modeling Episodic Fluid Migration in Salt Basins: Model Development

Preston Fussee-Durham
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Outline

- Introduction

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- Model Construction

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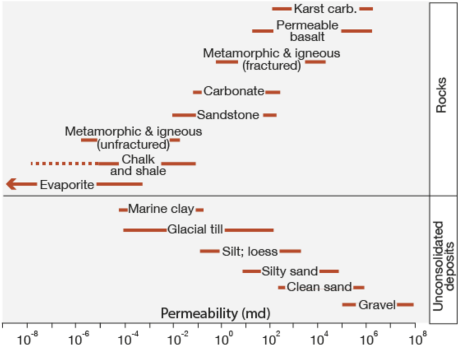
- Future Work

Salt: An absolute seal?

- Long been considered to be impermeable and provides a seal for hydrocarbon accumulations in geological structures



(Beauheim and Roberts, 2002)

Salt: An absolute seal?

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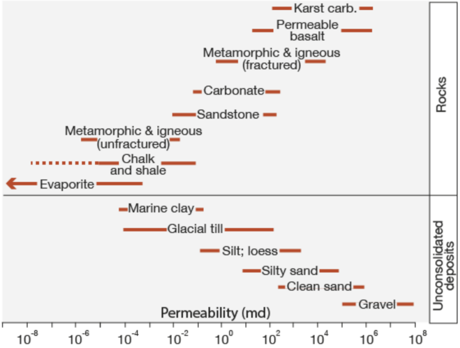
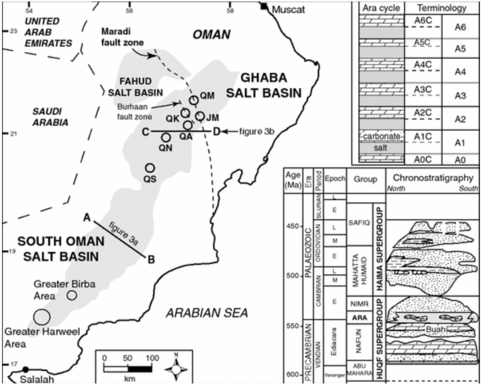
- Potential to isolate nuclear waste from ambient groundwater



(Beauheim and Roberts, 2002)

Field Observations: Ara Group, Oman

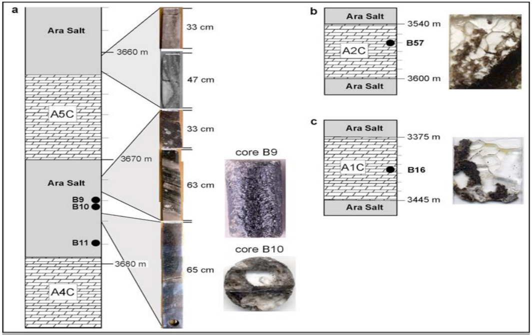
- Ara group (terminal Neoproterozoic to Early Cambrian age)
- Porous dolomitic carbonates encased in salt at depths of 3-5 km



(Schoenner et al. 2007)

Field Observations: Ara Group, Oman

- Ara Salt: One of the best examples of oil stained rock salt



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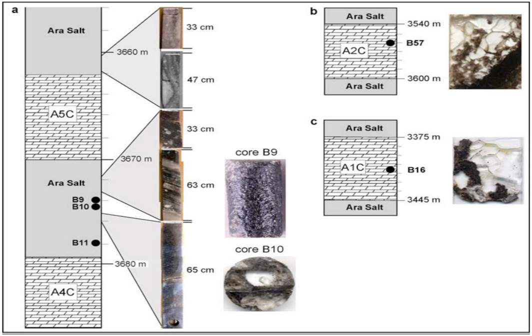

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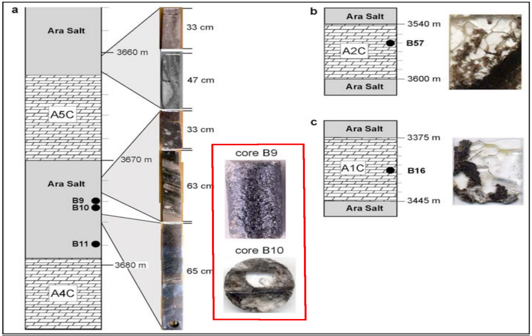

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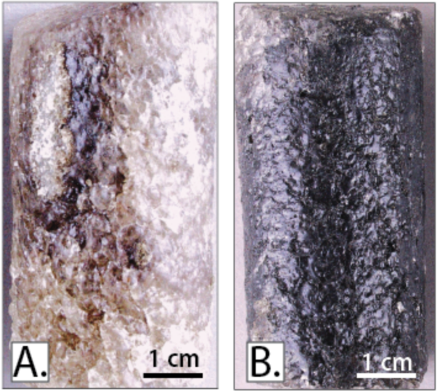
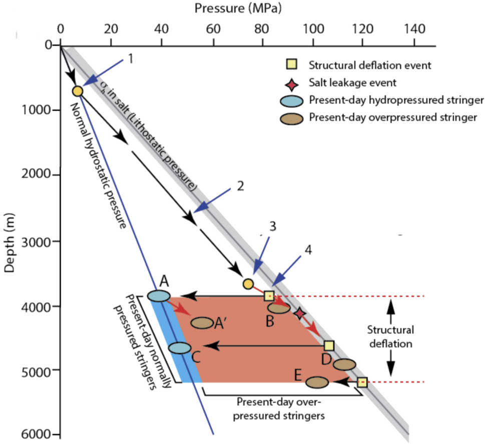


(Kukla et al., 2011a, b)

Burial History: Stringer Reservoirs, Oman

- **1.** Salt encases the carbonate stringer (zero fluid flow out of reservoir)



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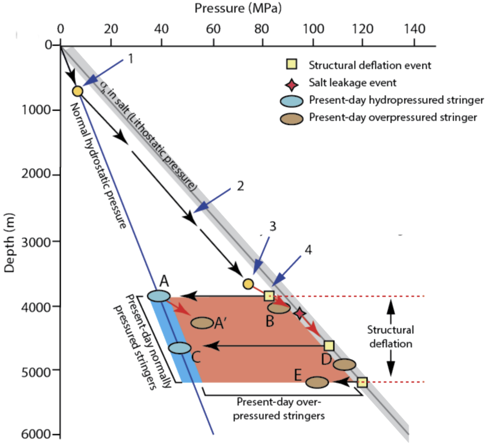

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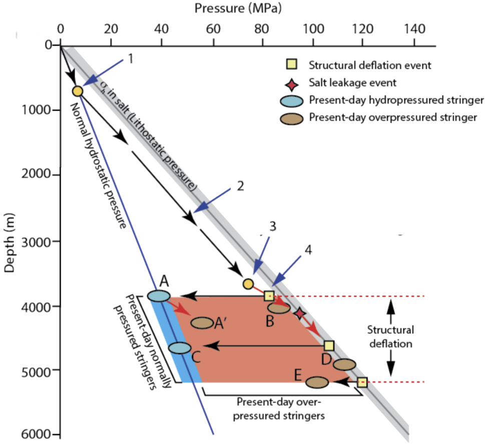

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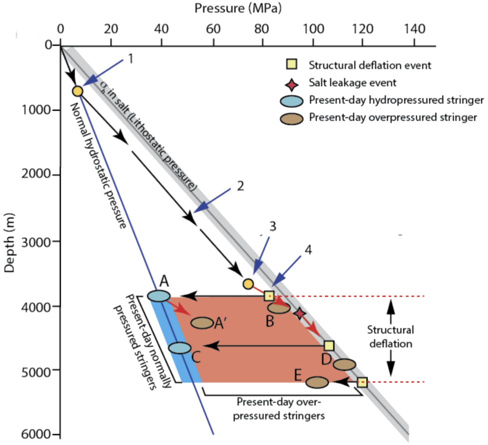
- **2.** Fluid pressure increases as a result of burial
- **3.** Onset of insitu generation of hydrcaros in encased stringers
- **4.** Fluid pressure in salt exceeds lithostatic pressure



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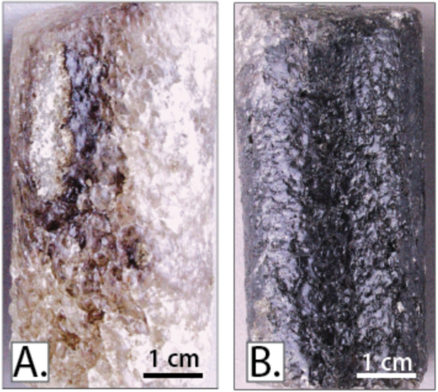
Field Observations: Ara Salt, Oman

Oil likely entered the salt at near-zero effective stress!



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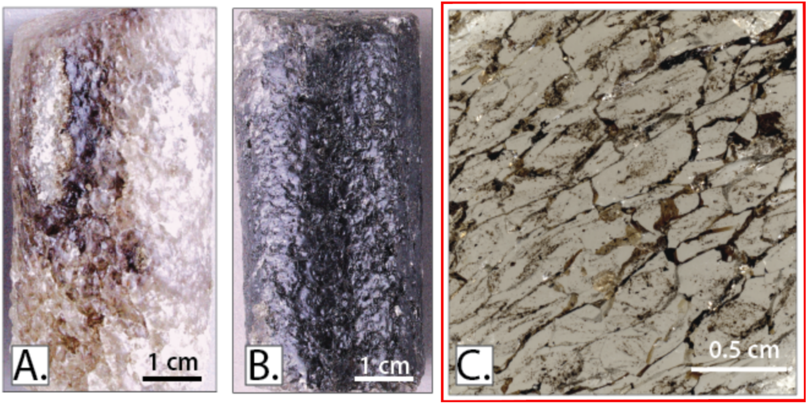
Field Observations: Ara Salt, Oman

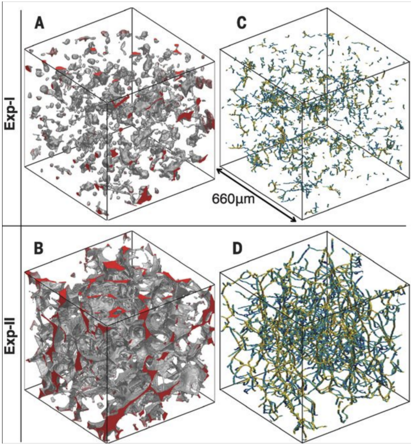
Presence of a connected pore network?



(Kukla et al., 2011a, b)

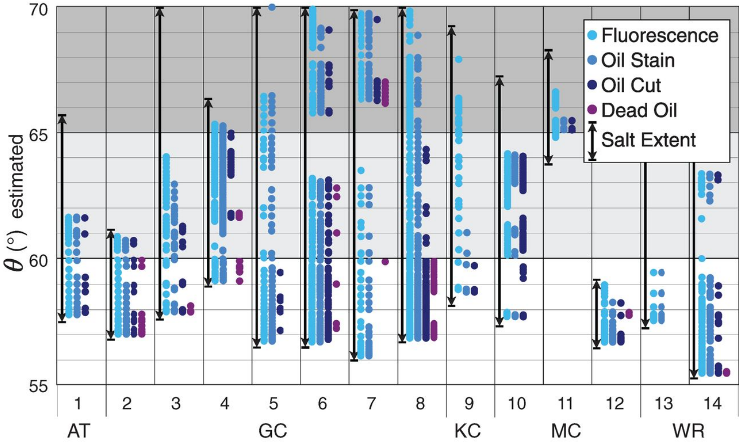
Connected Pore Network in Salt:

- Hydrostatic experiments on synthetic rock salt performed at $P = 20$ MPa and $T = 100°$C (Exp-1) and $P = 100$ MPa and $T = 275°$C (Exp-2)
- (**A** and **B**): 3D reconstruction of the pore network
- (**C** and **D**): Skeletonized pore network extracted from the reconstructed 3D volume



(Ghanbarzadeh et al., 2015)

Field Observations: Gulf of Mexico



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Remark

- The conditions for seal loss of rock salt are not well understood on geologic timescales

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  - **Observation:** elevated pore fluid pressures
  - **Observation:** connected pore network in salt

Research Questions

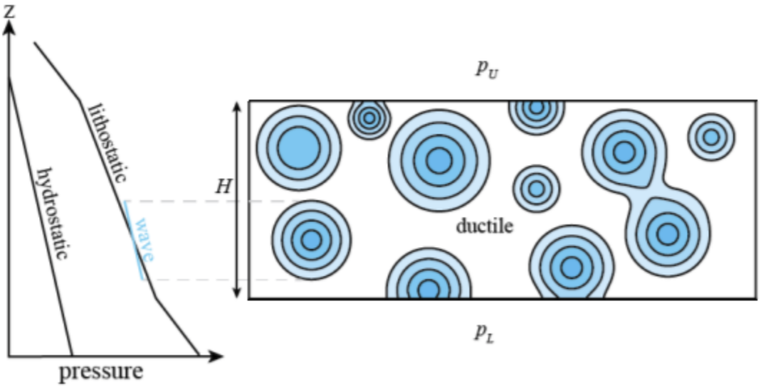
Question 1: What are the hydrodynamical consequences of assuming salt behaves as a viscous fluid?

Question 2: Under such a deformation mechanism, what conditions lead to the failure of a salt-seal?

Goal:

1. Construct a numerical model for fluid flow in a highly viscous deformable medium subjected to a constant fluid over-pressure ($p_f > p_s$)

Model 1: Concept



Model 1: Governing Equations

Evolution of the Porosity: Dimensionless

$$\frac{\partial \phi}{\partial t} = P\phi^m$$

Evolution of the Pore Fluid Pressure: Dimensionless

$$-\nabla \cdot [\phi^n \nabla P] + P\phi^m = -\nabla \cdot [\phi^n z]$$

- where $n \in [2, 3]$ and $m \in [0, 1]$

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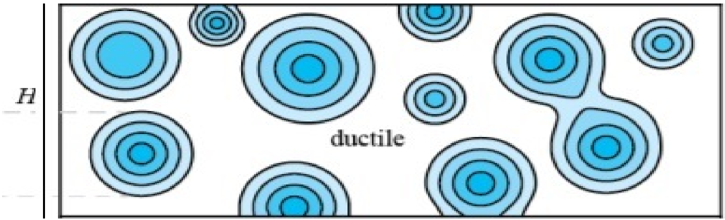
Model 1: Boundary Conditions

No Flow Boundary Conditions

$$\nabla P \cdot \hat{n} = 0 \quad \forall\, x, y \in \Gamma$$

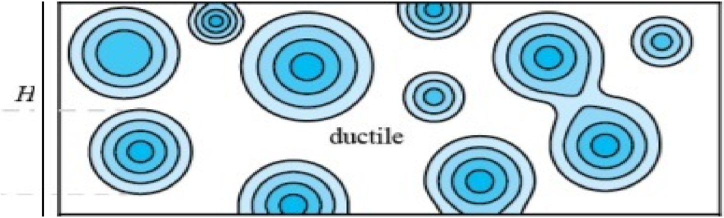


Model 1: Boundary Conditions

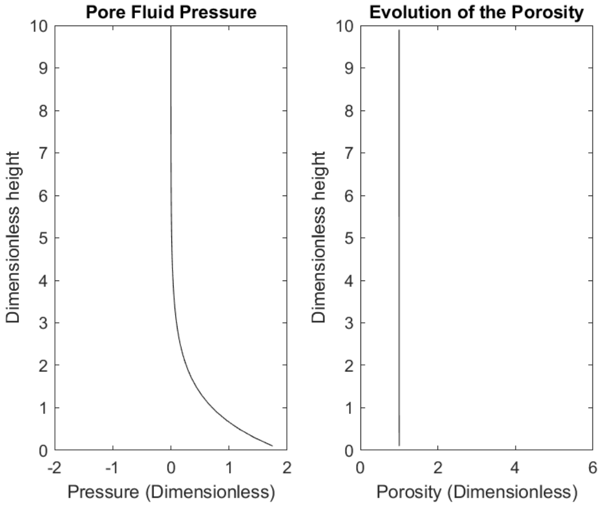
Pressure Boundary Conditions

$$P = 0 \quad \forall\, x, y \in \Gamma_{top}$$

$$P = 1.75 \quad \forall\, x, y \in \Gamma_{bottom}$$



Model 1: One-dimensional simulation



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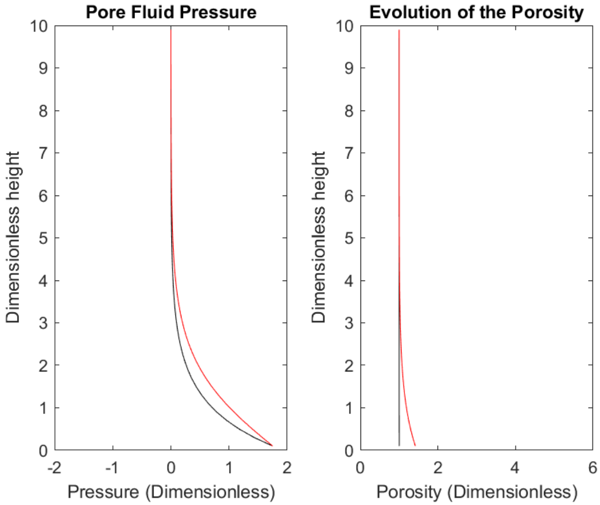

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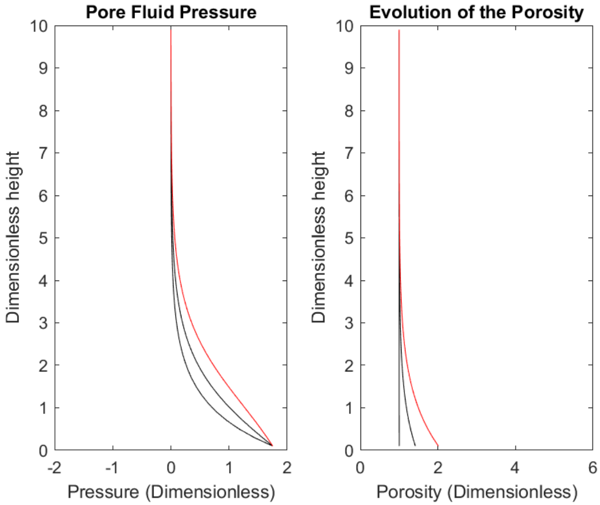

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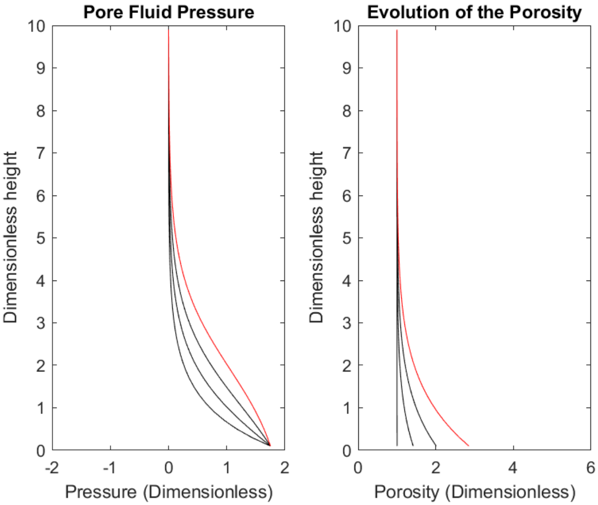

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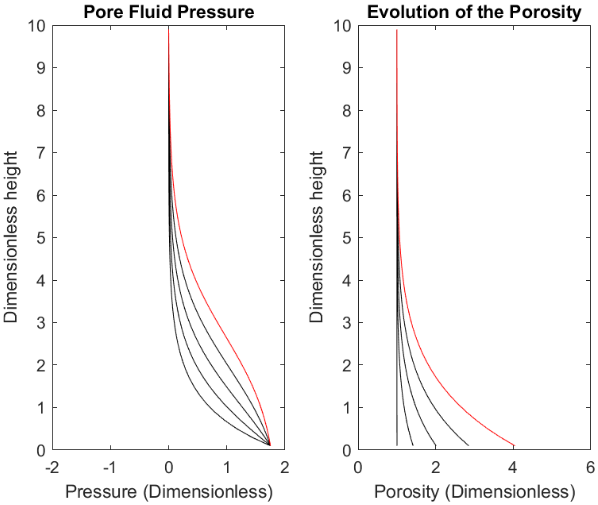

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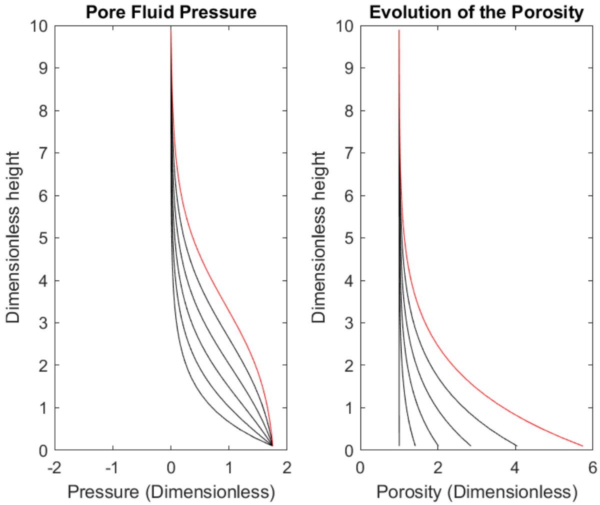

Model 1: Results

- Imposing a constant pore fluid overpressure at the base of a ductile layer leads to a system that lacks physical significance

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- Need to find constraints on the evolution of the porosity

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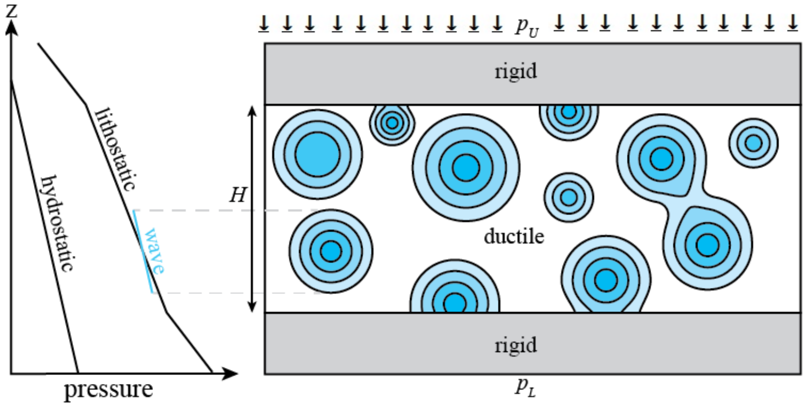
2. Construct a numerical model for fluid flow in a highly viscous deformable medium with both underlying and overlying elastic reservoirs

Model 2: Concept



Model 2: Governing Equations (Strong Form)

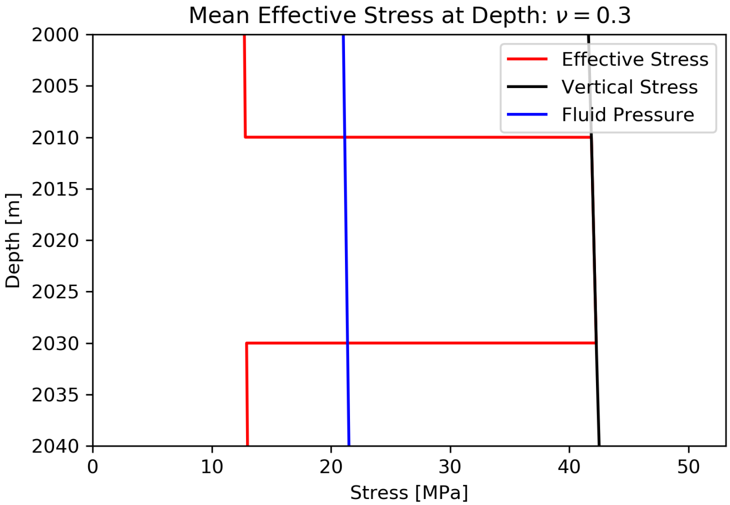
Fluid Pressure: Elastic

$$\underbrace{\alpha \frac{(1+\nu)}{3(1-\nu)} \frac{\partial p_f}{\partial t}}_{\text{Compaction}} - \underbrace{\nabla \cdot \left[\frac{k}{\mu} (\nabla p_f + \rho_f g \hat{z}) \right]}_{\text{Darcy's Law}} = \underbrace{\alpha \frac{(1+\nu)}{3(1-\nu)} \Psi \rho_{sed} g}_{\text{Sedimentation}} + f_s$$

Fluid Pressure: Viscous

$$\underbrace{\nabla \cdot \left[\frac{k}{\mu} \nabla p_f \right]}_{\text{Darcy's Law}} + \underbrace{\frac{\phi^m}{\zeta_0} p_f}_{\text{Deformation}} = \underbrace{\frac{\phi^m}{\zeta_0 (1-\phi)} \left[\int_0^z \rho_s g dz + \Psi \rho_{sed} g t \right]}_{\text{Sedimentation}} + f_s$$

Model 2: Stress analysis



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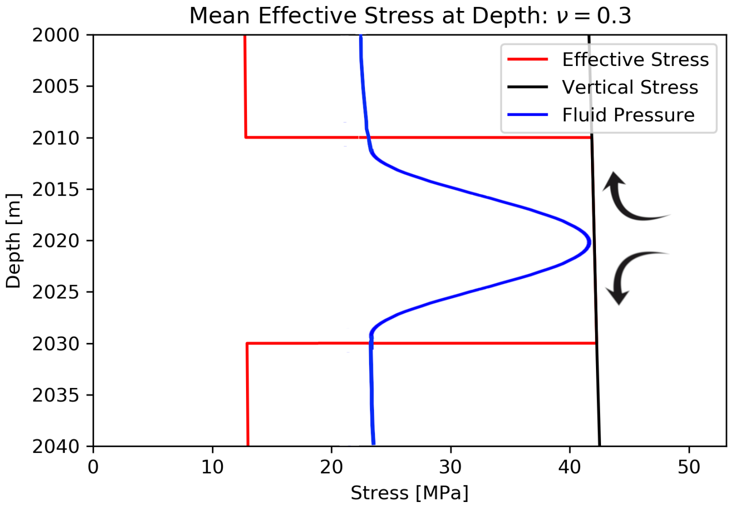

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- Likely need another source of pressure generation (kerogen transformation)

Future Work

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- Analyze system behavior

Acknowledgements

- Advisor:
  - Dr. Marc Hesse
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  - Evan Ramos
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  - Dr. Omar Ghattas
  - Dr. Nicholas Espinoza
- Dr. Jaime Barnes
- Dr. Mark Cloos
- Sarah Greer
- Honors Program

Questions

"Far better an approximate answer to the right question, which is often vague, than an exact answer to the wrong question, which can always be made precise" - John Tukey