Geostorage of CO_2
Estimating Accessible Rock Mass Pore Volume: De-Risking CCS Projects

Maurice B Dusseault

Earth and Environmental Sciences Dept.

University of Waterloo

PV - De-Risking CCS for Industry

- Drilling a well for detailed site assessment:
  - 5-10 MM$ onshore
  - **×10** ≈ 50-100 MM$ for offshore
- **Before this investment**, there must be confidence that **sufficient PV** is available
- Regional assessment of potential CO_2 **PV** available in Atlantic Canada is essential for de-risking
- But, **PV** for CCS is not the same as total **PV**!
  - Lithostratigraphic assessment (depth, thickness, etc.)
  - Petrophysical properties of the target stratum
  - Probabilistic estimates of parameters
  - Stress-state evaluation
  - …

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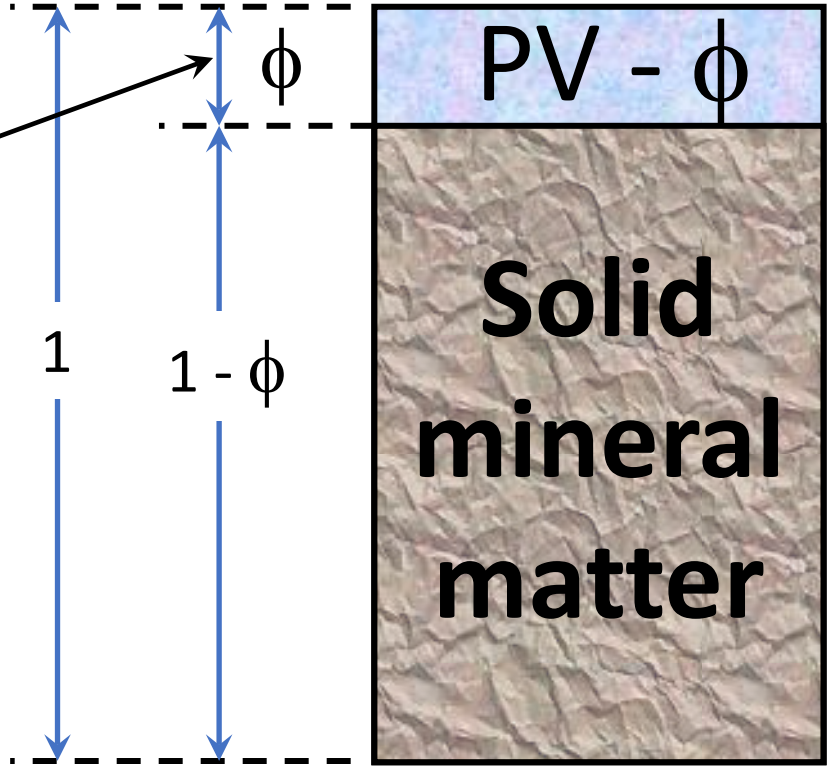
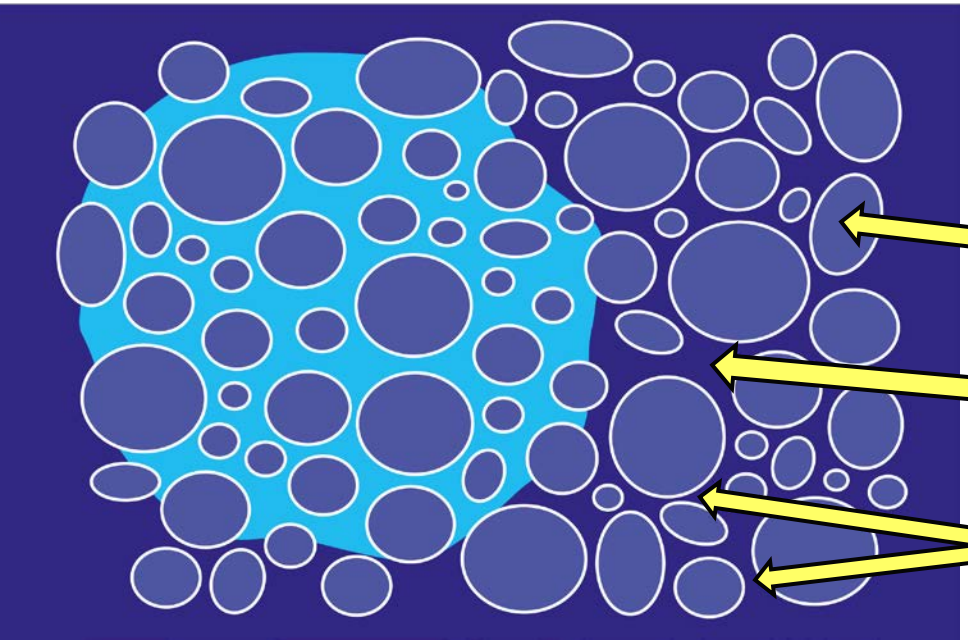
Pore Volume

ϕ is porosity

Total PV is $\phi \times V$

Accessible PV??





Mineral grains

- Quartz, limestone, clay…

PV – Pore Volume

- Brine-filled

Pore throats

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How Much PV is Needed?

- 1,000,000 t $scCO_2$/yr @ a density of 0.8 g/cm^3
- 1,250,000 m^3/yr of PV needed
- Assume 100% displacement in a ϕ = 0.2 sandstone
  - ➔ 6,250,000 m^3/yr of rock volume is needed
- However, realistically, perhaps 5-10% is reasonable
  - ➔ ≈100,000,000 m^3/yr of rock volume is needed
- Assume a 40 m thick repository zone…
  - ➔ ≈ 2.5 km^2/yr is needed
- The repository zone must have…
  - ➔ Sufficient accessible PV for 30 years: 75 km^2!
  - ➔ Adequate "injectivity" to reduce # of wells needed
  - ➔ Good seals for containment
  - ➔ …

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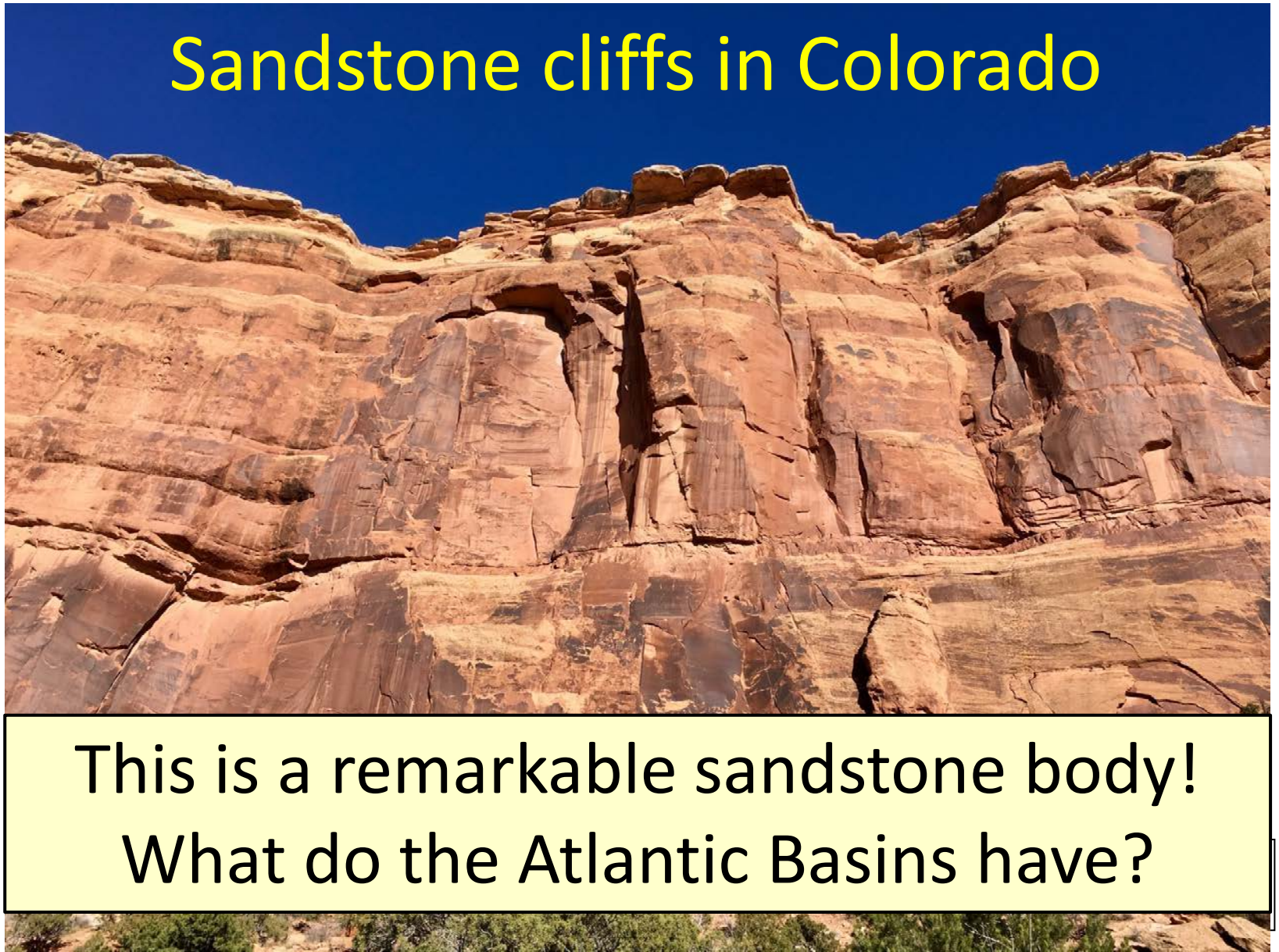
A Great Sandstone Repository



This is a remarkable sandstone body!
What do the Atlantic Basins have?

Limits to Pore Volume (PV) Access

- Vast pore volumes (PV) exist >800 m deep, but only a small fraction is accessible to CCS
- For example – PV in shales is not accessible, a sandstone surrounded by shale as well, and so on
- The important processes involved in injection:
  - **GRAVITY OVERRIDE**: $scCO_2$ is light, it is buoyant
  - **VISCOUS FINGERING**: low viscosity $scCO_2$ "fingers"
  - **HETEROGENEITY CHANNELLING**: $scCO_2$ under injection pressure will advance in the permeable channels
  - **CAPILLARY BLOCKAGE**: surface tension impedes displacement of H_2O by $scCO_2$ at small pore throats
  - **REGIONAL PRESSURIZATION** may develop
- Even in "decent" sandstones – perhaps only 10-15% PV might be accessed

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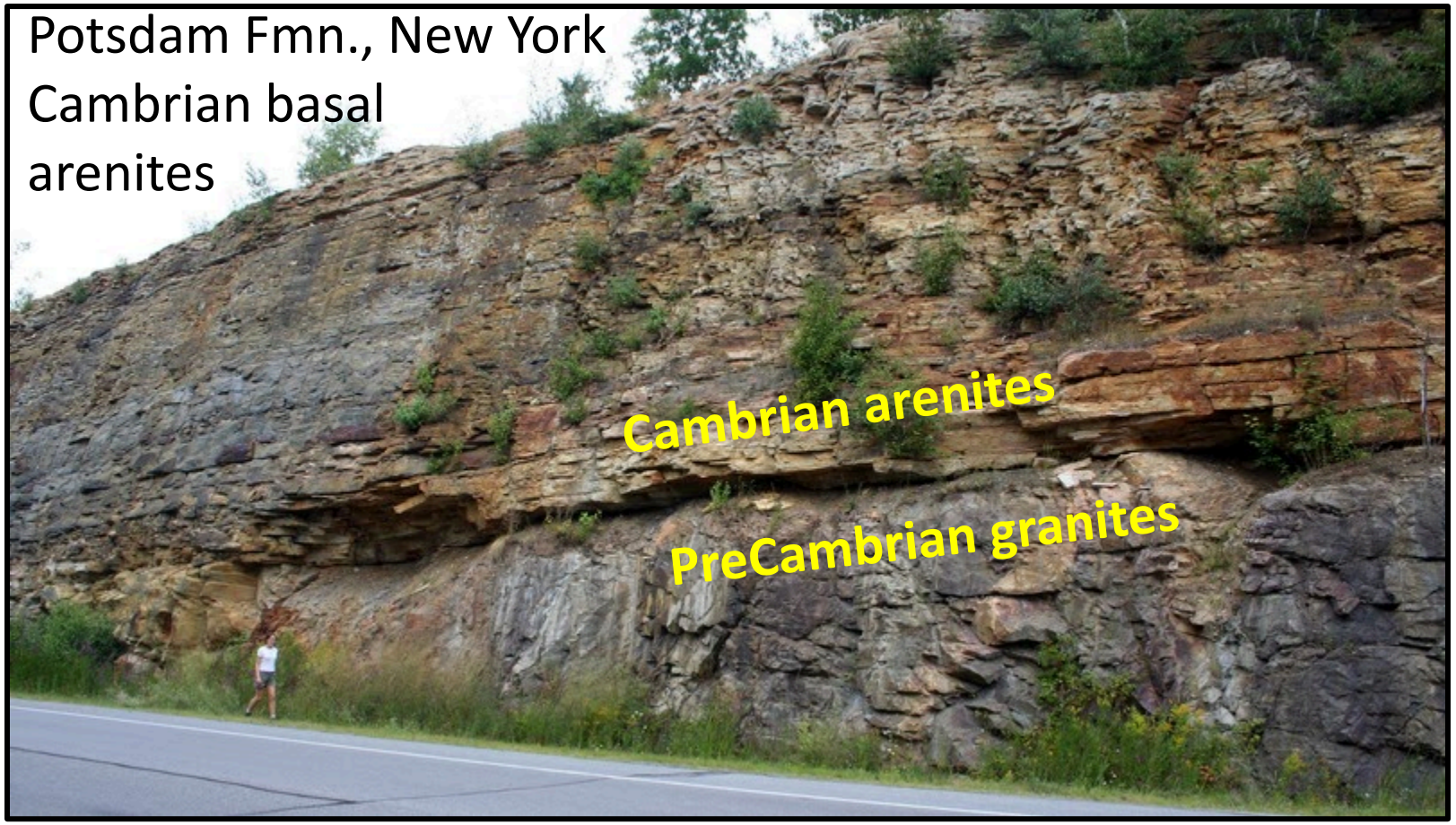
Limits to Pore Volume (PV) Access

- Heterogeneous, shale streaks, etc.



http://historyoftheearthcalendar.blogspot.com/2014/02/february-19-potsdam-sandstone.html

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Low Permeability Strata, Capillarity

- If the permeability (k) is less than ≈1 milliDarcy, replacing pore water with $scCO_2$ is not feasible
- Water/$scCO_2$ surface tension blocks displacement
- If the pores are gas-filled, no surface tension, and more of the PV may be accessible for $scCO_2$
- Low k beds and structures (salt, low porosity siltstones, shales, many dolomites and limestones) can form impenetrable barriers (seals), isolating suitable PV locations
- e.g.: Lorraine Group → no significant potential

>90% of strata >800 m in QC have too low permeability to consider

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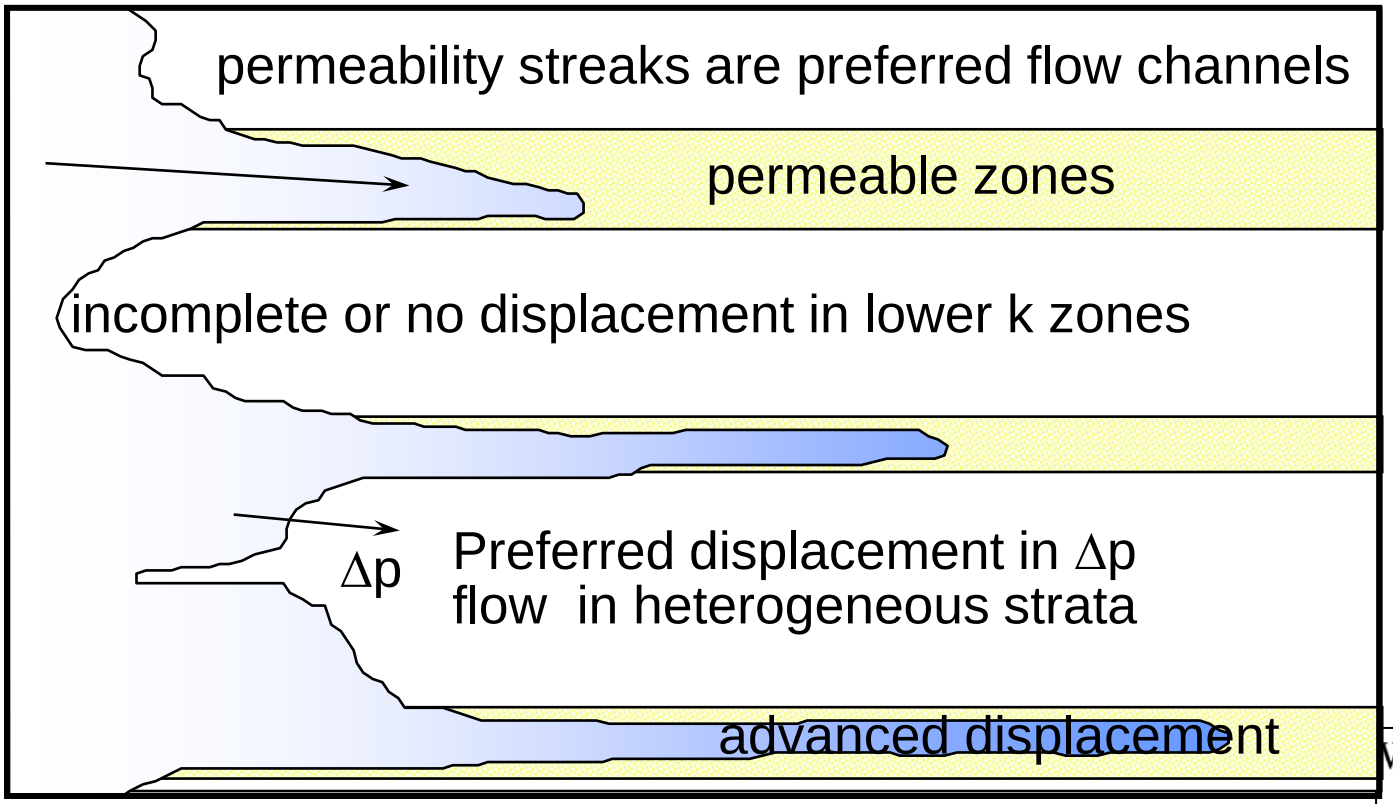
Shales, Fine-Gr. Silts, $CaCO_3$

- Shales have small pores, smaller pore throats…
- I.e.: “impermeable” to injection processes
- But, there may be natural fractures
- These, if open, issues may exist in terms of regional “seals”

Channelling in Heterogenous Strata

- Under injection pressure, low viscosity $scCO_2$ will advance faster in the more permeable streaks…
- …and PV in the less permeable streaks will be bypassed… …a **serious issue** in the Potsdam Fmn.



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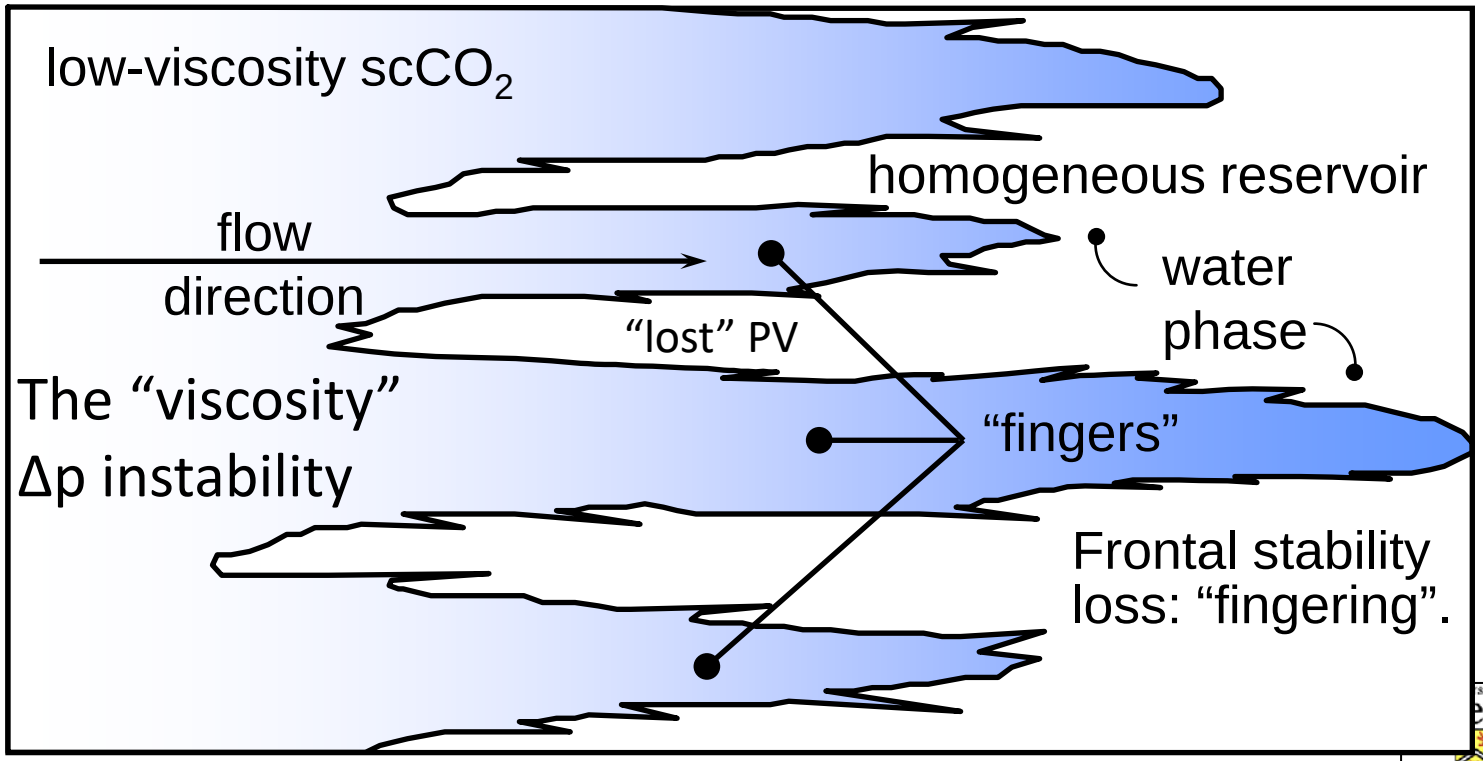
Potsdam Formation (Raquette R. NY)

https://www.wikiwand.com/en/Potsdam_Sandstone#Media/File:PotsdamSandstone_xbeds.jp

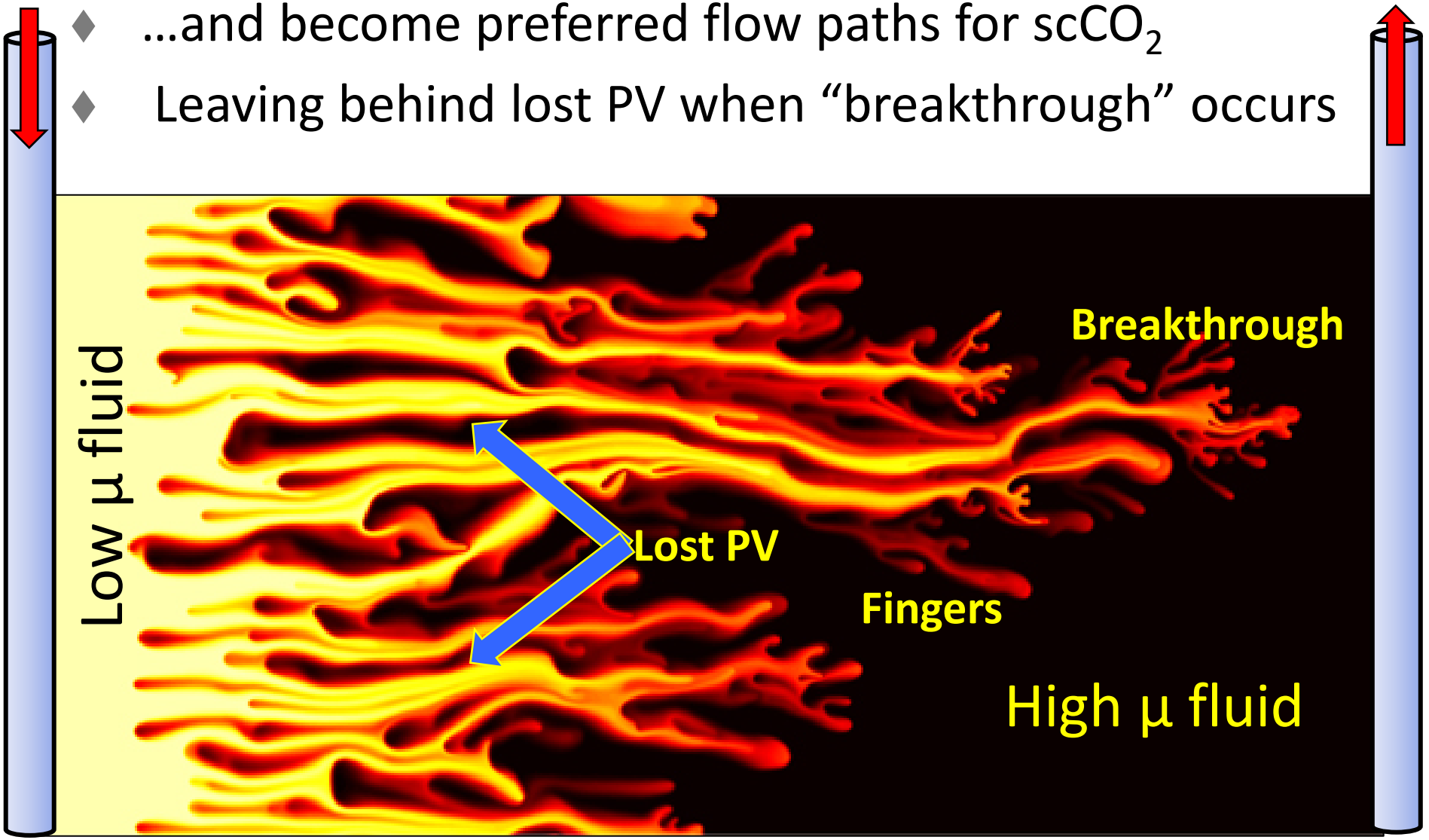
Viscous Fingering, Homogeneous Strata

- Low-viscosity (μ) $scCO_2$ will "finger" through even homogeneous brine-saturated porous media
- …and some PV will thereby be bypassed…
- μ of $scCO_2$ is about 5-10% μ of H_2O (brine)



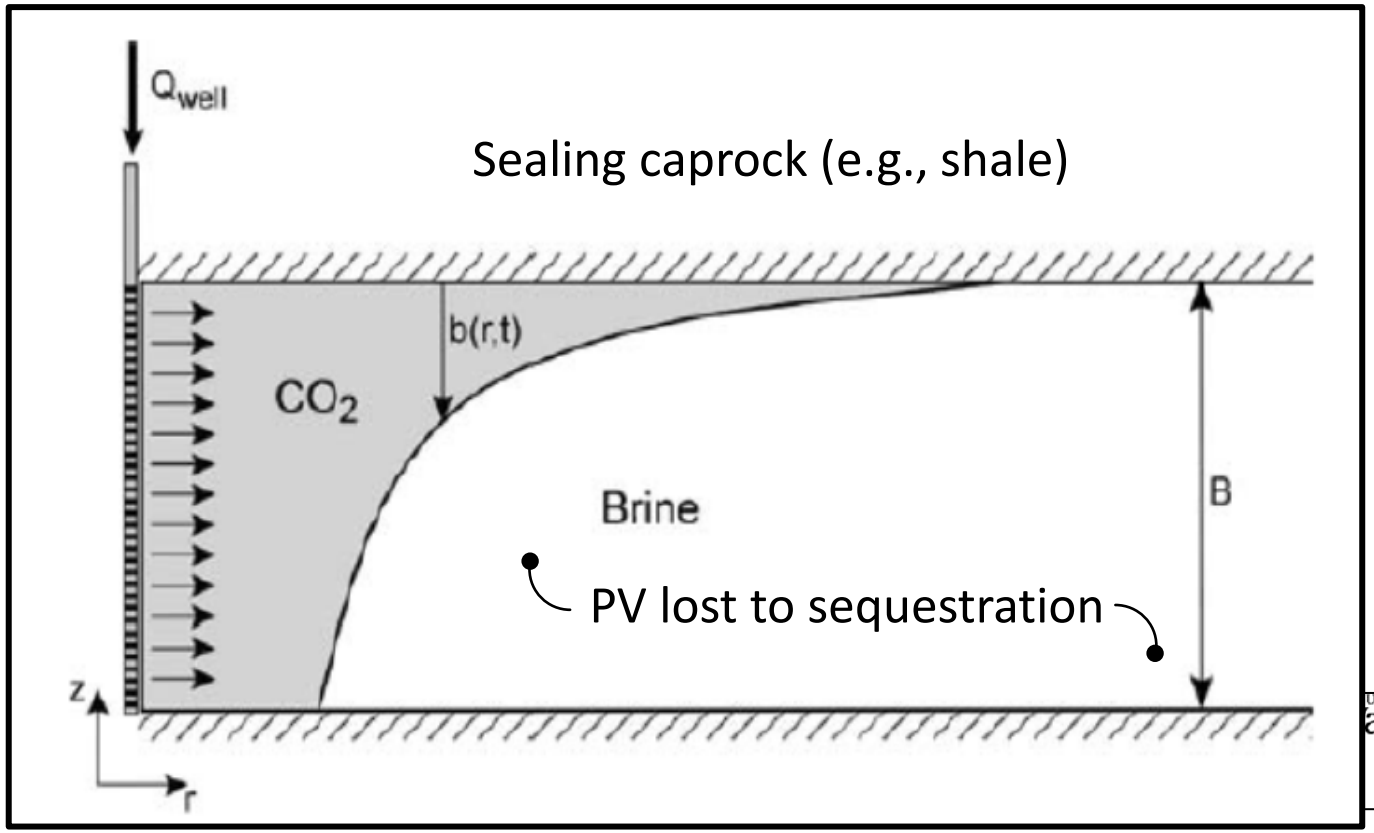
Viscous Fingering

- Low viscosity fluid-filled fingers develop naturally
- …and become preferred flow paths for $scCO_2$
- Leaving behind lost PV when "breakthrough" occurs



Gravity Override

- Low-density $scCO_2$ ($\rho \approx 0.75$ g/cm^3) is **buoyant**; compared to saturated brine ($\rho = 1.2$ g/cm^3)
- It will rise to the top of the reservoir interval
- …and lowermost PV will be bypassed…



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System Pressurization

- $scCO_2$ occupies PV; brine must be **displaced**.
  - ➔ If the system is open, regional pressurization stabilizes at an acceptable level ("quasi-steady-state")
  - ➔ If the system is closed at an engineering time scale (10 years), pressure must increase to accommodate ΔV
- Extremely large systems with good formational interconnectivity react as "open systems"
- Excessive pressurization can lead to…
  - ➔ Restricted injection rates and limited PV access
  - ➔ Increases in induced seismicity
  - ➔ Changes in stresses (reduction) in adjacent formations
  - ➔ Potential impairment in caprock integrity
- Injection of 10^6 m^3 of $scCO_2$ is quite different than injection of 100×10^6 m^3 if PV is limited.

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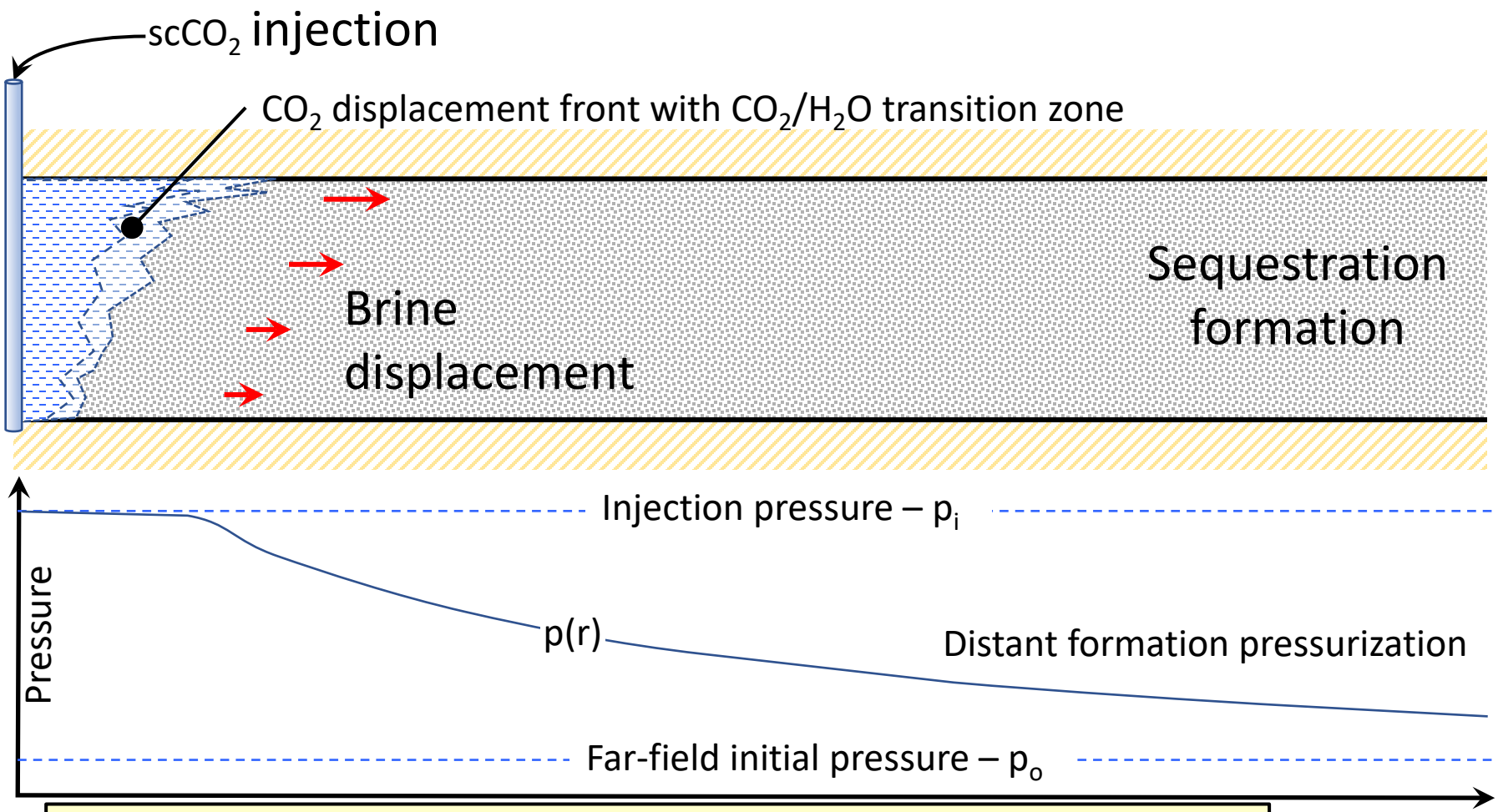
Pressurization and Displacement



Injectivity will decline as pressure builds up in the sequestration region

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De-Risking CCS Projects

- Before investing millions in specific sites, **Proponents need a reasonable probability** of:
  - The existence of available PV for a 20-year project at one million tonnes CO_2 /yr (1.25 million m^3/yr)
  - Adequate seals for long-term sequestration security
  - Repository permeability allowing injection for 20-30 years without substantive deterioration of injectivity
- This requires **regional-scale** assessment of basins
- …to develop a **probabilistic framework** for PV, k, seal integrity, etc.
- To allow Proponents to **develop project plans**
- …for **permitting** direct CCS site exploration

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So… What do We Need?

- **Regional** quantification of heterogeneity, porosity, permeability, etc. for target strata (saline aquifers)
- Sophisticated **mathematical modeling** that accounts for all relevant physical processes
- **Scenario** analysis (selected specified cases)
- Assessment of **best injection strategy**: Vertical or horizontal wells? Top-down or basal injection?
- **Stochastic analysis** to estimated accessible **PV**: e.g., probabilities: PV_{90}, PV_{50}, PV_{10}?
- **Optimal strategy** to maximize accessible **PV**
- **Field verification** by monitoring, measurements

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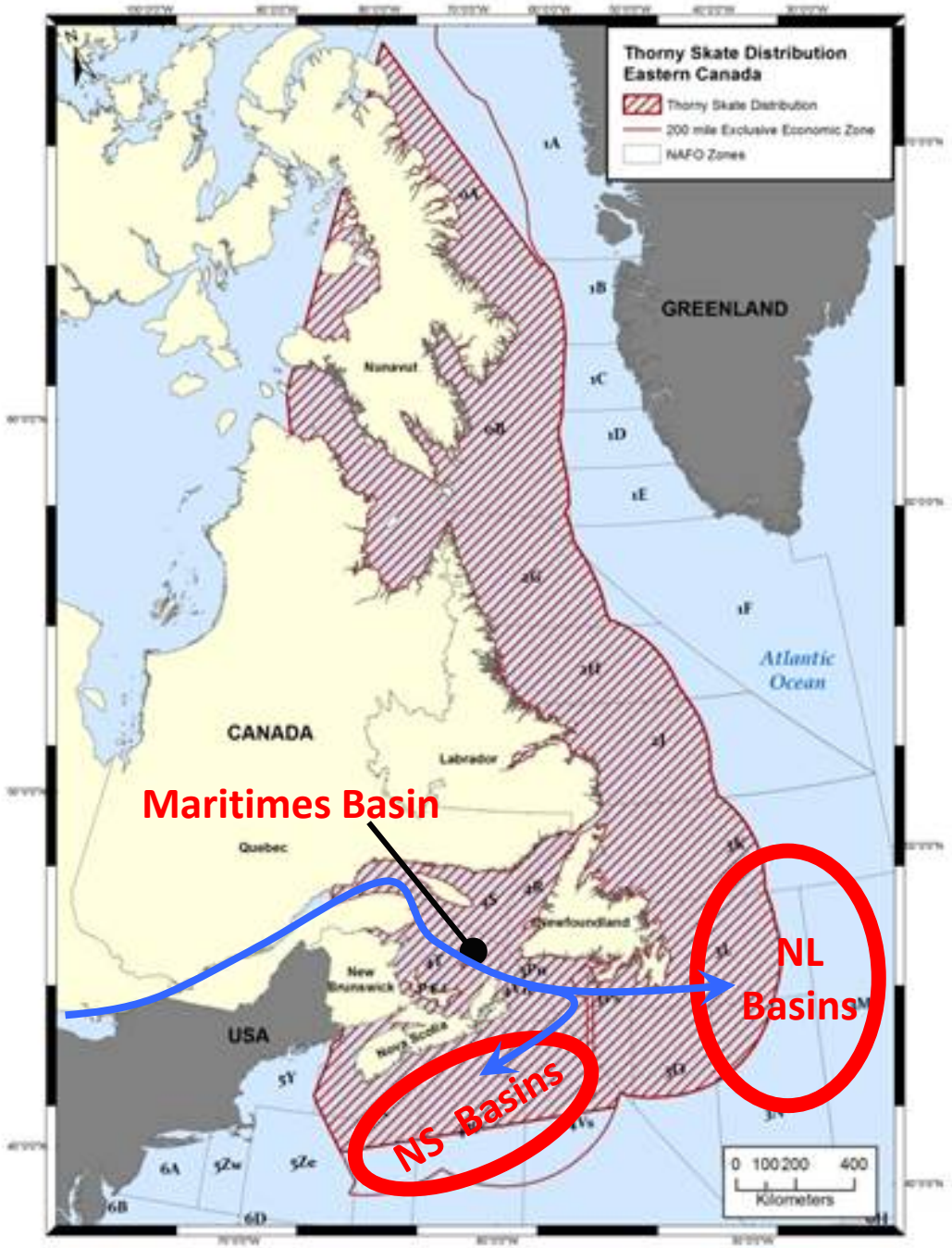

"Atlantica"

- General dispositions of basins are shown
- On-shore service industry for offshore sequestration exists
- Most likely, transport will be tankers (p)
- + On-land temporary CO_2 storage is needed

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General Comments (My Opinions)

- The Maritimes Basin is constrained in terms of permeability, accessible PV, etc.
  - ➔ Busy shipping corridor
  - ➔ Less faulting, no one living on top of the strata
- Shipping CO_2 to injection sites on the Atlantic continental shelf (NS, NL) is feasible…
- Very likely, large PV exist in many sites.
- But a regional-scale study is needed to de-risk the region for potential proponents
- This is a society need – otherwise proponents will not be likely to come forward to sequester CO_2

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Acknowledgements…

To the organizers, Grant, Russell, Adam, Lauren, Jennifer, and many others

In Canada, we have to get going quickly to achieve our stated goals by 2030.

Time is of the essence…

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