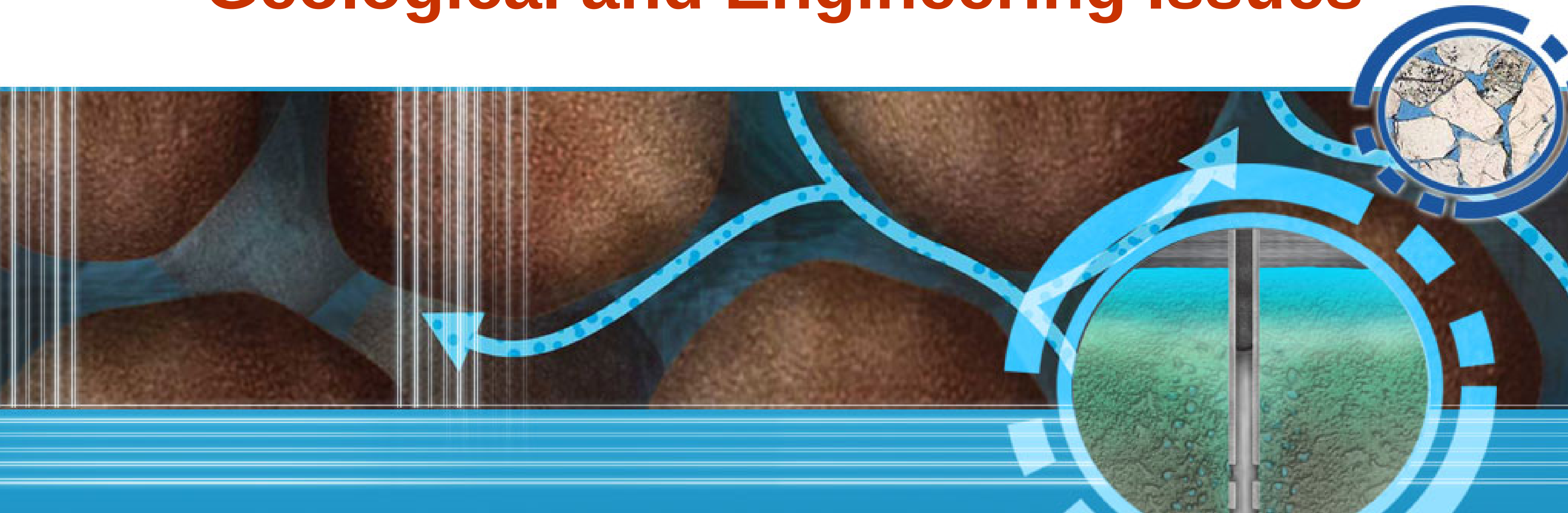
Evaluating Storage Capacity in Saline Aquifers and Depleted Oil and Gas Fields: Geological and Engineering Issues



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Chief Scientist

Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC)

China Australia Geological Storage of CO_2 Workshop

Geoscience Australia, Canberra, ACT
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CO2CRC participants

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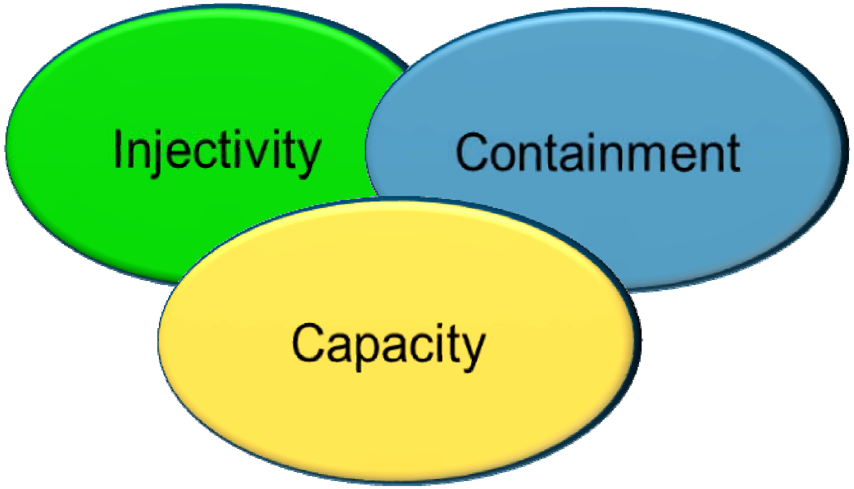
- Lincoln Paterson
- Bruce Ainsworth
- Other CO2CRC Colleagues

Outline

- Criteria for Site Selection / Characterisation
- Volumetric Capacity Estimation
  - History of “Efficiency Factor” (*E*)
- Geological Properties That Affect *E*
  - Trapping Mechanisms / Reservoir Architecture
  - Pore geometry / capillarity / relative permeability
  - Irreducible Water (S_{wirr}) / Residual CO_2 (Sr_{CO2})
- Engineering / Economic Considerations
  - Pressure / injectivity
- A Few Final Thoughts….

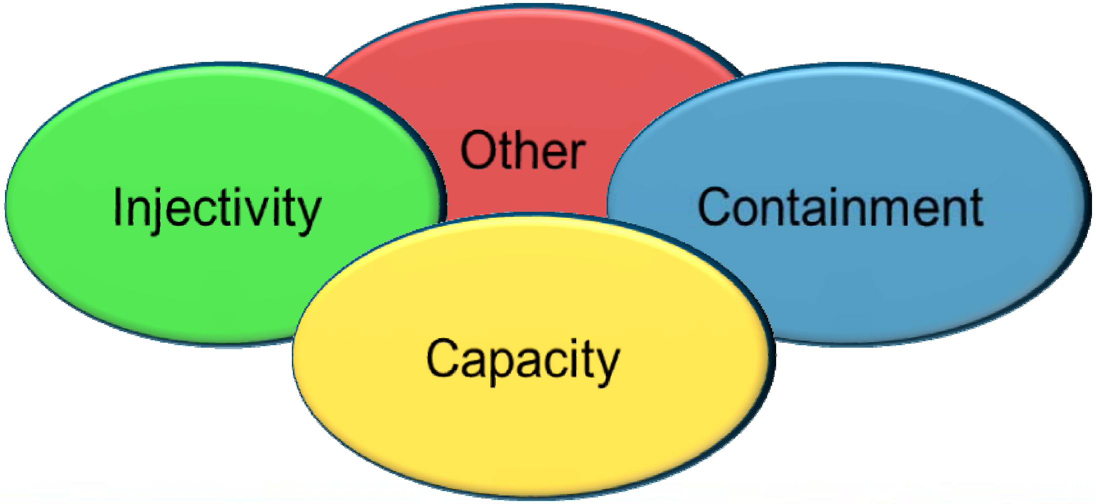
Geological criteria for site characterisation:

- **Injectivity** (can we put the CO_2 into the rock?)
- **Containment** (can we keep the CO_2 in the rock?)
- **Capacity** (what volume of CO_2 can the rock hold?)



Criteria for site characterisation:

- **Injectivity** (can we put the CO_2 into the rock?)
- **Containment** (can we keep the CO_2 in the rock?)
- **Capacity** (what volume of CO_2 can the rock hold?)
- **Other** (Economic, Regulatory, Legal, Community)



Volumetric Equation for Capacity Calculation

$$G_{CO2} = A\, h_g\, \phi\, \rho\, E$$

G_{CO2} = Volumetric storage capacity

A = Area (Basin, Region, Site) being assessed

H_g = Gross thickness of target saline formation defined by A

ϕ = Avg. porosity over thickness h_g in area A

ρ = Density of CO_2 at Pressure & Temperature of target saline formation

E = Storage "efficiency factor" (fraction of total pore volume filled by CO_2)

NETL DOE, 2006

E **= "efficiency factor" (fraction of total pore volume filled by CO_2)**

~ 3%	van der Meer, 1992
2 - 6%	van der Meer, 1995
1 - 4%	Holloway et al.,1996, 2006
1 - 4%	CSLF, 2007
1 - 4%	NETL DOE, 2007
1 - 4%	CO2CRC, 2008
1 - 4%	IEA GHG, 2008
4 – 20+%	EERC, 2009

a) Structural trapping based assumptions
b) Generally simple inverse of RF (recovery factor) despite no original CO_2 in place and no history match
c) We don't know what "*E*" to use… or if it matters!

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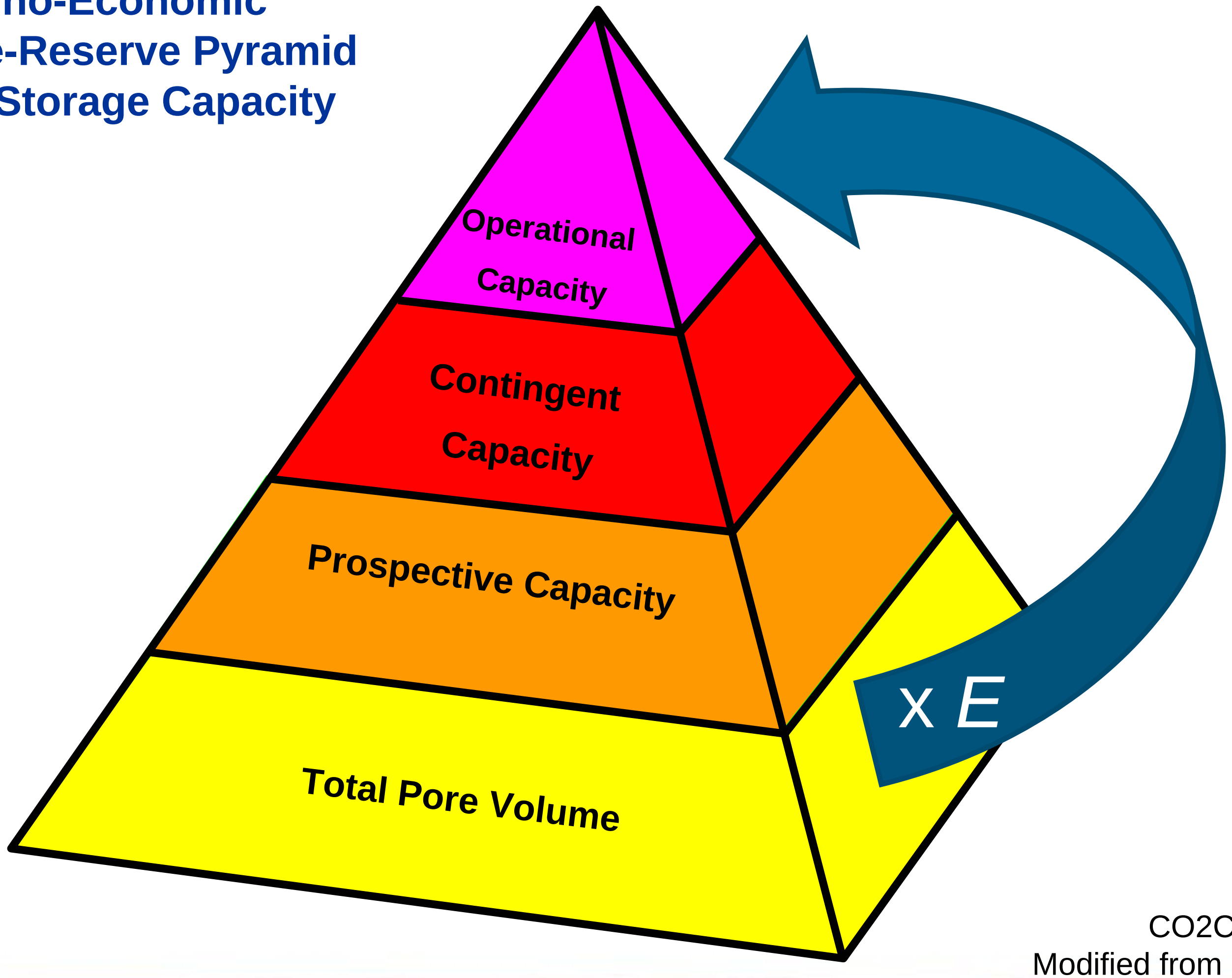
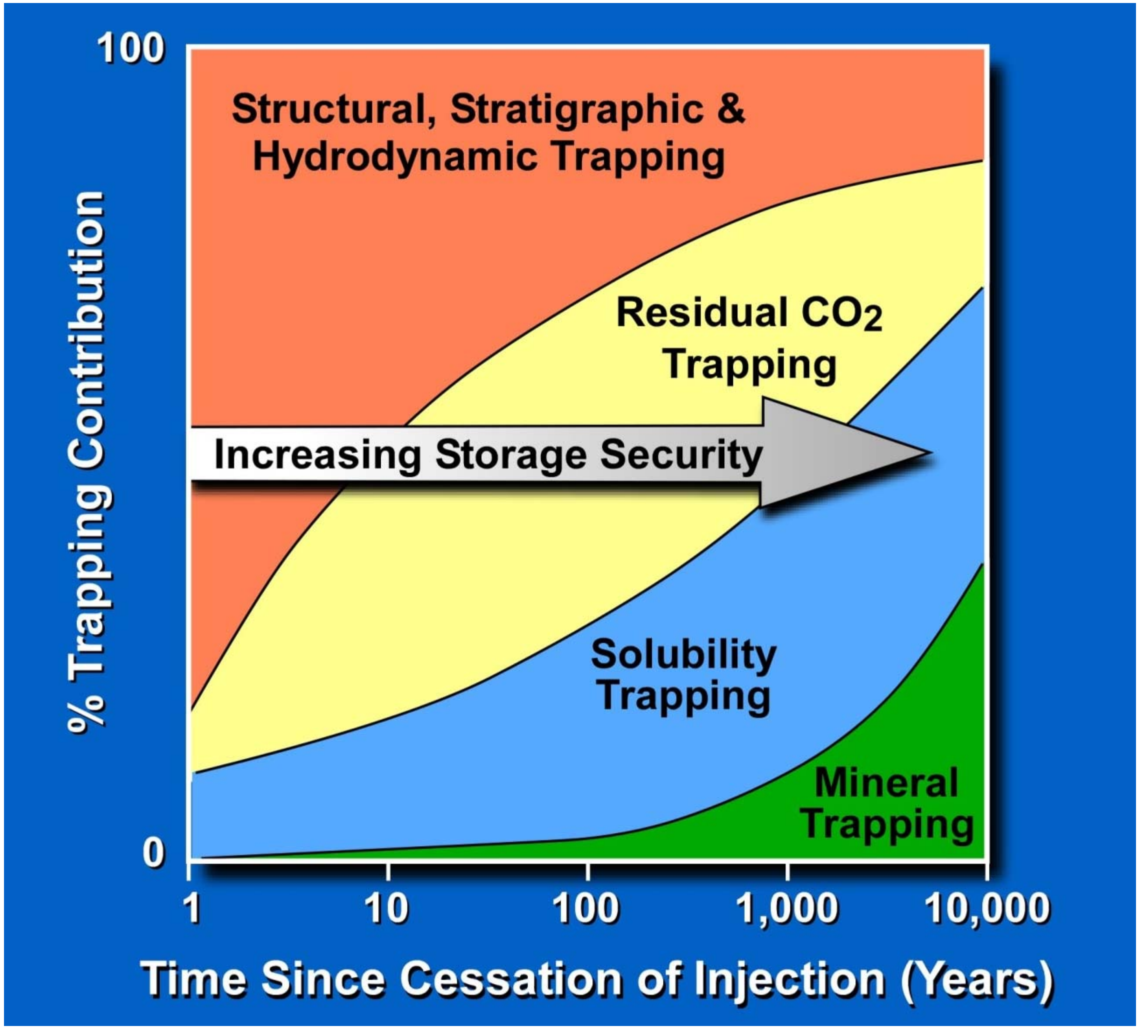
Storage Capacity Estimation

Techno-Economic Resource-Reserve Pyramid for CO_2 Storage Capacity



CO2CRC. 2008,
Modified from Bachu et al.,, 2007

CO_2 Storage Trapping Mechanisms

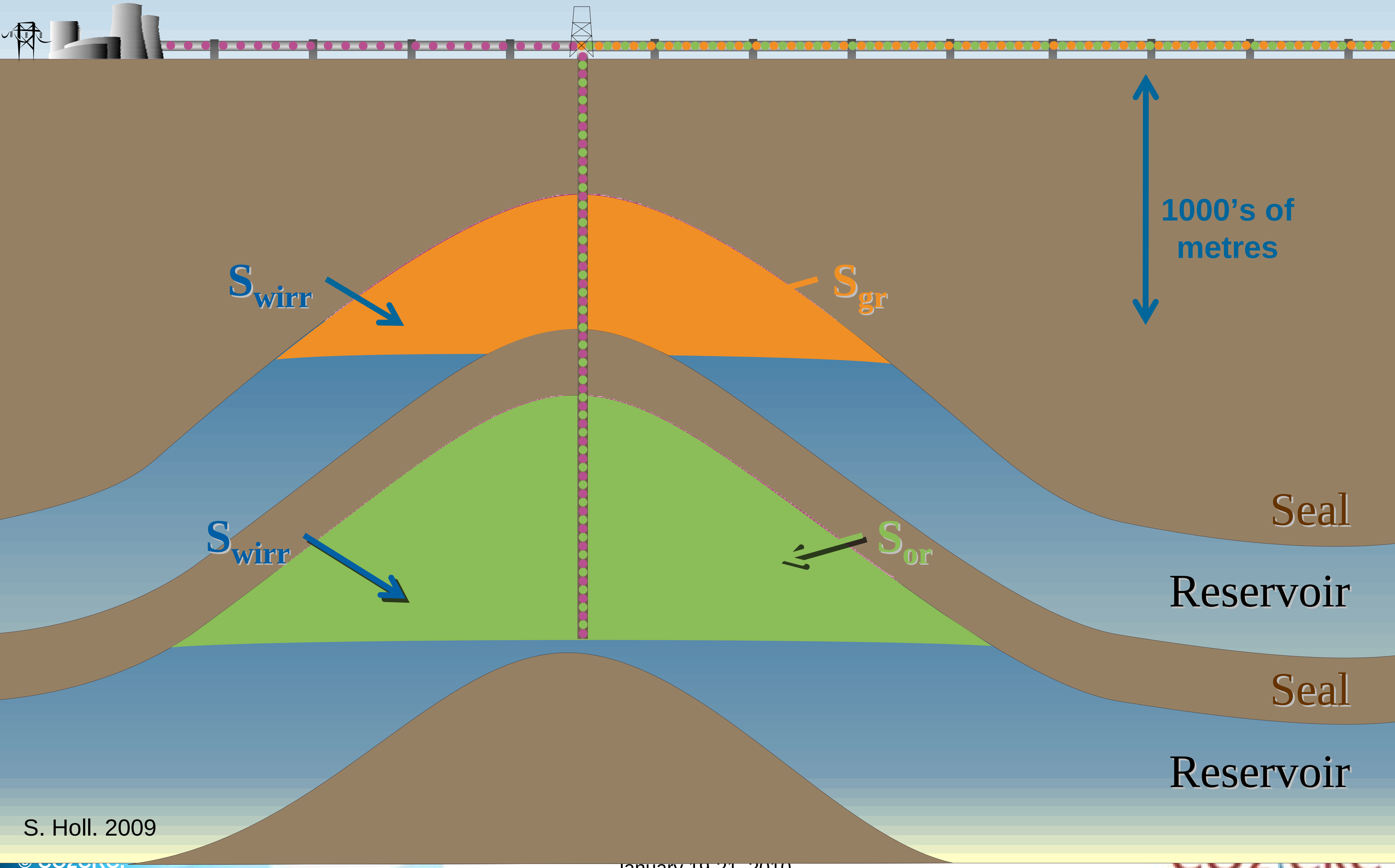


From IPCC SRCCS, 2005

Storage capacity:

- **Cumulative**
(sum of capacities of various trapping mechanisms)
- **Dynamic**
(over time percentages change)
- **Do we need a different "E" for each trapping mechanism?**

Storage Capacity Estimation in Depleted Reservoirs / Structural Traps



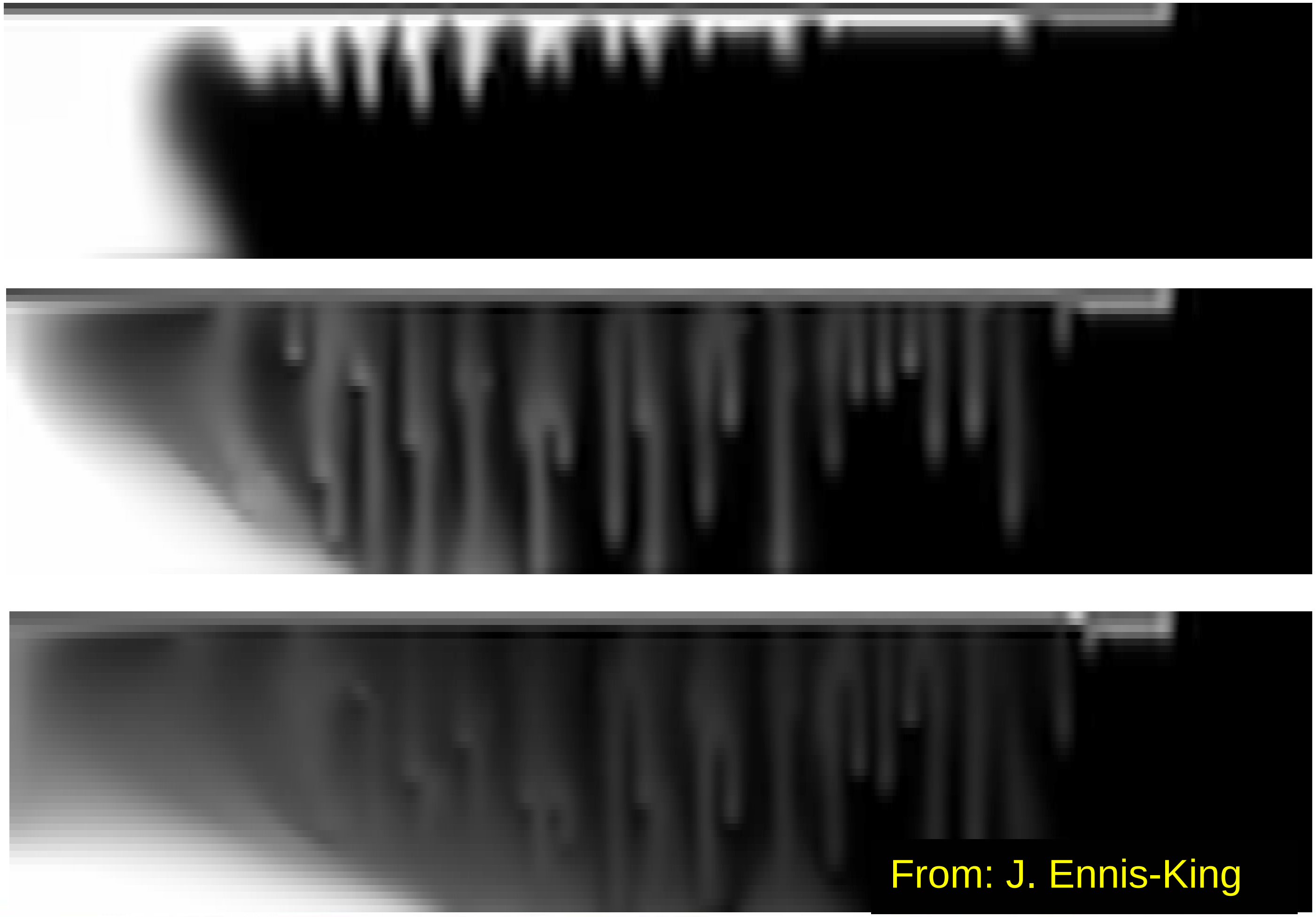
S. Holl. 2009

Volume of dissolved CO_2 time dependent

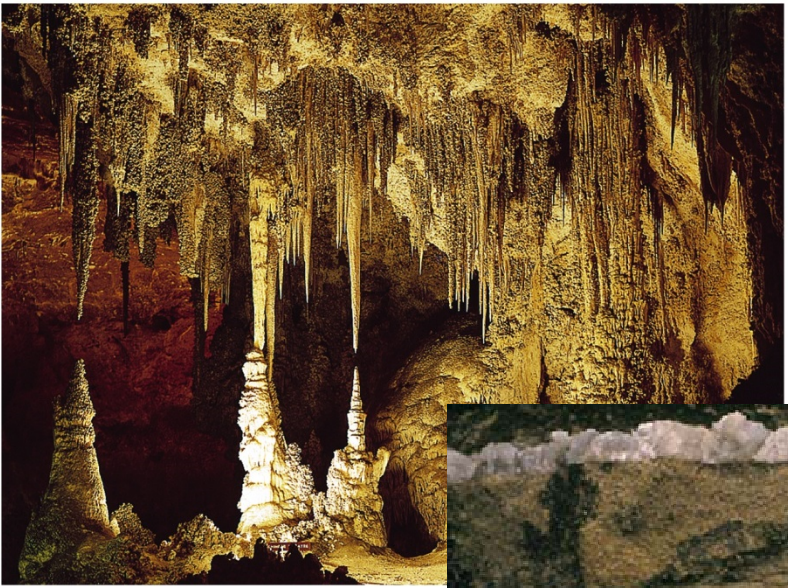
930 yr

1330 yr

2330 yr



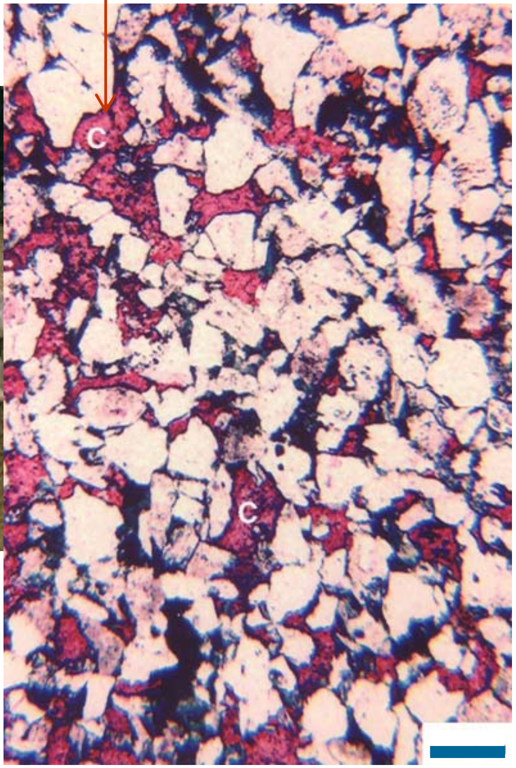
Mineral Trapping: also varies with time



1 m

1 cm

Calcite cement (red)



200 μm

$CaCO_3$ (Calcite) precipitation occurs at all scales at different rates

What controls "E" in saline aquifers?

- Subsurface conditions
  - Depth / temp / salinity / CO_2 composition / solubility
- Rock Properties
  - Reservoir architecture
  - Pore geometry (pore/throat; connectivity)
- S_{wirr}
- Sr_{CO2}
- Formation dip / Sweep / (migration path / rate)
- Hydrodynamics / Aquifer properties
- Pressure (injectivity / containment)
- Geochemistry / Mineral reactivity
- Others?

Otway Stage 2

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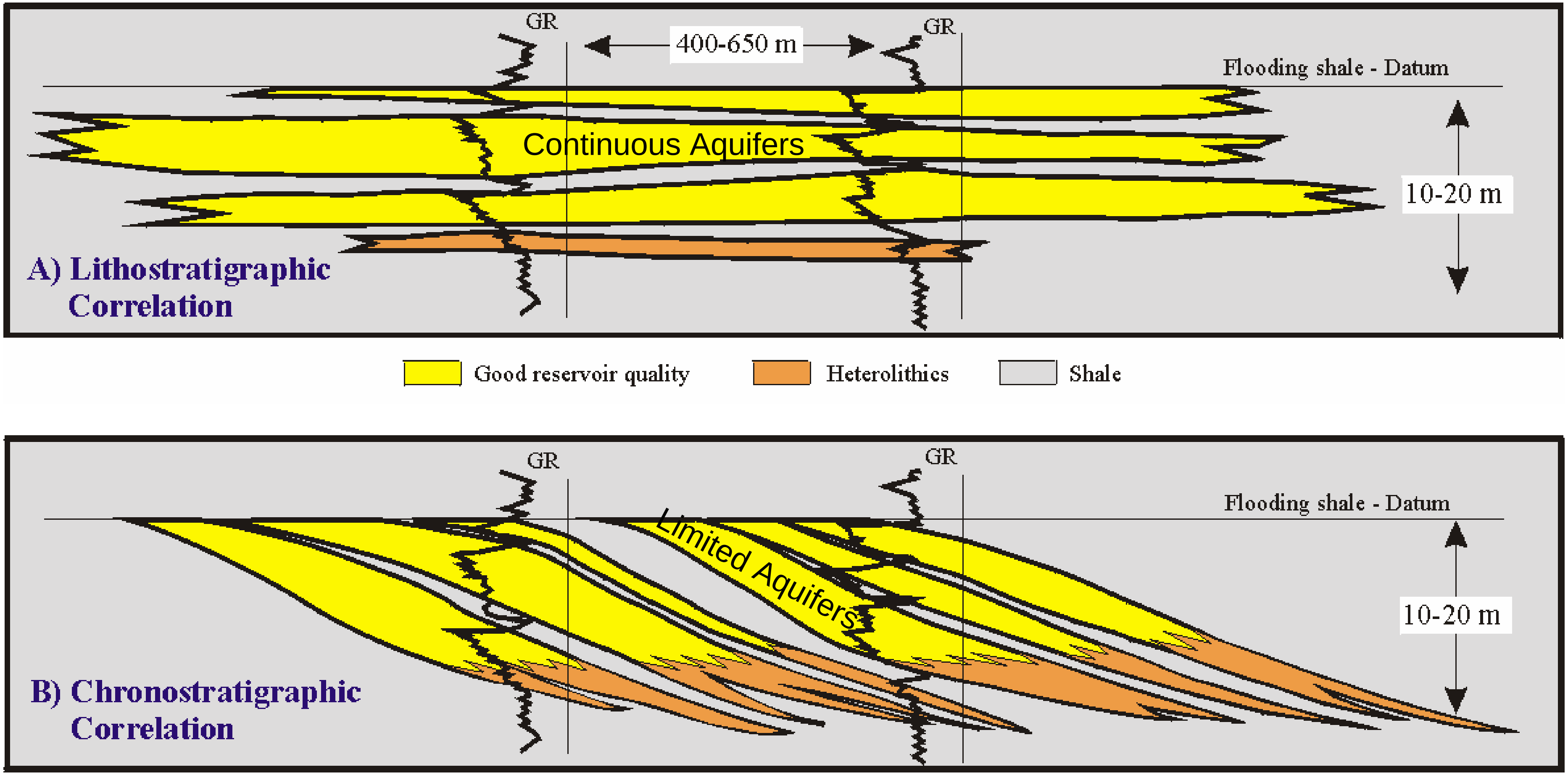
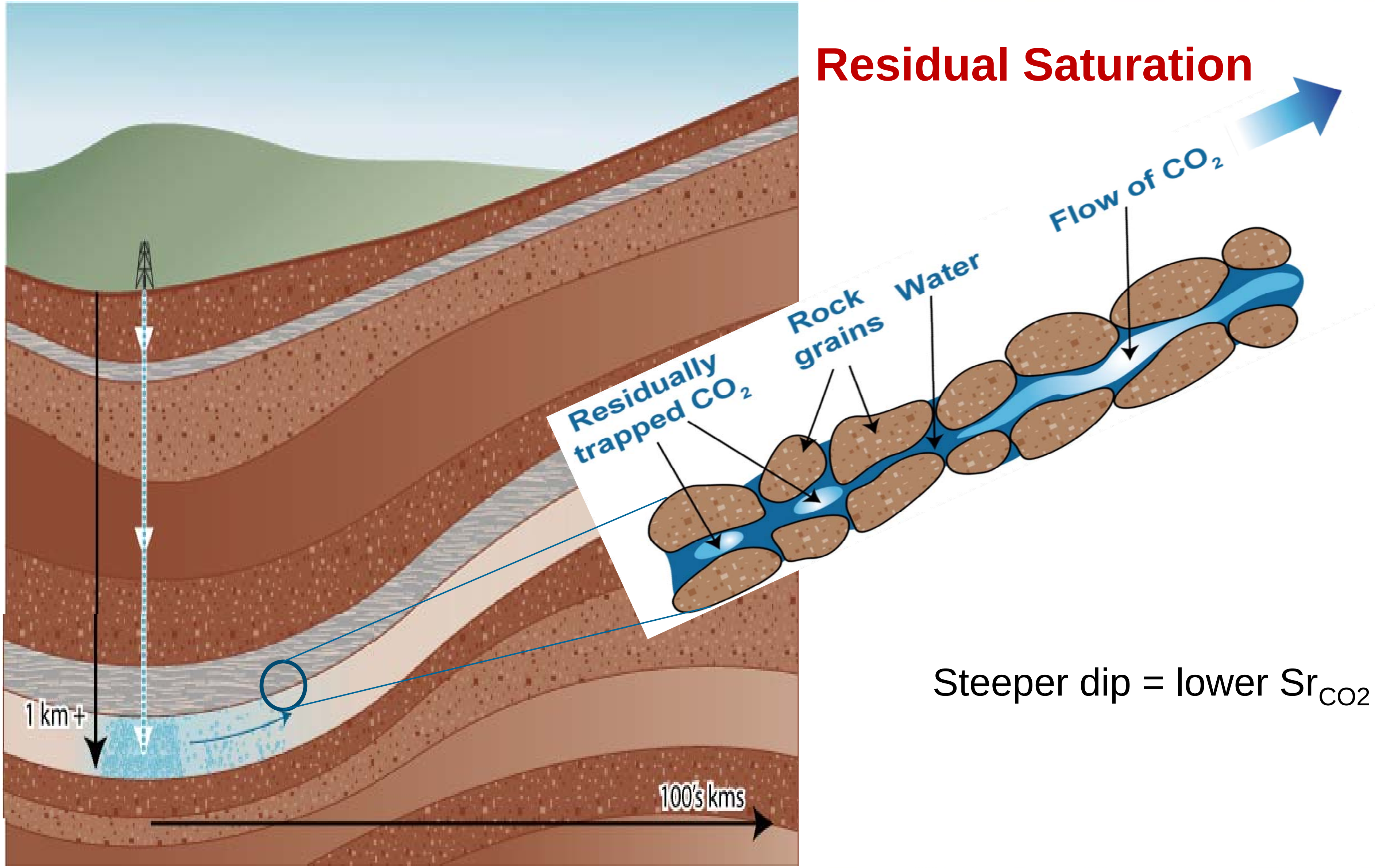
Reservoir Architecture: Deltaic Deposits



How to Correlate? Effects on injectivity, capacity?

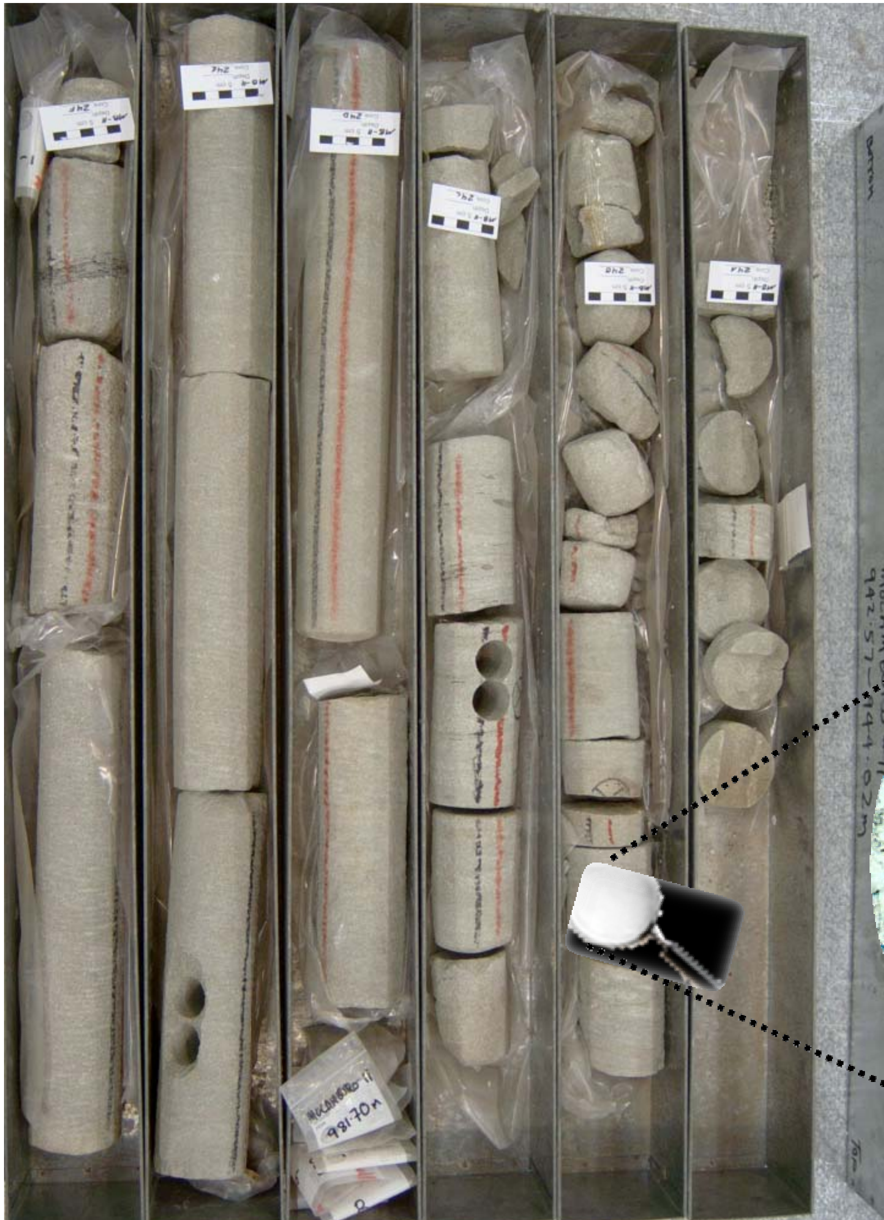
Ainsworth, 2008

Residual Saturation



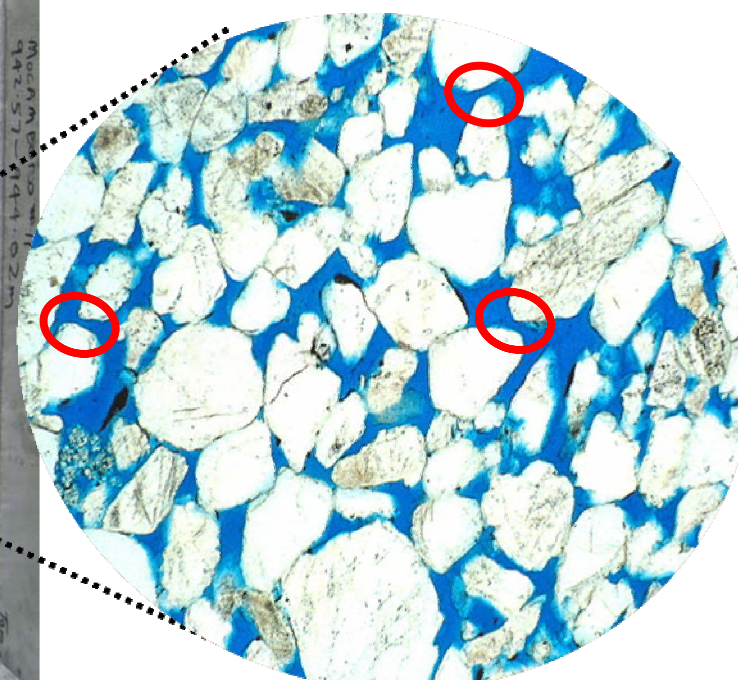
Steeper dip = lower Sr_{CO2}

Pore Geometry of Storage Reservoir Rocks

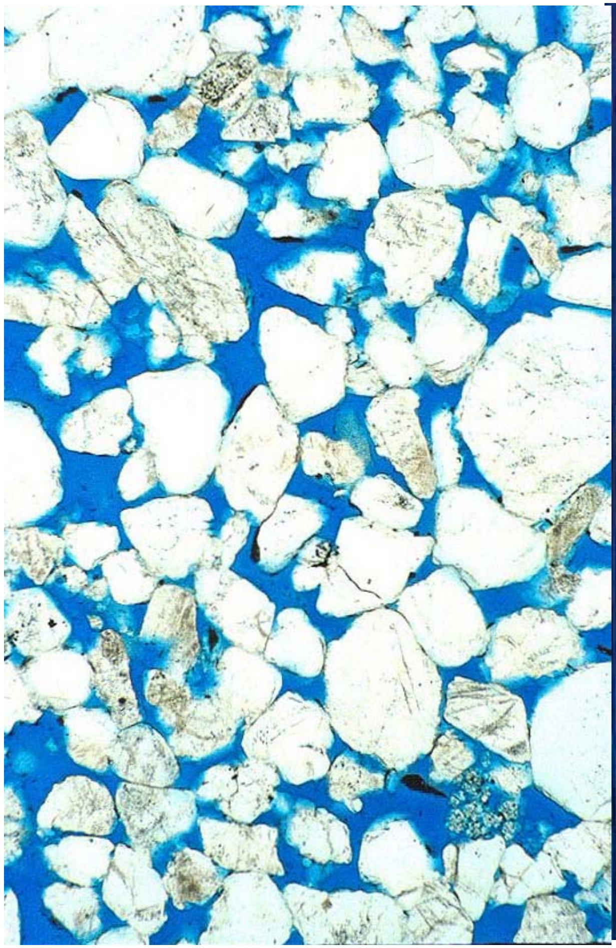


Porosity is the storage space in the rock for fluids (blue)

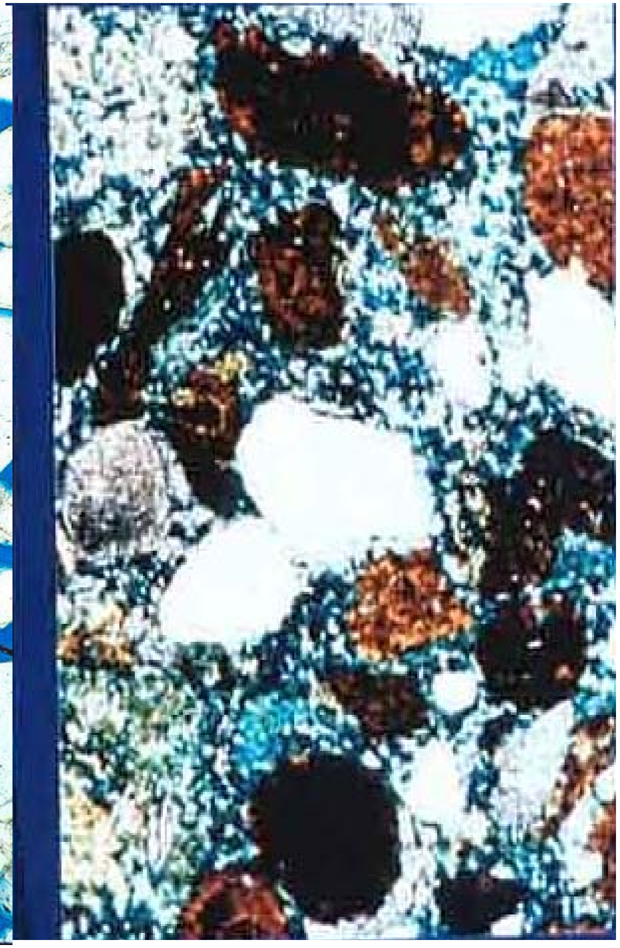
Permeability is a measure of the ability of the rock to allow fluid flow and is strongly affected by the geometry of the porosity – in particular the size and distribution of the pore throats connecting the pores in the rock (red circles).



Storage Capacity Controlled by Rock Type (Not Just Porosity)

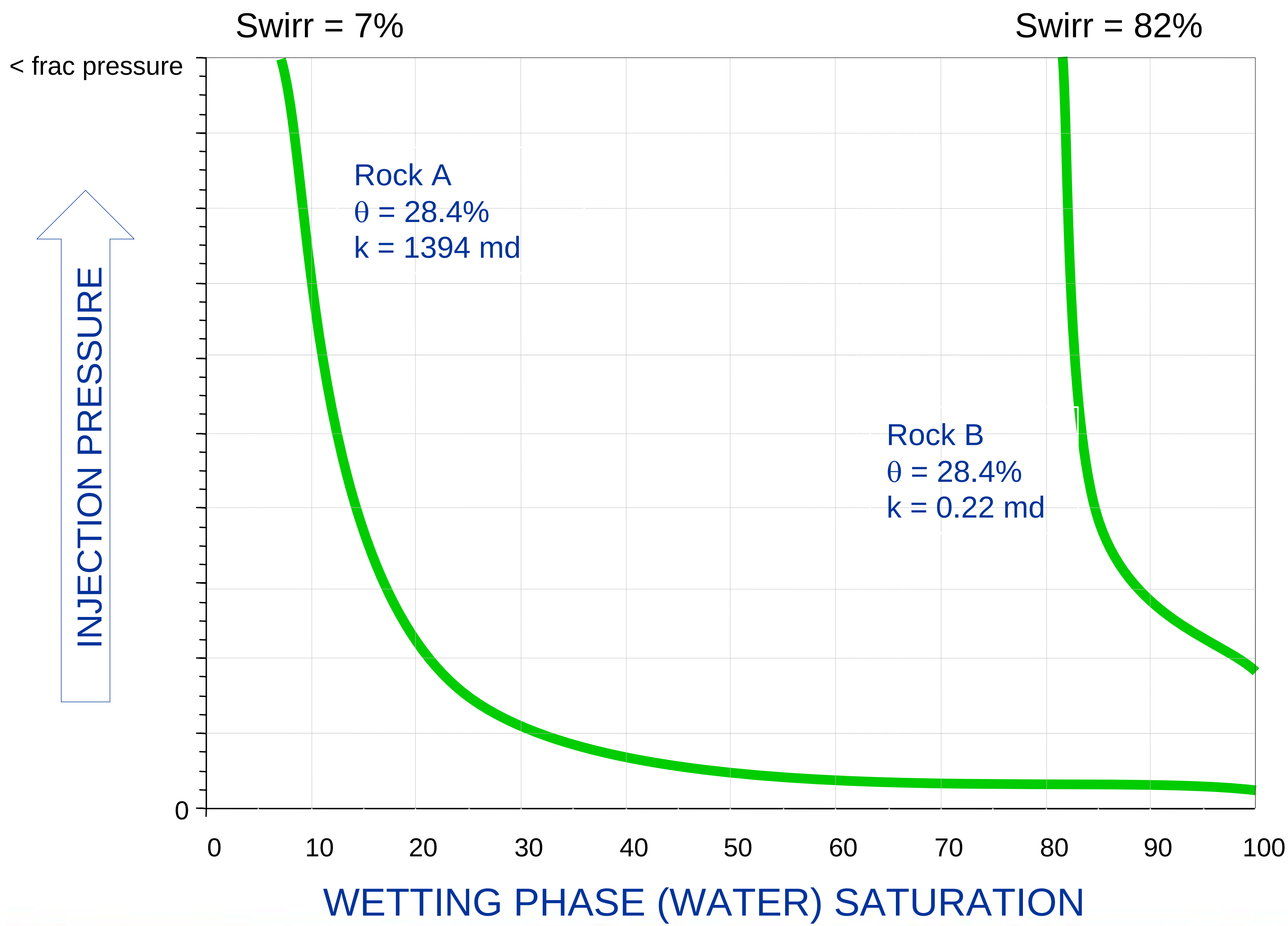


Rock A: ϕ = 28.4%
k = 1394 md



Rock B: ϕ = 28.4%
k = 0.22 md

Irreducible water saturation is a critical control on “E”



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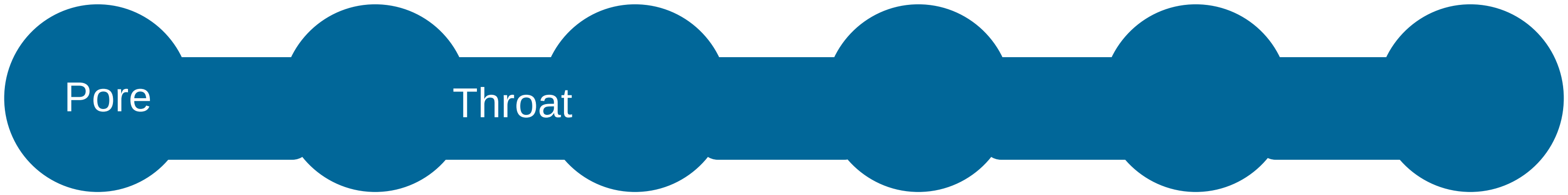
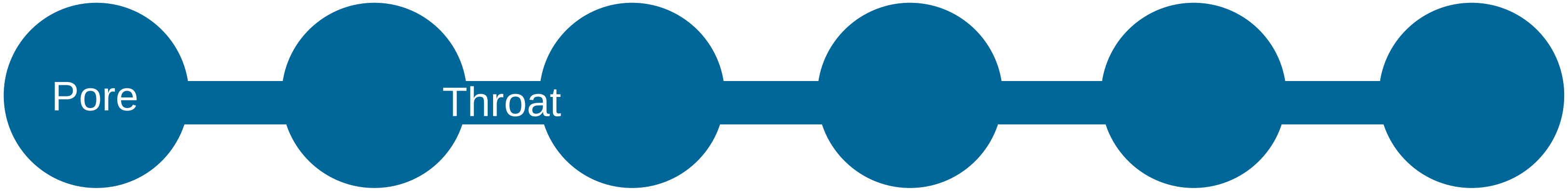
Pore Geometry: Pore / Throat Size (Aspect Ratio)

Low AR:
Higher O/G Recovery; Lower Srco$_2$



High AR:
Lower O/G Recovery; Higher Srco$_2$



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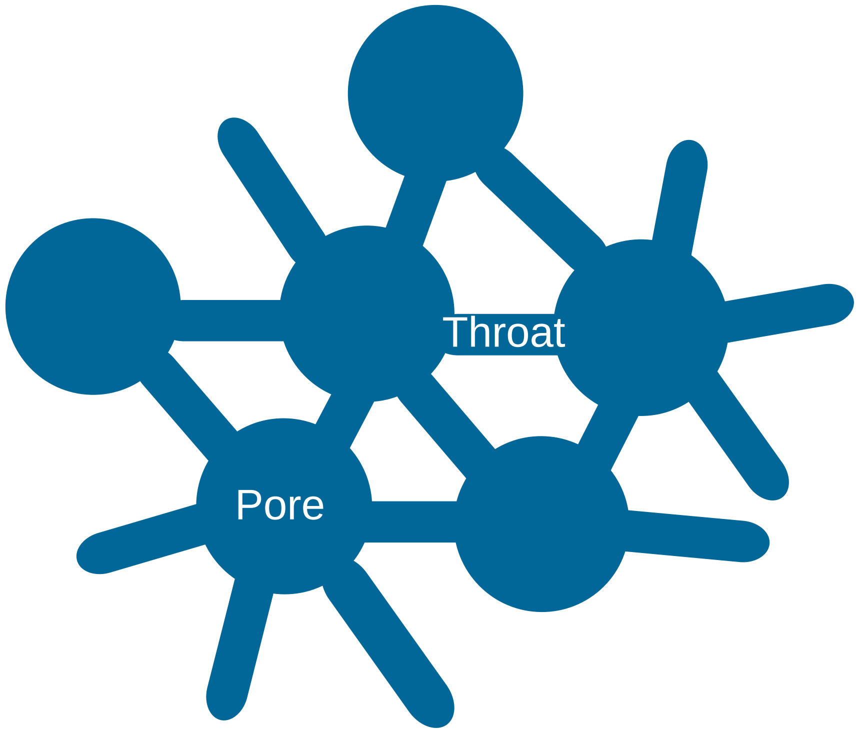
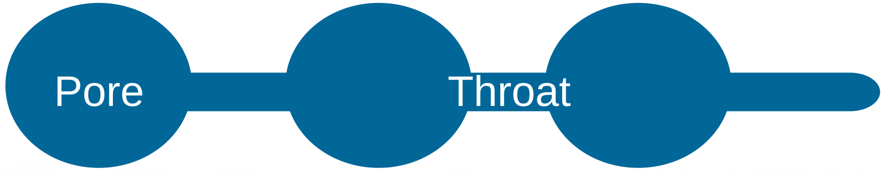
Pore Geometry: Coordination (Throats / Pore)

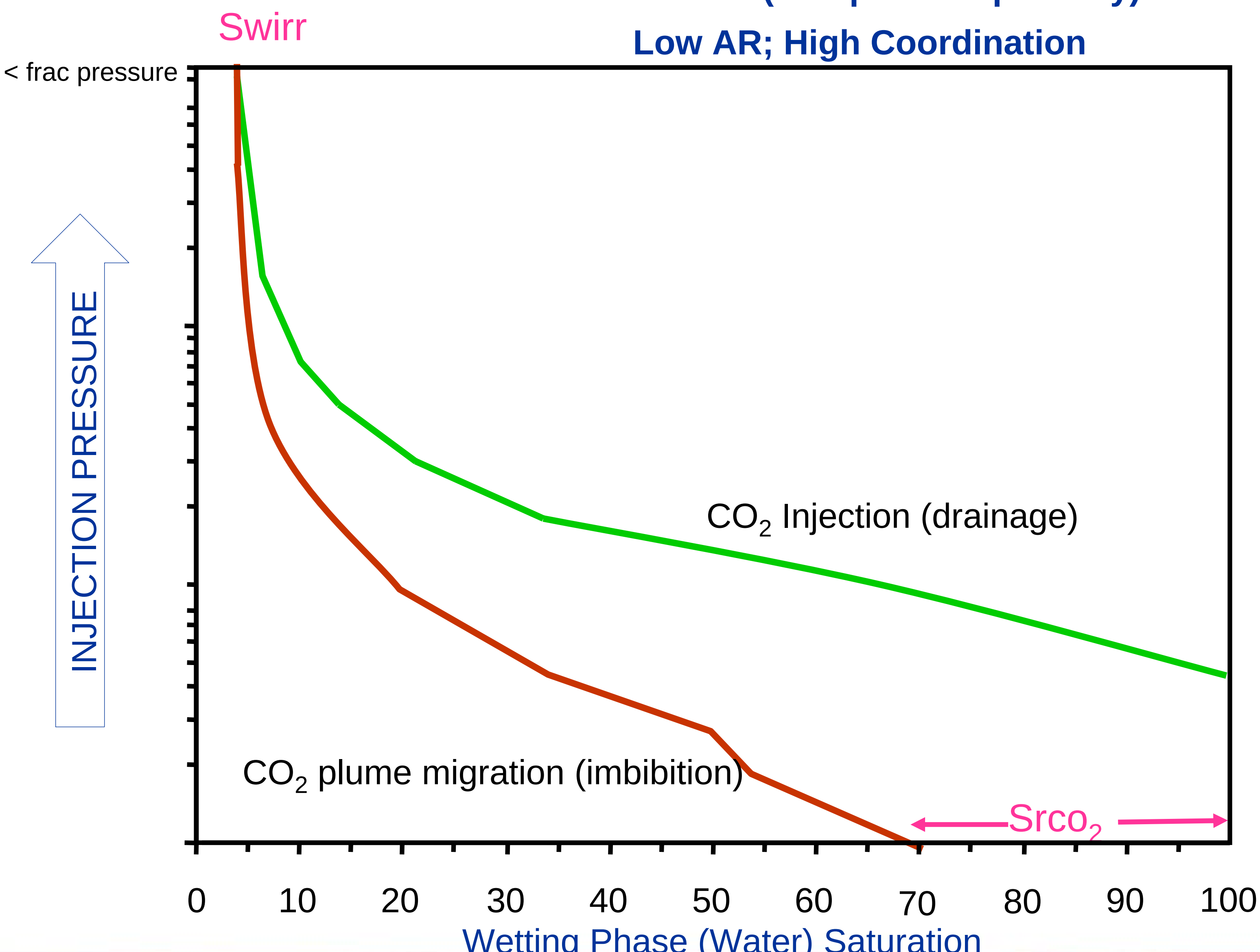
Higher Coordination
Better O/G Recovery
Lower Srco$_2$



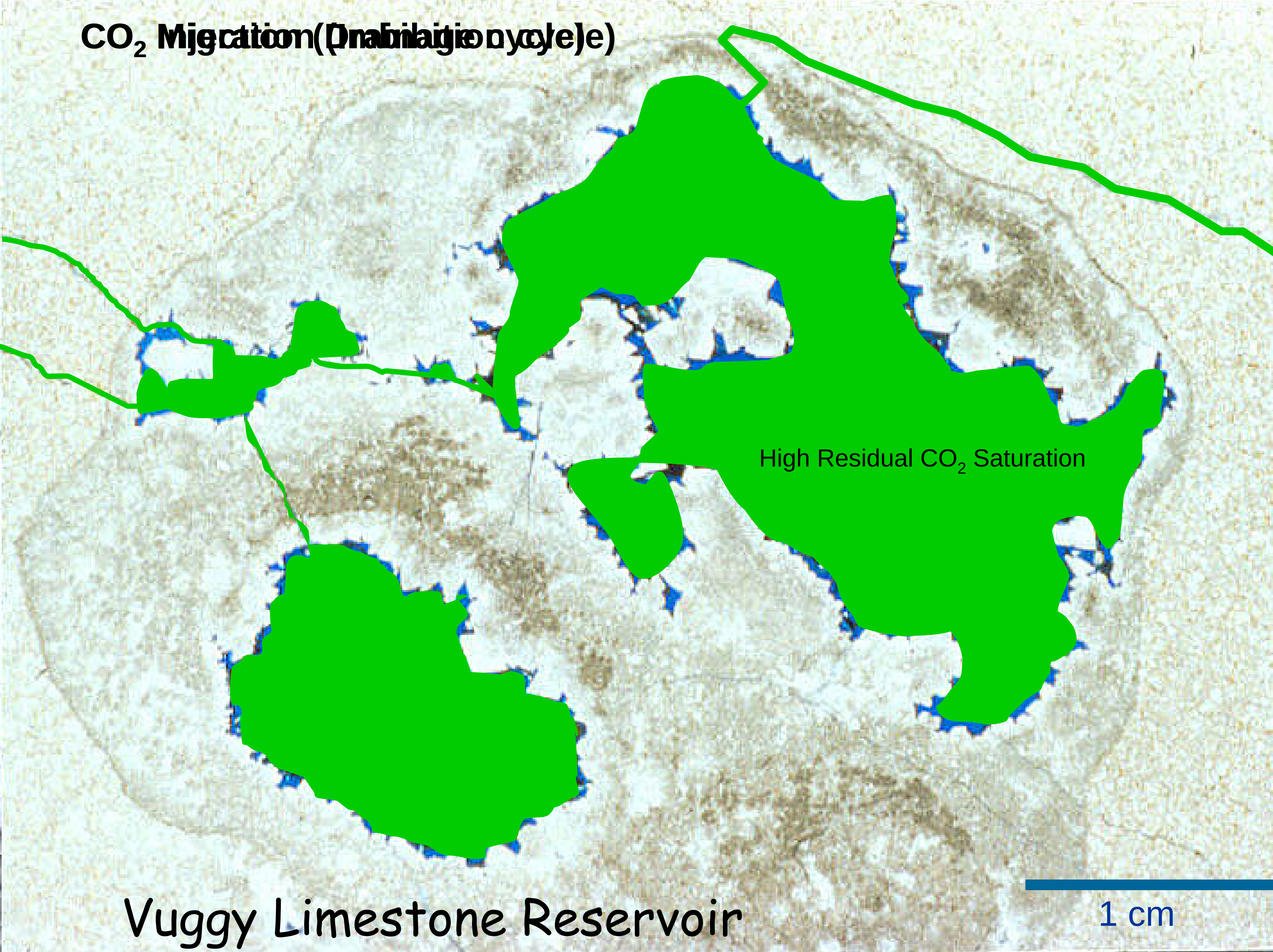
Lower Coordination
Worse O/G Recovery
Higher Srco$_2$



Rock A (interparticle porosity)
Low AR; High Coordination

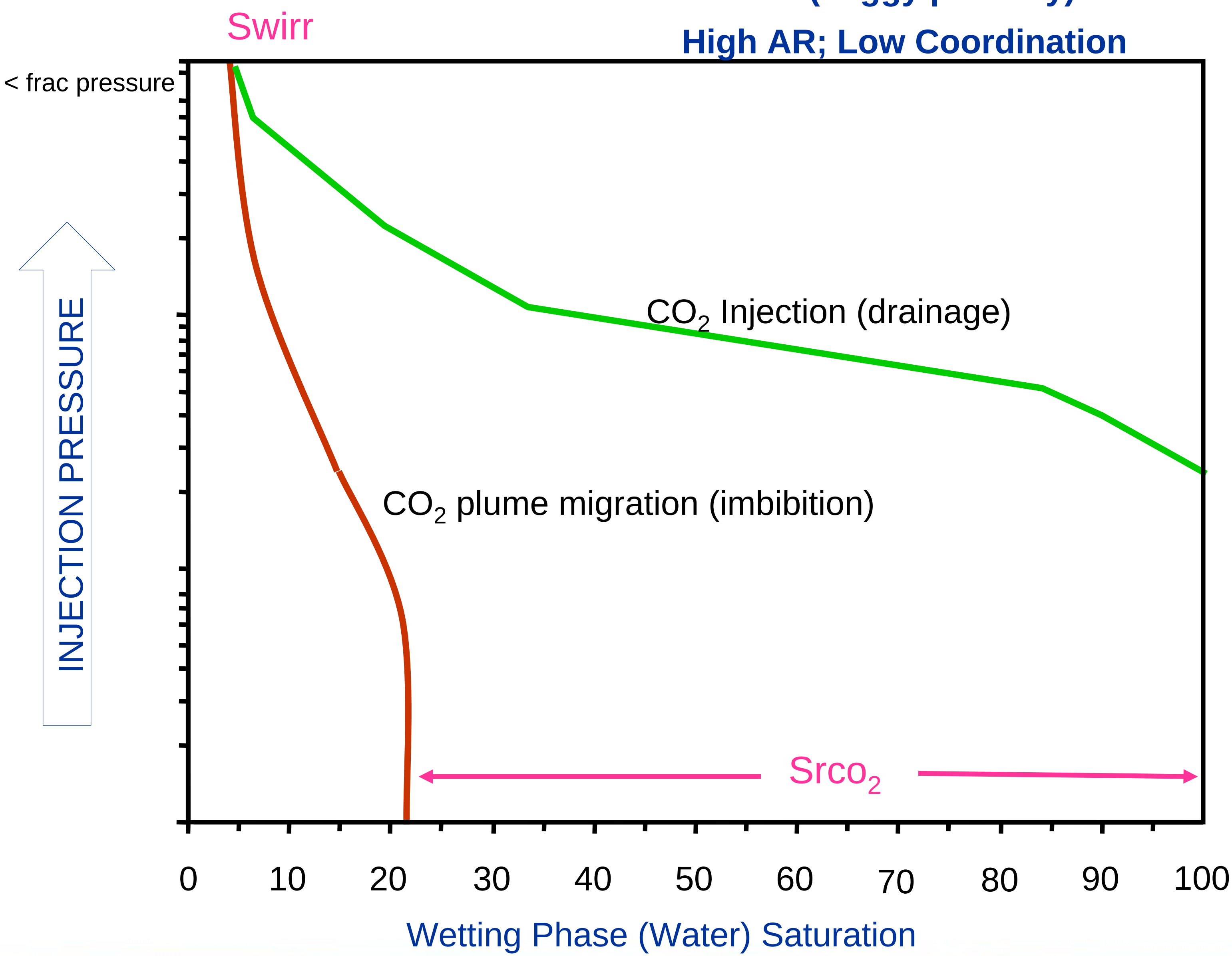


CO2 CRC

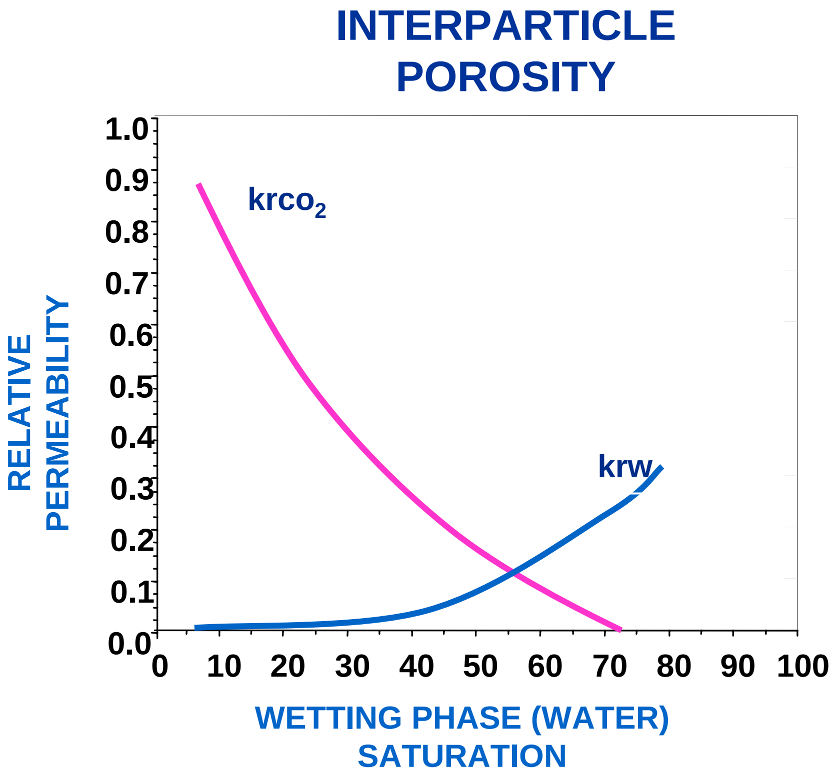

CO_2 Migration (Imbibition cycle)
CO_2 Injection (Drainage cycle)
High Residual CO_2 Saturation
1 cm
Vuggy Limestone Reservoir

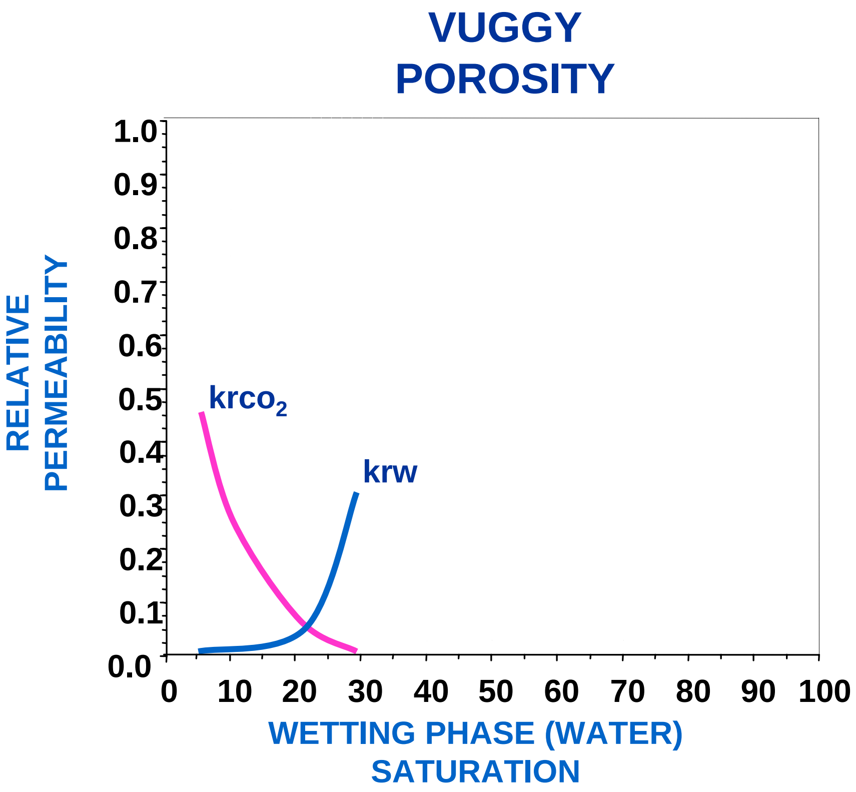
Rock C (vuggy porosity)

High AR; Low Coordination



Pore Geometry Affects Relative Permeability





Other Considerations: Pressure

•Injection of fluid (eg CO_2) causes reservoir pressure build up

•In depleted fields, pressure build-up may be neutral or beneficial

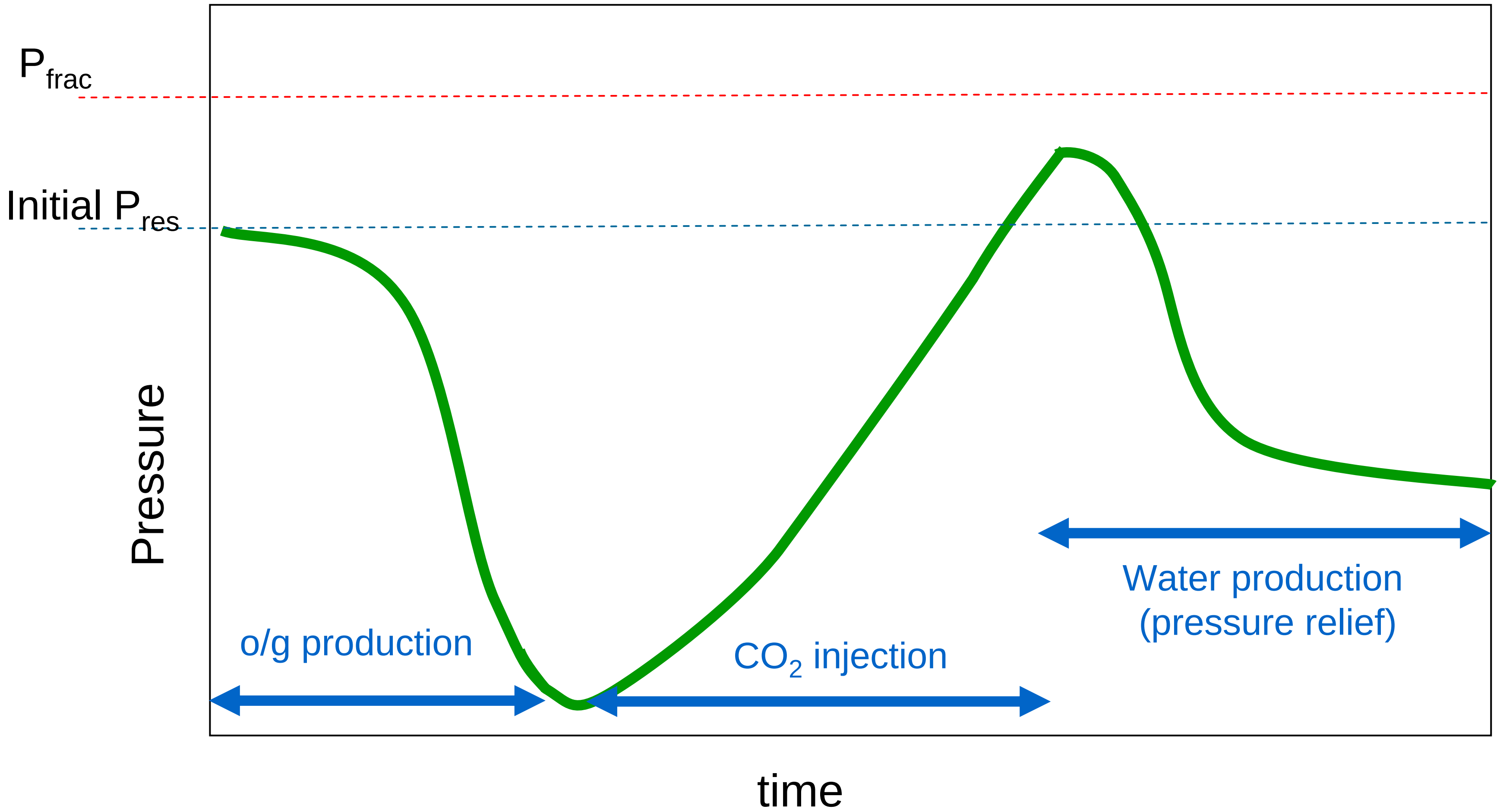
•In both depleted fields and saline aquifers, must maintain pressure below fracture pressure

•In low permeability reservoirs this may limit economic storage capacity due to decreased injection rate, requiring more wells

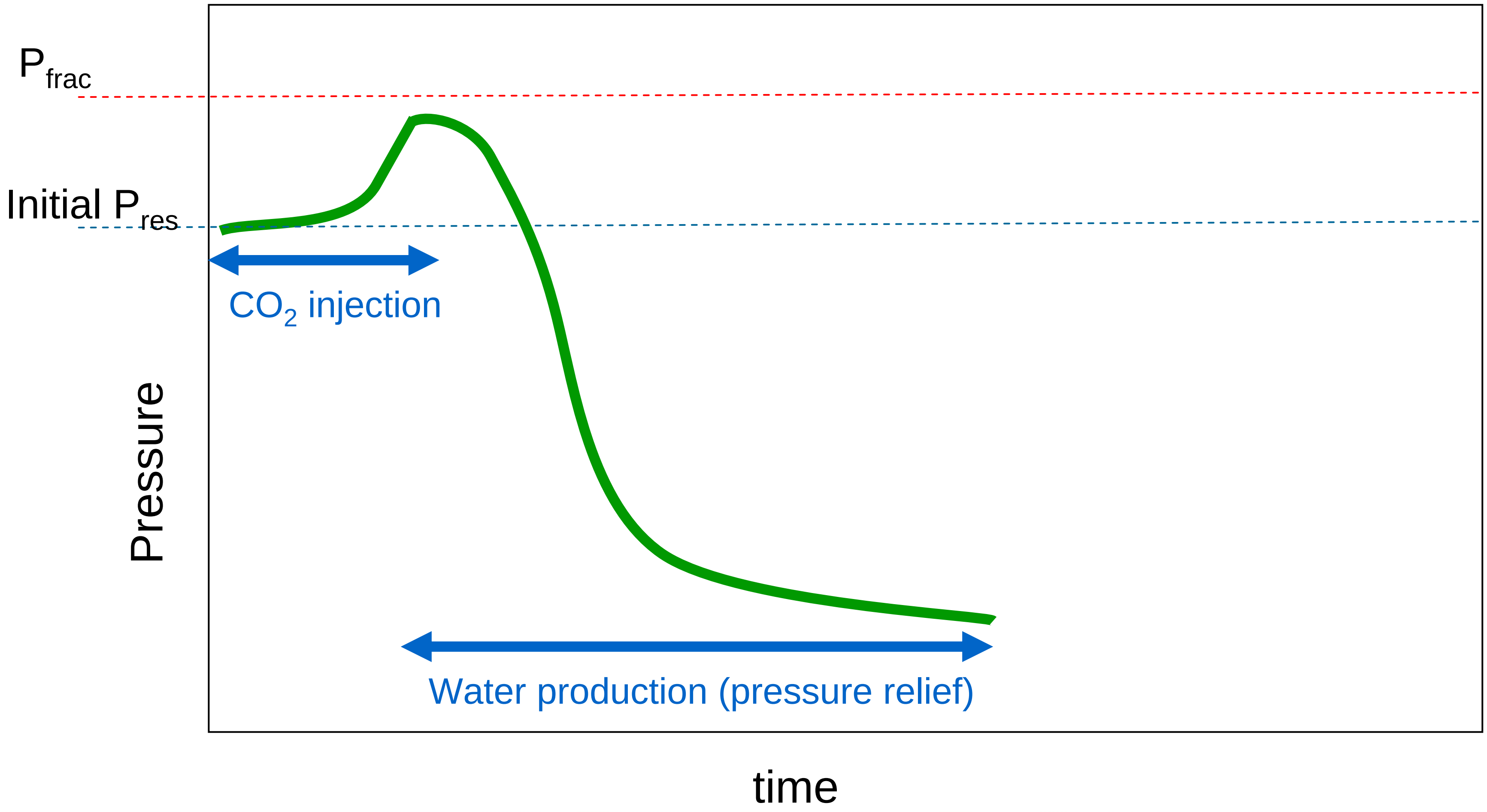
•Injection in saline formations may displace saline fluids & cause possible mixing with freshwater system

•Drilling pressure relief (water production) wells possible solution

Pressure v. Time (depleted field)



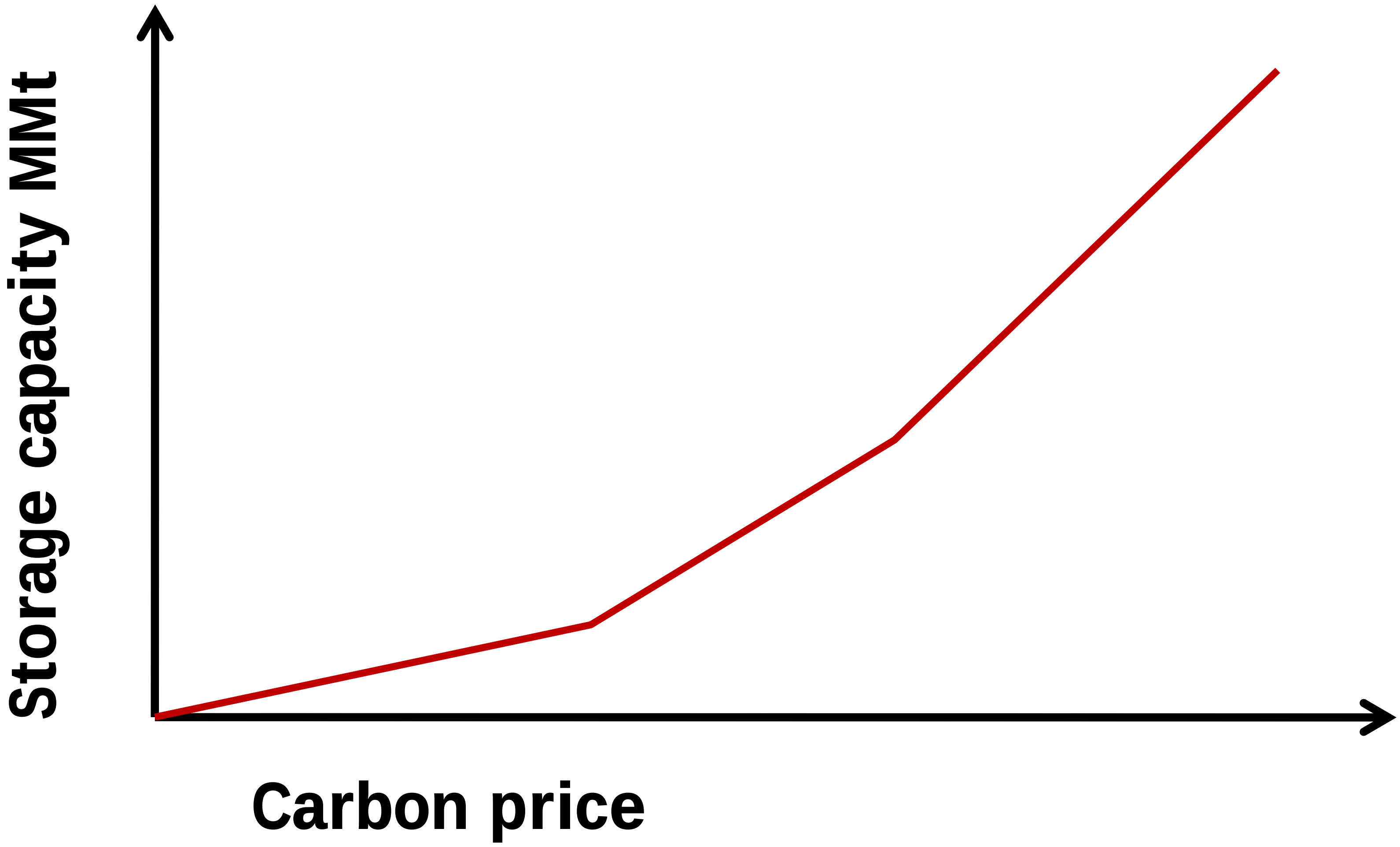
Pressure v. Time (saline aquifer)



Other Considerations: Injectivity

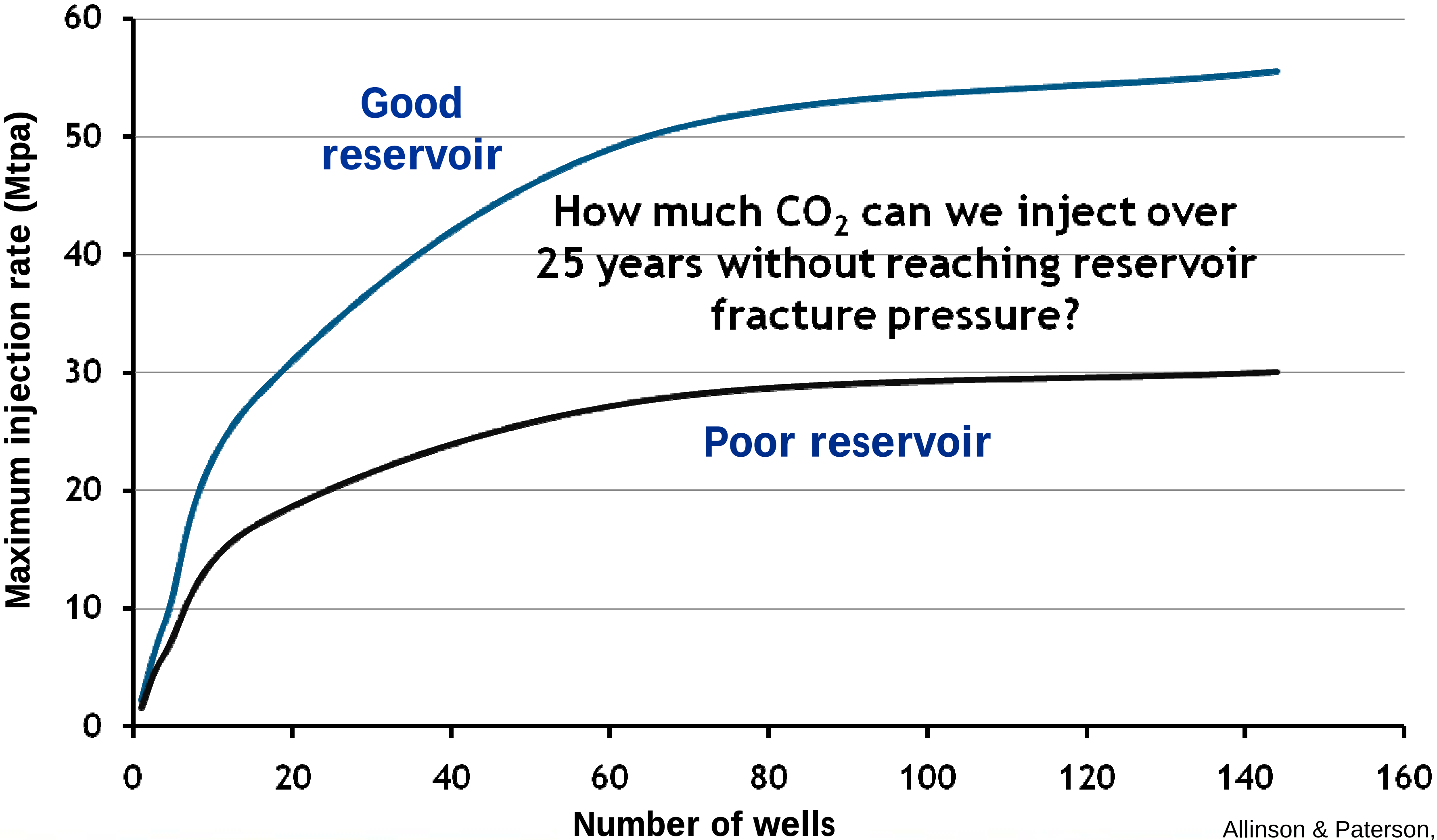
- Permeability
- Fracture pressure differential
- Heterogeneity
- Boundaries
- Strength of aquifer
- Pressure relief

Other Considerations: Economics



Allinson & Paterson, 2009

Modelling CO_2 storage capacity – the effect of injectivity and economics



Allinson & Paterson, 2009

Summary – the effect of injectivity and economics

- Volumetric estimates of storage capacity can be misleading.
- They ignore (a) injectivity and (b) economics.
- Reservoir modelling gives an estimate of injectivity.
- Economics tells us how much can be injected commercially at a given carbon price.

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SPE, WPC, AAPG definitions of reserves and resources:

Probabilistic; accepted by SEC

World Petroleum Council

Petroleum Resources Management System

2007

Sponsored by:

Prepared by the Oil and Gas Reserves Committee of
the Society of Petroleum Engineers (SPE);
reviewed and jointly sponsored by
the World Petroleum Council (WPC),
the American Association of Petroleum Geologists (AAPG);
and the Society of Petroleum Evaluation Engineers (SPEE).

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Summary – the effect of injectivity and economics

- Volumetric estimates of storage capacity can be misleading.
- They ignore (a) injectivity and (b) economics.
- Reservoir modelling gives an estimate of injectivity.
- Economics tells us how much can be injected commercially at a given carbon price.
- **SPE & WPC already have agreed definitions for reserves/resources. Shall we use these?**

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A few final thoughts...

Storage capacity is not only about the geology…..

- **It is also about engineering & economics!**

Existing methodologies for estimating storage capacity focus on volumetric calculations.

- **Are there alternatives eg probabilistic?**

“*E*” is very complex, variable, site and trapping mechanism specific

- **Does it actually mean anything?**