Methodologies for Storage Capacity Estimation and Site Selection for Geological Storage of CO_2*

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Abstract

The determination of carbon dioxide storage capacity and the selection and characterisation of potential sites for CO_2 storage are key issues in taking commercial-scale carbon capture and storage (CCS) projects forward. There is a need for better understanding of the issues surrounding capacity estimation as well as for a general agreement on assessment methodologies for the selection of appropriate sites to store carbon dioxide safely and securely. There are various scales of site selection and different levels of storage capacity estimation; of concern is which of these can be utilised for bankable projects. Most current storage capacity estimates are imperfect and there is a need for more understanding of the parameters that govern the efficiency factor (E) in our capacity estimates. Various rock and fluid properties affect storage capacity estimation (in particular “E”), and how these can be evaluated is a key challenge. Properties affecting “E” in saline formations include formation properties such as depth / temperature / pressure, as well as brine and CO_2 properties such as salinity / composition (density and purity). In addition, rock properties such as pore geometry (pore/throat size ratios; pore shape) in conjunction with relative permeability controls potential irreducible water saturations (Swirr) and residual CO_2 trapping ($SgrCO_2$). Dissolution trapping is a function of CO_2 residence time, which is in turn controlled by formation dip, CO_2 sweep (migration path / rate), hydrodynamics and aquifer properties. Rock/CO_2/fluid interactions are the principle controls on mineral trapping. These factors, plus the potential pore space reduction caused by residual oil or gas saturations affect capacity estimates in depleted fields. The natural variability and geological, engineering and economic complexity of any potential CO_2 storage site means that these properties need to be assessed individually for each potential storage site. However, a similar workflow can be applied to most capacity estimations. Such consistent and systematic methodologies can be used in assessing and classifying CO_2 storage volumes of potential storage sites and provide a uniform language that is understandable to (and usable by) the scientific community but can also be accepted by industry and the financial community.

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CSLF Carbon Sequestration Leadership Forum, 2007, Web accessed 5 August 2010, http://www.cslforum.org/

EERC Energy and Environmental Research Center, 2009, Web accessed 5 August 2010, http://www.undeerc.org/

IEA GHG International Energy Agency Green House Gas, 2008, http://www.ieaghg.org/

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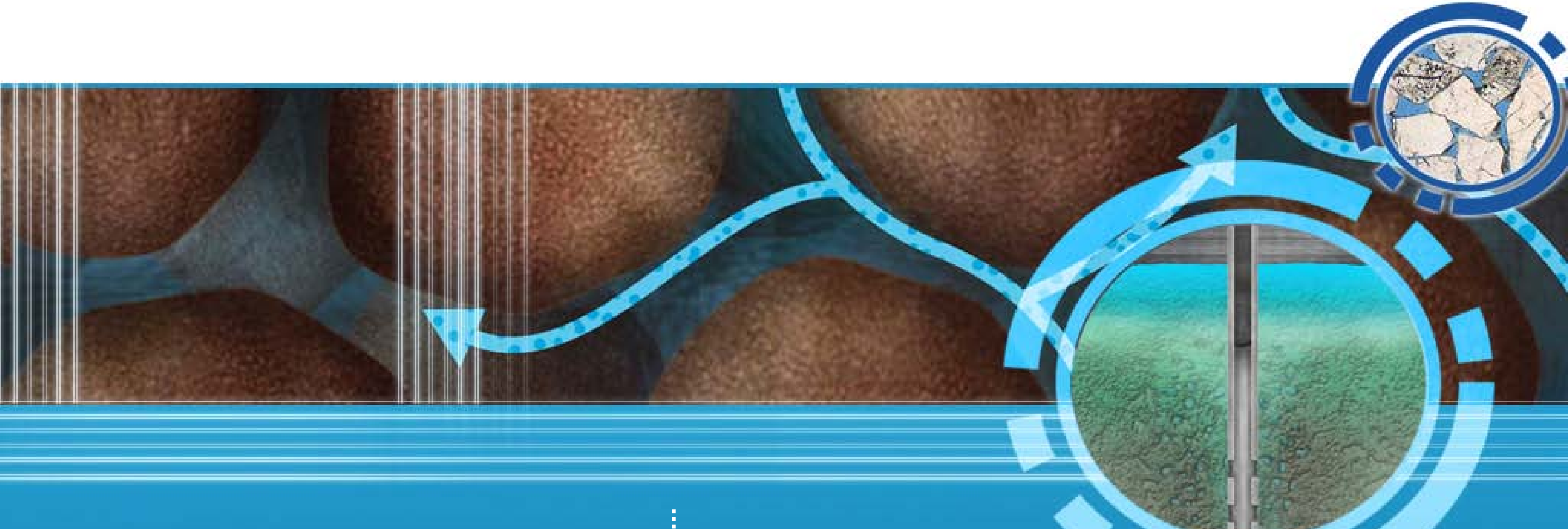
NETL DOE National Energy Technology Lab Department of Energy, 2006, Web accessed 5 August 2010, http://www.netl.doe.gov/ http://www.netl.doe.gov/energy-analyses/pubs/ccsregulatorypaperfinalreport.pdf

Methodologies for Storage Capacity Estimation & Site Selection for Geological Storage of CO_2



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CO_2 Sequestration:
Strategies and Technologies
for Storage and monitoring
AAPG, New Orleans,
13 April, 2010

CO2CRC

CO2CRC Participants

Supporting participants: Global CCS Institute, The University of Queensland, Process Group, Lawrence Berkeley National Laboratories

Established & supported under the Australian Government's Cooperative Research Centres Program

Outline

- Key Criteria for Site Selection
- Storage Capacity Estimation
  - "Efficiency Factor" (*E*)
- Geological Properties That Affect Capacity
  - Trapping Mechanisms (Structural / Stratigraphic / MAT)
  - Pore geometry / capillarity
  - Irreducible Water (S_{wirr}) / Residual CO_2 (Sgr_{CO2})
- Engineering / Economic Considerations
  - Pressure / Injectivity
- Conclusions

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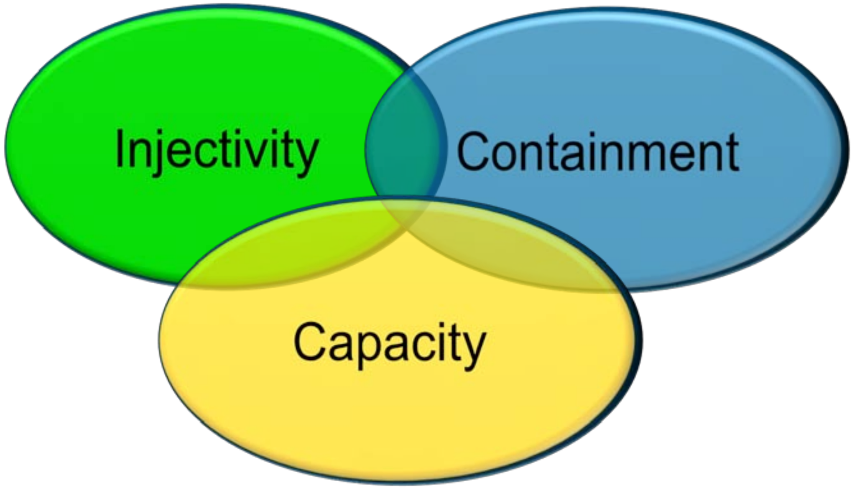
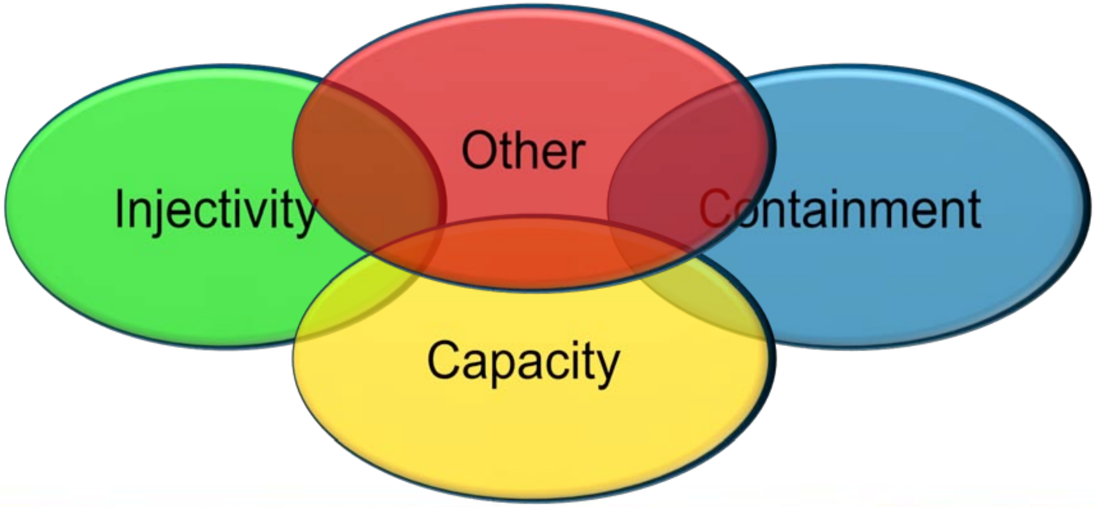
Key Criteria for Site Selection:

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



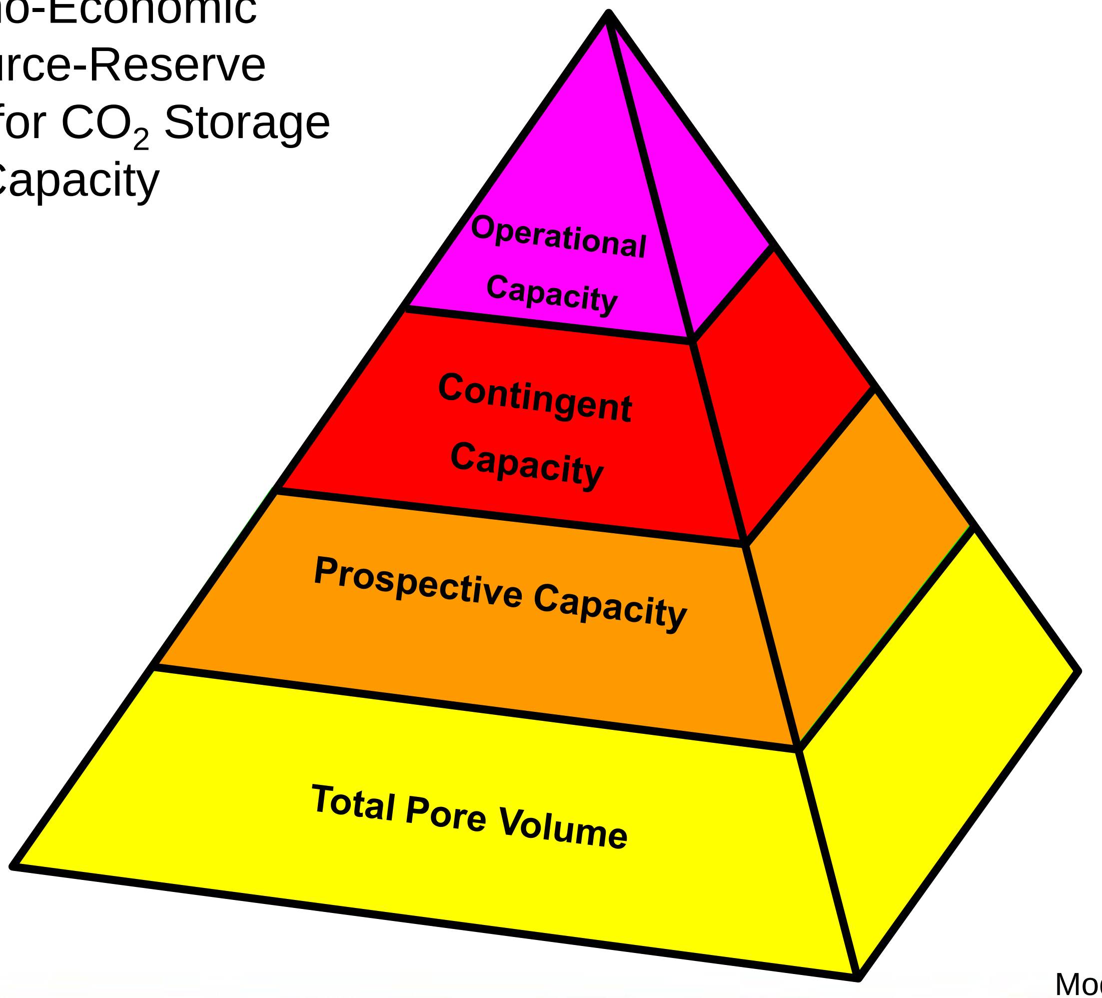
Key Criteria for Site Selection:

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



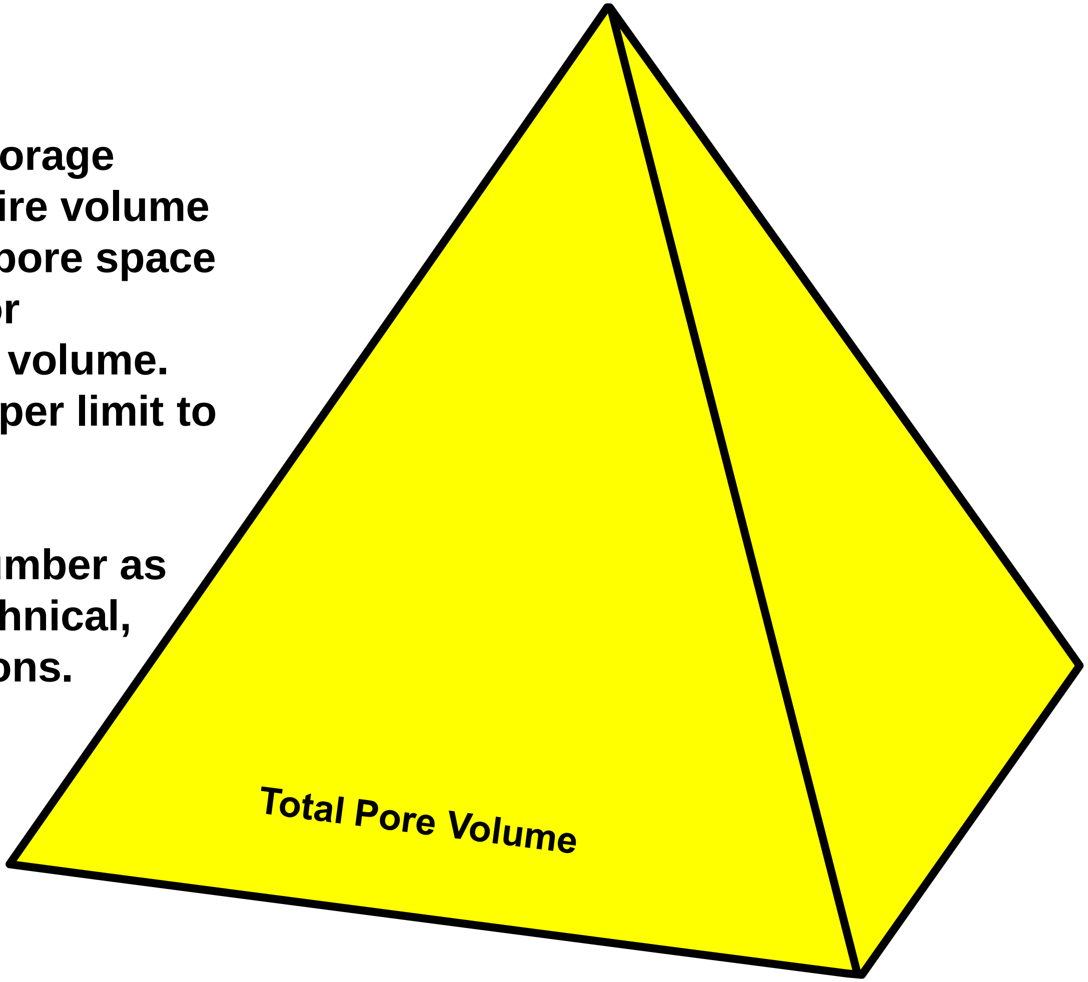
Storage Capacity Estimation

Techno-Economic Resource-Reserve Pyramid for CO_2 Storage Capacity



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

Storage Capacity Estimation



Total Pore Volume

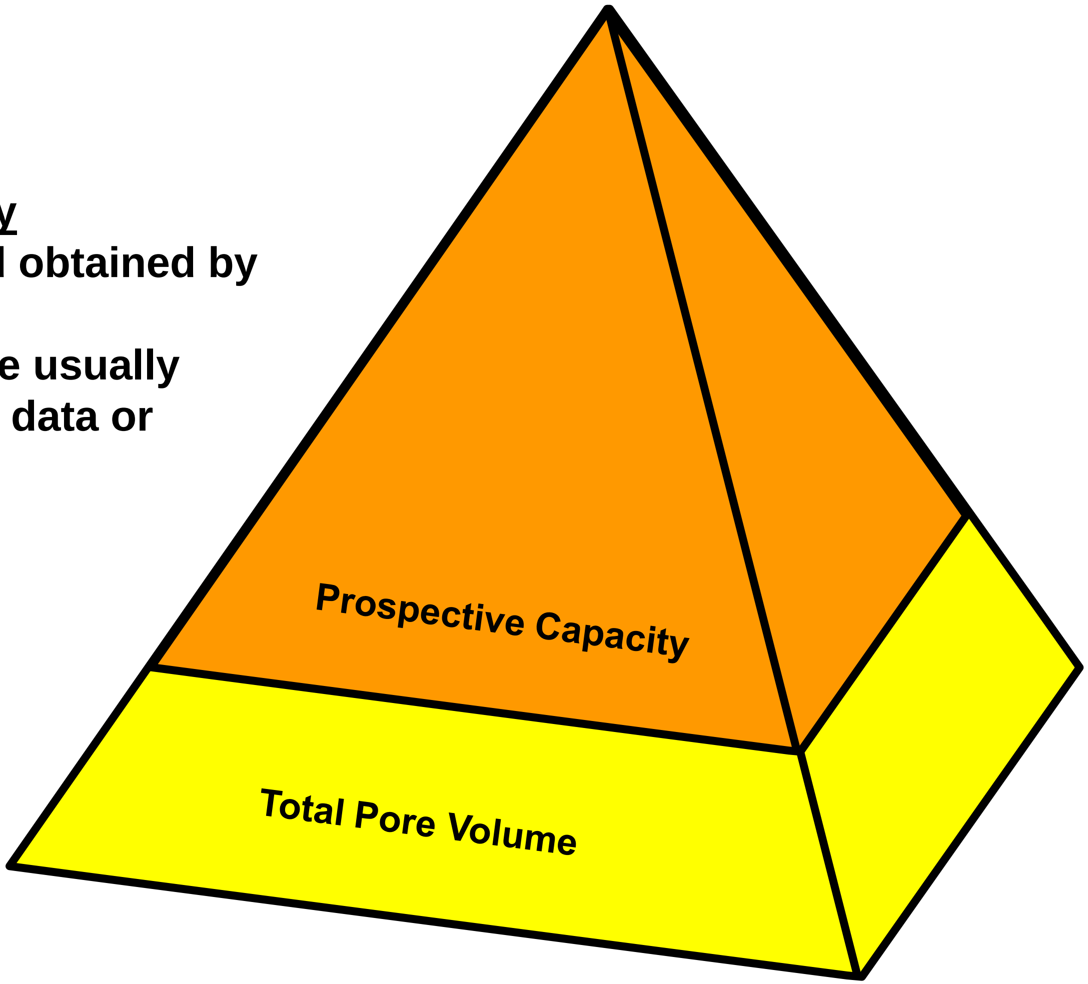
Total physical limit of what the storage system can accept. Assumes entire volume is accessible to store CO_2 in the pore space or dissolved in formation fluids or adsorbed at 100% onto total coal volume. This represents the maximum upper limit to a capacity estimate.

However, this is an unrealistic number as there will always be physical, technical, regulatory and economic limitations.

Storage Capacity Estimation

<u>Prospective Capacity</u>

Subset of Total Pore Volume and obtained by applying technical (geological & engineering) limits. This estimate usually changes with acquisition of new data or knowledge

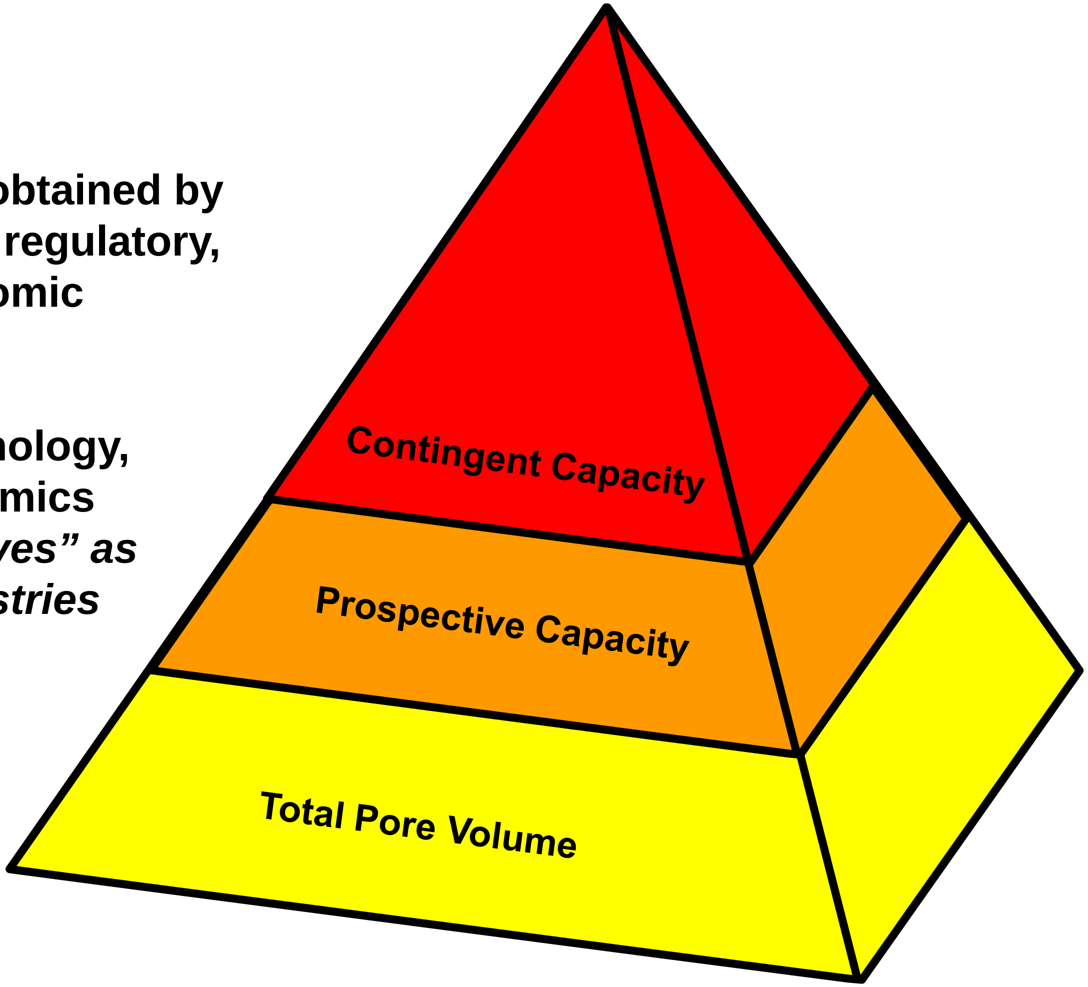


Storage Capacity Estimation

Contingent Capacity

Subset of prospective capacity obtained by considering technical, legal and regulatory, infrastructure and general economic barriers.

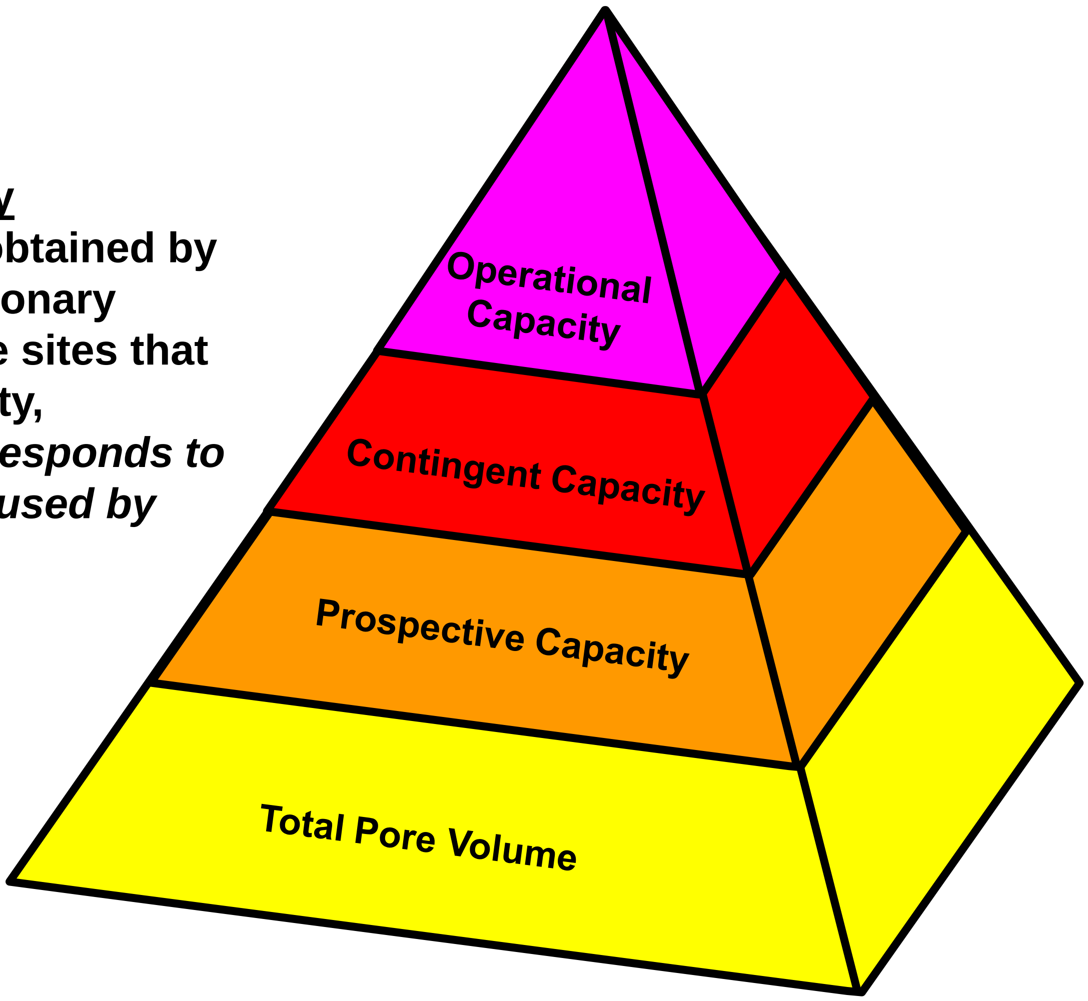
Value prone to changes as technology, policy, regulations and/or economics change. ***Corresponds to "Reserves" as used in energy and mining industries***



Storage Capacity Estimation

<u>Operational Capacity</u>

Subset of contingent capacity obtained by detailed matching of large, stationary sources with geological storage sites that are adequate in terms of capacity, injectivity and supply rate. *Corresponds to "Proved, marketable reserves" used by mining industry*



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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

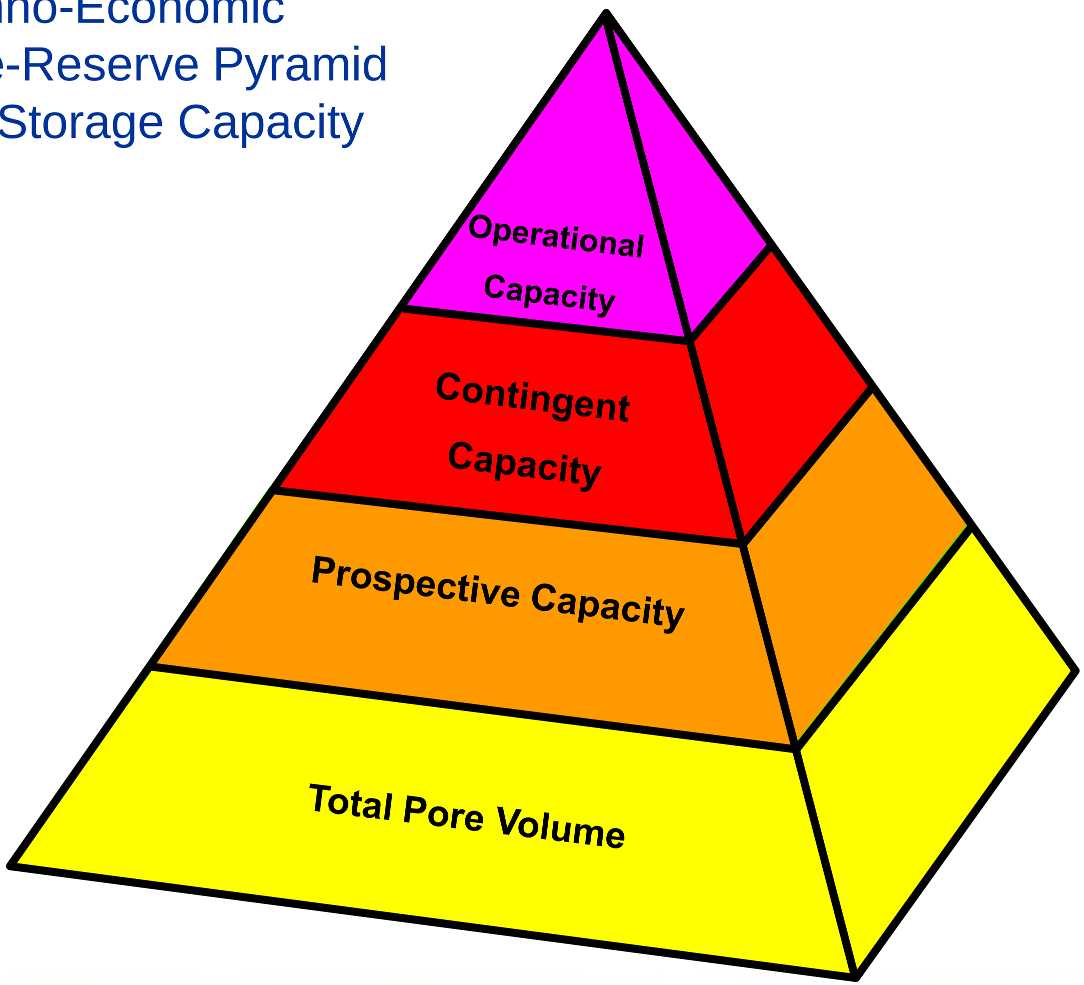
E = “efficiency factor” (fraction of total pore volume filled by CO_2)

~ 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 (no empirical data)
c) We don’t know what “*E*” to use…

Storage Capacity Estimation

Techno-Economic
Resource-Reserve Pyramid
for CO_2 Storage Capacity



Storage Capacity Estimation

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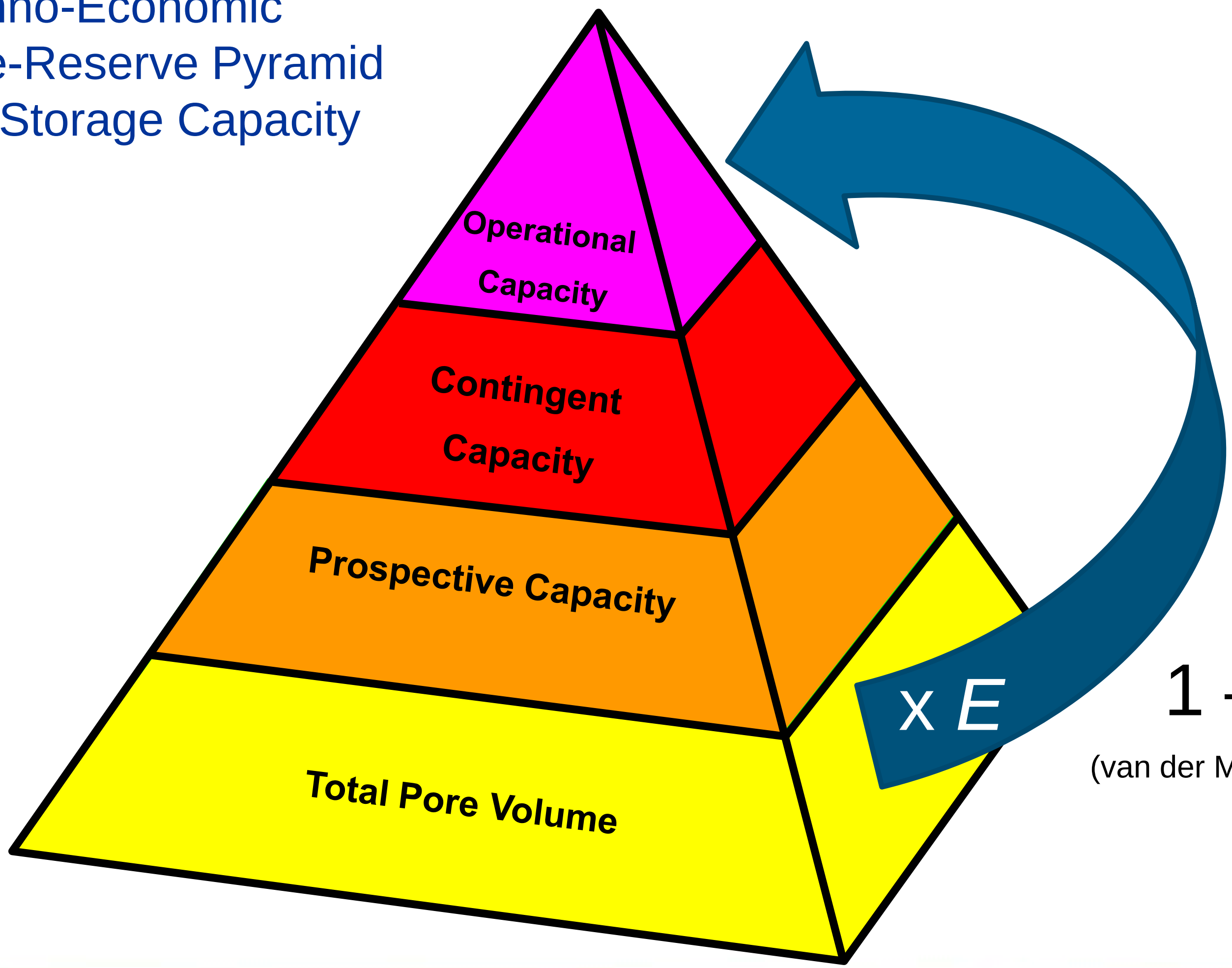
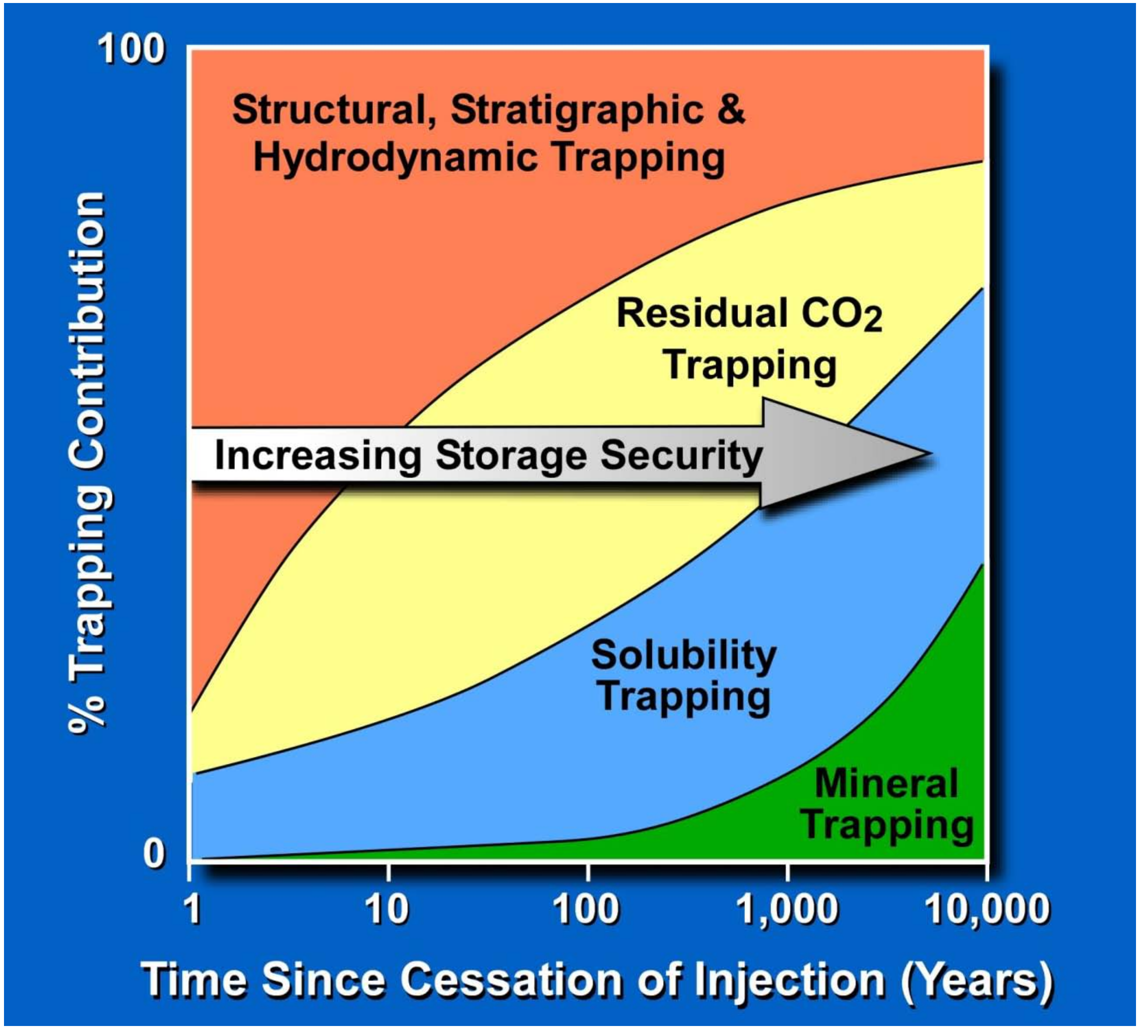


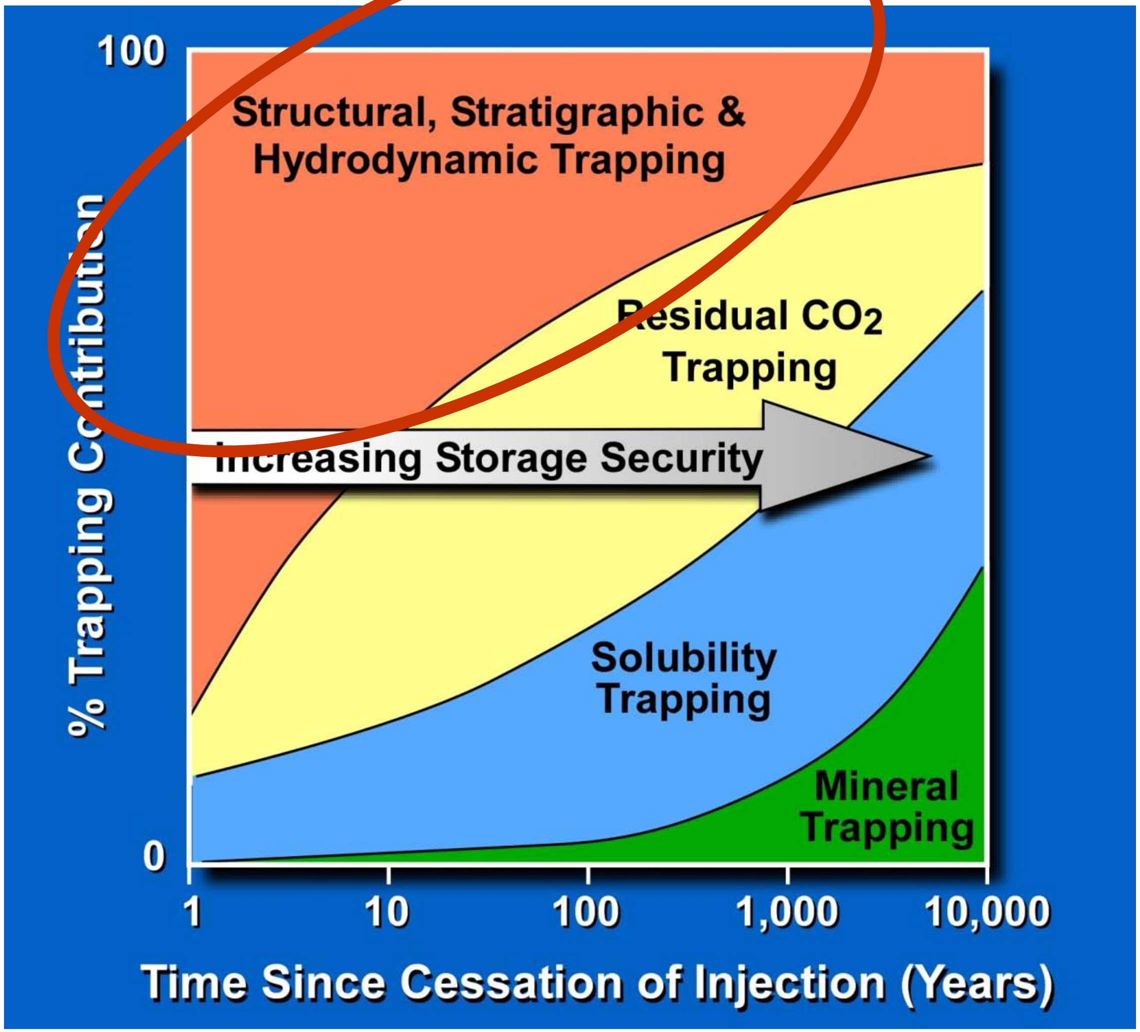
1 – 4%
(van der Meer and others)

CO_2 Storage Trapping Mechanisms



From IPCC SRCCS, 2005

CO_2 Storage Trapping Mechanisms



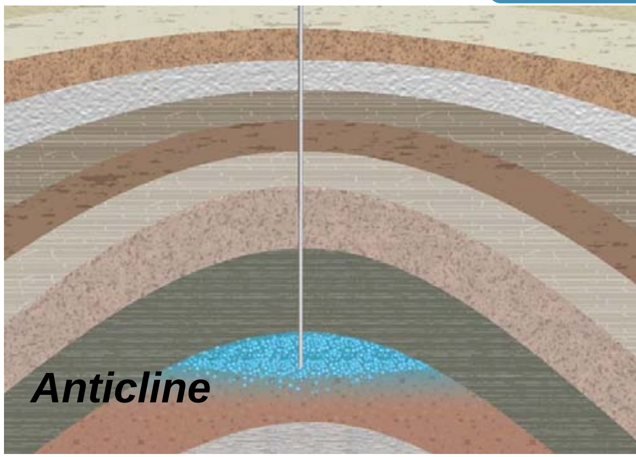
From IPCC SRCCS, 2005

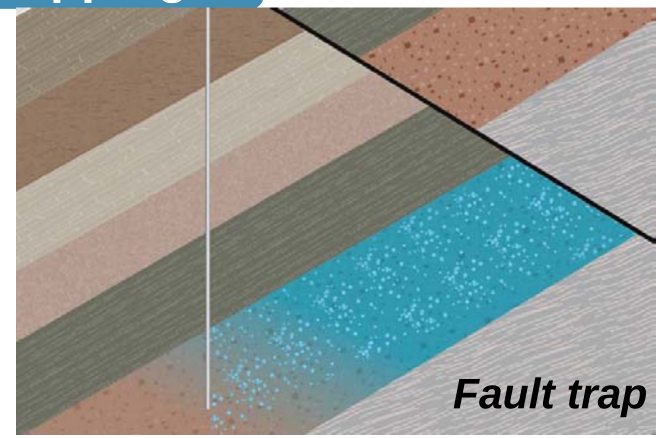
Structural / Stratigraphic Trapping (SST)

Most familiar; best understood; lowest risk

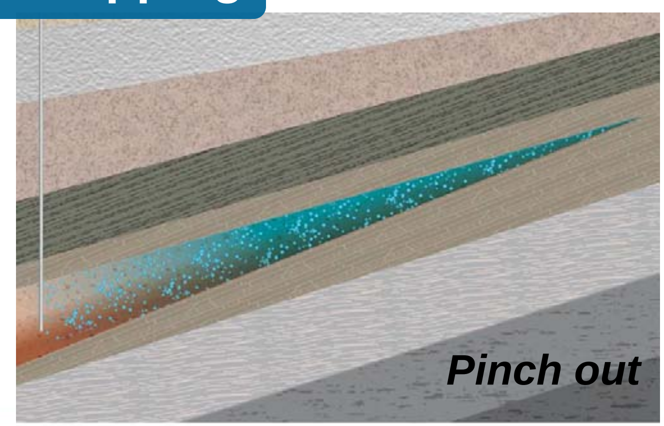
Structural / Stratigraphic Trapping

Structural trapping

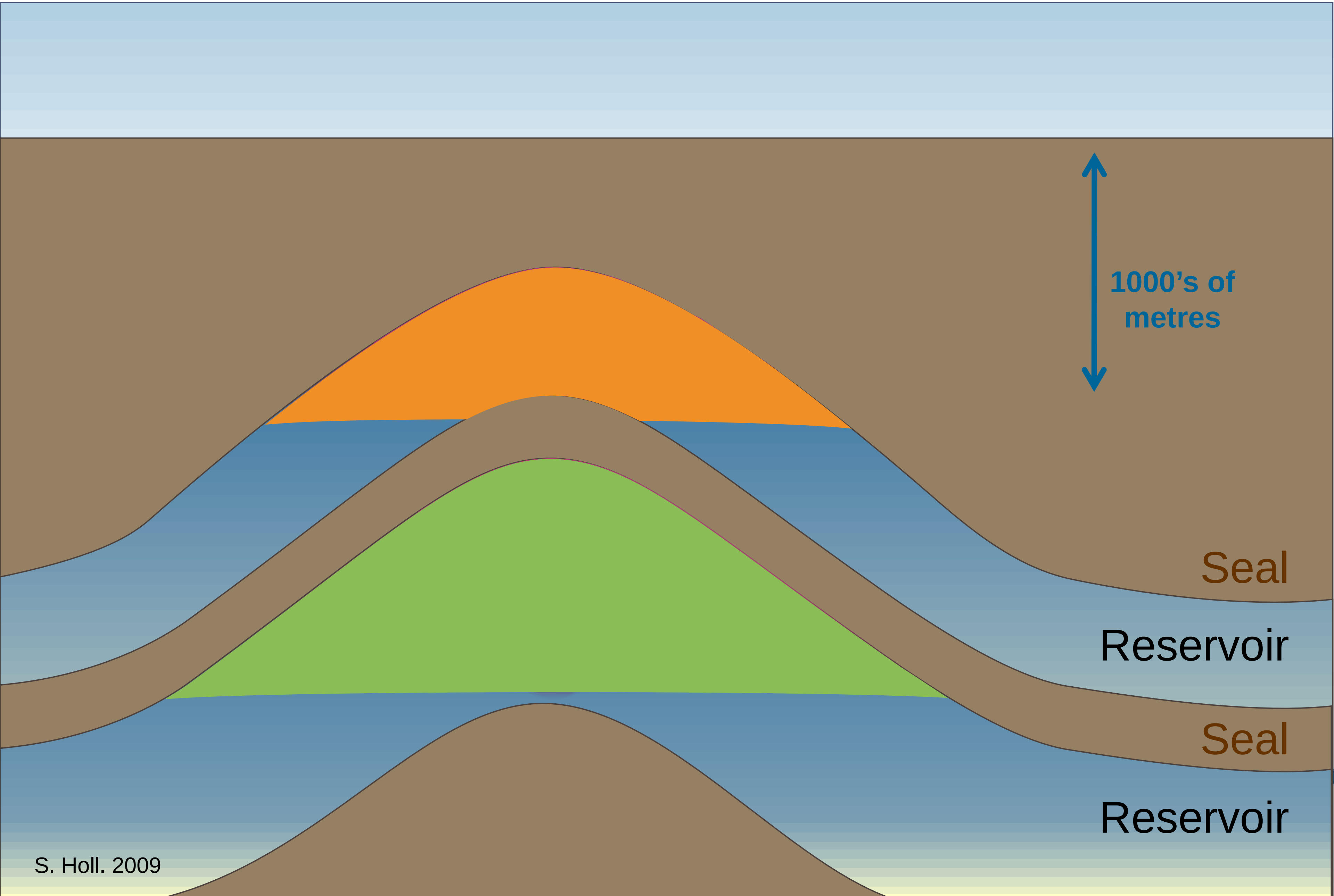




Stratigraphic trapping



Storage capacity issues in depleted reservoirs/structural traps



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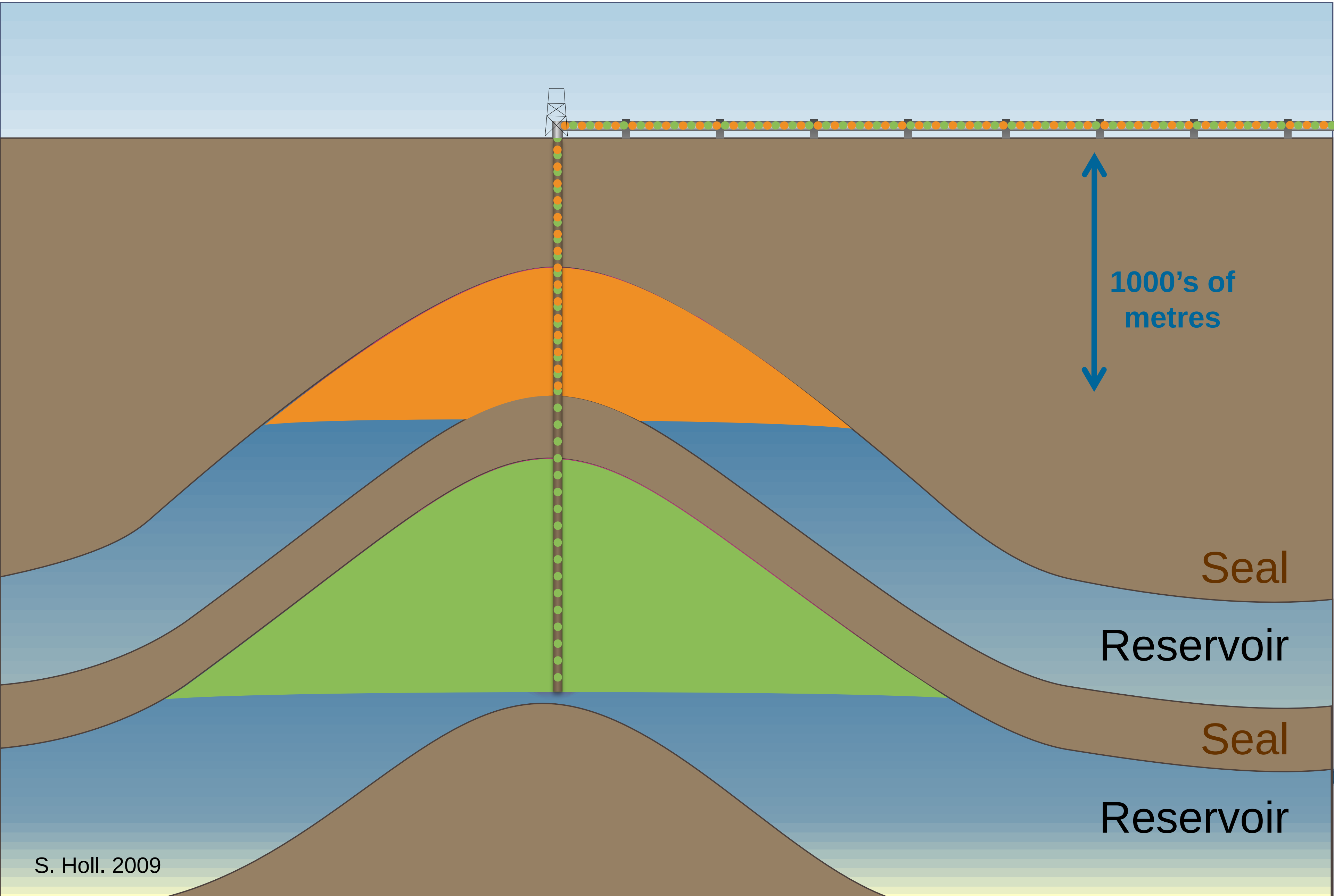

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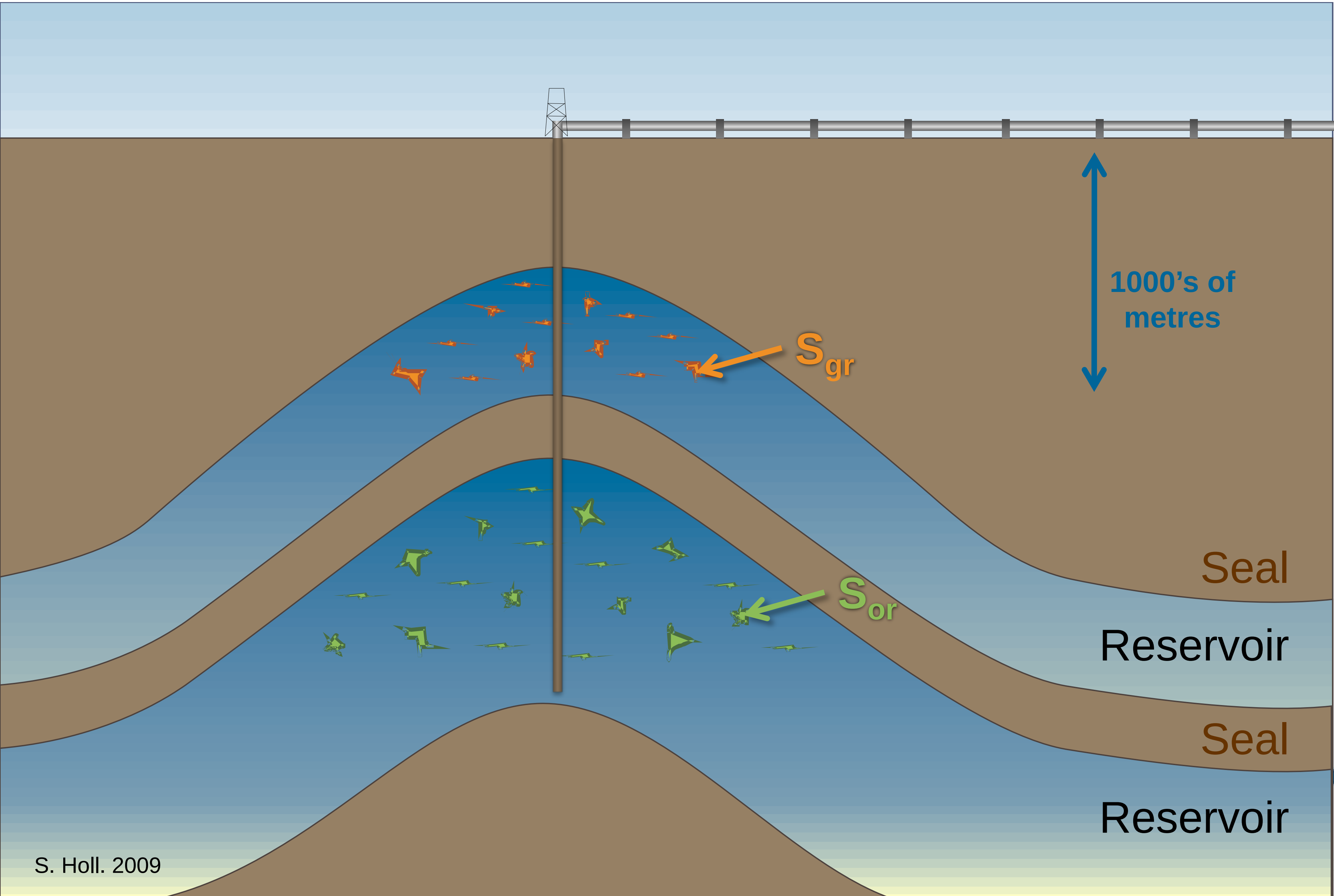

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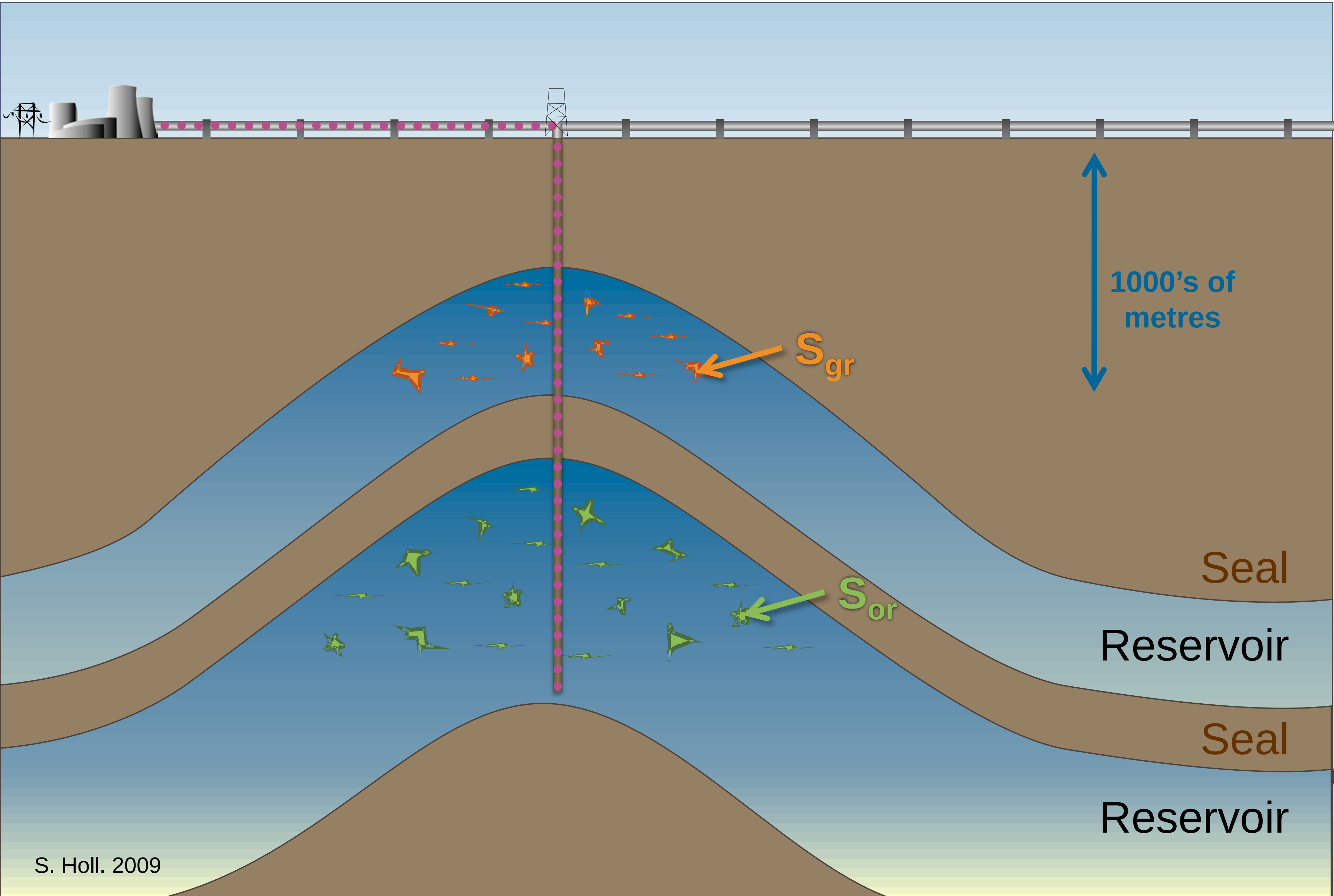

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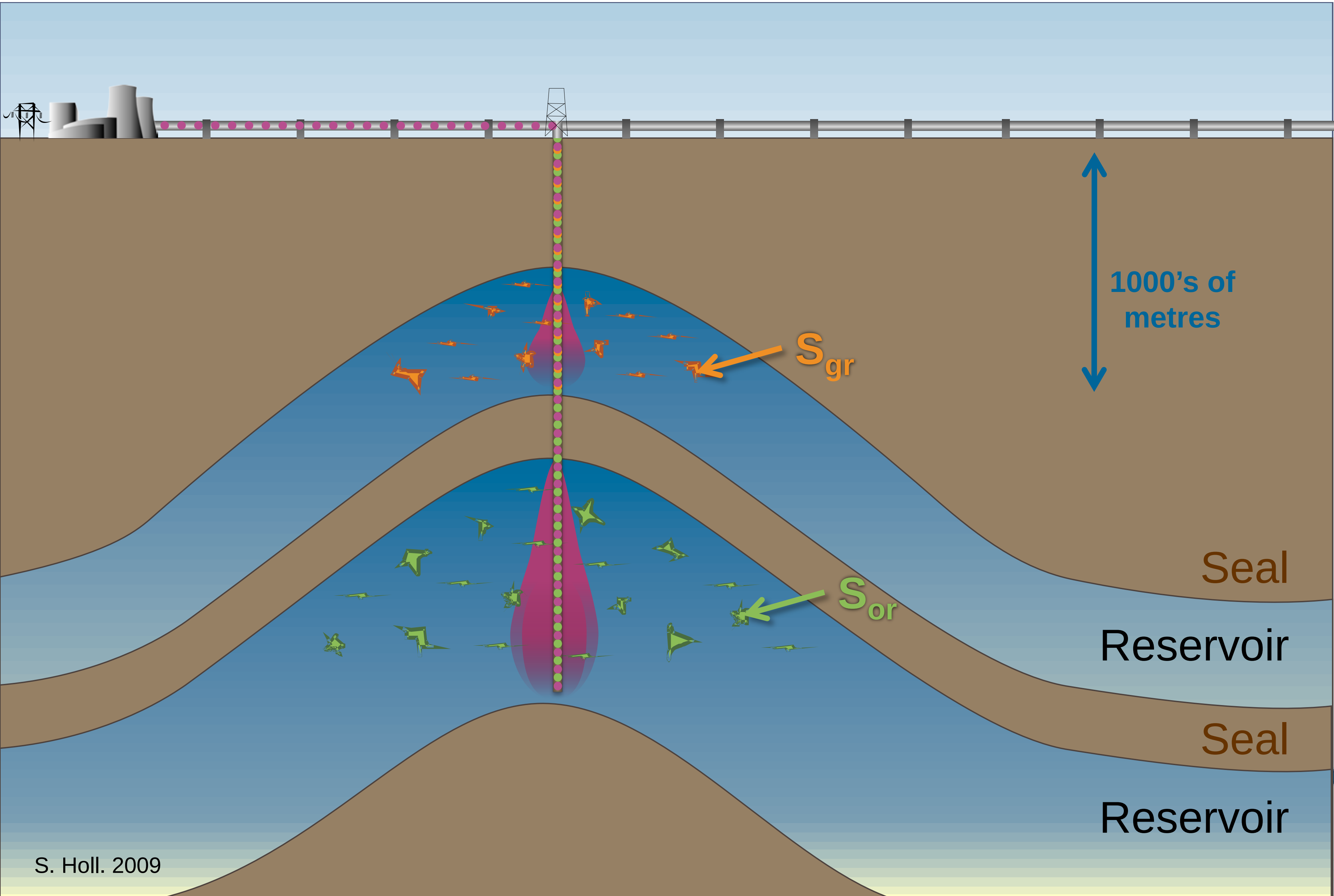

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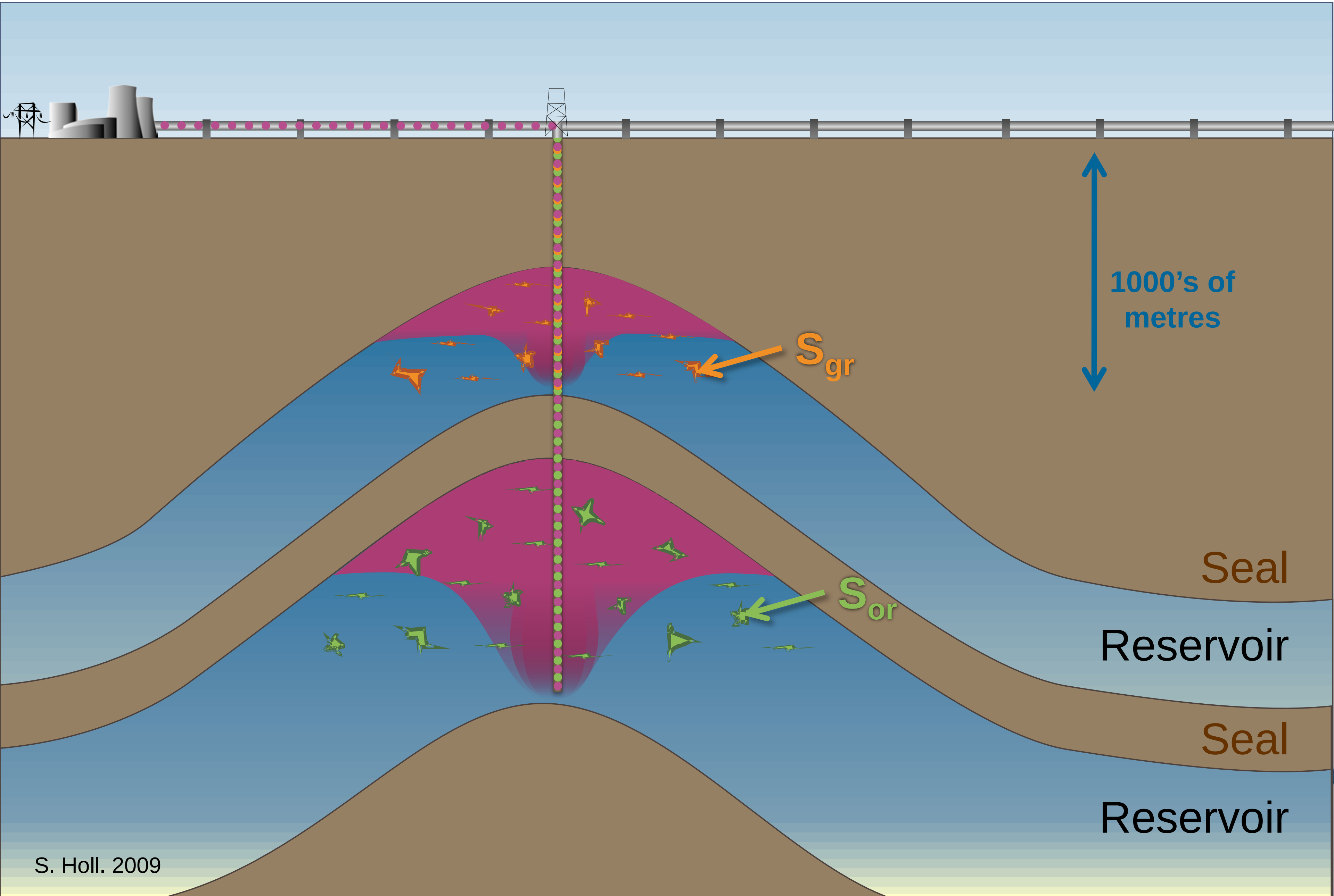
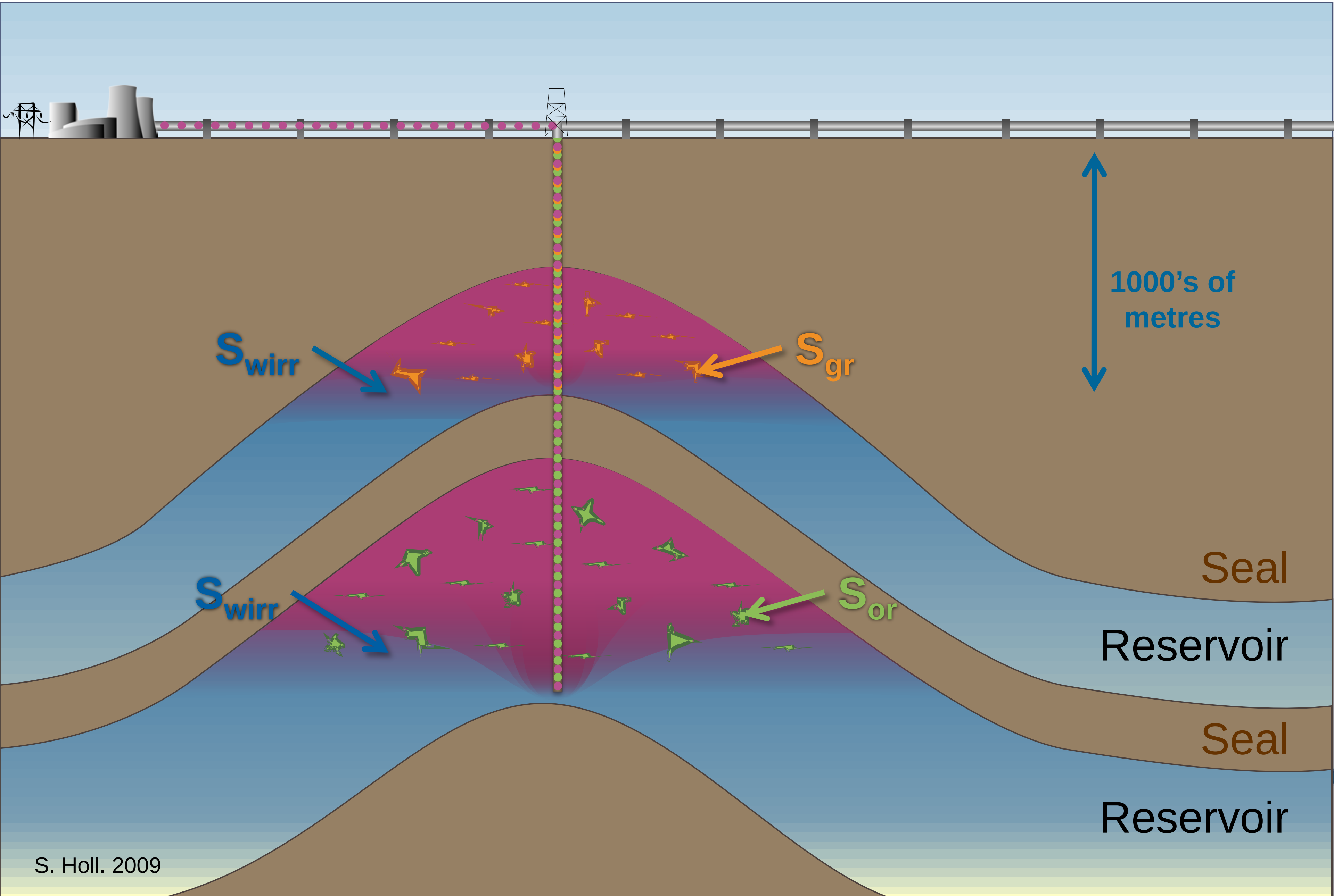
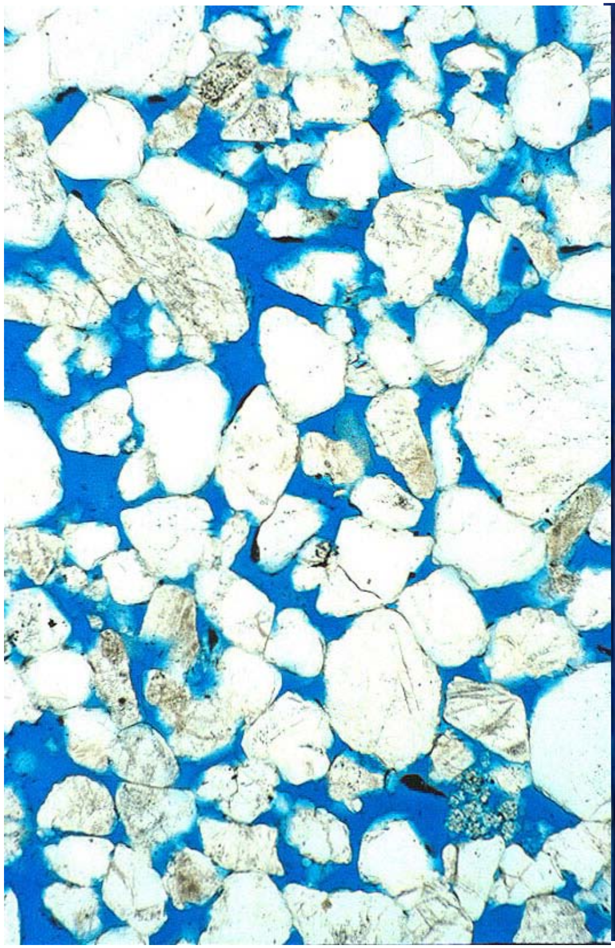
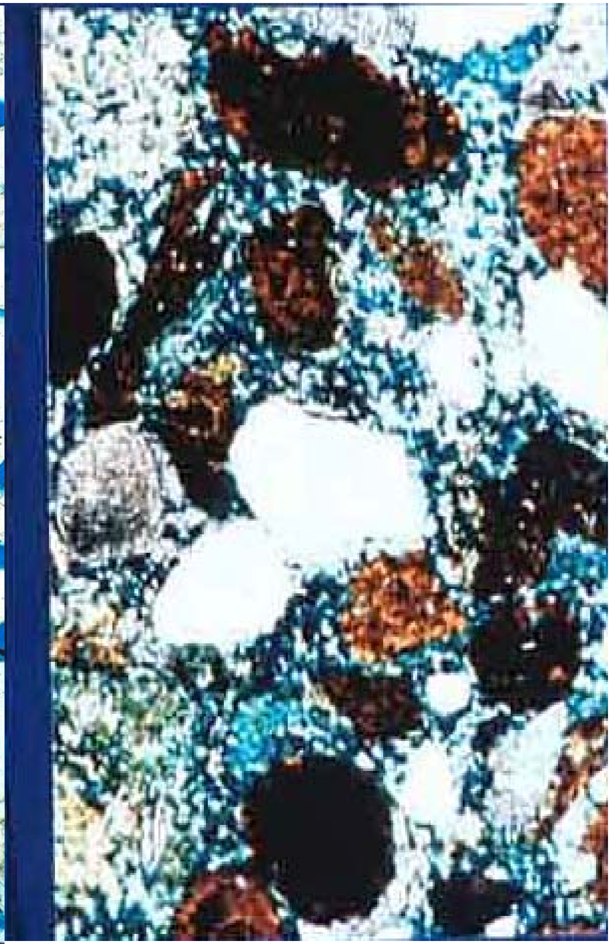


Storage capacity issues in depleted reservoirs/structural traps



Storage capacity controlled by rock type (not just porosity)



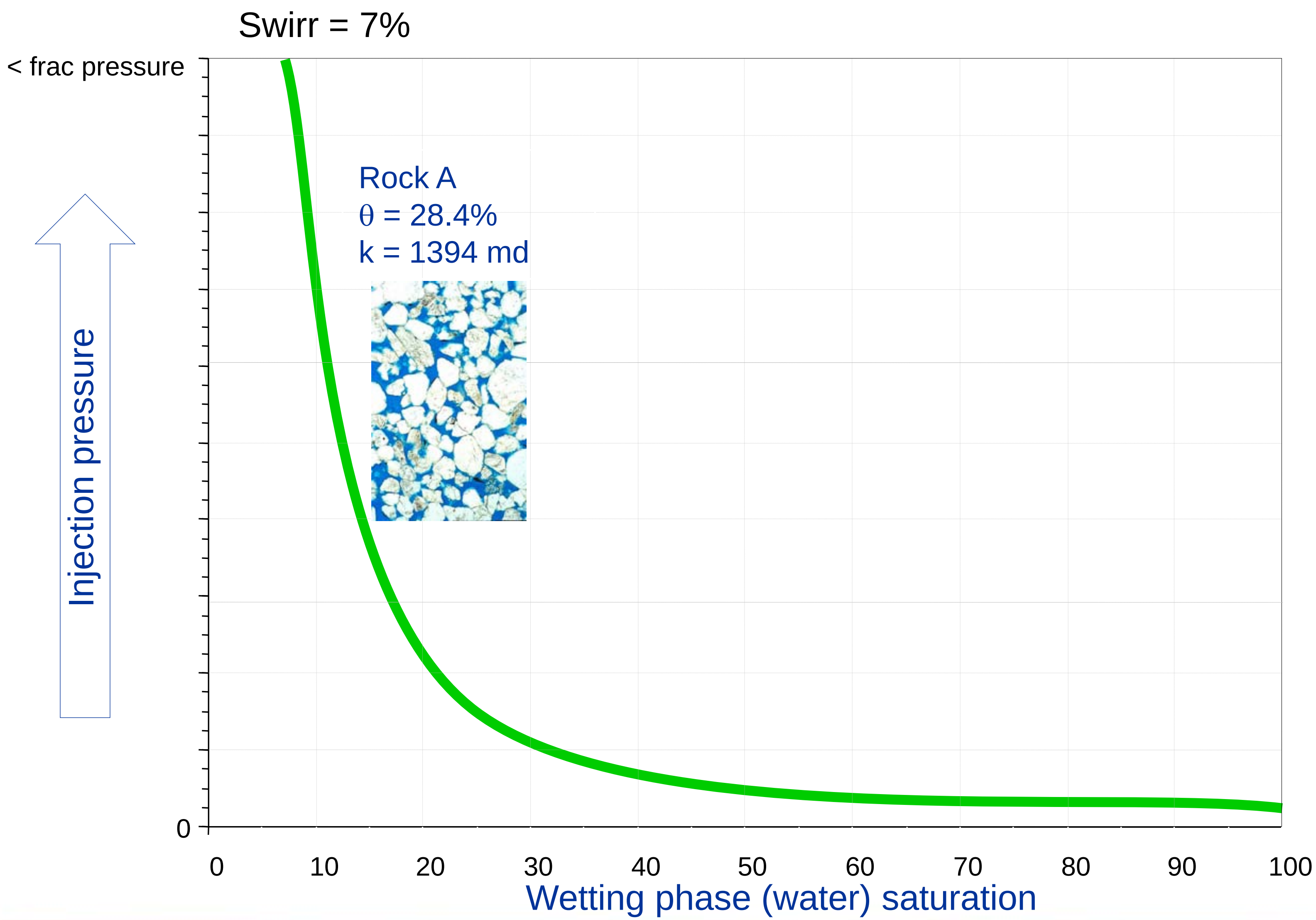


250 μm

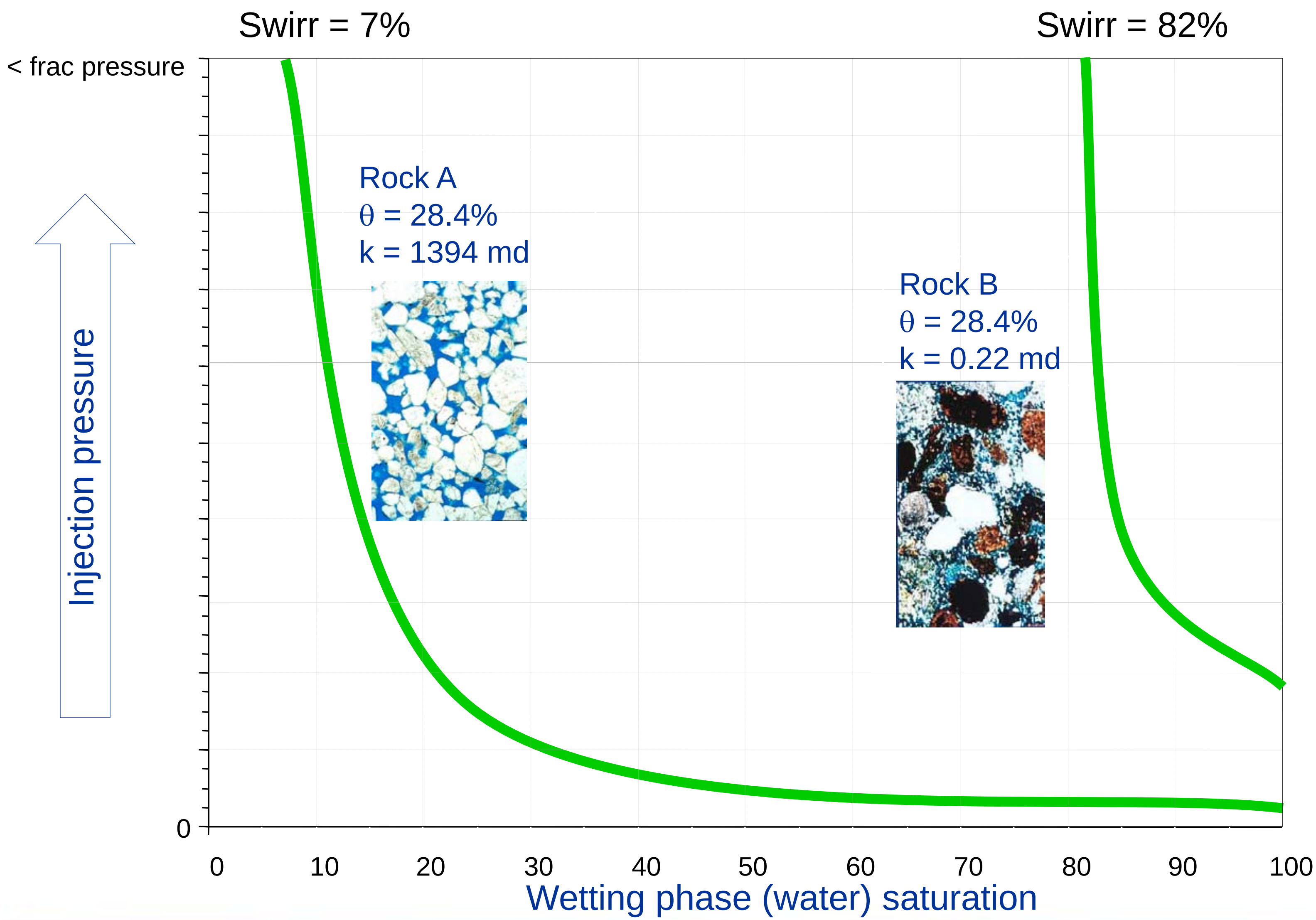
Rock A: $\phi = 28.4\%$
k = 1394 md

Rock B: $\phi = 28.4\%$
k = 0.22 md

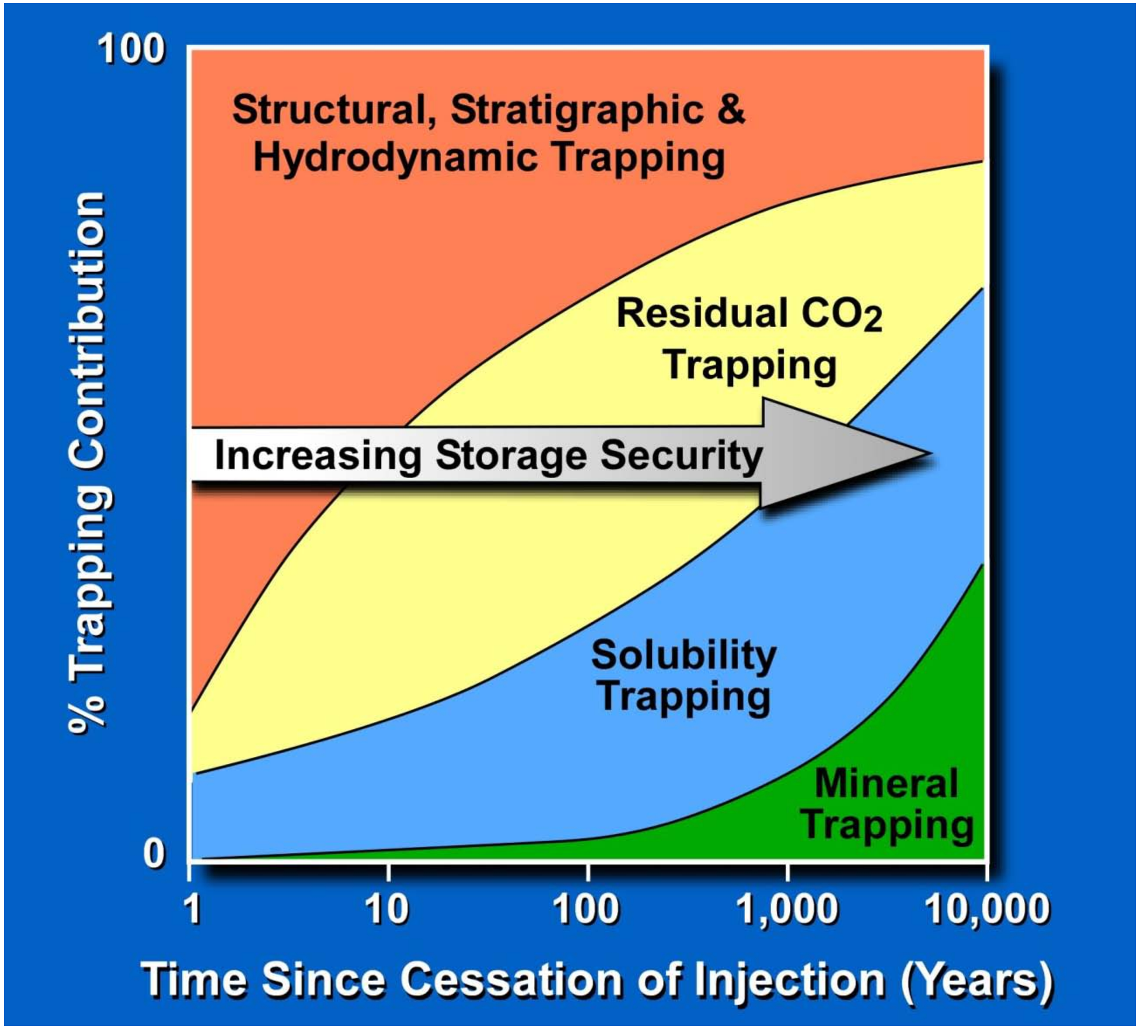
Irreducible water saturation: a critical control on storage capacity



Irreducible water saturation: a critical control on storage capacity

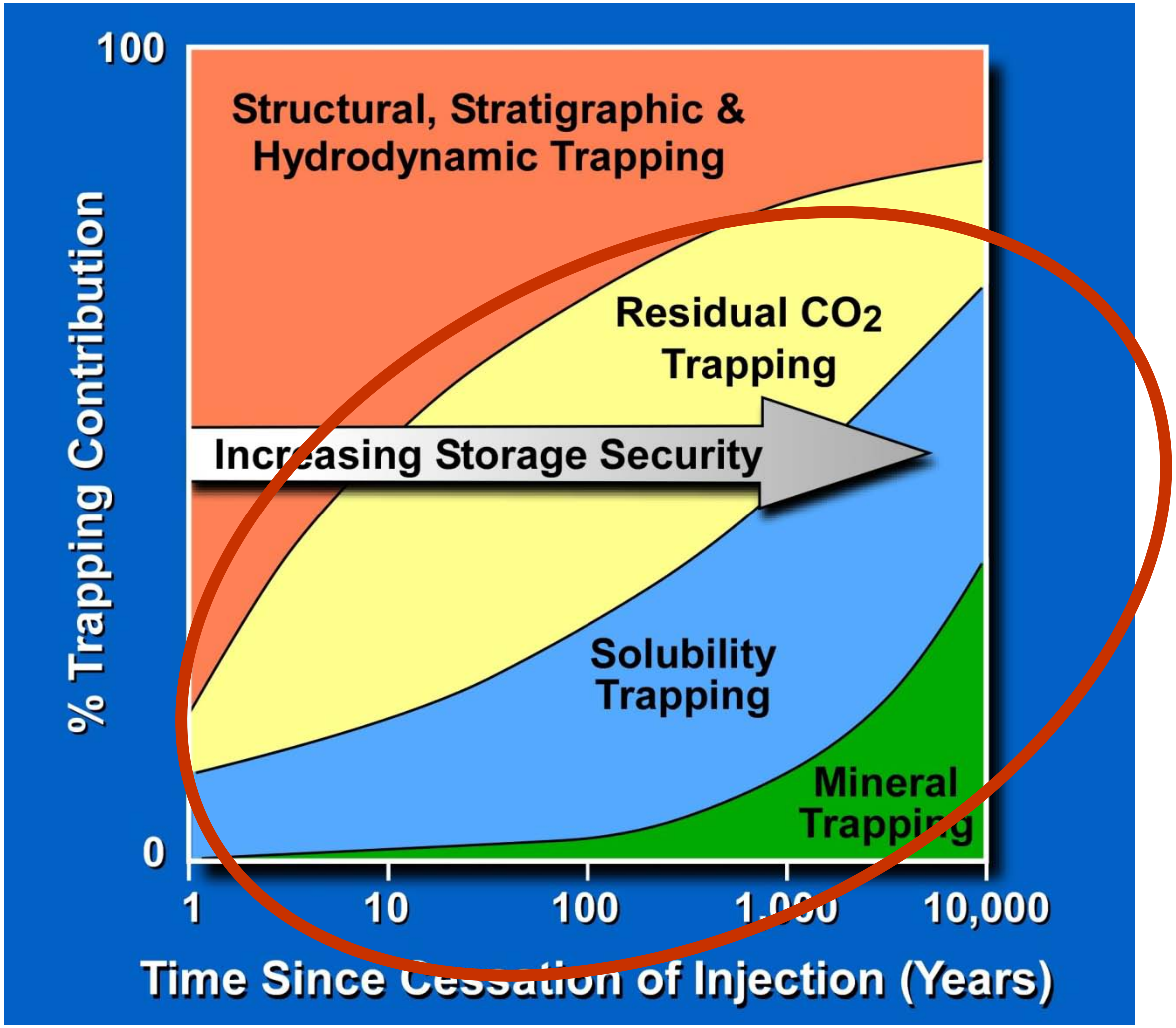


CO_2 Storage Trapping Mechanisms



From IPCC SRCCS, 2005

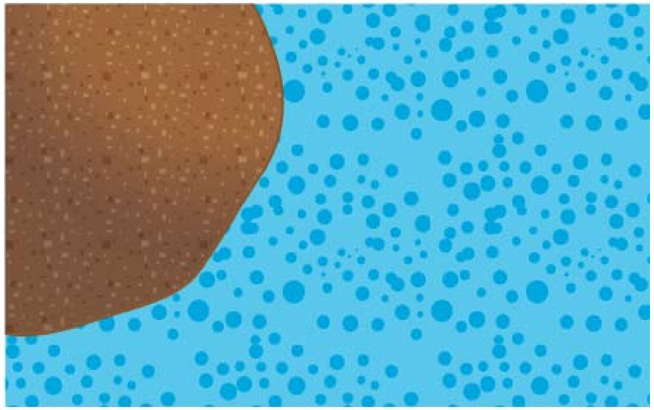
CO_2 Storage Trapping Mechanisms



Migration Associated Trapping (MAT)

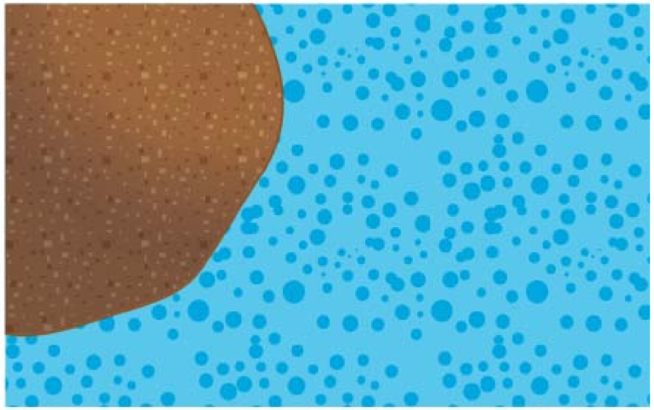
From IPCC SRCCS, 2005

Migration Associated Trapping (MAT)



CO_2 Trapped in solution

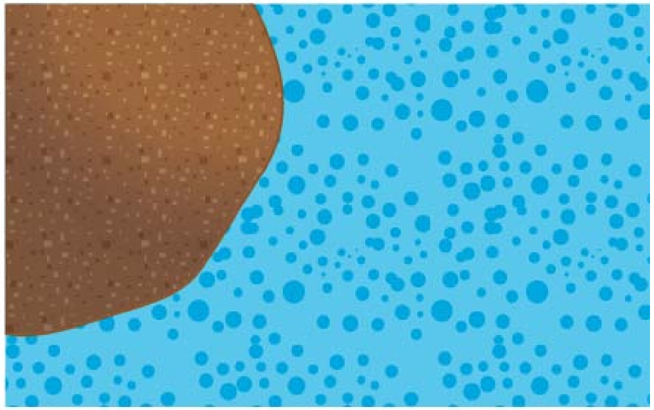
Migration Associated Trapping (MAT)



CO_2 Trapped in solution

CO_2 Trapped as a mineral

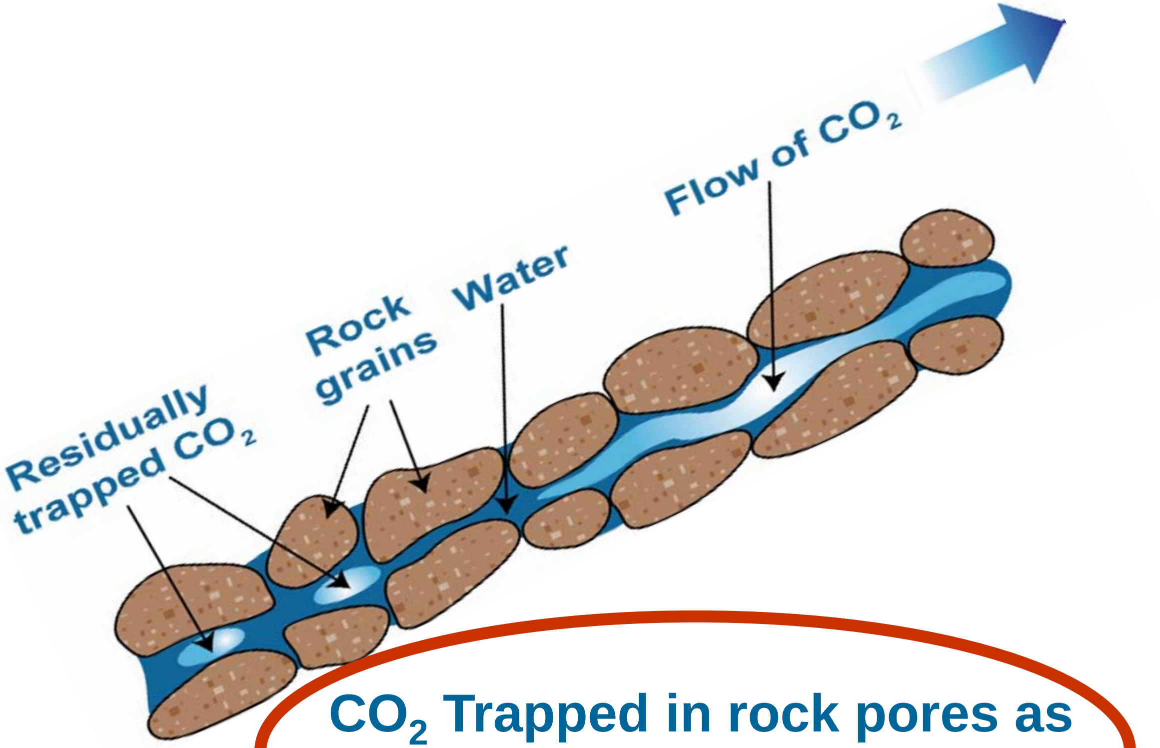
Migration Associated Trapping (MAT)



Click to View Notes by Presenter

CO_2 Trapped in solution

CO_2 Trapped as a mineral

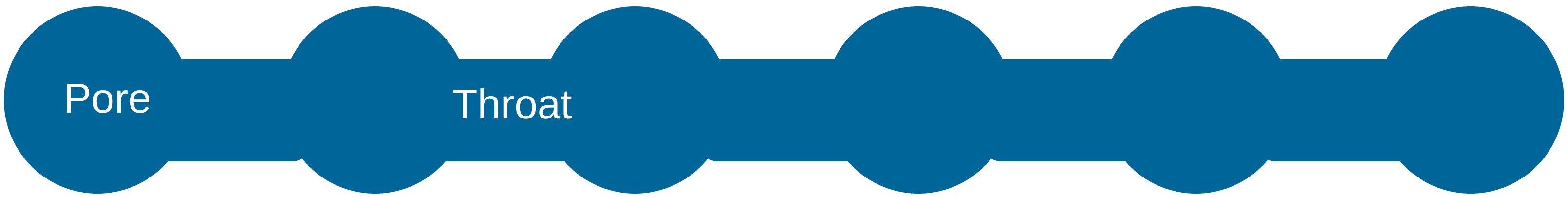


CO_2 Trapped in rock pores as Residual Saturation (Sgr_{CO2})

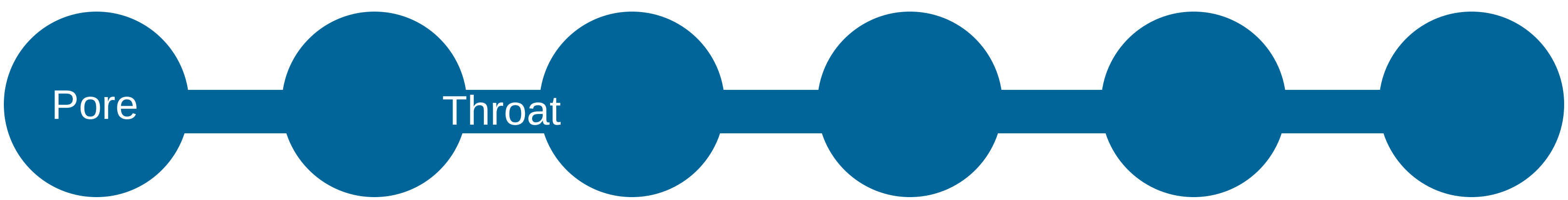
Notes by Presenter (for previous slide): The five basic mechanisms which hold the CO_2 in place are stratigraphical, structural, residual, solubility, and mineral trapping. Where the CO_2 is injected into horizontal or gently dipping reservoirs, or into saline aquifers, it can remain in the reservoir moving very slowly for a long time until eventually it is trapped by residual, solubility or mineral trapping. This is referred to as hydrodynamic trapping.

Residual Saturation (Sgr_{CO2}) Controlled by Pore Geometry: pore/throat size ratio

Low p/t ratio:
higher oil/gas recovery; lower Sgr_{co2}



High p/t ratio:
Lower oil/gas recovery; higher Sgr_{co2}



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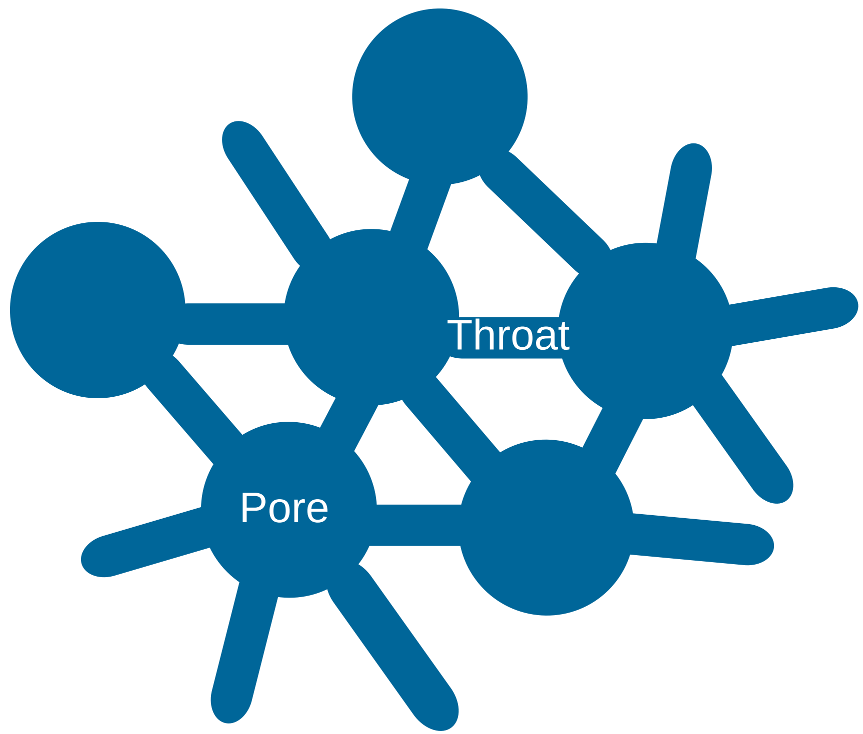
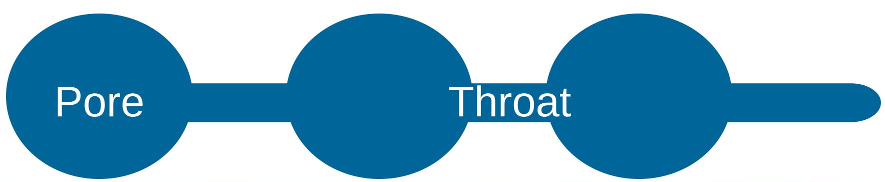
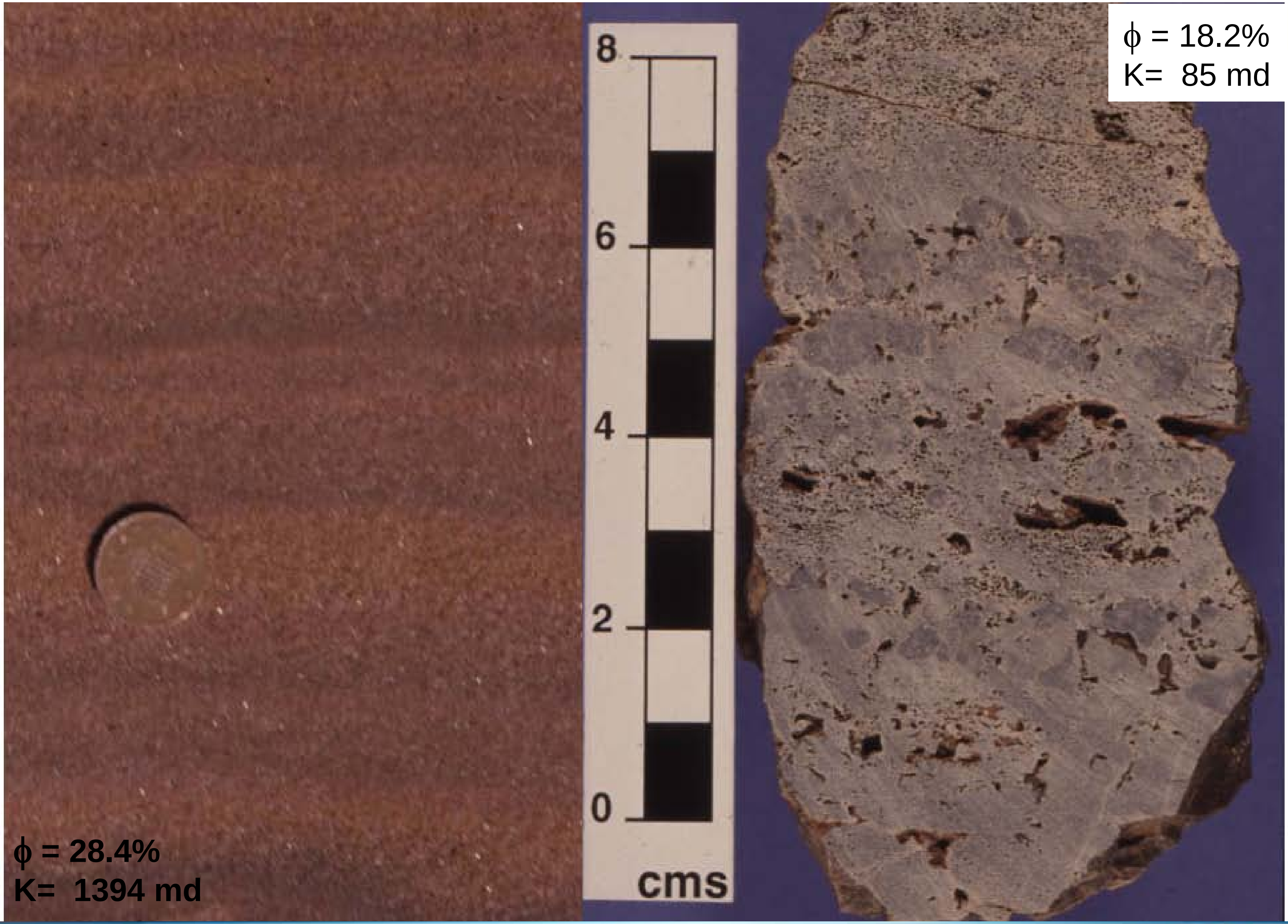
Pore geometry: coordination (throats/pore)

Higher coordination:
better oil/gas recovery
lower Sgr_{co2}

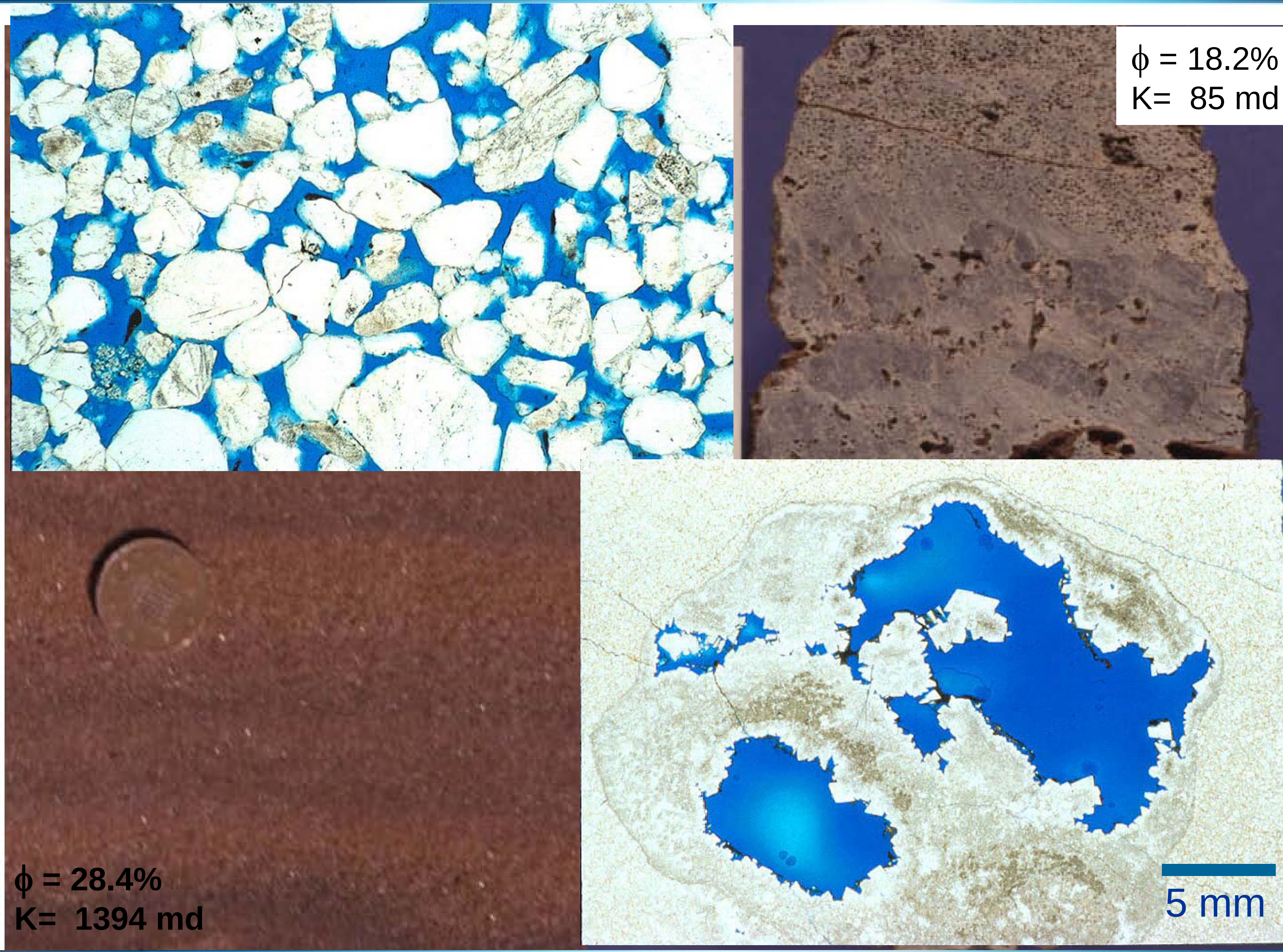


Lower coordination:
Worse oil/gas recovery
higher Sgr_{co2}





ϕ = 18.2%
K= 85 md
8
6
4
2
0
cms
ϕ = 28.4%
K= 1394 md



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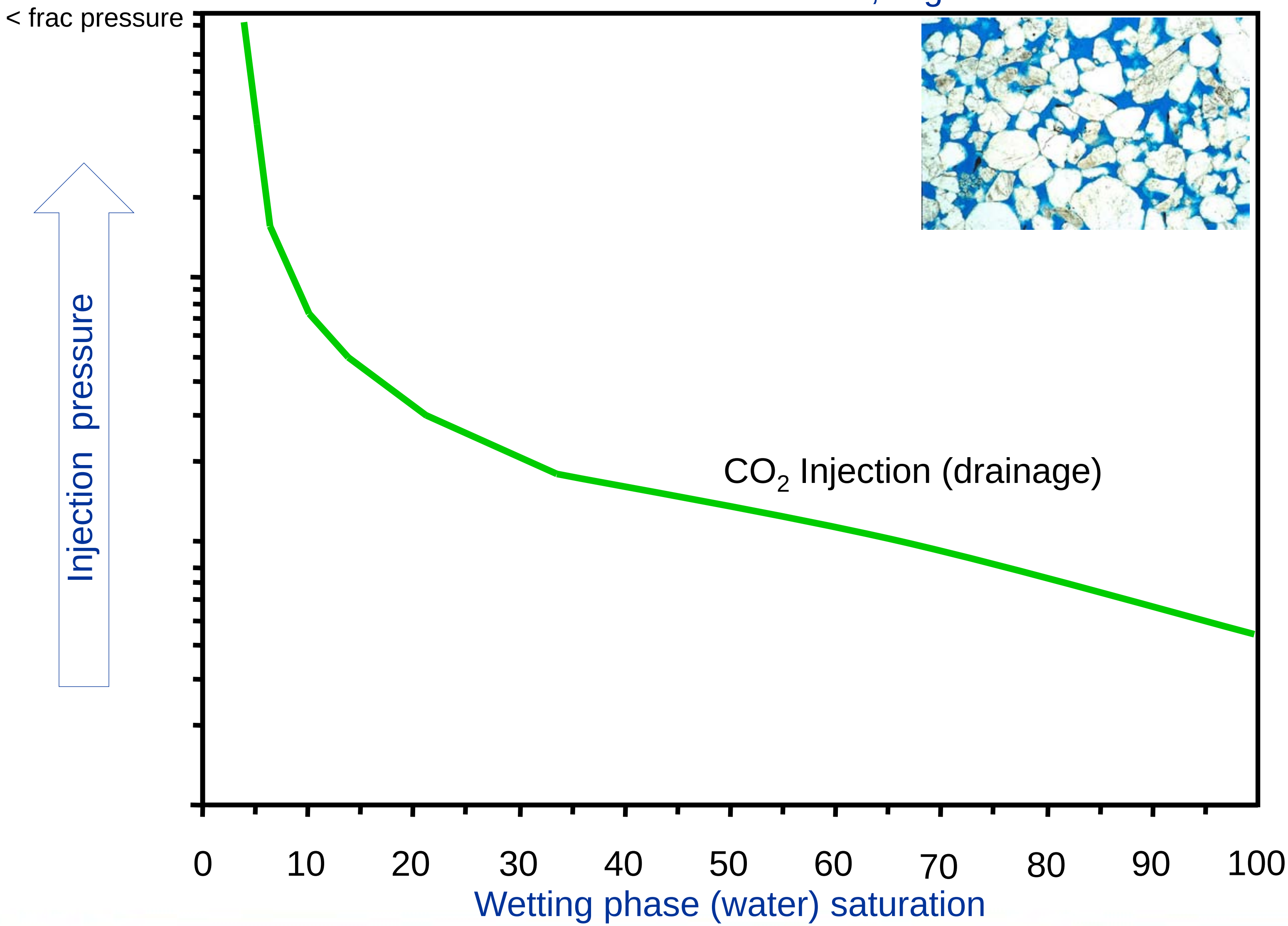
Rock A (interparticle porosity)

Low P/T Ratio; High Coordination



CO2CRC

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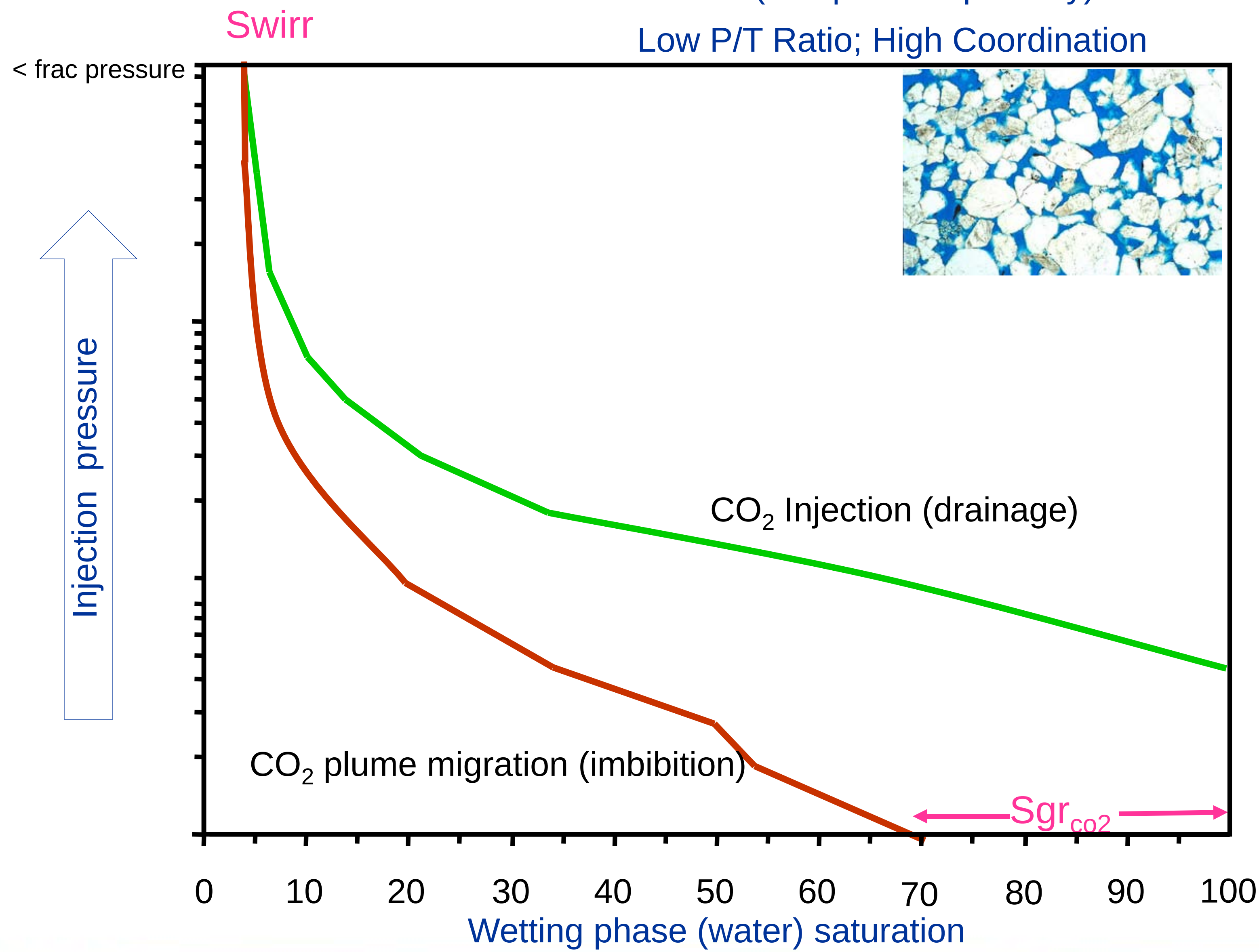
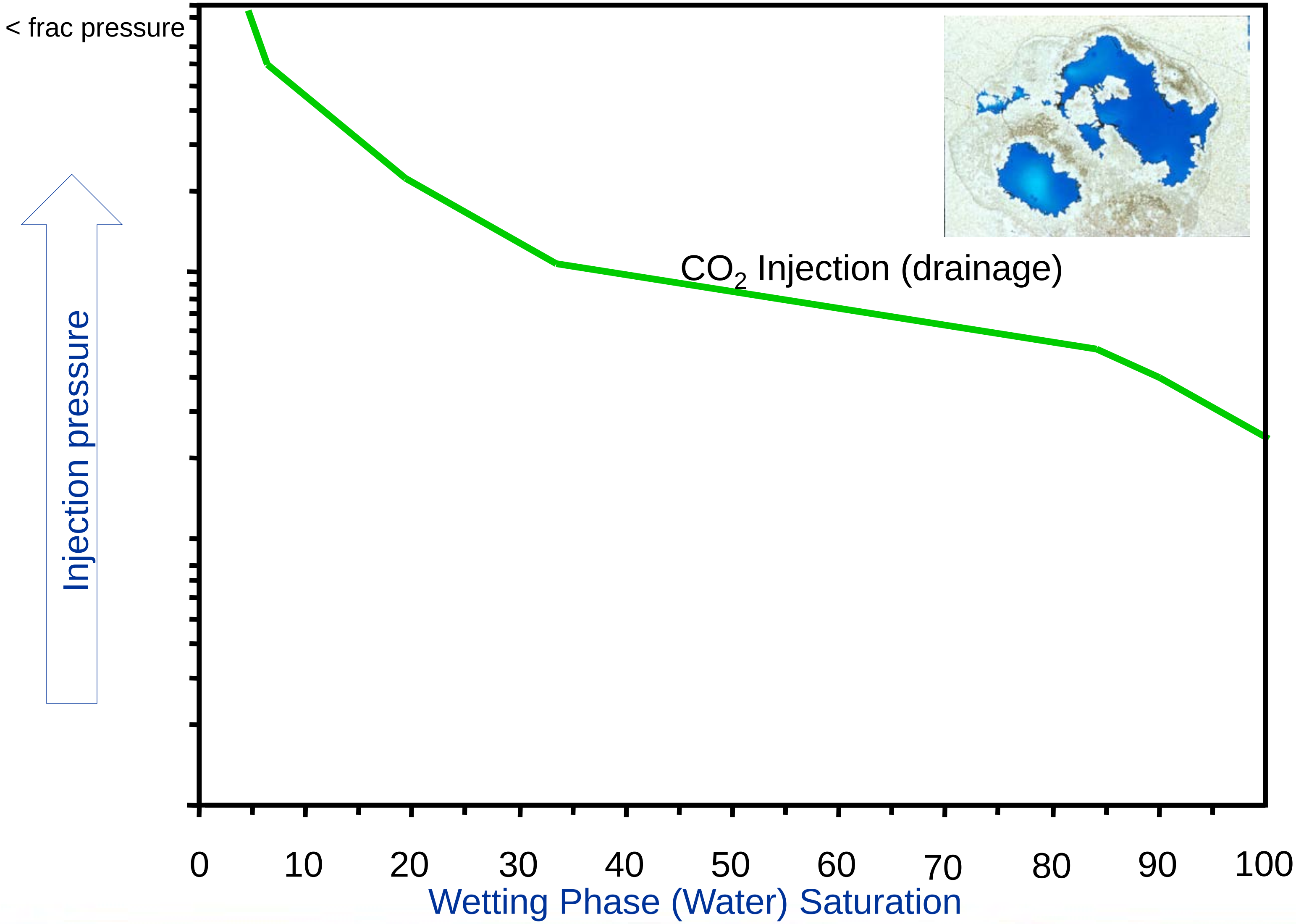
Low P/T Ratio; High Coordination



CO2CRC

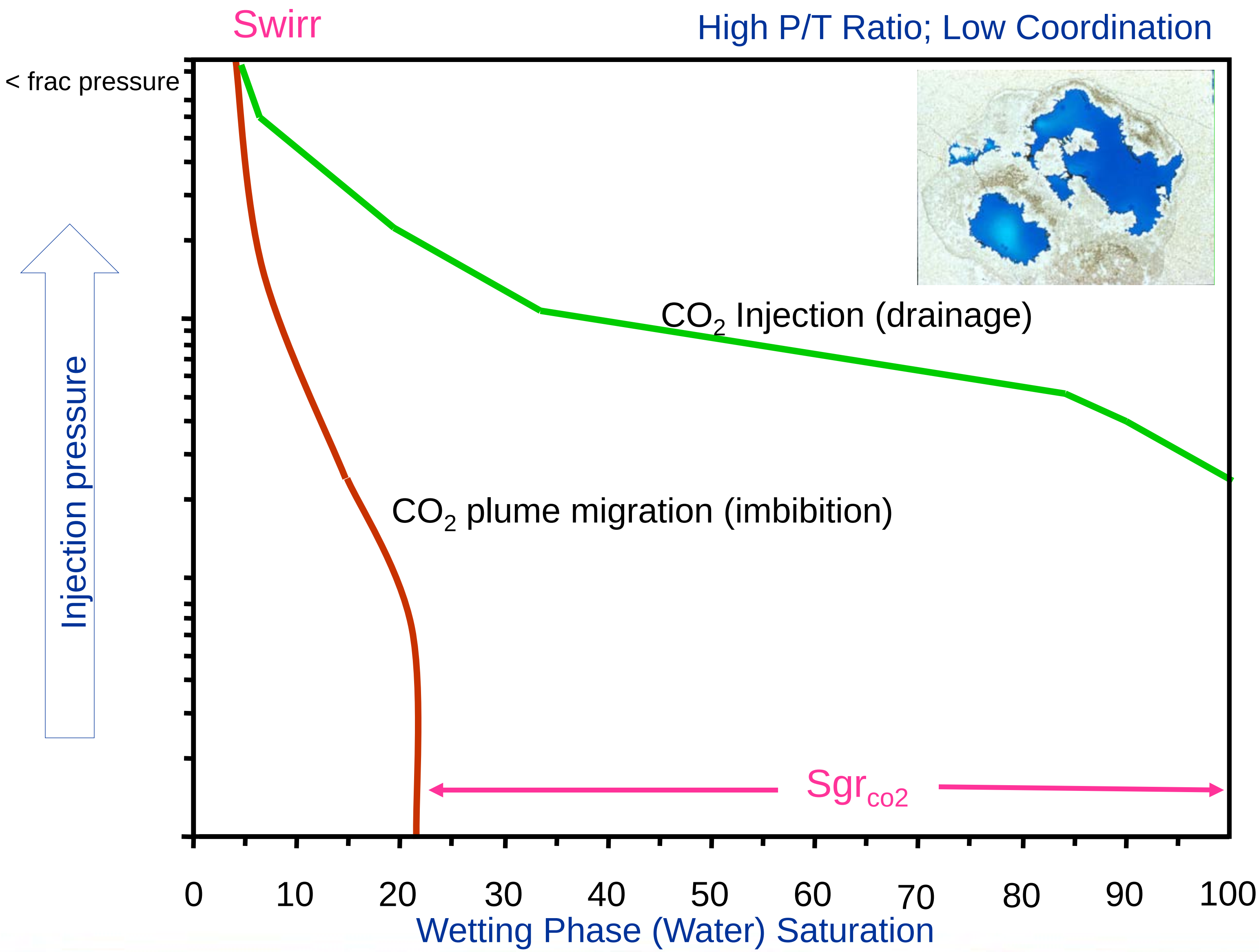
Rock C (vuggy porosity)

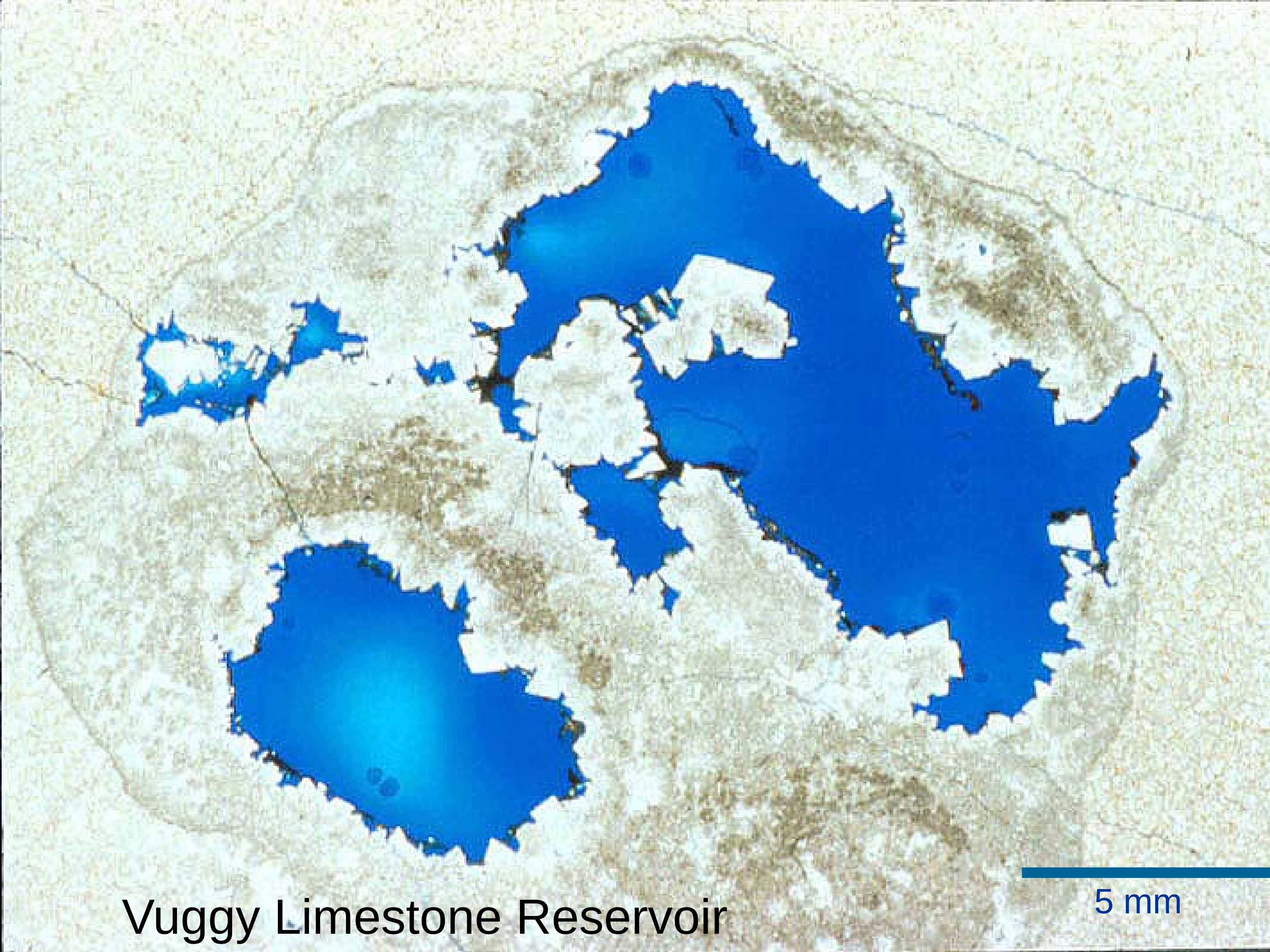
High P/T Ratio; Low Coordination



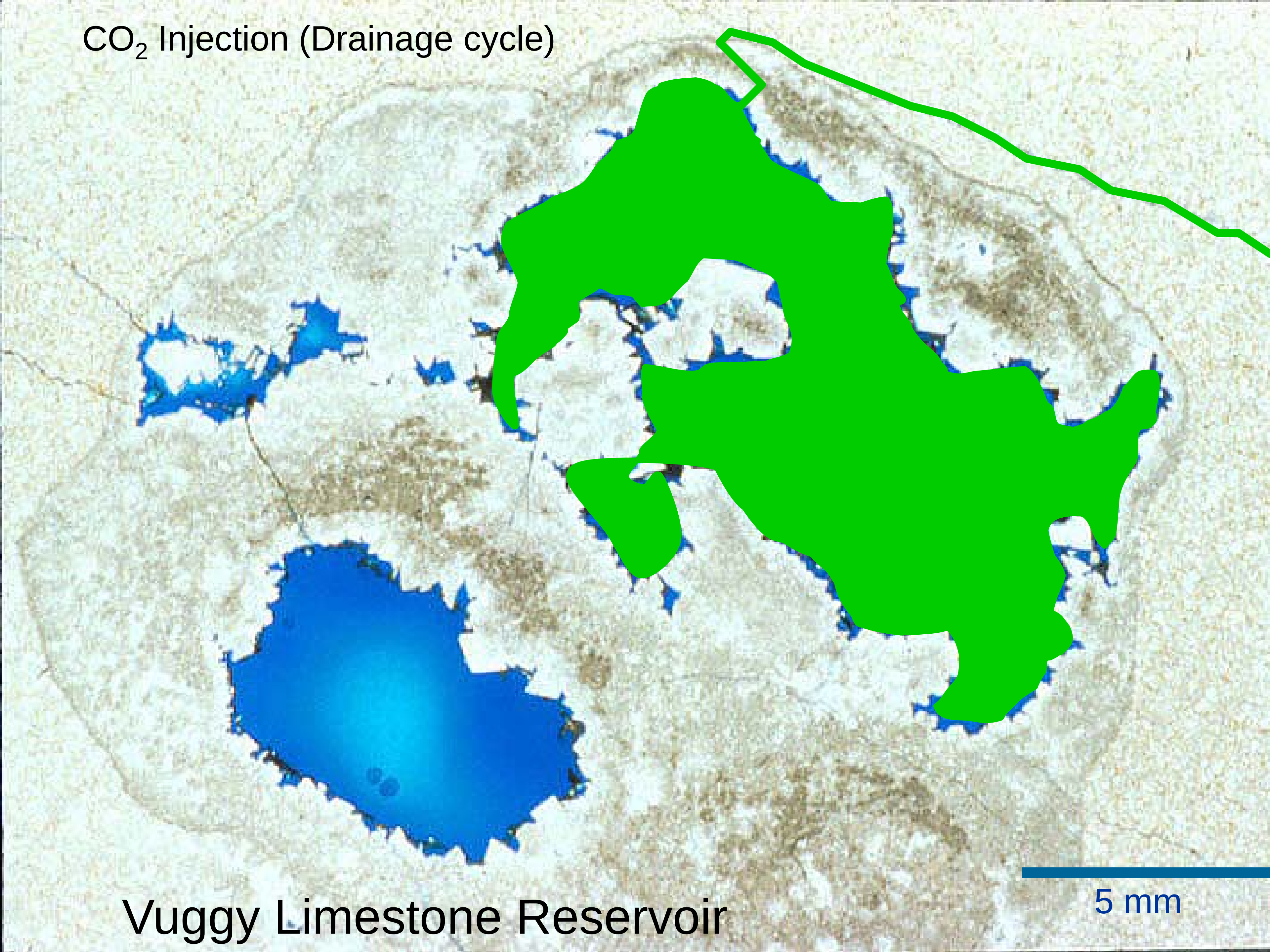
Rock C (vuggy porosity)

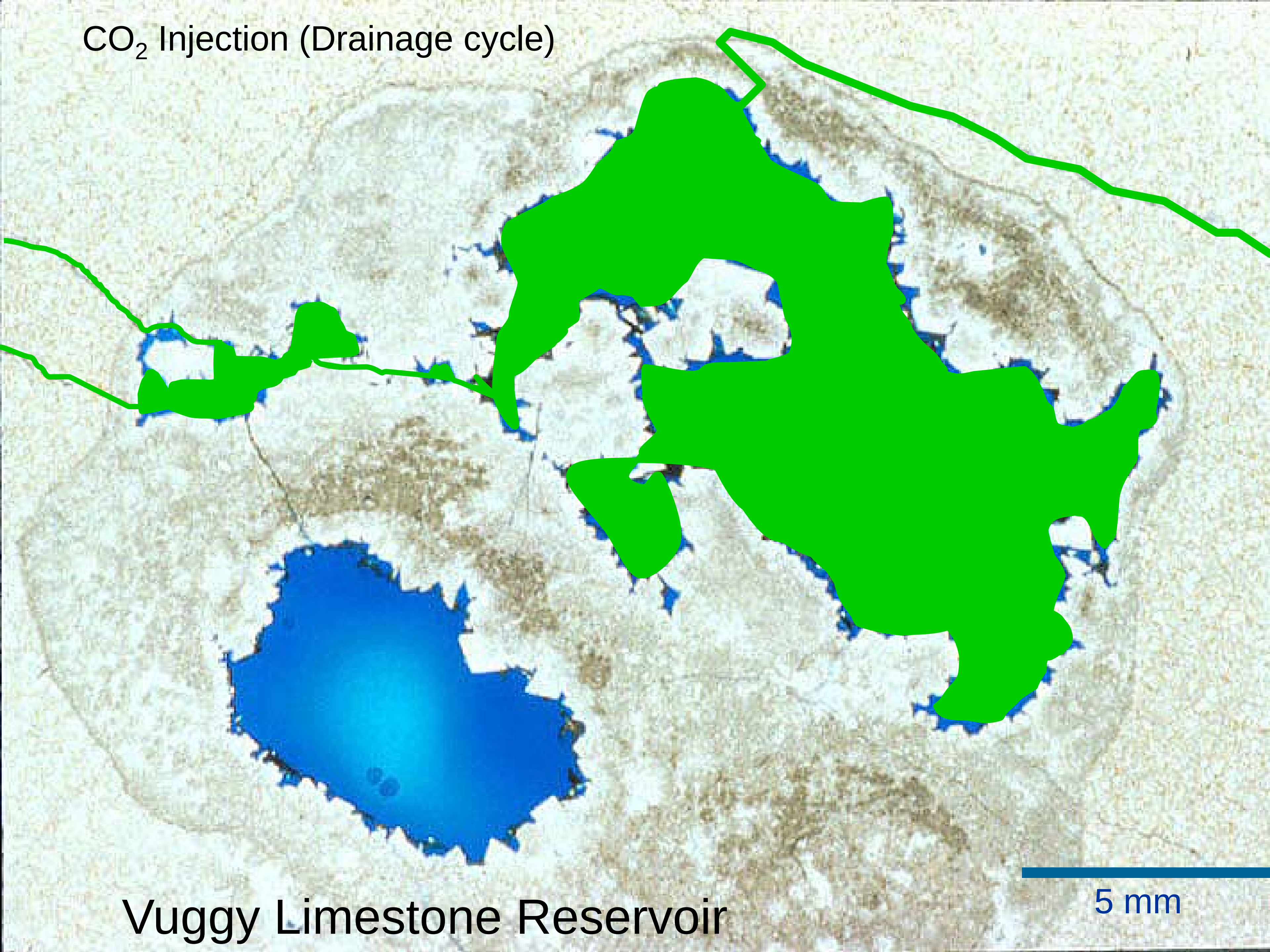
High P/T Ratio; Low Coordination





Vuggy Limestone Reservoir


CO_2 Injection (Drainage cycle)
5 mm
Vuggy Limestone Reservoir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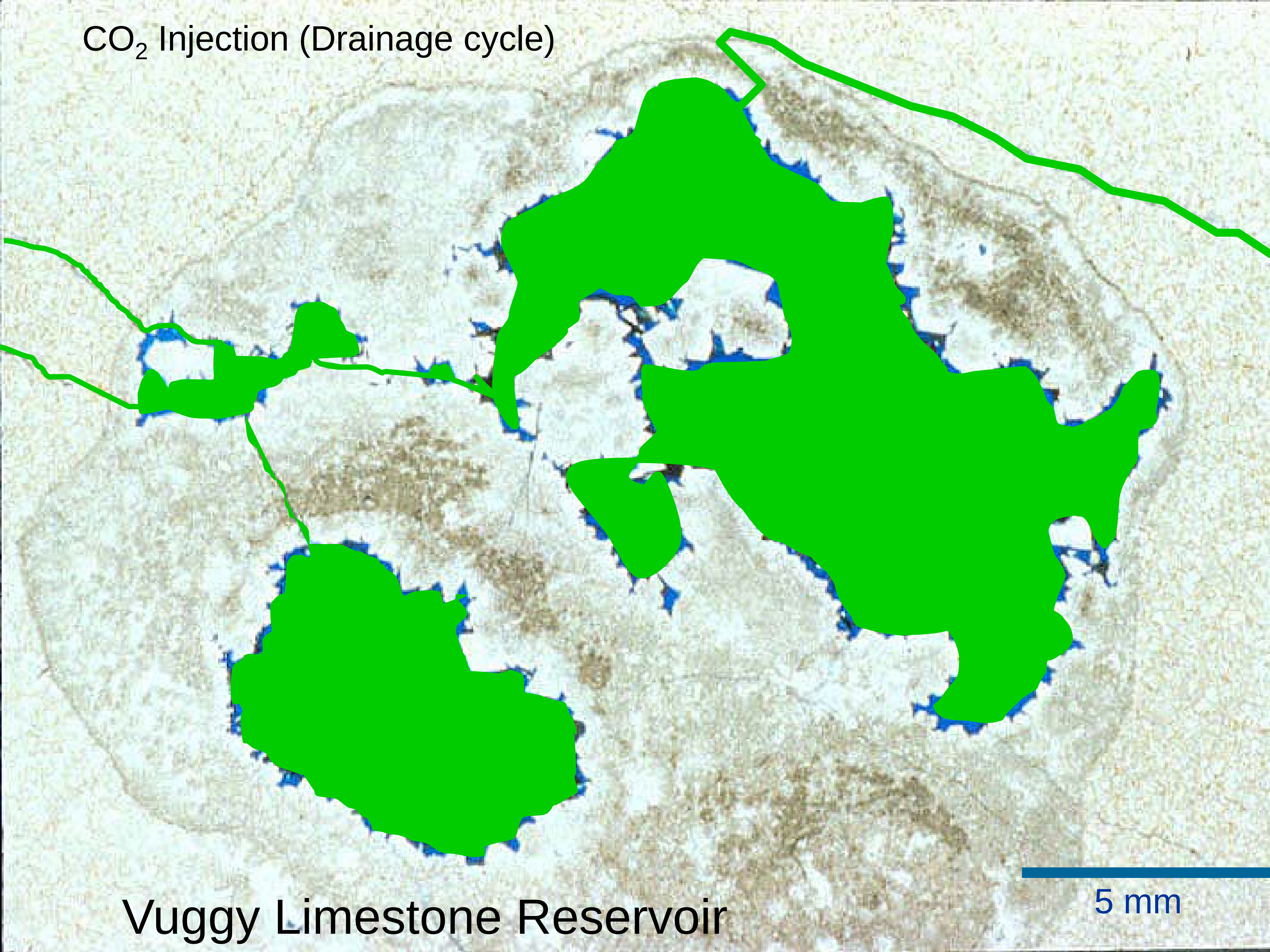
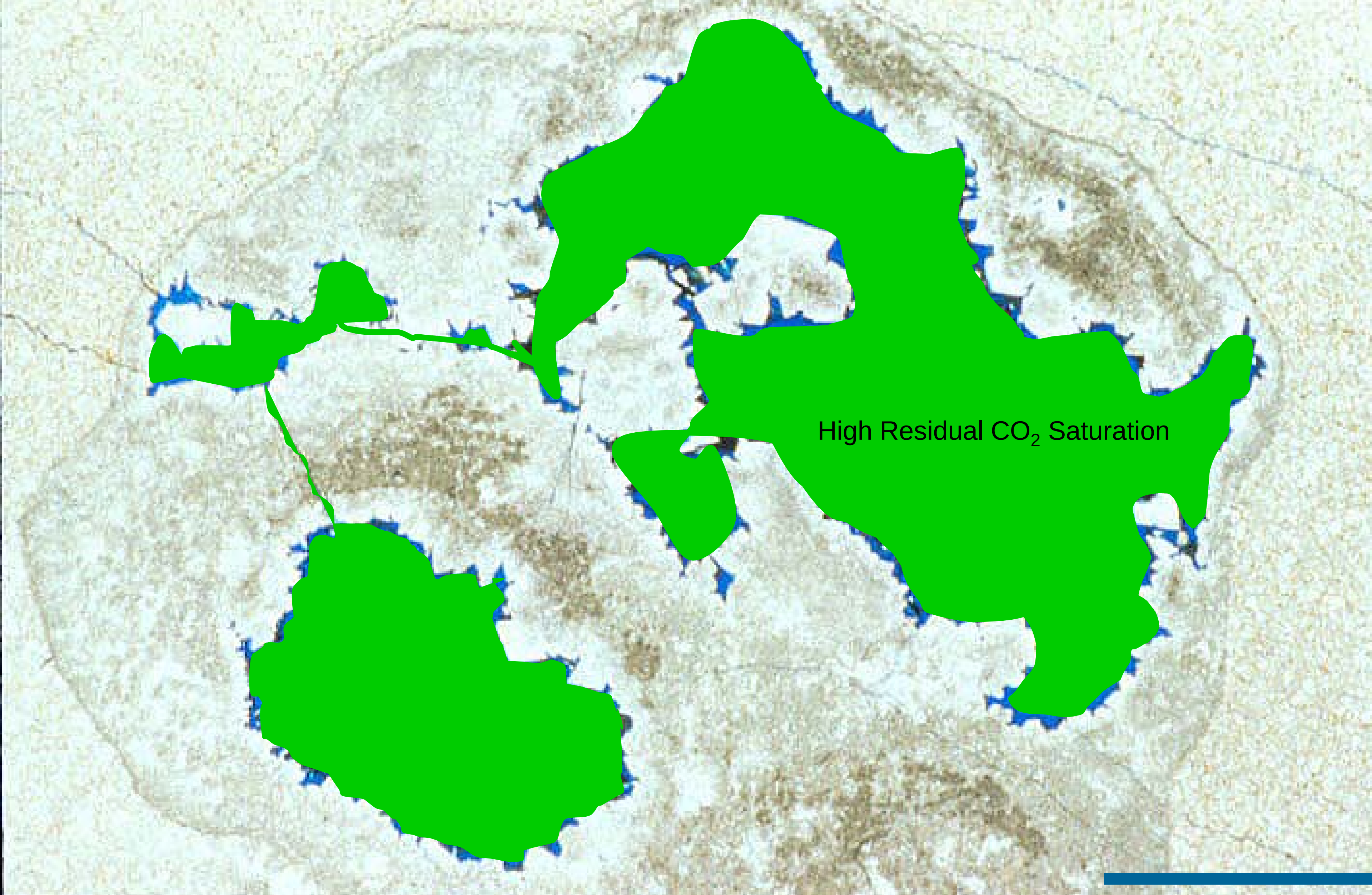


CO_2 Injection (Drainage cycle)
5 mm
Vuggy Limestone Reservoir

CO_2 Migration (Imbibition cycle)



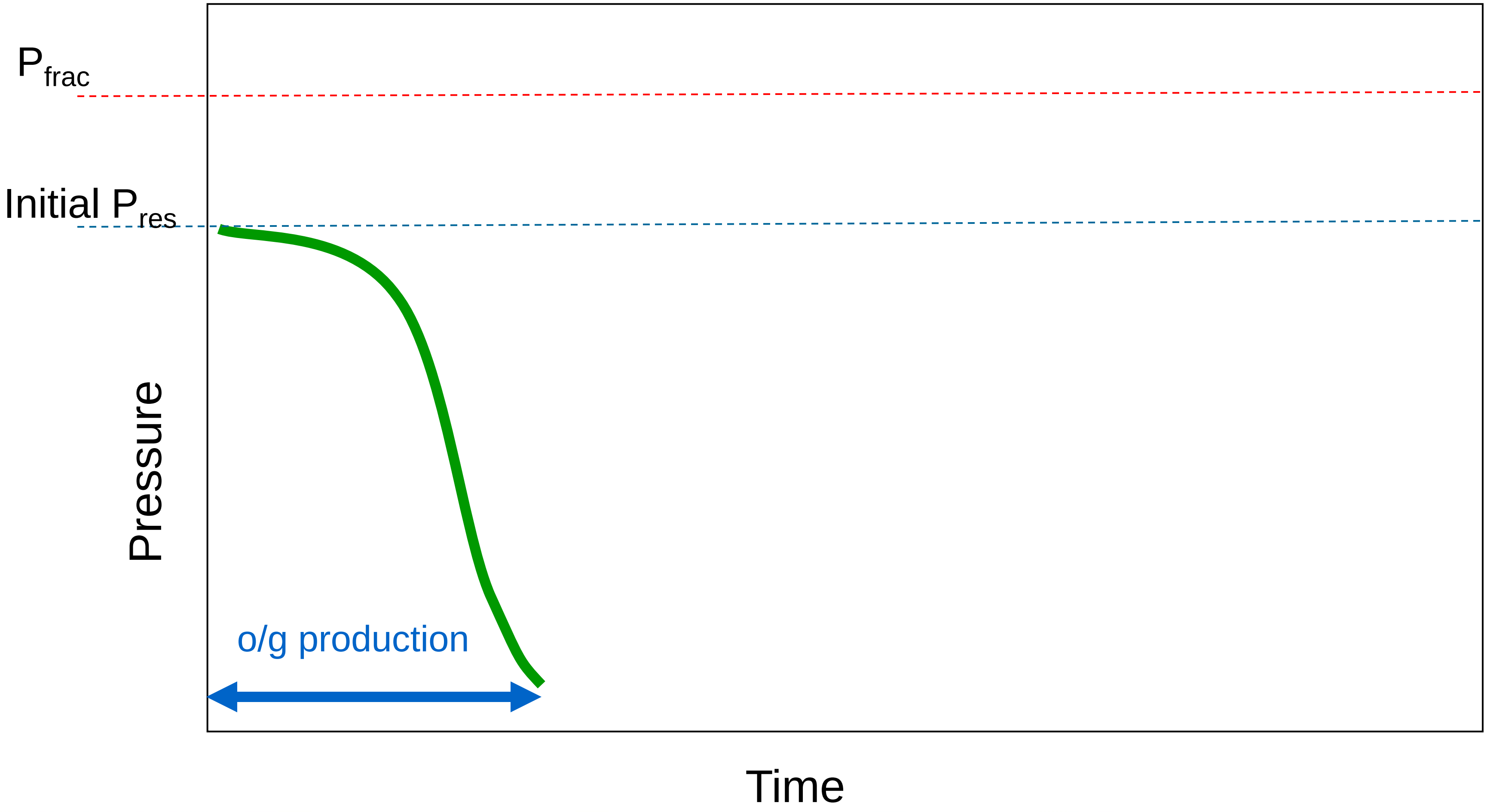
Vuggy Limestone Reservoir

Other Considerations: Injectivity / Pressure

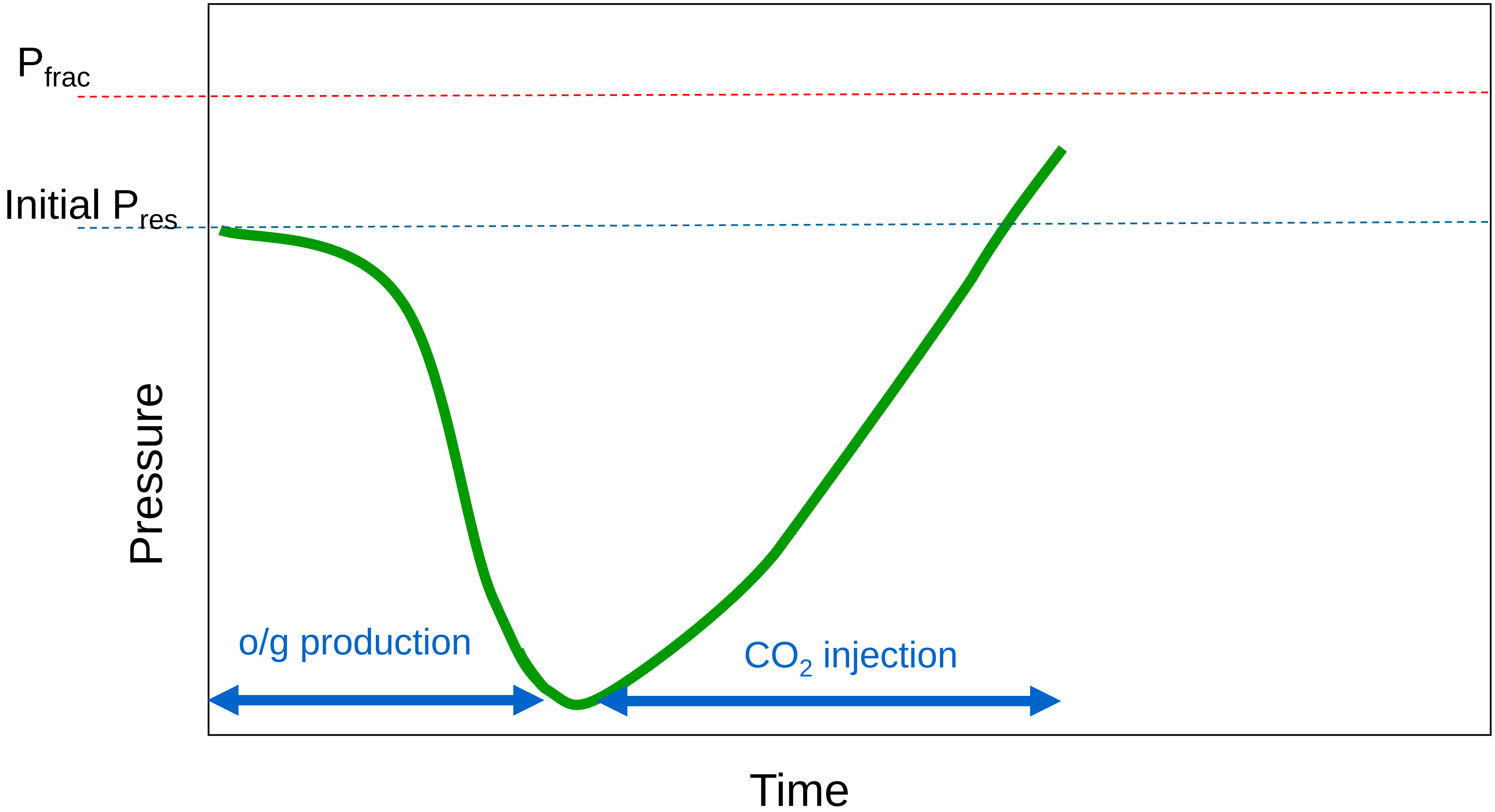
- Injection of fluids (eg CO_2) causes reservoir pressure build up
- In depleted fields, pressure build-up may be neutral or beneficial
- In both depleted fields and saline aquifers, must maintain pressure below fracture pressure
- In low permeability reservoirs this may limit economic storage capacity due to decreased injection rate, requiring more wells
- Injection in saline formations may displace saline fluids & increase risk of possible mixing with freshwater system
- Drilling pressure relief (water production) wells possible solution

CO2CRC

Depleted Field (pressure v. Time))

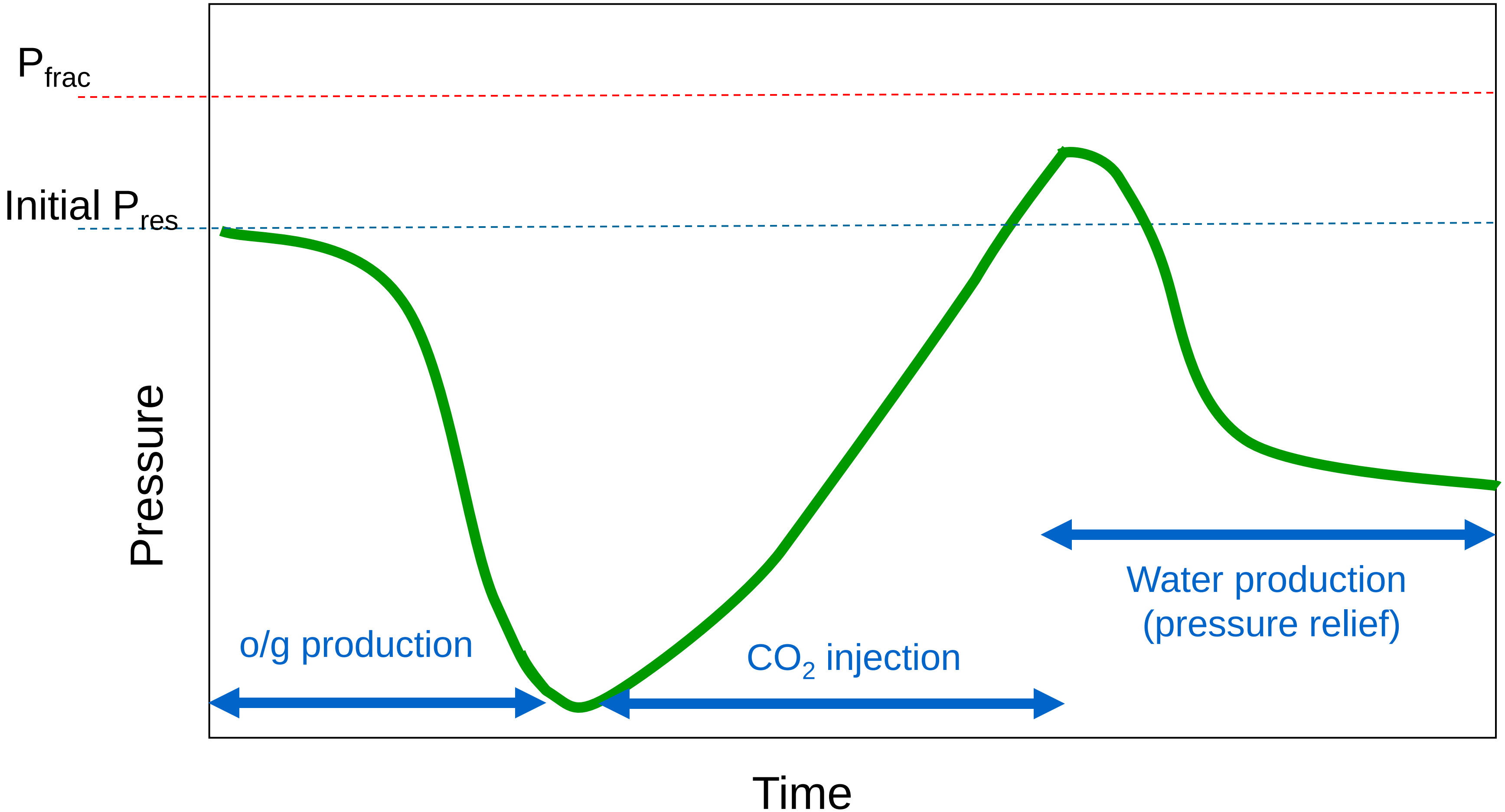


Depleted Field (pressure v. Time))

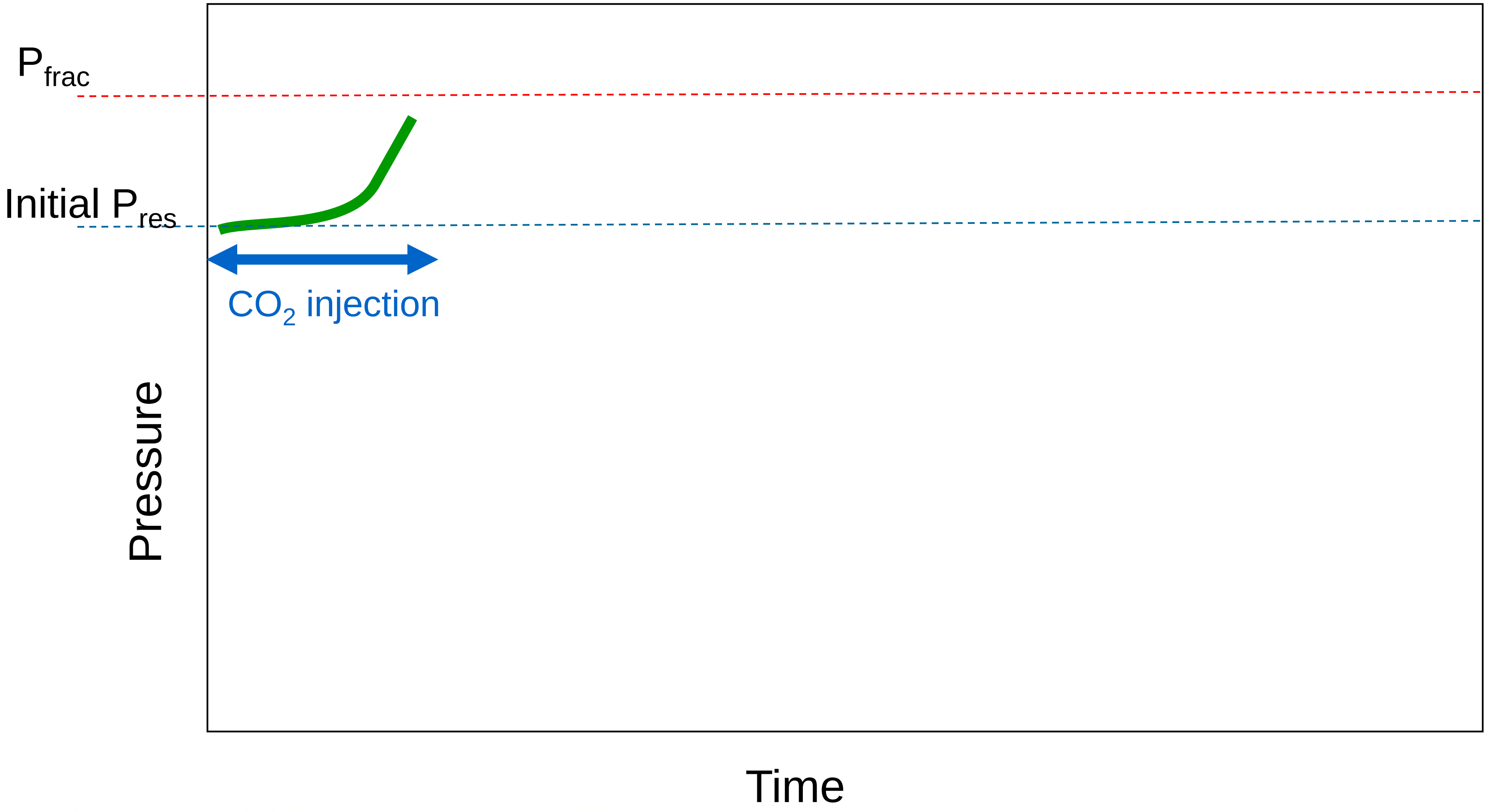


CO_2 Sequestration:
Strategies and Technologies for Storage and monitoring
AAPG ACE, New Orleans, 13 April, 2010

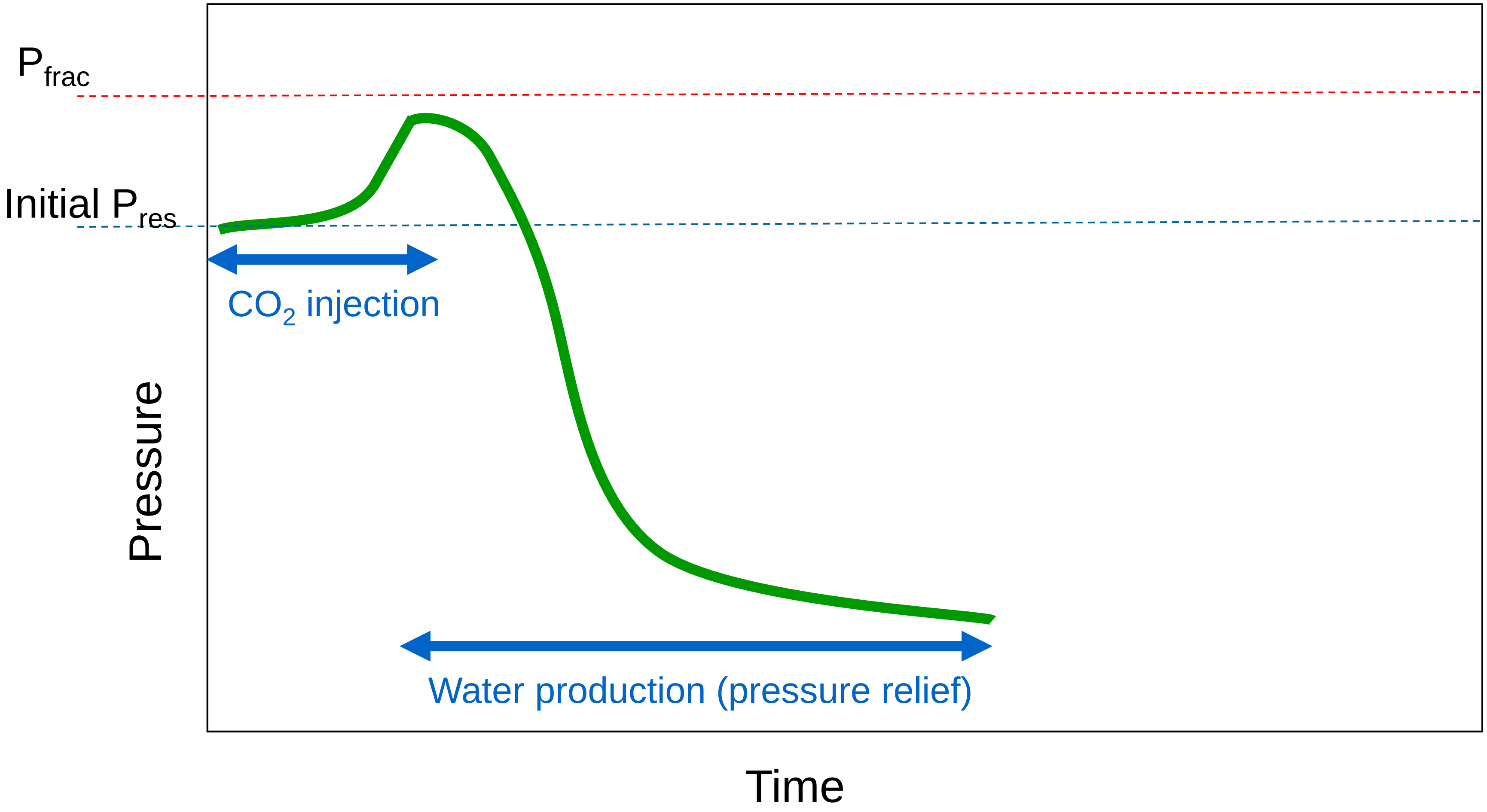
Depleted Field (pressure v. Time))



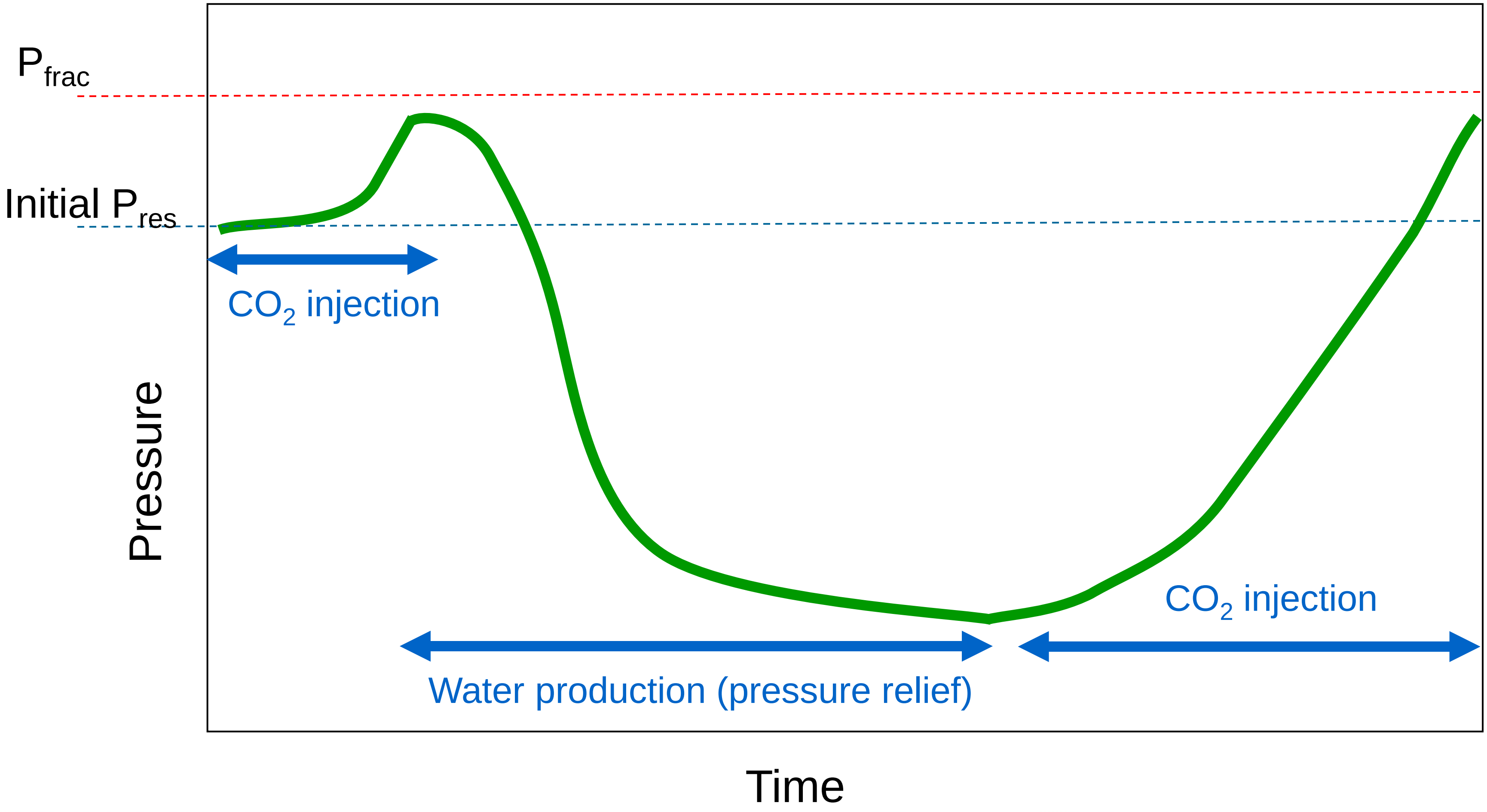
Saline Aquifer (pressure v. time)



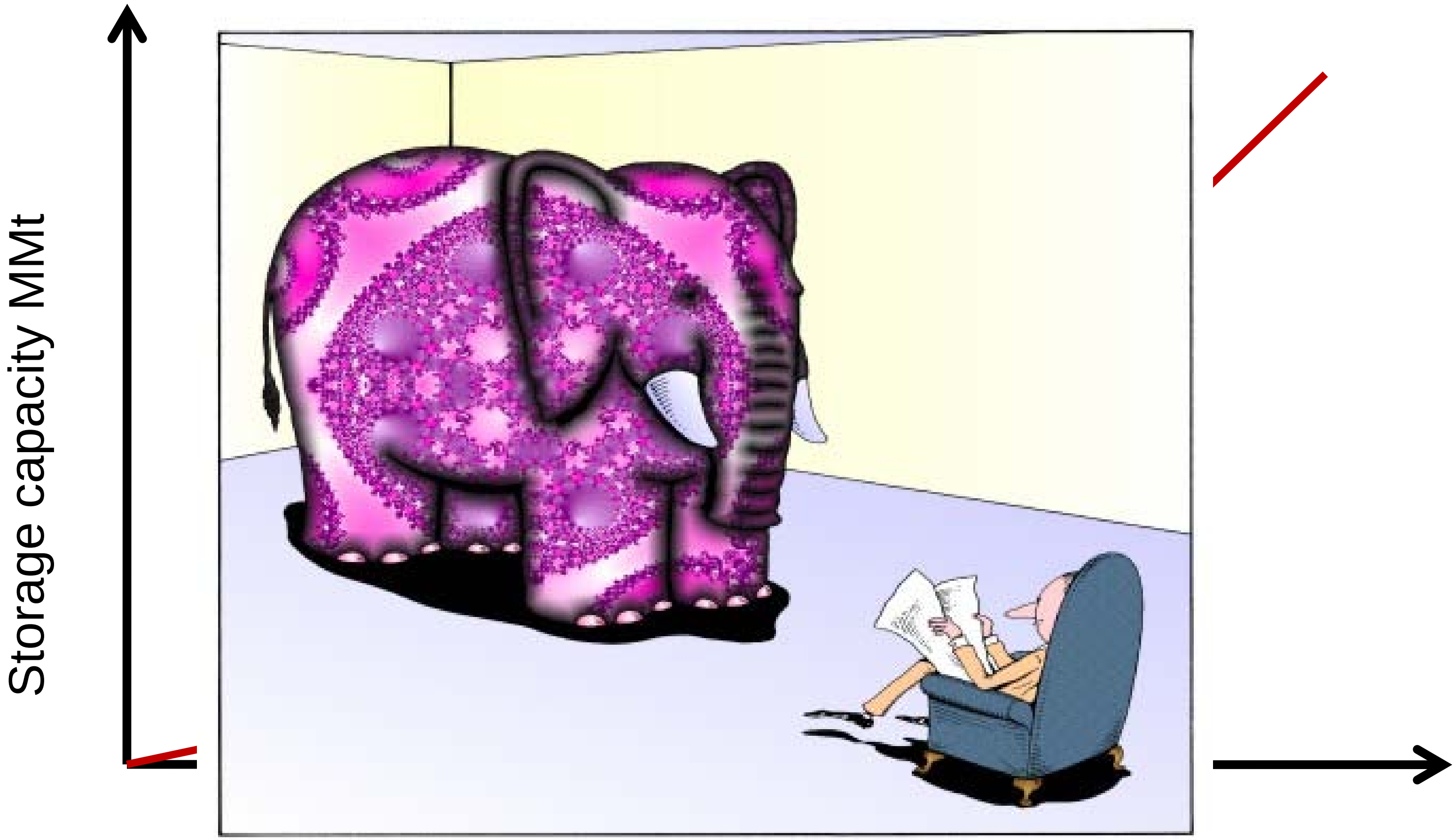
Saline Aquifer (pressure v. time)



Saline Aquifer (pressure v. time)



Other Considerations: Economics



Allinson & Paterson, 2009

Conclusions

- Site deployment for geological storage is all about injectivity, capacity estimation, containment risk assessment, economic evaluation, regulatory framework establishment, monitoring and verification, resolving liability issues and community engagement.
- All of the above need to be incorporated for "bankable" CCS projects to proceed
- But none of this works without a viable carbon price!!!

CO2CRC participants

Australian Government Geoscience Australia | CSIRO | Curtin University of Technology | MONASH University | The University of Adelaide Australia | The University of Melbourne | UNSW The University of New South Wales Sydney Australia

Anglo American | bhpbilliton | bp | Chevron | COAL21 Fund | ConocoPhillips

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GNS Science, genesis energy — NZ Resource Consortium | Origin energy | QER | Queensland Government | RioTinto

sasol reaching new frontiers | Shell | Solid Energy Coals of New Zealand | Stanwell Corporation Limited | Schlumberger

Total | State Government Victoria Department of Primary Industries | Government of Western Australia Department of Mines and Petroleum | woodside | xstrata coal

Supporting participants: Department of Resources, Energy and Tourism | CANSYD | Meiji University | Process Group | University of Queensland | Newcastle University | U.S. Department of Energy | URS

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Thank you