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Knowledge Transfer from Underground Natural Gas Storage and CO_2-EOR to CCS

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Outline

- Underground Natural Gas Storage (UNGS)
- CO_2 injection for Enhanced Oil Recovery (CO_2-EOR)
- Challenges in CCS
- Knowledge Transfer Opportunities
    - *Storage Site Selection*

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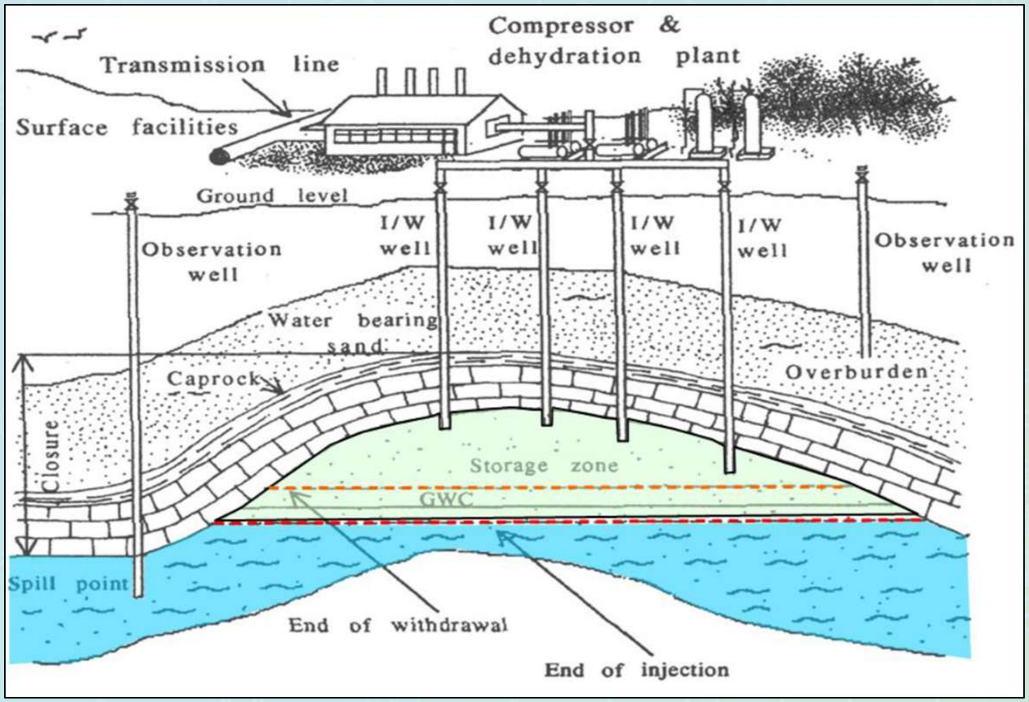
    - *Plume Monitoring*
- Conclusions

Underground Natural Gas Storage (UNGS)

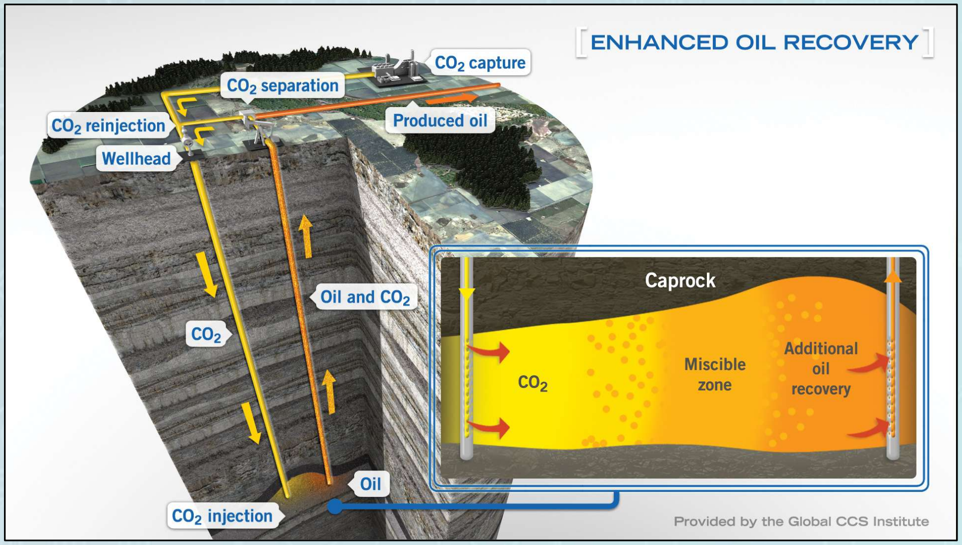
Underground natural gas storage (UNGS) is storing large amounts of natural gas in underground formations, including depleted oil/gas reservoirs, aquifers and salt caverns, for future use.



UNGS Reservoir (Tek, 1996)

CO_2-EOR

Technique used to recover oil from mature oil fields that are no longer productive using conventional recovery techniques.



Environmentally

CO_2-EOR recycles and utilizes CO_2

Economically

CO_2-EOR reactivates oil production in these older fields, which could otherwise be left idle.

Knowledge Transfer Opportunities

Knowledge transfer from established practices in UNGS and CO_2-EOR to the emerging field of CCS for de-risking the CCS projects

Challenges in CCS

- Storage site selection: deep saline aquifers, depleted oil/gas fields etc.
- Storage capacity estimation
- Monitoring and verification
- Risk assessment and management
- Economic viability
- Technological innovations

…

Knowledge Transfer Opportunities

- Storage reservoir selection
- Conversion of aquifer and depleted oil/gas fields to gas storage reservoirs
- Storage capacity estimation
- Geological data integration and understanding
- Well design
  Completion practices
  Injection techniques
  Injectivity optimization
- CO_2 phase behavior (between water/HC & solids)
- Geomechanics (rock integrity & rock property changes as a function of pressure)
- Plume movement and containment
- Leak detection / Risk management strategies
- Monitoring practices

etc.

Knowledge Transfer Opportunities

Storage Reservoir Selection Criteria

Site Screening → Site Ranking → Site Characterization

(Callas et al., 2022)

Storage capacity and injectivity optimization
Formation depth, permeability, porosity, thickness, amount of historical HC production

Data availability for extensive site characterization
Geological, petrophysical data, any numerical modeling work etc.

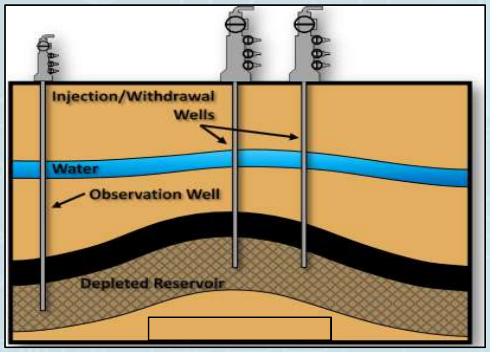
Environmental considerations
Storage location should be away from environmental areas to avoid any potential negative impacts on the environment or human health

Assessment of potential geomechanical risks and leakage
Faults, sub seismic activity record, caprock integrity, thickness of caprock, availability of secondary seal, availability of bottom seal, historical HC production pressures etc.

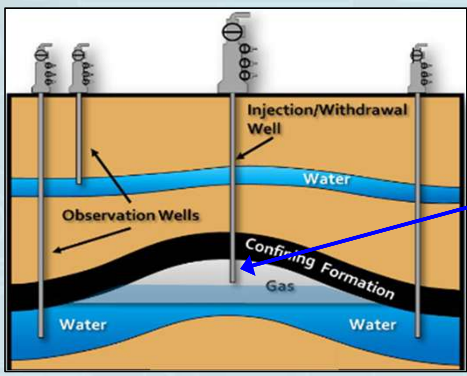
Economical limitations
CO_2-EOR opportunities, distance from CO_2 source, availability of CO_2 pipeline etc.

Regulatory framework
Permitting, monitoring, and verification of subsurface carbon storage projects is necessary to ensure safety, environmental integrity, and regulatory compliance

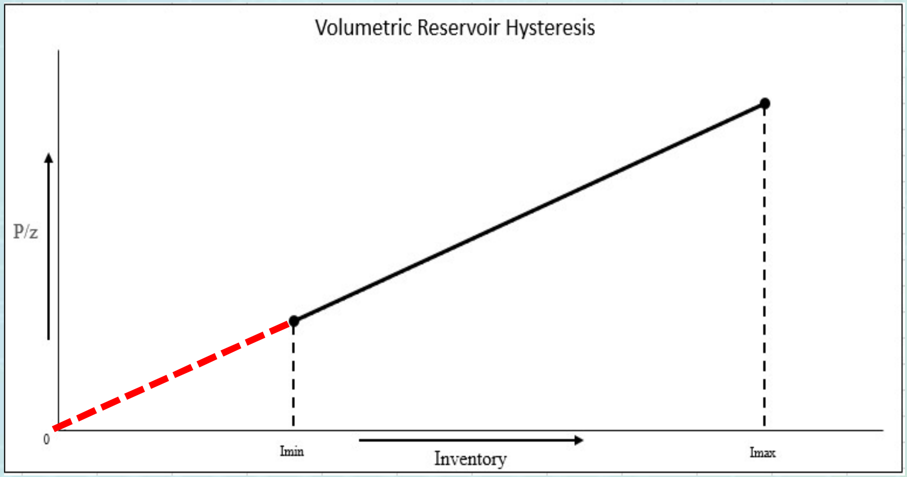
How does UNGS experience apply?

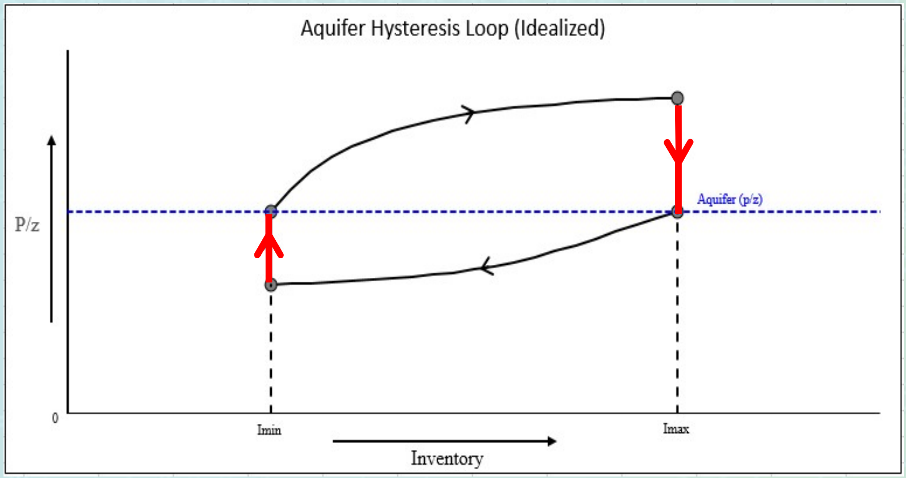


Depleted oil/gas reservoirs
No change in Gas Pore Volume



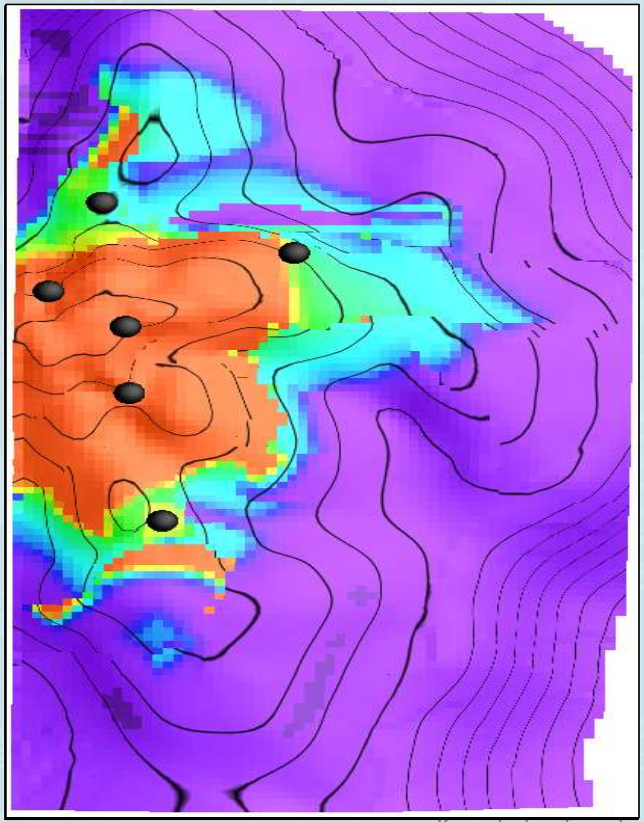
Aquifers
Gas-water transition zone Changes Gas PV





Depleted Oil/Gas Reservoirs vs Saline Aquifers – Modeling Example

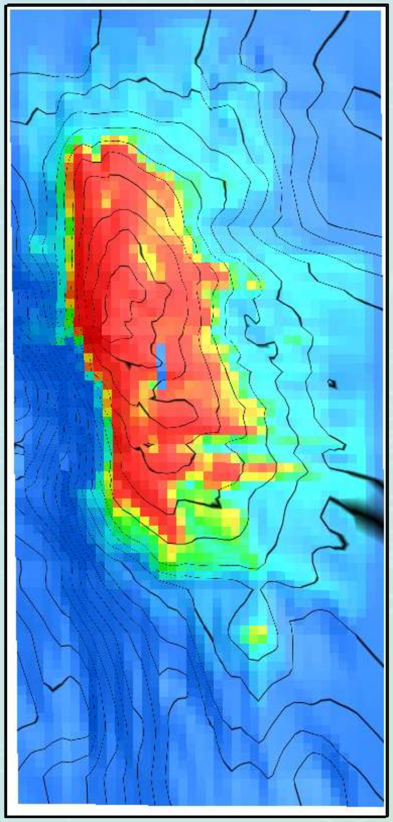
Depleted Oil/Gas Reservoir



Change in Gas Saturation

Spring to Fall

Aquifer Reservoir

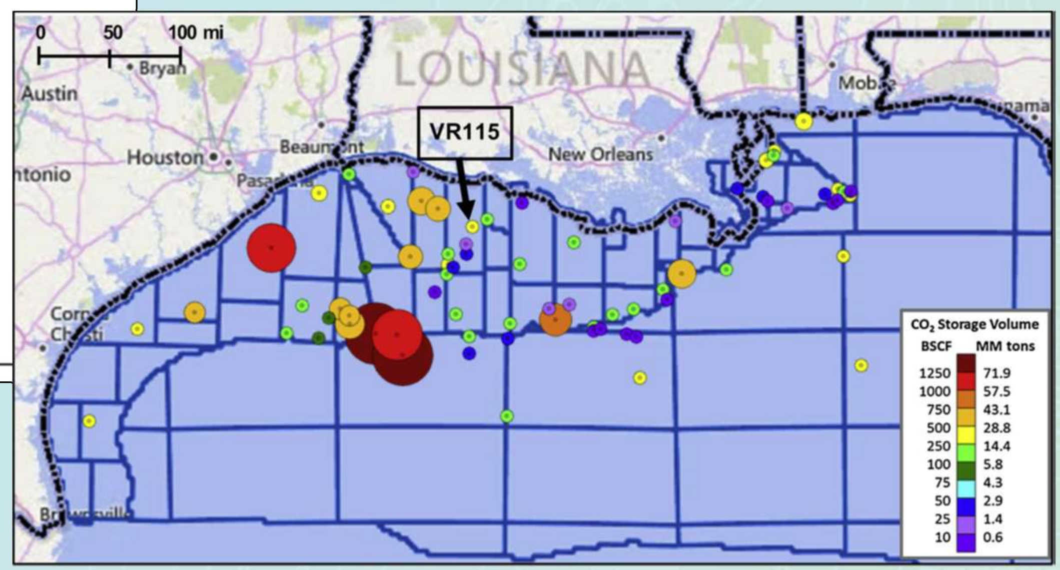


Depleted Oil & Gas Reservoirs – Selection Criteria Modeling Example

Project funded by DOE: CO_2 storage volumes of the depleted oil and gas fields in GOM were modeled.

Reservoir properties from the BOEM Reserves database (BOEM, 2013).

	Depleted Fields/Sands in the GOM
Initial Pressure, P_i (psia)	295–17,732
Subsea Depth, SS (ft)	605–21,920
Total Average Net Thickness, H (ft)	1–200
Area, A (acres)	1–11,464
Initial Temperature, T_i (F)	70–403
Permeability, k (mD)	1–3954
Porosity, ϕ (−)	0.10–0.38
Initial Gas Formation Volume Factor, B_{gi} (RCF/SCF)	0.00225–0.0417
Initial Oil Formation Volume Factor, B_{oi} (RBBL/STB)	1.05–2.8
Original Gas In Place, OGIP (BSCF)	0.6×10^{-3}–735.4
Original Oil In Place, OOIP (MMSTB)	1.05×10^{-3}–55.8
Recovery Factor, RF (%)	0–95



- Ranges of some of the reservoir parameters of the depleted oil and gas reservoirs in GOM
- Site selection is one of the key factors in CCS

(Agartan et al., 2018)

Why Modeling Solutions for CCS

What we CANNOT control

- Geology
- Structure, geomech., spill points, caprock
- Aquifer size and strength
- Mineralogy
- Existing well completions
- Uneven depletion

→ We have to understand their impacts

↓

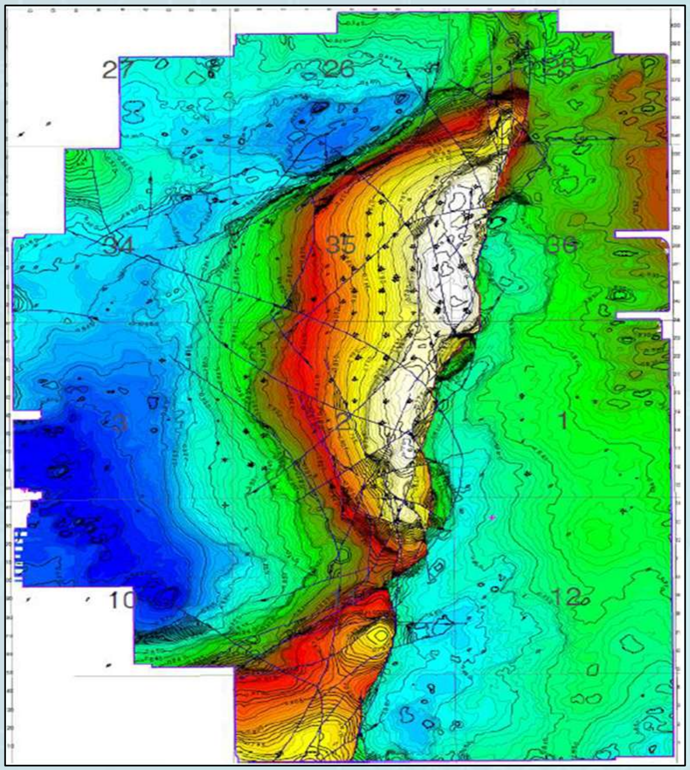
To successfully design and optimize these ←

What we CAN control

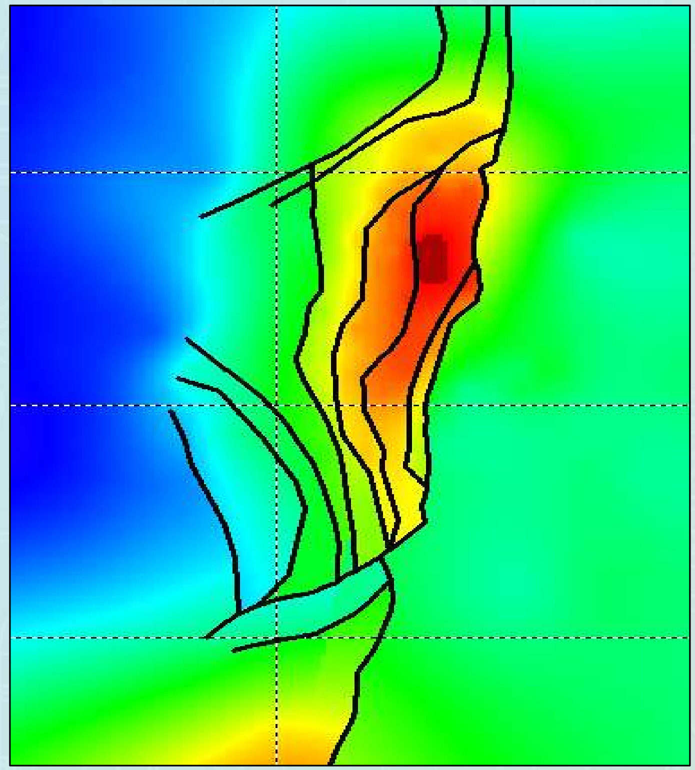
- Fill up time and volume
- Number of wells to utilize
- Injection rates
- Injection order
- Injection well locations
- Maximum injection pressure
- Well Scheduling
- Recompletion
- Locations for monitoring wells

Geological Data Integration and Understanding

Seismic Results to Simulation Fault Traces



Seismic Results



Structure Map w/Faults based on Seismic

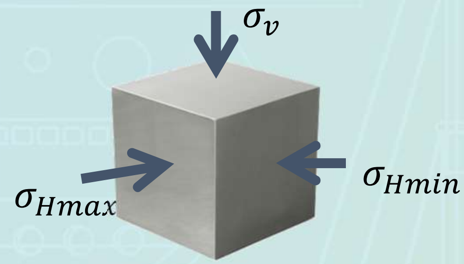
Geological Data Integration and Understanding - Geomechanics

Natural Fractures

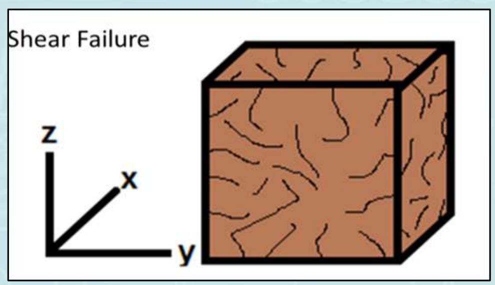
- **Tectonic and fault-related**
- **Bed-bound and diagenetic alteration**
- **Pore-pressure related**
- **Cooling and weathering related**

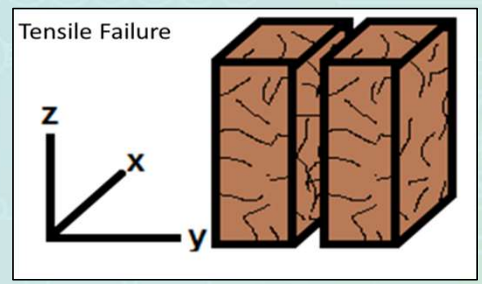
- **Earth stresses – principal stress planes**

σ_v – Overburden stress
σ_{Hmax} – Maximum horizontal stress
σ_{Hmin} – Minimum horizontal stress



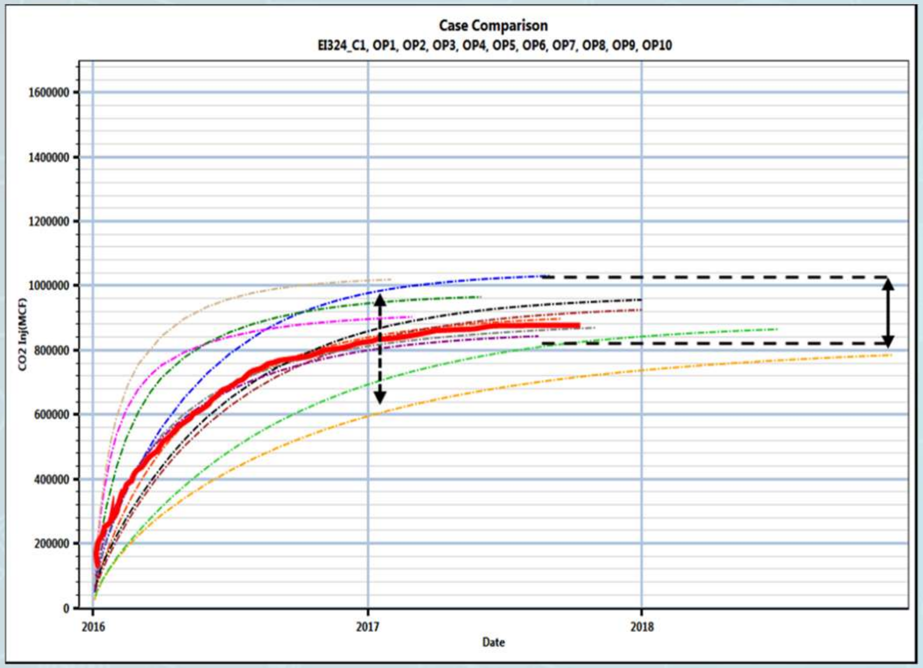
What happens when stresses change?

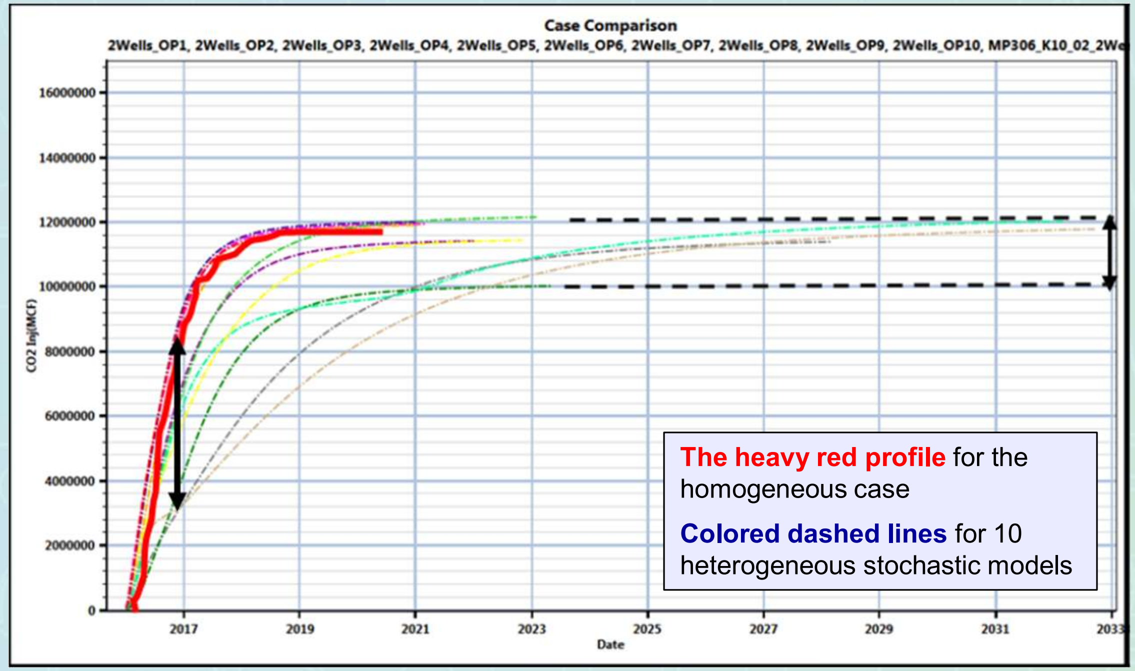




Failure mode depends on direction and magnitude of principle stress

Geological Data Integration and Understanding – Heterogeneity Example





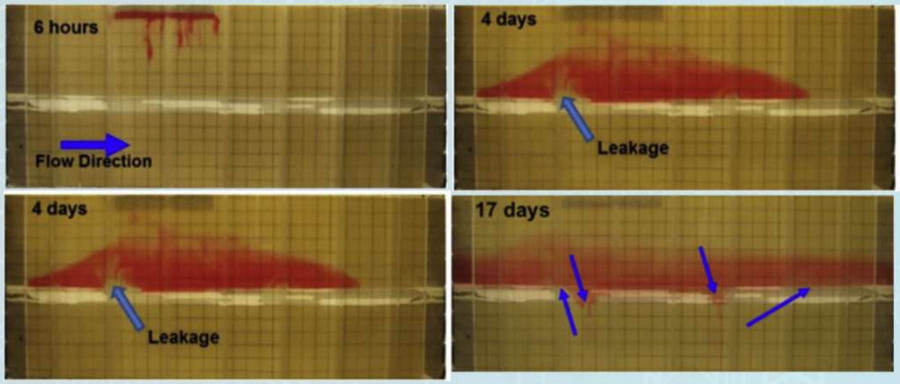
(Agartan et al., 2018)

Heterogeneity clearly impacts the CO_2 injection volume profiles at early times, and the maximum CO_2 storage volumes for all sands.

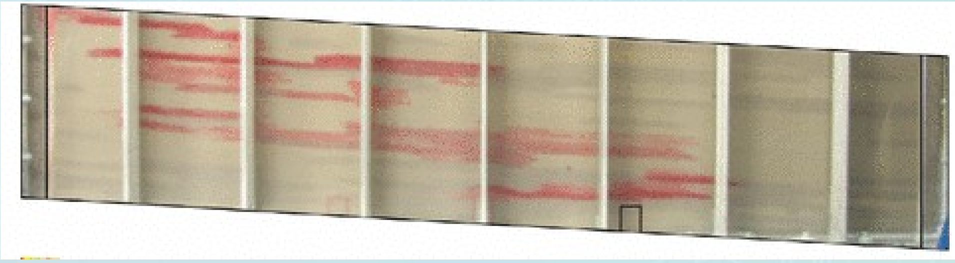
Storage Reservoir Characterization is one of the key factors in CCS

CO_2 Plume Movement & Reservoir Monitoring

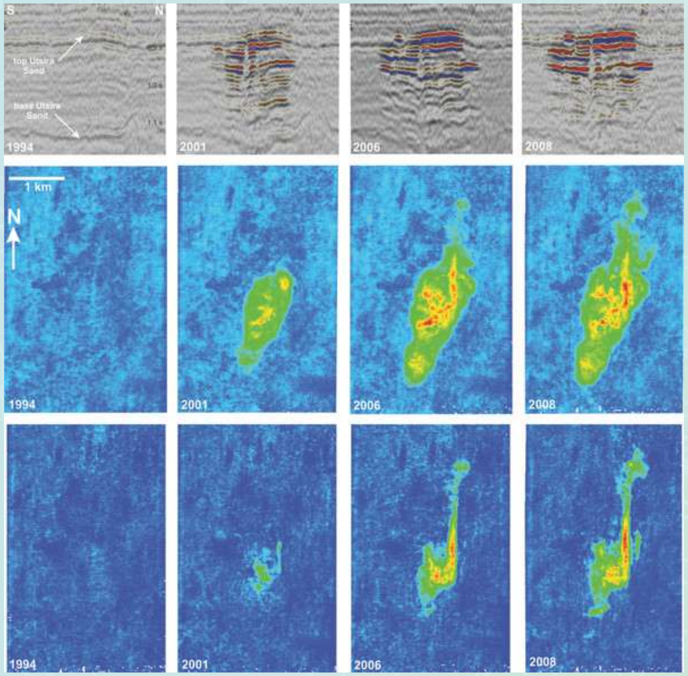
Various experimental and field examples on CO_2 plume migration and containment in heterogeneous formations highlighting the significance of good monitoring system



(Agartan et al., 2020)

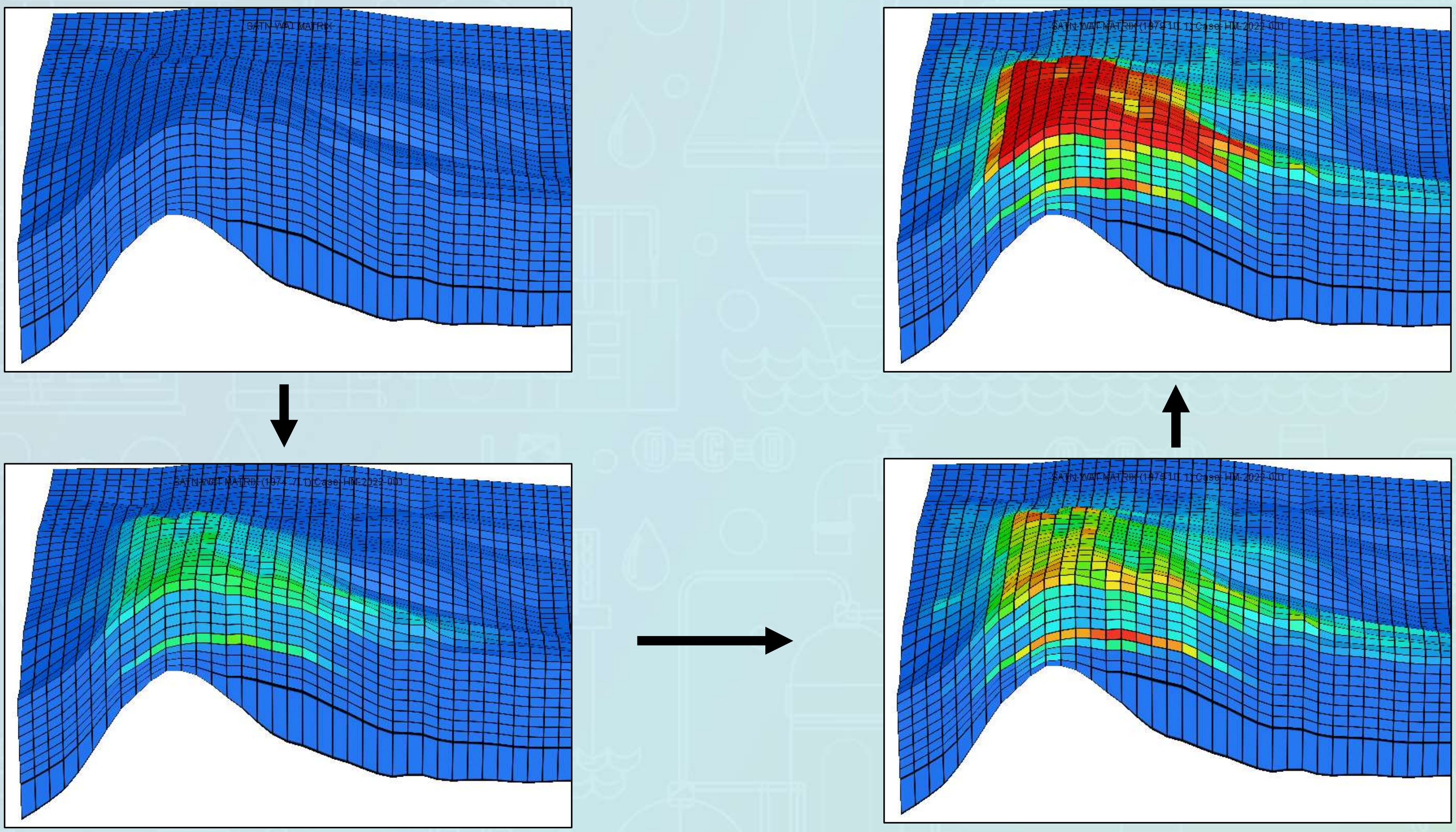


(Trevisan et al., 2017)

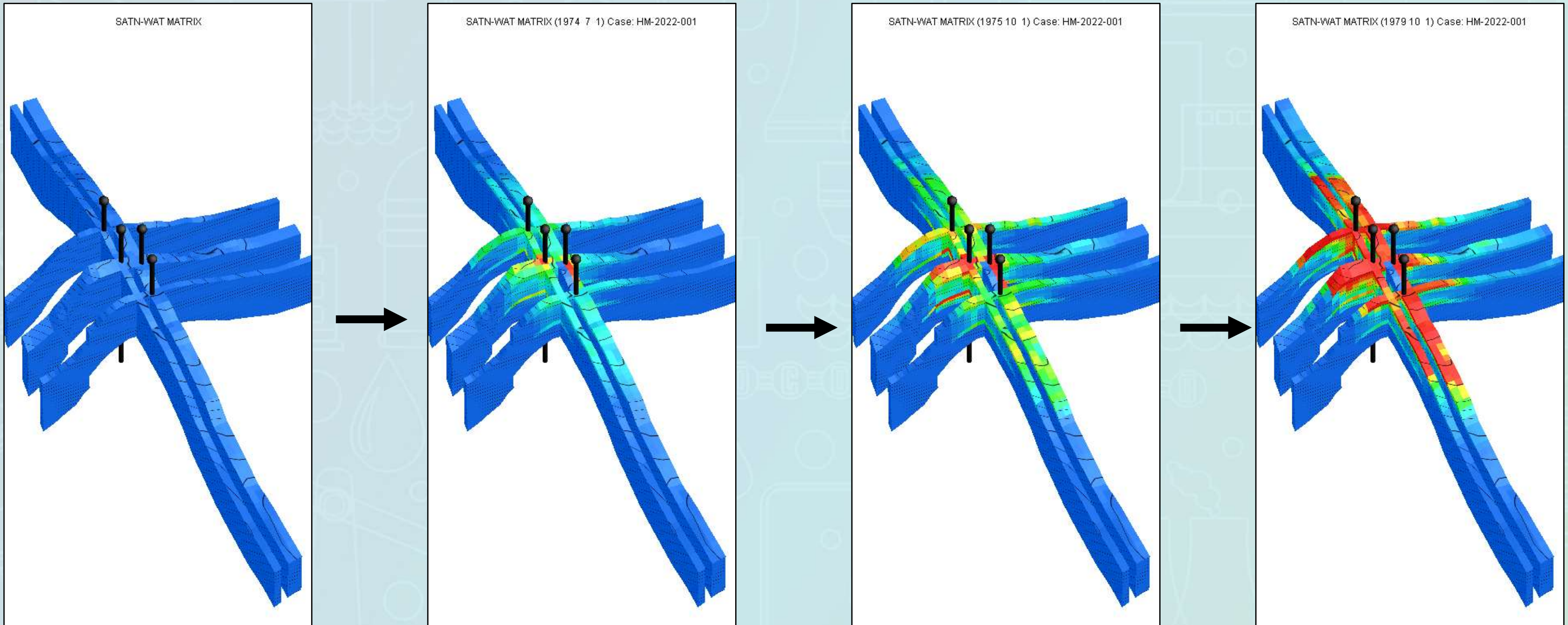


(Chadwick and Joy, 2015)

Gas Plume Expansion– Modeling Example



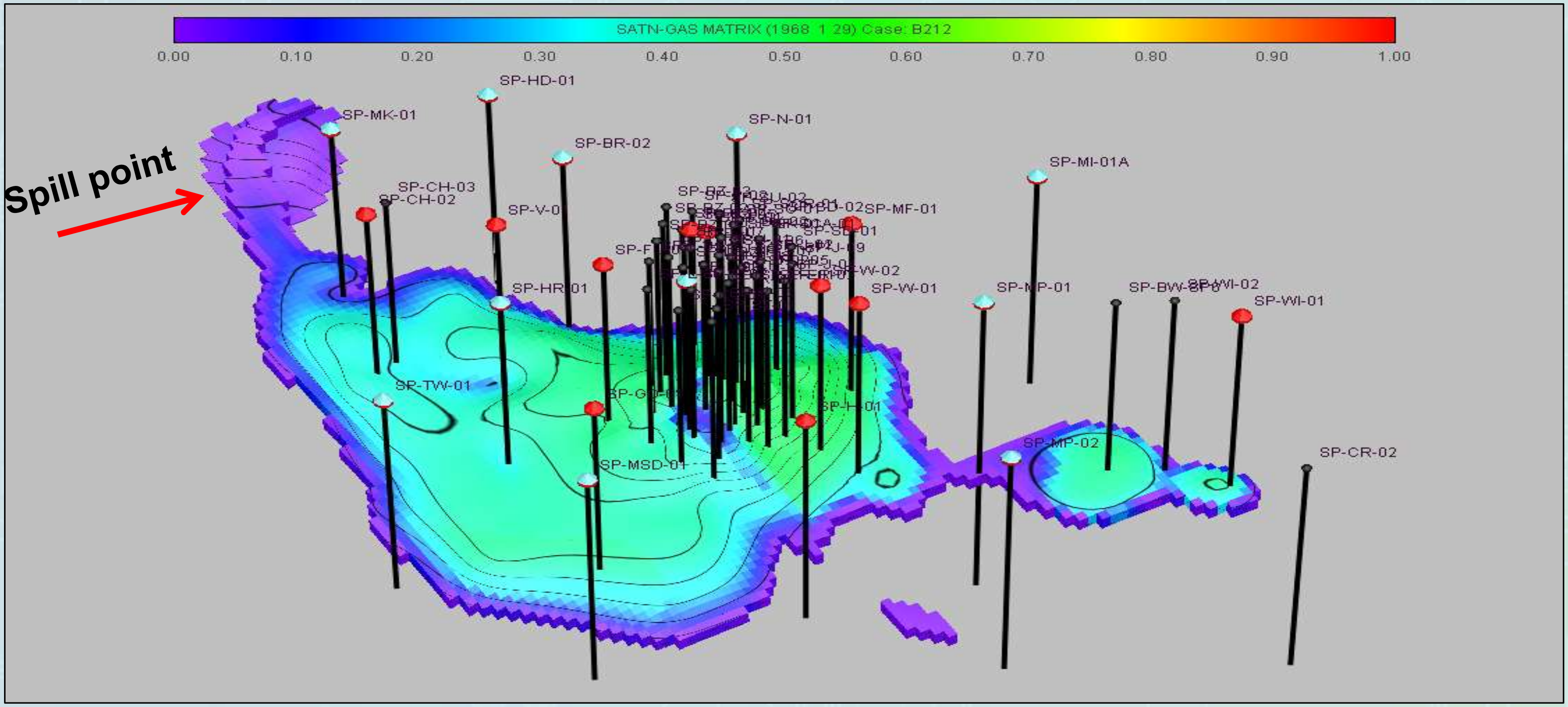
Gas Plume Expansion– Modeling Example



Effects of structure and reservoir heterogeneity on gas expansion

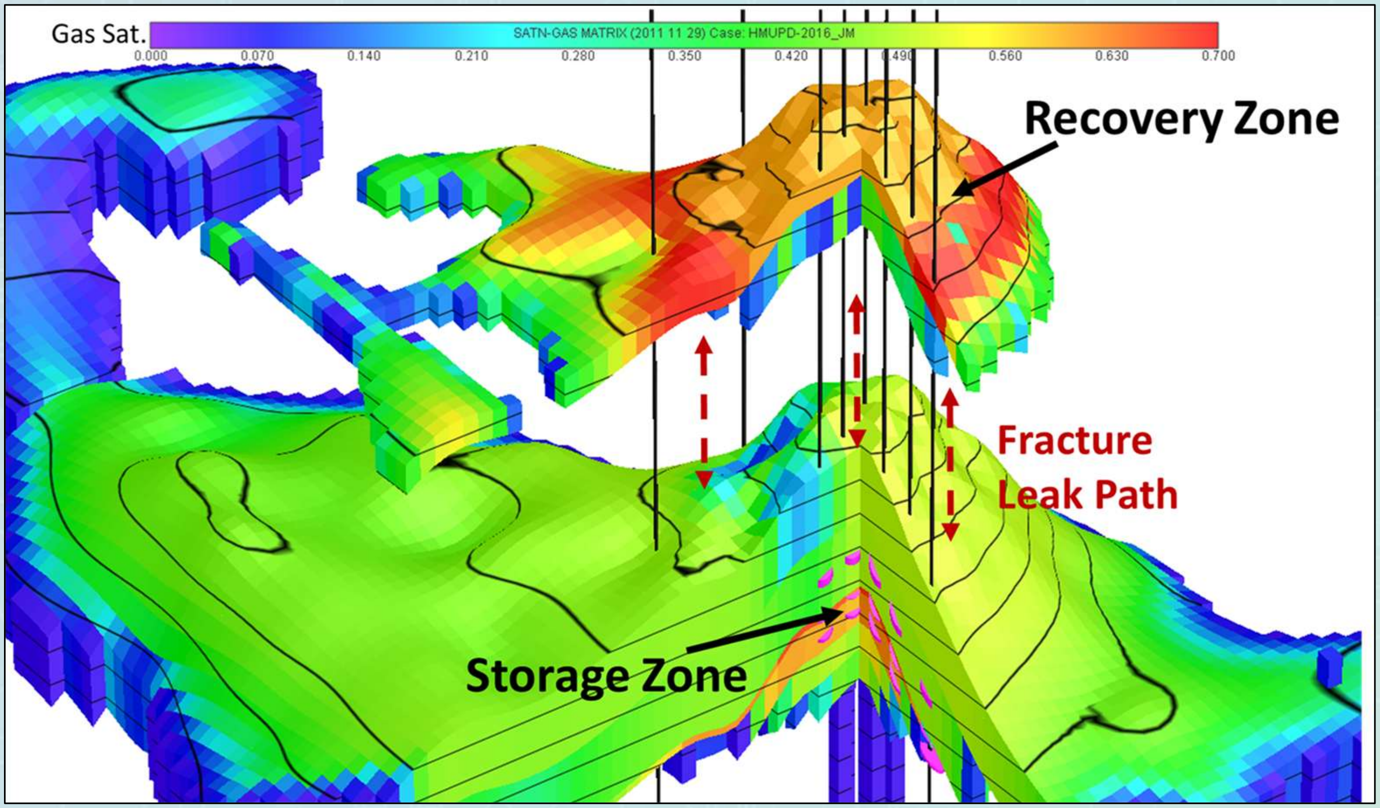
Leak Detection – Gas Storage Modeling Example

Gas Migration thru Saddle/Spill Point



Leak Detection – Gas Storage Modeling Example

Gas Migration thru Vertical Fracture

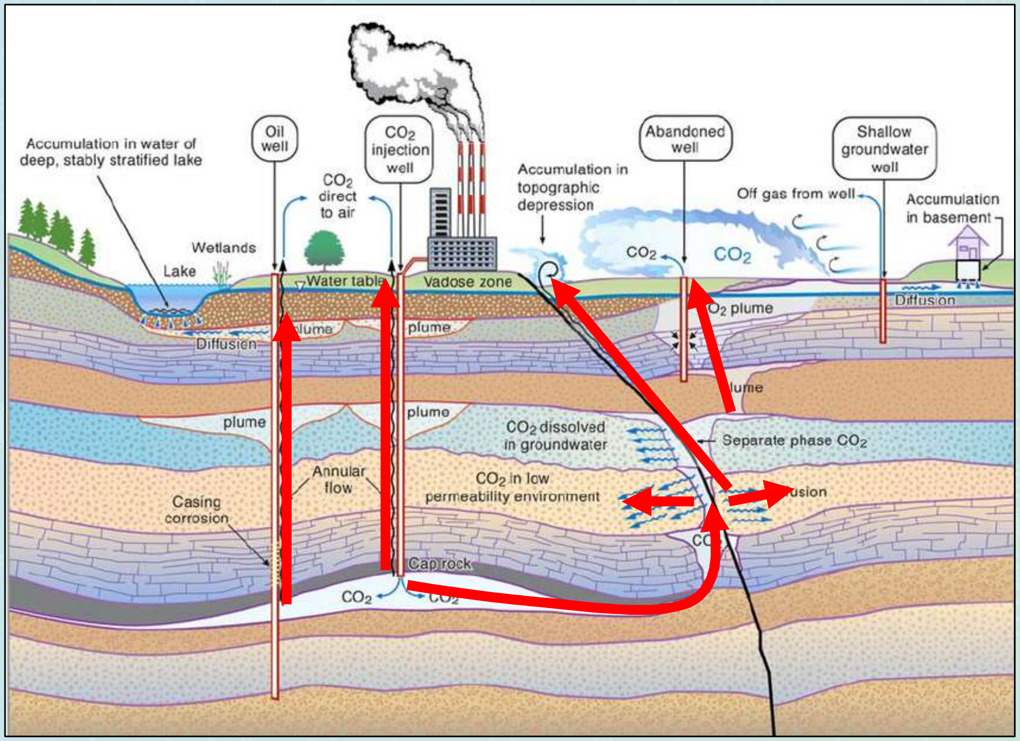


Reservoir Monitoring & Leakage Pathways of CO_2

One of the major risks in CCS is the potential leakage of CO_2 from underground storage sites, which can have negative impacts on health, safety and the environment.

Main CO_2 leakage and seepage pathways:

- **Existing faults and fracture networks and geological fissures**
- **Leakage pathways within seal layer**
- **Diffusion of CO_2**
- **Induced tensile or shear failure of caprock**
- **Abandoned or active injection and production wells**



(Oldenburg, 2005)

Reservoir Monitoring & Observation Wells

In UNGS, observation wells have an important role:

- **To identify changes from gas pressure to water level at different times, providing unique and important data to track gas movement,**
- **To do accurate estimations of inventory verification,**
- **To guide the numerical modelling process.**

Number of Observation Wells

In the presence of higher degree of heterogeneity, more observation wells should be used to monitor the plume movement better to reduce errors

Location of Observation Wells

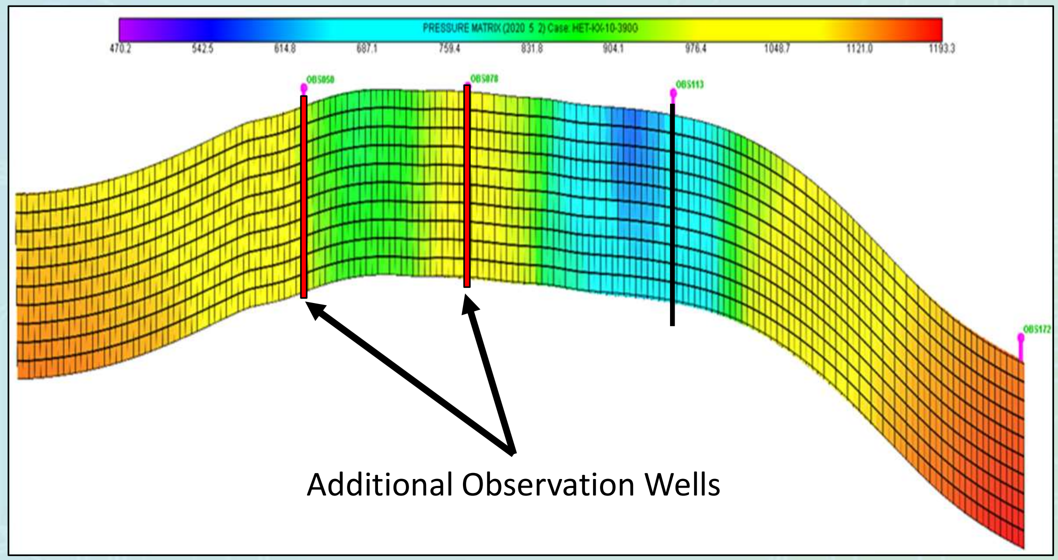
An observation well in a low-quality or poorly connected reservoir area yields inaccurate data, leading to major discrepancies in calculated versus actual inventory.

Reservoir Monitoring & Observation Wells – Gas Storage Modeling Example

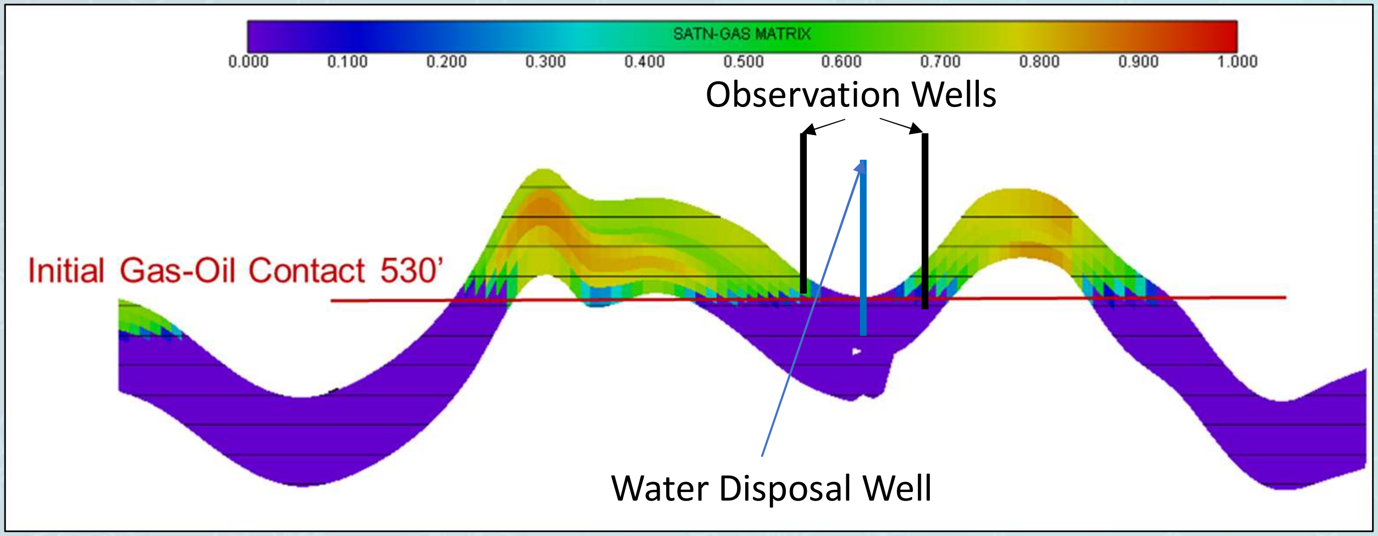
Importance of multiple observation wells:

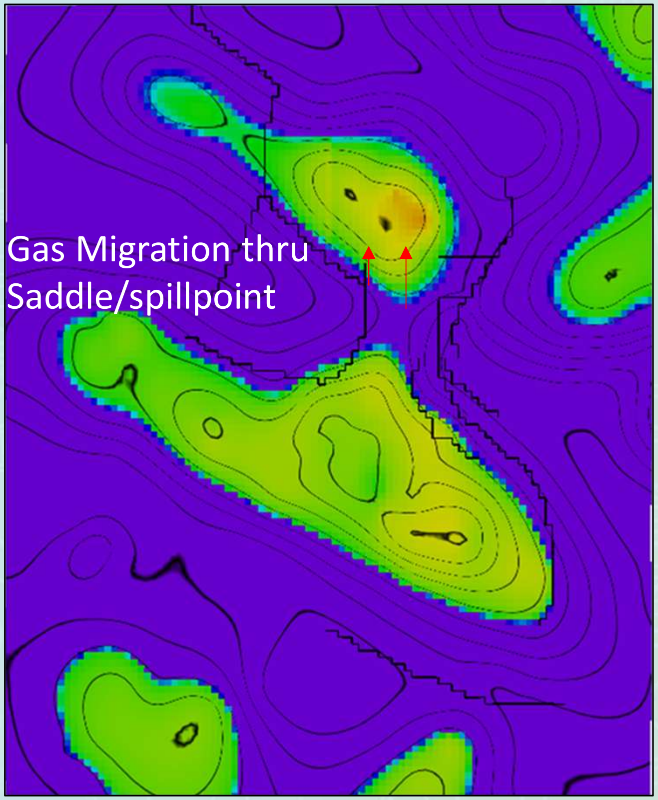
- **The incorporation of additional observation wells can decrease the error in the calculated inventory.**

Severe Heterogeneity		
Obs. Wells	Error (%)	ΔError (%)
1	17.2%	0.0%
2	5.3%	11.9%
3	1.9%	15.3%



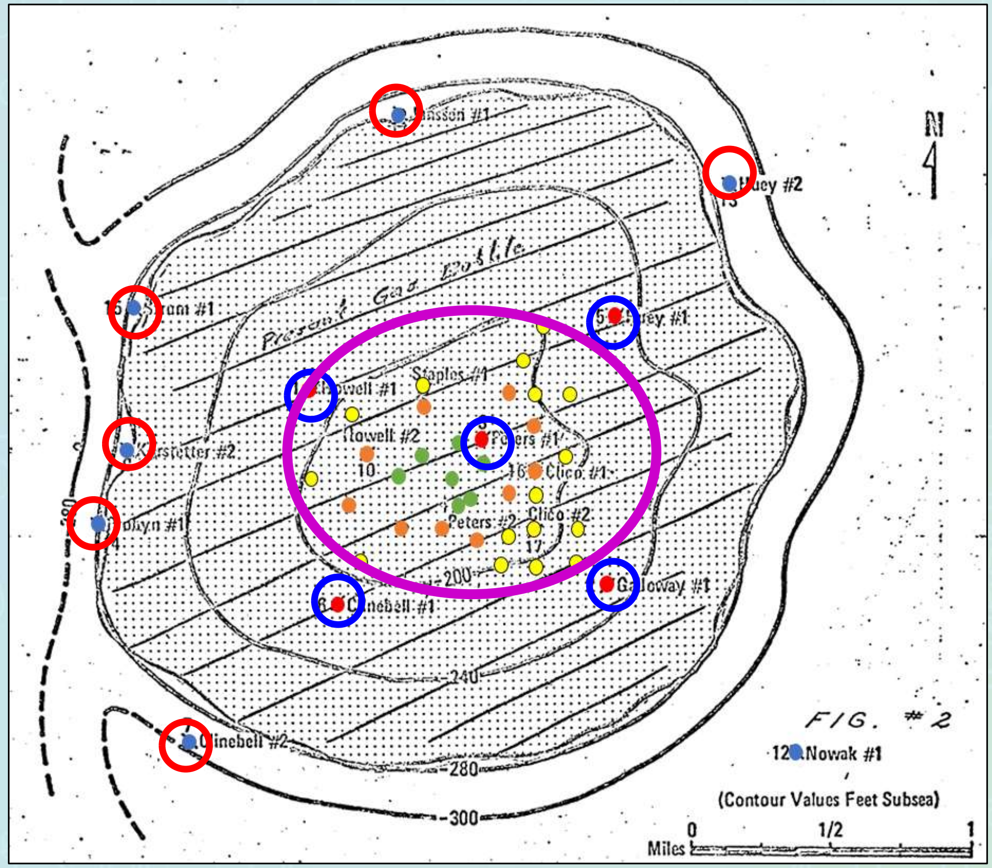
Leak Detection & Observation Well Placement – Gas Storage Modeling Example





Injection/Observation Well Placement – Gas Storage Modeling Example

- Initial Injection Wells
- Secondary Injection Wells
- Last Injection Wells
- Gas Observation Well
- Water Observation Well



Conclusions

- Experiences from UNGS and CO2-EOR provides valuable insights to reduce CCS project risks
- Key insights include:
  - Storage site selection: Depleted oil/gas fields vs deep saline aquifers
  - Storage capacity estimation
  - Modeling solutions
  - Geological data integration and understanding
  - Leak detection
  - Reservoir monitoring & plume migration
  - Observation well count and placement

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