Site-specific Monitoring Design

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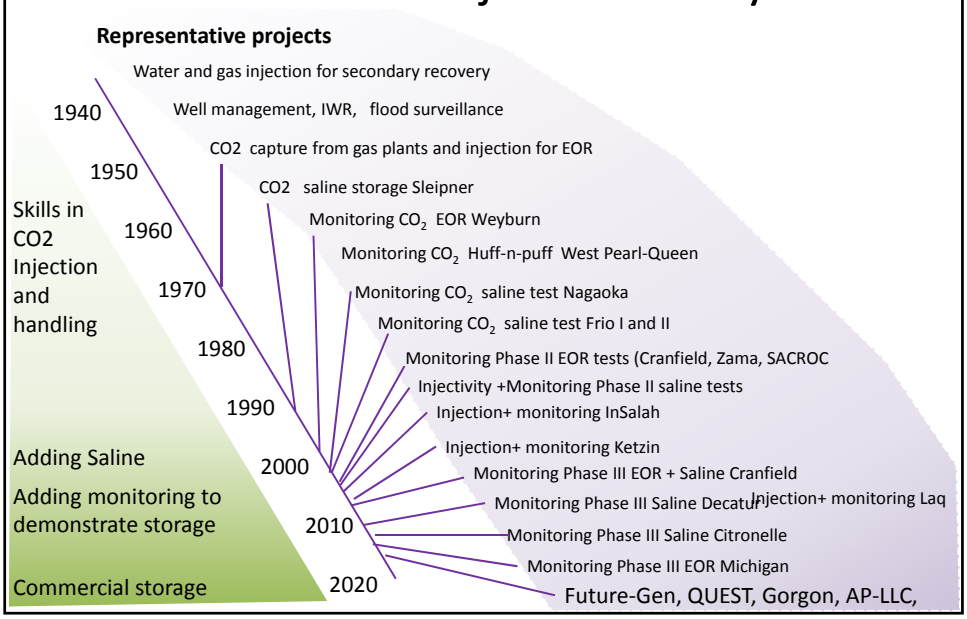
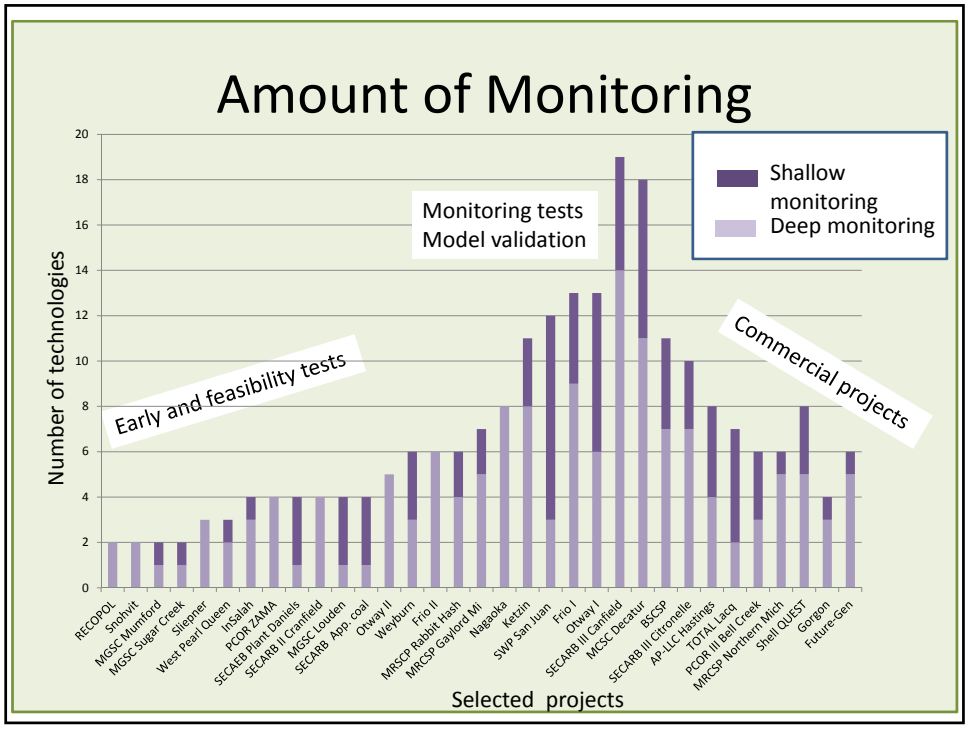
Safe and Effective Injection > 50 years

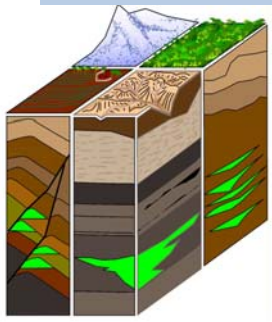




Site specific drivers of monitoring design

Project monitoring drivers:
Regulatory prescriptions
Regulatory choices
Supplier/Operator/Stakeholder needs

Site Specific Geotechnical Risks



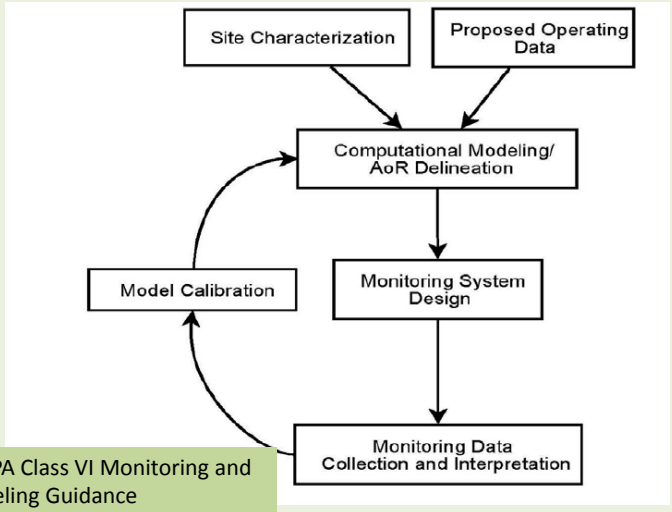
Monitoring targets

Monitoring Design

Site specific technology limitations

EPA STAR Project using SECARB data

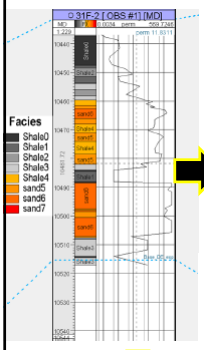
Regulator Expectation: monitor plume & match to models



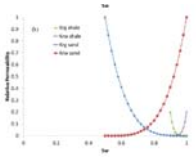
US EPA Class VI Monitoring and Modeling Guidance

Modeled expectations repeatedly adjusted to match measurements

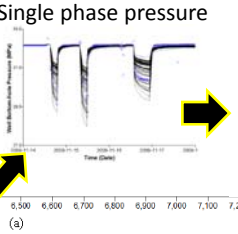
Reservoir characterization



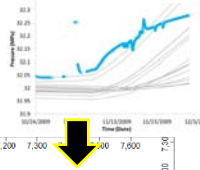
Relative permeablities



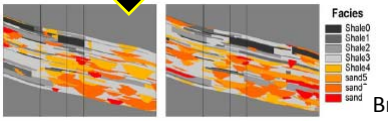
Single phase pressure

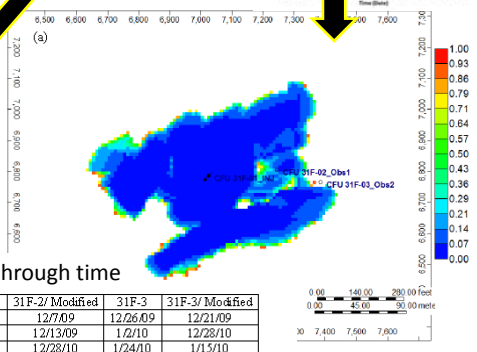


Multi phase pressure



Probabilistic realizations of reservoir architecture





Breakthrough time

Hosseini and others, 2013 Cranfield

Realization Number	31F-2	31F-2/ Modified	31F-3	31F-3/ Modified
35	12/8/09	12/7/09	12/26/09	12/21/09
18	12/15/09	12/13/09	1/2/10	12/28/10
8	1/3/10	12/28/10	1/24/10	1/15/10
15	12/20/09	12/16/09	1/11/10	1/2/10
ACTUAL		12/12/09		12/16/09

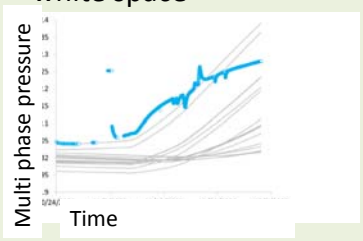
Value of a history-matched model

Accomplishments

- Improved understanding of reservoir and fluid properties
- Possible to make predictions
- Eliminate some scenarios

Limits

- Not " the right" answer
- Only probes calibrated conditions, not "in the white space"



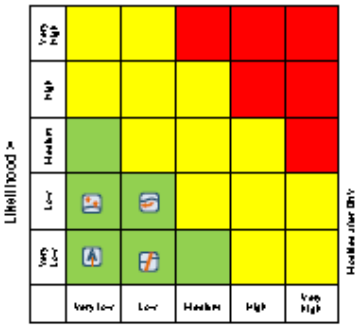
All models are wrong, but some are useful

GDP Box

Not all miss-matches are important to the project

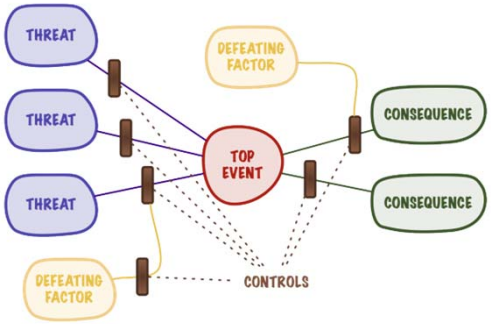
- A range of outcomes can meet most project objectives
- Need statement of what outcomes are unacceptable
  - "Failure"
  - "Leakage"
  - "Damage"
- Need a safe word: Assessment of low probability material impact ALPMI

"Risk assessment drives monitoring"



- Seepage through the caprock
- Spilling of CO_2 (spill-point) out of reservoir
- Leakage along faults
- Leakage along the well-bores

TNO -K12 B – CO2 CARE



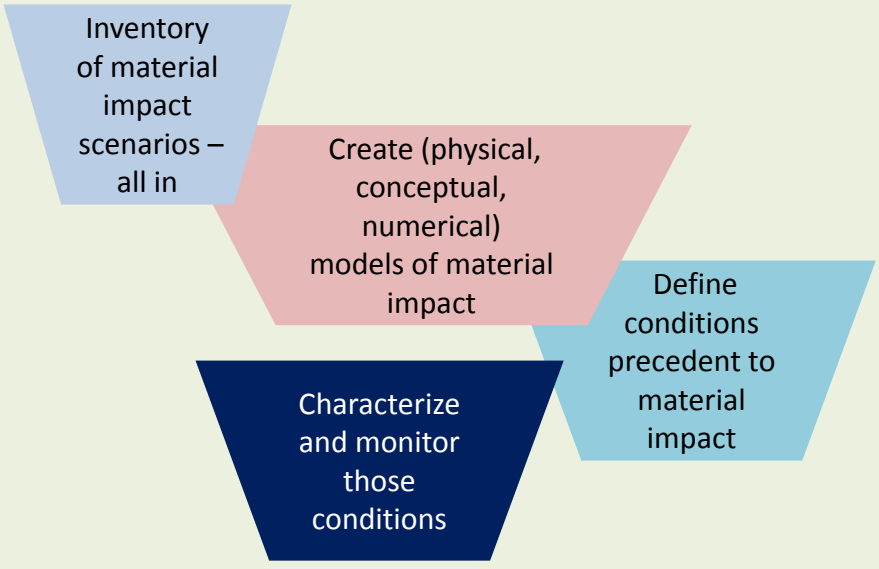
How exactly does risk assessment drive monitoring?

- Many mismatches between models and observed geosystem response
- Modeling expected reservoir response cannot predict response to low probability unexpected outlier conditions
- Monitoring cannot assess all outcomes

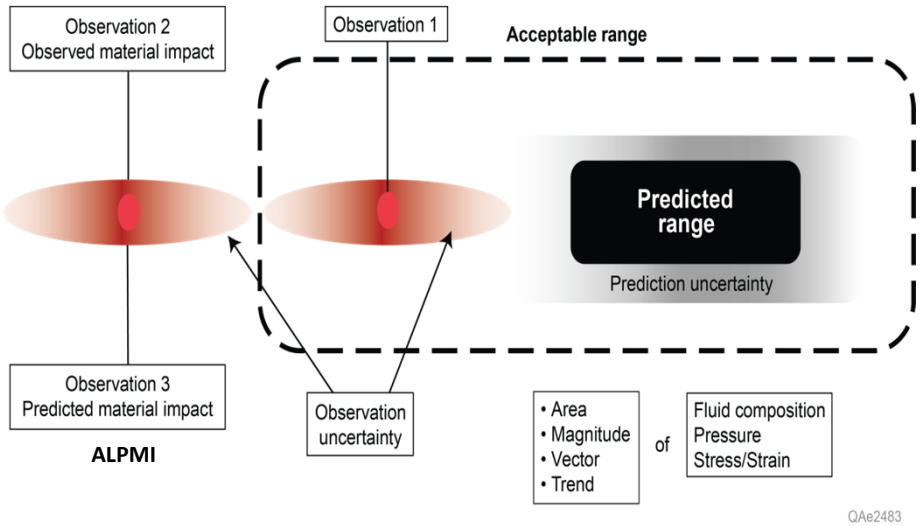
Monitoring designer should play antagonist role to armor the project

- Quantitative statement of project goals
- Assessment of material impact
- For each case, monitoring asks project " how do I know this material impact is not occurring and will not occur?"
- A method of answering:
  - Models created to illustrate material impact cases
  - Characterization/monitoring designed to disprove material impact scenarios.

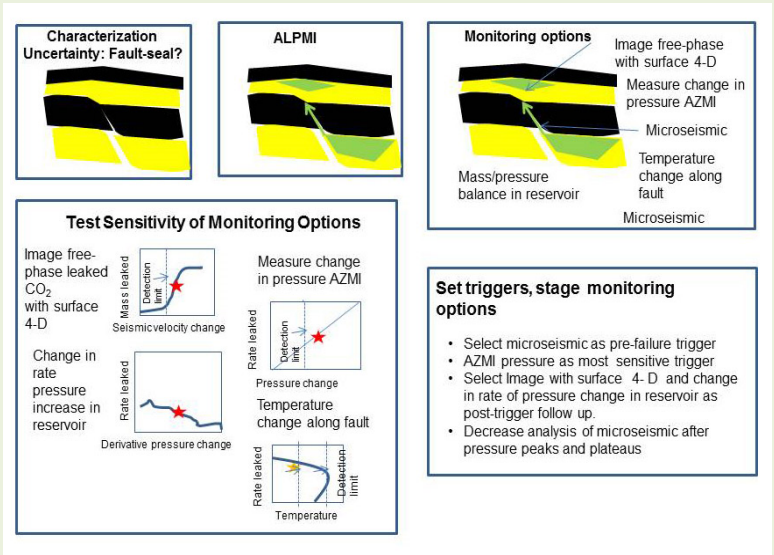
Solving the dilemma

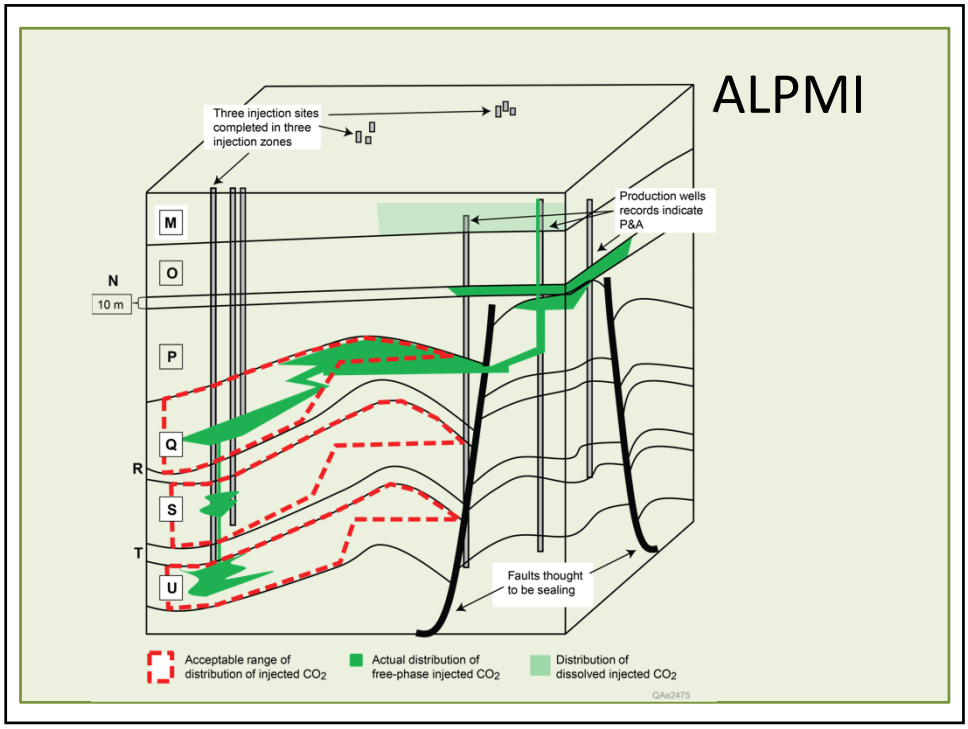


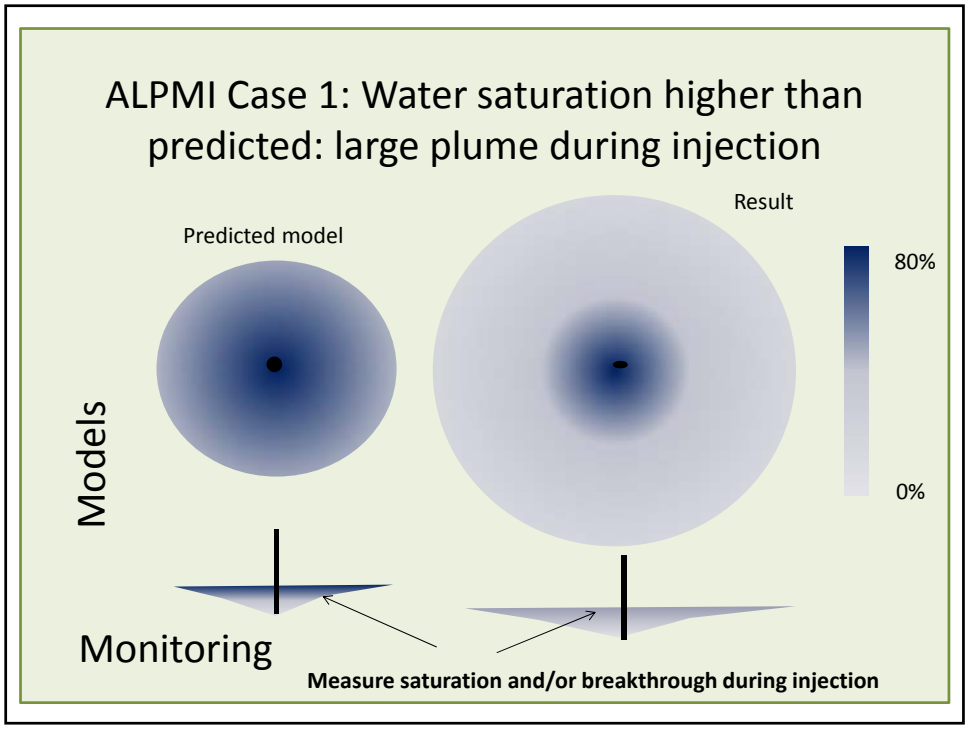
Assessing Low Probability Material Impact



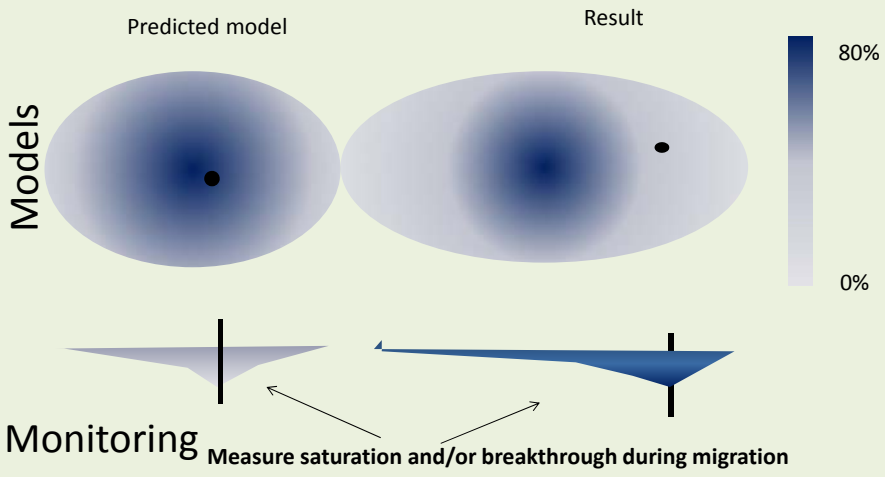
Using ALPMI to Design Monitoring



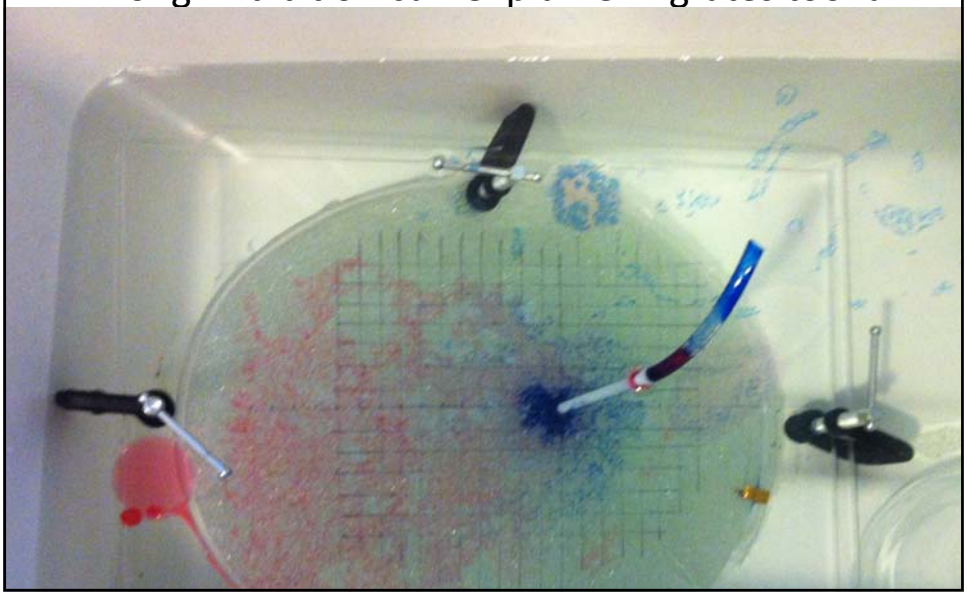

ALPMI
Three injection sites completed in three injection zones
Production wells records indicate P&A
M
O
N
10 m
P
Q
R
S
T
U
Faults thought to be sealing
Acceptable range of distribution of injected CO2
Actual distribution of free-phase injected CO2
Distribution of dissolved injected CO2
QAe2475


ALPMI Case 1: Water saturation higher than predicted: large plume during injection
Predicted model
Result
80%
0%
Models
Monitoring
Measure saturation and/or breakthrough during injection

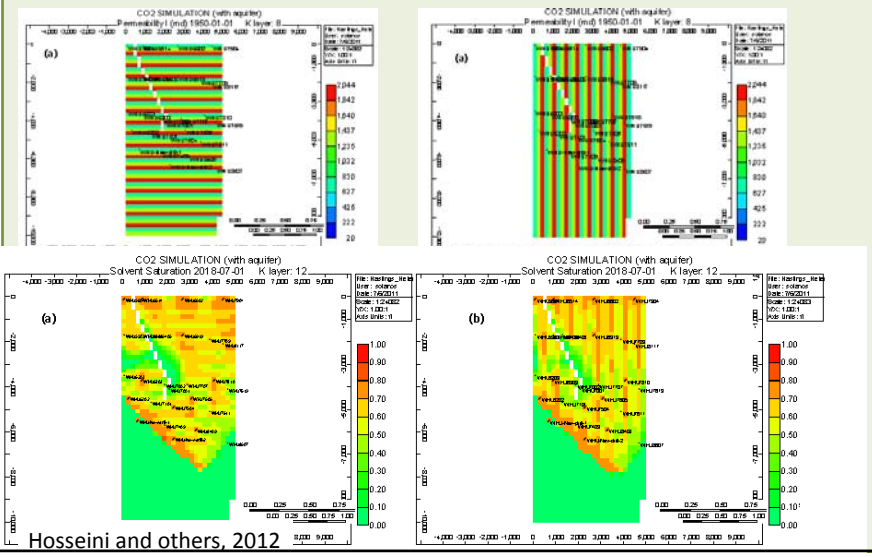
ALPMI Case 2: CO_2 residual saturation lower than predicted: large plume during migration



ALPMI 2 physical model
Wrong imbibition curve: plume migrates too far



ALMPI Case 3
Anisotropy such that plume migrates too far



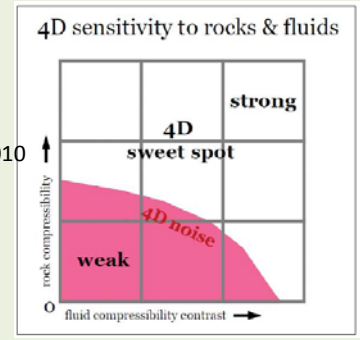
Hosseini and others, 2012

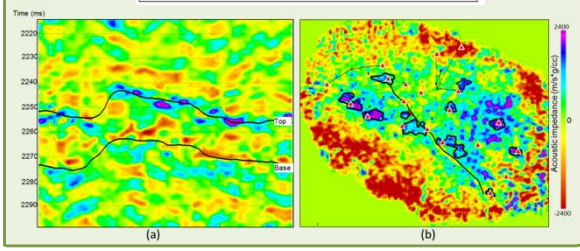
Site-specific Tool Sensitivity Case Studies

- Time-lapse 3-D Seismic for lateral CO2 migration
- Above-Zone pressure for vertical leakage detection
- Thermal perturbation for vertical leakage detection
- Freshwater aquifer geochemistry for CO2 leakage detection

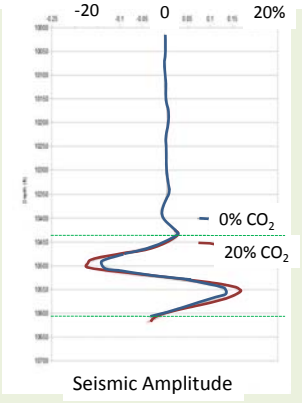
Seismic Sensitivity

Lumley, 2010



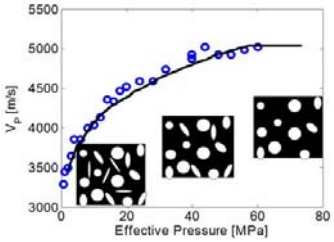


Modeled change in amplitude
Cranfield

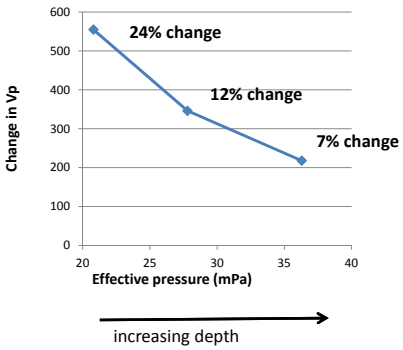


Zhang, 2012, 4-D survey
Cranfield reservoir

Site specific seismic sensitivity: velocity change with depth

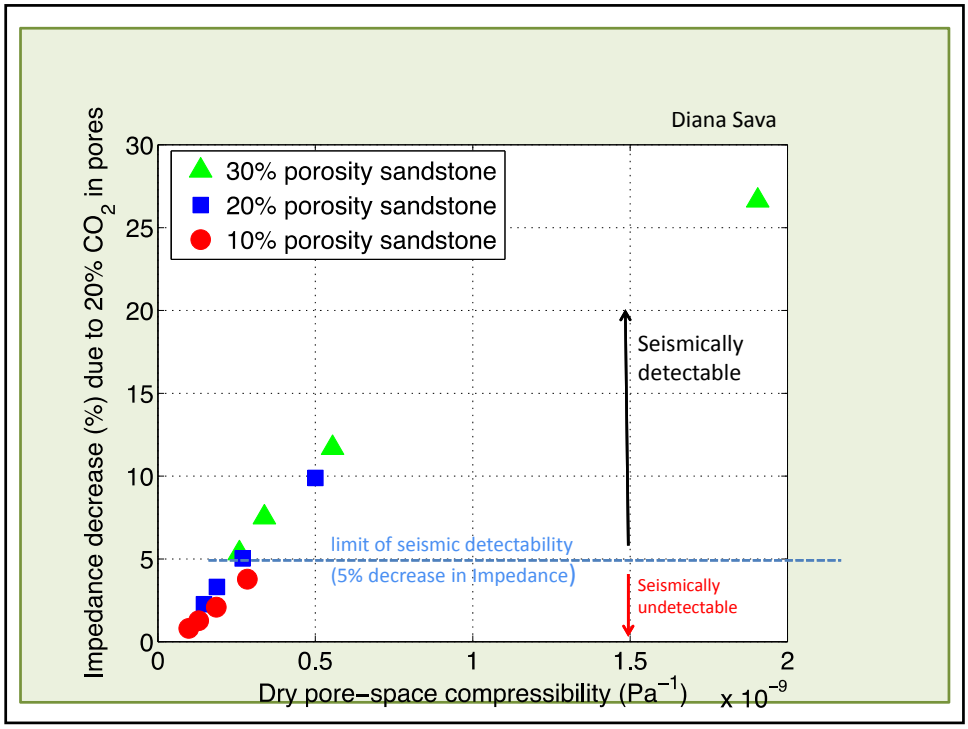


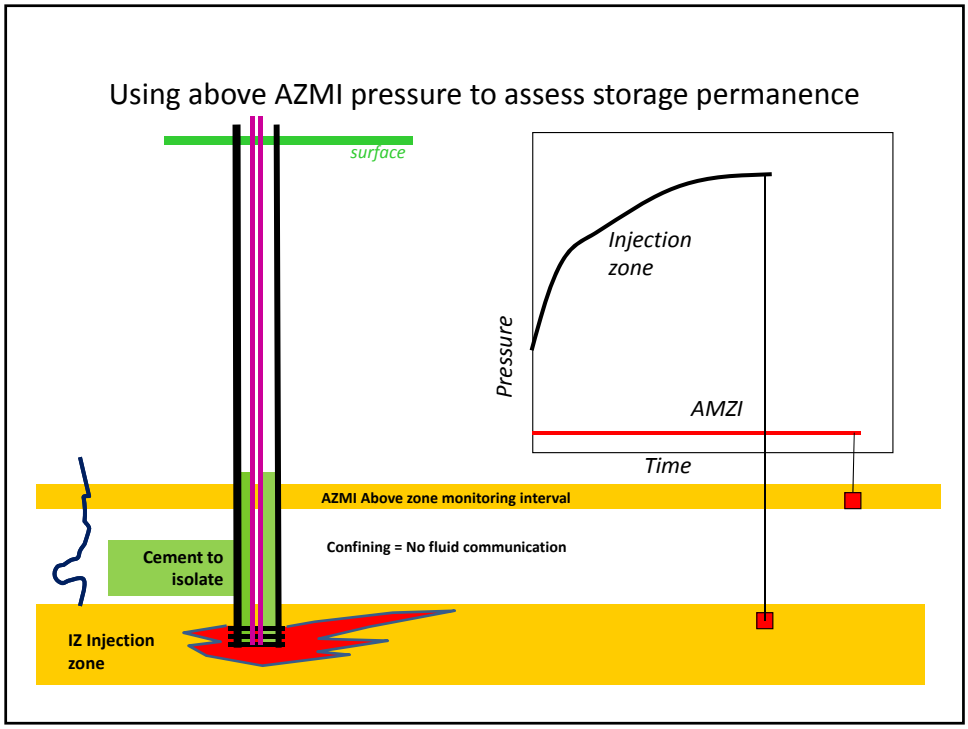
Rock physics model, self consistent approximations (Berryman 1995), data Purcell and Harbert University of Pittsburg



Diana Sava

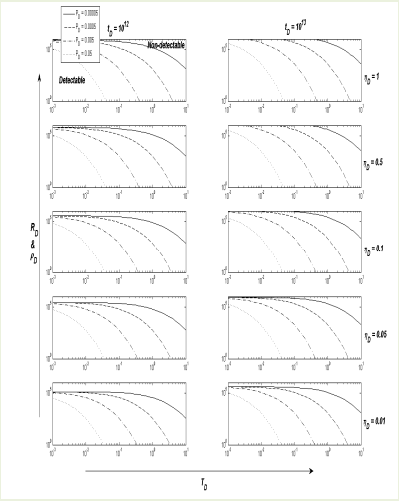
average elastic properties, Gassman (1951) theory, 30% porosity, 20% fluid substitution CO2 for brine, not changes to minerals, fluids do not support shear, Reuss (1929) model


Diana Sava
30% porosity sandstone
20% porosity sandstone
10% porosity sandstone
Seismically detectable
limit of seismic detectability
(5% decrease in impedance)
Seismically undetectable
Impedance decrease (%) due to 20% CO_2 in pores
Dry pore–space compressibility (Pa^{-1})
x 10^{-9}
0
5
10
15
20
25
30
0
0.5
1
1.5
2


Using above AZMI pressure to assess storage permanence
surface
Injection zone
Pressure
AMZI
Time
AZMI Above zone monitoring interval
Confining = No fluid communication
Cement to isolate
IZ Injection zone

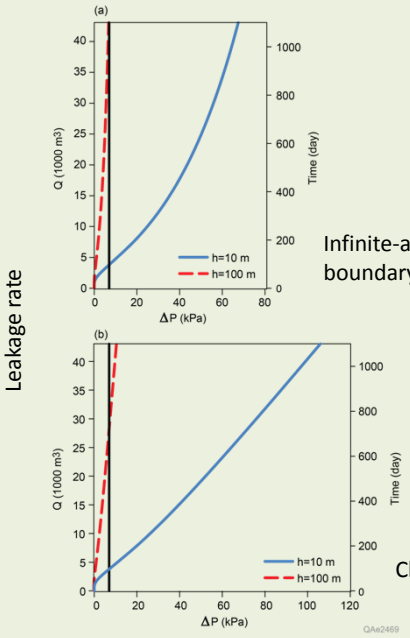
AZMI Pressure sensitivity for leakage detection: non parametric tables

Parameter
m, brine viscosity (Pa.s)
IZ formation compressibility (1/Pa)
IZ formation porosity (fraction)
k, IZ formation permeability (m^2)
h, IZ formation thickness (m)
h, diffusivity (m^2/s)
AZMI compressibility (1/Pa)
AZMI porosity (fraction)
k_a, AZMI permeability (m^2)
h_a, AZMI thickness (m)
h_a, AZMI diffusivity (m^2/s)
q, injection rate (Mt/year)
r_w, injection well radius (m)
r_l, Leak radius (m)
h_l, leakage interval (m)
B, CO_2 formation volume factor (Rm^3/stm^3)



Mehdi Zeidouni

AZMI thickness vs sensitivity

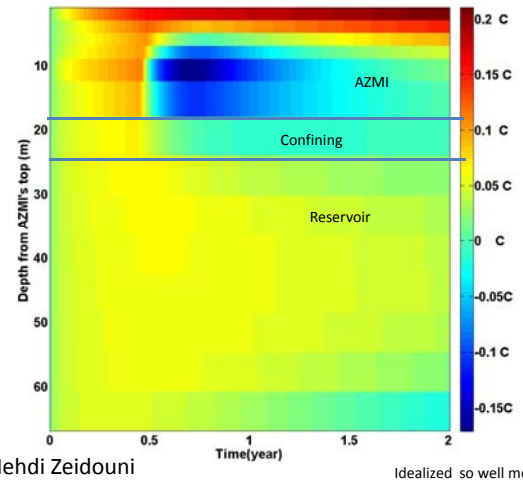


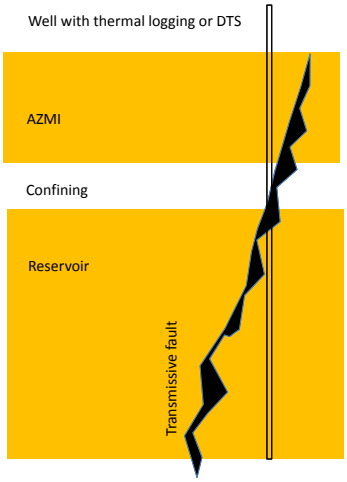
Leakage rate

Infinite-acting boundary conditions

Closed boundary at 6 km

Thermal Sensitivity of AZMI to leakage





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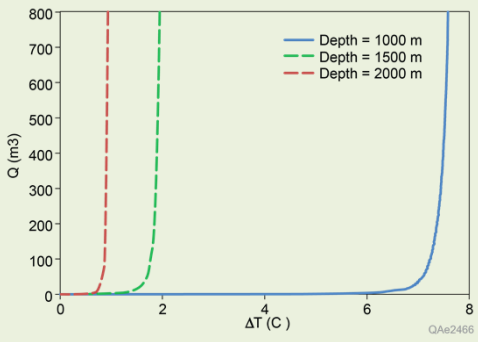
Idealized so well measured center of fault

Thermal sensitivity depth dependent



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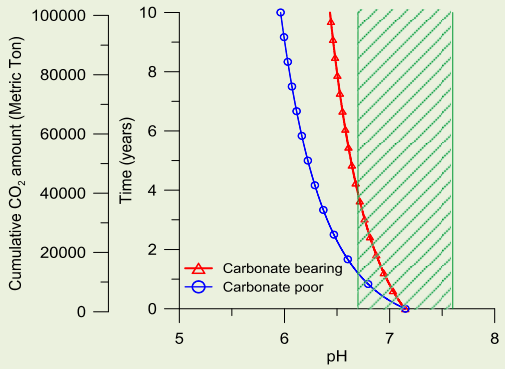
Site Specific Freshwater Geochemical Sensitivity



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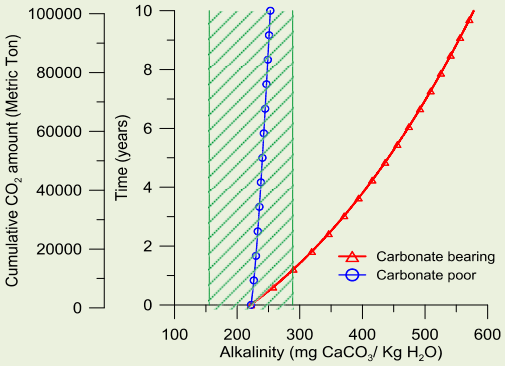
Site Specific Freshwater Geochemical Sensitivity-Alkalinity



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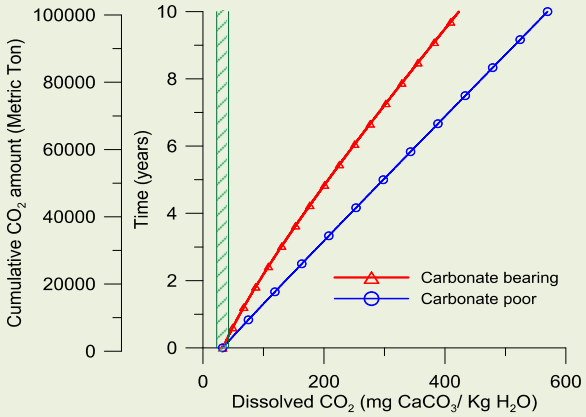
Site Specific Freshwater Geochemical Sensitivity- Dissolved CO_2



Changbing Yang

Conclusions

- Monitoring design depends on project goals and ALPMI
- Monitoring not used primarily for model match but for ALPMI
- For each ALPMI, monitoring can show that even though some uncertainties remain in terms of geologic response to injection, there is no trend to defined material impact

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