Welcome!

The program will begin soon.

You will not hear audio until we begin.

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Webinars

Role of Core Analyst Towards Industry Energy Transition Focus on Emerging Areas: CCUS

VITALY AFANASIEV

Dec 1st, 2022

SPE International

Business Development Manager
for SLB Reservoir Laboratories

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Prerequisites

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- C~~CU~~S = Geological Carbon Storage

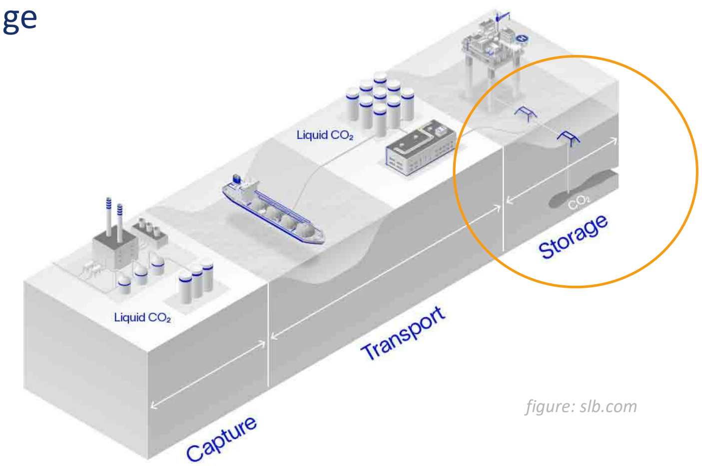

figure: slb.com

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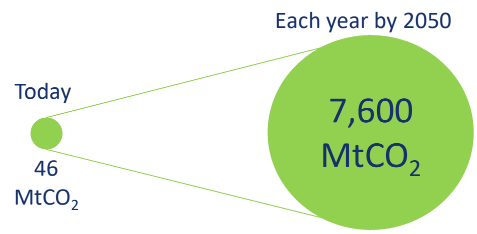
Prerequisites

- C~~CU~~S = Geological Carbon Storage
- Volume of storage must grow exponentially



source: IEA Net Zero Scenario, 2021

*Oil production in 2022: 100.1 Mb/d * 0.120 t/b * 365 d = 4,384 Mt*

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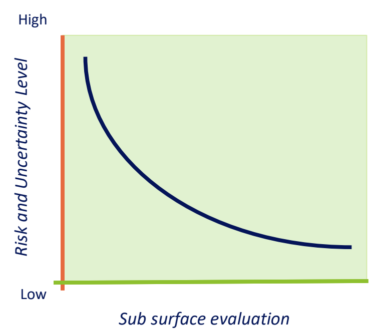
Prerequisites

Webinars

- C~~CU~~S = Geological Carbon Storage
- Volume of storage must grow exponentially
- Risks are to be reduced through measurements



83%

Variation in Storage Volumes*

40%

Drop in Injectivity Rates**

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Source:
** RYSTAD ENERGY TRANSITION REPORT, JANUARY 2021, CCS SOCIETY*
*** Proprietary data*

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Prerequisites

Webinars

- ~~CCUS~~ = Geological Carbon Storage
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- Risks are to be reduced through measurements
- Laboratory is at each stage

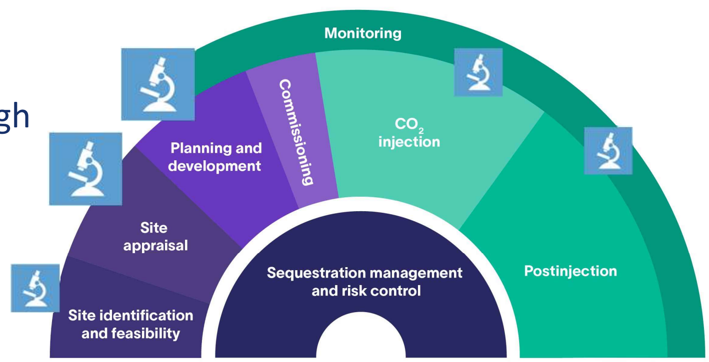

figure: slb.com

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Prerequisites

- C~~CU~~S = Geological Carbon Storage
- Volume of storage must grow exponentially
- Risks are to be reduced through measurements
- Laboratory is at each stage
- No two carbon storage projects are the same...

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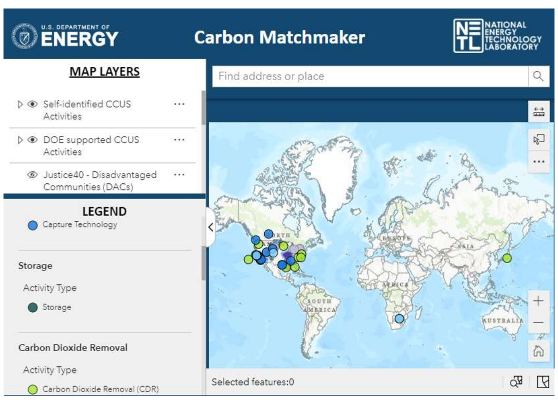
No two carbon storage projects are the same



https://www.energy.gov/fecm/carbon-matchmaker

slb.com

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Carbon storage projects differ

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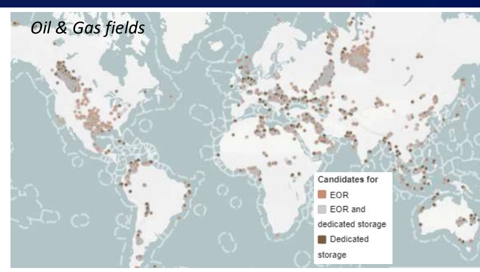

source: Rystad

North America

Rest of World

Public domain — Awareness and engagement — Confidential

Clearly regulated — Requirements — Loosely defined

Dedicated Aquifer — Purpose — EOR

Independent — Operators — National/Int. Oil Companies

Small / Medium (0.1-5 Mta) — Size — Medium / Giant ..-20 Mta

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Common denominator for uncertainties and risks

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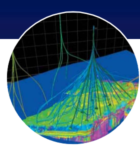
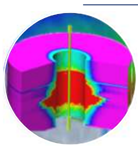


Storage characterization

Caprock integrity and injection rates



Containment and conformance

Laboratory Measurements

Pristine rock and fluids

CO_2-fluids-rock sensitivity

Physical and digital twins

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Risk and Uncertainties vs Lifecycle

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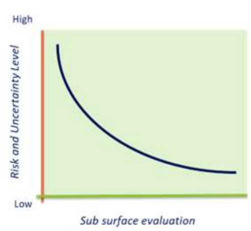

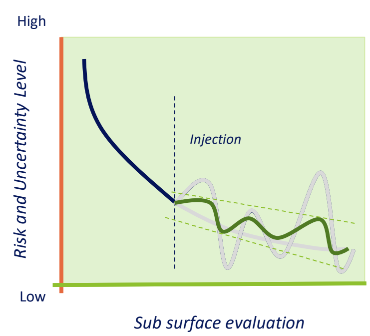

Geological Carbon Storage

- Catastrophic release of CO_2
- Sub economic assets unable to store or inject at planned volume

→ Characterize reservoir and seal rock mechanics and flow properties.

→ Study processes 10^3 years long.

→ Prepare for future

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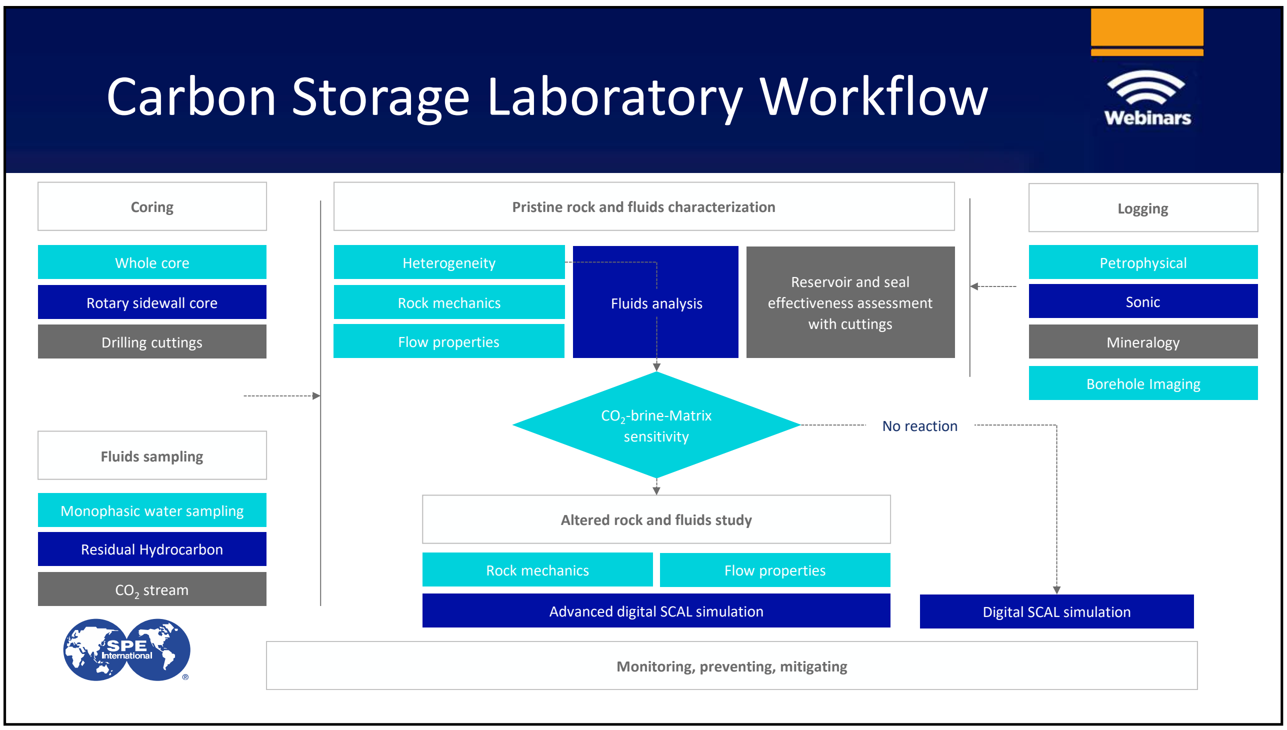
Carbon Storage Laboratory Workflow
Webinars
Coring
Whole core
Rotary sidewall core
Drilling cuttings
Fluids sampling
Monophasic water sampling
Residual Hydrocarbon
CO_2 stream
Pristine rock and fluids characterization
Heterogeneity
Rock mechanics
Flow properties
Fluids analysis
Reservoir and seal effectiveness assessment with cuttings
Logging
Petrophysical
Sonic
Mineralogy
Borehole Imaging
CO_2-brine-Matrix sensitivity
No reaction
Altered rock and fluids study
Rock mechanics
Flow properties
Advanced digital SCAL simulation
Digital SCAL simulation
Monitoring, preventing, mitigating
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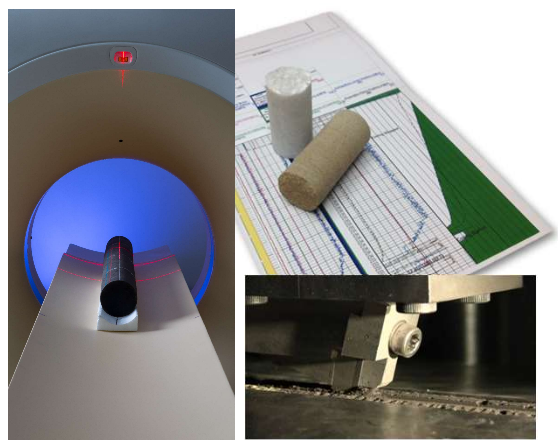
Heterogeneity

Target Reservoir Rock

- Honoring heterogeneity
- Comprehensive petrophysical and petrological description
- Continuous measurements
- Geological description with petrology and mineralogy
- Fracture analysis
- Connected to the field through logging program

+ Seal(s)

- Seal (primary and secondary) characteristic



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Fluids analysis

- CO_2 Stream composition, impurities
- Isotopic fingerprint (δC and δO) – for geochemistry-aided monitoring

Dissolution

$CaCO_3 + CO_2(aq) + H_2O \Leftrightarrow Ca^{+2} + 2HCO_3^-$

$CaMg(CO_3)_2 + 2H^+ \rightarrow Ca^{+2} + Mg^{+2} + 2HCO_3^-$

Argillaceous carbonate formations

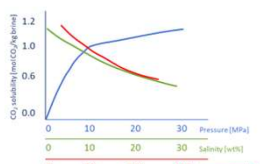
$(Mg,Fe)_5Al_2Si_3O_{10}(OH)_8 + CaCO_3 + CO_2 \Leftrightarrow Ca(Mg,Fe)(CO_3)_2 + SiO_2 + Al_2Si_2O_5(OH)_2$

Siliciclastic/arkosic formations

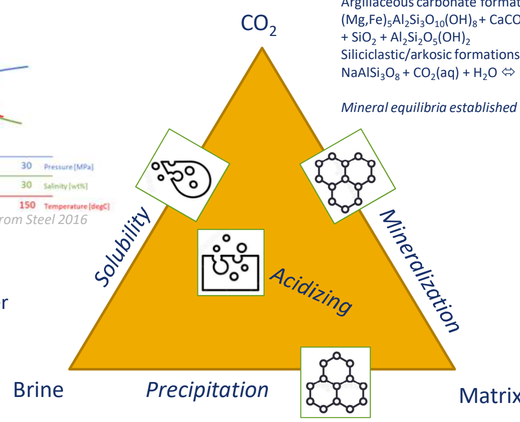
$NaAlSi_3O_8 + CO_2(aq) + H_2O \Leftrightarrow NaAl(CO_3)(OH)_2 + 3SiO_2$

Mineral equilibria established ~ 10^2 - 10^3 years

- Modeling of compatibility brine-CO_2
- Brine – CO_2 solubility – as $f(p, T, z_i)$
- Density, Viscosity, Interfacial tension as $f(p, T, z_i)$

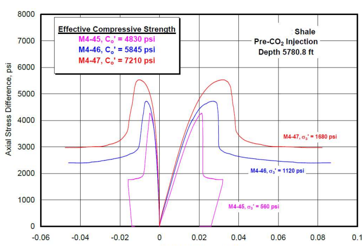


modified from Steel 2016



- Brine representative sampling – target, and above
  - Bottomhole, Monophasic, Preserved
- Comprehensive brine characterization, including gas/water ratio, salinity, ionic composition, organic acids, and metals

Rock mechanics. Pristine rock



Masoudi 2013. IPTC 16703

Reservoir Target

- Failure and elastics (static/dynamic) properties measured from standard testing suite (UCS, Triaxial, Tensile strength)
- Rock Integrity during Injection/Depletion simulation
  - Hydrostatic Compression Tests
  - Uniaxial-Strain Pore Volume Compressibility Tests (UPVC)
- Thermal expansion / contraction

+ Seal(s)

- Assessment of anisotropy (TI)
  - Multi-stress compression
  - Static and Dynamic Elastic relationships
  - Thomsen parameters and MANNIE coefficients

Geomechanical modeling

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Flow properties

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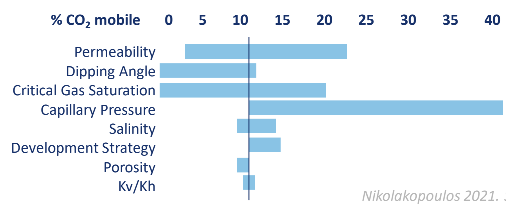
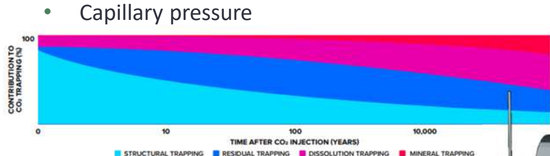
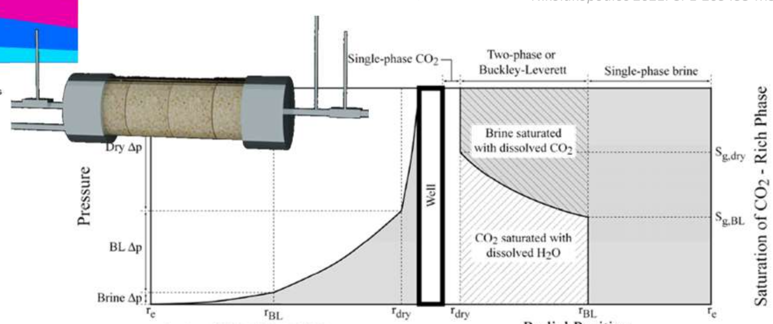


Nikolakopoulos 2021. SPE-205453-MS

Reservoir parameters affecting CO_2 mobility

- Horizontal permeability
- Critical gas saturation
- Capillary pressure





Burton 2008. SPE 113937

Corefloods to assess injectivity evolution

- Unsteady-state: dry CO_2 flood
- Steady-state: 2-phase flow
- Specific liquid permeability

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Exposure to CO_2

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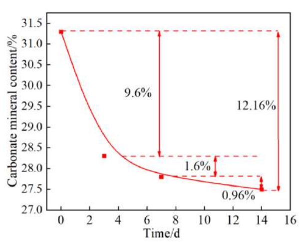
Reservoir Target and Seal(s)

- Identify and quantify reaction
- Mass transfer $f(\tau, z)$
  - Composition change for aqueous phase (IC, ICP)
  - Rock matrix change (XRD, SEM, MicroCT)



Meng, 2021, ACS Omega

- Followed by study of impact on rock macro properties

Rock, Brine, CO_2

CO_2-brine-Matrix sensitivity

No reaction

Pristine rock

Reaction

Crushed sample

Aging twins

Flow through

Stressed

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Advanced Geomechanics. CO_2 treated

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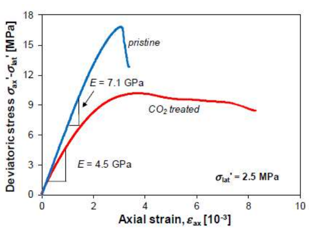
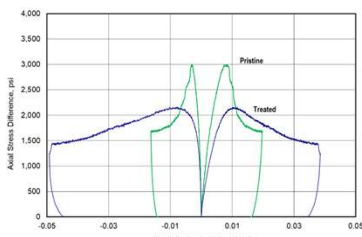
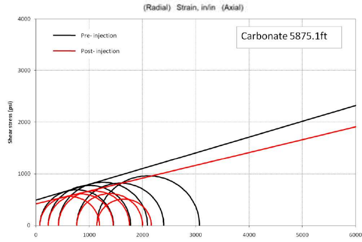


Effect of CO_2 injection on the Geomechanical response of limestone test

Kim 2018. Fluids

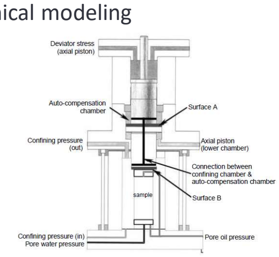




Rahim Masoudi 2013. IPTC 16703

Reservoir Target and Seal

- Rock sensitivity under P & T vs time: volumetric changes as response to interaction with CO_2
- Effect of fluids on failure and elastics properties of twins (UCS, Triaxial, Tensile strength, TWC)
- Geomechanical modeling



De Gennaro 2009

Reservoir parameters couplings

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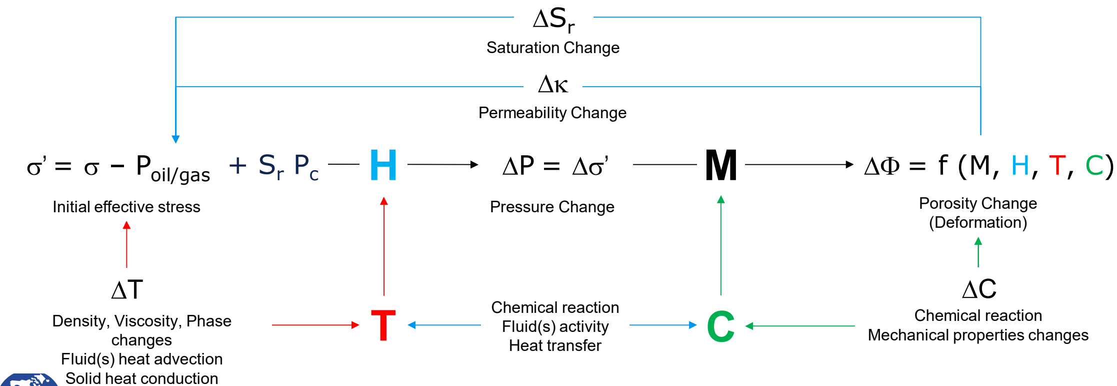
- Change in effective stress is the basic example of static Hydraulic-Mechanical coupling
- Processes are dynamic and implicit (interconnected)



T = Temperature **H** = Hydraulic **M** = Mechanical **C** = Chemical

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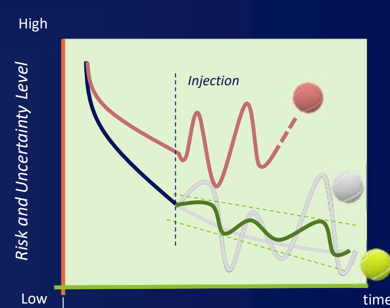
Current industry demand…



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Role of Core Analyst to balance and innovate

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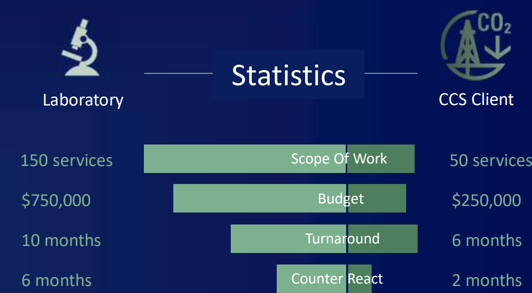

- Promote safest way to store through more measurements
- Search for optimal solution
- Adapt new technologies
- Be agile

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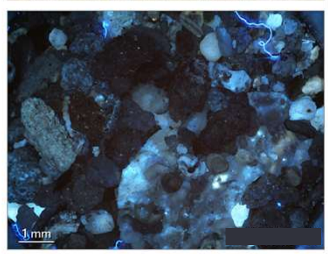
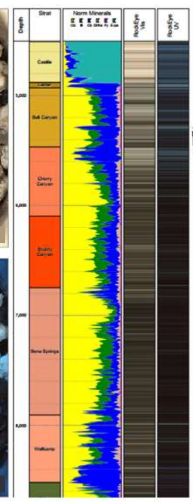
Cuttings: Expanding coverage

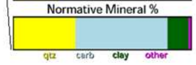
- Reservoir, primary seal, secondary seal
- Profile of the well bore:
  - Elemental composition
  - High resolution photo WL & UV
- Individual, selected samples:
  - Organic Geochemistry (TOC, REVI)
  - Organic Petrography (Organic matter, Vitrinite Reflectance)
  - Fluids Inclusion properties: API, salinity, geochemistry
  - CO_2-Fluids-Rock Sensitivity
- Cuttings do not replace core





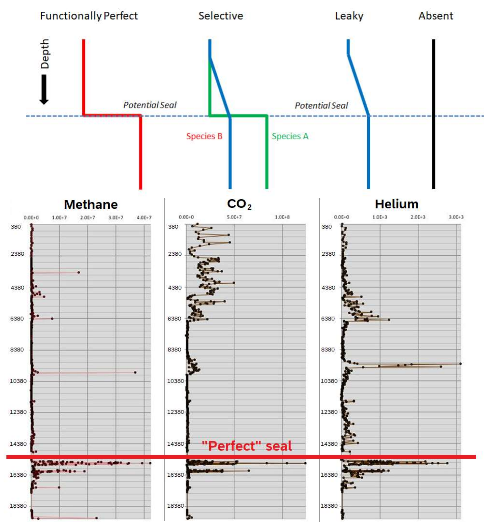
Element	ppm	Element	ppm
Mg	---	Rb	28
Al	15,512	Sr	466
Si	169,348	Zr	241
P	---	Nb	15
S	3,693	Mo	30
Cl	---	Pd	---
K	4,824	Ag	---
Ca	193,558	Cd	---
Ti	2,092	Sn	---
V	---	Sb	---
Cr	354	Ba	---
Mn	---	W	---
Fe	22,619	Au	---
Ni	---	Pb	---
Co	---	Bi	---
Cu	155	Th	56
Zn	215	U	---
As	---	Bal	586,795
Se	---		

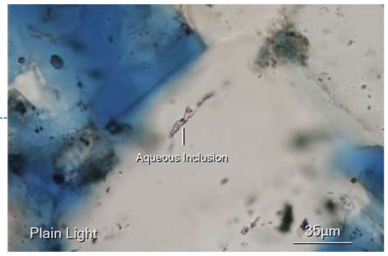
Normative Mineral %

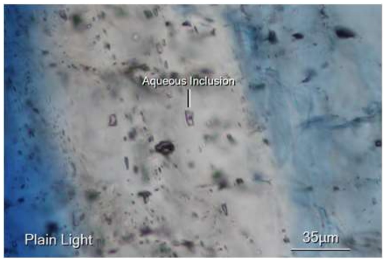


Cuttings: Seal efficiency

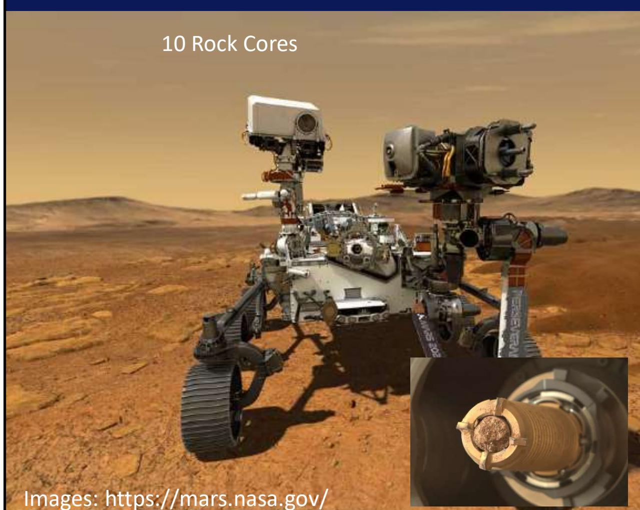
- Effectiveness of seal/caprock over geological time
  - mobile molecules CO_2, CH_4, He
- Basin-wide evaluation of sealing units
  - Sub-optimal seals
  - Compartmentalization
  - Present/past migration pathways
- Zoom-in
  - Fluid Inclusion Petrography
  - Microthermometry (API, salinity)







Perseverance



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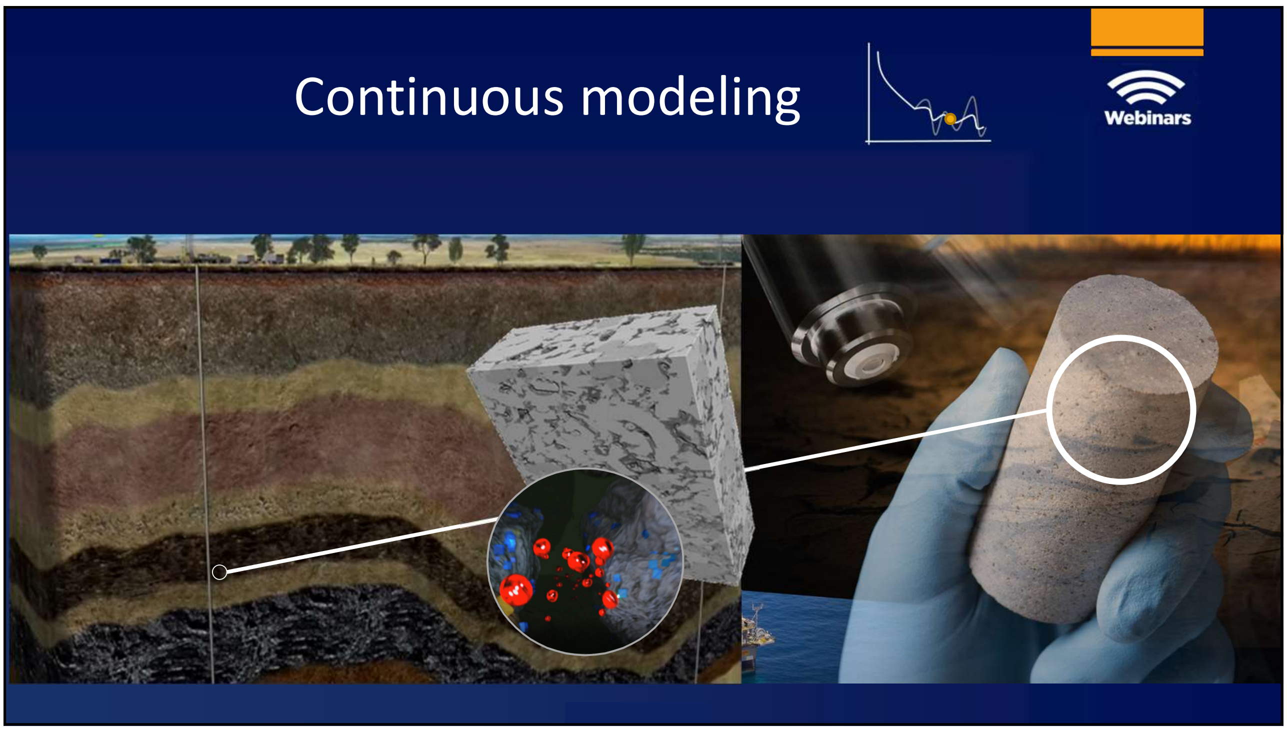

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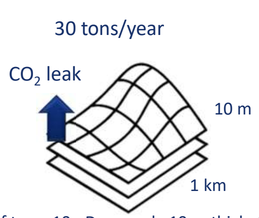
Necessity of digital measurements

Feasible:

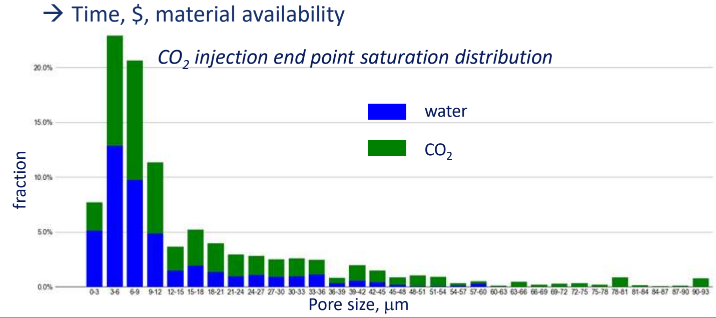
→ Pristine rock and fluids characterization
→ Define impact of dissolution / deposition
→ Fluids analysis
→ Twin analysis

Not feasible:

→ Equipment limitation (T, concentrations, resolution)
→ Tight rock flow properties
→ Observe & quantify complex co-occurring phenomena
→ 3D porous space change: Dissolution / Precipitation / Mineralization
→ Study processes 10^{-2}…10^{3} years long
→ Time, $, material availability



Rule of tens: 10 nD caprock, 10 m thick, 10 psi differential



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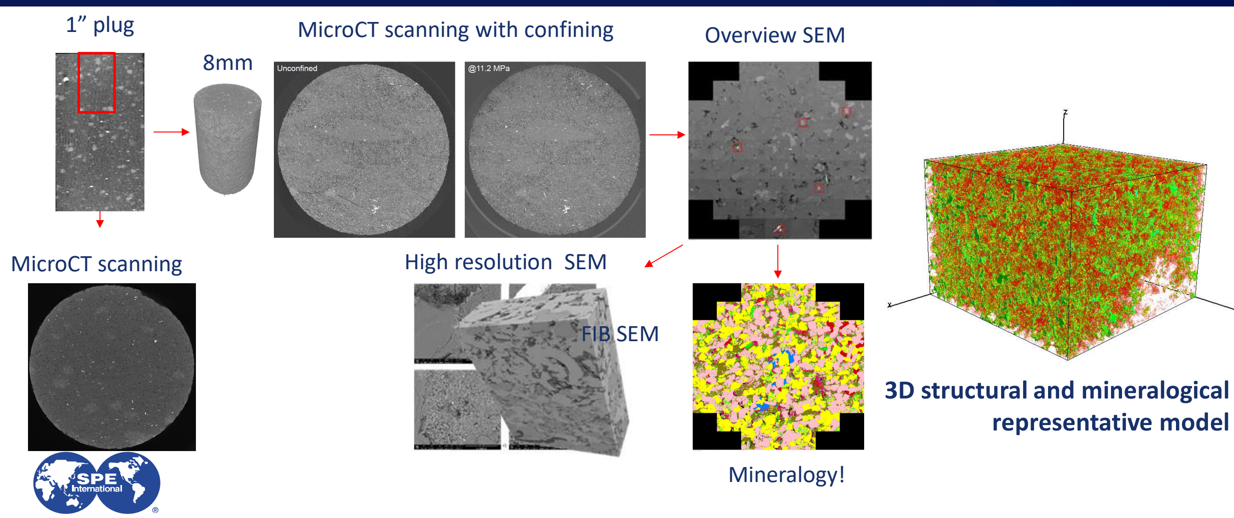
Multiscale imaging with mineralogy for representative rock model



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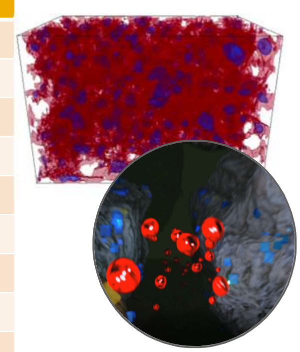
Requirements for CO_2 Digital Simulators

Requirements	SCAL	CO_2 SCAL
Fundamental laws of multiphase physics at pore scale	☑	☑
1, 2- and 3-phase flow	☑	☑
True geometry of rock with wide range of porosities	☑	☑
Fluids compositional model w/ phase transition	☑	☑
Multiscale “nested” imaging and upscaling	☑	☑
3D mineralogy / rock surface properties: adsorption / absorption / wettability	☑	☑
Tight rock transport and nanoscale physics	☑	☑
Chemical reactions		☑
Solid transport incl. phase transition dissolution/precipitation		☑
Geomechanics in elastic region		☑
History match to physical exp. (if present)	☑	☑



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Conclusion

Webinars

- No two CCUS projects are the same – as such suite of measurements
  - Lab is common denominator for risk and uncertainties
- Industry is searching for optimal solutions
  - Labs balance and innovate
- Lab is unique tool to getting us ready for surprises
  - Enhancement through digital simulation
  - Right simulator is the only way

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Acknowledgments

- SLB Laboratories community
- SLB Reservoir Performance Experts
- Customers and partners

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