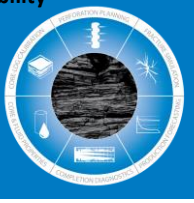
OVER 80 YEARS OF INNOVATION

CCUS in Aquifer Planning

Injectability….Confinability….Compatibility

Shreveport Geological Society
January 24 2023



1

First things first…..

- All injection wells must have cores
  - Rotary sidewalls or conventional core plugs
  - Percussion sidewalls not acceptable, but can still be useful in monitor wells
- Project must have at least 1 conventional core
- No set distance between injection wells and monitoring wells
  - All wells must correlate
- Upstream is downstream and downstream is upstream
  - The reservoir is downstream….
- EPA/LDNR reservoir simulator is your daddy…
  - You can apply with 1 plug, but……
- State primacy ~Q1 2023

2

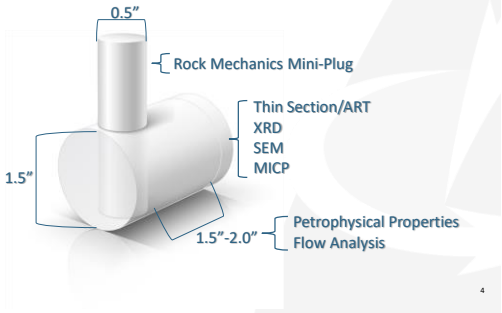
2

Background

Geological Description	Identify Lithologies; intelligent sampling ;calibrate geological interpretation for lateral extent
Petrophysical & Geomechanical	Calibration of reservoir geomechanical and petrophysical properties
Petrography	Calibration of petrophysical properties to thin sections (Thin Sections, XRD, SEM)
Reservoir Properties	Calibrate porosity, perm in representative lithologies
Special Core Analysis	Seal Capacity Evaluation; Reservoir Model evaluation for trapping and CO2 migration; Fluid Interaction and Injectivity evaluation

3

Plug Analysis



4

4

Early Reservoir Properties - DECT

What:

- Mineralogy, Porosity, Rock Strength

Why:

- Finer sampling density, so aids in measured data application for calibration of Petrophysical, Reservoir, Geomechanical, and Seismic Models

Key Points:

- Use of Dual Energy CT for guided sample selection – refinement of DECT with data for high resolution core data

5

Geological Description

Why:

- Identify lithologies
- Calibrate geological interpretation for lateral extent evaluation
- Intelligent sampling of representative lithologies
- Calibration of Petrophysical Models and SCAL Properties
- Identification and location of potential damaging mineralogy

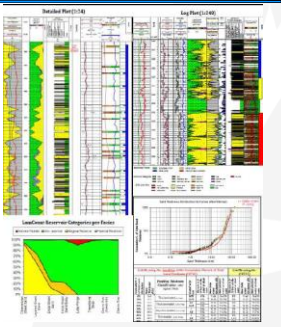
6

Core Description – LAMCount™

High Resolution Net-to-Gross Reservoir Evaluation

- Petrophysical and Facies Integration
- Depositional Model

The LamCount™ technique uses a hyper detailed core description to quantify net-to-gross to classify every potential lamina and bed as potential, marginal or non-reservoir units. The input data can be used for reservoir simulation and log modeling



7

Relative Perm

What:

- **Gas-Water RelK, with hysteresis**

Why:

- **Calibrate Reservoir Model**
- **Forecasting for CO_2 migration and trapping**
- **Formation Damage Potential – Injectivity Issues; Salt Deposition**

8

CO^2 Injectivity and Flow

- **Relative Permeability**
- **Clay Types**
- **Formation Damage**
  - Fluid Interactions
  - High Salinity
  - Injection rates etc

9

9

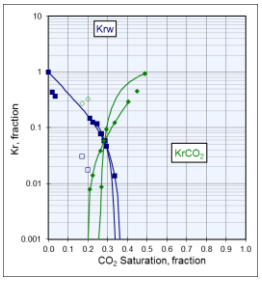
CO2-Water Relative Permeability

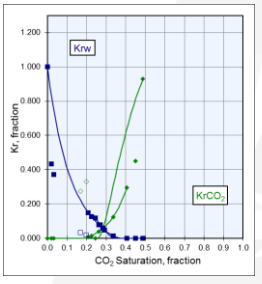
Sample Number	Sample Depth, feet	Permeability to Air, millidarcies	Porosity, fraction	Initial Conditions: Water Saturation, fraction pore space	Initial Conditions: Specific Permeability to Brine, millidarcies	Injection Rate, cm^3/min	Terminal Conditions: Water Saturation, fraction pore space	Terminal Conditions: Effective Permeability to CO_2, millidarcies	Terminal Conditions: Relative Permeability to CO_2*, fraction	Water Recovery, fraction pore space	Water Recovery, fraction water-in-place
Composite 1	10451.44 - 10452.38	189.	0.234	1.00	21.0	12.0	0.595	6.20	0.295	0.405	0.405
						24.0	**0.551**	**9.49**	**0.452**	**0.449**	**0.449**
						36.0	**0.513**	**19.5**	**0.929**	**0.487**	**0.487**
Composite 2	10466.62 - 10467.38	80.9	0.272	1.00	14.9	6.00	0.549	6.91	0.464	0.451	0.451
						12.0	**0.505**	**8.45**	**0.567**	**0.495**	**0.495**
						24.0	**0.497**	**17.0**	**1.14**	**0.503**	**0.503**

Sample Number	Sample Depth, feet	Permeability to Air, millidarcies	Porosity, fraction	Initial Conditions: Water Saturation, fraction pore space	Initial Conditions: Effective Permeability to CO_2, millidarcies	Injection Rate, cm^3/min	Terminal Conditions: CO_2 Saturation, fraction pore space	Terminal Conditions: Effective Permeability to Water, millidarcies	Terminal Conditions: Relative Permeability to Water*, fraction	CO_2 Recovery, fraction pore space	CO_2 Recovery, fraction CO_2-in-place
Composite 1	10451.44 - 10452.38	189.	0.234	0.513	19.5	6.00	0.246	2.46	0.117	0.241	0.495
						12.0	**0.033**	**7.79**	**0.371**	**0.454**	**0.932**
						24.0	**0.020**	**9.09**	**0.433**	**0.467**	**0.959**
Composite 2	10466.62 - 10467.38	80.9	0.272	0.497	17.0	6.00	0.298	0.606	0.0407	0.205	0.408
						12.0	**0.065**	**2.18**	**0.146**	**0.438**	**0.871**
						24.0	**0.035**	**3.46**	**0.232**	**0.468**	**0.930**

10

CO2-Water Relative Permeability



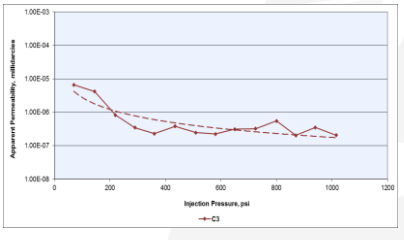


11

Threshold Entry Pressure

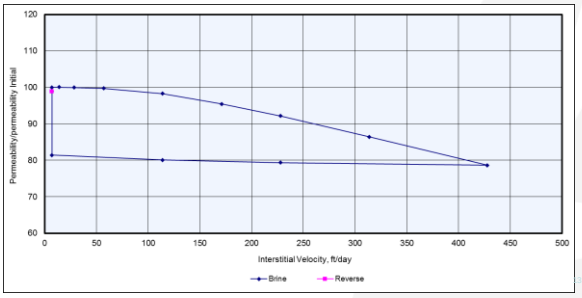
Days per Pressure	Sample C3: Gas Inj. Pressure, psi	Sample C3: Perm. to Water*, md
2	70	6.62E-06
2	145	4.17E-06
2	220	8.27E-07
3	290	3.47E-07
3	360	2.29E-07
3	435	3.83E-07
3	510	2.45E-07
3	580	2.23E-07
3	650	3.12E-07
3	725	3.22E-07
3	800	5.47E-07
3	870	2.03E-07
3	940	3.50E-07
3	1015	2.05E-07

The objective is to determine at what pressure the liquid permeability begins to increase



12

Critical Velocity



13

Confinability - Rock Mechanics

What:

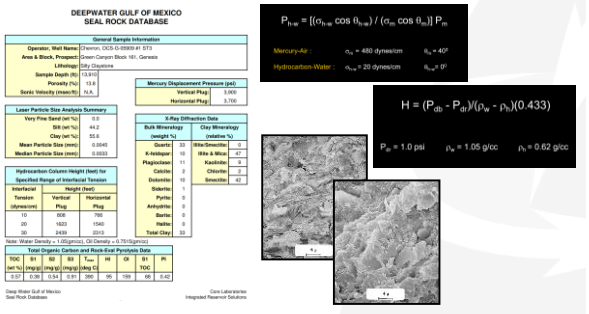
- Triaxial Tests; thermal expansion coefficient, Biot; Cohesion; Friction; dilation angle; compressibility – bore hole stability - injectivity

Why:

- Calibrate calculation of reservoir frac gradient and seismic model

14

Seal Evaluation



15

HPMI – Seal Capacity

Sample Number	Depth, ft	Swanson Permeability, md	Porosity, fraction	Mercury Sat'n at 55,000 psi, fraction	Approximate Threshold Pressure (Gas-Water), psi	Approximate gas column height, ft (pore entry)	Median Pore Throat Radius, µm
8m	8026.00	0.370	0.100	1.000	24.3	50.6	0.346
12m	8400.00	0.00011	0.069	0.642	596.6	1244.	0.0033
17m	11665.00	0.000040	0.070	0.558	417.6	871.	0.00223
18m	1167.00	0.000006	0.015	0.863	417.6	871.	0.00310

	Entry Pressure, psia	
System	Lab	Resv
A-Hg	125.4	-
G-W	24.3	16.9

SUMMARY OF CALCULATION PARAMETERS

Fluid System	(θ) Contact Angle	cosine Contact θ	(T) Interfacial Tension	T cosine θ
Laboratory				
Gas-water	0.0	1.00	72.0	72.0
Oil-water	30.0	0.866	48.0	41.6
Gas-oil	0.0	1.00	24.0	24.0
Air-mercury	140.	0.765	485.	372.
Reservoir[1]				
Oil-water	30.0	0.866	30.0	26.0
Gas-water	0.0	1.00	50.0	50.0

16

16

Rock Mechanics Testing

ASA-Plugging

- Non-destructive
- Plugging from every lithology type
- Unlimited sample shape and size
- Multiple plugs from same "source" rock
- No lubricants or coolants needed

Testing Capabilities:

- Axial Load: 1M lbf
- Confining Pressure: 30K psi
- Pore Pressure: 30K psi
- Testing Temperature: 300OF
- Miniplug - recommended for Shale/Carbonate/Tight Sand

17

Electrical Properties with Pc

What:

- FF/RI with Pc

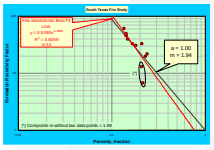
Why:

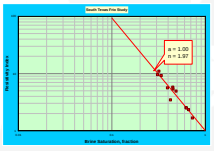
- Calibrate Capillary and Electrical Properties for calibration of reservoir model and log analysis
- Future Case-hole logging comparison to understand "current" water saturation

18

Electrical Properties

- Considerations
  - Including assessment of excess conductivity from clay





19

Compatibility – Minerology, Formation Damage

Minerology, Geochem
- XRD, XRF, SEM

Completion Fluid Evaluation
- Scale and Corrosion Inhibitors, Surfactants, Clay Stabilizers and Acid Treatments

Critical Salinity
- Base fluids such as drilling muds & fracture fluids

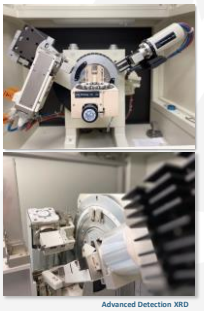
Critical Velocity
- Evaluate damage potential of formation waters at high velocity

20

20

X-ray Diffraction (XRD)

- Mineralogy and Composition Determined by XRD —
  - **Whole rock analysis** by powder diffraction
  - **Detailed clay analysis** (<4µm ESD) on oriented clays
  - Advanced digital detection system
  - Multiple mineral and crystal structure databases (ICDD, FIZ/NIST, in-house proprietary library, etc.)
  - Compositional analysis integrating additional analytical testing including Total Organic Carbon
  - Calculation of mineral volumes and derived XRD sample grain density as well as weight percent composition
  - Non-destructive test - allows for additional testing on the very same sample (e.g. X-ray fluorescence)
  - Clay analysis verified using comprehensive computer-simulated phyllosilicate database

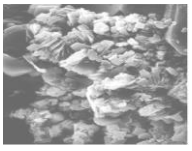


Advanced Detection XRD

21

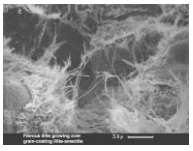
Common Clays

Kaolinite



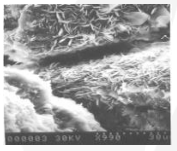
- Non-expanding
- Low cation exchange capacity
- Platelets or booklets
- May migrate

Illite



- Non-expanding
- Moderate to low cation exchange capacity
- Fibrous or thin irregular platelets
- May migrate
- May be susceptible to damage on drying in cores

Chlorite



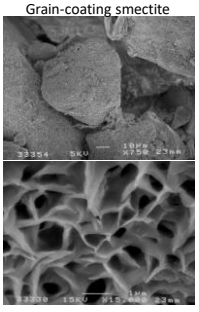
- Non-expanding
- Moderate cation exchange capacity
- Platelets or honeycomb aggregates
- May migrate
- Contact with HCl Acid releases iron (Iron Hydroxide)

22

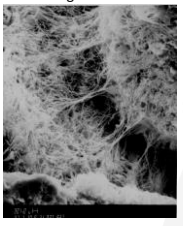
22

Scanning Electron Microscopy (SEM) + EDS

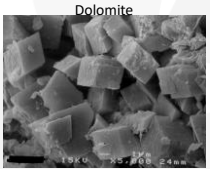
Grain-coating smectite



Authigenic illite



Dolomite



23

23

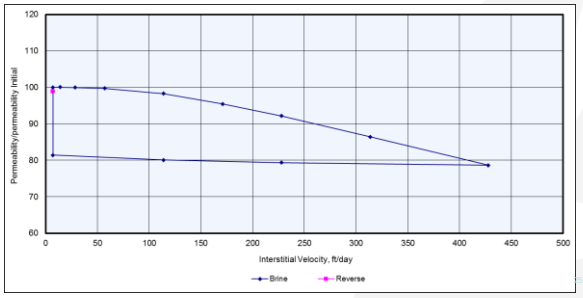
Permeability versus Throughput Testing

- **Permeability versus Throughput**
  - testing monitors specific or effective permeability to various fluids as a function of number of pore volumes injected through reservoir rock
- **Begins with a fluid that is considered non-damaging as a baseline permeability**
- **Next and subsequent fluids injected have permeability continuously monitored for 10-100 pore volumes to evaluate rock-fluid compatibility**
- **If a reduction in permeability is observed, permeability in the reverse flow direction is measured to investigate for mobile fines**
- **Regain Permeability is calculated as permeability divided by initial permeability**

24

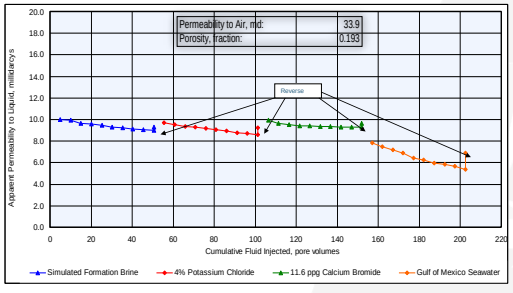
24

Critical Velocity



25

Brine-Formation Sensitivity Injection and/or Completion Fluids



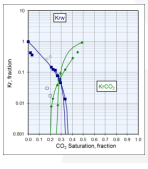
26

Summarizing…

Injectability – permeability, relative permeability, formation damage

Confinability – rock mechanics/seal evaluations, permeability

Compatibility – geochemistry/mineralogy, injection rates, fluid-fluid reactions, rock-fluid reactions, socio-economic-geological reactions…..



27

27

Thanks for having me
Questions?

28