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

Background

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

- Rock Mechanics Mini-Plug
- Thin Section/ART
- XRD
- SEM
- MICP

Petrophysical Properties

Flow Analysis

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

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
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.

Relative Perm

What:
• Gas-Water RelK, with hysteresis

Why:
• Calibrate Reservoir Model
• Forecasting for CO₂ migration and trapping
• Formation Damage Potential – Injectivity Issues; Salt Deposition

CO₂ Injectivity and Flow

- Relative Permeability
- Clay Types
- Formation Damage
  • Fluid Interactions
  • High Salinity
  • Injection rates etc
The objective is to determine at what pressure the liquid permeability begins to increase.

### Threshold Entry Pressure

<table>
<thead>
<tr>
<th>Sample</th>
<th>Days</th>
<th>Gas Inj.</th>
<th>Perm. per Pressure, to Water*</th>
<th>Pressure psi</th>
<th>md</th>
<th>CO2 Recovery to Water*</th>
<th>Rate fraction</th>
<th>Depth, number of feet</th>
<th>Permeability to Water*</th>
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Critical Velocity

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

Seal Evaluation
HPMI – Seal Capacity

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Depth, ft</th>
<th>Mercury Pore Volume, ft³/ft⁴</th>
<th>Porosity, %</th>
<th>Mercury STH at 50,460 psi, ft³/ft⁴</th>
<th>App Threshold Pressure</th>
<th>App Pore Pressure (first), psi</th>
<th>Median Pore Throat Radii, μm</th>
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<table>
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<th>Entry Pressure, psia</th>
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<tr>
<td>A-Hg 125.4 - G-W 24.3 16.9</td>
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</table>

**testing capabilities:***
- Axial Load: 1M lbf
- Confining Pressure: 30K psi
- Pore Pressure: 30K psi
- Testing Temperature: 300°F

**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

Rock Mechanics Testing

**testing capabilties:**
- Axial Load: 1M lbf
- Confining Pressure: 30K psi
- Pore Pressure: 30K psi
- Testing Temperature: 300°F
- Miniplug – recommended for Shale/Carbonate/Tight Sand

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
Electrical Properties

• Considerations
  • Including assessment of excess conductivity from clay

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

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
Common Clays

- Kaolinite
- Illite
- Chlorite

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

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

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

Scanning Electron Microscopy (SEM) + EDS

- Grain-coating smectite
- Authigenic illite
- Dolomite

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
Critical Velocity

Brine-Formation Sensitivity Injection and/or Completion Fluids

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...
Thanks for having me

Questions?