WORK PERFORMED UNDER AGREEMENT
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U. S. Department of Energy
National Energy Technology Laboratory

DOE/EPA Collaborative Review – Tracking Geologically-Sequestered CO2: Monitoring, Verification, & Accounting (MVA), Simulation, and Risk Assessment

Quantification of wellbore leakage risk using non-destructive borehole logging techniques

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Schlumberger

Outline

- Objectives
- Research Partners
- Background
- Tasks
- Summary

Co-Investigators

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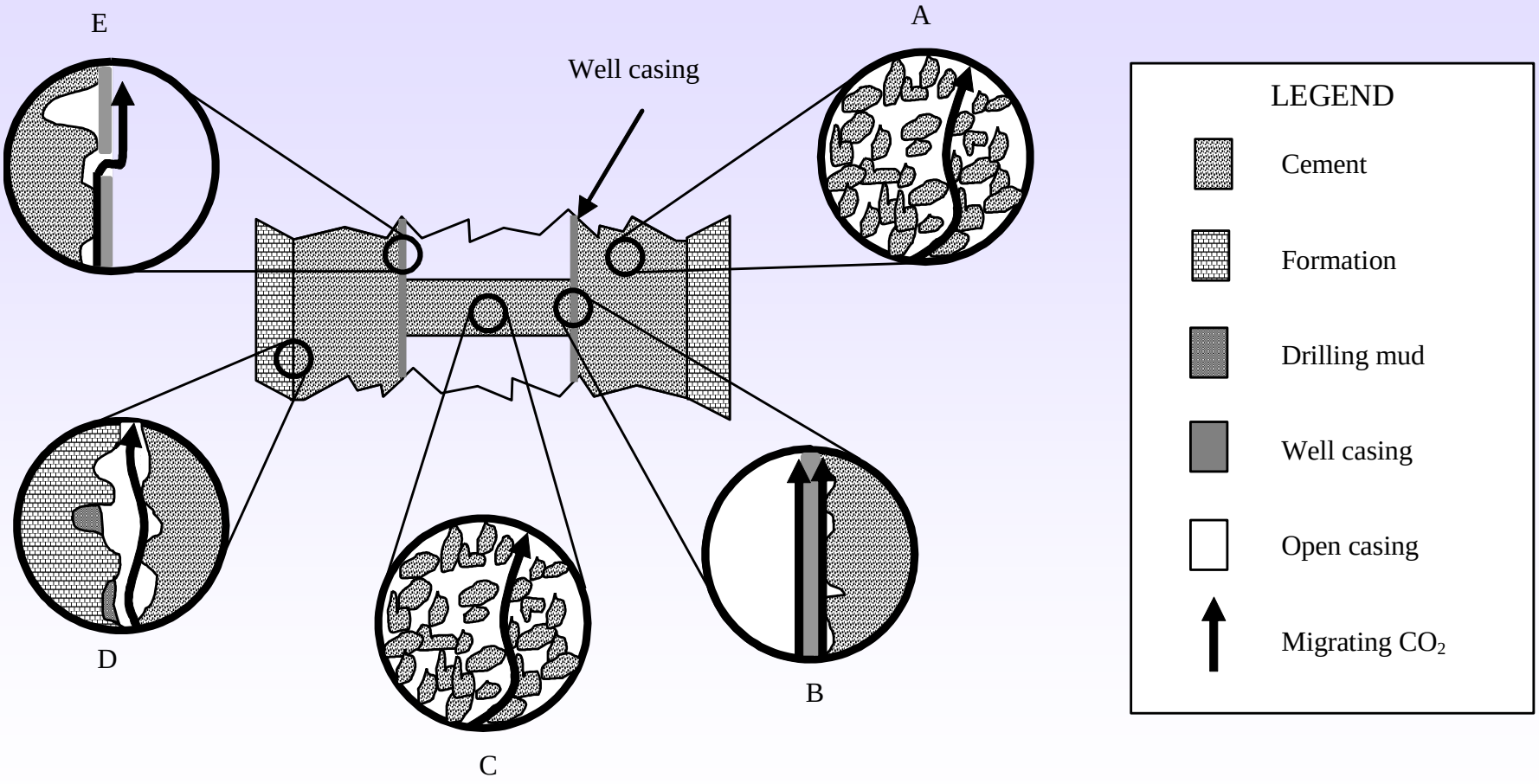
- Mike Celia
- Bill Carey

Objectives

- Develop methods to establish the average flow parameters (porosity and permeability or mobility) from individual measurements of the material properties and defects in a well.
- Develop a correlation between field flow-property data and cement logs that can be used to establish the flow-properties of well materials and well features using cement mapping tools.
- Establish a method that uses the flow-property model (Objective 2) to analyze the statistical uncertainties associated with individual well leakage that can provide basis for uncertainty in risk calculations.

Potential avenues for leakage



Background: Typical well cement composition

- Unhydrated

Phase	Percent
$3CaO \bullet SiO_2$	50
$2CaO \bullet SiO_2$	30
$3CaO \bullet Al_2O_3$	5
$4CaO \bullet Al_2O_3 \bullet Fe_3O_3$	12

- Hydrated

Phase	Abbreviation	Percent
$Ca_3Si_2O_7 \bullet 4H_2O$	C-S-H	50-70
$Ca(OH)_2$	CH	20-25
$3(3CaO \bullet Al_2O_3 \bullet CaSO_4 \bullet 12H_2O)$	AFm	10-15
$4CaO \bullet (Al,Fe_2O_3) \bullet 13H_2O$	AFt	

Data from Nelson, 1990

Background: Cement degradation reactions

- $Ca(OH)_2$ dissociation

  $Ca(OH)_2 \leftrightarrow Ca^{2+} + 2OH^-$

- CO_2 dissociation

  $CO_2 + H_2O \leftrightarrow H_2CO_3^* \leftrightarrow H^+ + HCO_3^- \leftrightarrow 2H^+ + CO_3^{2-}$

- Cement dissolution

  $Ca(OH)_2(s) + 2H^+ + CO_3^{2-} \rightarrow CaCO_3(s) + 2H_2O$

  $Ca_3Si_2O_7H{\bullet}4H_2O(s) + 2H^+ + CO_3^{2-} \rightarrow CaCO_3(s) + SiO_xOH_x(s)$

  $Ca(OH)_2(s) + H^+ + HCO_3^- \rightarrow CaCO_3(s) + 2H_2O$

  $Ca_3Si_2O_7H{\bullet}4H_2O(s) + H^+ + HCO_3^- \rightarrow CaCO_3(s) + SiO_xOH_x(s)$

- Calcium carbonate dissolution

  $CO_2 + H_2O + CaCO_3(s) \leftrightarrow Ca^{2+} + 2HCO_3^-$

  $2H^+ + CaCO_3(s) \leftrightarrow CO_2 + Ca^{2+} + H_2O$

May open up new porosity

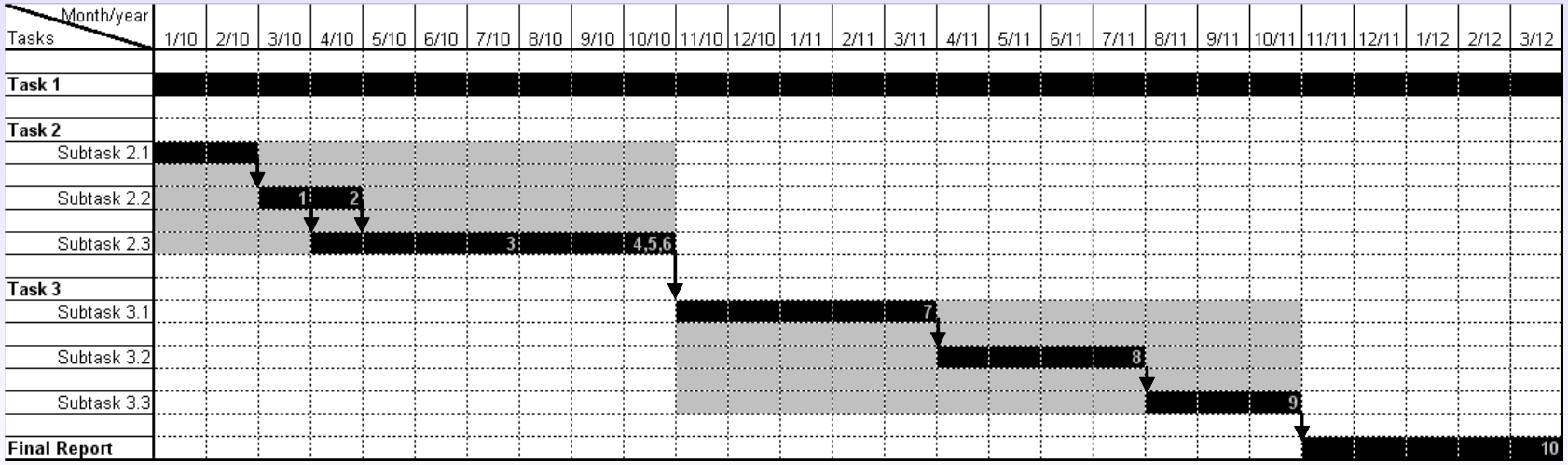
Precipitation of $CaCO_3$ blocks connected pores and reduces permeability

Opens pores blocked by $CaCO_3$ precipitation and additional porosity created by the dissolution of cement reaction products

Project Tasks

- Task 1 Project Management and Reporting
- Task 2 Data Collection and Analysis
- Task 3 Model Development

Timeline


Month/year
Tasks
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Task 1
Task 2
Subtask 2.1
Subtask 2.2
Subtask 2.3
Task 3
Subtask 3.1
Subtask 3.2
Subtask 3.3
Final Report
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3
4,5,6
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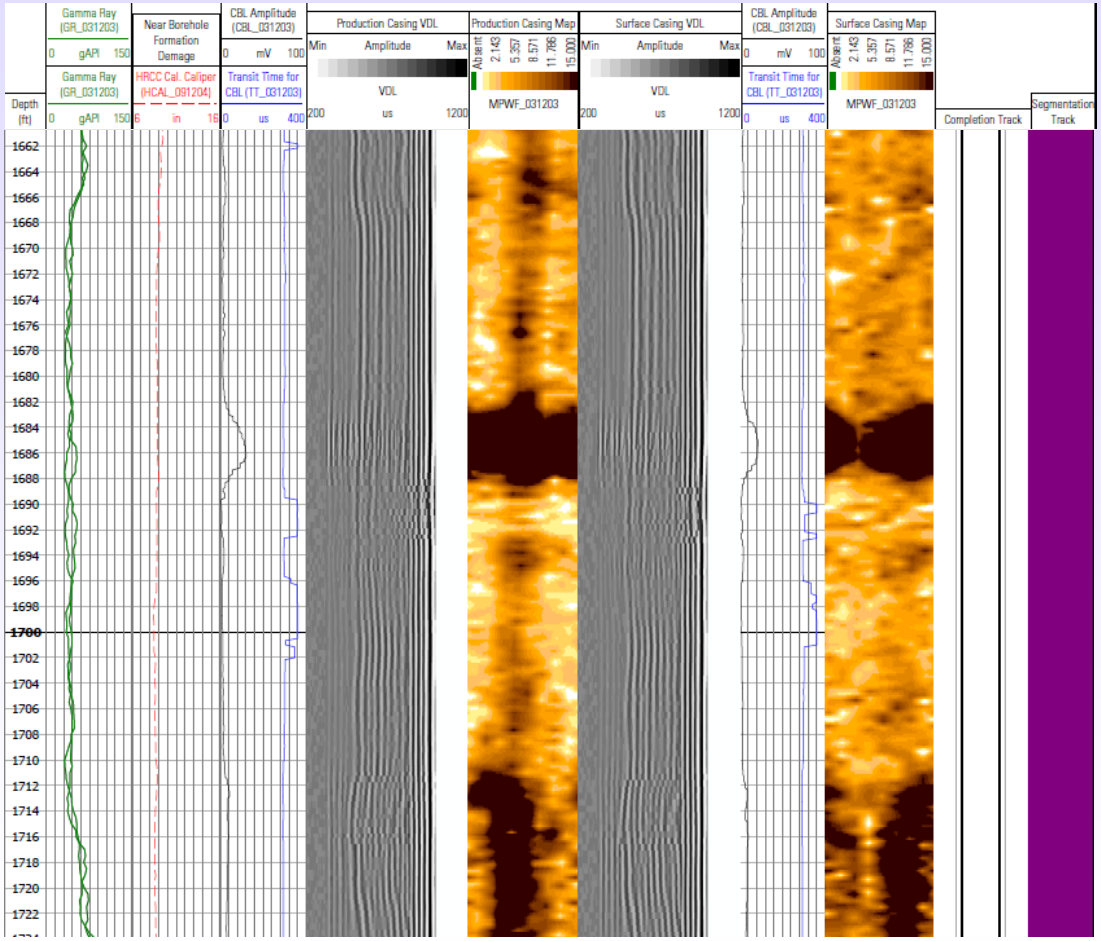
10

Task 2 Data Collection and Analysis

- Subtask 2.1 Final Well Selection
- Subtask 2.2 Data Collection and Characterization Effort
  - Industry Wells — Data Collection Completed
  - DOE Wells
- Subtask 2.3 Data Analysis

Existing data

- All three industry wells had existing open- and cased-hole Schlumberger logs



2.2 Data Collection

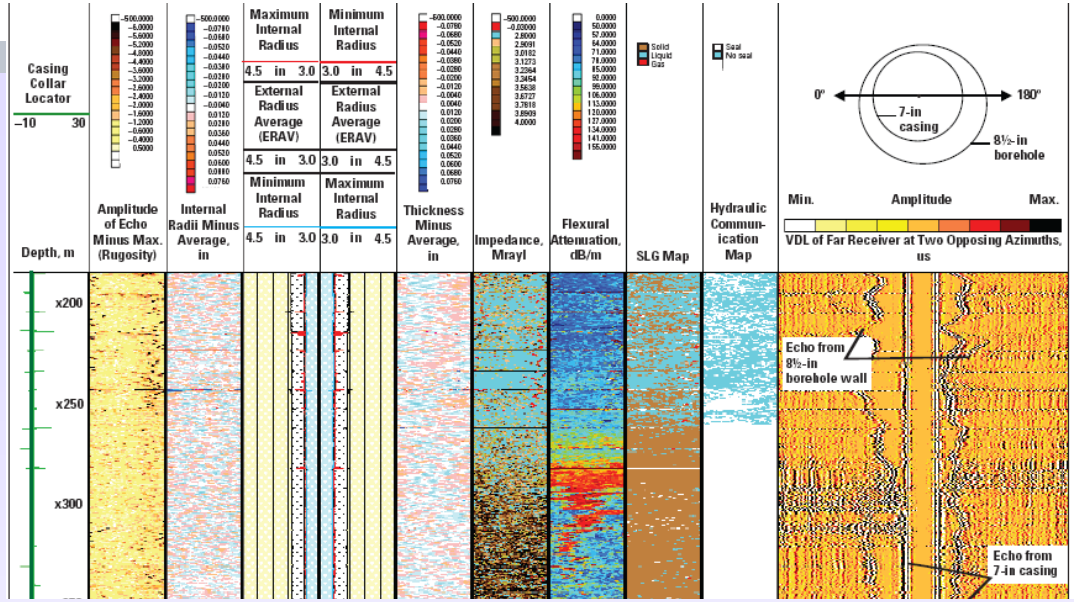
- Logging Tools
  - Isolation Scanner
  - Sonic Scanner
  - Slim Cement Mapping Tool (SCMT)
  - Cement Bond Tool (CBT)
  - Reservoir Saturation Tool (RST)-(Only if gas is detected in the testing zones)
- Testing and Sampling Tools
  - Cased-Hole Dynamics Tester (CHDT)
  - Modular formation Dynamics Tester (MDT)
  - Mechanical Sidewall Coring Tool (MSCT)

Logging and Sampling Plan

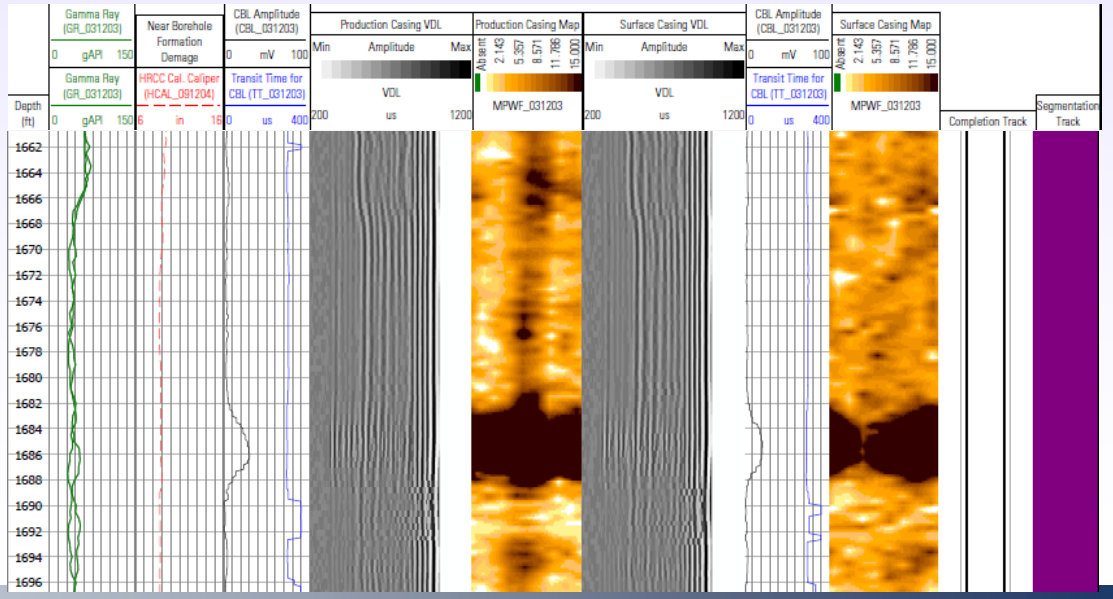
	Industry Wells			DOE Wells	
	Well 1	Well 2	Well 3	Well 1	Well 2
Completion Year	2002	2004	2004	1996	1985
Run 1	JB – Gauge – CCL	JB – Gauge – CCL	JB – Gauge – CCL	JB – Gauge – CCL	JB – Gauge – CCL
Run 2	SCMT-GR-CCL	SCMT-GR-CCL	SCMT-GR-CCL	CBT-GR-CCL	CBT-GR-CCL
Run 3	IBC-GR-CCL	IBC-GR-CCL	IBC-GR-CCL	IBC-GR-CCL	IBC-GR-CCL
Run 4	Sonic Scanner	CHDT	~~CHDT~~		
Run 5	~~Temp/Pressure/RST*~~			Temp/Pressure/RST*	CHDT
Run 6	CHDT			CHDT	
Run 7	Perf			Perf	
Run 8	MDT VIT			MDT VIT	
Run 9	MSCT 10 CH Cores			MSCT 10 CH Cores	
Run 10	IBC-GR-CCL			IBC-GR-CCL	

Cement logging

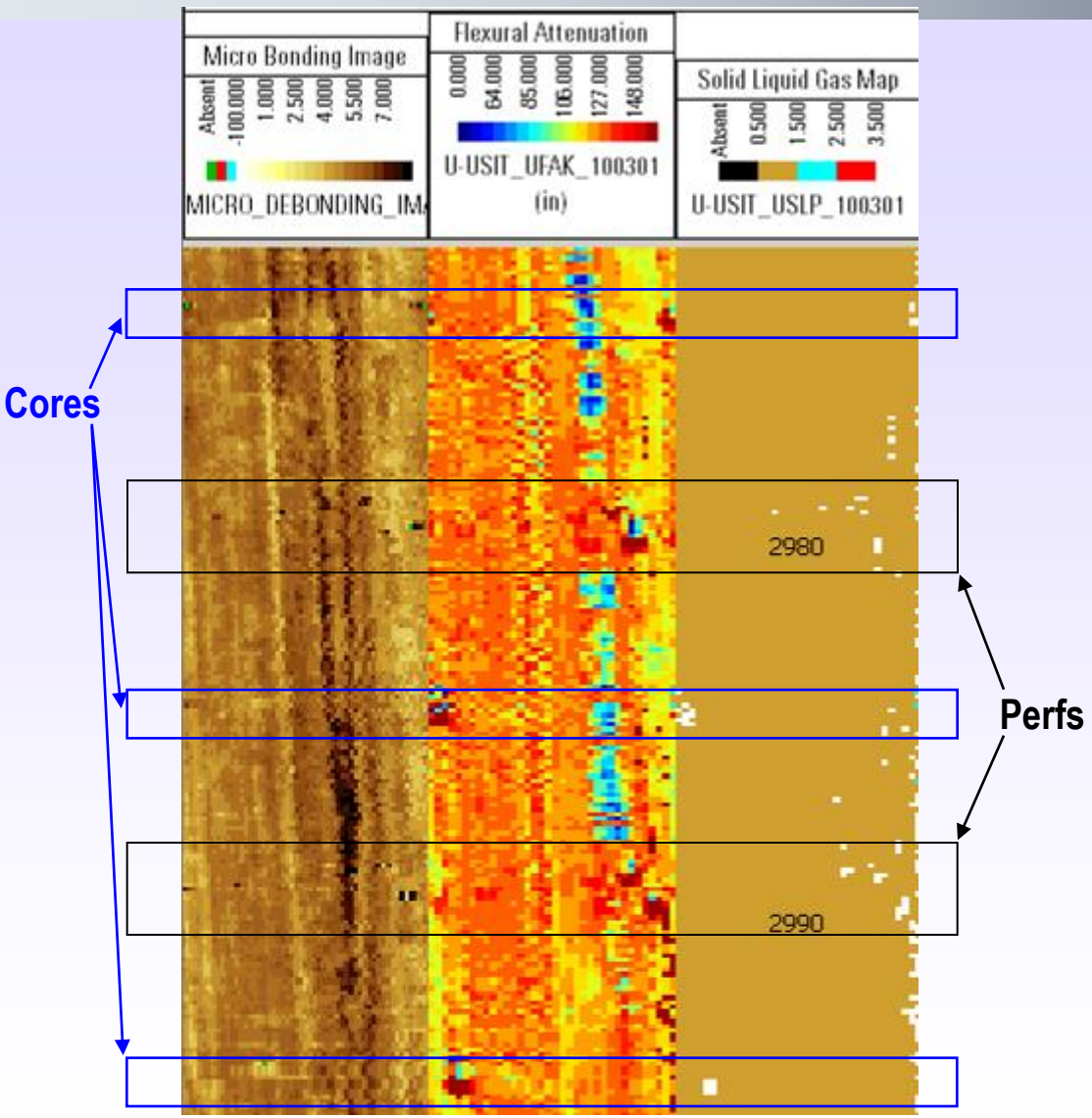
- Isolation Scanner

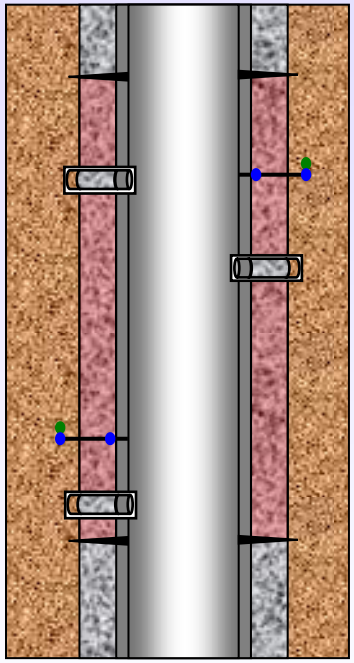


- SCMT/CBT



Well Sampling

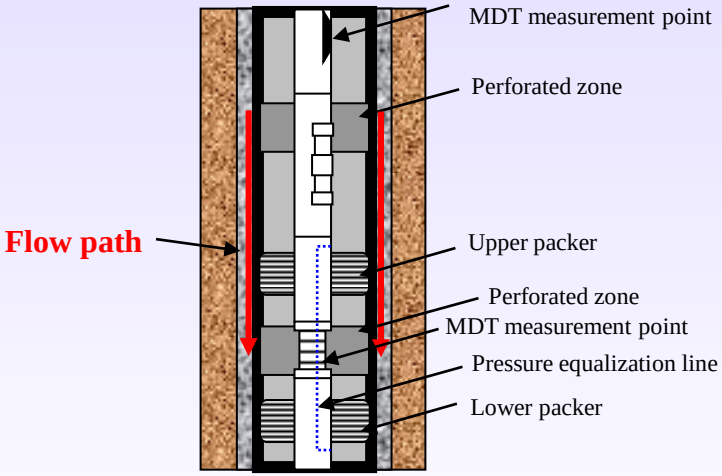


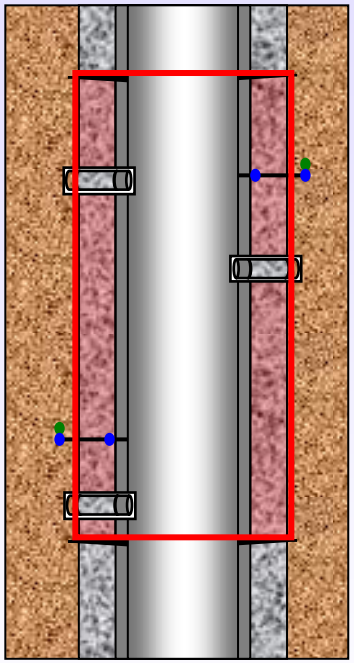


LEGEND

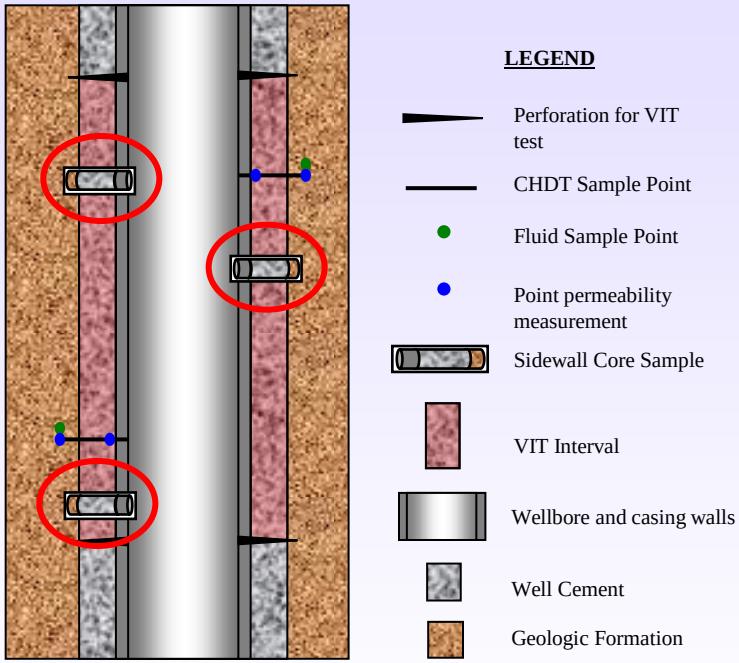
- Perforation for VIT test
- CHDT Sample Point
- Fluid Sample Point
- Point permeability measurement
- Sidewall Core Sample
- VIT Interval
- Wellbore and casing walls
- Well Cement
- Geologic Formation

Well Sampling-MDT

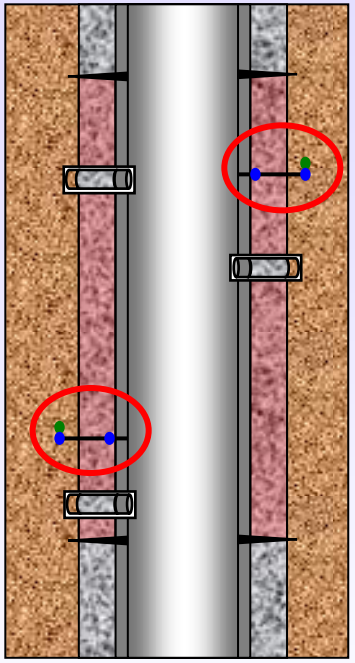


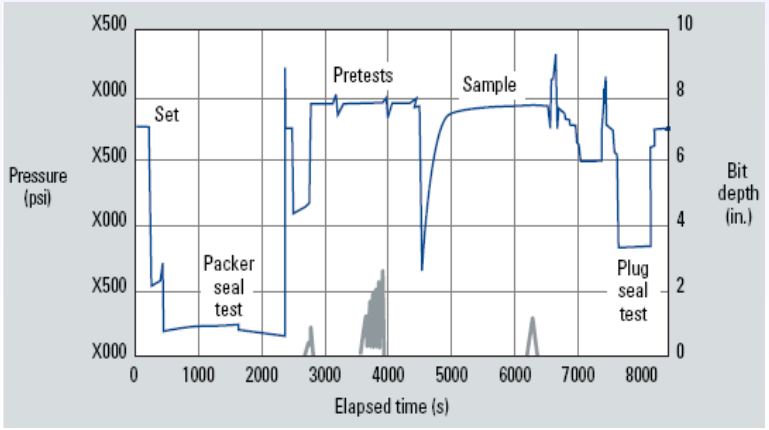


Well Sampling-MSCT



Well Sampling-CHDT





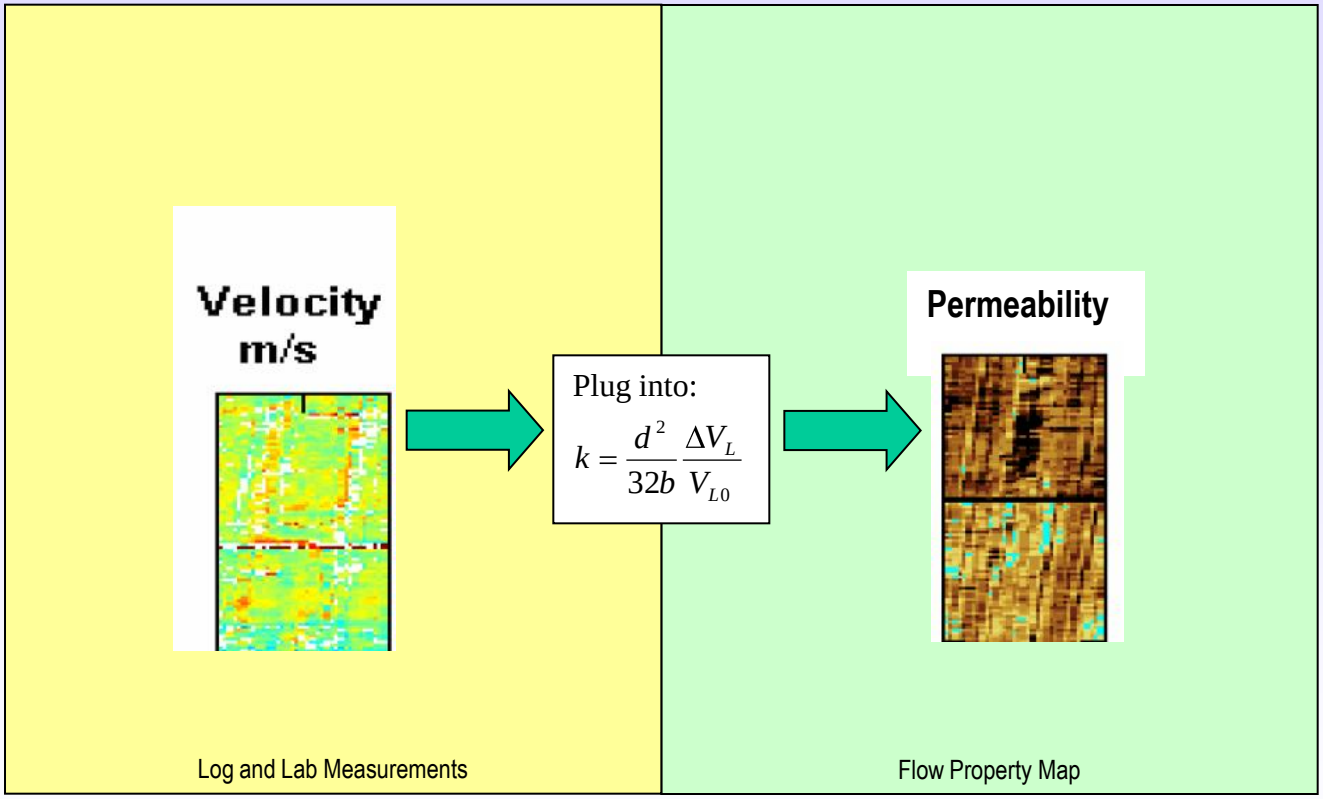
2.3 Expected Analysis

- QA/QC Isolation scanner logs, identify changes between 1st and 2nd run, create parameter maps (Z, flexural attenuation, radii, etc)
- QA/QC SCMT/CBT logs, identify changes between original logs and new logs
- VIT Analysis: Develop a model to estimate the average flow properties using the continuity equation for single phase compressible flow in a porous medium. The model will be used to fit the data and back out the average permeability.
- The CHDT mobility tests in the cement sheath will be analyzed by numerically fitting the data backing out the permeability using a novel process that is currently undergoing the US patent process.
- The CHDT fluid samples will be analyzed for at reservoir pressure and temperature. The fluid will be analysis consist of an extended water analysis and a live water pH measurement. The extended water analysis will provide the concentrations of the ionic constituents present in the fluid samples
- Sidewall Core Analysis: Porosity, Permeability, Young's Modulus, Poisson's Ratio, XRD, SEM, X-Ray Map, Optical Microscopy

Task 3 Model Development

- **Subtask 3.1 – Synthesis of relationships between flow parameter measurements**
  - Depend on the magnitudes of the values of the flow parameters and on the distribution of cement and defects within the well.
  - Possible that the measurements will correlate without the need for any sort of relationship, although this is unlikely. It is more likely that an averaging or scaling technique will be needed to relate the point estimates to the estimate of the average flow properties.
- **Subtask 3.2 – Correlation of flow parameter data with cement maps**
- **Subtask 3.2 – Analysis of measurement and model uncertainty and implications for incorporation into performance and risk models**
  - The data from the flow property maps will be used to create probability density functions (PDFs) of well permeability.
  - The permeability PDFs will be sampled in a Monte Carlo fashion to create a population of simple well leakage models that can be used to determine the probability of leakage by taking the ratio between leaky simulations and total simulations.

3.2 Create Flow Property Maps from Cement Maps



Summary

- This project expects to relate ultrasonic cement properties to flow properties, allowing the creation of flow property maps of primary well cement
- Sampling and testing techniques will be used to validate the flow property models
- The flow property models will be used to simulate and examine leakage probabilities and uncertainties in wells
- Will provide some information on the effect of brine on cements prior to CO_2 injection