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

FE0001040

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U.S. Department of Energy

National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Developing the Technologies and
Infrastructure for CCS

August 20-22, 2013

Partners

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- J. William Carey, Los Alamos National Lab,
- Mike Celia, Princeton University,
- Nikita Chugunov, Schlumberger-Doll Research,
- Sarah Gasda, Uni Research
- Susan Hovorka, University of Texas as Austin (GCCC, BEG)
- T.S. Ramakrishnan, Schlumberger-Doll Research,
- Vicki Stamp, True Oil Company
- James Wang, Princeton University

- Denbury Onshore
- Rocky Mountain Oilfield Testing Center

Presentation Outline

- Benefits to the program
- Project overview
- Summary
- Accomplishments
- Appendix

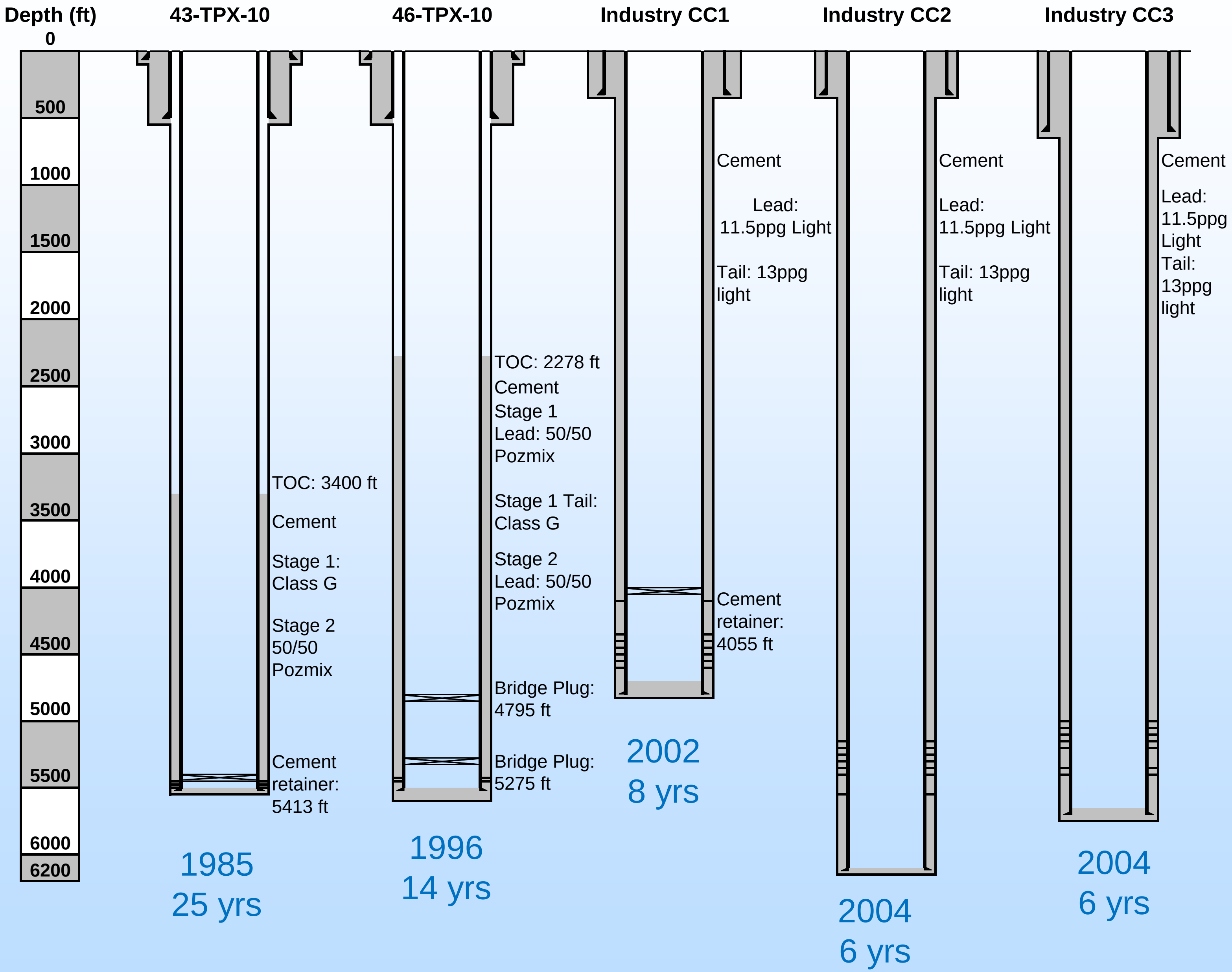
Benefit to the Program

- Develop and validate technologies to ensure 99 percent storage permanence.
  - This research project is developing methods to estimate the permeability of potential leakage pathways in a well between casing and the formation. This technology will provide an improved understanding of well leakage pathways and well leakage risk. This technology contributes to the Carbon Storage Program's effort of ensuring 99 percent CO_2 storage permanence (Goal).

Project Overview: Goals and Objectives

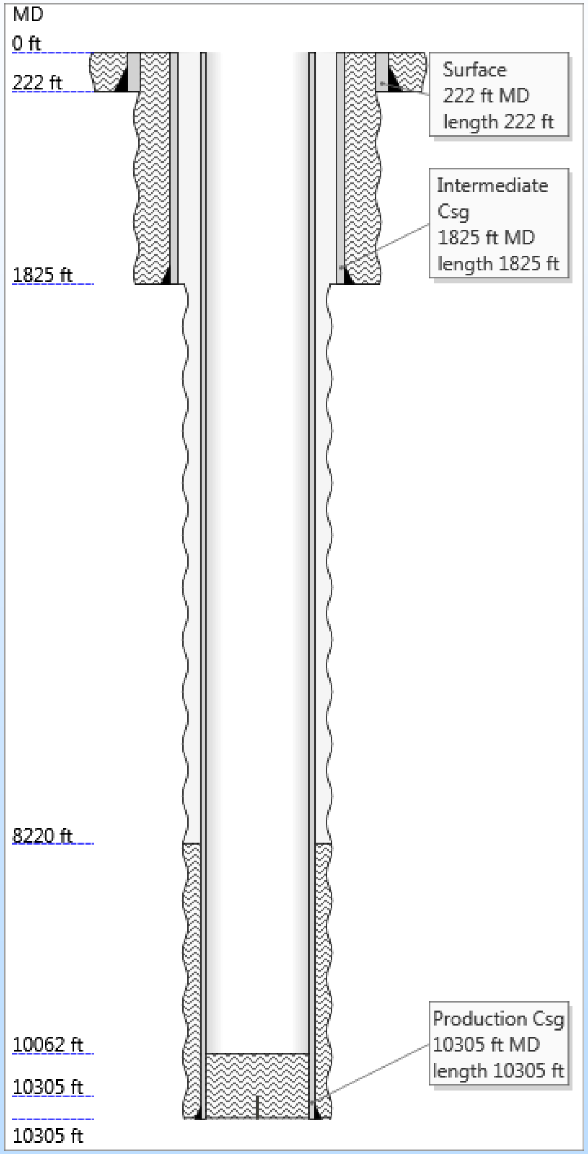
- Investigate methods to establish average flow parameters (porosity/permeability/mobility) from individual material properties measurements and defects in a well.
- Investigate correlation between field flow-property data and cement logs – used to establish flow-properties of well materials and well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

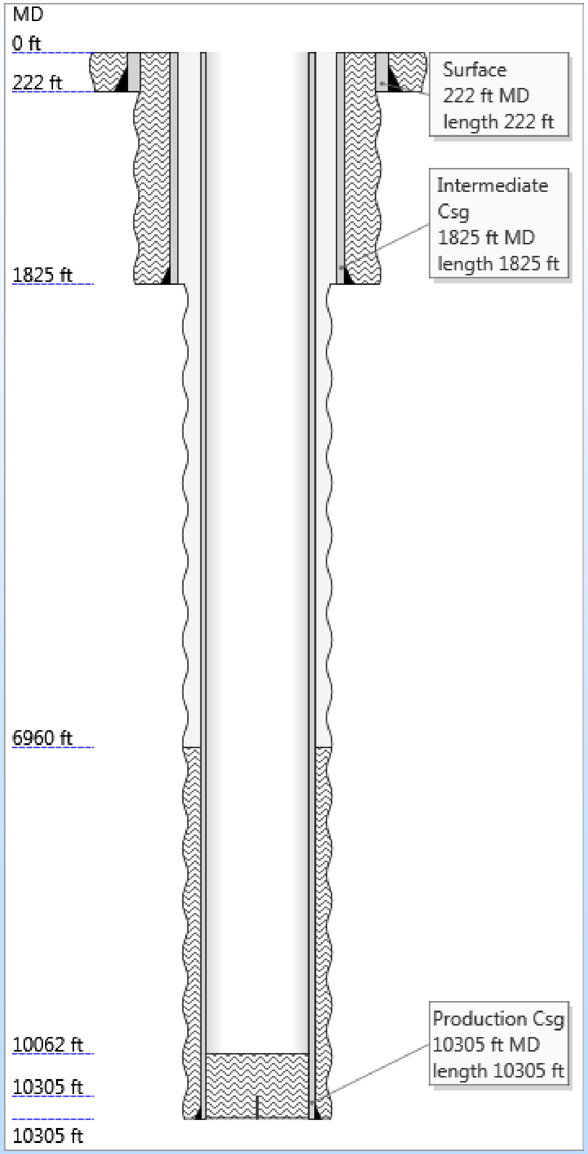
Project Wells (WY, 2010)



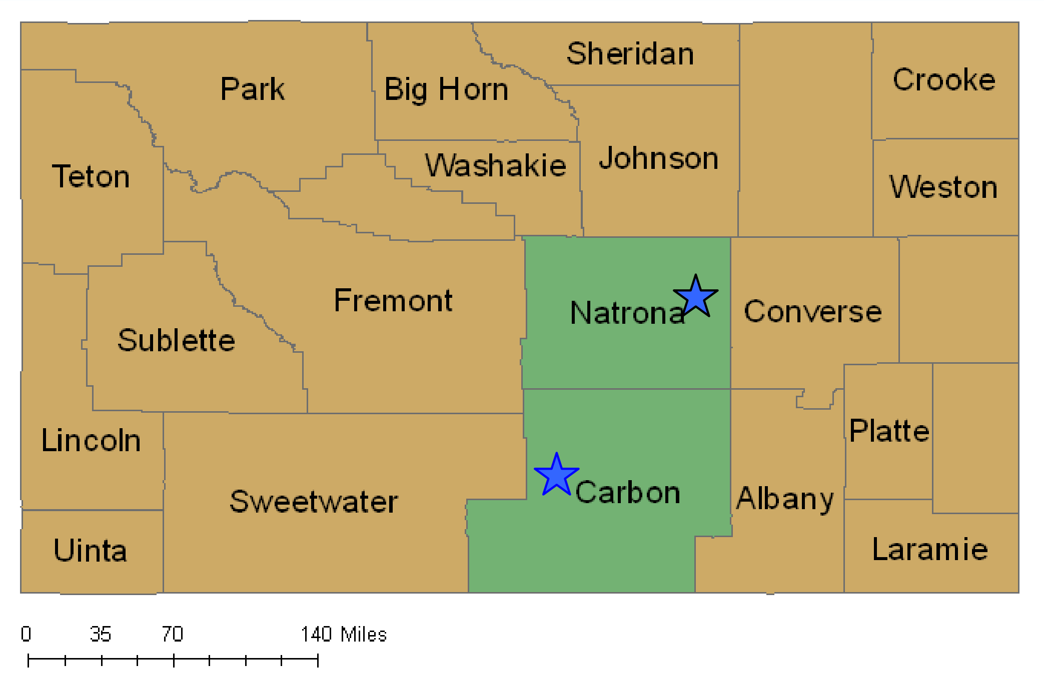
Project Wells (MS, 2013)

1945
68 yrs

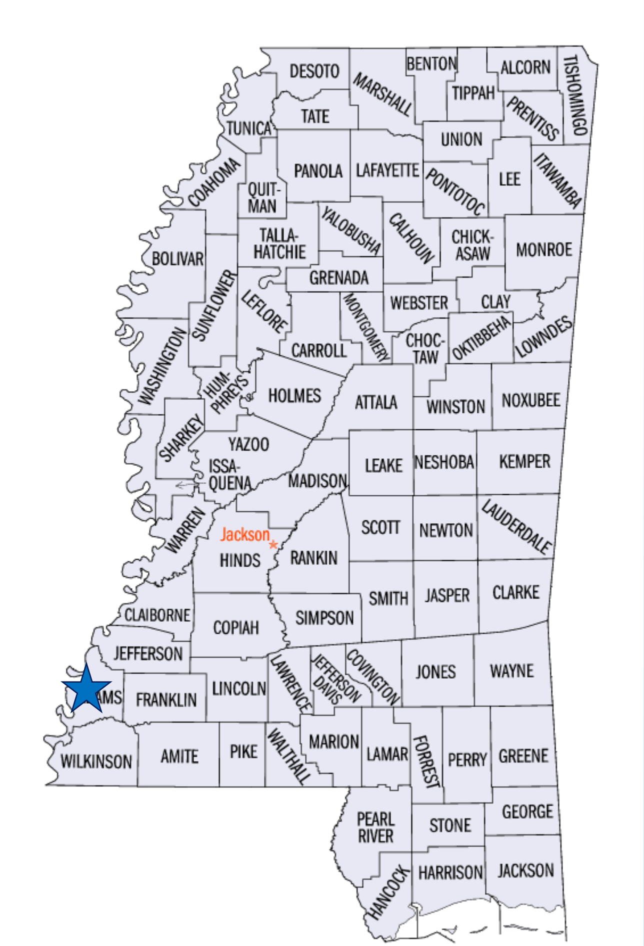




Well Sites



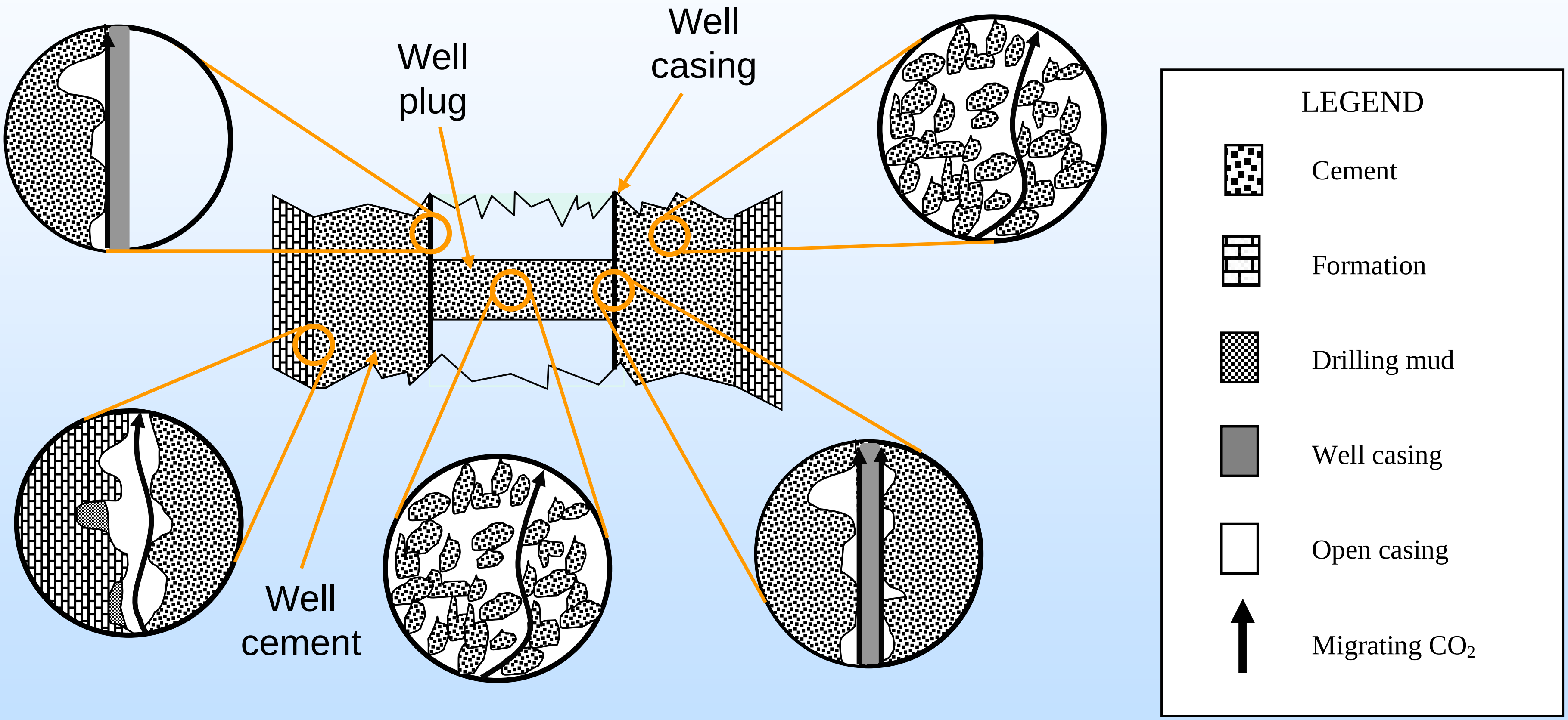
WY, 2010



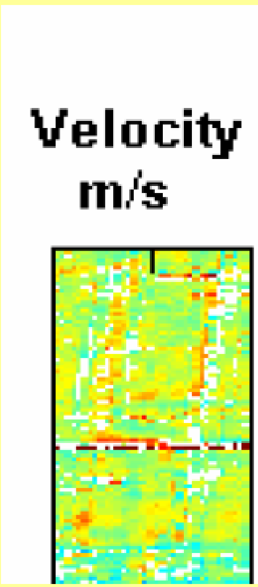
Adapted from quickfacts.census.gov

MS, 2013

Potential Avenues for Leakage



Create Flow Property Maps from Cement Maps

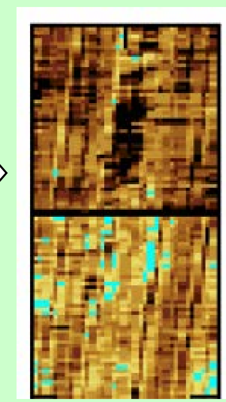


Plug into:

$$k = \frac{d^2}{32b}\frac{\Delta V_L}{V_{L0}}$$

$$p = \frac{1}{b}\left(1 - \frac{V_L}{V_{L0}}\right)$$

Permeability / Porosity



Log and Lab Measurements

Flow Property Map

$$b = 15\frac{1-\nu_0}{7-5\nu_0}$$

k=permeability

V_L=longitudinal acoustic velocity

d=capillary tube diameter

E=Young's Modulus

ν=Poisson's Ration

p =Porosity

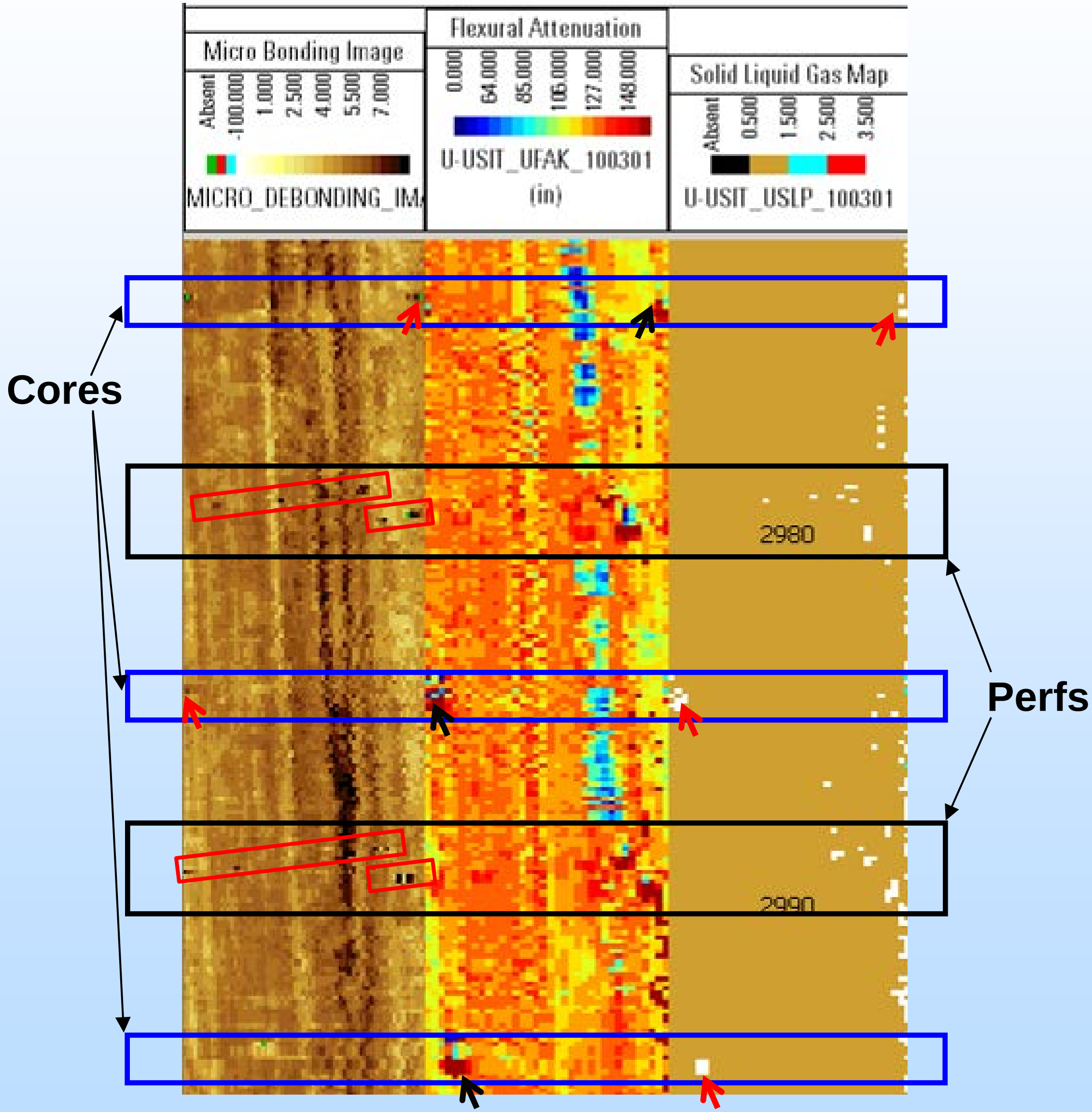
Note: the subscript 0 denotes 0-porosity cement

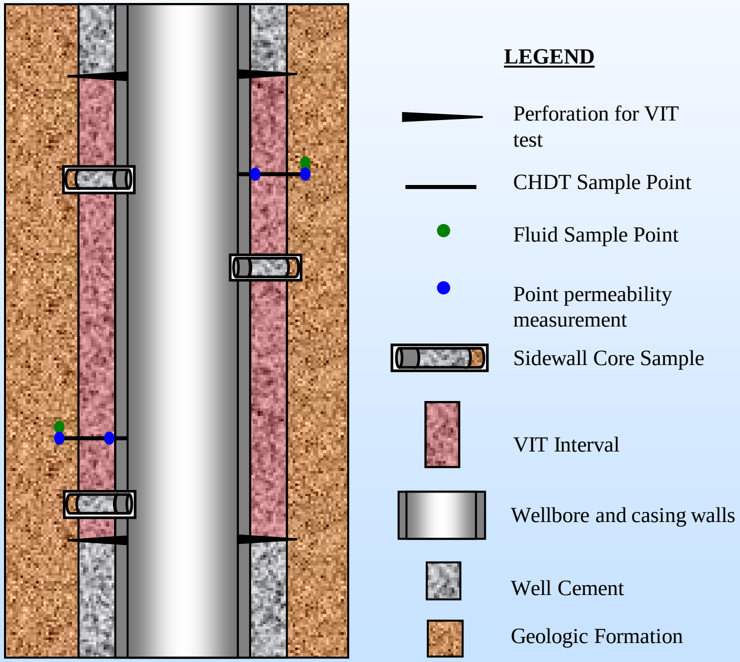
Data Collection

- <u>Logging Tools</u>
- Isolation Scanner* cement evaluation service
- SCMT* slim cement mapping tool

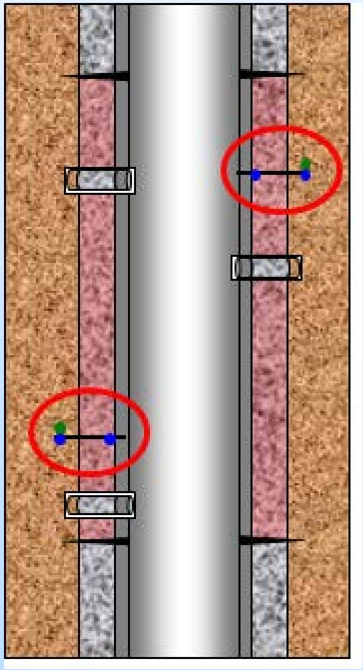
- <u>Testing and Sampling Tools</u>
- CHDT* cased hole dynamics tester
- MDT* modular formation dynamics tester
- MSCT* mechanical sidewall coring tool

Well Logging and Sampling

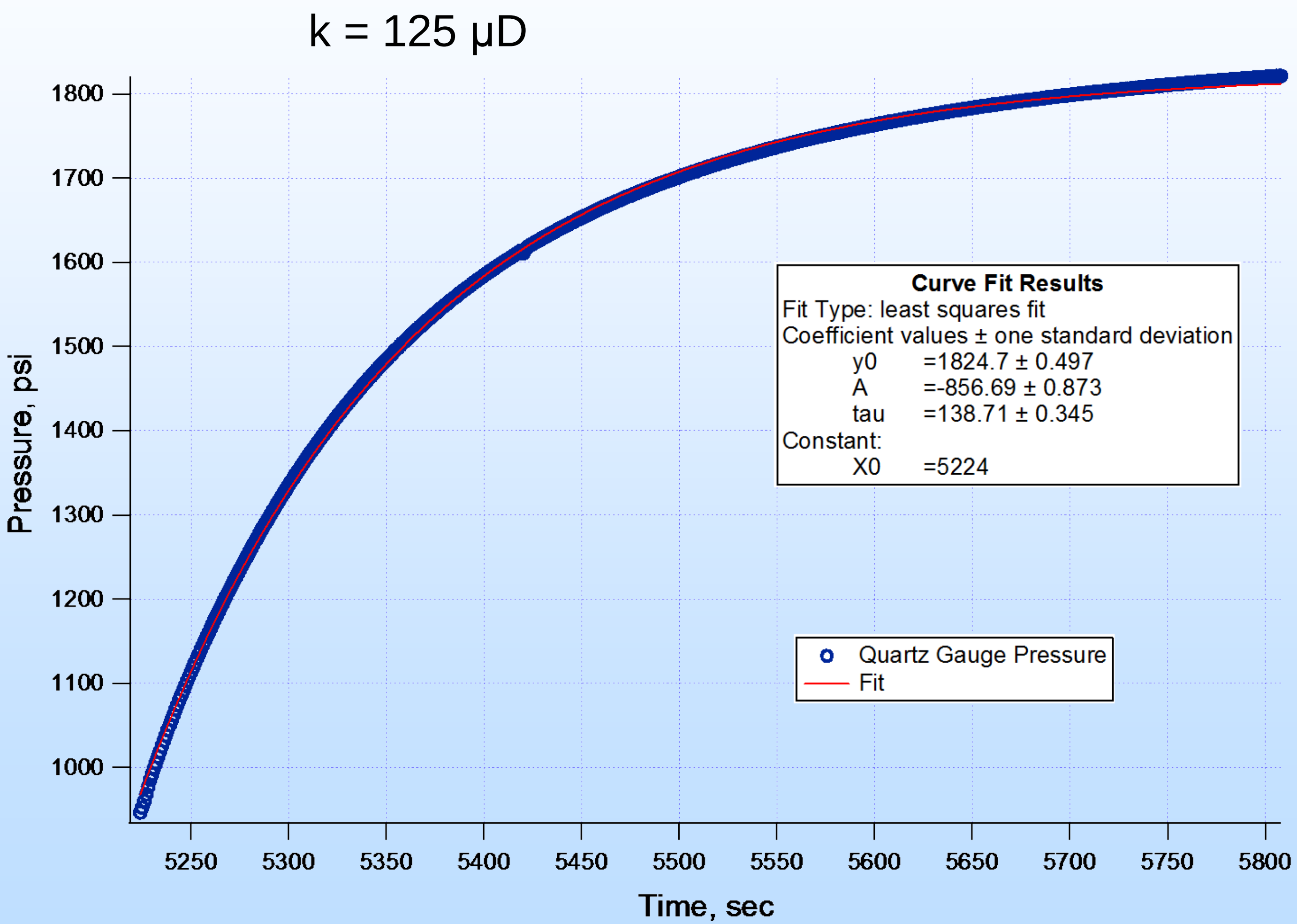




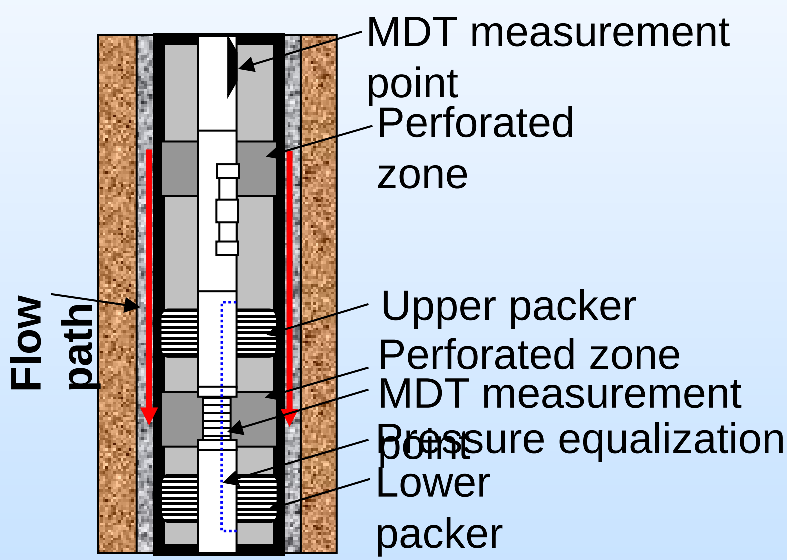
Well Sampling – CHDT

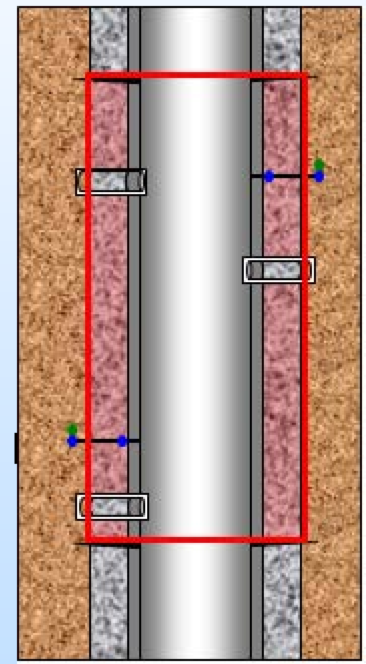


CHDT Analysis

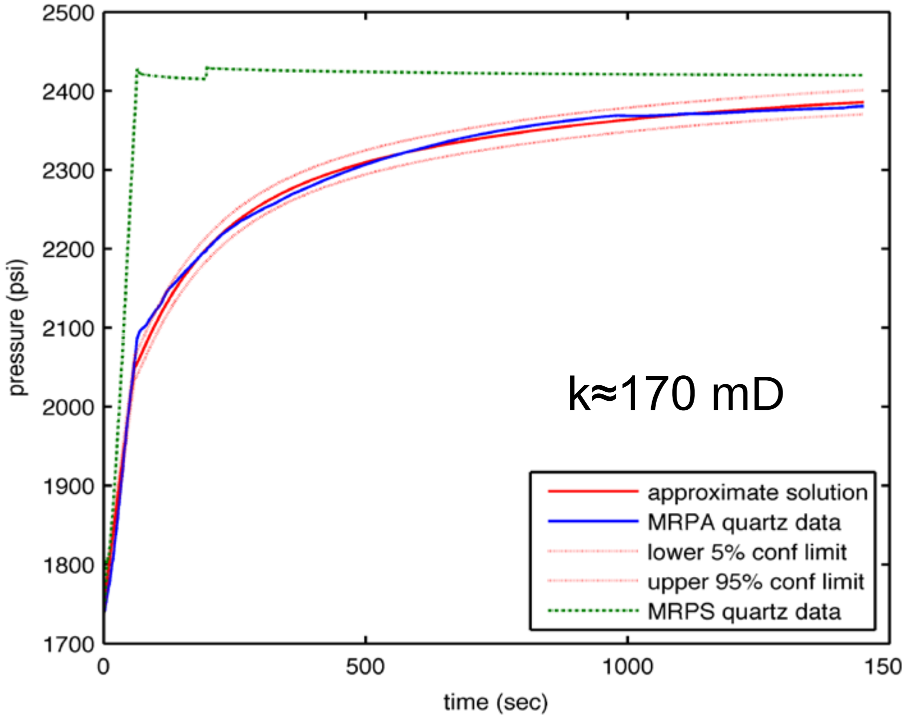


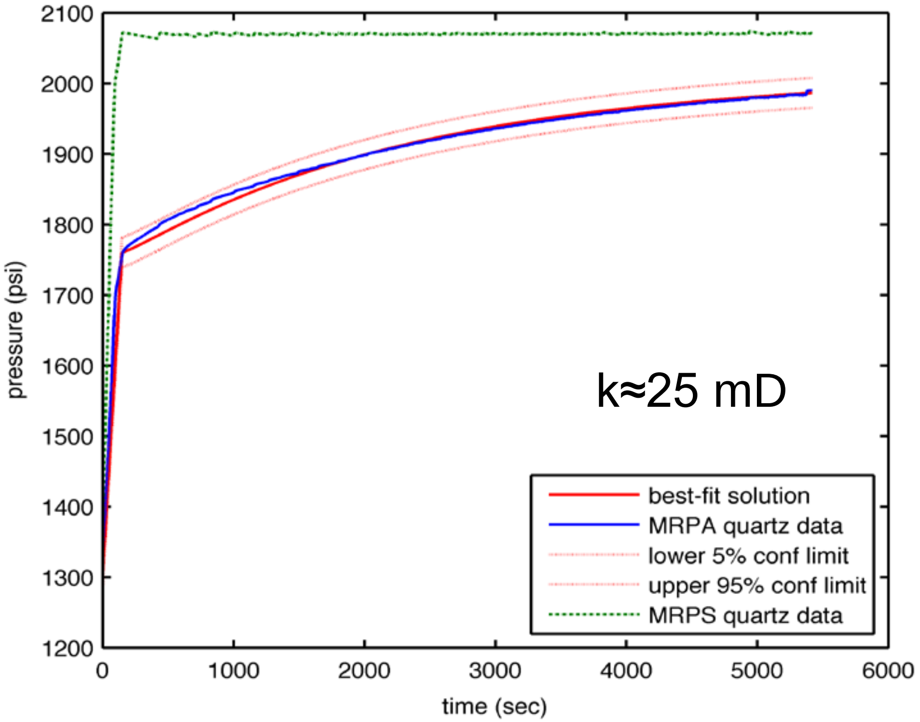
Well Testing – MDT





MDT VIT Model Results



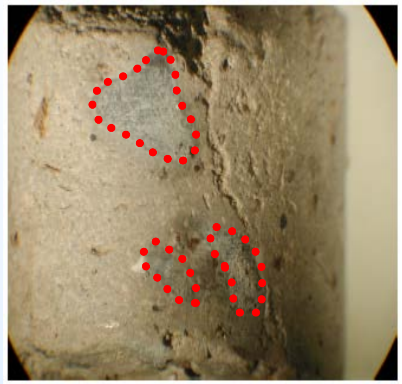


Best-fit model results to VIT data from the 46-TPX-10 (left) and CC1 (right) wells.

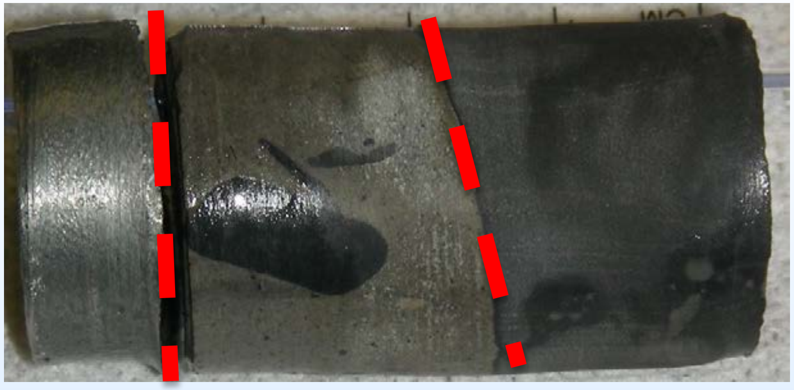
- Shown (in red) are the measured MRPA data in blue and the model results obtained from parameter estimation. The 95% confidence in the best-fit solution is bracketed by the dotted red lines.

Sidewall Cores

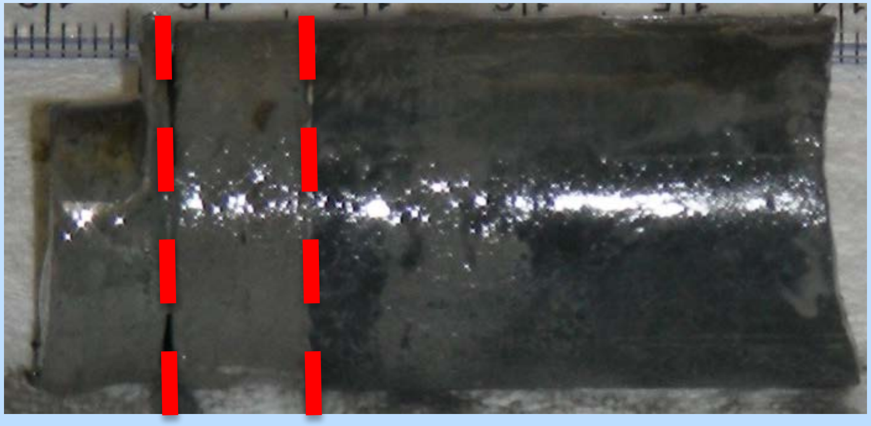
CC1 1111.9 m (3648 ft)



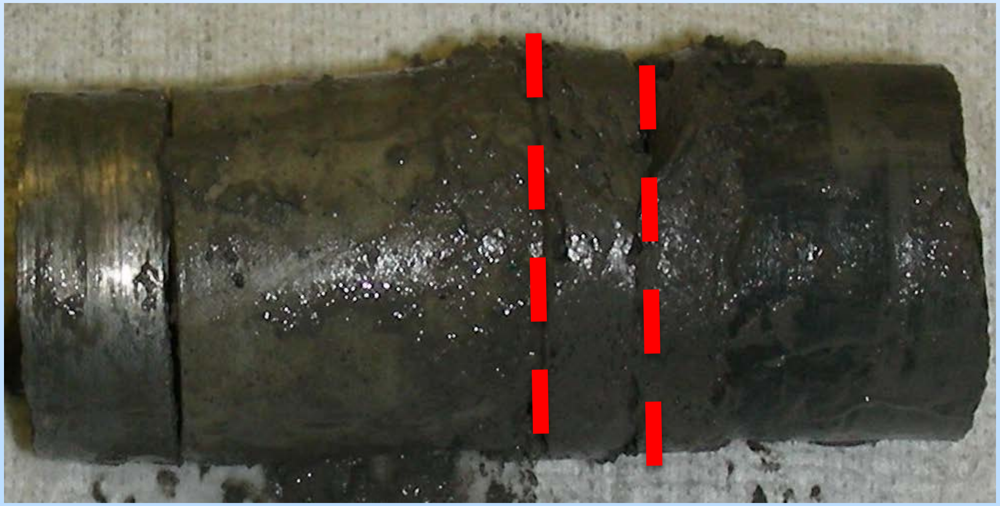
46-TPX-10 1223.8 m (4015 ft)



CC1 1051.6 m (3450 ft)

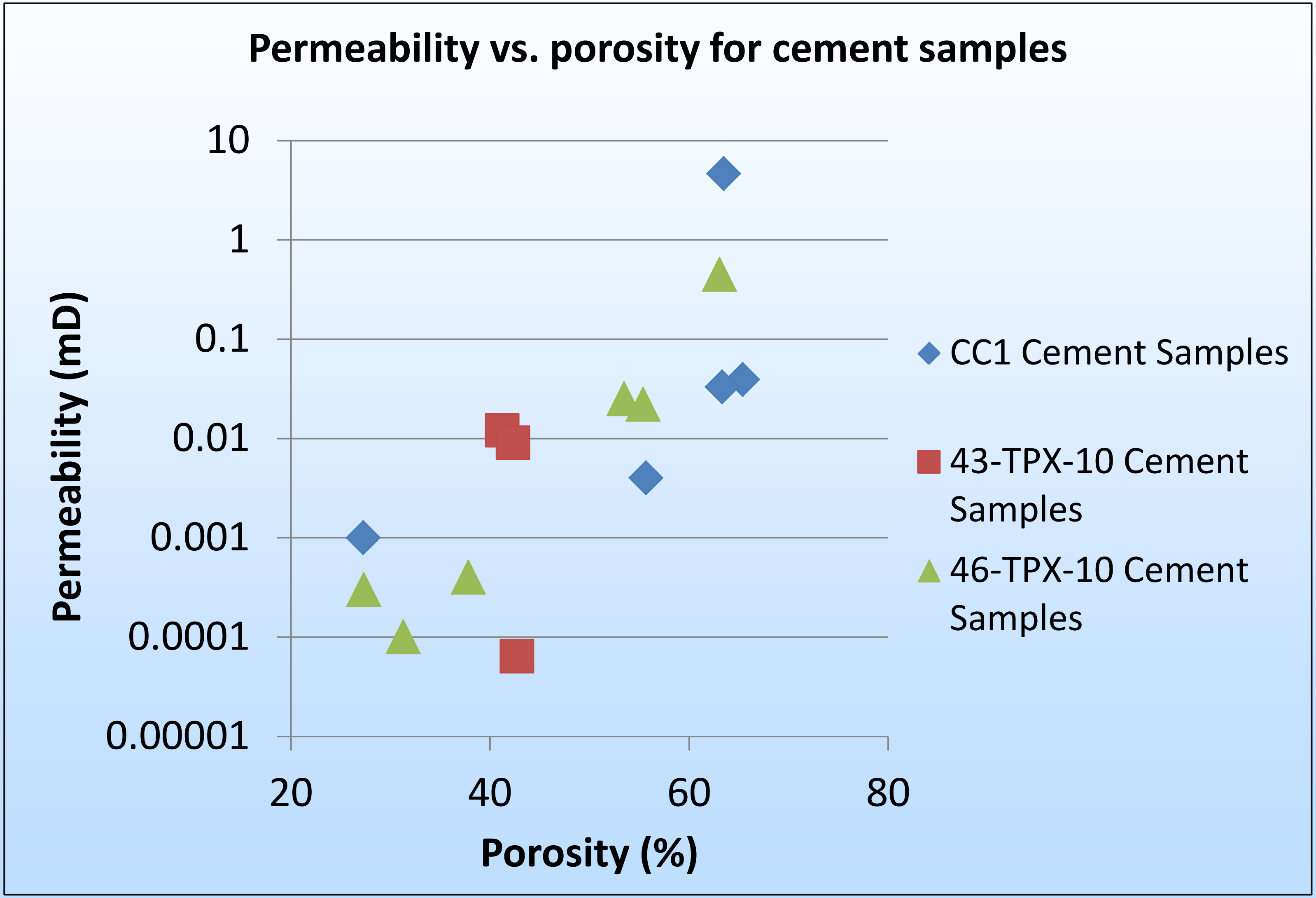


46-TPX-10 1220.7 m (4005 ft)

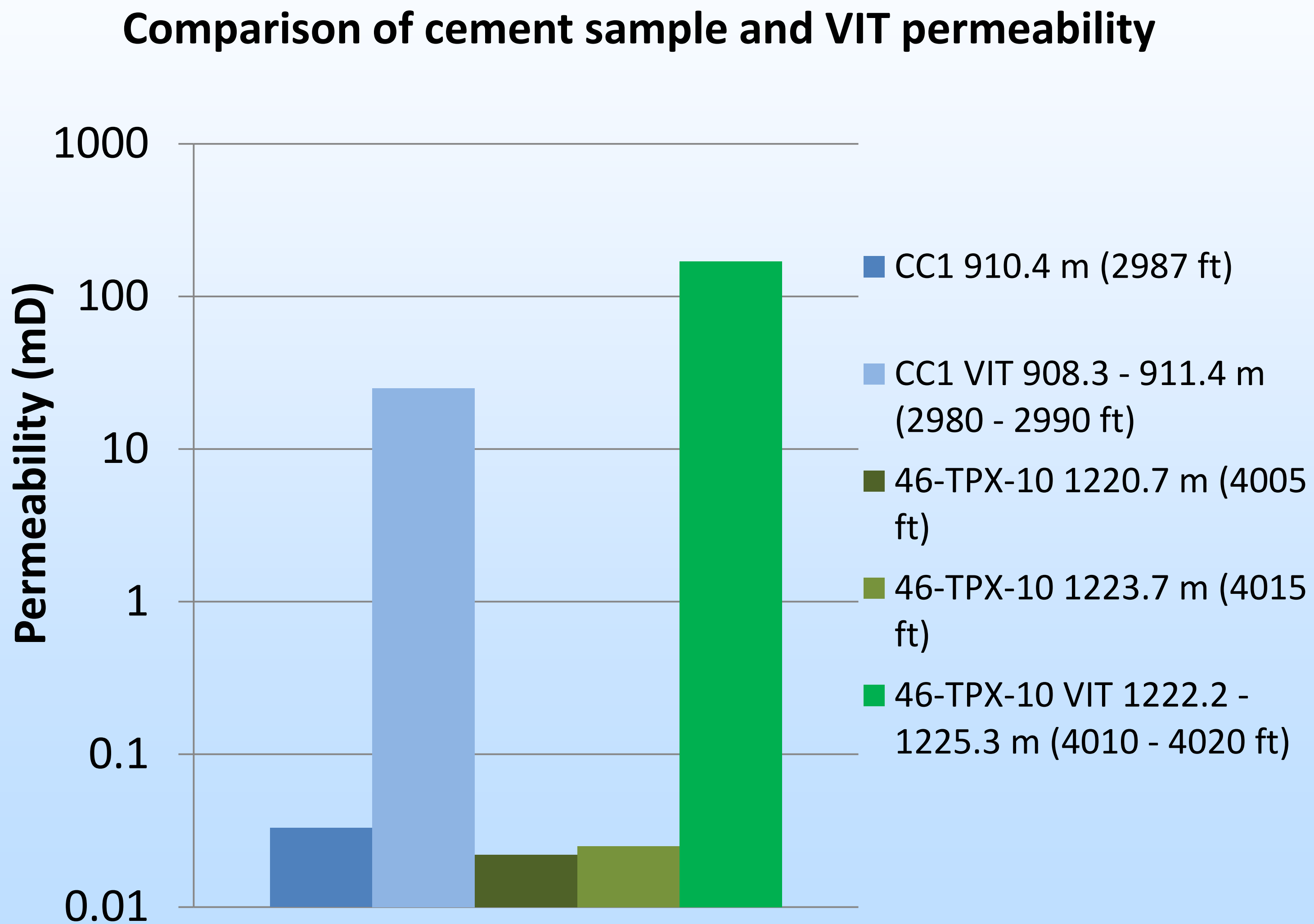


CC1 960. 1 m (3150 ft)

Permeability



Permeability



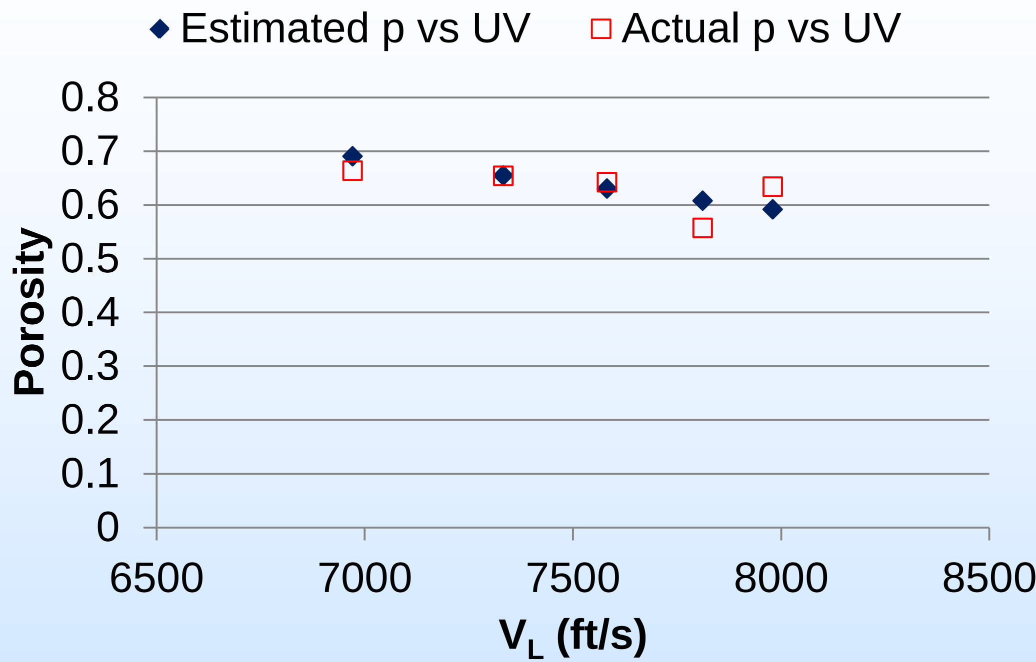
Lab Cements

TerraTek* rock mechanics and core analysis services

Well	Unique number	Sample Number	Pressure (psi)	Temperature (f)	W/C	Density (PPG)	Cement	Length (mm)	Diameter (mm)
Industry Well 1	9	IW1-14.9PPG-3	475	89	0.5	14.9	35/65	95.5	26
Industry Well 1	10	IW1-14.9PPG-2	475	89	0.5	14.9	35/65	92.5	26
Industry Well 1	11	IW1-13.65PPG-1	475	89	0.7	13.65	35/65	93.5	26
Industry Well 1	12	IW1-13.65PPG-2	475	89	0.7	13.65	35/65	98.5	26
Industry Well 1	13	IW1-12.8PPG-2	475	89	0.9	12.8	35/65	98	26
Industry Well 1	14	IW1-12.8PPG-3	475	89	0.9	12.8	35/65	92	26
Industry Well 1	15	IW1-12.18PPG-4	475	89	1.1	12.18	35/65	89	26
Industry Well 1	16	IW1-12.18PPG-2	475	89	1.1	12.18	35/65	91	26

CC1 Field Porosity Data and Estimates

$$p = \frac{1}{b}\left(1 - \frac{V_L}{V_{L0}}\right)$$

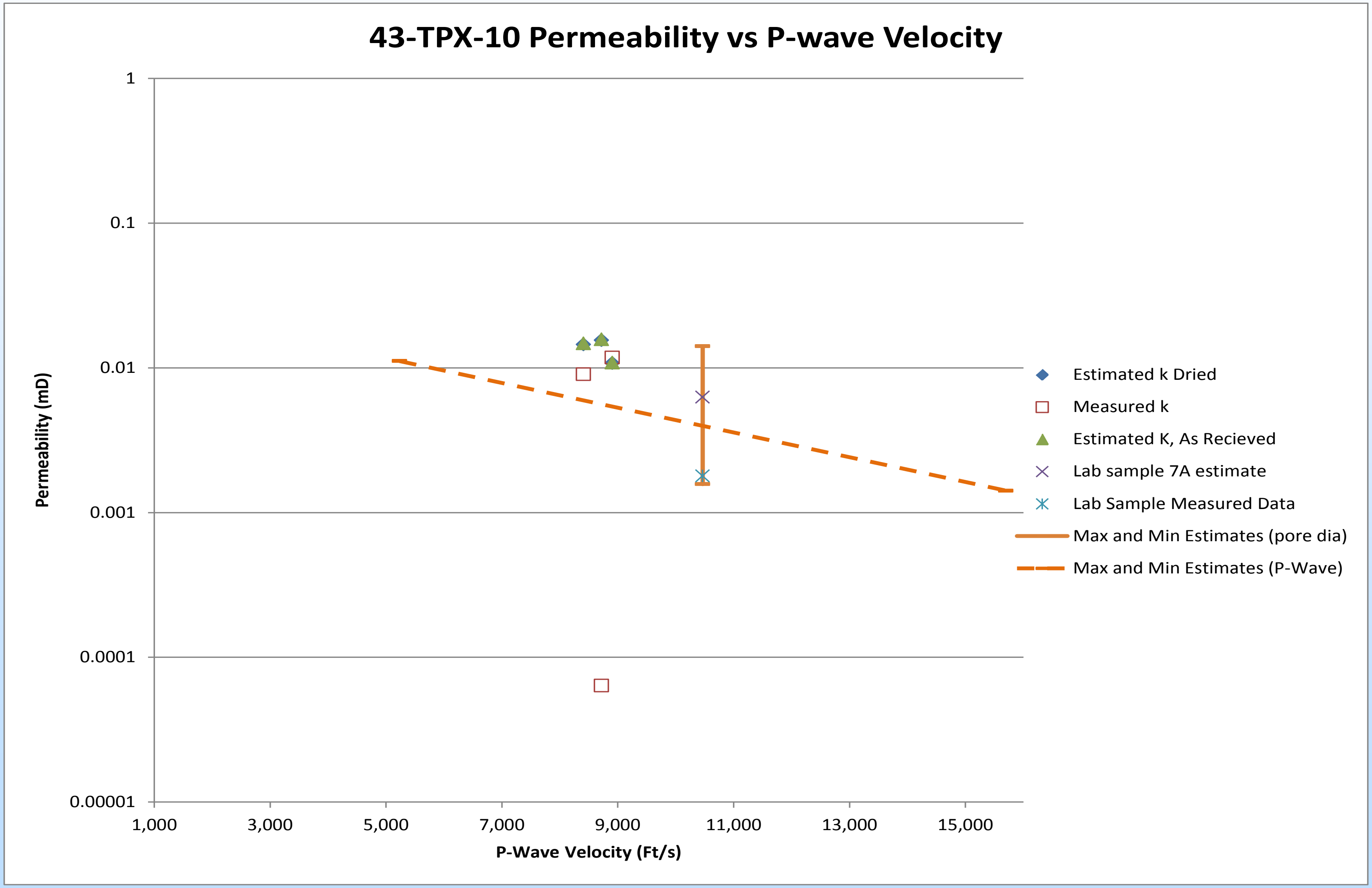


Dried samples

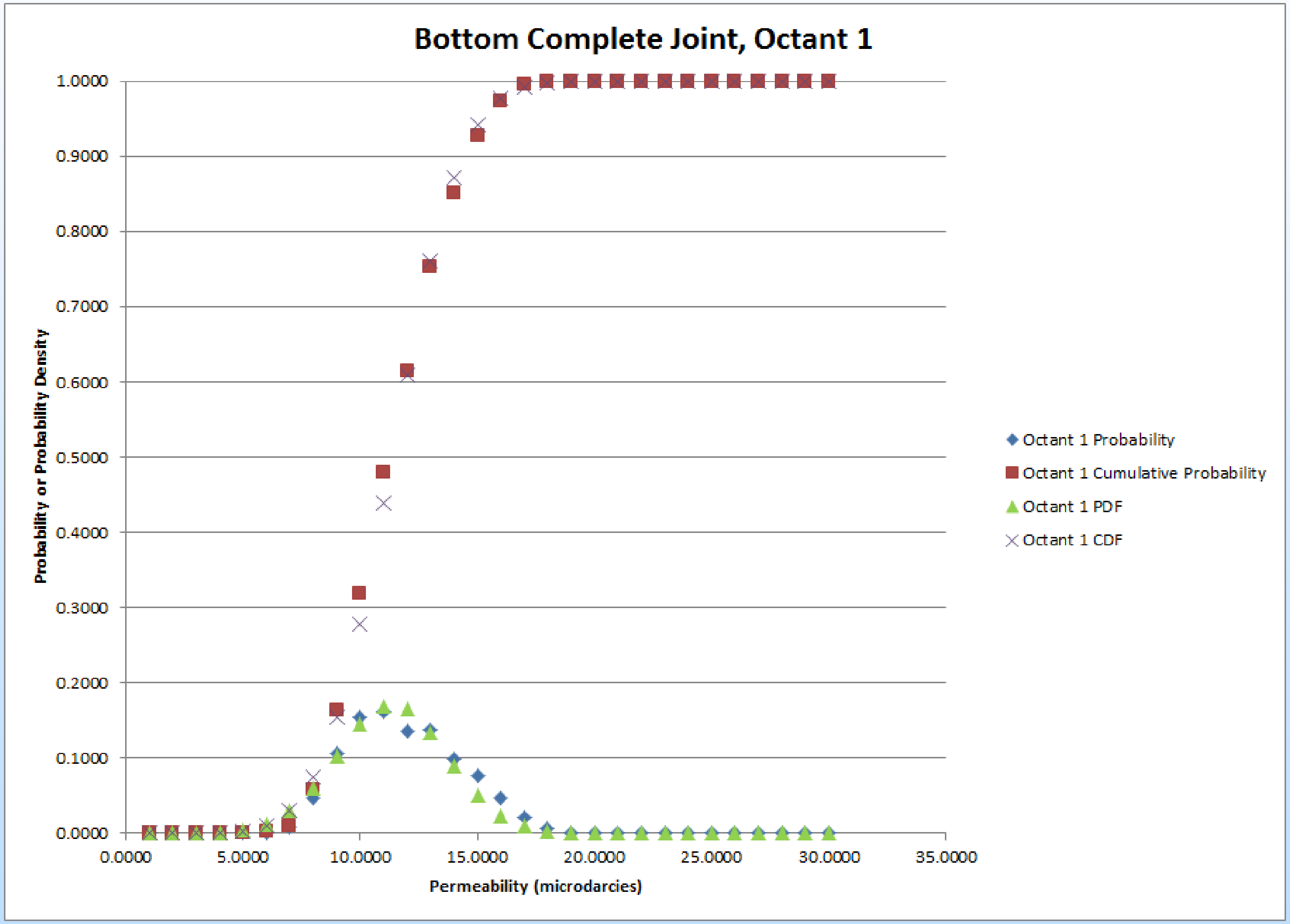
Material	Sample Depth (ft)	Ambient Porosity	V_L (P-Wave Velocity) (ft/s)	Estimated Porosity
Cement	2260	0.654	7333	0.654
Cement	2410	0.6417	7582	0.630
Cement	2987	0.6334	7980	0.591
Cement	2995	0.6635	6971	0.690
Cement	3648	0.5568	7812	0.607

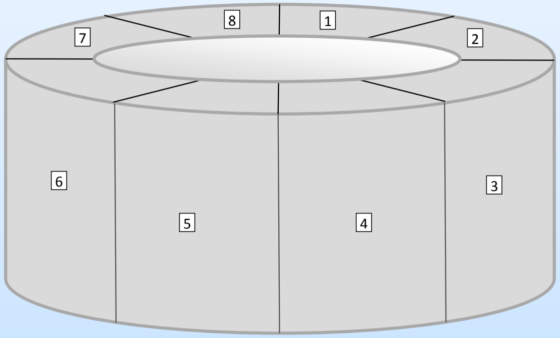
Constants	
V_{Lo}	14003
b	0.7277

Permeability Estimates



Density Functions





Summary

– Log results, taken in conjunction with the lab measurements, indicate that interfaces and/or problems with cement placement due to eccentering provides preferential flow paths for fluids, which can increase the effective permeability of the barrier several orders of magnitude above the permeability of intact cement.

– The results of the maps created using logging tools indicating that the cement condition and bond are generally good, identify a need for more research to understand how logs can be used to predict effective well permeabilities such as those measured by the VITs in this study.

– The next steps are to collect and analyze logs, cores, and samples at Ella G Lees 7 and incorporate them into the project (In progress). And use the PDFs and CDF to study risk assessment techniques in old wells

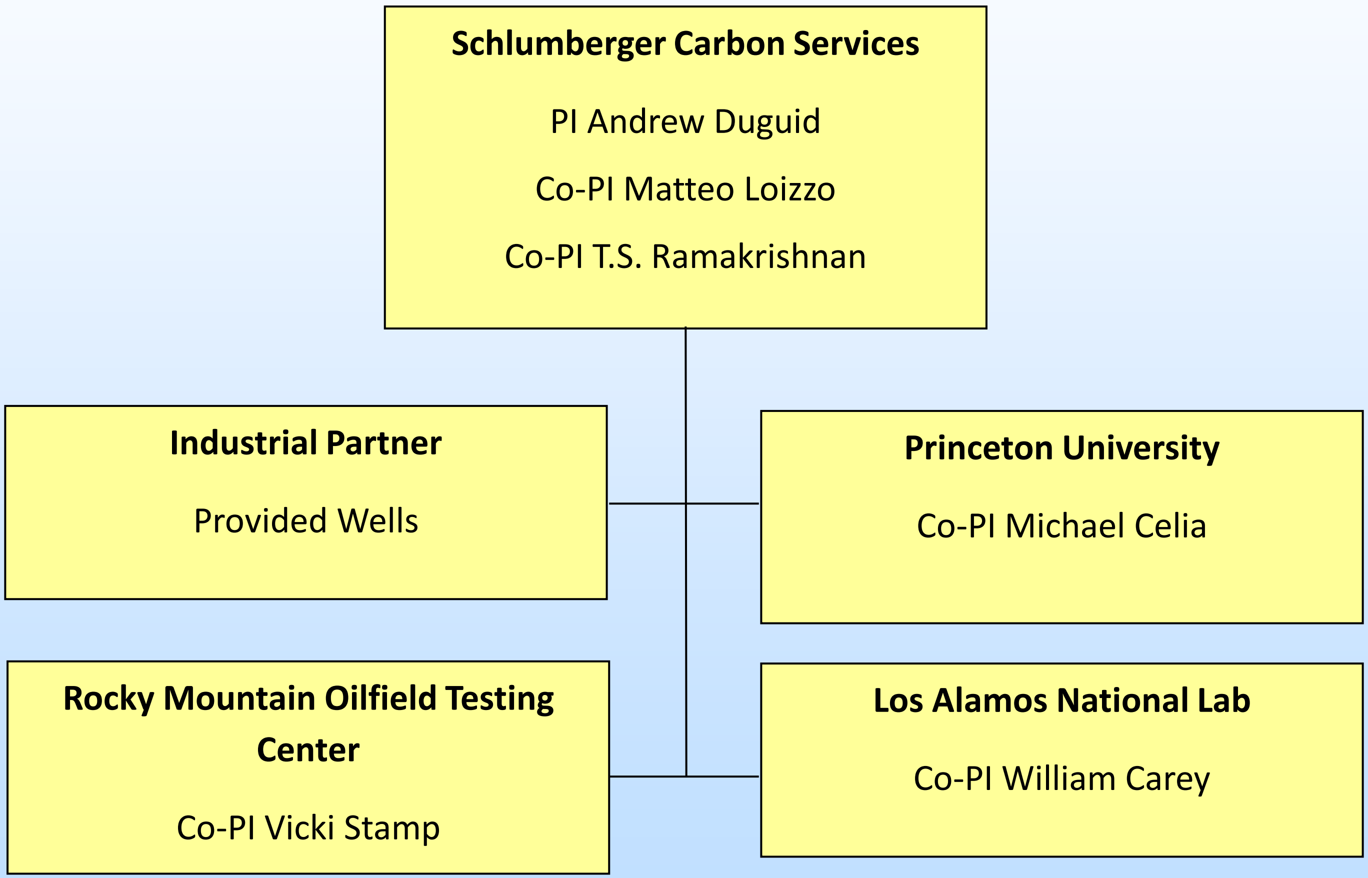
Accomplishments to Date

- Samples, tests, and logs in 6 old wells
- Modeling of point permeability measurement
- Modeling of the VIT measurements
- Modeling of cement permeability using ultrasonic log data
- Development of methods to create CDFs and PDFs

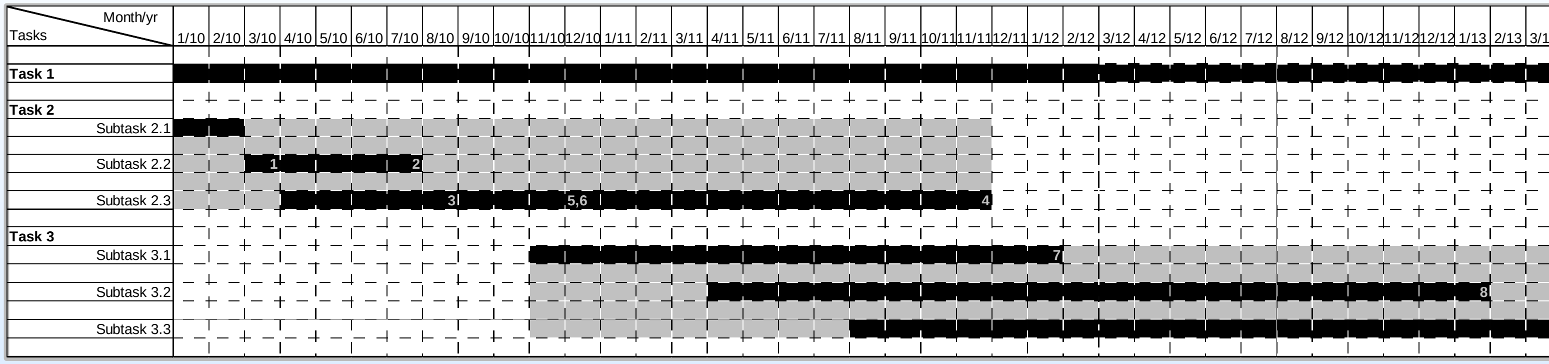
Appendix

– These slides will not be discussed during the presentation, but are mandatory

Organization Chart



Gantt Chart


Month/yr
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1/10
2/10
3/10
4/10
5/10
6/10
7/10
8/10
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Task 1
Task 2
Subtask 2.1
Subtask 2.2
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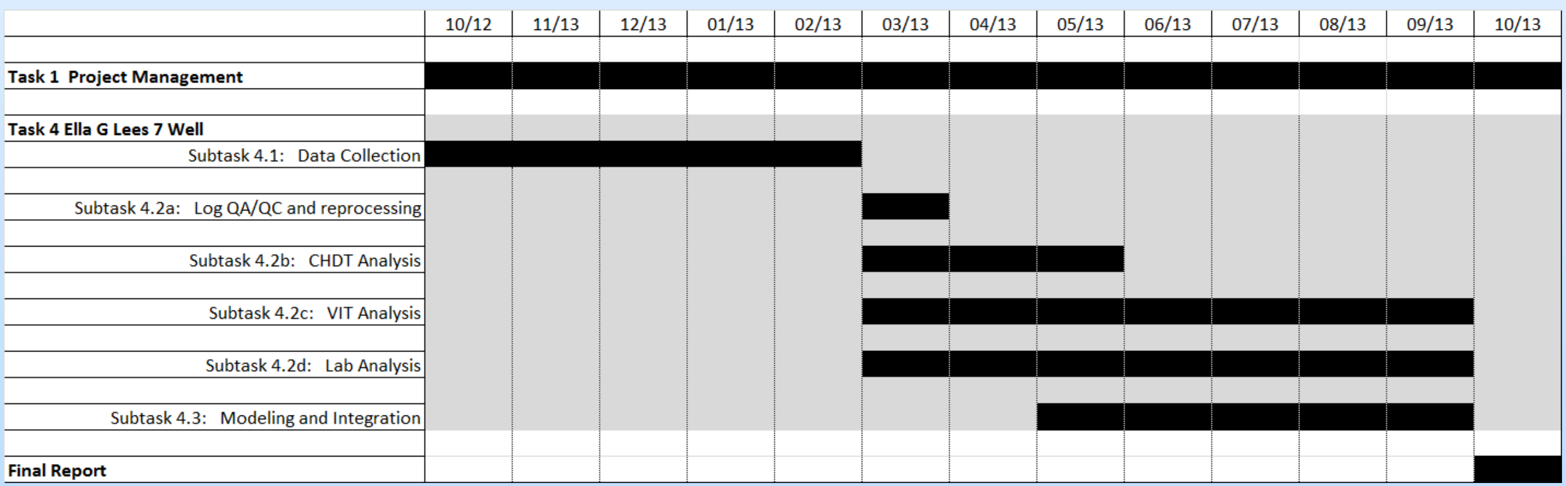
Task 3
Subtask 3.1
7
Subtask 3.2
8
Subtask 3.3
9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11/13
12/13
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03/13
04/13
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06/13
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08/13
09/13
10/13
Task 1 Project Management
Task 4 Ella G Lees 7 Well
Subtask 4.1: Data Collection
Subtask 4.2a: Log QA/QC and reprocessing
Subtask 4.2b: CHDT Analysis
Subtask 4.2c: VIT Analysis
Subtask 4.2d: Lab Analysis
Subtask 4.3: Modeling and Integration
Final Report

Bibliography

To date, no manuscripts have been submitted for peer review. However, The following conference proceedings from the project are available:

- **Duguid, A.**, Butsch, R., Carey, J.W., Celia, M., Chugunov, N., Gasda, S., Ramakrishnan, T.S., Stamp, V., and Wang, J. Pre-injection Baseline Data Collection to Establish Existing Wellbore Leakage Properties. *Proceedings of the 11th International Conference on Greenhouse Gas Technologies*, Kyoto, Japan, September, 2012. Available at: http://www.sciencedirect.com/science/article/pii/S1876610213007315

- Gasda, S., Celia, M., Wang, J., and **Duguid, A**. Wellbore permeability estimates from vertical interference testing of existing wells. *Proceedings of the 11th International Conference on Greenhouse Gas Technologies*, Kyoto, Japan, September, 2012. Available at: http://www.sciencedirect.com/science/article/pii/S1876610213007327

- **Duguid, A.**, Butsch, R. J., Loizzo, M., and Stamp, V., "Collection of Baseline Wellbore Leakage Risk Data in Multiple Wells in the Same Field," *10th International Conference on Greenhouse Gas Control Technologies*, September 19-23, 2010, Amsterdam, Netherlands. Available at: http://www.sciencedirect.com/science/article/pii/S1876610211007685