CCUS Well Integrity

ARB Carbon Capture and Sequestration Technical Discussion Series: Well Mechanical Integrity

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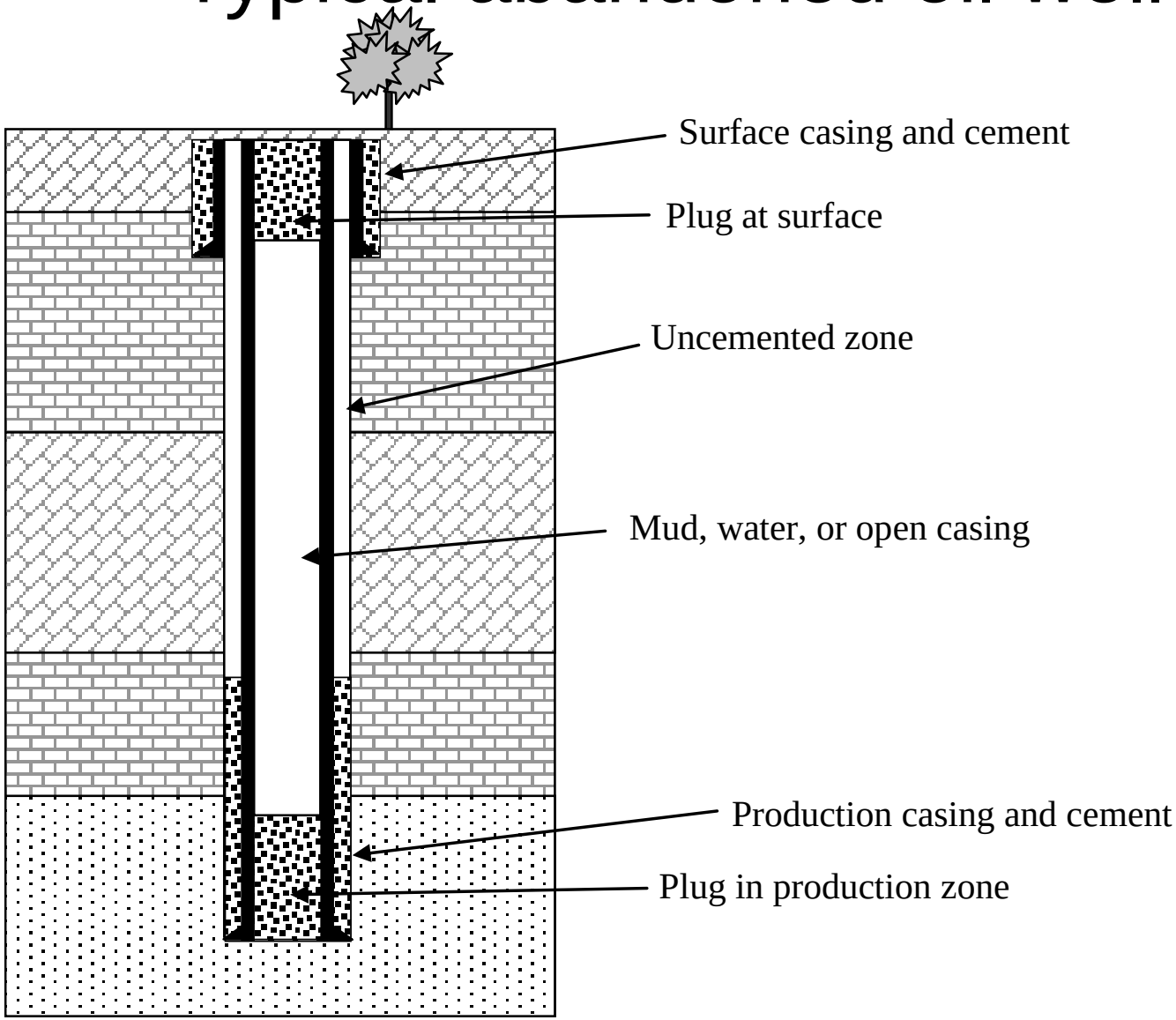
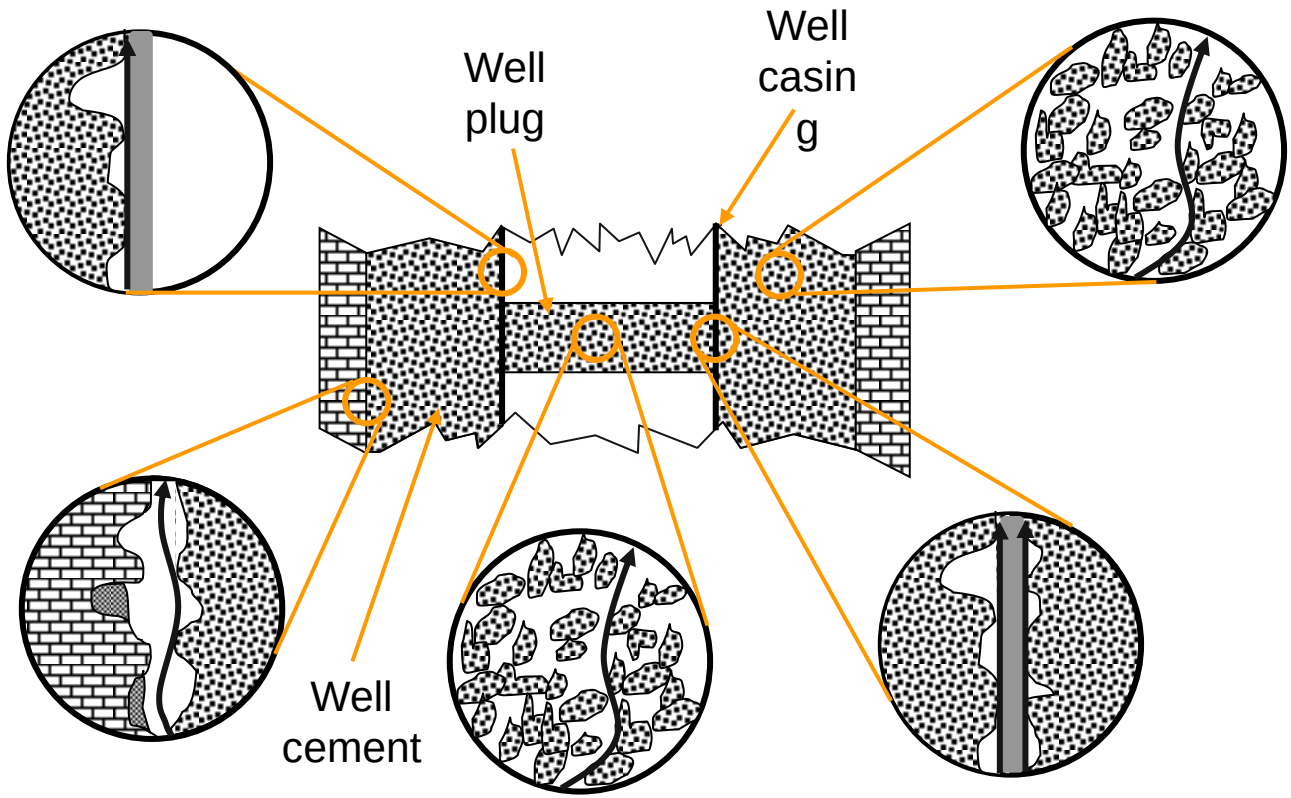
Presentation Outline

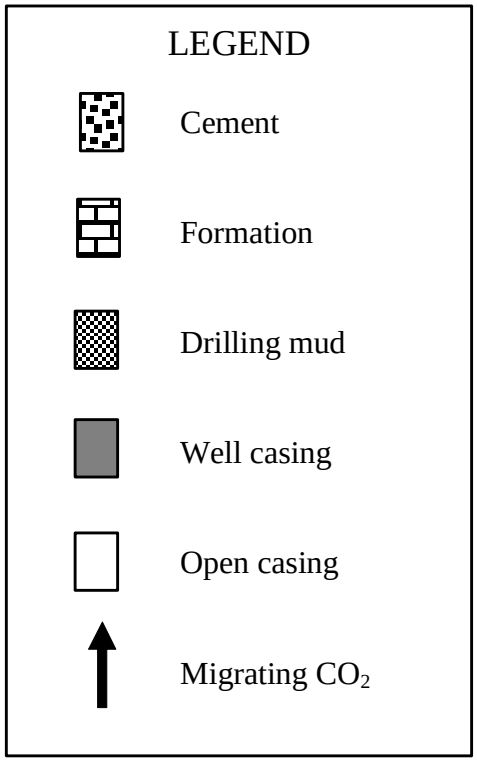
- Background / Leakage Pathways
- Well Construction
- Cement
- Examples and measurements
- Summary

Typical abandoned oil well



Potential Avenues for Leakage



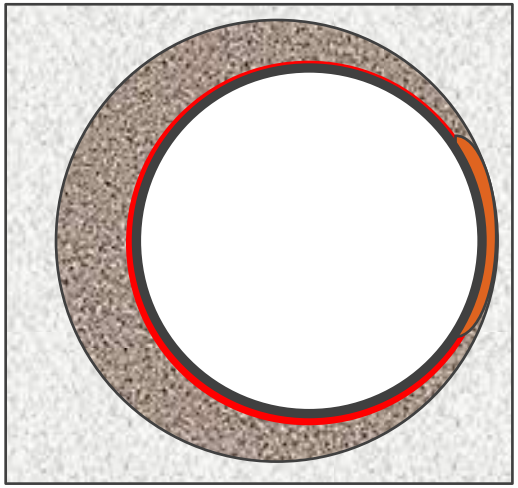


Well Construction

- The wells must be designed to function under the expected pressures, temperatures, and volumes. Wells must provide isolation for the life of the project
  - Design for temperature, tensile stress, maximum internal, maximum external, and triaxial loadings.
- Formation Properties
  - Pressure
  - Permeability
  - Gas/fluid chemistry
- Material Properties
  - Steel/Fiberglass
  - Cement
- Drilling Techniques
  - OBM/WBM
  - Mud Removal
- Well Use
  - Injection/Production

Construction: Cement sheath defects

- Placement defects
  - Poorly centralized casing can lead to channels that bypass the narrow side of the annulus
  - Mud films can also create pathways and reduce zonal isolation
- Gas migration during cement hydration may cause channels
  - Driven by a drop in cement pore pressure during hydration
- Thermomechanical effects
  - Cracks caused by cement failure in compression/tension, microannuli caused by debonding at the interfaces with casing and/or rock



These can all lead to direct communication to the casing and may increase transport by establishing a communication path vertically

Construction practices should minimize the chances for defects. (proper slurry design, WOC, centralizers)

Materials: Casing and Elastomers

- Typical carbon steel casing is vulnerable to degradation by anodic dissolution, exposure to chloride laden waters, and exposure to carbonic acid [Anstice et al, 2005 and Stone et al., 1989]
  - A passive layer is created between the cement and the casing that protects the casing from degradation
  - Lack of cement or degradation of the cement can lead to a breakdown of the passive layer allowing for corrosion of the steel
- Corrosion resistant alloy casing does exist and may be needed in CO_2 exposed zones (stainless steel etc.)
- Elastomers can be degraded by CO_2. Degradation can include explosive decompression and blistering.

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

Cement degradation reactions

- $Ca(OH)_2$ dissociation

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

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

May open up new porosity

- Cement dissolution
- $Ca(OH)_2(s) + 2H^+ + CO_3^{2-} \rightarrow CaCO_3(s) + 2H_2O$
- $Ca_3Si_2O_7H{\bullet}4H_2O(s) + 2H^+ + CO_3^{2-} \rightarrow CaCO_3(s) + SiO_xOH_x(s)$
- $Ca(OH)_2(s) + H^+ + HCO_3^- \rightarrow CaCO_3(s) + 2H_2O$
- $Ca_3Si_2O_7H{\bullet}4H_2O(s) + H^+ + HCO_3^- \rightarrow CaCO_3(s) + SiO_xOH_x(s)$

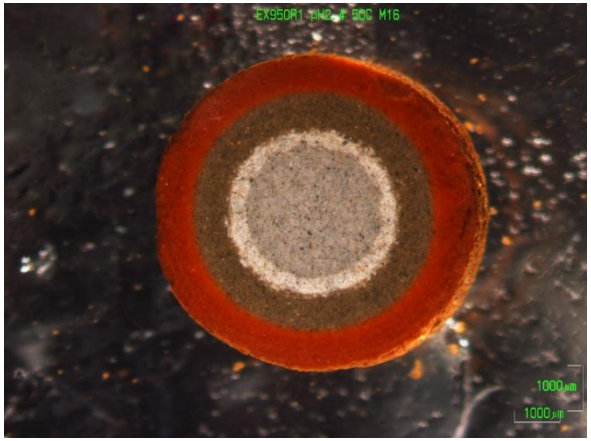
Precipitation of $CaCO_3$ blocks connected pores and reduces permeability

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

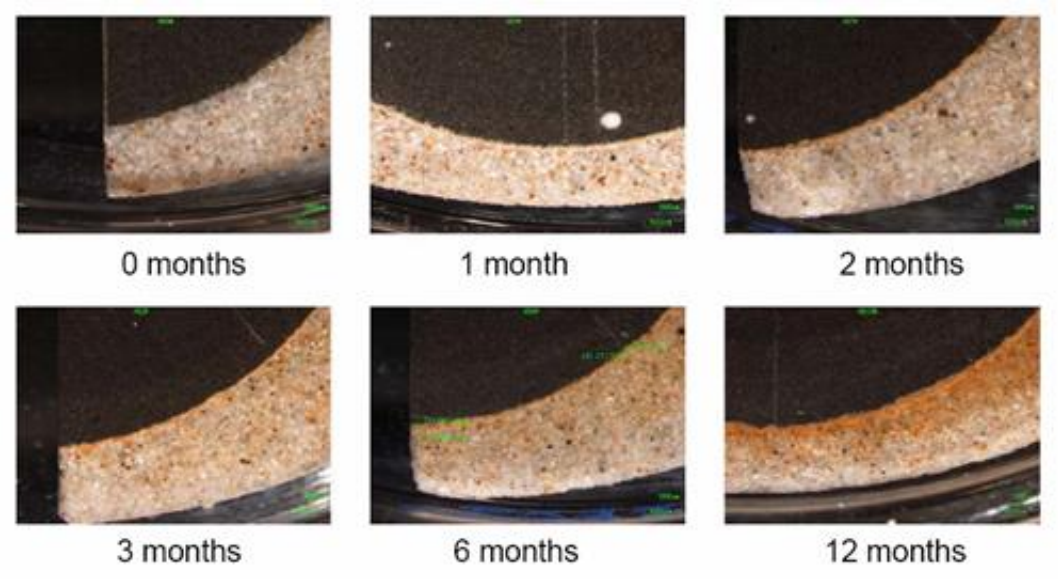
Opens pores blocked by $CaCO_3$ precipitation and additional porosity created by the dissolution of cement reaction products

Materials: Reactions At The Cement-Rock Interface--Lab

Neat cement pH 2.4 and 50°C

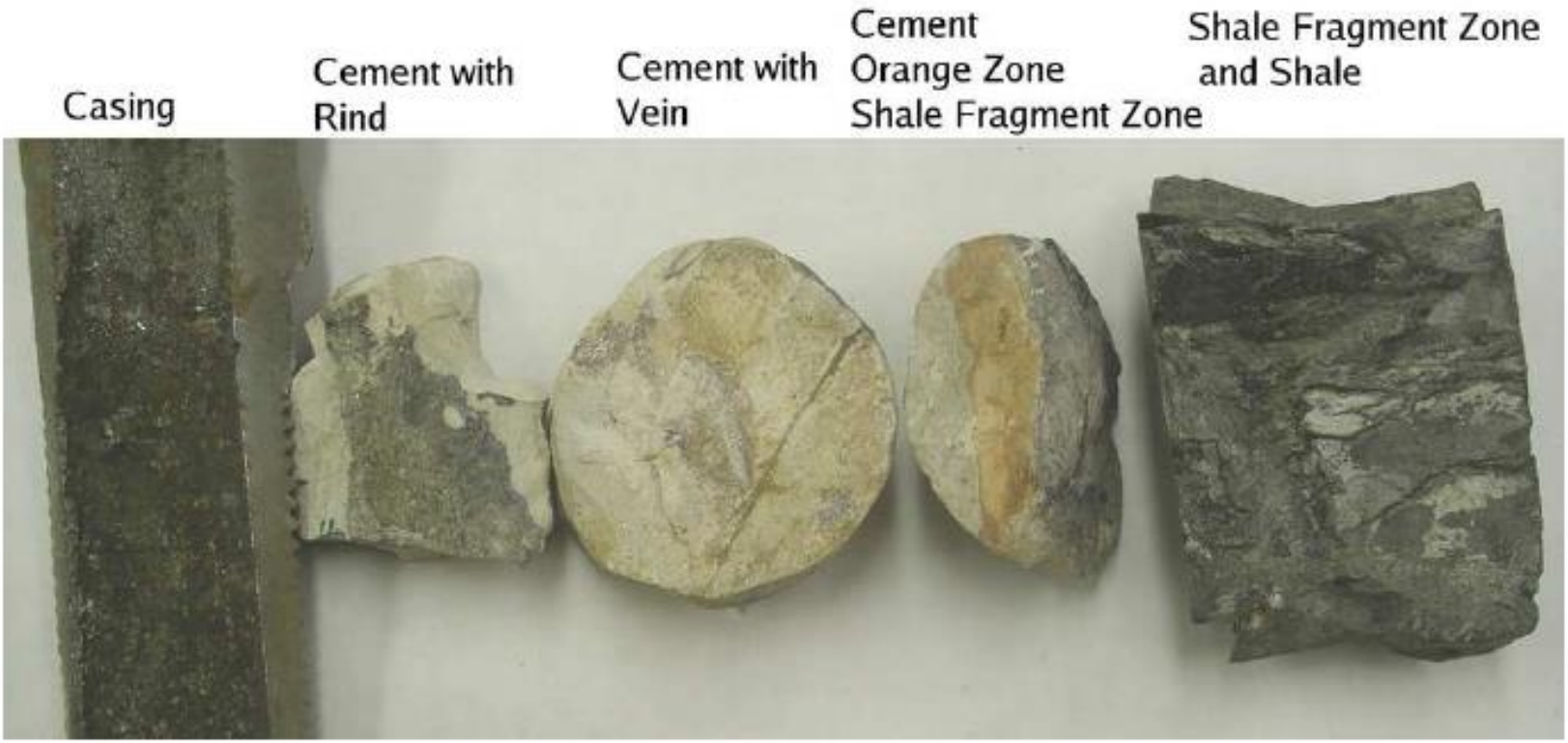


Sandstone-cement at pH 3 and 20°C



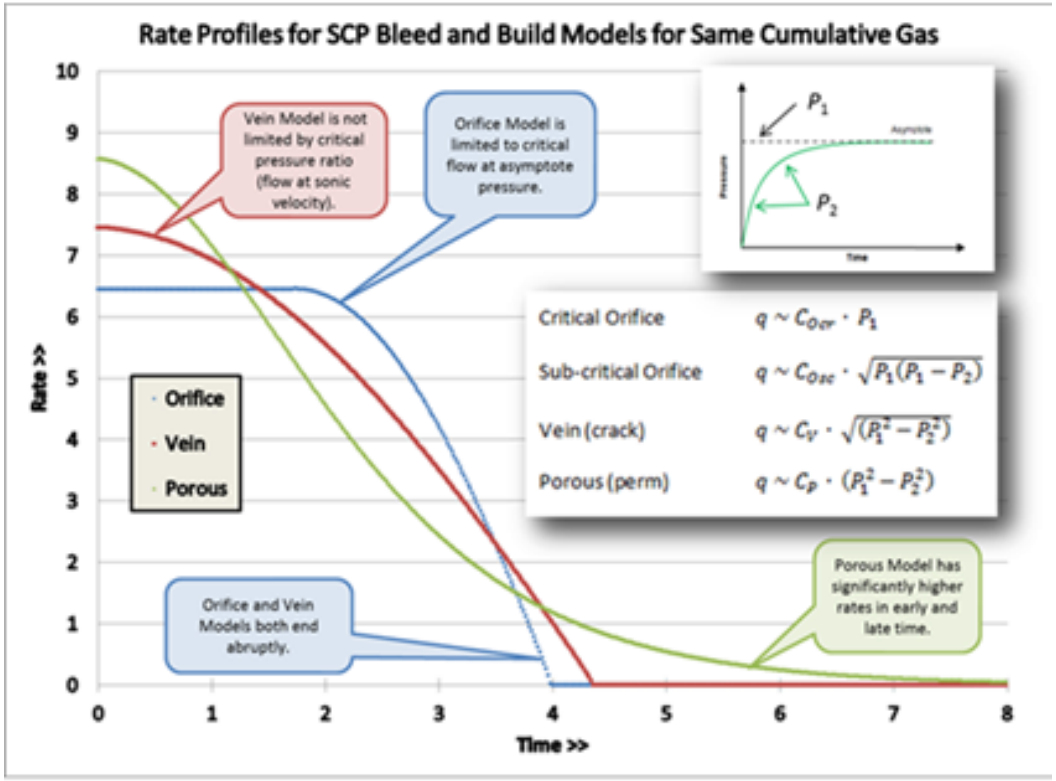
Materials: Reactions At The Cement-Rock Interface--Field

SACROC Field Cement



Carey et al. 2006

Sustained Casing Pressure Analysis



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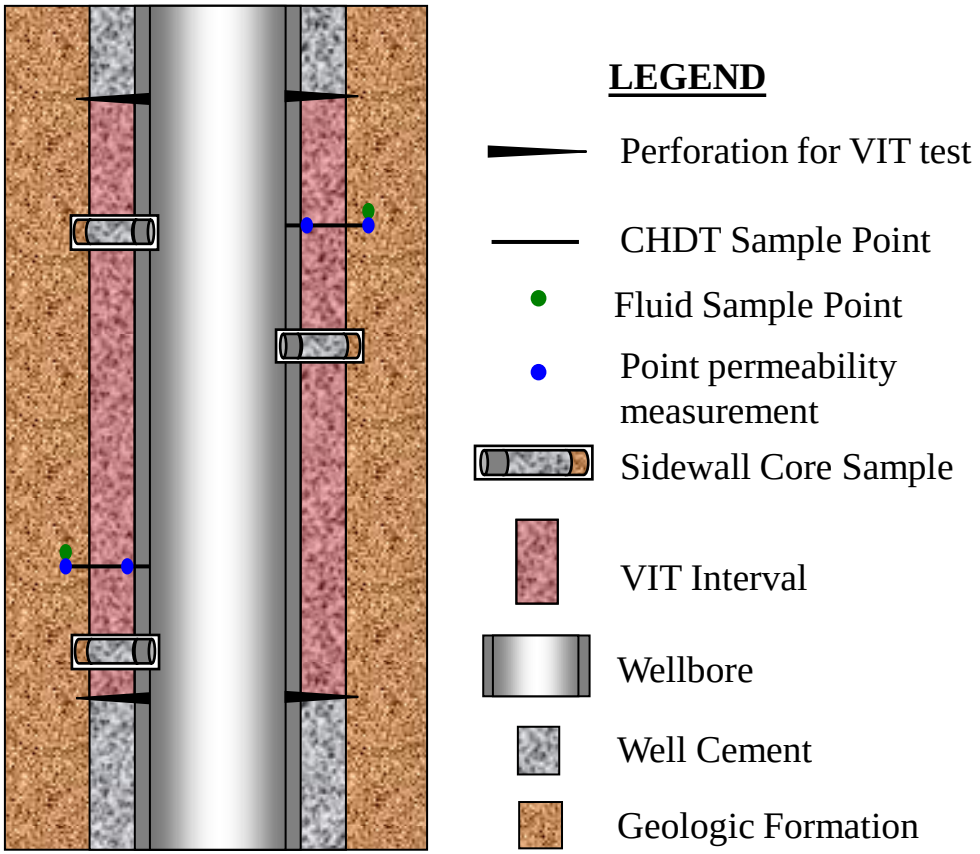
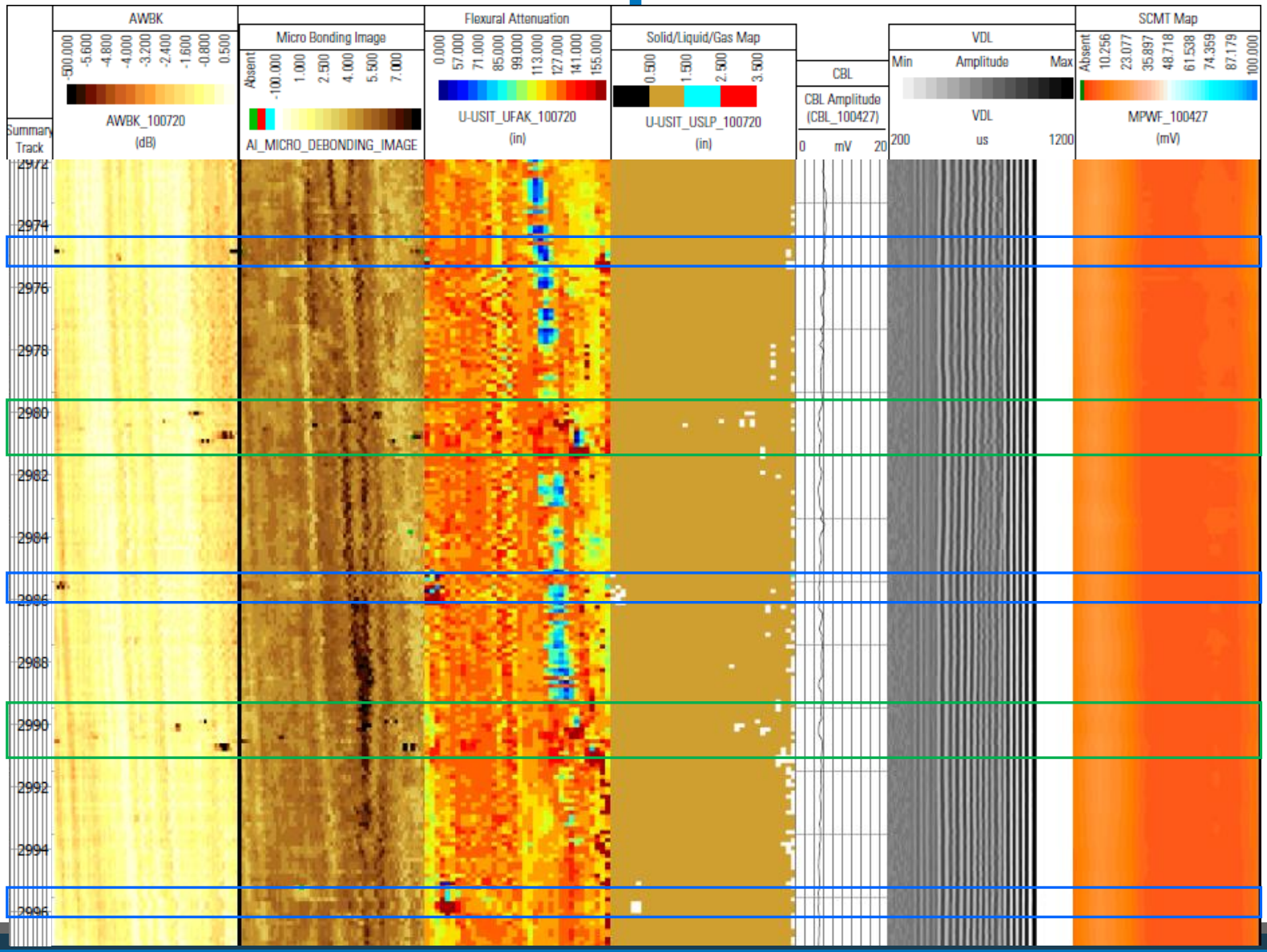
Data Collection

- Logging Tools
- Isolation Scanner* cement evaluation service
- SCMT* slim cement mapping tool

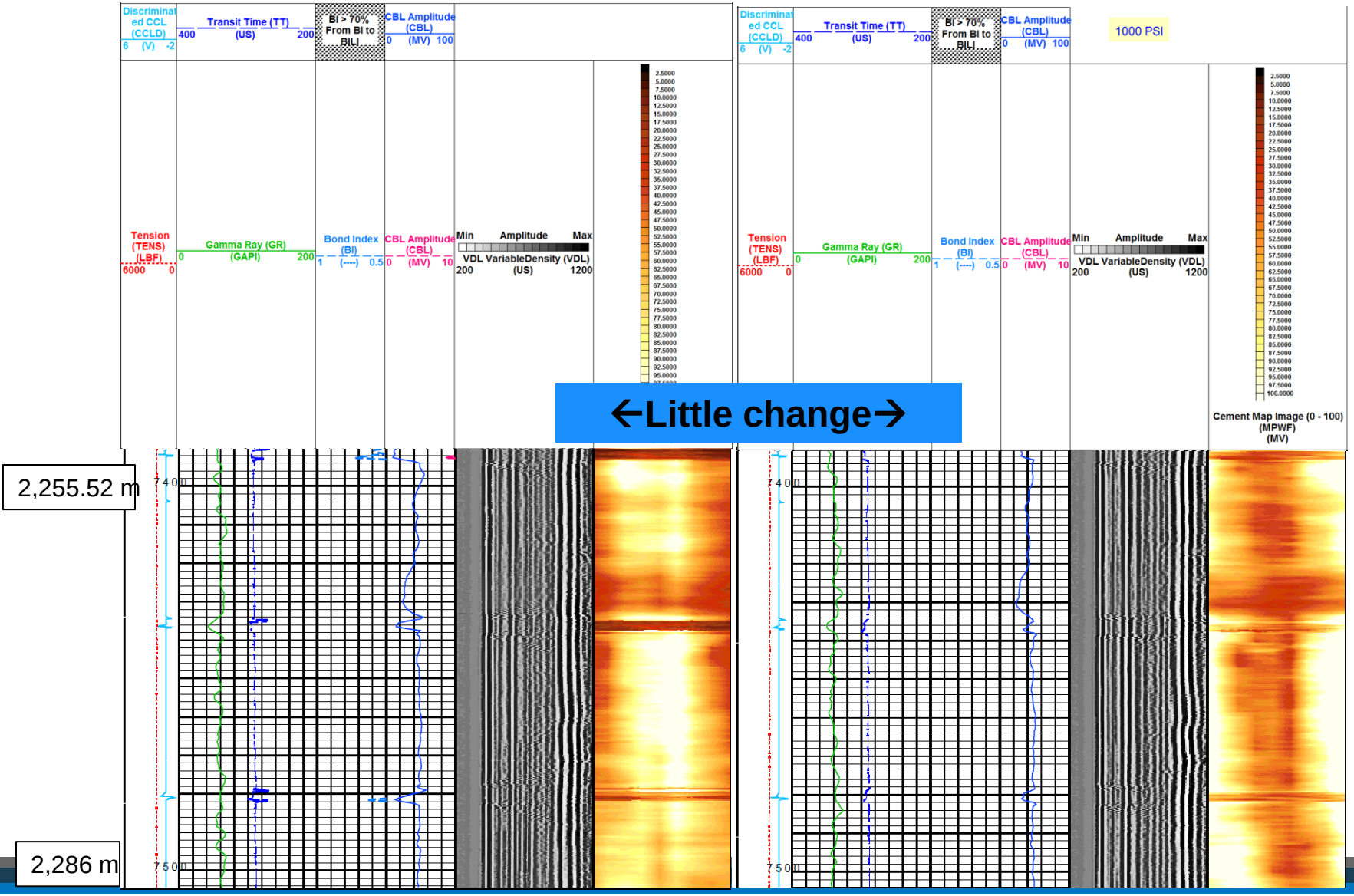
- Testing and Sampling Tools
- CHDT* cased hole dynamics tester
- MDT* modular formation dynamics tester
- MSCT* mechanical sidewall coring tool



CC1 Cement Maps



EGL7 SCMT (CBL) Well Annulus



No Pressure

1100 psi

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Casing Expansion (Lower Bound on Annulus)

Casing expansion = 70.55 μm (0.00278 in)

Circumferential Hoop Stress

$$\sigma_c = \frac{p_i r_i^2 - p_o r_o^2}{r_o^2 - r_i^2} - \frac{r_i^2 r_o^2 (p_o - p_i)}{r^2 (r_o^2 - r_i^2)}$$

Hooke's Law

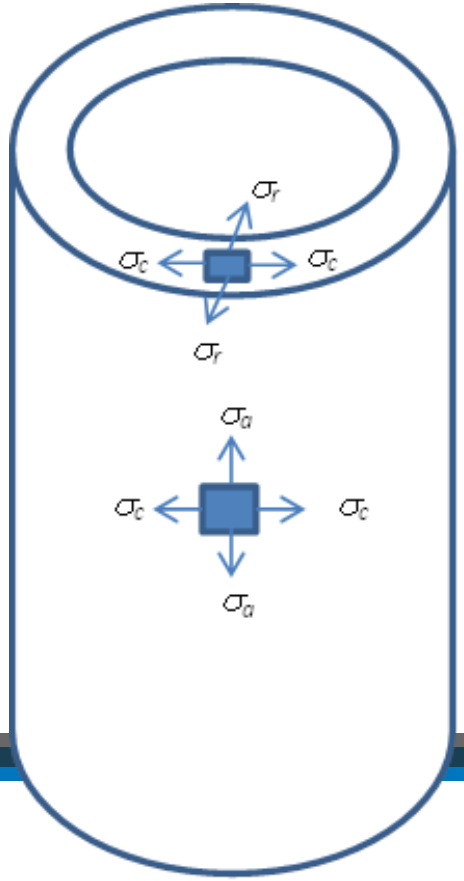
$$\varepsilon = \frac{\sigma}{E}$$

Definition of Strain

$$\varepsilon = \frac{\Delta C}{C}$$

Circumference of a Circle

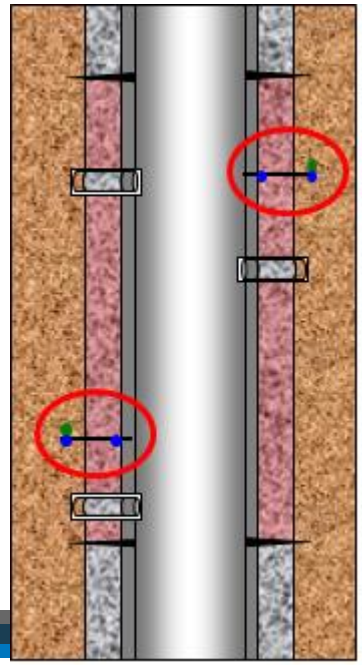
$$C = 2\pi r$$



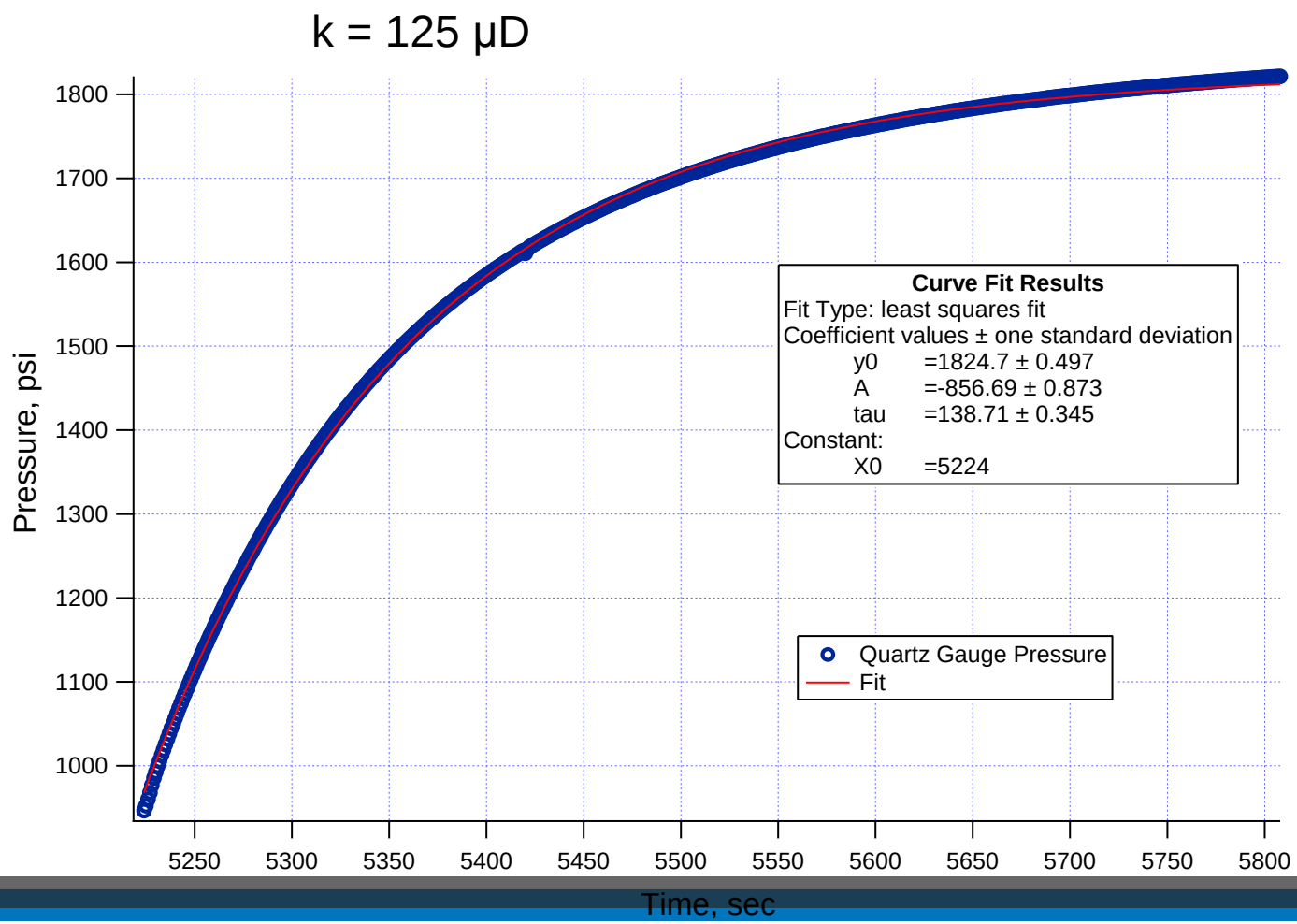
Where:

σ_c = Circumferential stress (psi) [**23,013 psi**]
p_i = Pressure in the well (psi) [4,550 psi]
p_o = Pressure outside the well (psi) [3,500 psi]
r_i = Internal radius of the casing (in) [3.363 in]
r_o = Outer radius of the casing (in) [7.000]
r = Radius of interest in the casing (in) [7.000]
ε = Strain (in/in) [**0.00079**]
σ = Stress (psi) [σ_c]
E = Young's Modulus (psi) [29 x 10^6 psi]
C = Circumference (in) [21.99115]

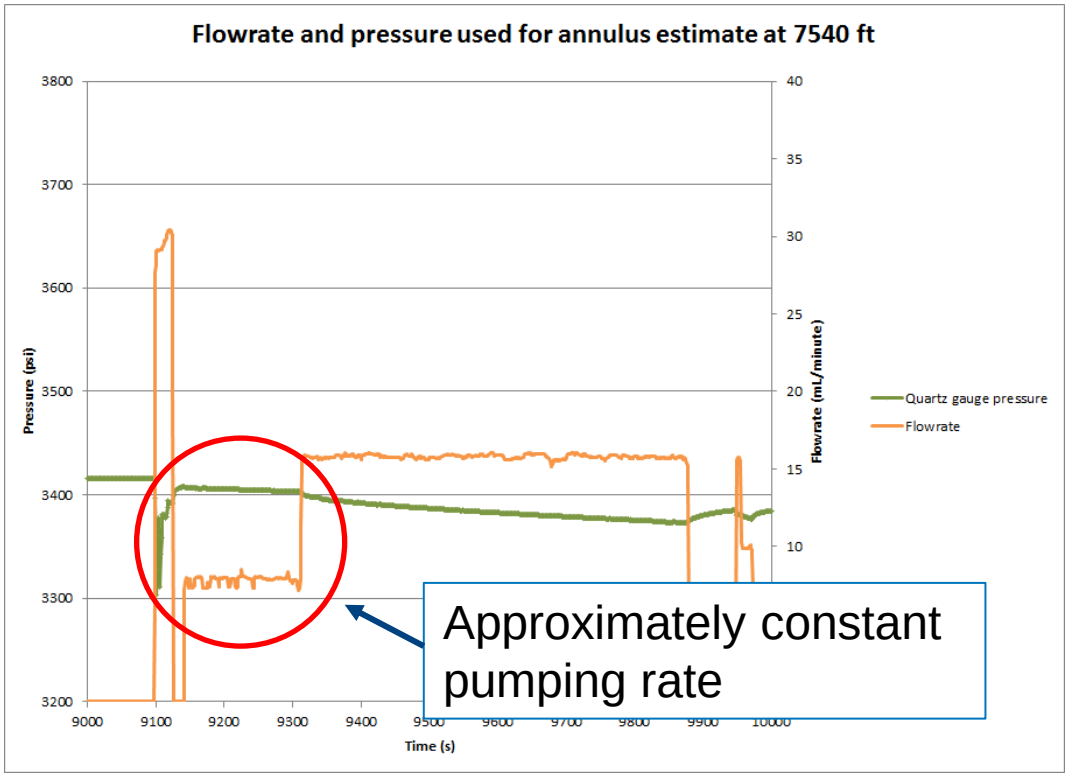
Well Testing – CHDT

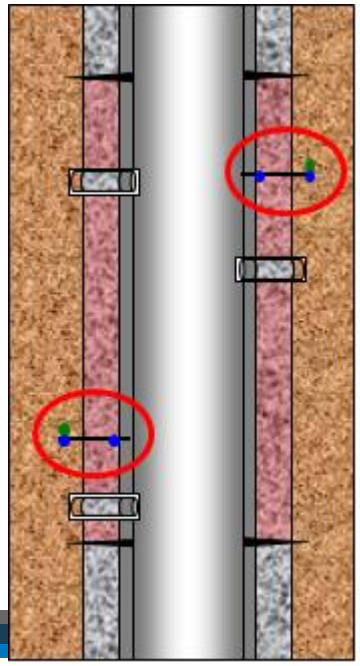


CHDT Analysis



EGL7– CHDT





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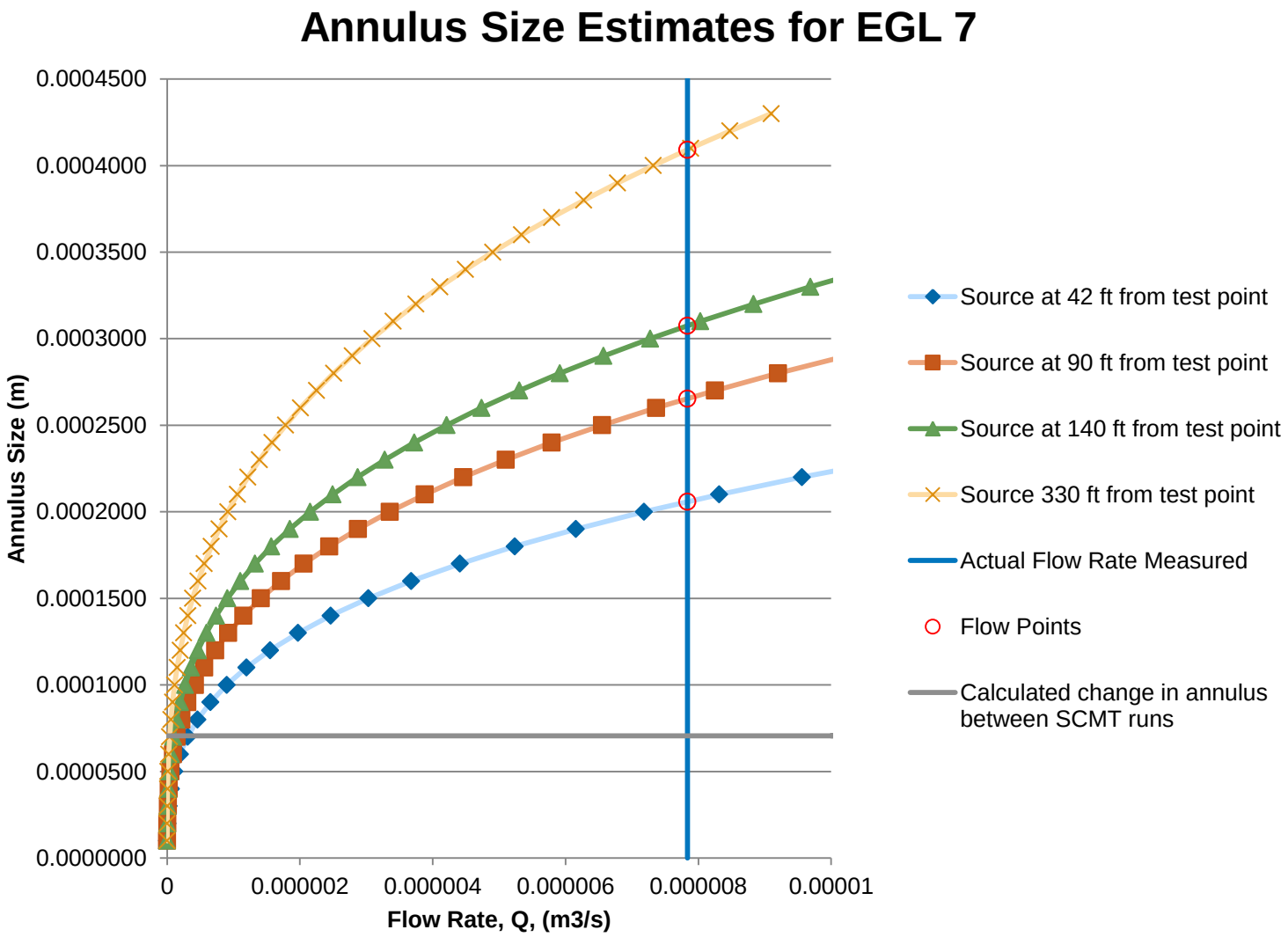
EGL7-CHDT



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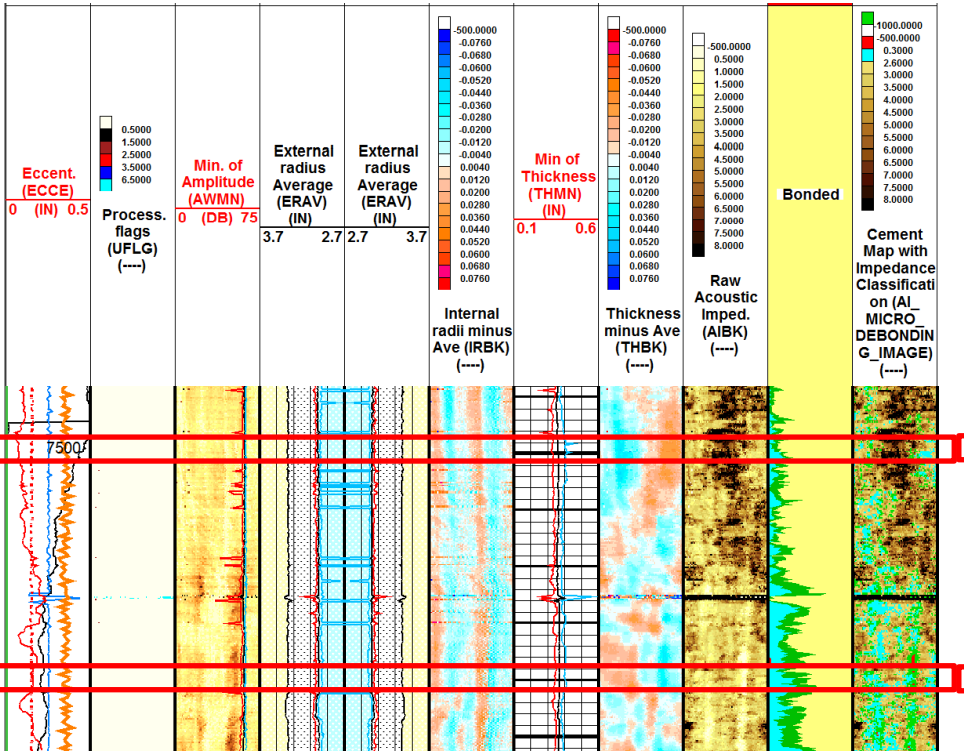
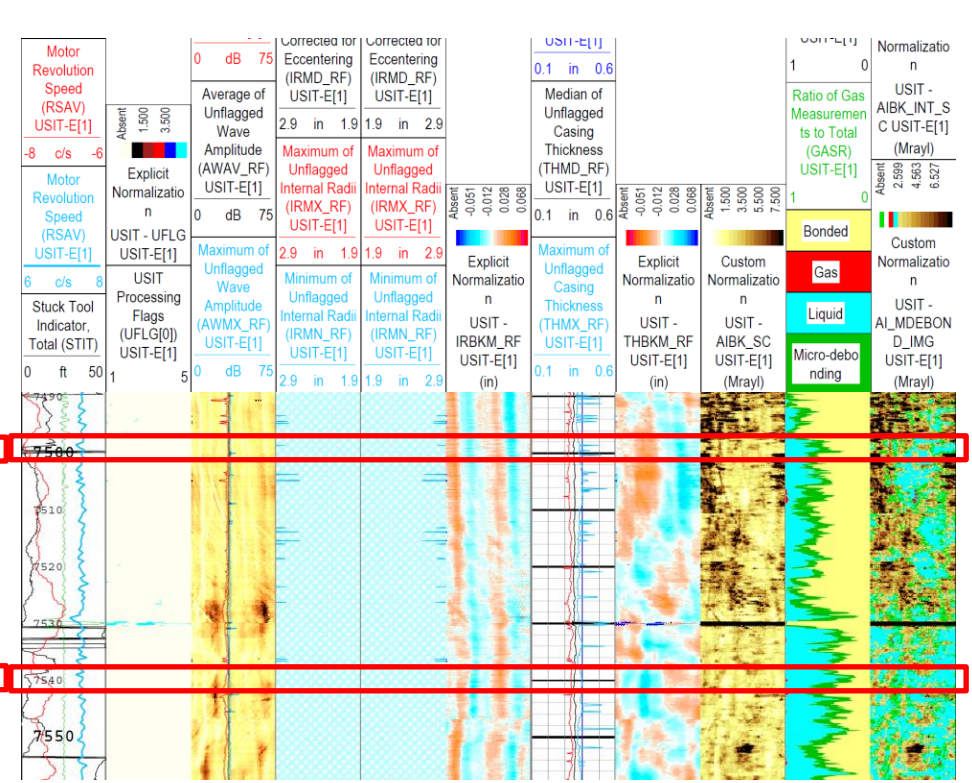
EGL7 Isolation Scanner Log Sections from 2008 and 2013 Over CHDT Test Zone Showing Material Removed





2008

2013

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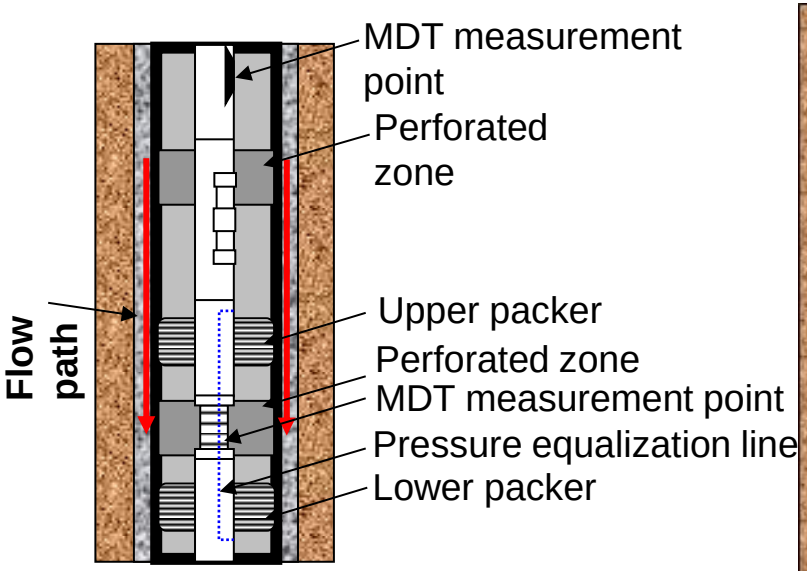
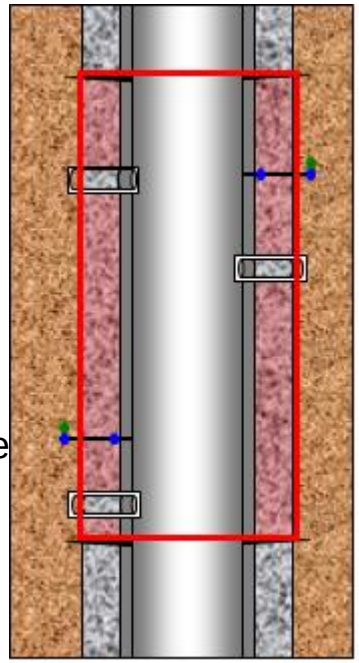
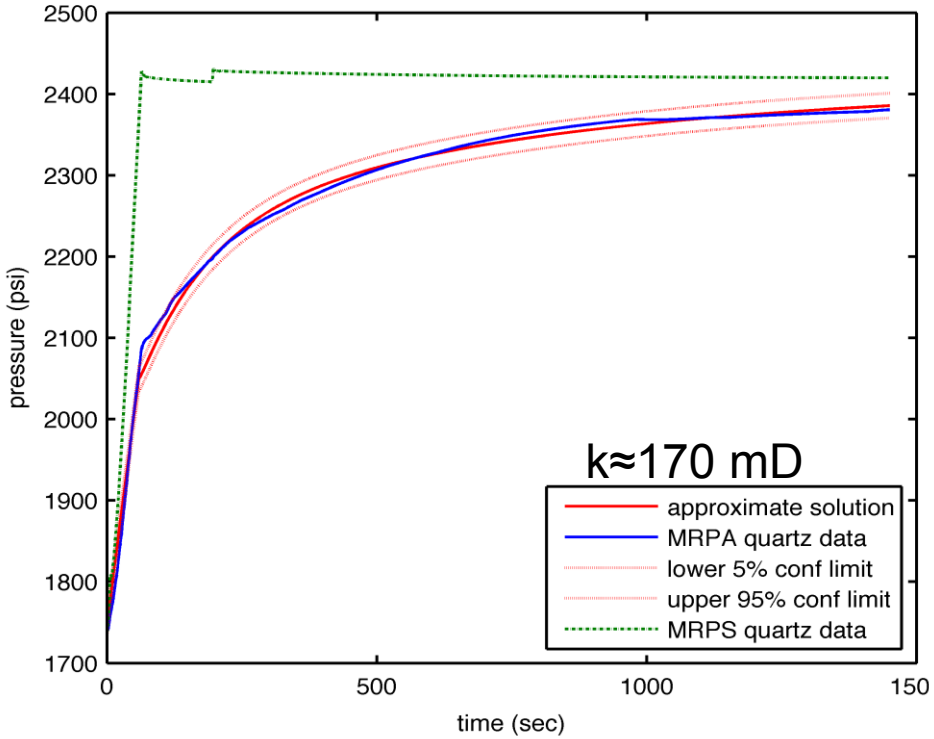
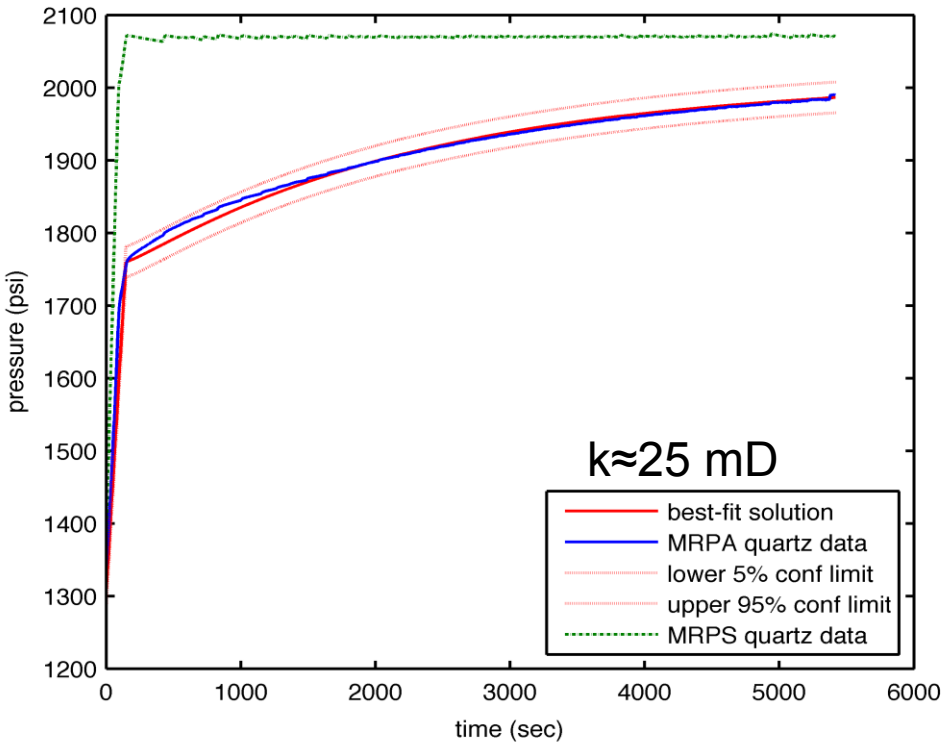
Well Testing – MDT





MDT VIT Model Results



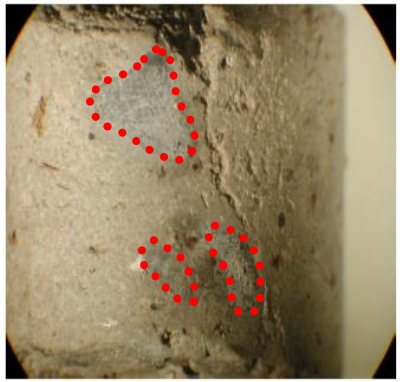


Best-fit model results to VIT data from the 46-TPX-10 (left) and CC1 (right) wells.

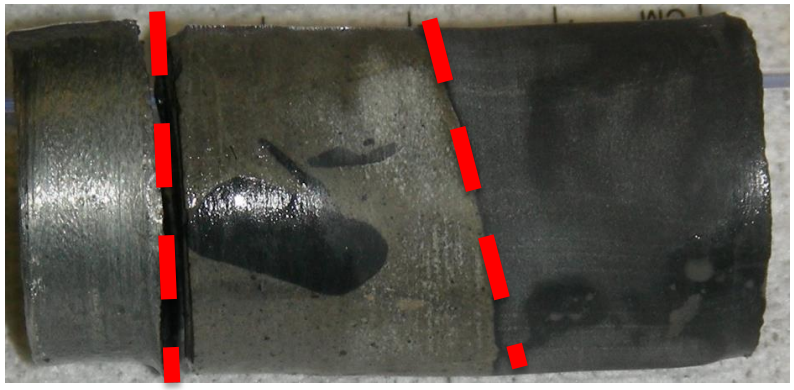
- Shown (in red) are the measured MRPA data in blue and the model results obtained from parameter estimation. The uncertainty of the best-fit solution is tied to the PDF of estimated wellbore permeability values produced by a parameter estimation algorithm. The 95% confidence in the best-fit solution is bracketed by the dotted red lines.

Sidewall Cores

CC1 1111.9 m (3648 ft)

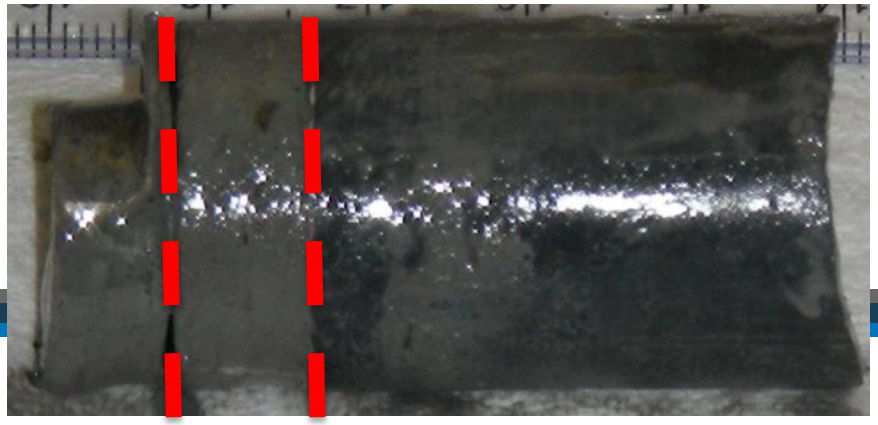


46-TPX-10 1223.8 m (4015 ft)

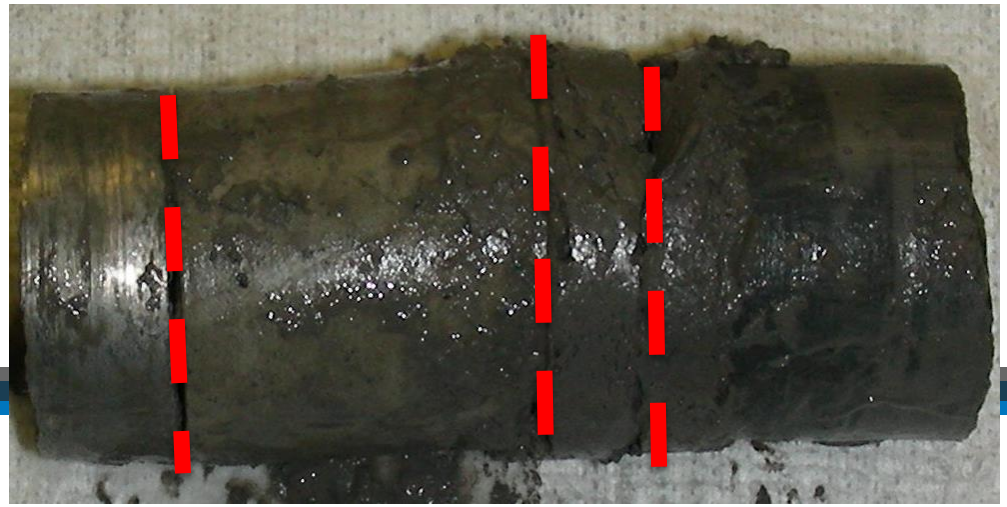


CC1 1051.6 m (3450 ft)

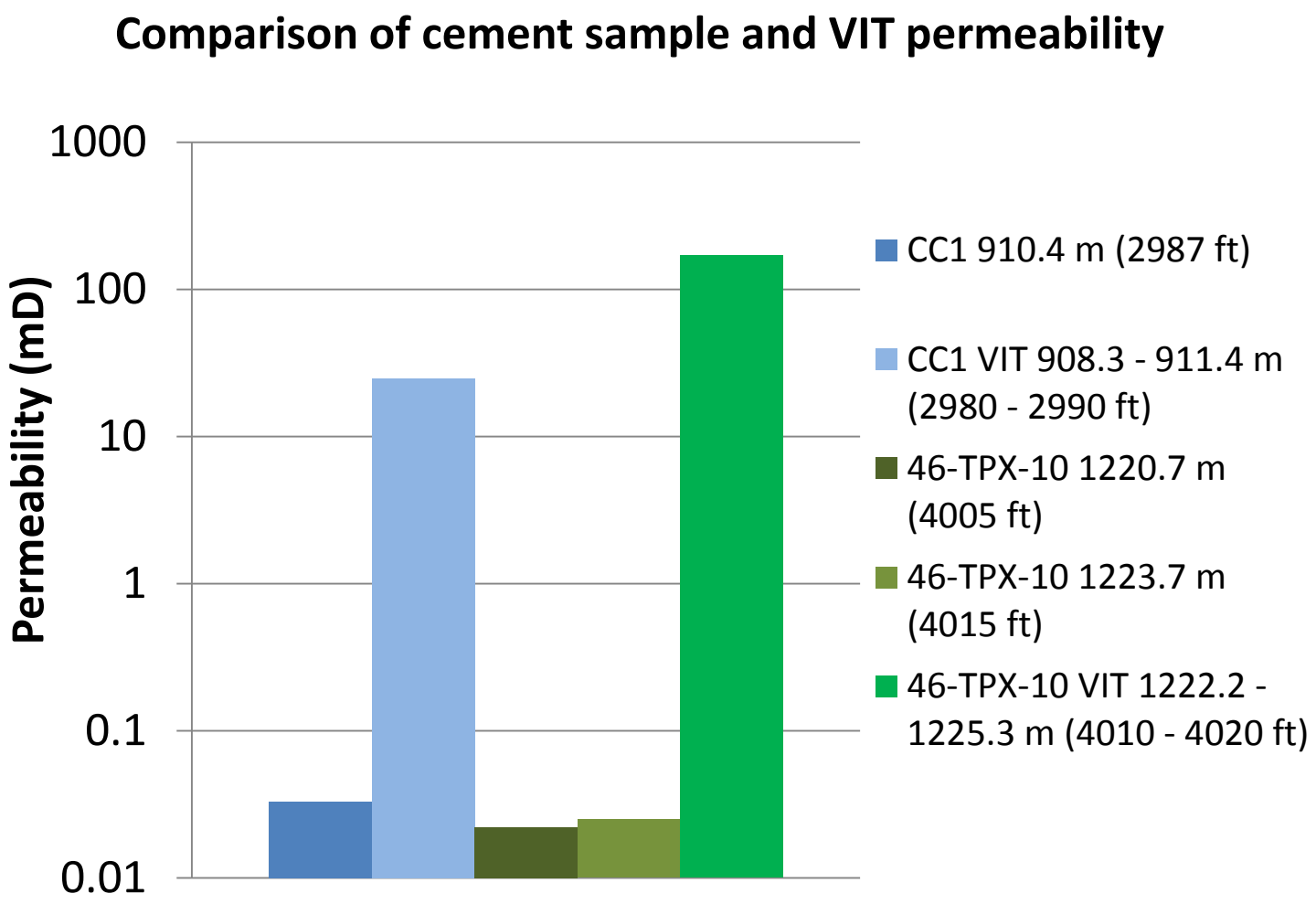
46-TPX-10 1220.7 m (4005 ft)



CC1 960. 1 m (3150 ft)



Permeability



Summary

- Leakage is more likely at cement interfaces than through the cement pore structure
- Well construction is a key factor and establishing and maintaining well integrity
  - Care should be taken selecting and placing materials
  - Best industry practices should be followed
- Although example zones with poor integrity can be located in many wells a full analysis is needed to establish that well is leaking
- Even a small zone of good cement may keep a well from being a leakage pathway
- Field experience has shown that reactions in the ground are probably much slower than what has been seen in the lab [Duguid et al., 2014, Crow et al., 2010 and Carey et al., 2006] but do occur.
- CO_2 resistant portland cements have been used and are currently available

Collaborators

- Robert Butsch, Schlumberger Carbon Services
- J. William Carey, Los Alamos National Lab
- Mike Celia, Princeton University
- Nikita Chugunov, Schlumberger-Doll Research
- Sarah Gasda, Uni Research
- Boyun Guo, University of Louisiana at Lafayette
- Susan Hovorka, University of Texas at Austin
- Mark Moody, Battelle
- Runar Nygaard, Missouri University of Science and Technology
- T.S. Ramakrishnan, Schlumberger-Doll Research
- Joel Sminchak, Battelle
- Vicki Stamp, True Oil Company
- Rebecca Thingelstad
- James Wang, Princeton University,

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Thanks!

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