Sixth Annual Conference on Carbon Capture & Sequestration

Well Integrity [4-C]

Well leakage pathways and their importance to CO_2/cement reactions: Analysis of long-term cement competence as part of a certification framework for CO_2 sequestration projects

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What Starts Here Changes the World

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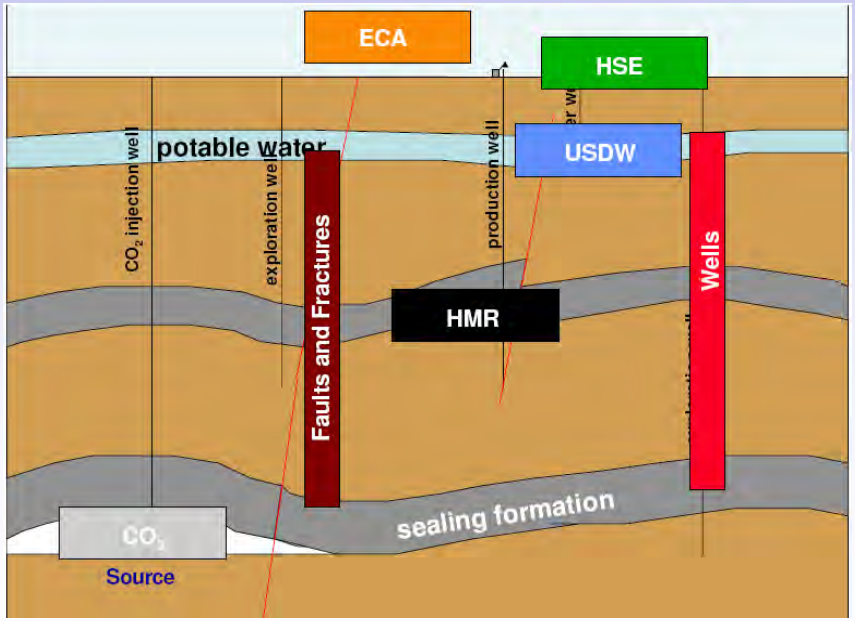
GEOLOGICAL CO2 STORAGE

Why do we care about well integrity?

- CO_2 sequestration is only useful if we can ensure *long-term* storage of injected carbon dioxide
- Leakage of CO_2 can pose a risk to:

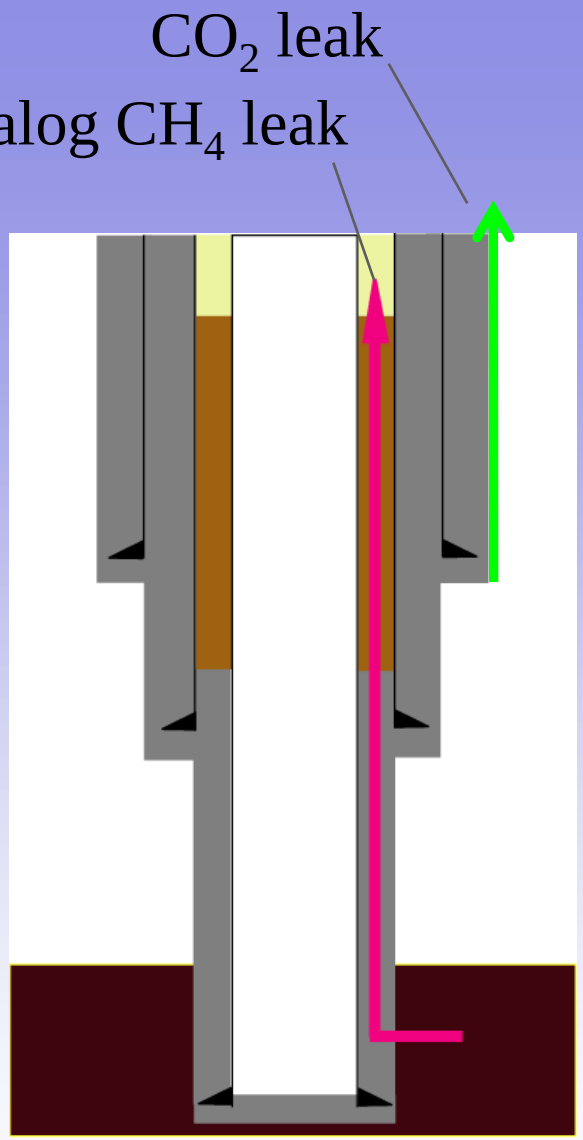
-Underground Assets

-HSE

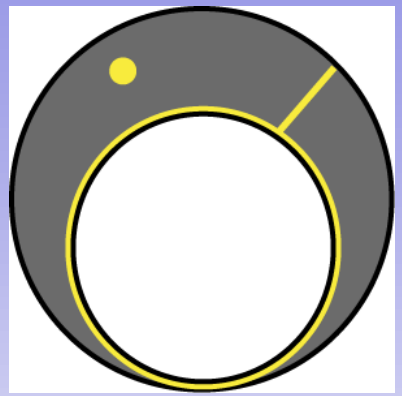


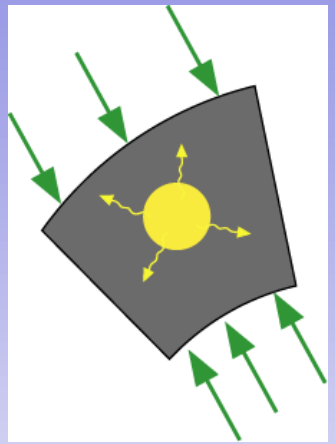
Motivation of work

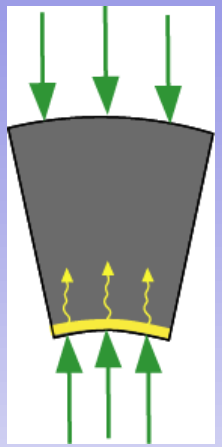
1. Quantify leakage rates through cement / well / earth system using *field data* from an analog system
2. Gain insight into leakage *pathway geometry* by applying models to the field data
3. Couple leakage paths with *cement degradation* and *geomechanical models*
4. Develop a *certification framework* for CO_2 sites taking into account the leakage rates, geometry, and chemical / geomechanical considerations

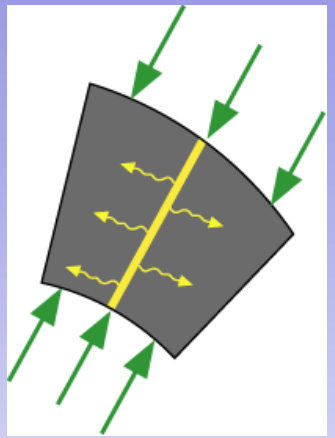


Prevalence and geometry of leakage up a well









Effect of pressure

Poor cement jobs

Fig. 19—Conventional cement after cycling.

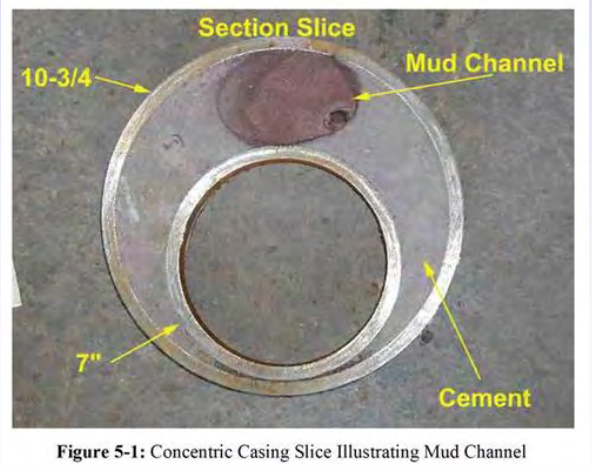


Figure 5-1: Concentric Casing Slice Illustrating Mud Channel

Figure 5-5: Close up of 7 and 10 ¾-in. Casing on the Rack

Heathman, 2006

Soter Thesis, 2003

Modeling approach

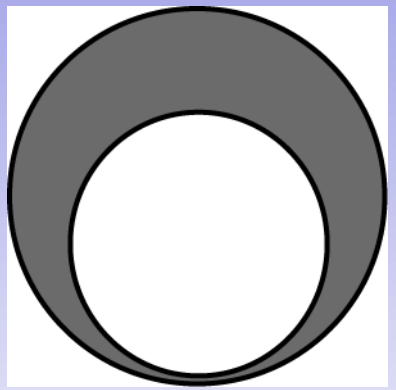
A. Simple models, with application to field data

I. Effective medium via Darcy's law equation (Xu and Wojtanowicz, 2001)

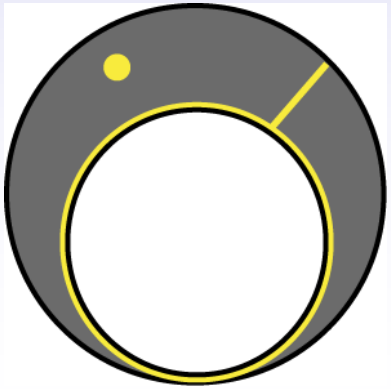
II. Leakage pathway via shell momentum balance equations

B. More complex leakage model, coupled with geochemical / geomechanical considerations

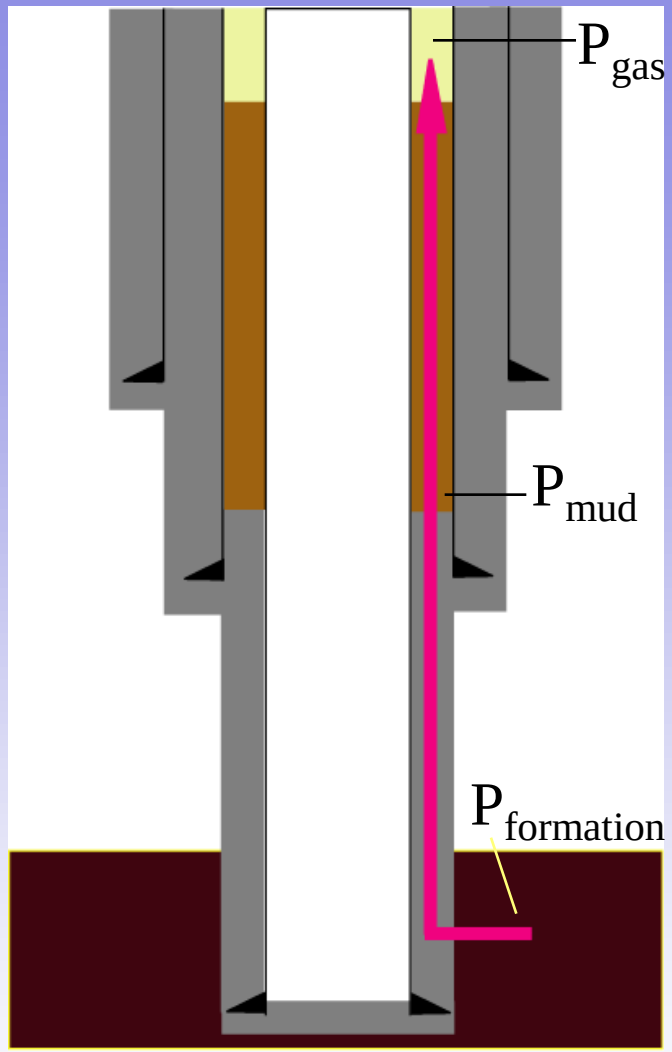
Effective Medium



Geometry Dependent



Sustained Casing Pressure (SCP) Model



Buildup History

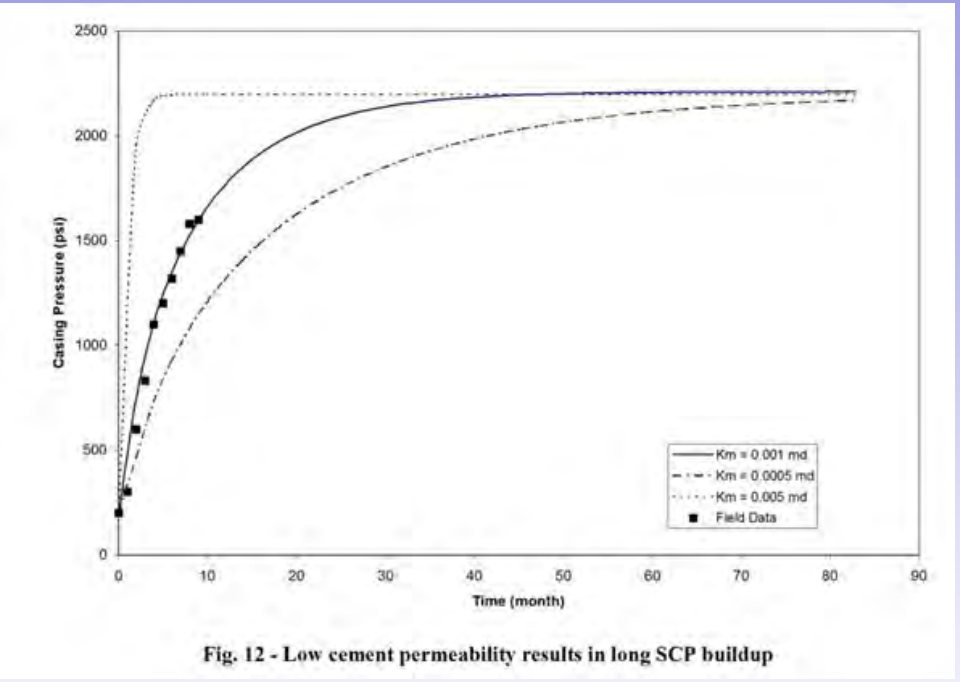
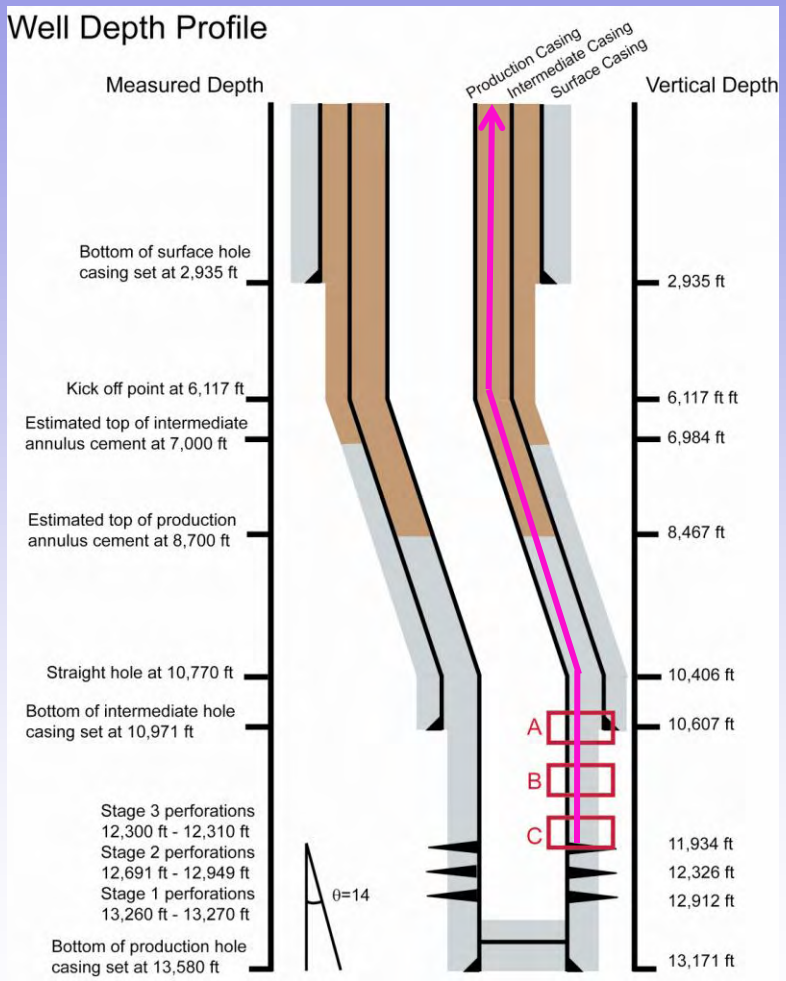


Fig. 12 - Low cement permeability results in long SCP buildup

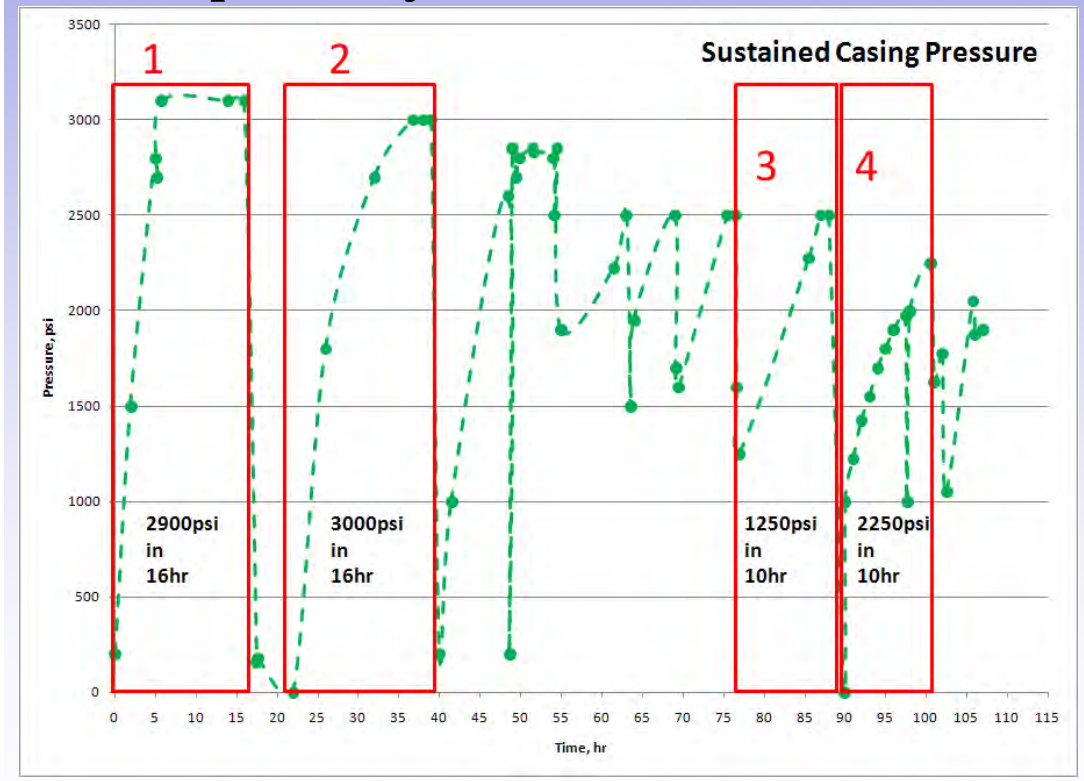
(Xu and Wojtanowicz, 2001)

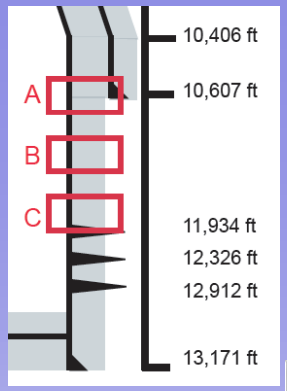
- If $P_{mud} + P_{gas} < P_{formation}$: Gas flow occurs
- Buildup rate controlled by permeability of cement
- Equilibrium P controlled by $P_{formation}$, height of the mud column

Field example of sustained casing pressure measurements

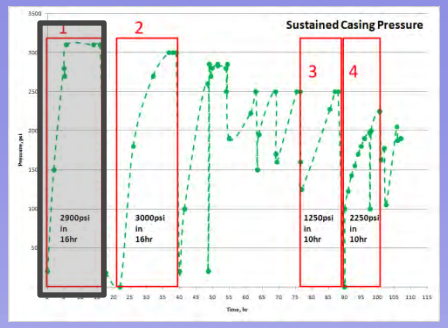


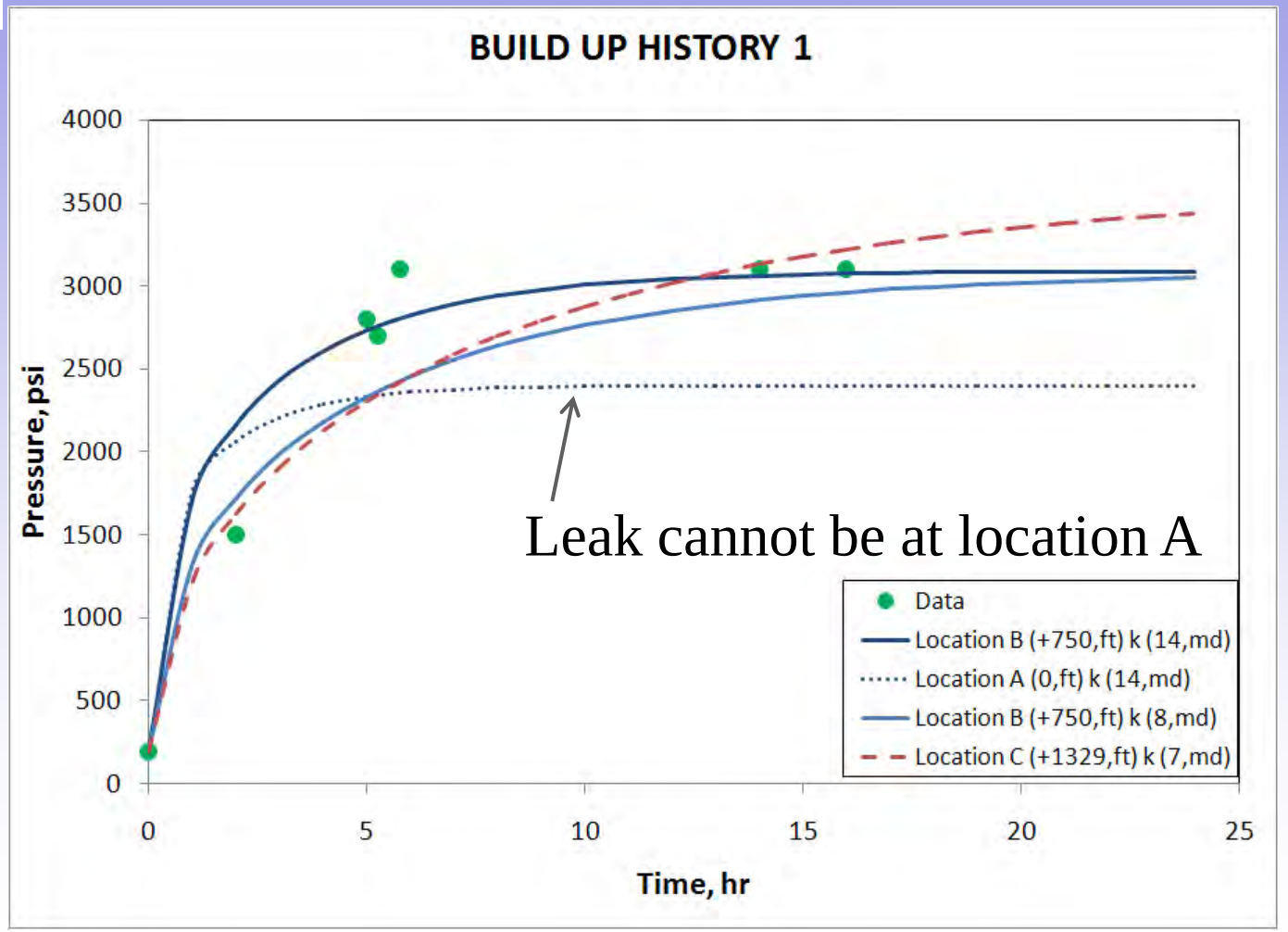
Build up history

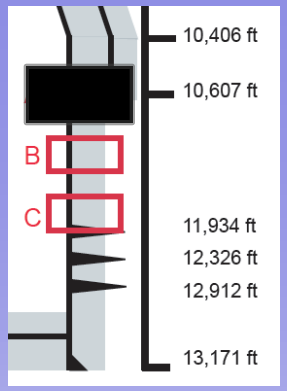




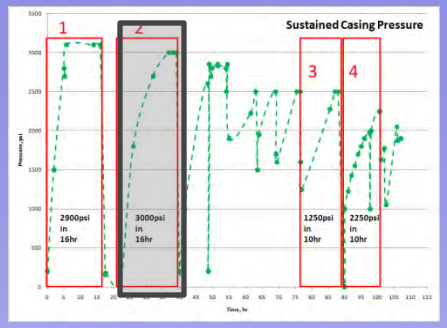
Analysis of build-up period 1

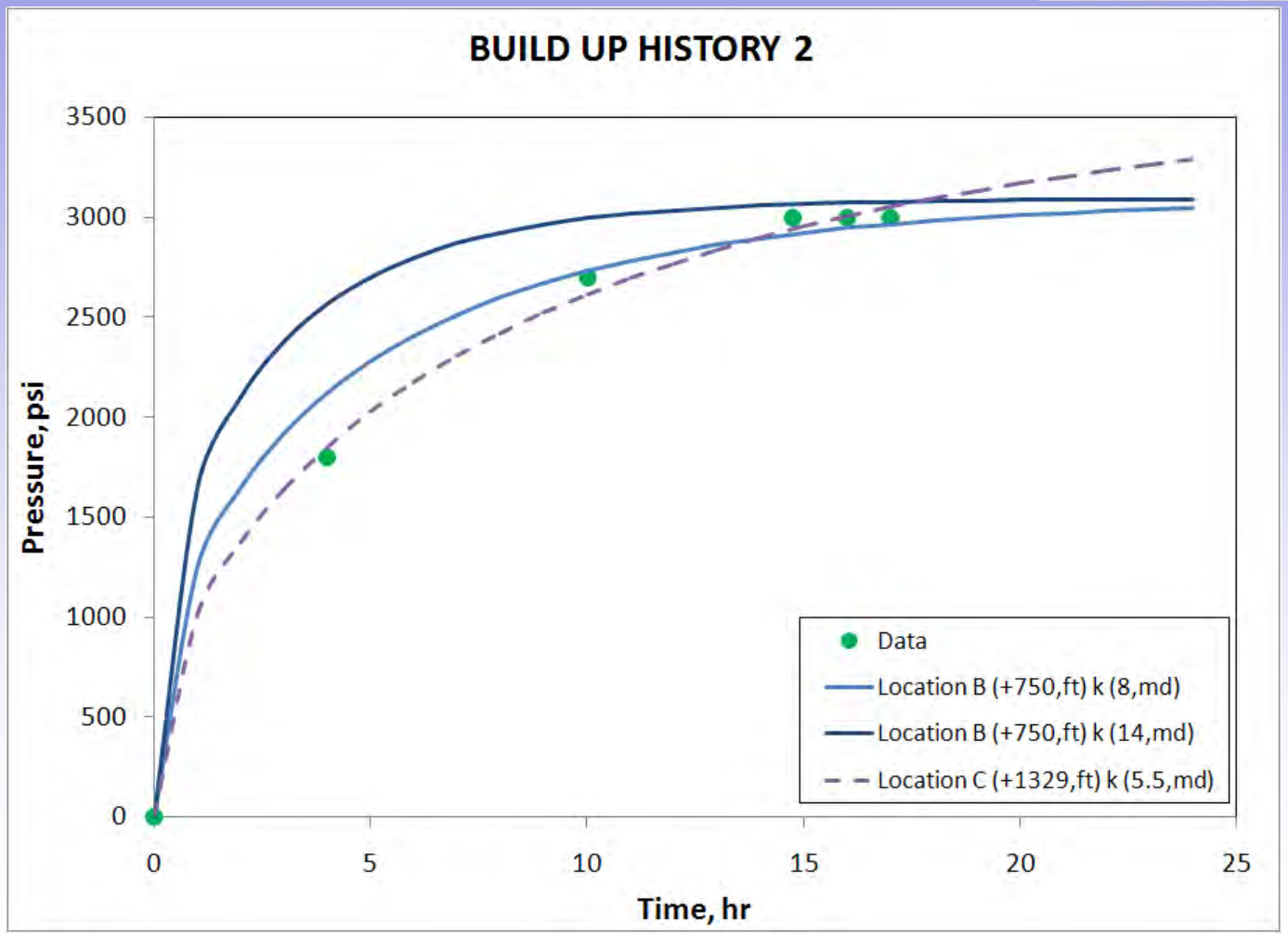


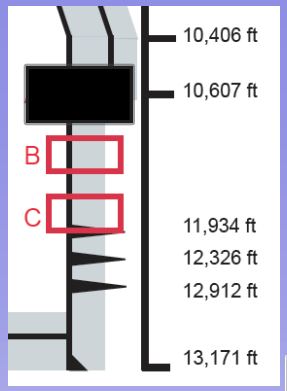




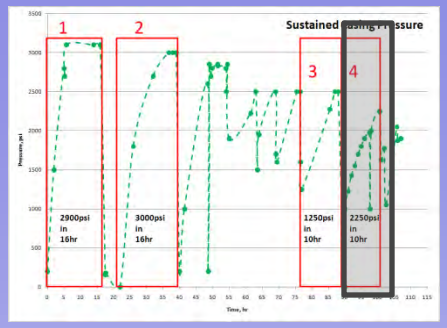
Analysis of build-up period 2

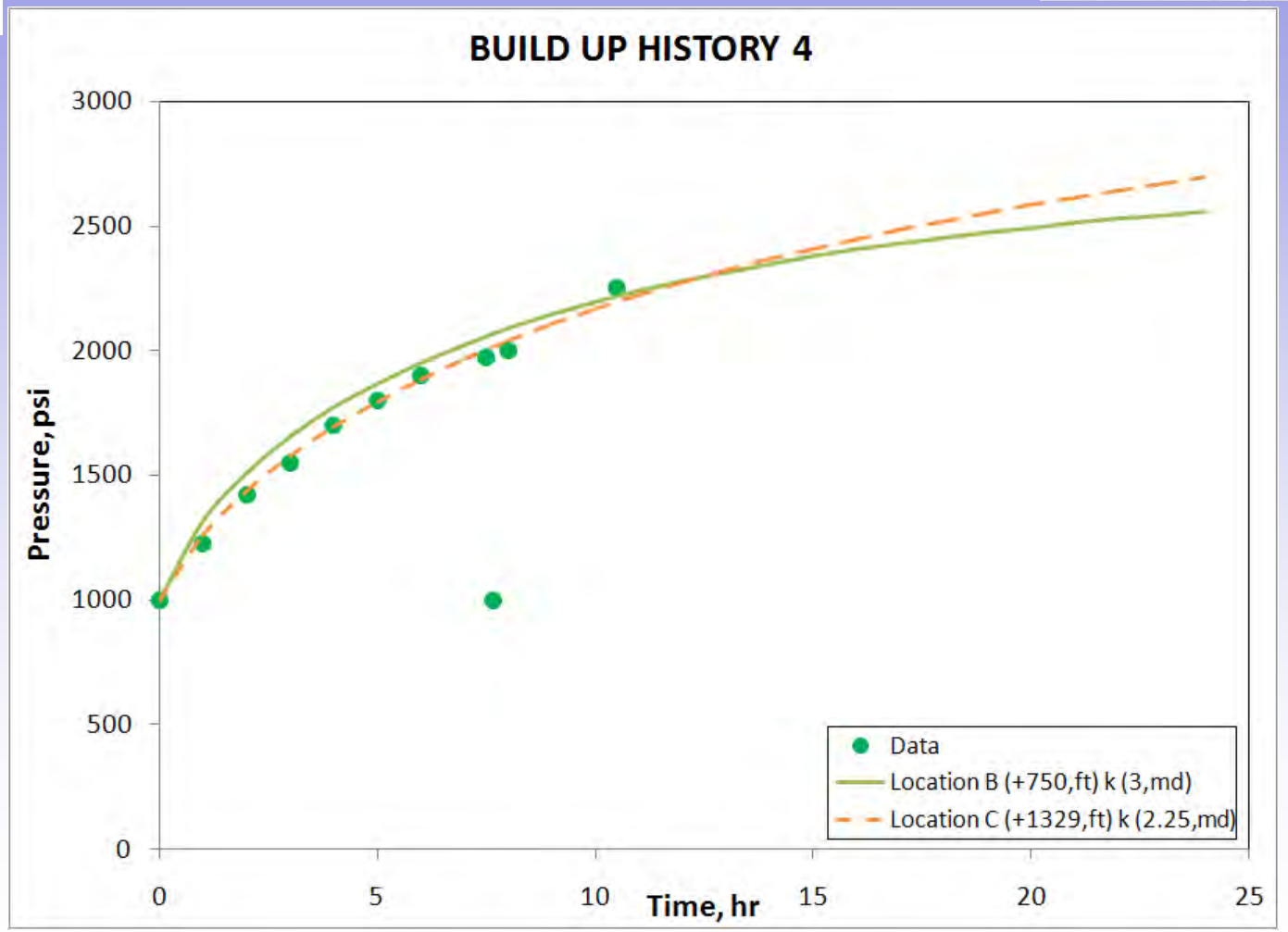






Analysis of build-up period 4





Summary of SCP

- Permeability is on the order of 1-10md
  - significantly higher than intact cement
- Depth of leak was significantly below the casing seat
- Lack of stable build ups prevents us from tying down a definitive depth

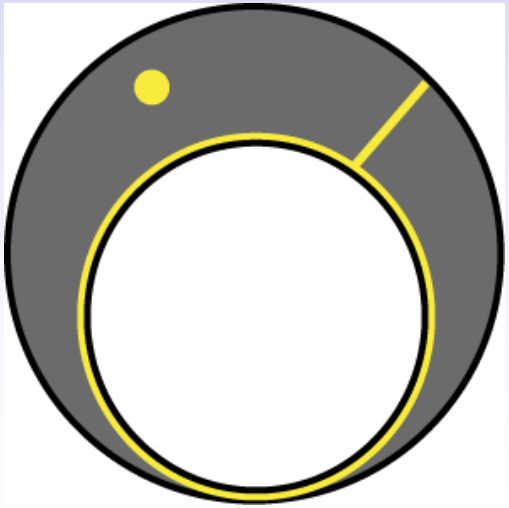
Equivalent Geometry for Leakage Path

- Permeability assumes leak distributed uniformly as matrix flow through the cement annulus
  - Unlikely situation, if $k_{leak} >> k_{intact\ cement}$
  - Continuum model difficult to use mechanistically in geomechanical and geochemical modeling
- Use shell momentum balance to compute plausible geometries for leak:

I. Gas channel

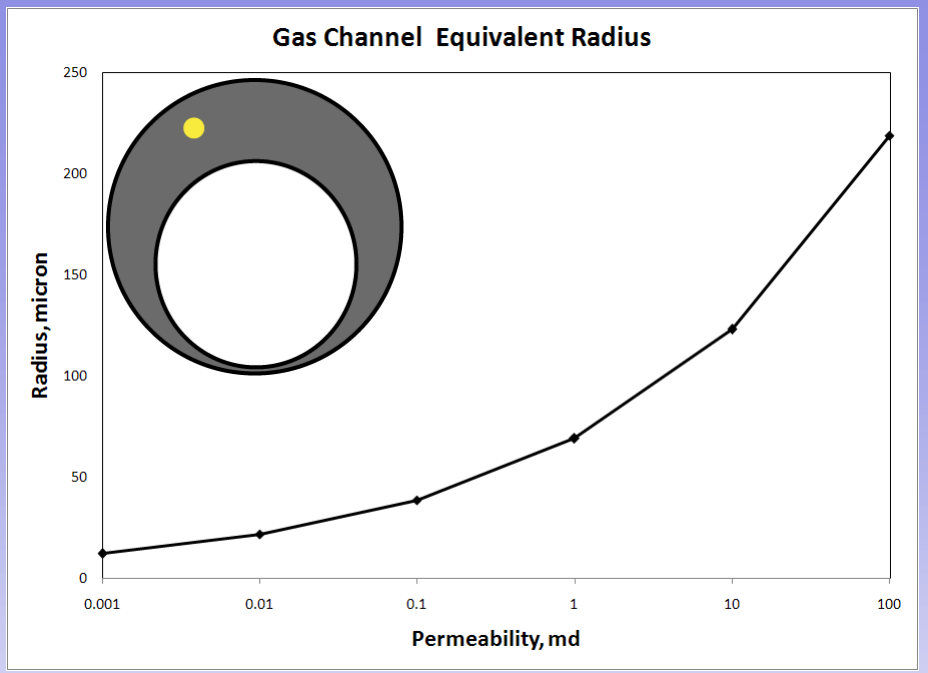
II. Fracture

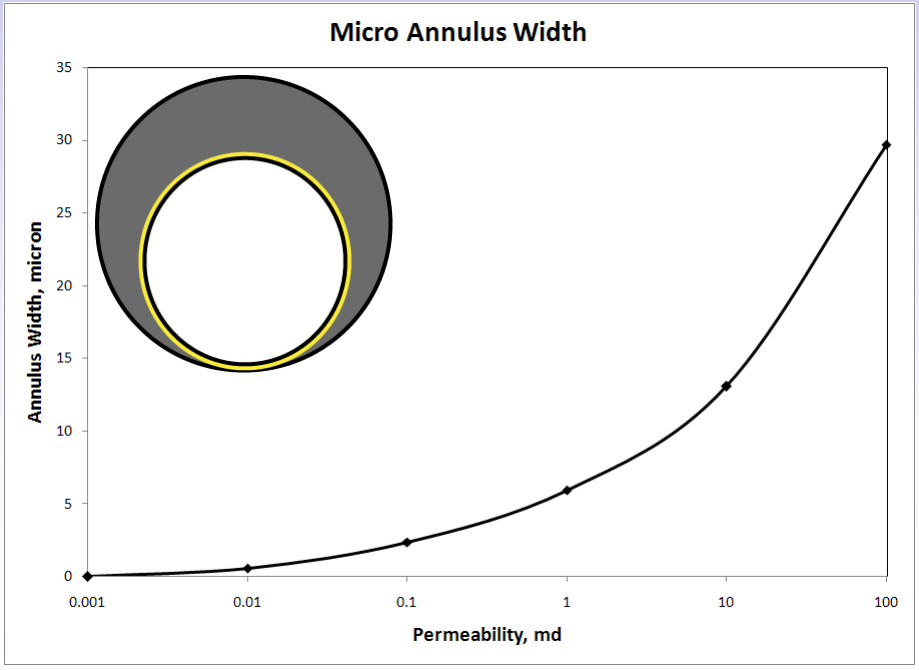
III. Microannulus

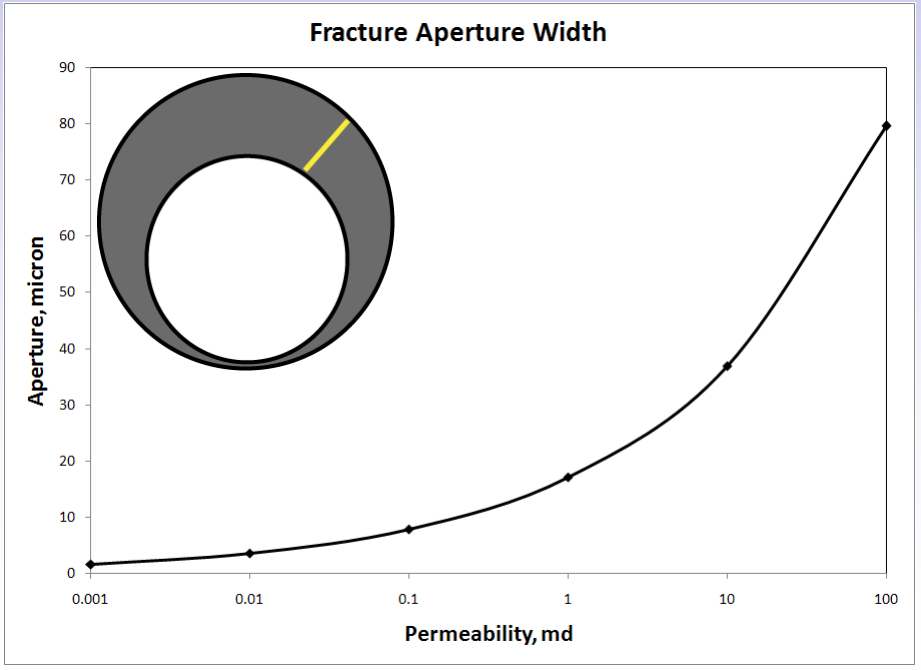


SCP in this well is consistent with several leakage path geometries

Permeability, md	8
Micro annulus thickness, μm	12
Fracture aperture, μm	30
Gas channel radius, μm	110





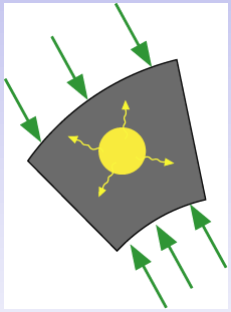


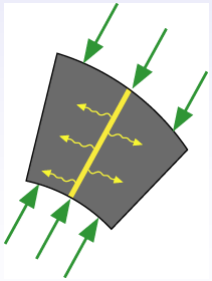
Results- Equivalent Geometry

- Values for equivalent geometry are not unrealistic
- Leakage pathway most likely one of these
  - SCP observed immediately after cementing
- Flow, geochemical alteration, geomechanical response in these geometries different than in a continuum matrix

Toward combination with geomechanical / geochemical models

- **What is the importance of enhanced stress/pressure on the cement due to (Boukhelifa, 2005):**
- Formation pressure increase
- Inner casing pressure increase
- Pressure increase below cemented annulus or plug
- **What would stress/pressure do to each geometry**
- Gas channel, not much ?
- Microannulus, a lot ?
- Fracture ?
- **How would cement degradation alter cement?**
- How would carbonation alter the leakage pathway ?
- Importance of geometry to chemical models





Conclusion

- Sustained Casing Pressure is useful analog for characterizing leakage paths involving wellbore cement
- Simple models combined with field data permit good estimates of
  - Effective permeability
  - Geometry of plausible leakage path

    *When: $k_{leak} >> k_{intact\ cement}$
- Expect geometry to provide better prediction of geomechanical/geochemical effects on CO2 leakage along cement/earth interface

Acknowledgements

- Geological CO_2 Storage Joint Industry Project
  - Chevron
  - CMG
  - ENI
  - ExxonMobil
  - Shell
  - TXU
- CCP2