LA-UR-14-27343
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Title: Failure (Escape of Fluids) of Wellbore Systems

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Intended for: Webinar presentation to CAFRACK, a California group interested in well integrity and hydraulic fracturing

Issued: 2014-09-19

Failure (Escape of Fluids) of Wellbore Systems

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September 22, 2014 • CAFRACK Web Seminar

Acknowledgements: LANL LDRD Program

What Does Wellbore Integrity Failure Look Like?

Crystal Geyser: CO_2 from abandoned well
http://www.4x4now.com/cg.htm

Deep Horizon Blowout
Natural gas and oil
http://whistleblowersblog.org
Credit: US. Coast Guard.
4 of 3533 wells drilled in Marcellus had blowouts (Considine et al. 2013 Env. Geosci)

Slow casing leak
Natural gas
Watson and Bachu 2007

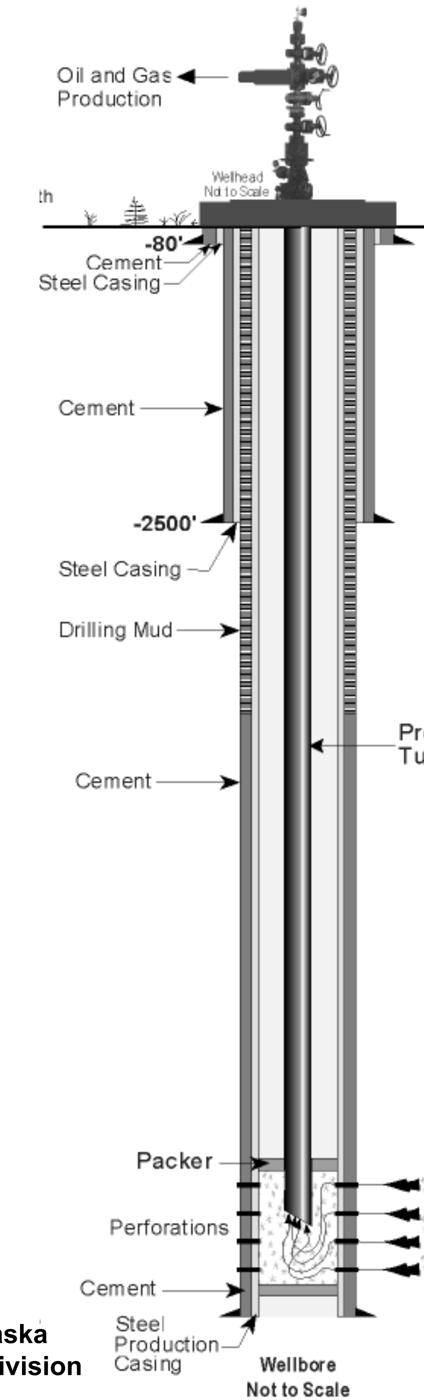
Why do wells leak?

Pre-Production

- Formation damage during drilling (caving)
- Casing centralization (incomplete cementing)
- Adequate drilling mud removal
- Incomplete cement placement (pockets)
- Inadequate cement-formation, cement-casing bond
- Insufficient cement coverage of well length
- Cement shrinkage
- Contamination of cement by mud or formation fluids

Post-Completion

- Mechanical stress/strain
  - Formation of micro-annulus at casing-cement interface
  - disruption of cement-formation bond
  - Fracture formation within cement
  - Role of well stimulation (fracking)?
- Geochemical attack
  - Corrosion of steel casing
  - Degradation of Portland cement
    - Carbonation
    - Sulfate attack
    - Acid attack



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Do Leaking Wells Impact Groundwater?

- A small fraction of well “violations” (about 10%) impact groundwater
  - see King and King (2013) on concept of multiple barriers
- Ohio (65,000 wells): 185 groundwater events in 25 years (12 per 100,000 well-years) from Kell 2011
  - 14 related to failure of subsurface well elements during production or injection (primarily corrosion)
  - 41 due to orphaned wells
- Texas (250,000 wells): 211 groundwater events in 16 years (5 per 100,000 well years) from Kell 2011
  - 7 related to well integrity failure
  - 28 due to orphaned wells
- Neither Texas or Ohio had known incidents related to well stimulation (fracking) (Kell 2011)
- Majority of incidents were not well integrity related
- Significant reductions in incidents with time
- “Well Leaks, Not Fracking, Are Linked to Fouled Water” (NYT `15 September 2014)

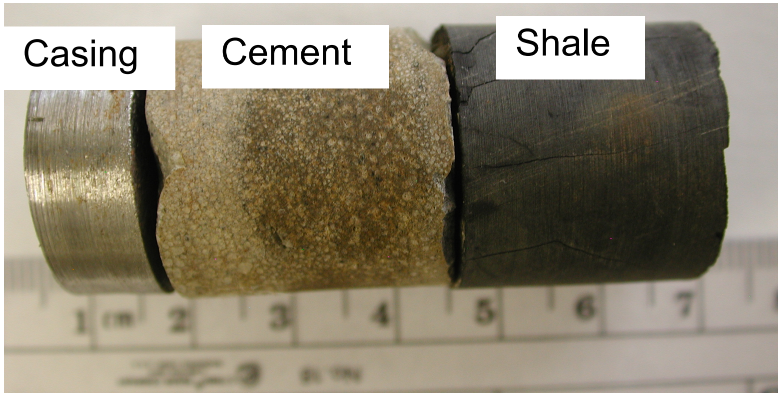
Field Evidence from Wells for Leakage

Migration of CO_2 behind casing

Miscible CO_2 Flood

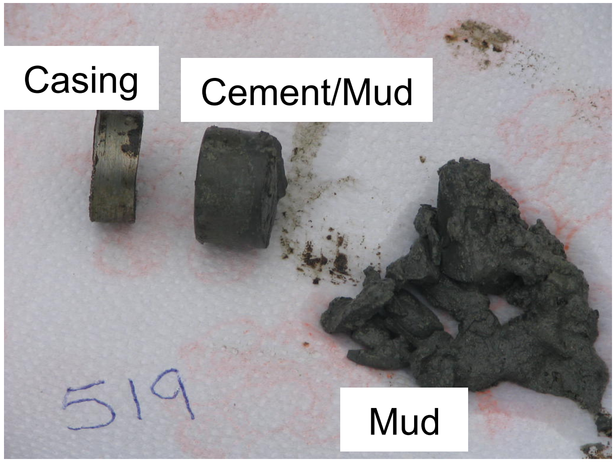
Carey et al. (2007) IJGGC

Natural CO_2 Reservoir



Crow et al. (2007) IJGGC

Immiscible CO_2 Flood

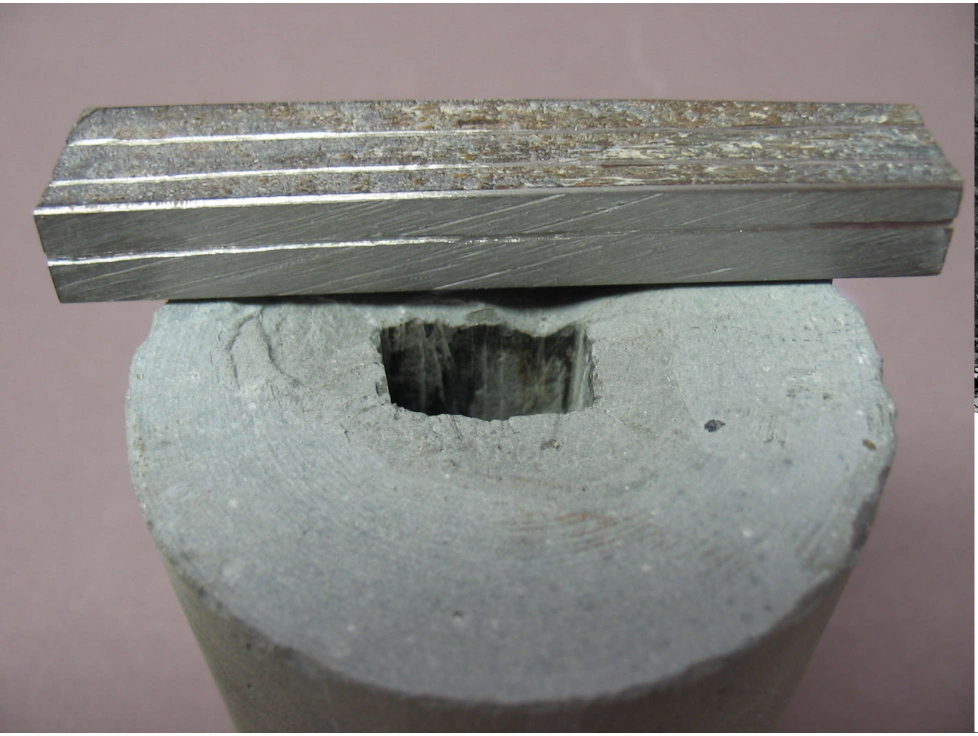


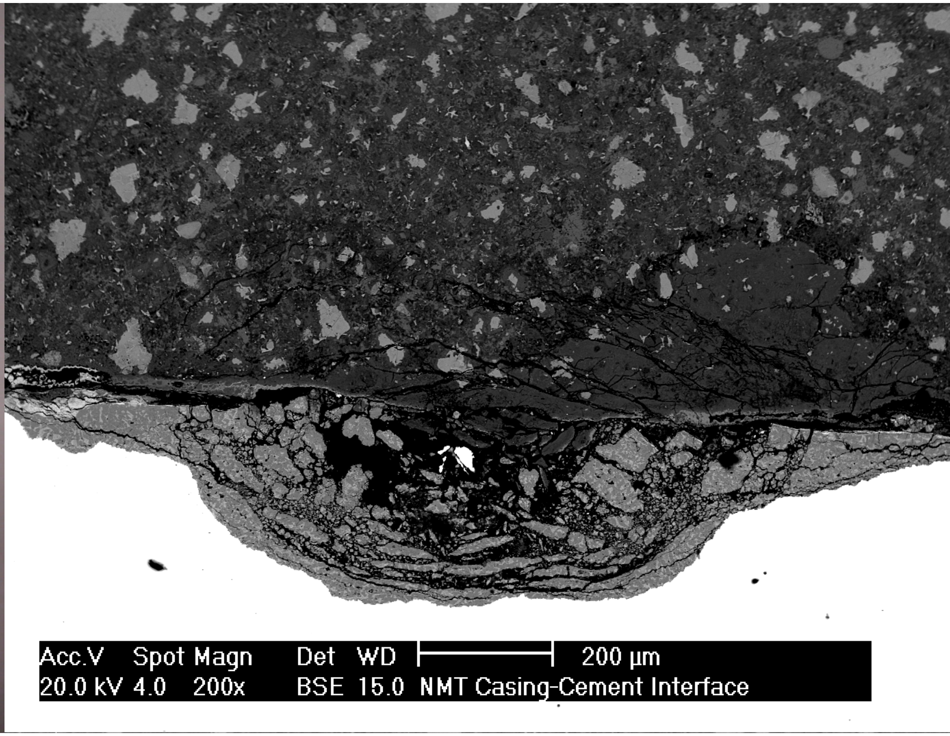
Crow, Carey (unpublished)

Duguid et al. (2014)

These findings were not associated with known groundwater impacts

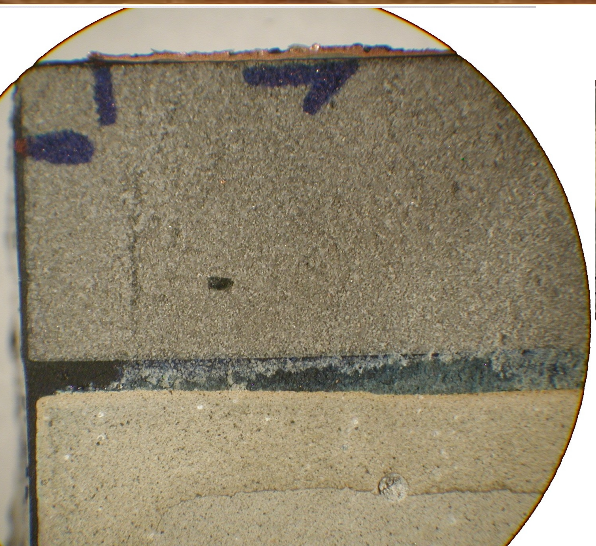
Experimental Studies of Wellbore Integrity: Self-Healing



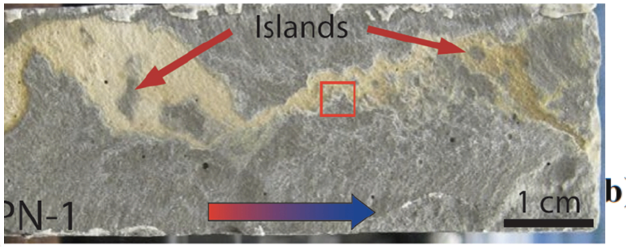


Corrosion Products Fill Defects and Reduce Permeability
Carey et al. (2010)

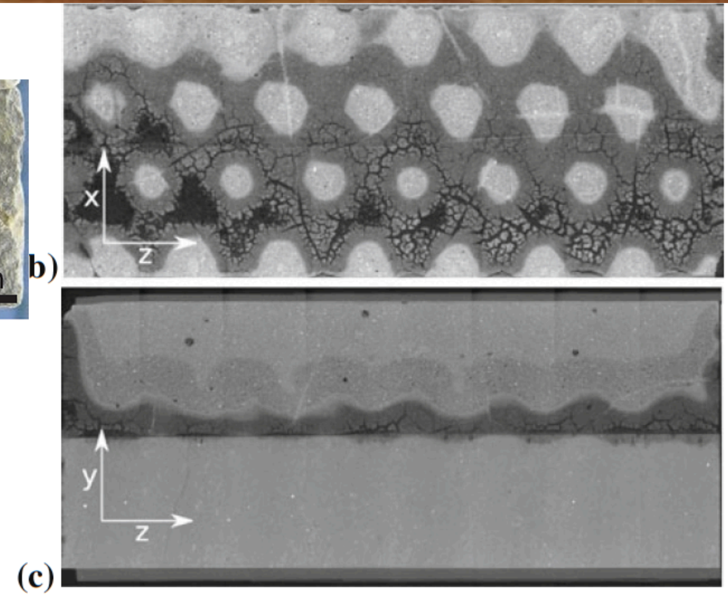
Experimental Studies of Wellbore Integrity: Self-Healing



Newell and Carey (ES&T 2013)



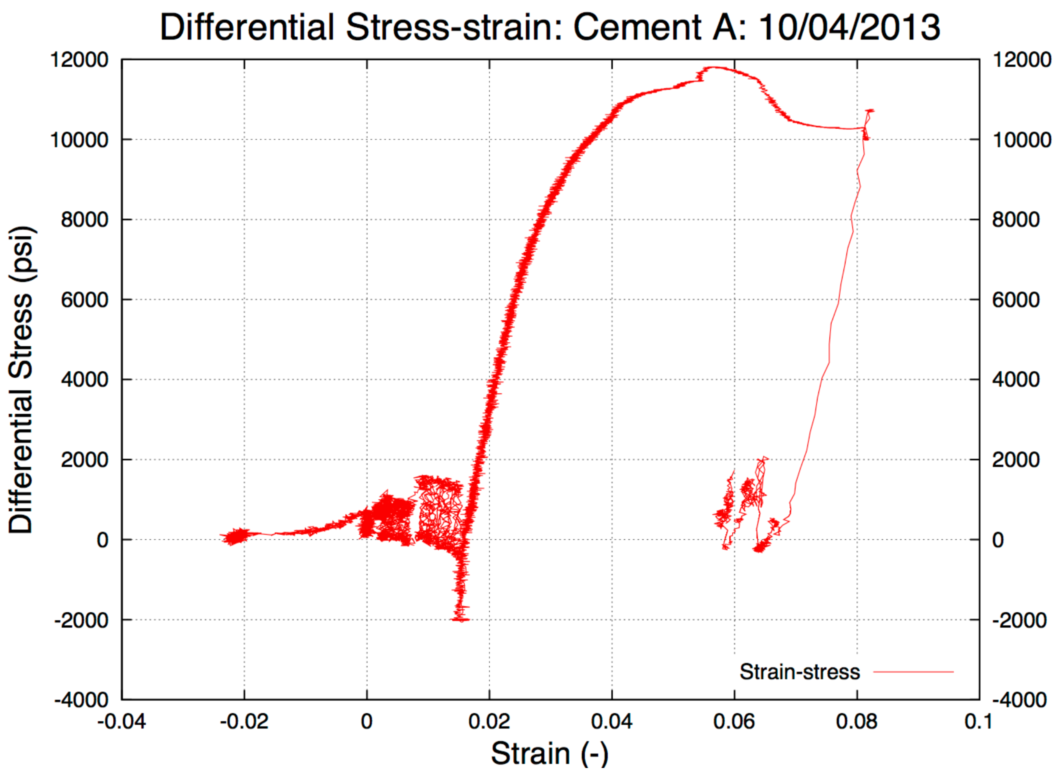
Huerta et al. (ES&T 2013)

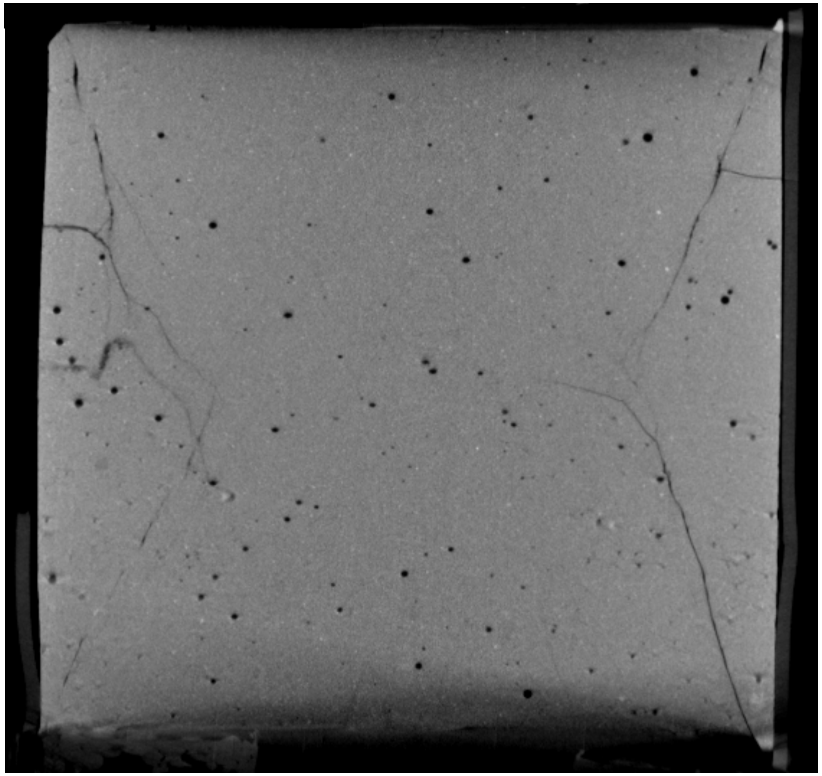


Walsh et al. (Rock Mech. Rock Eng. 2013)

- **Single phase (water+CO_2, water+HCl), multiphase (water+scCO_2, water +ethane)**
- **Diffusive carbonation of cement; no carbonate in interfaces**
- **Formation of leached layers of silica or other amorphous silicate**
- **Channelized fluid flow**
- **Migration of cement fines**

Plasticity in Deformation of Portland Cement





Permeability not
Measurable
at < 1 μD

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Do Well Defects Self-Heal?

- Field and experimental observations show reduced permeability at interfaces and in defects (Carey et al. 2007, 2010; Bachu and Bennion 2009; Huerta et al. 2013; Walsh et al. 2013; Luquot et al. 2013)
- Cement deformation may close annuli and defects (Liteanu and Spiers 2011; unpublished data)
- Corrosion may be limited by iron-carbonate precipitation (Carey et al. 2010; Han et al. 2011)
- A few studies have found enhanced permeability: Yalcinkaya et al. (2011); Luquot et al. (2013)
- Weak caprock can seal the external annulus (Williams et al. 2009; Ardila et al. 2009)

Does Hydraulic Fracturing Increase Risks of Damage to Wellbore Integrity?

- Hydraulic fracturing has been done for decades. What is new:
  - Horizontal, multi-stage
  - Larger injected volumes; different water chemistry
- Kell's 2011 work found no evidence for a link between groundwater contamination and HF
- Ingraffea et al. (2014) found distinctly higher notice of violations for unconventional wells in Pennsylvania
- Watson and Bachu (2007) found that deviated wells were more likely to develop sustained casing pressure or gas migration
- Opinion: HF isn't the issue so much as risks associated with additional O&G development

Conclusions

- There is abundant evidence that well integrity problems are real and can lead to groundwater impacts
- The rate of problems is small
  - Lustgarten's (2012) summary of UIC Class II violations finds 22 alleged groundwater incidents in 2008-2010 (150,000 wells nationally; rate = 5 per 100,000 well years). Note: CA = 12!
- Regulations, standards and testing can play a key role in minimizing impacts
- Geology (depth, natural fracture systems), density of old wells, and the character of USDW are clearly important to risk assessment
- Most groundwater impacts are related to surface oil and gas activities
- Experimental and field work suggest that most well integrity problems originate in the pre-production stage rather than stress-induced damage (e.g., Jordan 2012)

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