When rocks stop leaks: geological barriers in Well Integrity

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1

Poll Question

What is your main interest? (check all that apply)

2

Poll Question

What industry do you work in? (check all that apply)

3

Poll Question

Who is your employer? (check one)

Poll Question

What geographic region are you from? (check one)

Goals of this webinar

- Setting the scene
  - Well integrity and barriers: how do we prevent and control well leaks?
- Making wells safer with rocks
  - Can formations seal the annulus?
    - Evidence from literature and Paris, France
  - Why do some rocks "creep"?
    - And why they self-heal, again and again
    - Can we predict creep?
  - How can we engineer geological barriers?
- Wrap up, open questions and discussion

Definitions – well integrity

Webinars

- *"Application of [technical, operational and organizational] solutions to reduce **risk** of **uncontrolled release** of formation fluids and well fluids throughout the **life cycle** of a well"*
  - NORSOK D-010
  - Design ➔ Construct ➔ Operate ➔ Maintain ➔ Abandon
- Part of asset integrity
  - Ability of an asset to perform its function effectively, efficiently and **safely**
- System reliability
  - Probability of failure, under stated conditions for a given time

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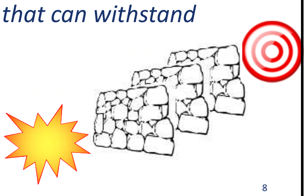
7

Definitions – barrier

Webinars

- *"Envelope of […] dependent **barrier elements** preventing fluids or gases from flowing unintentionally from the formation, into another formation or to surface"*
  - NORSOK D-010
- *"Containment elements that can withstand a specific **design load**"*
  - King & King, 2013
  - Mitigation (robustness)
- Barrier is a metaphor



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What if barriers fail?

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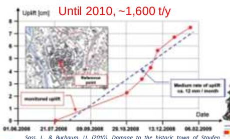
- Damage to resources
  - Drinking water (e.g. Navajo aquifer, US-UT)
  - Oil and gas reservoirs/storage
  - Geothermal energy
- Soil subsidence or uplift
  - OKN-32 (Algeria)
  - Staufen in Breisgau , Landau in der Pfalz (Germany)

Since 1981, ~2 10^7 t/y

Izri N.& Skander K. (2005). Le cratère d'effondrement du puits OKN32. Colloque International sur les Ressources en Eau Souterraines dans le Sahara, Ouargla (Algeria)

Until 2010, ~1,600 t/y



Sass, I., & Burbaum, U. (2010). Damage to the historic town of Staufen (Germany) caused by geothermal drillings through Anhydrite-Bearing formations. Acta Carsol, 39, 233-245.

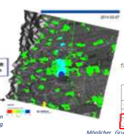


Tabelle 1: Auszug aus den Wasseruntersuchungen der Brauchwasserbrunnen des Geothermiekraftwerkes

	Festgestellter Wert in Brauchwasserbrunnen	Grenzwert Trinkwasserverordnung
Chlorid	bis 764 mg/l	250 mg/l
Natrium	bis 213 mg/l	200 mg/l
Arsen	bis 2,6 mg/l	0,01 mg/l

Möglicher Grundwasserschaden auf Grund des Betriebes des Geothermiekraftwerkes in Landau, FAQ (2014)

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What else if barriers fail?

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- Safety
  - Aliso Canyon
- Environment
  - Seeps and bug food
  - Greenhouse gases

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10

How about abandoned wells?

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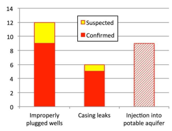
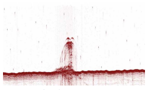
- LA basin, >70 fields produced since the 1890's
  - Playa del Rey (<1942) and Montebello (1930's) UGS leaks through P&A wells (Chilingar & Endres, 2005)
  - "Methane Seepage District Regulations", part of City of LA Building Code issued in 1985
- 9 confirmed aquifer pollution cases from brine injection through improperly P&A wells
  - US General Accounting Office, 1989
- Methane emission from two abandoned wells in Norway
  - IFM-GEOMAR, 2011
- Methane emissions from 19 wells in US-PA, 0.1 t/y, 6 10^4 background
  - Mary Kang, 2014





IFM-GEOMAR (2011) RV ALKOR Cruise Report AL374

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11

All well leaks are not equal

Webinars

- Blowouts
  - Low probability, through pipe or borehole
    - Very large, e.g. Aliso Canyon (US-CA) 0.5 Mt y^{-1}
- Annular leaks
  - Frequent, across long cemented intervals
    - Small, hard to spot: typically <0.5 t y^{-1} (up to 100 t y^{-1})
- Marginal safety risk
  - Intermediate collection zone
- Regulators and methane emissions
- Easy to spot offshore
  - Side-looking sonar, ROV

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12

Two sorts of geological barriers

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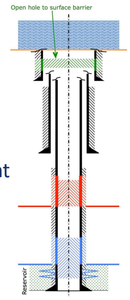
- In-situ formation
  - Around the borehole and annular seal
  - Caprock, permeable formation seal
- Creeping formation
  - Across the borehole
  - Annular seal, alone or together with cement
  - "Robust"
  - Clay matrix, rock salt, maybe ice?
- Geological annular barriers



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13

Early evidence of creep

Webinars

- Clark et al., 2005
  - Orange County, US-TX
  - 27 m section of shale, 865 m deep
  - Monitored closure process around tubing and pressure tested barrier
- Nicot, 2009
  - Why are leaks in Texas rare?
  - "natural barriers", such as heaving (creeping) shales or sink zones "might retard or prevent a leak"
- Rock salt as seal for radioactive waste repositories
  - Studies in Germany, but few publications
  - Experiment proposal for the Altmark gas field, Germany
    - CLEAN research project
    - Hou et al., 2011

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14

Creep meets O&G

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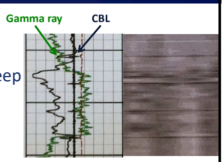
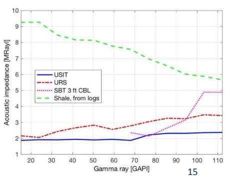
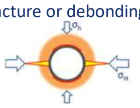
- Williams et al., 2009
  - Hordaland Green Clay, offshore Norway
  - Explained by viscoelastic/viscoplastic creep
    - Excluded osmotic swelling
- Catalyst of change
  - 2013 revision to NORSOK D-010, adding "creeping formation"
  - JIP on shale for abandonment
  - Clay rush in the North Sea
- Issues
  - Failure mode? Fracture or debonding?
  - Role of logs?







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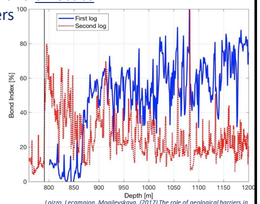
15

Creep in the Paris Basin

Webinars

- Gault Clay
  - Above Albian-Neocomian fresh water aquifers, ~800 m deep
  - Outcrops contain mostly kaolinite, illite and smectite
  - Other creeping layers protecting aquifers
- Evidence
  - Drilling and milling
  - 2 CBL logs, 21 years apart
    - Before 2nd log, pressure was increased to 9.1 MPa
    - Cement debonded, clay "rebonded"
  - Flow rate during test roughly consistent with local stress regime
    - Closure stress gradient ~250-500 kg m^{-3} ED



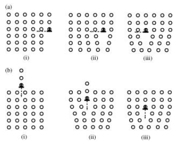
Loizzo, Lecampion, Mogilevskaya. (2017) The role of geological barriers in achieving robust well integrity, Energy Procedia

16

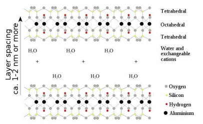
Why do rocks creep?

Webinars

- Rock salt
  - Dislocation glide and jump (around inclusions)
    - Solution-precipitation…
  - Temperature, stress, structure, water/gas inclusions
  - Mostly halite (NaCl)
    - Carnalite (K salt) higher rates
- Smectite
  - a.k.a. montmorillonite or bentonite
  - Swelling clay
  - Dislocation glide
- (Visco)plastic deformation



Danas & Deshpande. (2013) Plane-strain discrete dislocation plasticity with climb-assisted glide motion of dislocations, Mod. Sim. in Mat. Sci. and Eng.



Andreas Trepte, Image:Montmorillonit.svg, CC BY-SA 2.5, Wikipedia

17

Modeling creep

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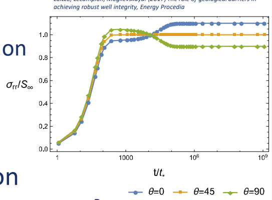
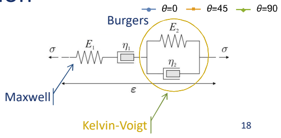
- Key questions
  - What is the closure stress on a microannulus?
  - How long does it take to bridge the annulus?
- Viscoelastic approximation
  - Properly calibrated
    - Model agnostic

Loizzo, Lecampion, Mogilevskaya. (2017) The role of geological barriers in achieving robust well integrity, Energy Procedia





18

Modeling – looking under the hood

- Laplace or time domains
- Finite elements
  - Very difficult with steady-state creep (Maxwell dashpot) and anisotropy
    - Rock "flows" around wellbore
    - Must impose far-field stress and no displacement
- Analytical
  - Multi-layer, anisotropic far-field stress

19

Engineering geological barriers

- Cannot be designed…
  - …but if present can be part of well design
  - Opportunity and frustration
- Key questions:
  - How do we spot them?
  - What is their safe operating envelope?
    - And mitigation potential
  - How long does it take to gain and regain bond?
  - How best can we use them for well construction and abandonment?

20

Finding and qualifying geological barriers

- Any smectite-rich clay matrix is a good candidate
- Logs
  - Caliper, triple combo
  - Cement evaluation
    - CBL great, but time-lapse logging is essential
    - Viscosity parameters
    - Ultrasonic mapping tools using cement and casing
  - Geomechanical characterization (mechanical properties, stresses)
- Pressure test or casing instrumentation/monitoring

21

Conclusions

- Creeping formations are ideal barriers
  - Robust, self-healing
  - Key role in well abandonment
- Finding, understanding and predicting
  - Risk assessment
    - Leakage pathways through the well lifecycle
  - Careful characterization planning

22

Open questions

- How do geological barriers fail?
- How do we determine stress regimes cheaply?
  - Closure stress with shales/marls less than horizontal stress
- How do we predict creep parameters from logs?
- Involving regulators and sharing barrier characterization at basin scale

23

Thanks

- Chris Jenkins, Marcel Boucher and Andrea Kuesters, for making this webinar possible
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