Wellbore Integrity for Unconventional Reservoirs

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US DOE/NETL

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Presentation Outline

Effects of Pressure and Temperature Cycling on Microannular Crack Formation
Eilis Rosenbaum (PI)[1], Dustin Crandall[1]; 1. Department of Energy-National Energy Technology Laboratory

Characterize Physical and Chemical Conditions that Affect UOG Wellbore Integrity
Eilis Rosenbaum (PI)[1], Barbara Kutchko[1], Mehrdad Massoudi[1], Igor Haljasmaa[1,2], Richard Spaulding[1], James Fazio[1,2], Kaushik Dayal[3,4], Chengcheng Tao[1,3], Julie Vandenbusche[5]; 1. Department of Energy-National Energy Technology Laboratory, 2. LRST, 3. Oak Ridge Institute for Science and Education, 4. Carnegie Mellon University 5. University of Pittsburgh

Mineral Scale Precipitation Mechanisms on Unconventional Production String Components
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Technical Status

Effects of Pressure and Temperature on Microannular Crack Formation

Goal

- Improve the understanding of the causes for loss of well integrity due to stresses induced on the well system by thermal and fluid pressure influences

Challenge

- The well system is comprised of materials with significantly different properties.
- Thermal and fluid pressure changes and cycling during regular well operations can have a deleterious effect on the well system.

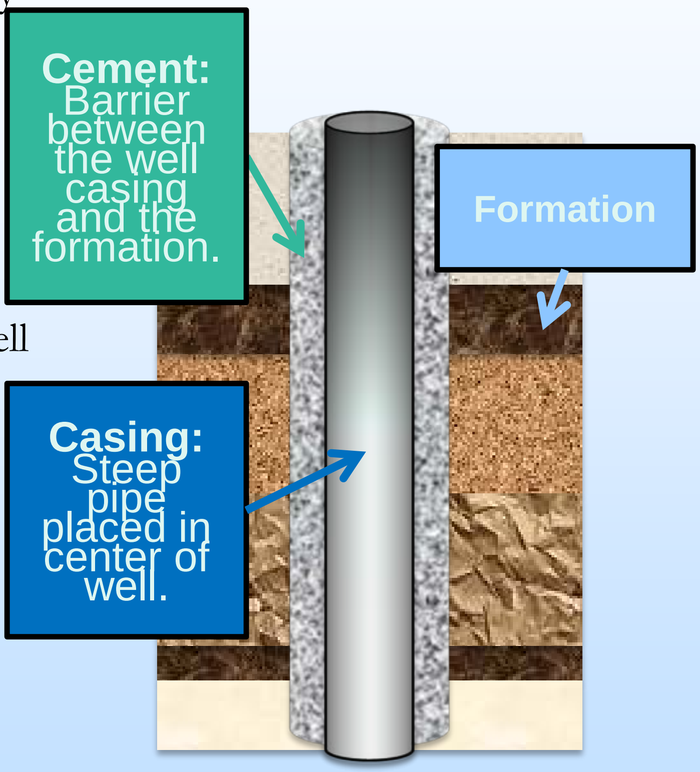
Research Question

- What conditions cause well instability and loss of well integrity?

Approach

- Study the interfaces of the casing-cement-rock system.
- Experiments with laboratory-scale casing-cement-rock system at relevant conditions.
- Develop a model or partner with another entity that has a model.
- Collaborative effort with Industry and other potential partners (DEP, universities).

Well Structure



Effects of Pressure and Temperature on Microannular Crack Formation

Motivation

- Maintaining well integrity is critical for long-term performance of any unconventional well.
- Detailed understanding is lacking for the subsurface geomechanics where all parts of the well system are studied as a whole.

Background

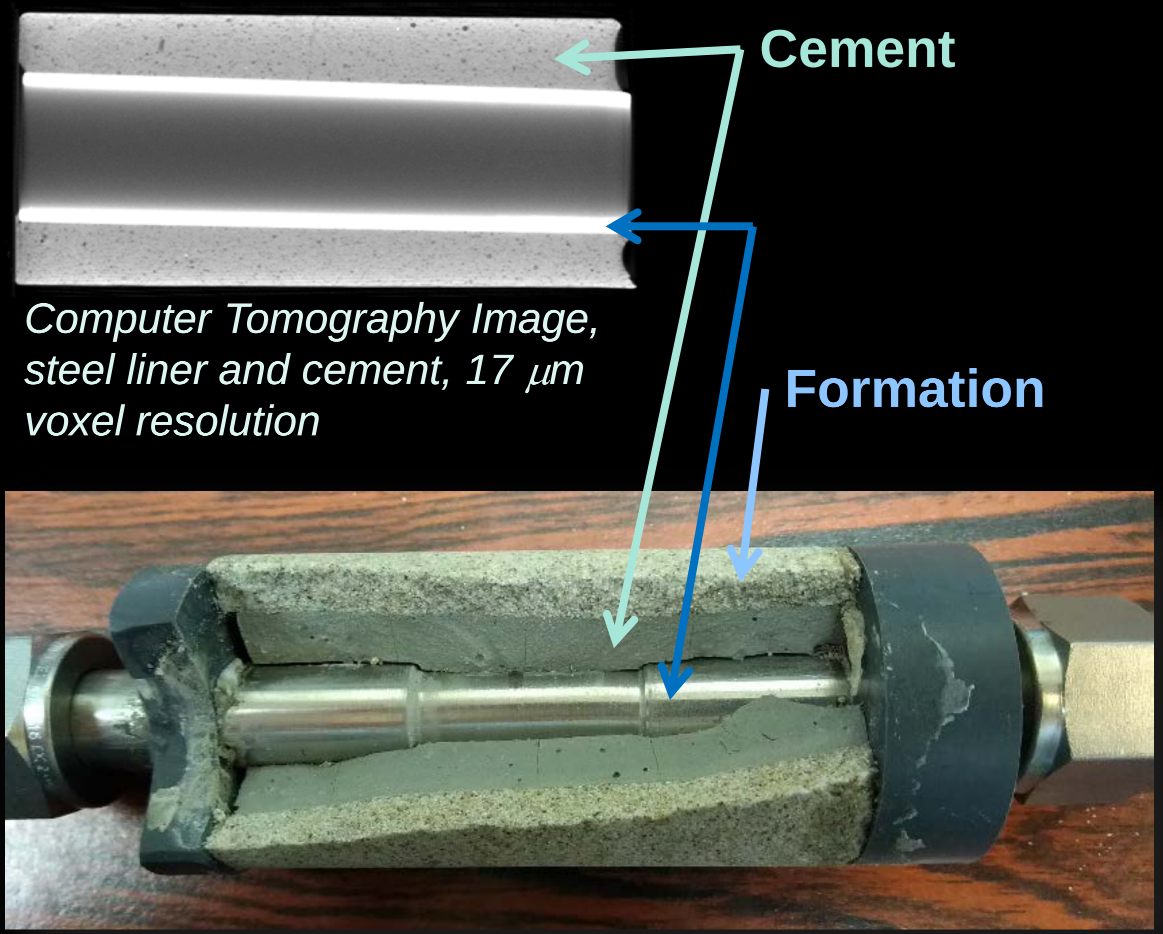
- Casing-cement-rock system is designed and built.
- System tested in Computer Tomography Scanner.
- A method to cause system failure (loss of isolation) has been developed.

Outcomes

- Preliminary results show that the interfaces can be distinguished in the CT Scans.

Effects of Pressure and Temperature on Microannular Crack Formation

Experimental Casing-Cement-Rock System



Shown after intentional failure event

Technical Status

Physical and Chemical Conditions that Affect UOG Wellbore Integrity

Goal

- Minimize drilling risks in the onshore environment by better defining the conditions that could affect the UOG wellbore integrity.

Problem

- Gas invasion into the wellbore cement after placement can lead to loss of well control or freshwater contamination.
- SGS (Static Gel Strength) is current standard testing method for cement.
  - Overestimated – costs money.
  - Underestimated – safety and environmental issues possible.
- Previous research: NETL and U. of Pittsburgh → Limitations of SGS alone to prevent fluid migration.

Research Question

- What other method/measurement can better identify when cement has gained sufficient strength?

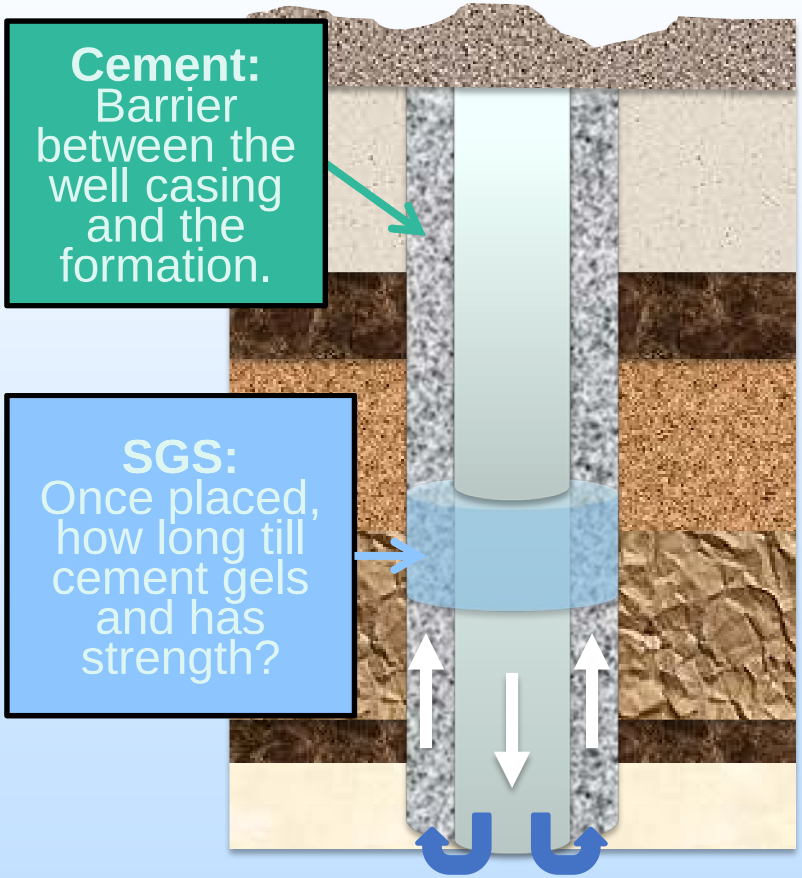
Approach

- Experiments with wellbore simulation chamber under realistic onshore wellbore conditions.
- Constitutive cement model – cement flow at onshore wellbore conditions.
  - Collaborative effort with Industry (API), University of Pittsburgh, DEP

Physical and Chemical Conditions that Affect UOG Wellbore Integrity

- Gas can migrate into the cemented annulus of a wellbore before early gelation when hydrostatic pressure within the cement slurry drops
- SGS is the most widely accepted method in describing the strength development of hydrating cement
- However, SGS does not accurately predict gas migration

Crook and Heathman, 1998



Physical and Chemical Conditions that Affect UOG Wellbore Integrity

Motivation

- Fluid migration into unset cement still occurs.
- High importance to American Petroleum Institute.

Background – University of Pittsburgh

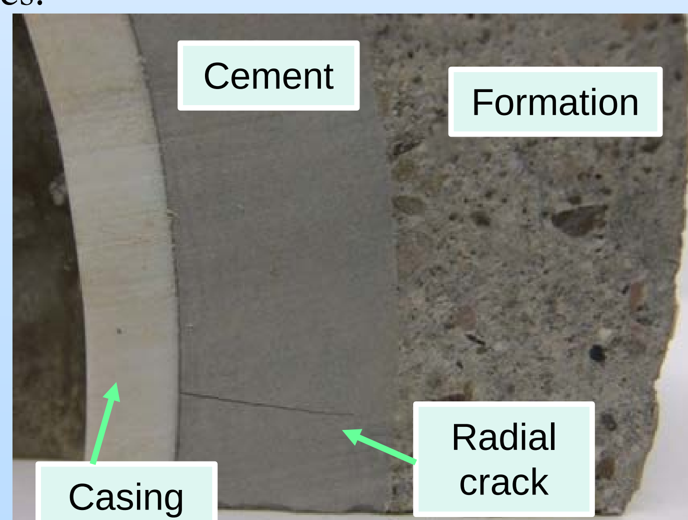
- Wellbore Simulation Chamber (WSC) can simulate onshore well conditions.
- Testing methods have been developed.
- NIST hydration model for elastic properties.
- Early findings: w/c ratio and formation porosity are key factors in determining transition time

Outcomes

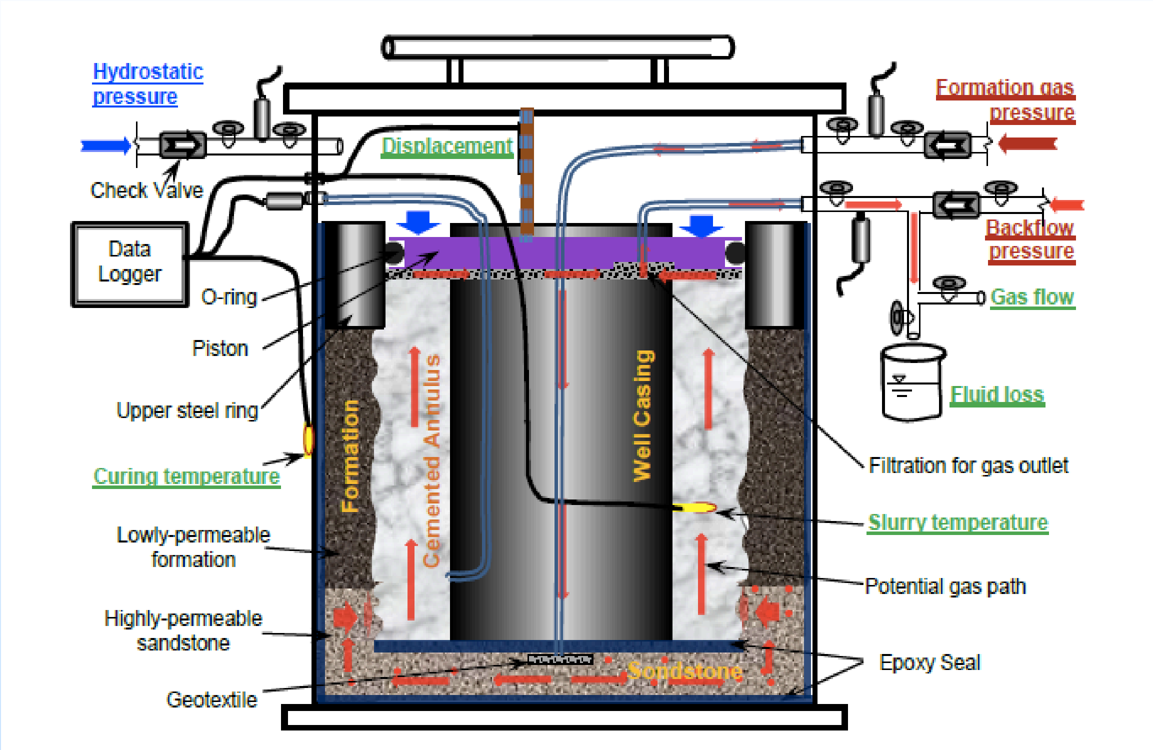
- Showed limitations of SGS - need fundamental property.
- Existing model has limitations in regards to viscous properties.

Max 1500 psi
(~depth 1850 ft)

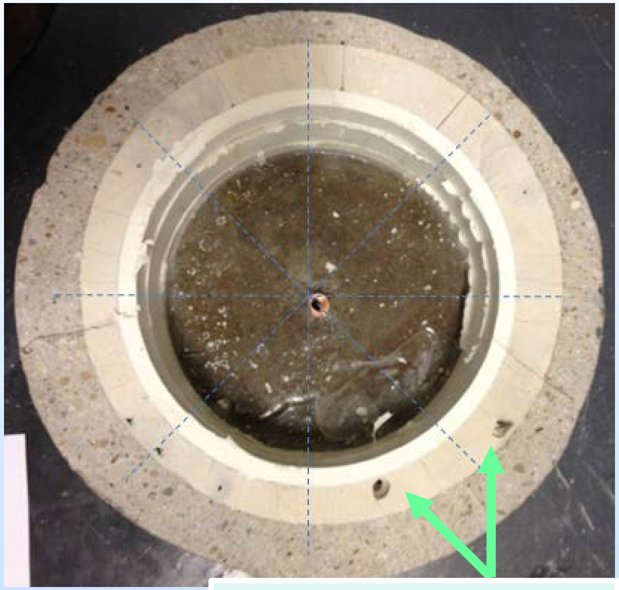
20°C to 60°C



Physical and Chemical Conditions that Affect UOG Wellbore Integrity



University of Pittsburgh's
Wellbore Simulation Chamber



Previous experimental work at
University of Pittsburgh

Theory-Based Review of Limitations with Static Gel Strength in Cement/Matrix Characterization, SPE-178923
A Newly Developed Wellbore-Simulation Apparatus to Study Performance of Oilwell Cements, SPE 191129

Technical Status

Mineral Scale Precipitation Mechanisms on Unconventional Production String Components

Goal

- The objective of the effort is to investigate mineral scale deposition on wellbores (i.e. barite, calcite) including scale reaction rates and possible inhibitors.

Challenge

- Scales will coat perforations, casing, production tubulars, valves, pumps, and downhole completion equipment ***limiting production and eventually requiring abandonment of the well*** (see Figure).

Approach

- Use laboratory experiments and field samples for direct observation and characterization.

Barite deposition in casing (pipe) during production. *From Stack, https://www.epa.gov/sites/production/files/documents/stack.pdf*

This project is only in its first year – so we will only be discussing laboratory experiments in this presentation

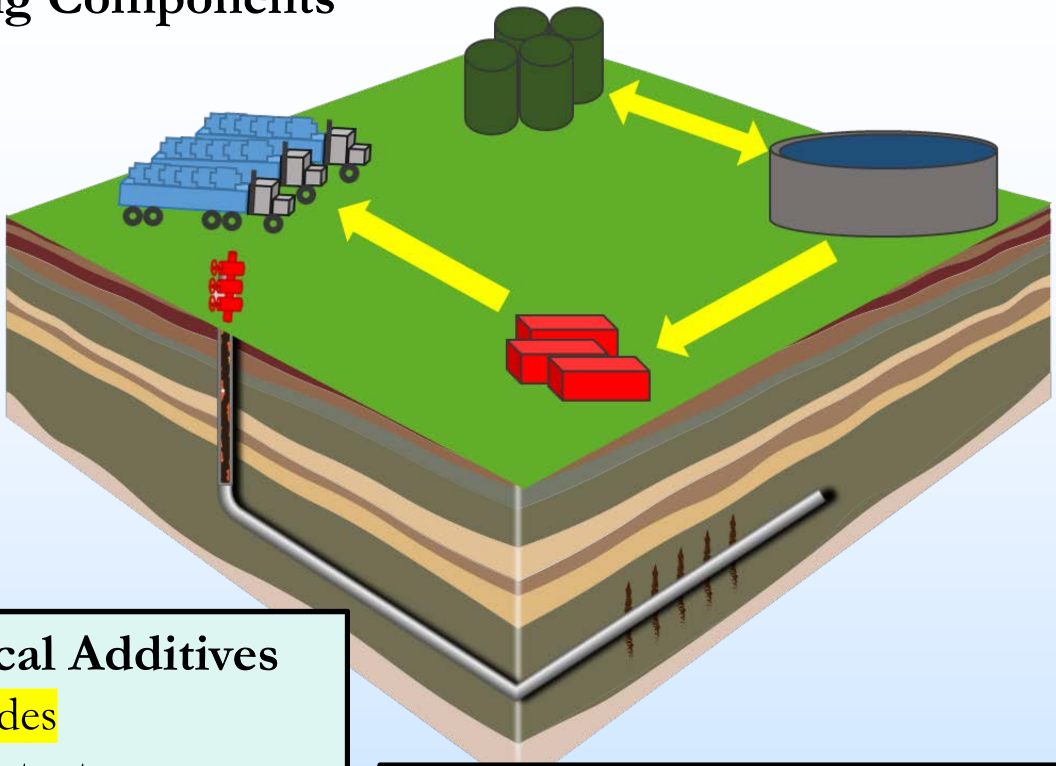
Mineral Scale Precipitation Mechanisms on Unconventional Production String Components

Fracking is an impressive combination of complex aqueous chemistry, fluctuations in pH, pressure differentials and surface complexation sites (i.e. chokes, changes in flowpath directions, surface defects, etc.).

Comprises 60%-70% of the total cost of the well (EIA, 2016).

Image of completion operations on MSEEL pad (MSEEL.org)

Mineral Scale Precipitation Mechanisms on Unconventional Production String Components



Production water

- High TDS
- High Salinity and Ionic Strength
- High Alkaline Earth Metals

Surface Water

- Low TDS
- High SO_4
- Organic Matter
- Microbiology
- Supersaturated relative to sulfate minerals

Chemical Additives

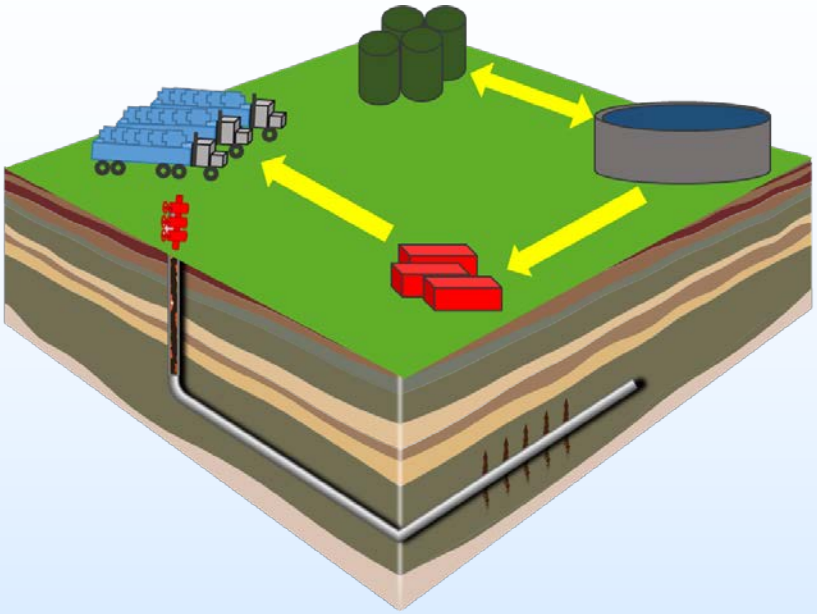
- Biocides
- Surfactants
- Cross Linkers
- Scale Inhibitors
- Buffers
- Gelling Agents
- Breakers
- Friction Reducers
- Clay Stabilizers
- Corrosion Inhibitor

Injected at High Pressure

- Increases in pressure
- Interaction with steel production string during injection and "soak"

Aerated, caustic fluid supersaturated in minerals....

What is going on within the wellbore?



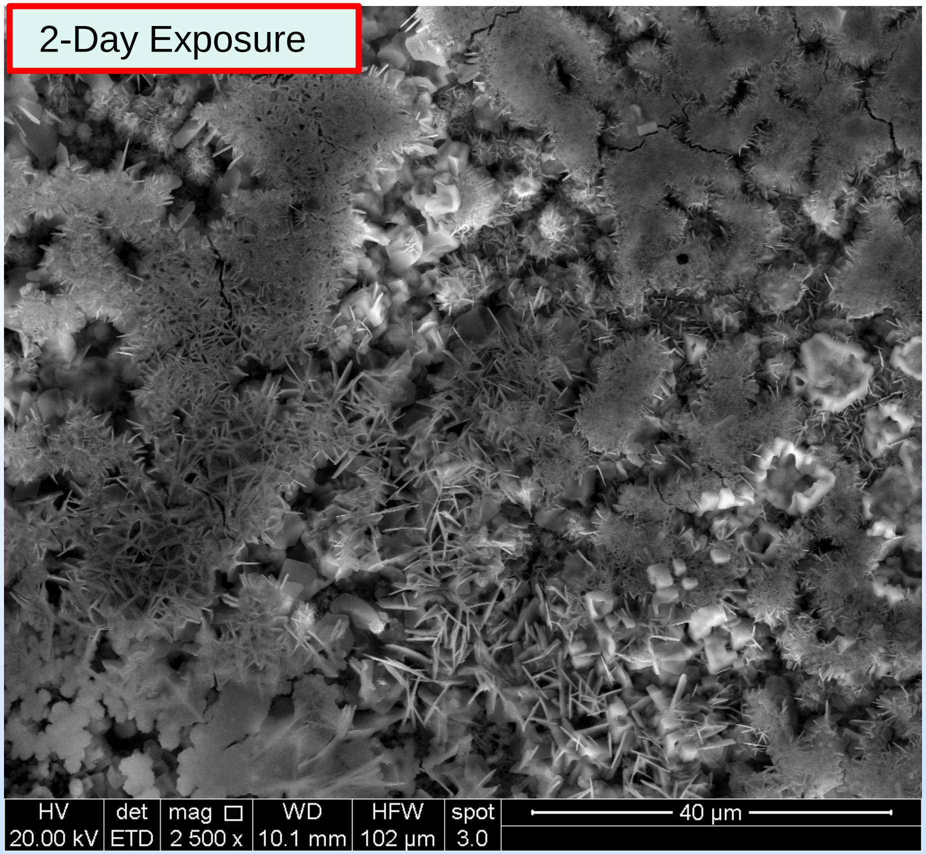
Research Questions:

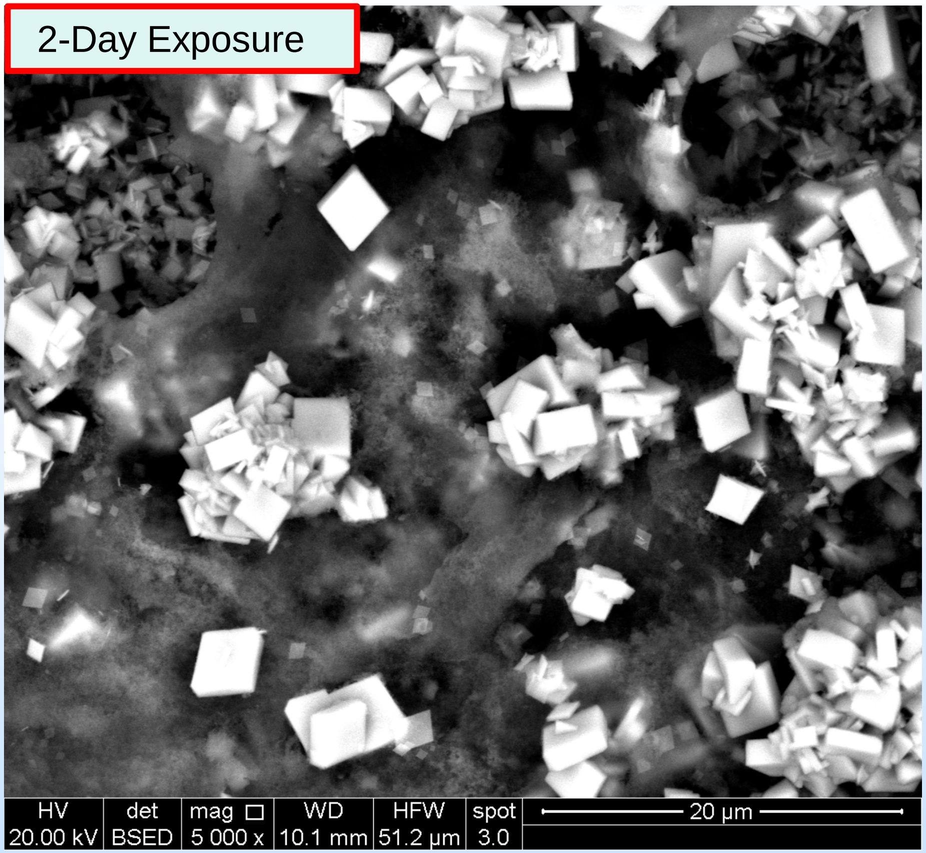
- What minerals reactions are occurring within the production string during the shut-in period?
- What is the timing of mineral precipitation?
- Are current water management practices sufficient to inhibit its formation?

Approach:

- Low carbon steel samples
- Exposed to aerated synthetic HFF
  - (50^{o}C, 2000 psi)
- Nitrogen atmosphere
  - 2, 7, 14, and 28-day intervals.

Mineral Scale Precipitation Mechanisms

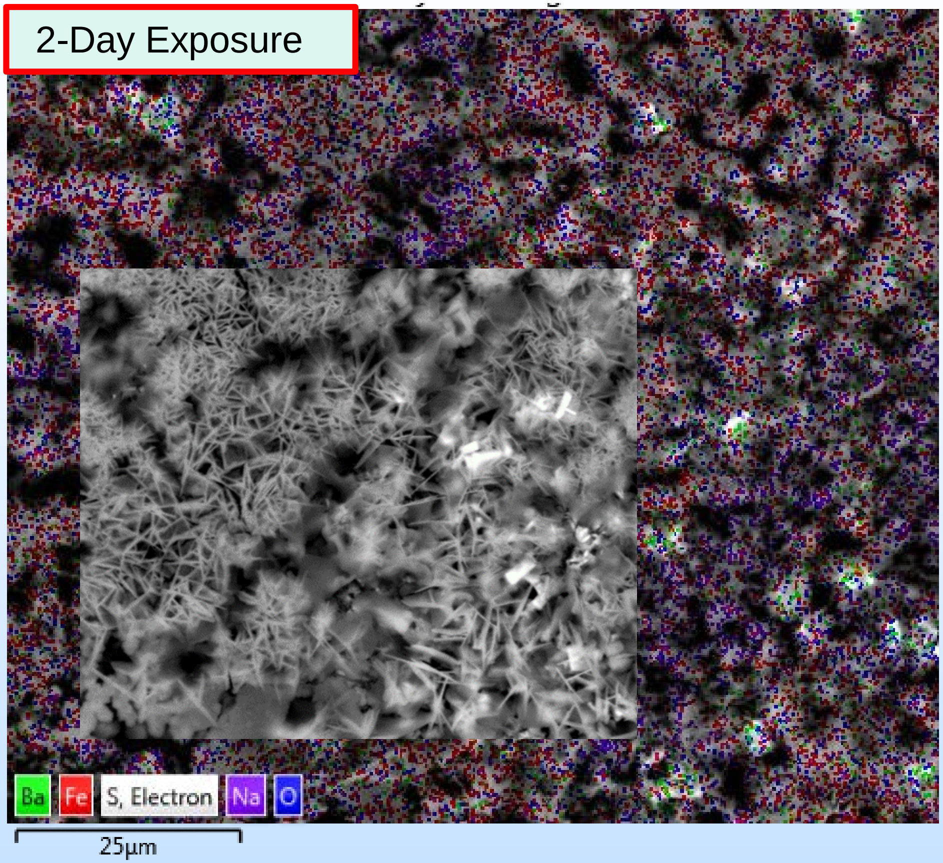


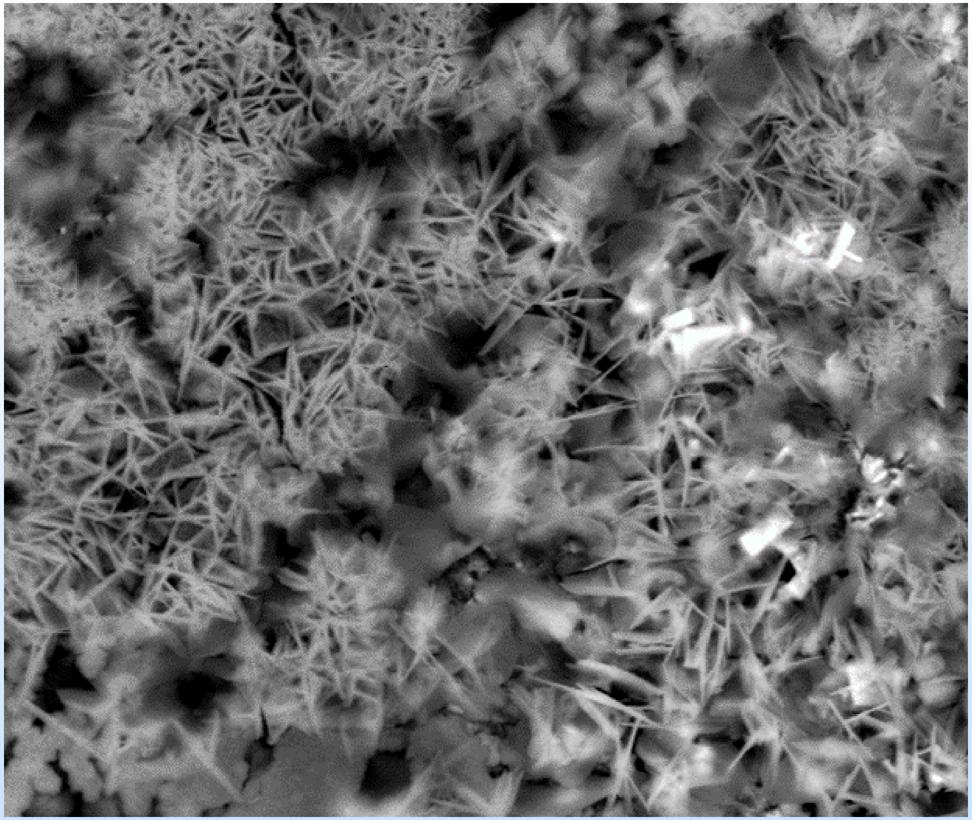


- **FeOOH** occurred in mixed morphologies of amorphous, fibrous and flakey
  - No chloride.
  - Mainly Lepidocrosite (iron oxide-hydroxide mineral)

- **$BaSO_4$ Crystals**
  - Euhedral with tabular crystal habit
  - Both single crystal and twinned aggregates
  - On surface and within interstitial corrosion fabrics

Mineral Scale Precipitation Mechanisms



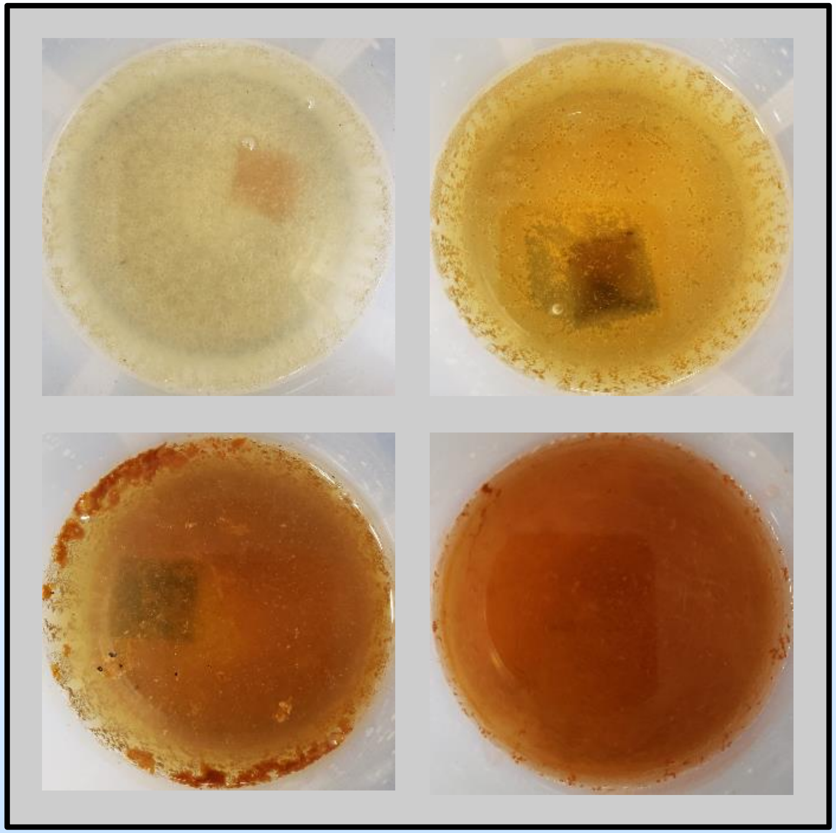


BSED images showing Z-contrast reveal adsorption of Ba onto FeOOH lattice

Mineral Scale Precipitation Mechanisms

Major Findings:

- Mineral scale precipitation occurs early on (first 48 hours) in solutions before interaction with reservoir mineralogy.
- Barite scale can occur within the wellbore despite the addition of scale inhibitors to the injection fluid.
- Colloidal barite likely passes through tertiary filters and is transported into the formation.
- Scale formation is, in part, dually facilitated and worsened from sulfate release during oxidation of steel by persulfate breakers and the presence of iron oxyhydroxides.



Color of reacted effluent clockwise from upper left (2 days, 7 days, 14 days, and 28 days).

Is It in the Water? Elucidating Mineral Scale Precipitation Mechanisms on Unconventional Production String Components, URTEC-2019-444-MS

Future Work

- Continue laboratory experiments
- Start characterizing field samples

Production tubing filled with various types of mineral scale:

- 45 3-foot samples with a sample interval of a total of 21,000 feet
- Freshly pulled production casing – purged with N_2 and capped to preserve the mineral scale (avoid oxidizing, etc.)
- Industry is offering us more samples

Benefit to the Program

- Mineral scale will coat perforations, casing, production tubulars, valves, pumps, and downhole completion equipment ***limiting production and eventually requiring abandonment of the well***
- It's expensive to deal with (often requiring the removal/replacement of the production lining) and makes for an unsafe environment around the well.

Bibliography

- A paper and presentation was accepted for a presentation and paper at the Unconventional Resources Technology Conference (URTeC) in Denver, CO July 22-24 2019
  - ***"Is It In The Water? Elucidating Mineral Scale Precipitation Mechanisms On Unconventional Production String Components".***
    - **Justin Mackey***[1,2], James Gardiner[1,3], Barbara Kutchko[1], Meghan Brandi[1,2], James Fazio[1,3], and J. Alexandra Hakala[1];
      - 1. Department of Energy-National Energy Technology Laboratory, 2. Oak Ridge Institute for Science and Education, 3. LRST

Acknowledgements / Thank You / Questions

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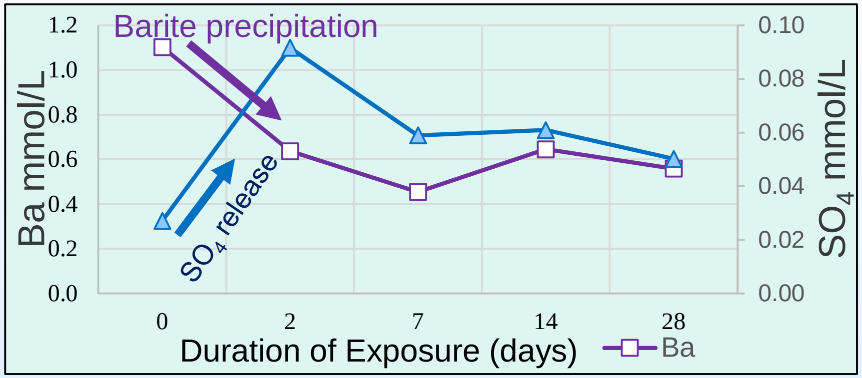
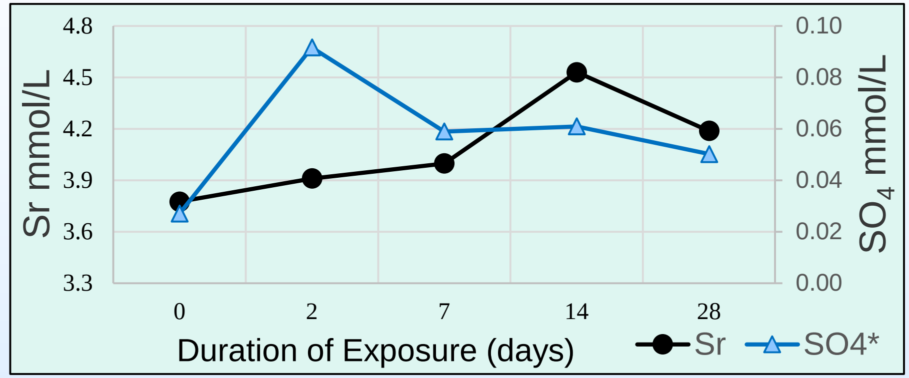
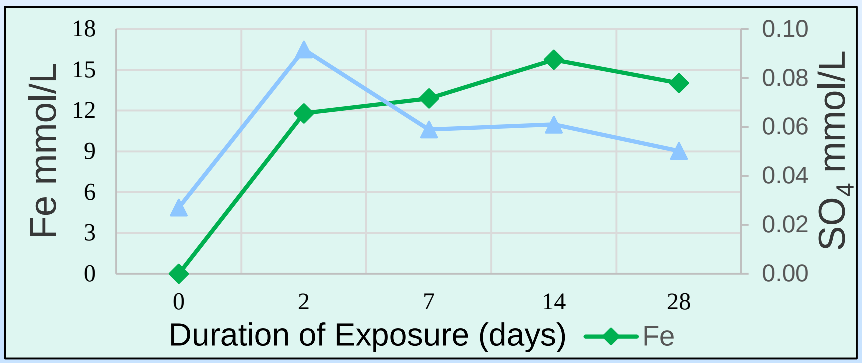
Appendix

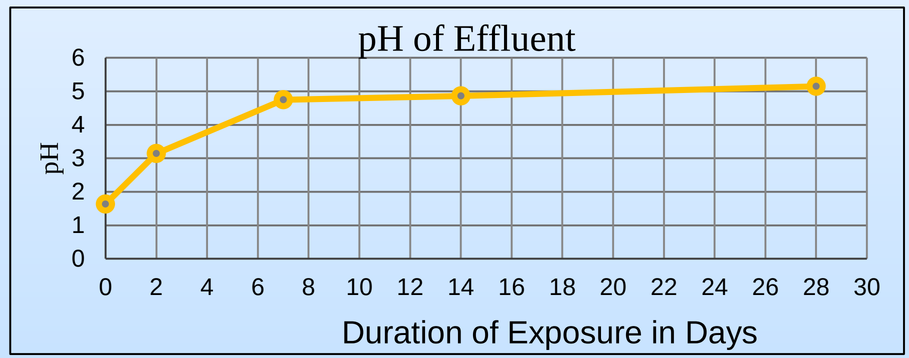
– Extra Slides

Mineral Scale Precipitation Mechanisms



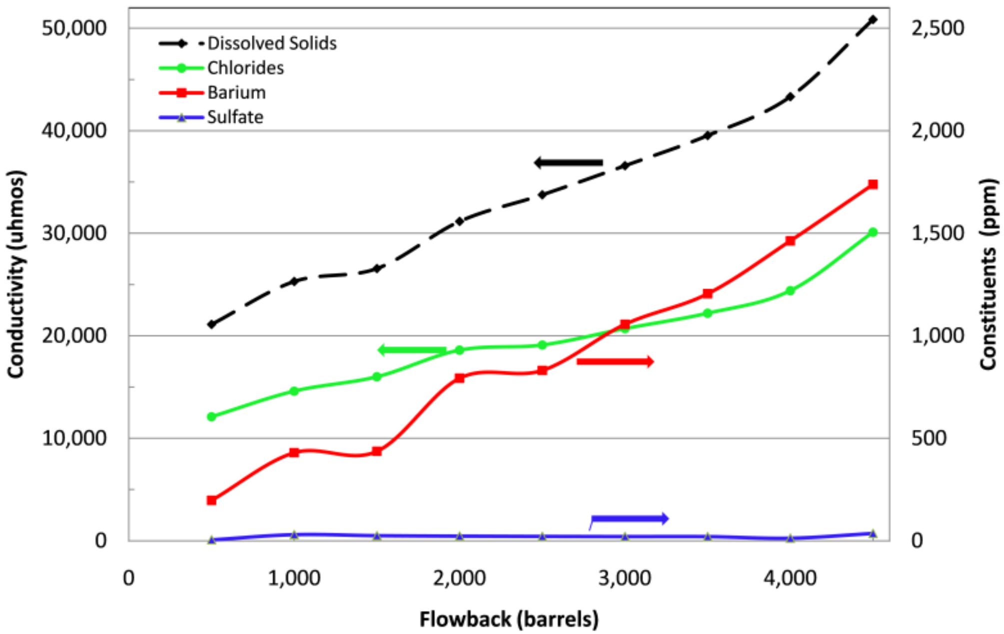






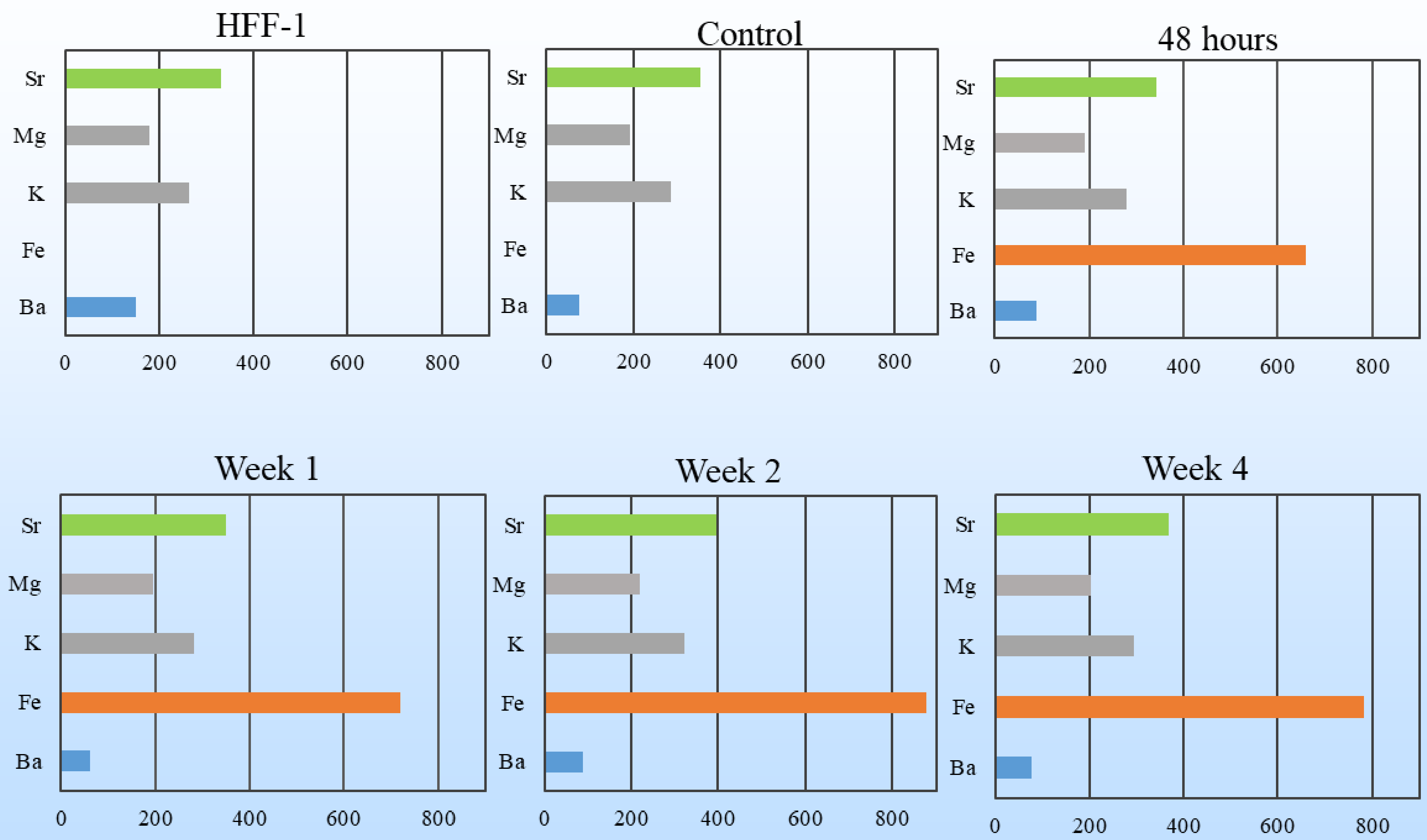
Wellbore Integrity – Oilfield Scale Management Technology

- Barite scale problem is one of the most troublesome scale challenges in O&G production
- Better prediction of the fate of barium sulfate in reservoir modeling is useful to prevent formation damage or unexpected barite scale formation
- Barite is one of the most common scale-forming mineral due to its **low solubility product (pKO sp = 9.97)**
  - compared with other typical scale minerals such as calcite and celestite ($SrSO_4$)



SPE 114062; Colloids & Surfaces 2001; Hummel et al., 2002

Mineral Scale Precipitation Mechanisms



Bar graphs of major cations (ICP-OES) measured in original HFF and HFF reacted with low carbon steel at different temporal scales.

Mineral Scale Precipitation Mechanisms

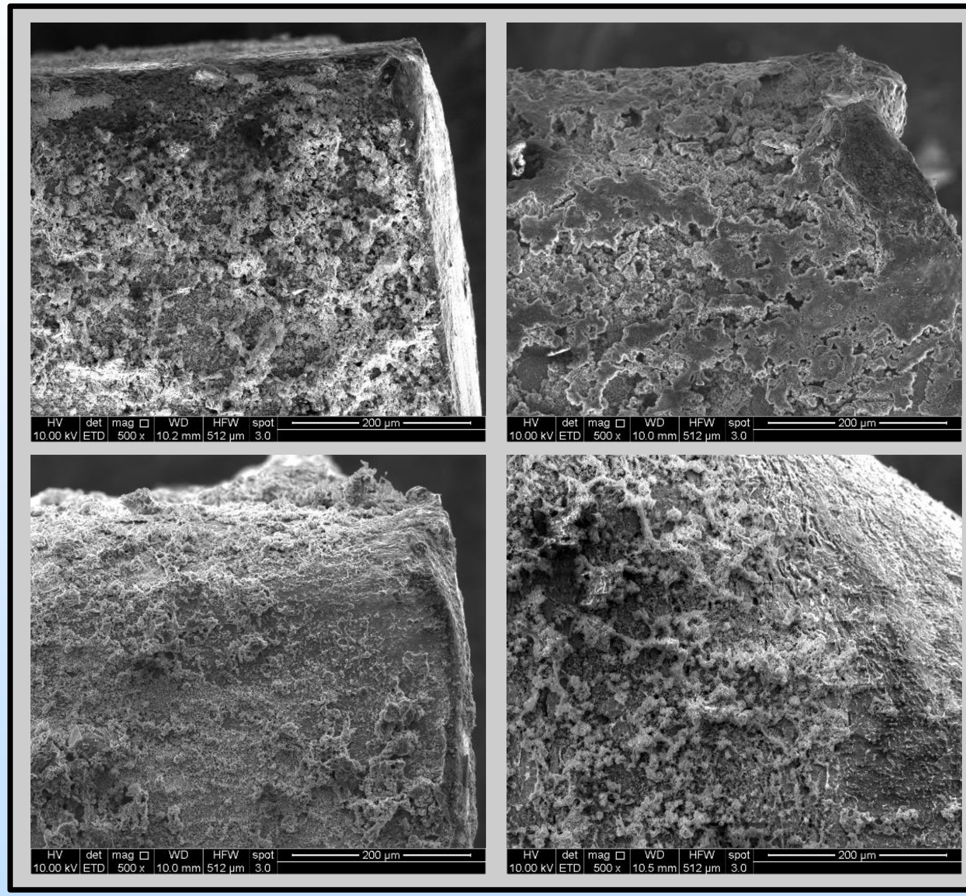
Significant & uniform corrosion

- **Corrosion Rate = 0.17 mm/y**

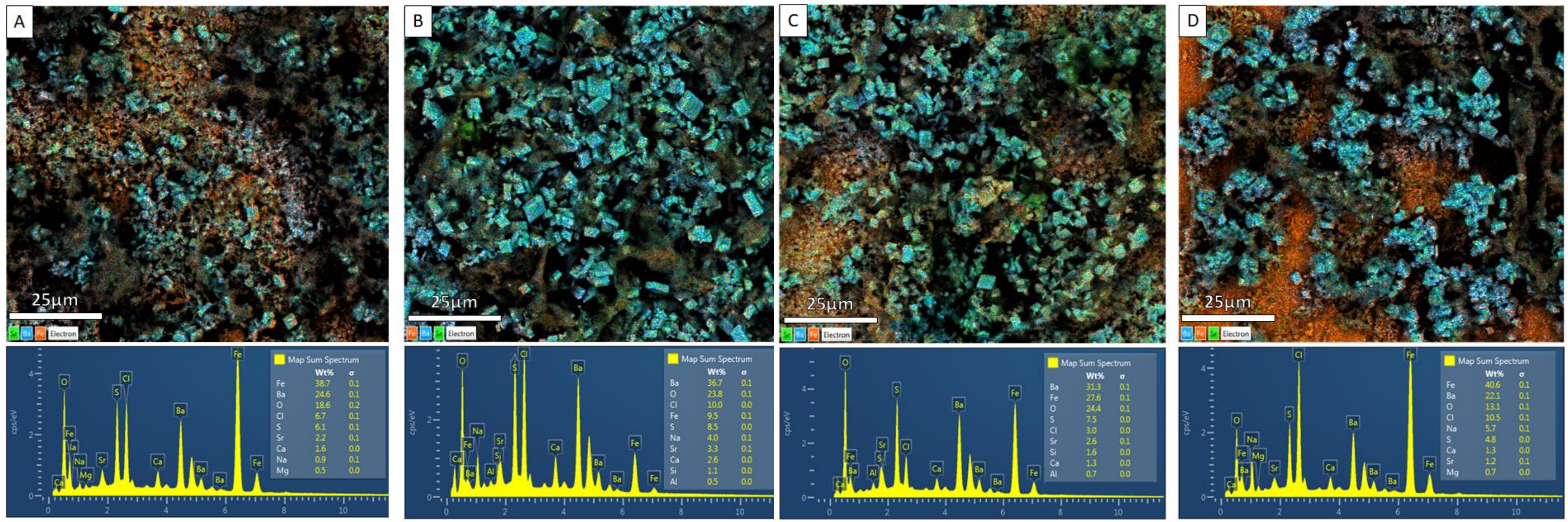
- **Reduction of dissolved oxygen**
  - $O_2 + 2H_2O + 4e = 4OH^-$

- **Reduction of H^+ (**pH~1.6**)**
  - $2H^+ + 2e = H_2$

- **Reduction of $(NH_4)_2S_2O_8$**
  - $S_2O_8{}^{2-}{}_8 + 2e^- \rightarrow 2SO_4$



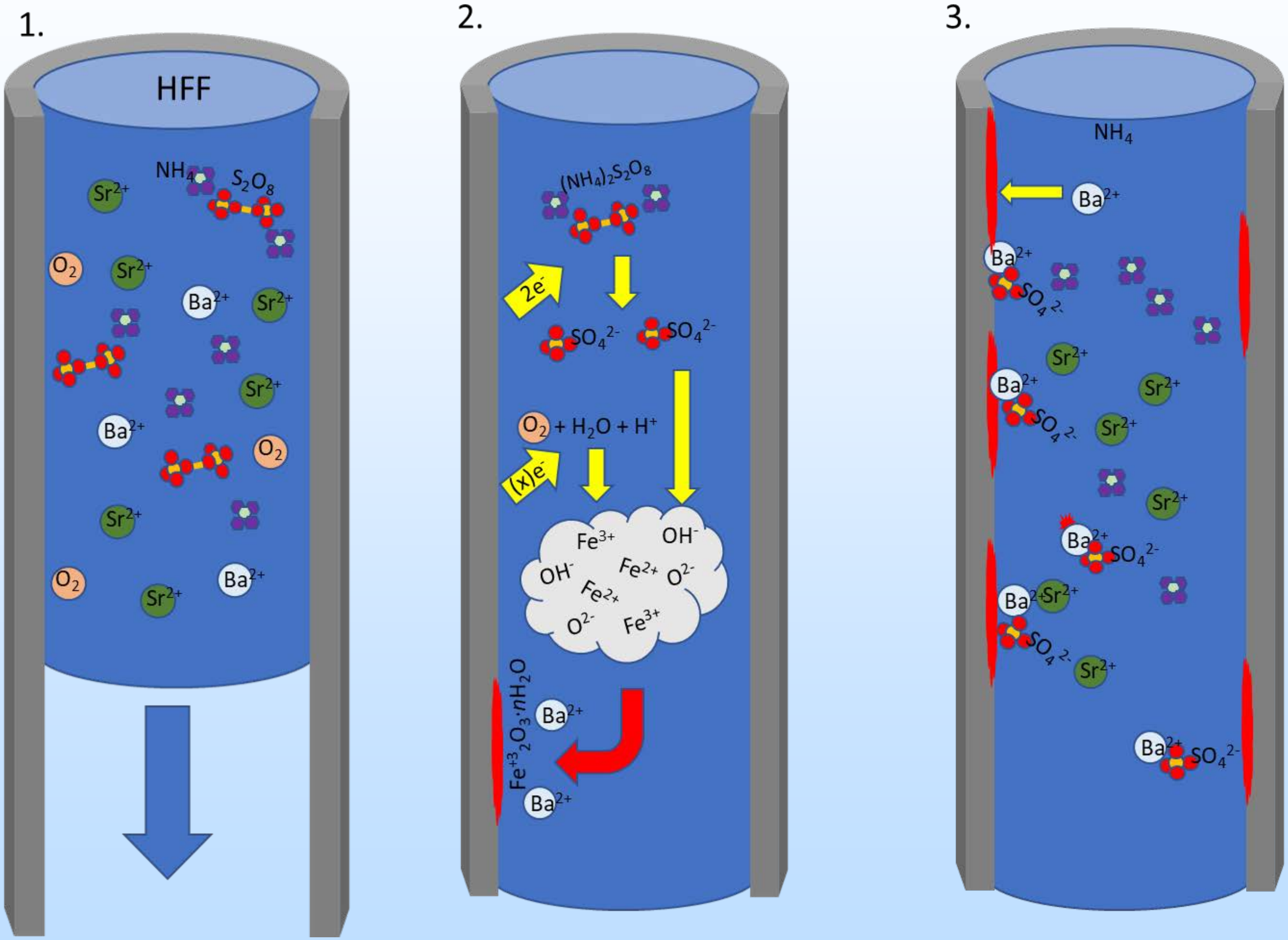
Mineral Scale Precipitation Mechanisms



EDS elemental maps and accompanying spectra of low-carbon steel coupons exposed to synthetic HFF for (A) 2 days, (B) 7 days, (C) 14 days, and (D) 28 days. Occurrences of strontium (green), barium (blue) and iron (orange) are highlighted.

Primary mineral precipitates are barite ($BaSO_4$), iron oxyhydroxides ($Fe^{+3}{}_2O_3 \cdot nH_2O$), and halide group minerals ($NaCl$, $CaCl_2$, $SrCl_2$)

Mineral Scale Precipitation Mechanisms



Mineral Scale Precipitation Mechanisms

- Corrosion of steel is significant (Corrosion Rate = 0.17 mm/y)
- Barite scale readily occurs despite addition of inhibitors
  (ethylene glycol and ethanolamine)
- Scale formation happens early on.
- Heterogenous nucleation via barium adsorption onto FeOOH is an influential adherence mechanism.
- Tertiary filtration is not effective at removing colloidal barium from injection fluids.
- Injection of oxidizing breakers may facilitate scale formation.