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Critical Application Cementing – Redefining The Issues

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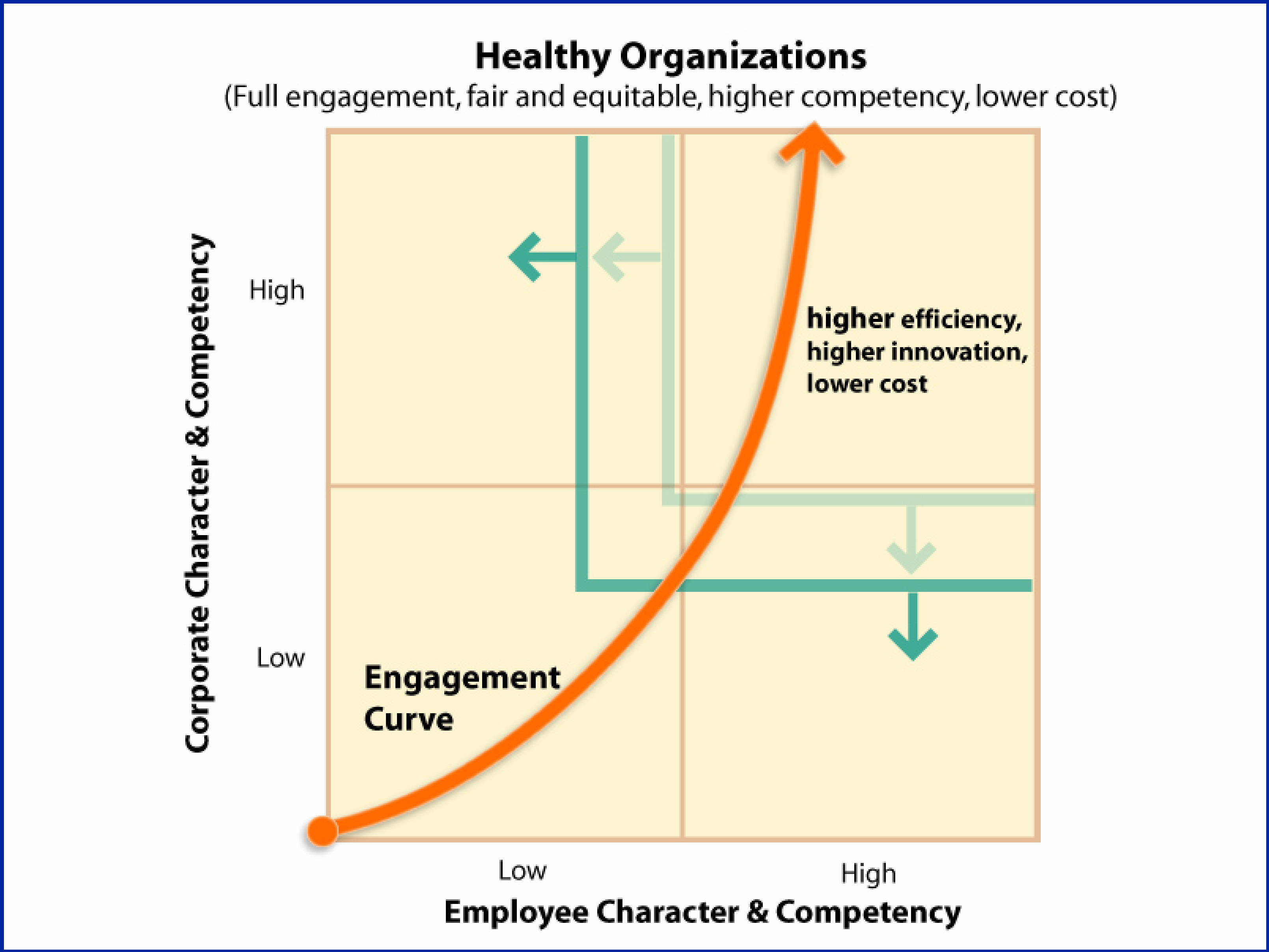
What are some of the “Critical” Hot Buttons That Come to Mind?

- Formation water/gas migration
- Sustained annular casing pressure
- High temperature
- High pressure
- Corrosion (acid gas, CO_2, etc.)
- Narrow Equivalent Circulating Density (ECD) windows
- Displacement mechanics
- Mechanical failure - point loading, Annular Pressure Buildup (APB)
- Any combination of the above

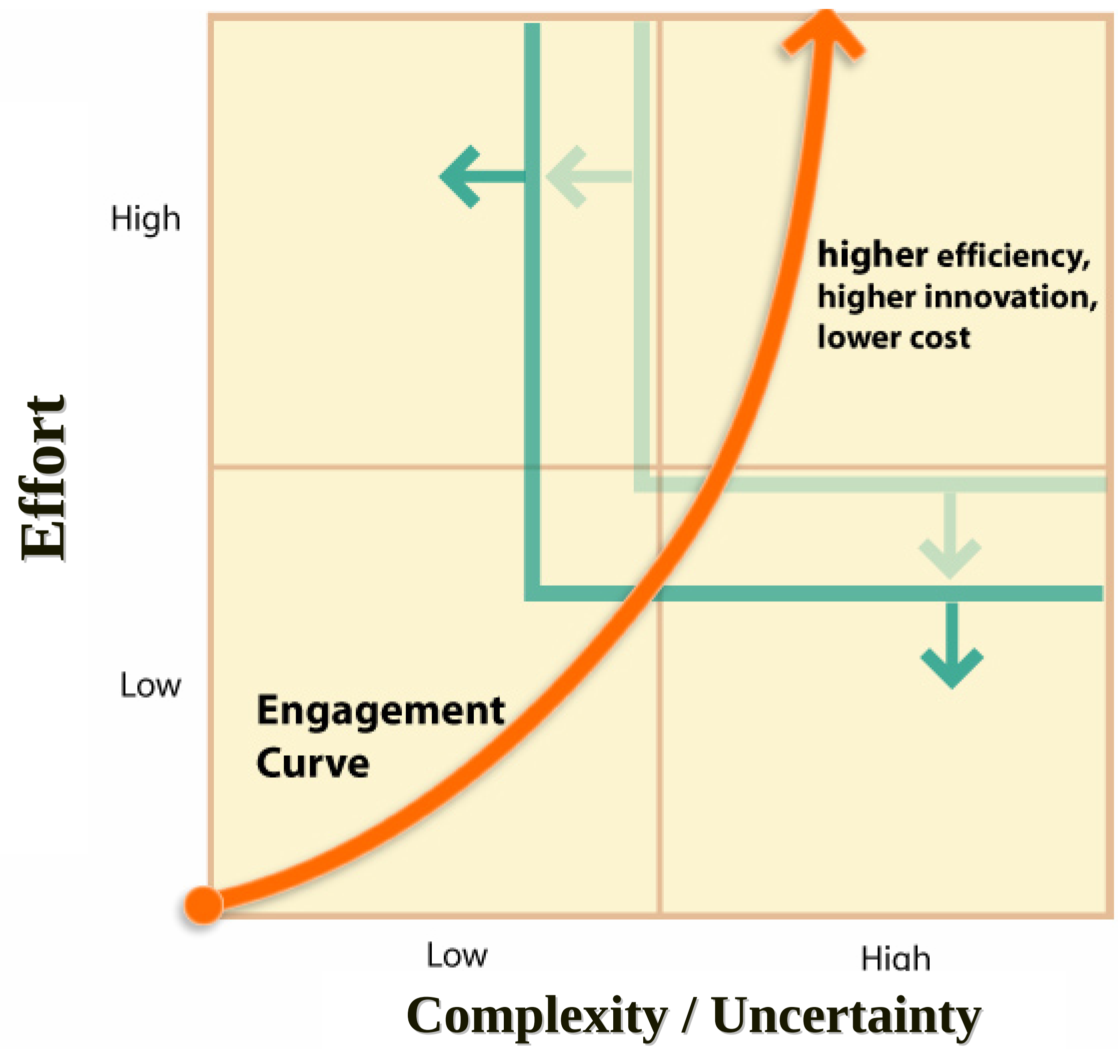
Issues Ranked as #1 in Priority by Various Respondents on SPE TIG Discussions

- Density control/delivery of homogenous slurry
- Bulk blending quality control
- Appropriate use of cement and additive chemistry
- Centralization – both extremes observed
- Hole quality
- Mud filter cake quality (presumably thin and impermeable)
- Mixing water quality
- Gas migration
- Must always run an External Casing Packer (ECP) to prevent annular gas flow
- Must always have a very high compressive strength
- Shoe track length
- Always pump as fast as you can
- Always achieve turbulent flow



Slide Courtesy of Abdul Jaleel Khalifa, 2007 SPE President

Job Design Behavior



Critical Application Cementing – What is it REALLY all about?

- Zonal isolation
- Casing protection
- A necessary step to effectively produce reserves
- Enhancement (cement) to a conduit (casing) connecting a subterranean formation to the surface

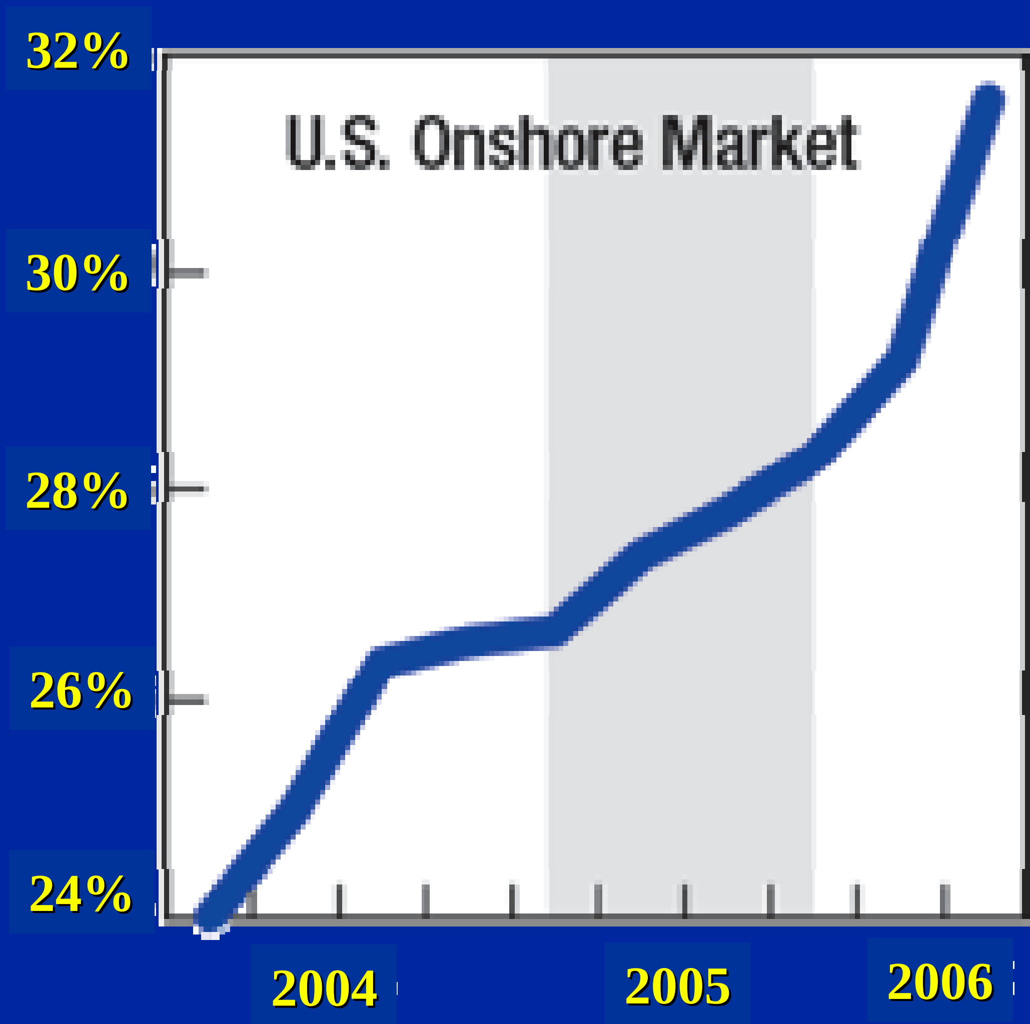
Today's Challenge - Revise the Frame of Reference for What are "Critical" Issues

Understand that in today's environment, cementing requires a true multi-disciplinary approach

- Chemical engineering to understand the thermodynamic variables that affect cement design and longevity
- Mechanical engineering to understand the material behavior of cement, rocks, and metals and how they interrelate to each other
- Chemistry to understand the effects of long term corrosion on both metals and cements
- Petroleum engineering to understand the reservoir changes that contribute to stresses on a cemented wellbore

Example Proxy of Well Complexity Trends -

Non-Vertical New Wells



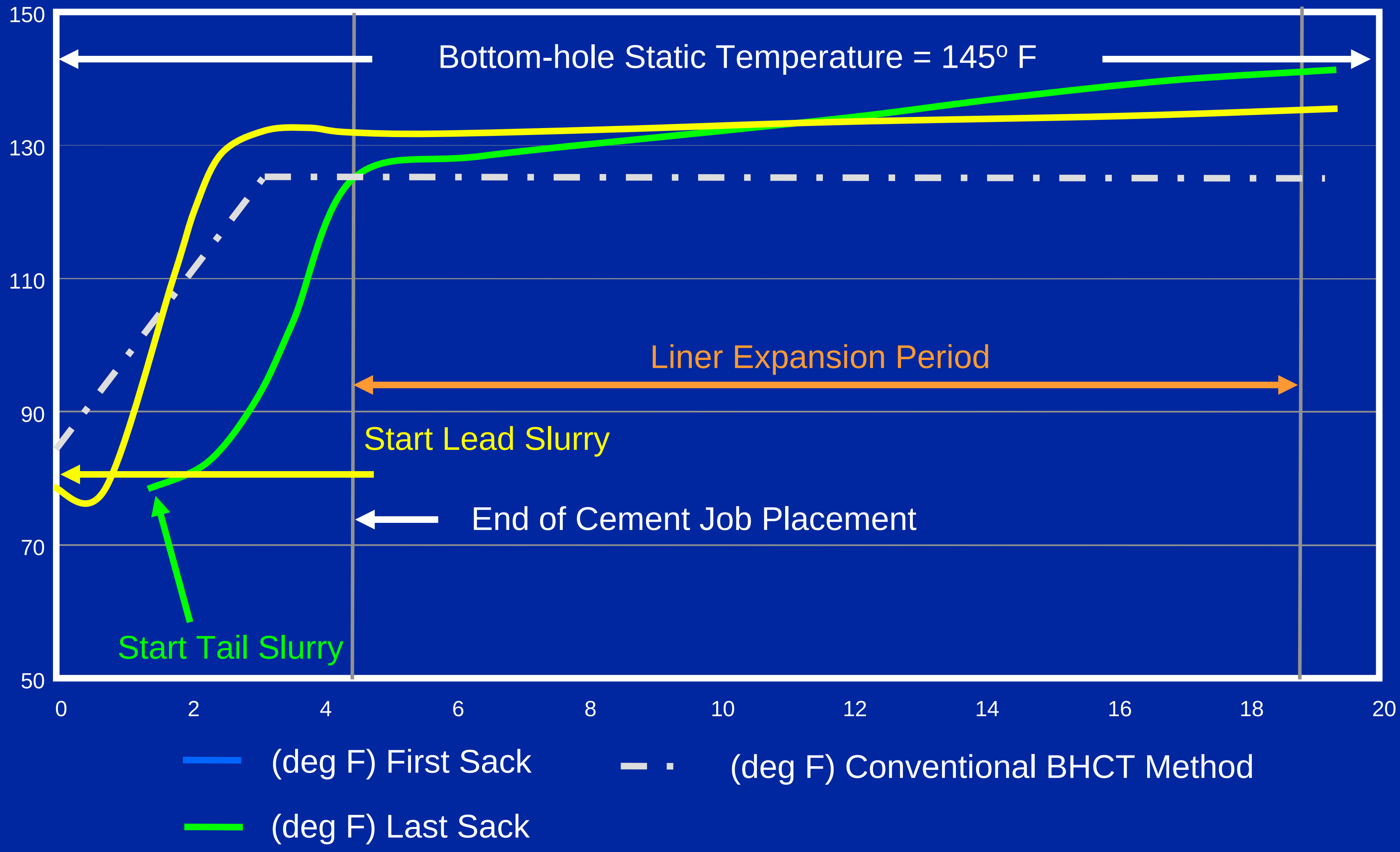
- Year-over-year nominal quarterly effects
  - Increase of 200 non-vertical rigs
  - Vertical drilling grew by 49%
  - Non-vertical then grew by 119%
- This month (Feb 5, 2007)*
  - US Horizontal Rig count – 324
  - One Year ago Today – 230
  - One year ago September – 171

Source: Mason, World Oil, August 2006, page 44
*** Smith International**

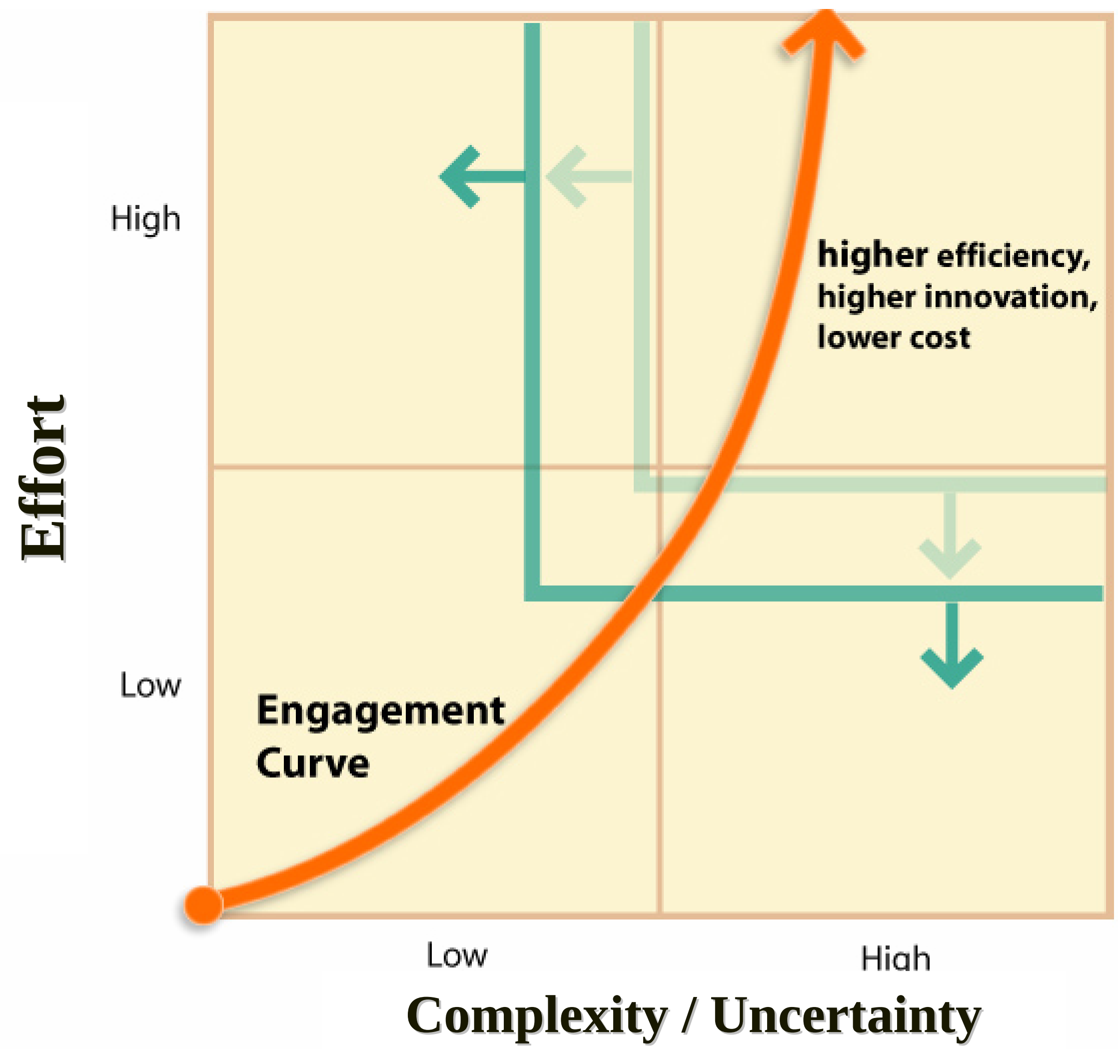
Key Cementing Issues That Don’t Always Get the Attention They Deserve

- Wellbore thermal modeling
- Formation-cement interaction
- Mechanical modeling of the cement sheath interactions with the casing and formation

Real-World Comparison: Static Estimation Schedules Versus Dynamic Computer Simulation – Expandable Liner Job



Job Design Behavior



Part 2 - Formation Issues Related to Cement Design

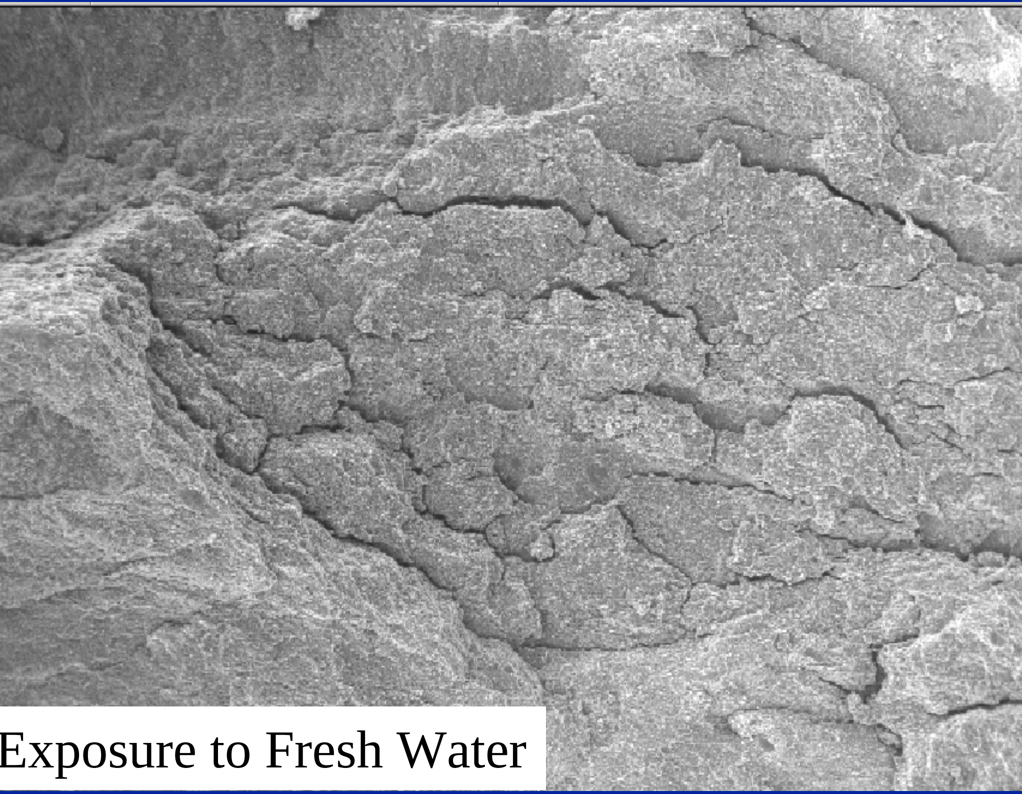
- Interactions between cementing fluids and formations
  - may affect formation integrity (shales) in much the same way as drilling fluids
  - water-soluble formations – evaporites such as halite - can be a problem in ways other than simple wellbore washout

REF: SPE 79913

Traditional Arguments – Salted vs Fresh-Water Cement Slurries

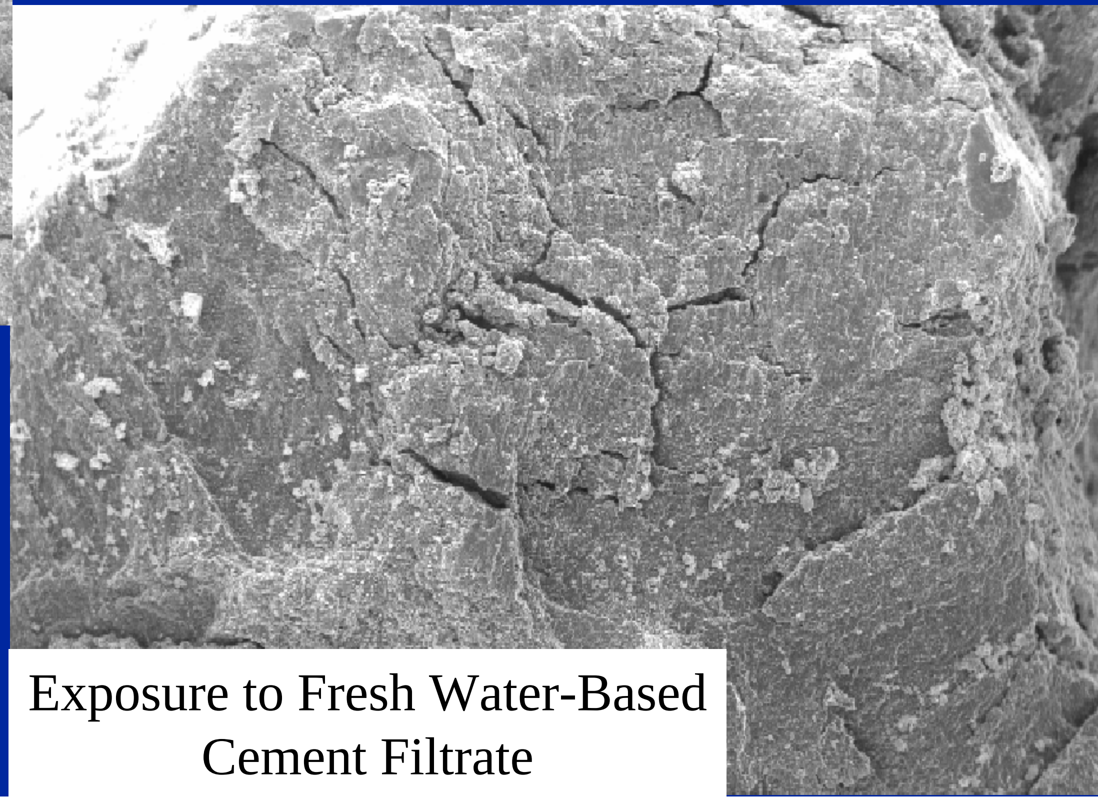
- Pros
  - Usually offsets hydration bulk shrinkage
  - Easier to retard slurry at medium to high temperatures
  - Thought to be easier to design around compatibility issues at times
- Cons
  - Adversely affects admixture performance
  - Lowers ultimate compressive strength
  - Hard to accelerate hydration at low temperatures
- The big "debatable" areas
  - Formation/slurry interactions – what are they and are they meaningful?
  - Compressive strength development – what is really important and what is simply arrived at via supposition?
  - What is the cumulative effects on fluid mechanics?
  - Is the final result really as intended?

Water-Sensitive Formations -



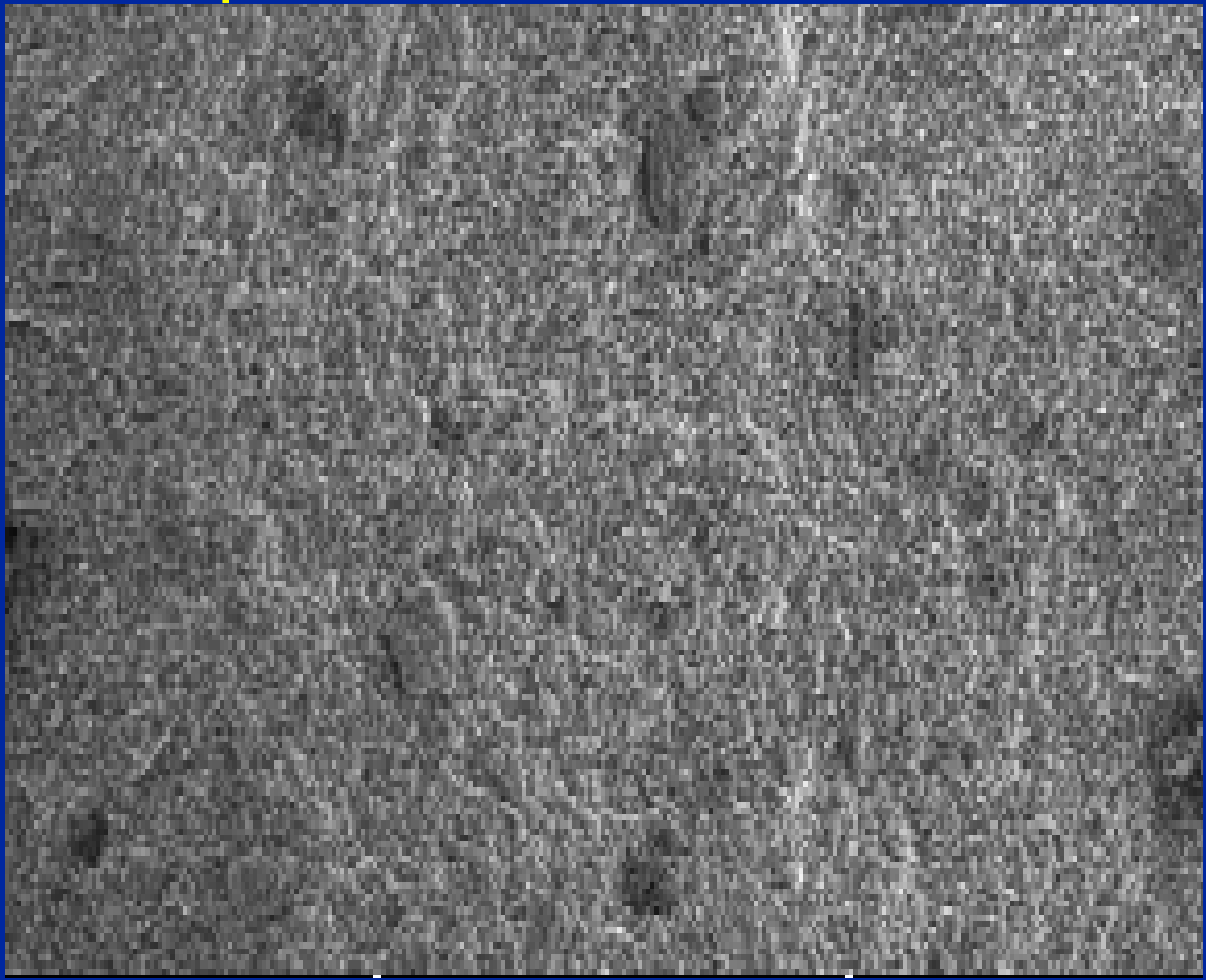
Exposure to Fresh Water

Our version of “Myth Busters!”



Exposure to Fresh Water-Based Cement Filtrate

Water-Sensitive Formations -
Exposure to 7% KCl Filtrate



Effects of Formation Salt on Cements

Halite samples from +18,000 ft TVD

Formation Sample Source	Salt Description*	12 hr Comp. Strength	24 hr Comp. Strength	36 hr Comp. Strength
FW Reference	0	2230	2640	NT
Sat. Reference	**37% NaCl**	**1380**	**1840**	**NT**
Contamination of Fresh-Water Reference Slurry				
S-1	10%	1000 psi	NT	NT
S-2	10%	1020 psi	NT	NT
S-3	10%	1060 psi	NT	NT
S-1	**Saturation**	**0**	**0**	NT
S-2	Saturation	0	0	1440 psi
S-3	Saturation	0	0	600 psi

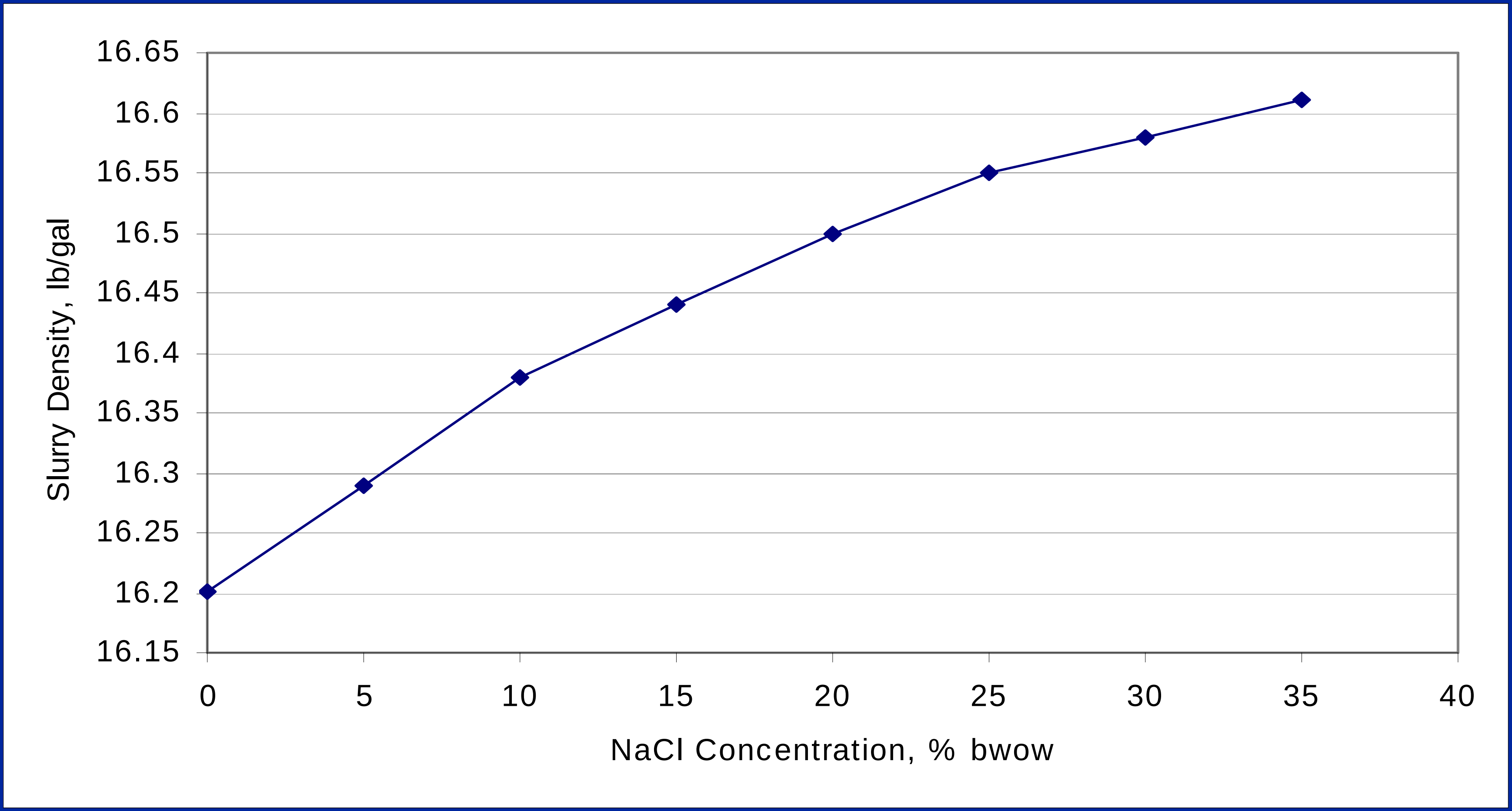
* Salt concentrations based on weight of water

Elemental Scan by XRF

Sample Number	S-1	S-2	S-3
NaCl	~ 93%	~ 89%	~ 88%
S_2O	1.3	2.3	2.7
C_aO	2.1	6.0	7.5
Misc. trace elements	3.1	2.1	1.3

REF: AADE 06-DF-HO-36

Effect of Formation Salt Dissolution on Slurry Density



REF: AADE 06-DF-HO-36

Mechanical Properties Comparison

Class H cement mixed at 16 lb/gal, cured at 100^{o}F & 1000 psi for 28 days

Parameter under confining load	Fresh-water cement, cured in fresh water	NaCl-Saturated cement, cured in saturated brine
Young Modulus, psi	1.68 x 10E06	1.16 x 10E06
Poisson Ratio	0.12	0.146
Tensile Strength, psi	450	280
Friction Angle, degrees	7.25	8.52
Cohesion, psi	2479	1267
Bulk volume Change, %	-1.8	0.55
Compressive Strength, psi	6238	3291

REF: AADE 06-DF-HO-36

Salt vs No Salt – An Improved Mindset

- Pros to running salt systems
  - Newer synthetic additives not as affected (by salts)
  - More desirable mechanical properties
  - Less detrimental to slurry/formation interactions
  - Design around formation contamination issues
  - Ultimate compressive strength is generally not a deciding factor
- Cons
  - Still difficult to accelerate some high-salt slurries at very low temperatures

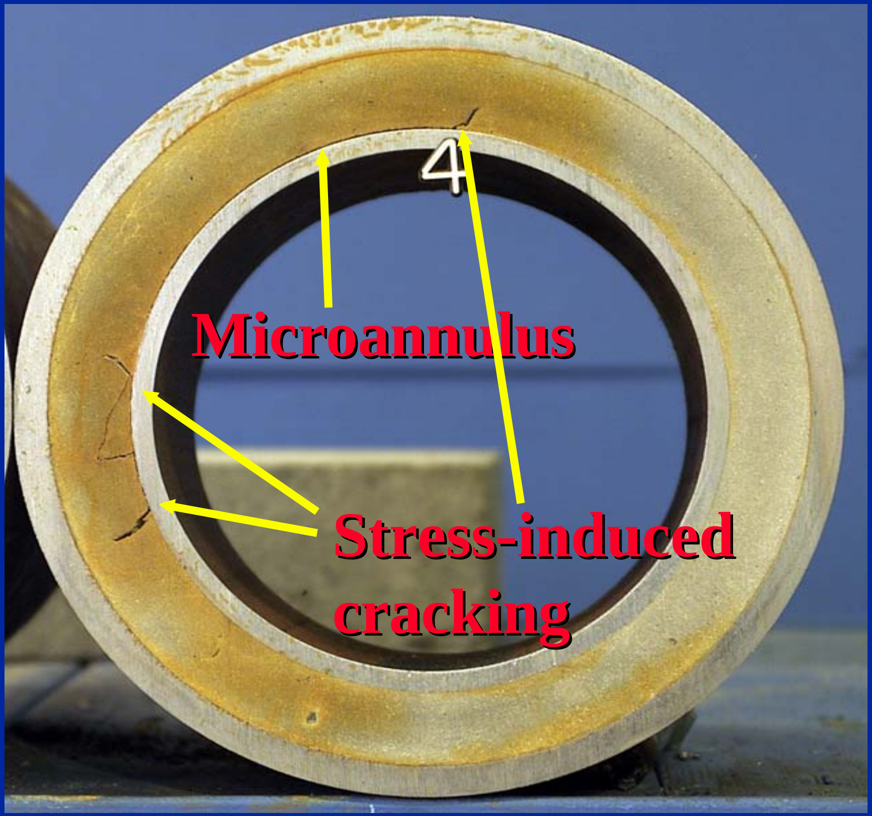
Part 3 - More or Less Elastic?

Extreme examples are used
to make a point, but this
practice in itself can be misleading.

Cement Mechanical Integrity – Cement Compressive Strength is Not Enough

- Portland cement by nature is brittle and low in tensile strength. The higher the cement Young's Modulus, generally the higher the likelihood of sheath failure, which can lead to sustained casing pressure, casing collapse, and loss of wellbore integrity.
- The mechanical behavior of the entire system – the cement, casing, formation, and associated interfaces - with Finite Element Analysis should be studied under realistic wellbore conditions.

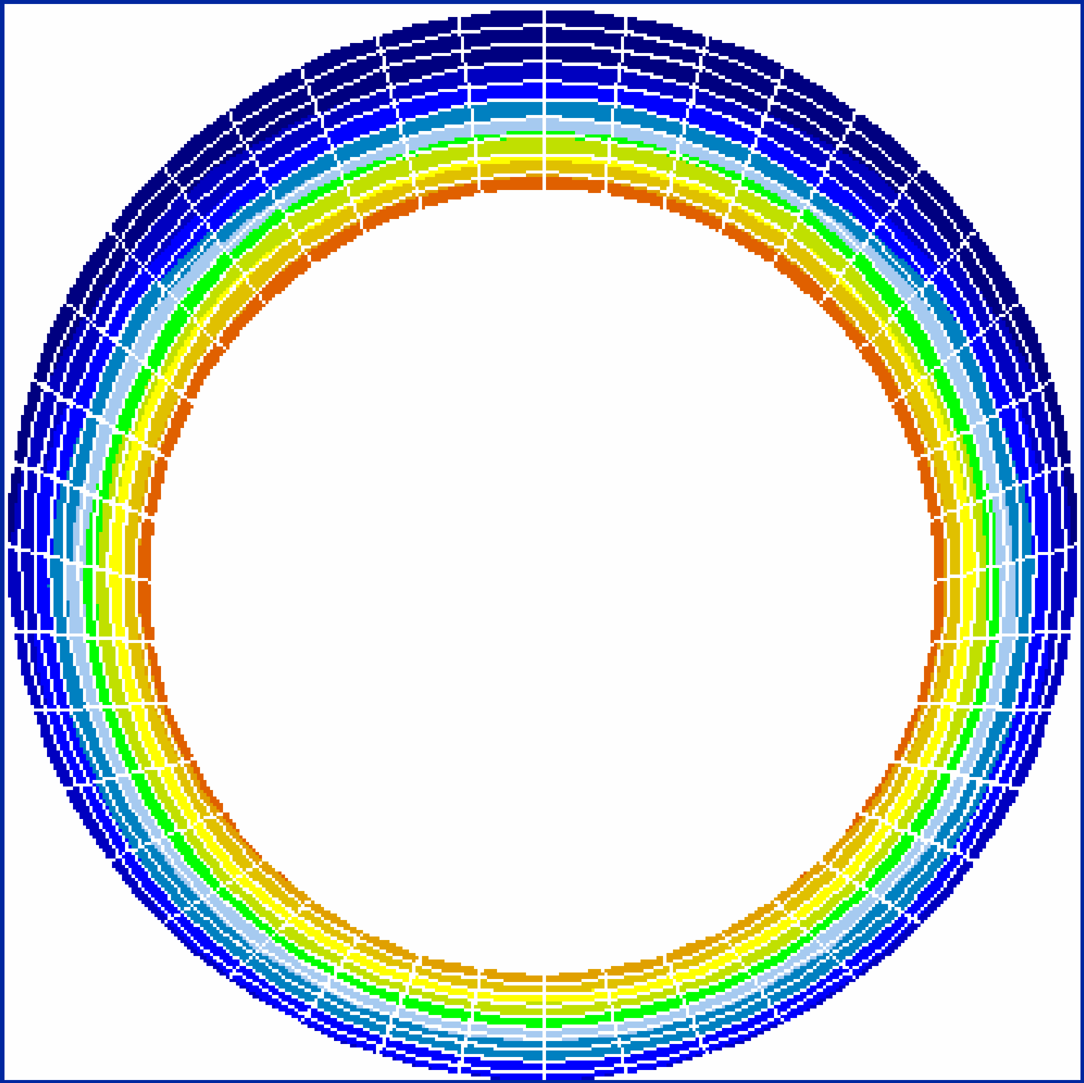
Conventional Cement Design



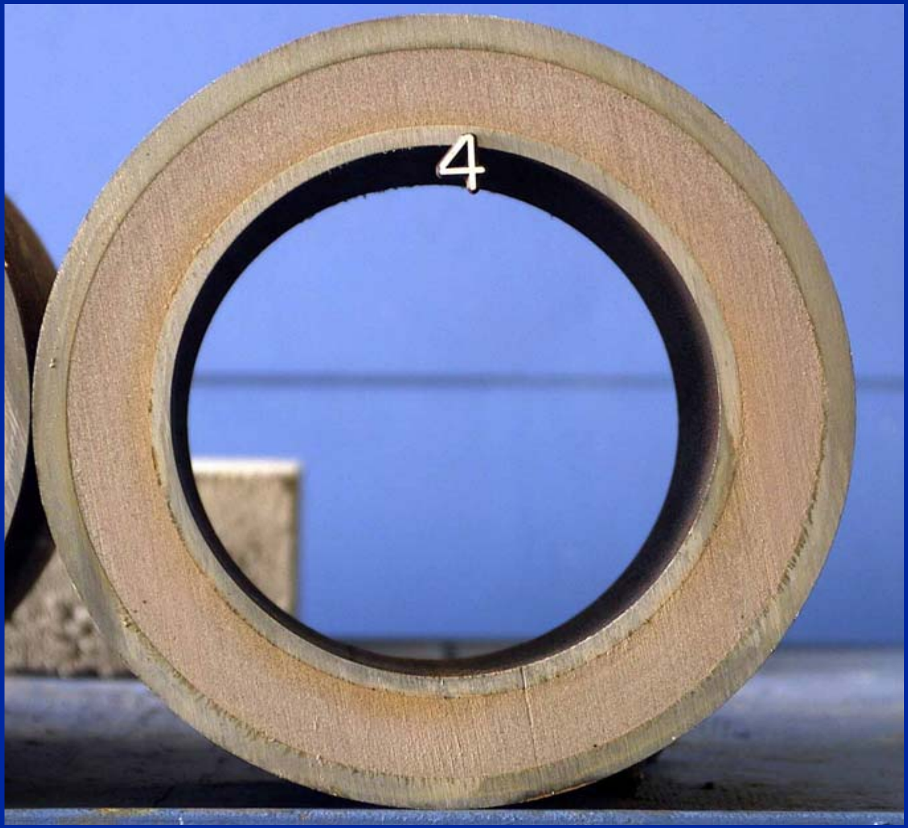
- Subjected to over 100 pressure cycles
- Failed integrity test
- Stress cracking evident

REF: SPE 99869

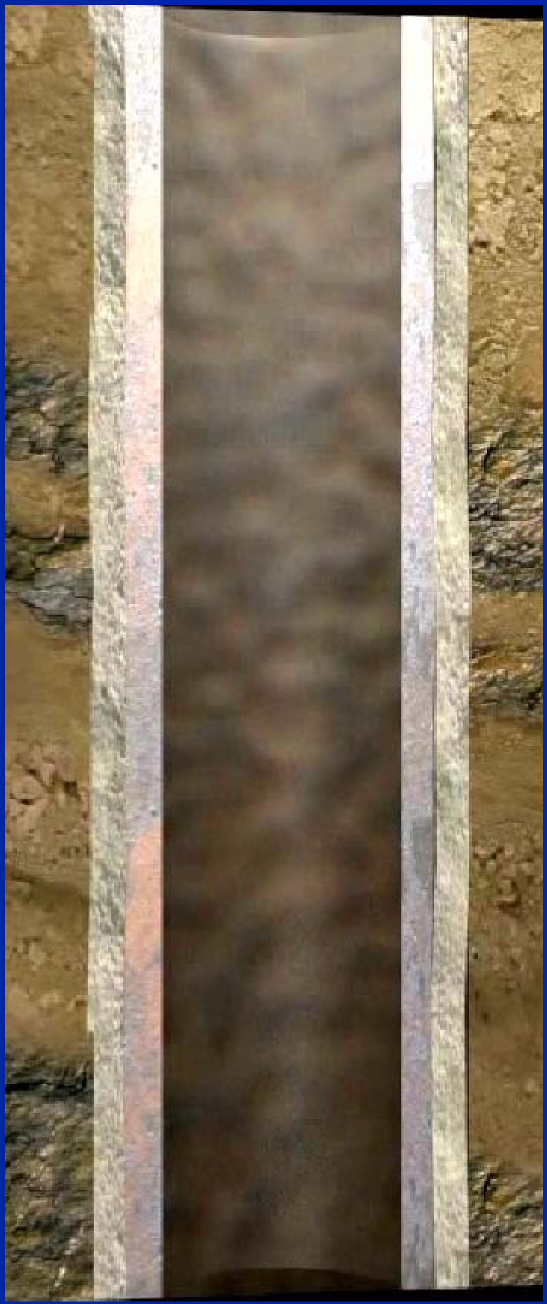
FEA Model Verified Failure Modes of Cemented Annulus



“Elastic” Cement Design



- **Modified cement blend, plus elastomer beads**
- **Subjected to over 100 pressure cycles**
- **Passed annular integrity test**
- **Casing, coupling, and completion design still had to be changed drastically to prevent collapse**



This may be
our expectation

But this may be
what we get!

So how do we make sure we have all of the necessary design parameters properly framed?

- Stop & Remove all assumptions
- Re-establish the chain of substantiation so as to differentiate between
  - Facts
  - Intuition
  - Guessing
- Reassemble the proof or facts so that observations make sense and fit the underlying logic

Design Behavior Should Not Be Sequential

The same underlying principles apply to all levels of complexity for all well types

Without Excellent Execution, Planning is Meaningless

Summary Remarks

- Technology – old and new - is our greatest asset
- Poor execution, or even misuse, of technology is our greatest liability
- Behavior is at the root of all execution

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