



**ouronova** 

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Accelerating DeepTech Innovation

# Factors impacting cement integrity



# Introduction

1

Hydrocarbon wells are often drilled in a CO<sub>2</sub>, H<sub>2</sub>S and/or a high temperature environment. These gases and/or high temperature can degrade set cement, negatively impacting cement integrity.

2

Workover, stimulation, EOR and similar interventions in a well may also impact cement sheaths inside a well.

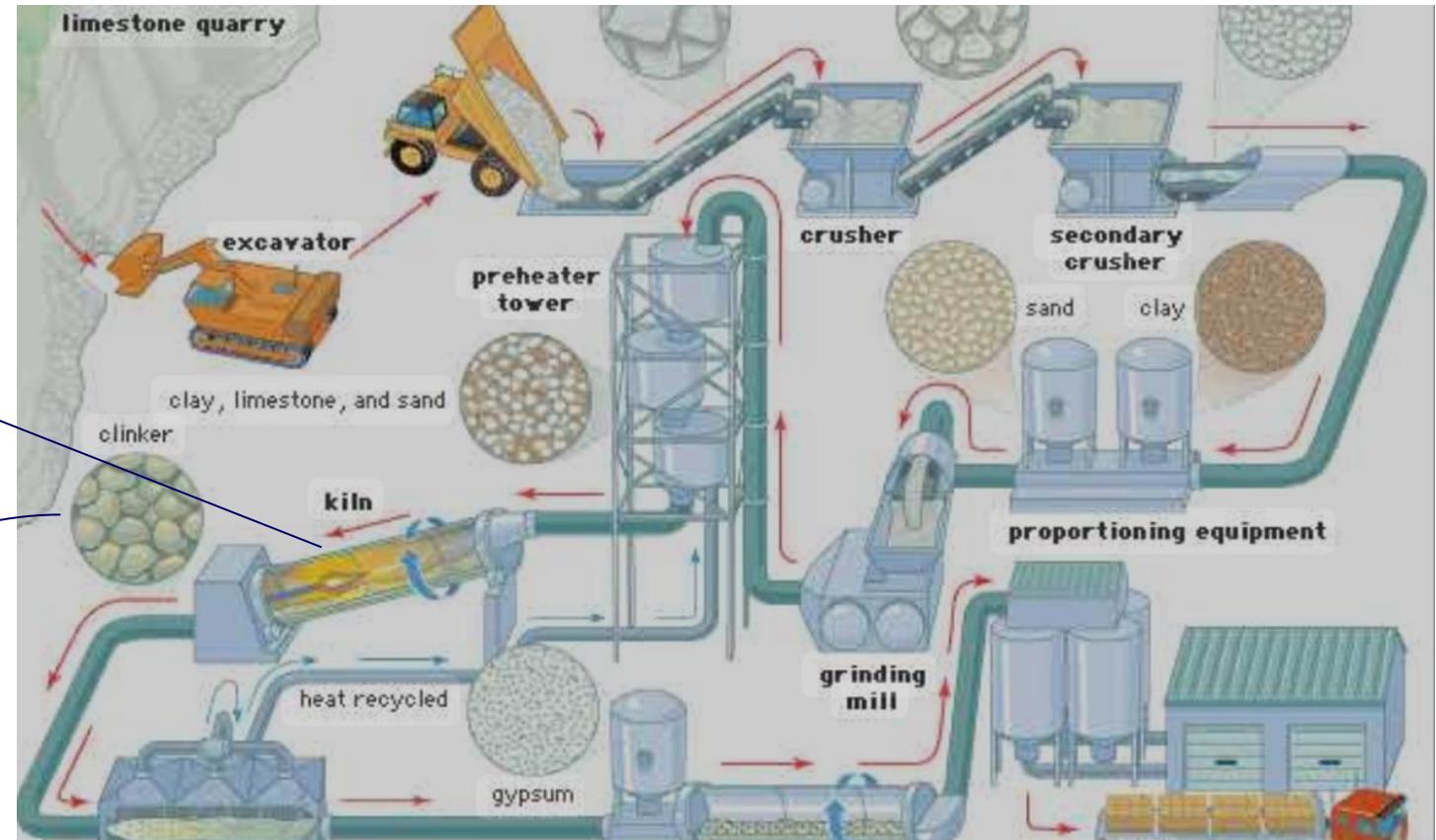
3

It is important to understand how these factors may lead to structural failures of set cement, so a mitigation strategy can be put in place and extend the life of the well.

# Cement manufacturing



Forno rotativo de clinquerização em Cantagalo  
(Lafarge, 2011)



# Clinker Composition

Compound	Abbreviation	Chemical Formula	%	Contribution on performance
Tricalcium Silicate (Alite)	C <sub>3</sub> S	3 CaO. SiO <sub>2</sub>	45 - 60%	Durability and total resistance
Dicalcium Silicate (Belite)	C <sub>2</sub> S	2 CaO. SiO <sub>2</sub>	15 - 30%	Long term durability
Tricalcium aluminate	C <sub>3</sub> A	3 CaO. Al <sub>2</sub> O <sub>3</sub>	5 - 12%	Durability and early setting
Tetracalcium aluminoferrite	C <sub>4</sub> AF	4 CaO. Al <sub>2</sub> O <sub>3</sub> Fe <sub>2</sub> O <sub>3</sub>	6 - 12%	No effect on durability
Gypsum (added during grinding)	CSH <sub>2</sub>	CaSO <sub>4</sub> 2H <sub>2</sub> O	2 - 10%	Prevents early setting



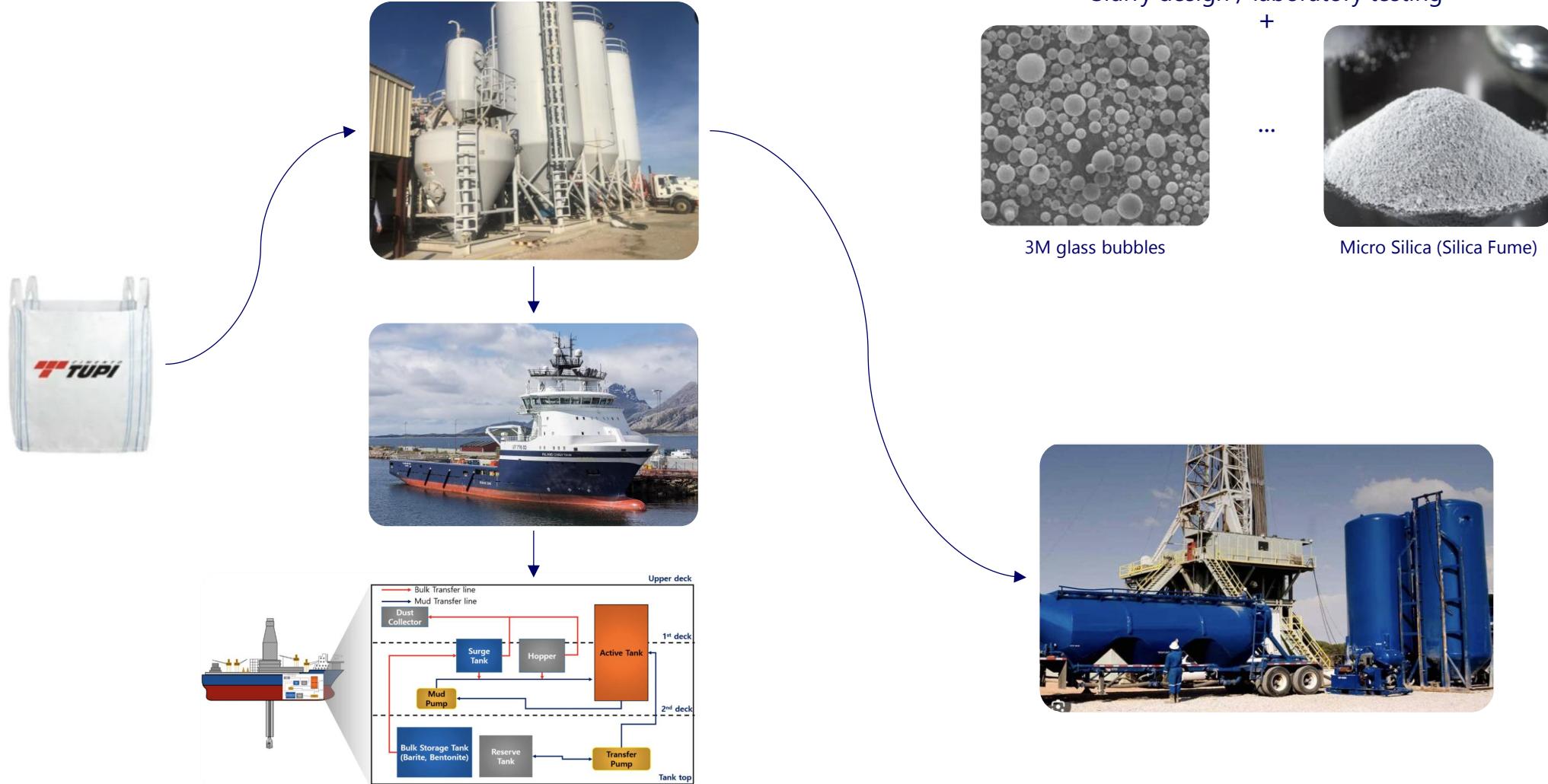
# Types of Cement

API Class	Depth		Temperature		Composition
	ft	m	°F	°C	
A-C	60000	1830	80 - 170	27 - 77	Low C3A No retarder
F	10000 - 16000	3048 - 4877	230 - 320	110 - 160	Low C3A Retarder present
G, H	-	-	80 - 200	27 - 93	Coarse - grained Type II & Type V portland cement No retarder
J	> 20000	> 6100	> 350	> 177	Essentially beta dicalcium silicate & pulverized sand

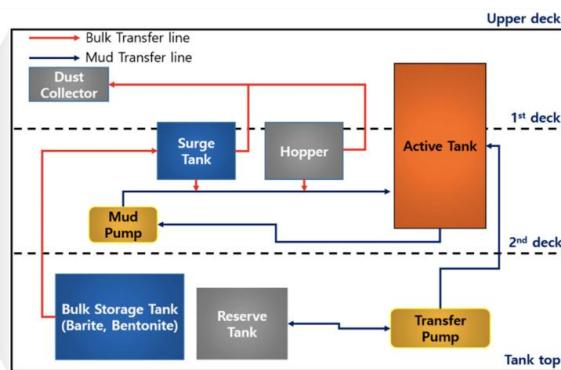
# Cement Logistics (pathways)



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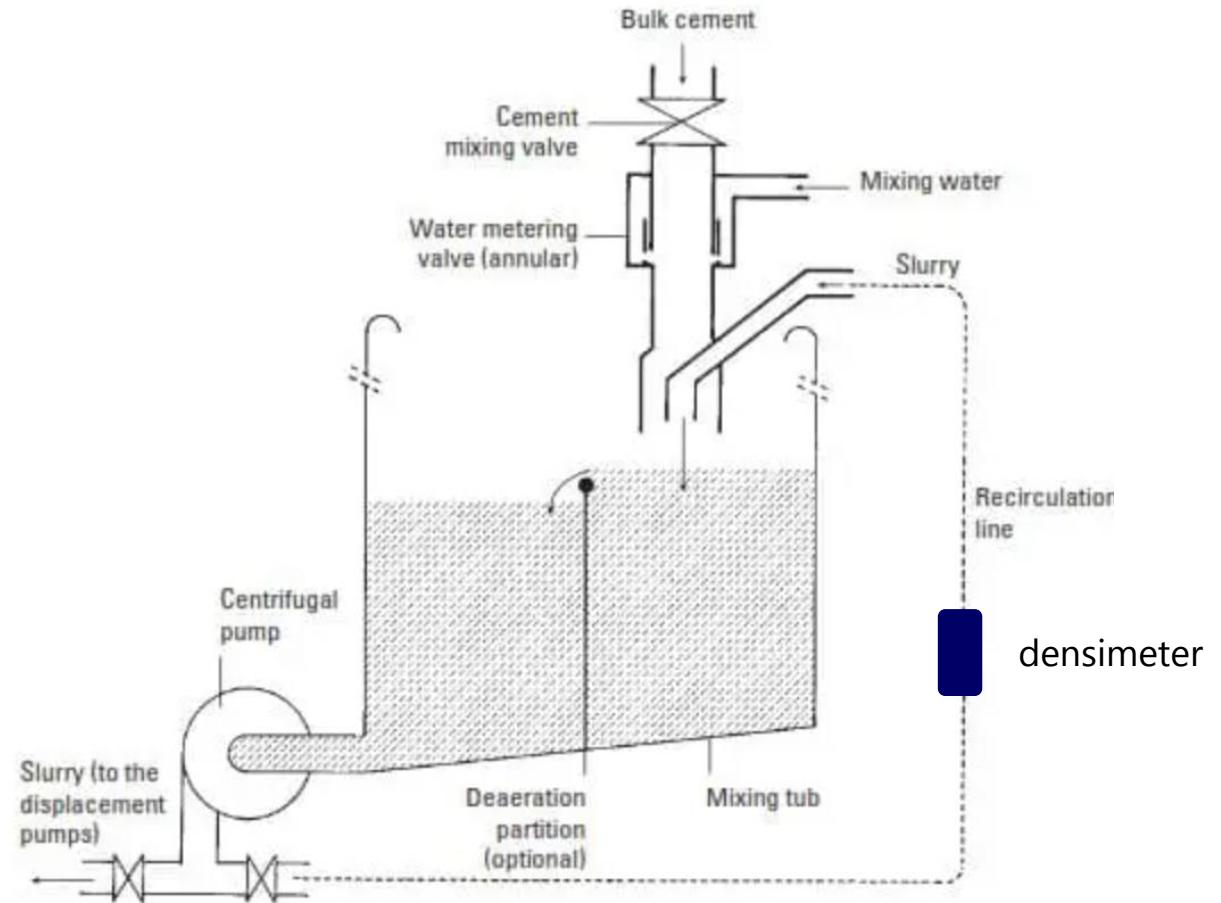
Slurry design / laboratory testing



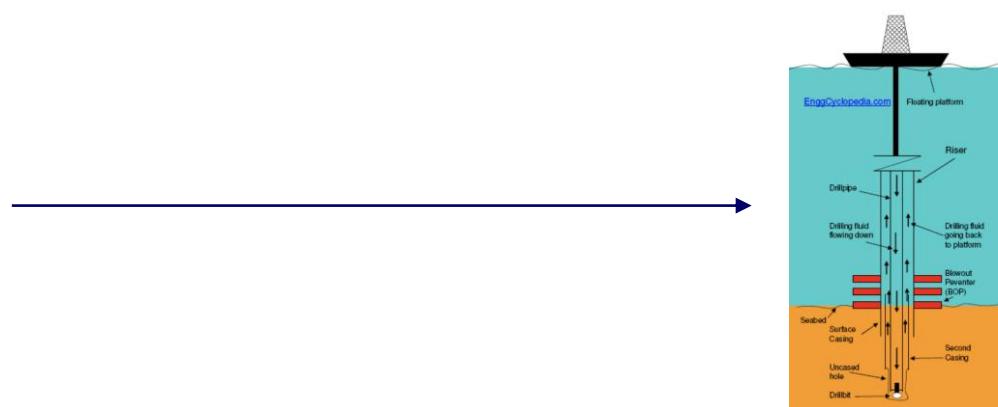
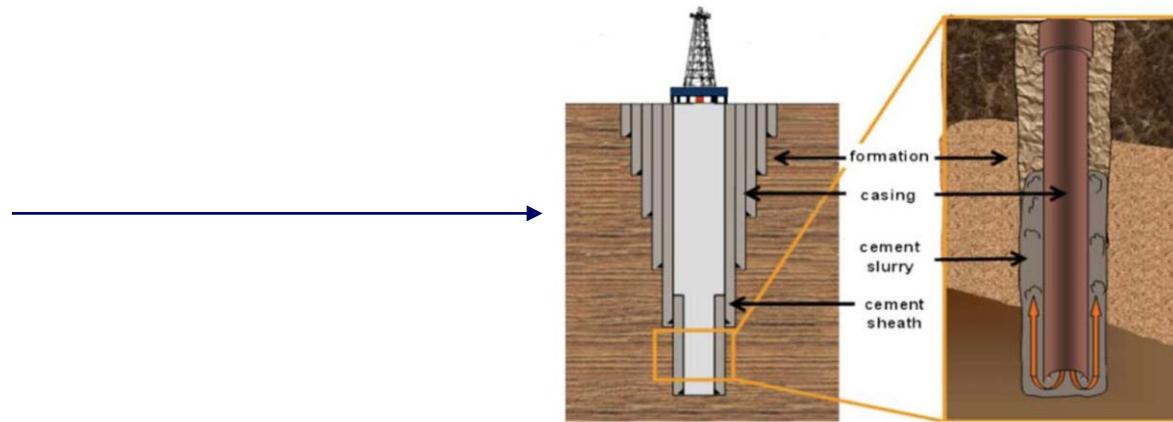
# Cement Logistics (pathways)



Mixing and pumping of liquid cement slurry



# Cement Logistics (pathways)



# Cementing Process

- Cementing is a process which includes:
  - Identification and definition of the work to be done;
  - Slurry design and slurry testing (with chemicals);
  - Simulators (specialized softwares);
  - Mixing and pumping through a pumping unit;
  - Cement job evaluation.
- Cement slurry:
  - Result of adding mix water and chemical additives to dry neat or blended cement.



Pumping Unit- offshore



Laboratory Equipment



Silos



Pumping unit- onshore



Monitoring and recording



Downhole tools

# Why chemical additives are added to cement?

## Different goals:

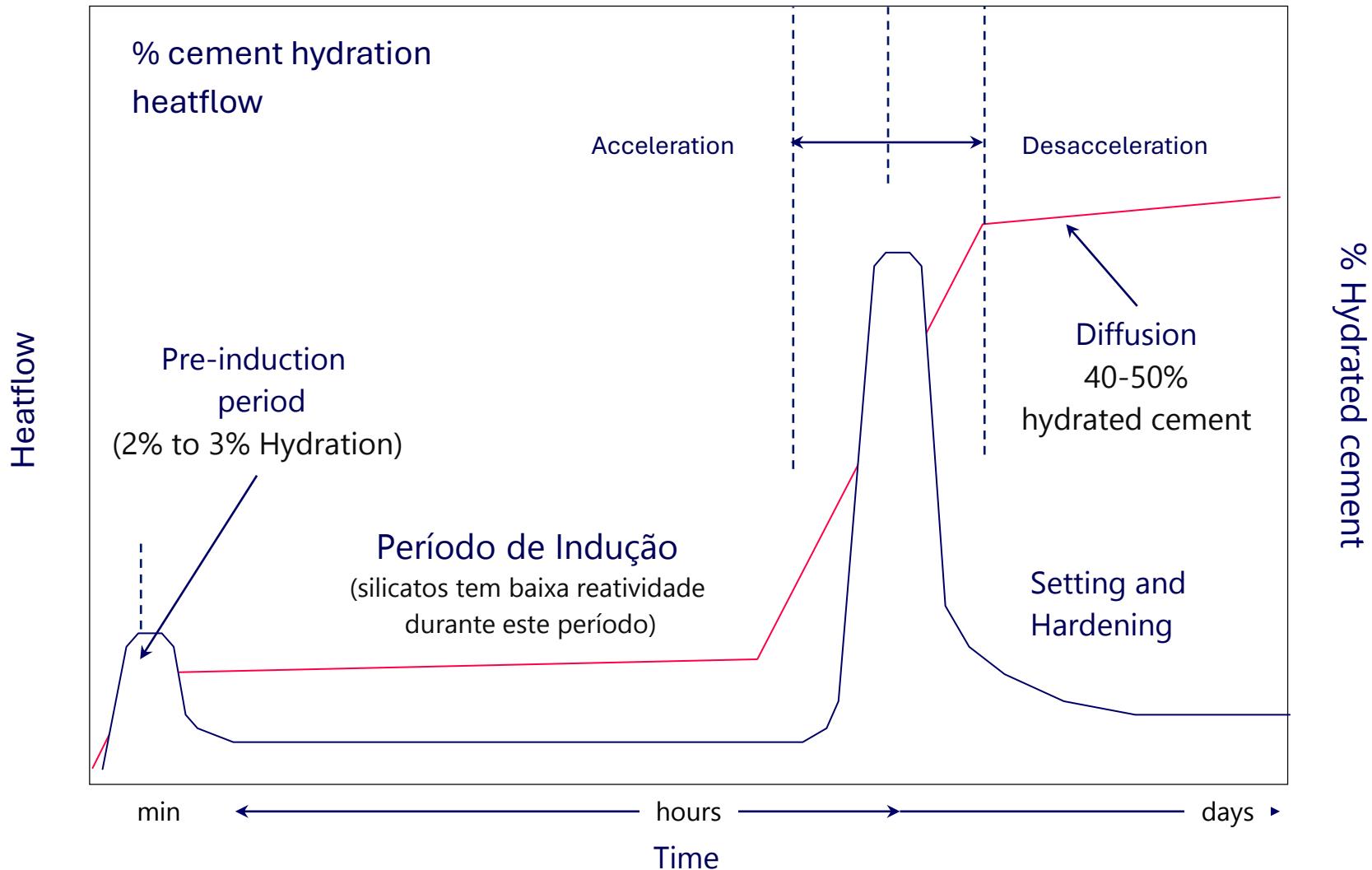
- Fast setting, or slow setting;
- High viscosity - or lower viscosity;
- Compatibility with mud and spacers;
- Use with sea water or industrial water;
- Low cost; gas control; high resistance...;
- High filtrate, or lower filtrate;
- High, low, or no free water.

## Different types of work:

- Surface casings – low cost slurry design;
- High temperature and deep critical liners;
- Loss circulation;
- High pressure squeezes;
- Blow out control;
- Well abandonment.



# Heatflow during cement hydration



# Types of cementing additives

- Accelerators;
- Extenders;
- Retardaders;
- Dispersants;
- Defoamers;
- Loss circulation materials;
- Free water control;
- Densifiers;
- Strength retrogression aditives;
- Fluid loss control;
- Gas influx control...

## QUIZ TIME

# Types of cementing additives

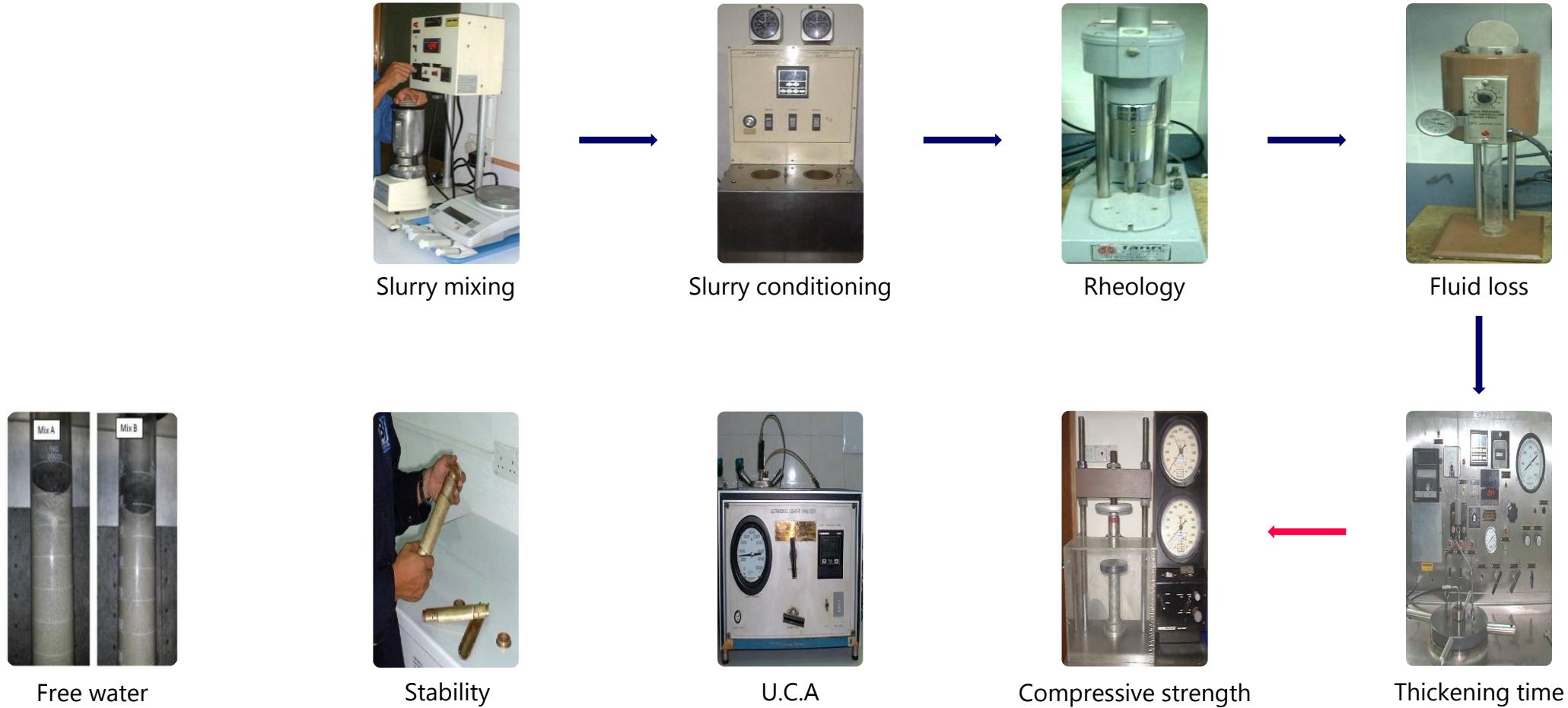
What is the usual number of chemical additives used in cement slurries placed across hydrocarbon-bearing zones?

1 1 to 3

2 3 to 5

3 More than 5

# Standardized lab tests (API RP10 B2)



## QUIZ TIME

# Standardized lab tests (API RP10 B2)

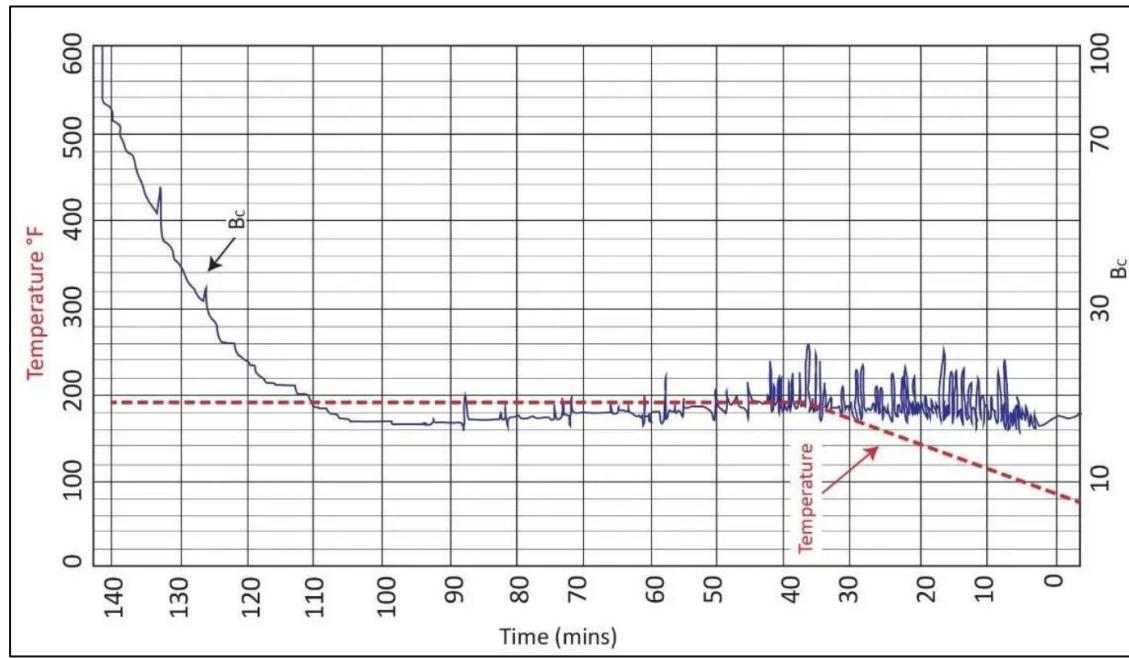
How many cement slurry laboratory tests are typically performed for intermediate casing strings?

1 Up to 3

2 Up to 5

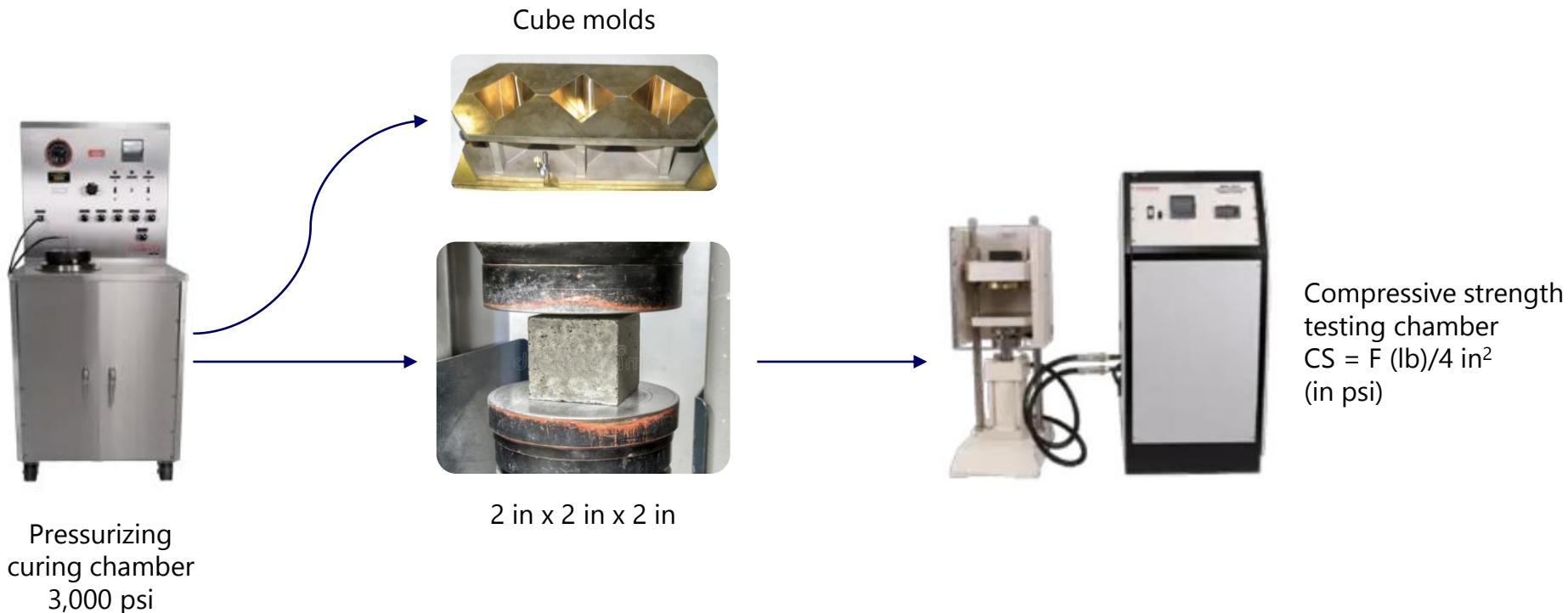
3 Up to 8

# Thickening time



Bc – Bearden Units of Consistency

# Compressive strength test (destructive)



## QUIZ TIME

# Compressive strength

Which set cement properties you consider the most important for preventing gas migration through a cement slurry?

1 Porosity and permeability

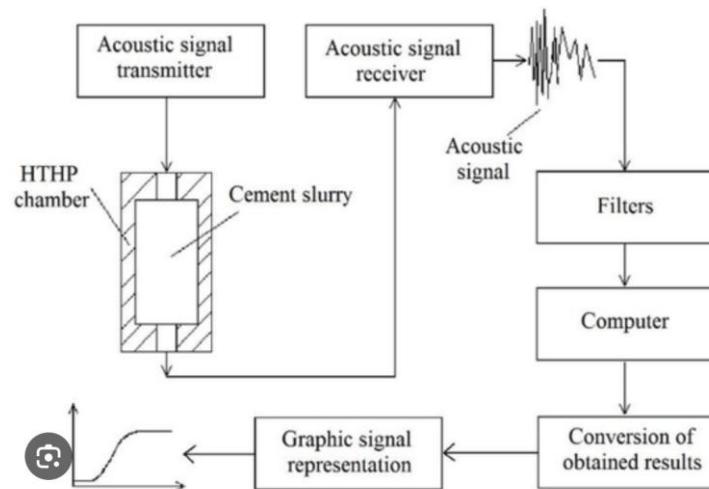
2 Quick transition from liquid to solid

3 Density

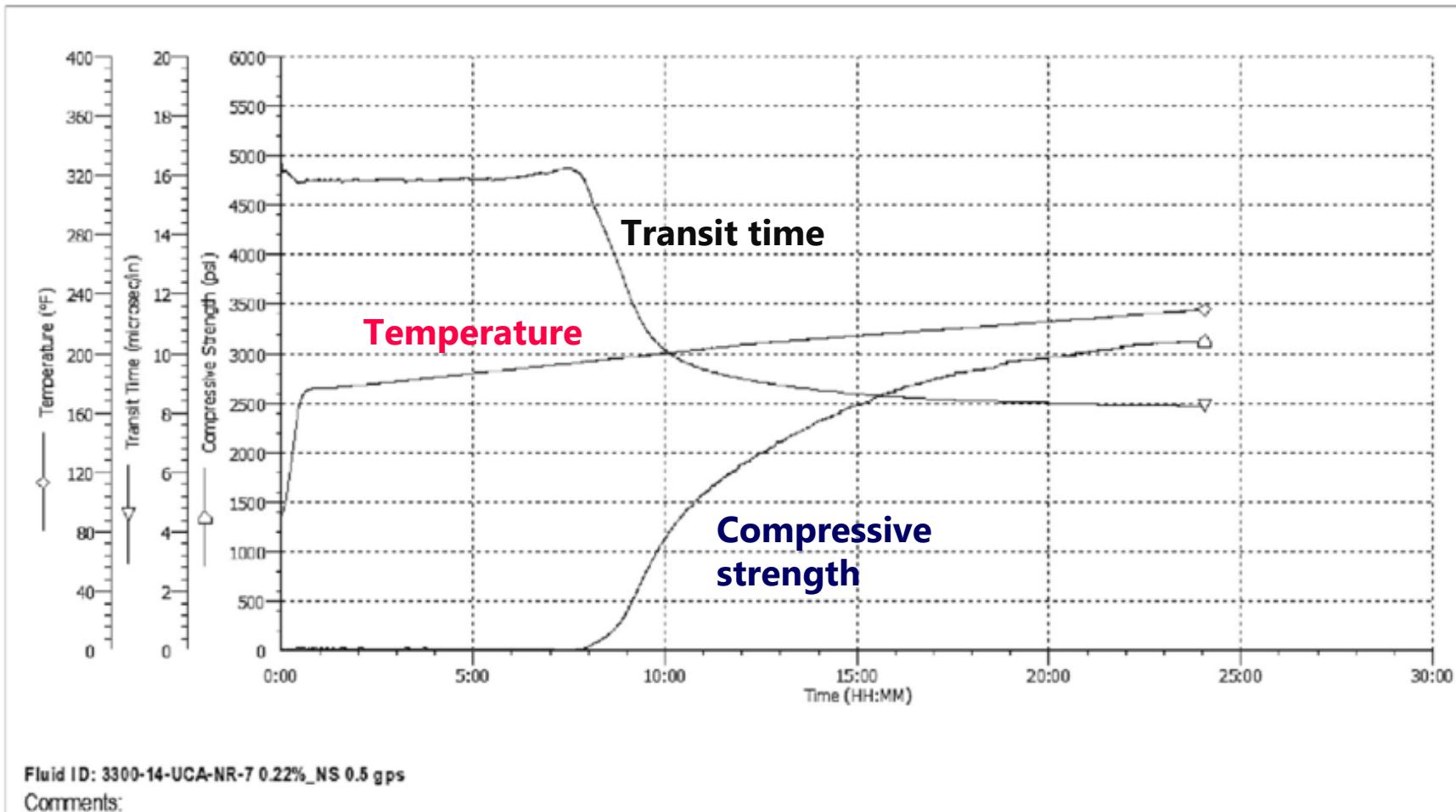
4 All the above

# Compressive strength (non destructive) Ultrasonic Cement Analyzer (UCA)

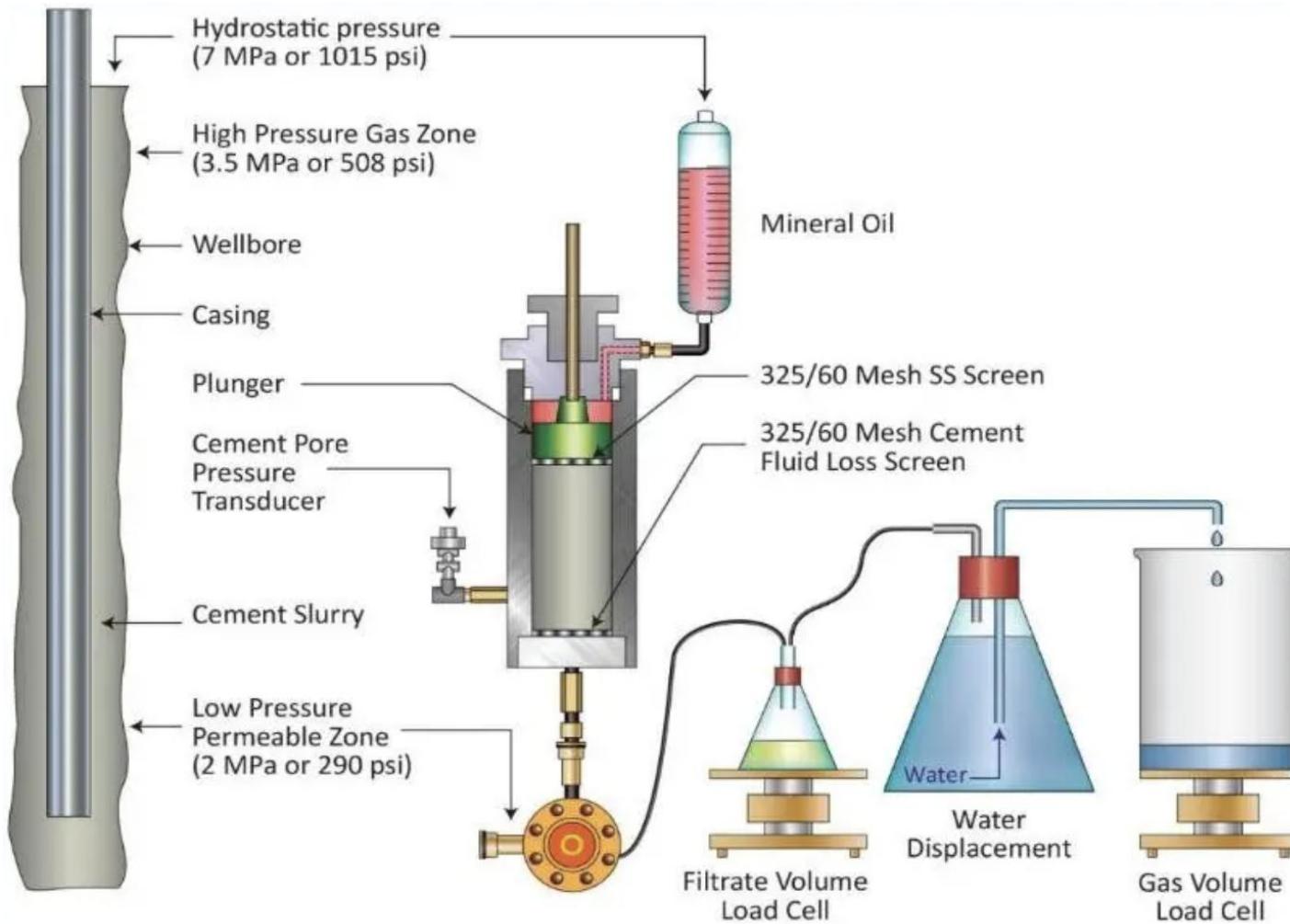
24 hours @ BHTP –  
measures the ultrasonic  
transit time passing  
through the cement slurry  
and correlates it to  
compressive strength by  
means of an algorithm of  
the control unit.



# Compressive strength (non destructive) Ultrasonic Cement Analyzer (UCA)



# Gas influx/migration test



# API testing for CO<sub>2</sub> environments

- There is no API RP protocol for testing cement slurries exposed to CO<sub>2</sub>;
- API TR 10TR3 covers, however:
  - General view of CO<sub>2</sub> chemical attack (carbonation process);
  - Discussion of strategies on cement designs exposed to CO<sub>2</sub> environment;
  - Orientation on materials selection (for example, pozzolans, silica, special binding materials);
  - Recommendations and considerations on set cement durability, micro-structure analysis, and required chemical additives.

# CO<sub>2</sub> testing (other organizations)

## AMPP (Association of Materials Protection and Performance)

The screenshot shows the AMPP website's search interface. At the top, there is a navigation bar with links for EDUCATION & CERTIFICATION, STANDARDS & TECHNICAL, QP PROGRAMS, MEMBERSHIP, EVENTS, ADVOCACY, MEDIA, and ABOUT. Below the navigation is a search bar with a placeholder "Search" and a "Shop AMPP" button. To the right of the search bar are a magnifying glass icon and a red "Login" button.

The main content area displays search results for "CO2". On the left, a sidebar shows filters: "All Content 8" (Communities 1, Q&A Threads 1, Web Pages 6), "More Filters" (Community, Created), and "Sort By: Relevance".

The search results list two items:

- Effect of dry CO<sub>2</sub> on epoxy surface condition** (Question by Andrew Lindsay, added 11-06-2023, View Community)
- Carbon Capture and Storage** (Community by Added 05-03-2022, View All Communities, View Community)

# CO<sub>2</sub> testing (other organizations)

CSA GROUP

The screenshot shows the CSA Group website for the CSA Z625:16 (R2021) standard. The top navigation includes a search bar, a cart icon (Cart (0)), user login options, language selection (English), currency selection (USD), and a CSA OnDemand link. The main content area displays the product title "CSA Z625:16 (R2021)" and its description: "Well design for petroleum and natural gas industry systems". It provides details like SKU: 2424656, publication year 2016, reaffirmed in 2021, and 48 pages. A "Buy" button is shown with a price of \$275.00 USD, quantity selector, and "Add To Cart" button. A note states the product is only available to residents of Canada. Below the product details are links for Preface/Scope, Updates, FAQs, Contact Us, and Email Product. The sidebar contains two sections with red borders:

**1.2**  
This Standard addresses

- a) casing, including casing design for various types of wells, including but not limited to horizontal and directional wells;
- b) cementing, including cement design and centralization issues and practices; and
- c) wellhead, including design, and assembly.

**1.3**  
This Standard does not apply to

- a) completion;
- b) operations;
- c) abandonment;
- d) remedial cementing;
- e) interventions;
- f) suspensions;
- g) competencies;
- h) management system requirements;
- i) drilling operations;
- j) emerging technologies;
- k) design tools; and
- l) offshore and arctic applications.

**QUIZ TIME**

## **CO<sub>2</sub> testing (other organizations)**

Where else do we see sulfate attack on set cement?

# CO<sub>2</sub> testing (other organizations)

## ISO 27916



Standards

Sectors

About ISO

Insights & news

Taking part

Store

The screenshot shows the ISO website with the ISO 27916:2019 standard page. The page features the ISO logo at the top left. A navigation bar with links to Standards, Sectors, About ISO, Insights & news, Taking part, and Store. The main content area displays the title "ISO 27916:2019" in large bold letters, followed by a subtitle "Carbon dioxide capture, transportation and geological storage — Carbon dioxide storage using enhanced oil recovery (CO<sub>2</sub>-EOR)". A green leaf icon is positioned next to the subtitle. Below the title, a summary text reads: "Published (Edition 1, 2019)". To the left of the main text, there is a thumbnail image of the ISO 27916:2019 standard document cover, which includes the title, edition information (Edition 1, 2019), and a brief description: "Carbon dioxide capture, transportation and geological storage — Carbon dioxide storage using enhanced oil recovery (CO<sub>2</sub>-EOR)". At the bottom left, a button labeled "Read sample" is visible.

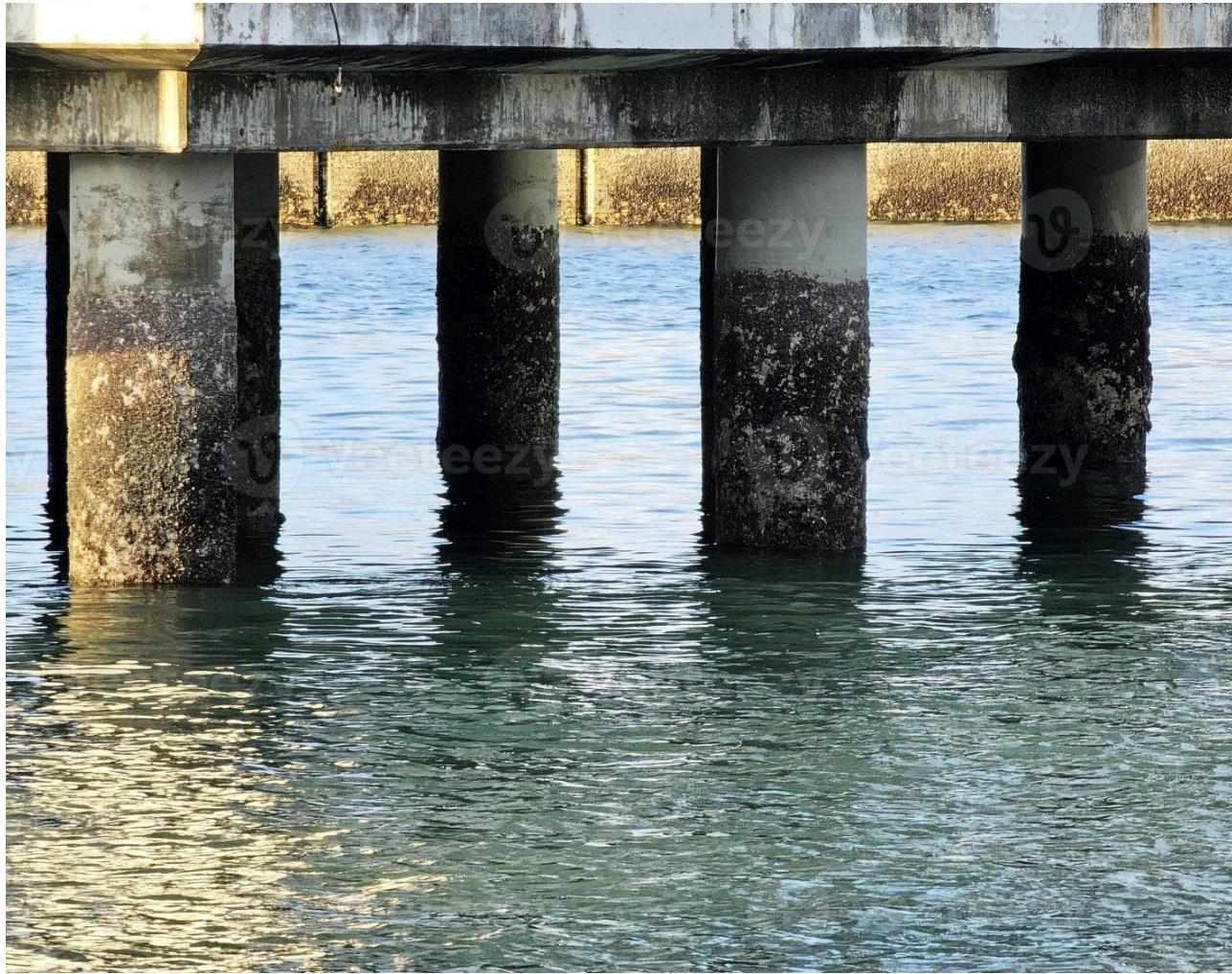
# API testing for H<sub>2</sub>S

- There is no API RP or exclusive TR to test cement resistance to H<sub>2</sub>S. However, H<sub>2</sub>S resistance is indirectly approached through specifications of sulfate resistant cements and general cement testing protocols.
- Service companies, operators and research institutions lean on:
  - Exposure tests in autoclave machines with H<sub>2</sub>S rich gas mixtures;
  - Long immersion of set cement in sulfide brines;
  - Petrographic analysis, SEM and XRD of set cement degradation;
  - Strength and permeability testing after exposure to H<sub>2</sub>S / sulfate brines;
  - Special binding materials (for exemple: pozzolanic mixtures, Classe G + silica fume, latex modified systems...)

# API Specifications - Sulfate Resistance

- API cement graduation in respect to sulfate resistance:
  - O (ordinary )
  - MSR (moderate sulfate resistance to SO<sub>4</sub>)
  - HSR (high sulfate resistance)

# API Specifications - Sulfate Resistance



# H<sub>2</sub>SO<sub>4</sub> testing (other organizations)

## ASTM C1898-20

- Standard Test Methods For Determining The Chemical Resistance Of Concrete Products To Acid Attack
  - These test methods are intended to evaluate the chemical resistance of cement paste, mortar and concrete materials. This method is loosely based on Test Methods C267, however the solution is more rigorously defined and flexural strength is used. These test methods provide for the determination of changes in the following properties of the test specimens and test medium after exposure of the specimens to the medium:
    - Mass of specimen
    - Appearance of specimen,
    - Appearance of test medium, and
    - Strength of specimens.

This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guide and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

 Designation: C1898 – 20

**Standard Test Methods for Determining The Chemical Resistance of Concrete Products to Acid Attack<sup>1</sup>**

This standard is issued under the fixed designation C1898; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last suppressed. A superscript epsilon (ε) indicates an editorial change since the last revision or suppression.

**1. Scope**

1.1 These test methods are intended to evaluate the chemical resistance of cement paste, mortar and concrete materials. This method is loosely based on Test Methods C267, however the solution is more rigorously defined and flexural strength is used. These test methods provide for the determination of changes in the following properties of the test specimens and test medium after exposure of the specimens to the medium:

1.1.1 Mass of specimen,  
1.1.2 Appearance of specimen,  
1.1.3 Appearance of test medium, and  
1.1.4 Strength of specimens.

1.2 Guide C1894 provides a standard guide for Microbially Induced Corrosion (MICC) products. This standard is used for assessing the chemical resistance of concrete products to acid attack caused by MICC; however as described in the guideline document for MICC products the content document only applies for Stage III of corrosion. This document is not intended to be a guideline document for the complete evaluation of MICC or for assessing the efficacy of antimicrobial additives used to reduce MICC.

1.3 This standard supplements Test Methods C267 to improve the consistency of reported results for acids generated by MICC or other sources.

1.4 This standard does not cover tests in which acidification is achieved by bacterial activity. Testing protocols for bacterial activity are described in Guide C1894.

1.5 The values stated in SI units are to be regarded as standard. The values given in parentheses are mathematical conversions to alternative units (typically inch-pound units) that are provided for information only and are not considered standard.

1.6 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

1.7 This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guide and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

**2. Referenced Documents**

2.1 ASTM Standards:  
C14 Specification for Nonreinforced Concrete Sewer, Storm Drain and Culvert Pipe  
C70/C70M Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)  
C125 Terminology Relating to Concrete and Concrete-Aggregates  
C102/C102M Practice for Making and Curing Concrete Test Specimens in the Laboratory  
C267 Test Methods for Chemical Resistance of Mortars, Grouts, and Monolithic, Surface, and Polymer-Concrete  
C522 Terminology Relating to Concrete Pipe and Related Products  
C904 Terminology Relating to Chemical-Resistant Nonmetallic Materials  
C1780/C1780M Practice for Accelerated Curing of Concrete Cylinders  
C1894 Guide for Microbially Induced Corrosion of Concrete Products  
E4 Practices for Force Verification of Testing Machines

**3. Terminology**

3.1 Definitions:  
3.1.1 For definitions of terms used in this standard, refer to Terminology standards C125 and C522.

**4. Significance and Use**

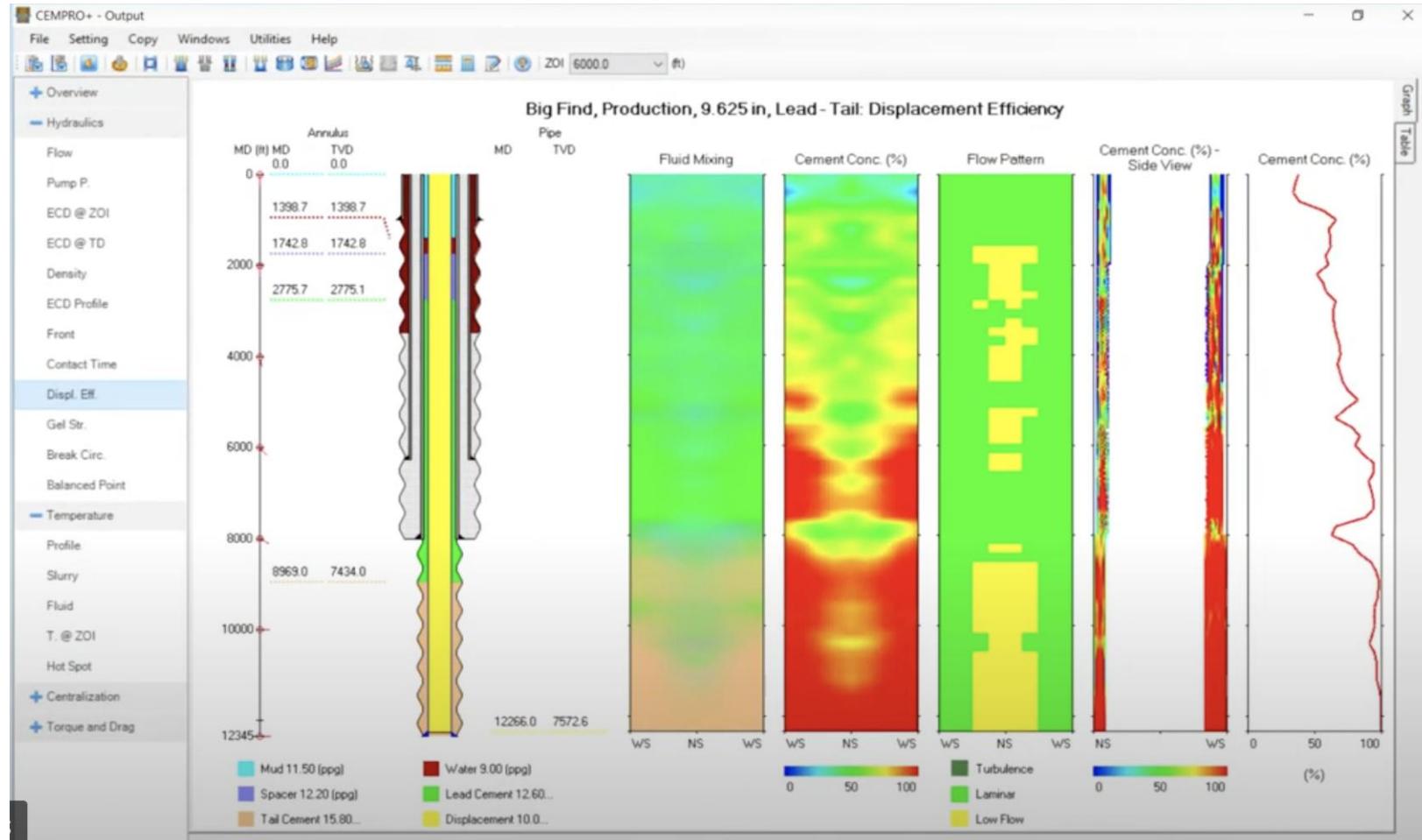
4.1 As described in Guide C1894, the MICC is considered to be a three-stage process with the reduction in pH (Stage I) (for example, 12.5 > pH > 9.0), the establishment of biofilms (which further lowers the pH (Stage II) (for example, 9–10 > pH > 4.0) and eventual deterioration due to biogenic acid exposure

<sup>1</sup> This test method is under the jurisdiction of ASTM Committee C11 on Concrete and in the direct responsibility of Subcommittee C11.09 on Determining the Effects of Biogenic Activities, Soil on Concrete Pipe and Structures. Current edition approved May 1, 2016. Previous May 2006. © 2016 ASTM International.

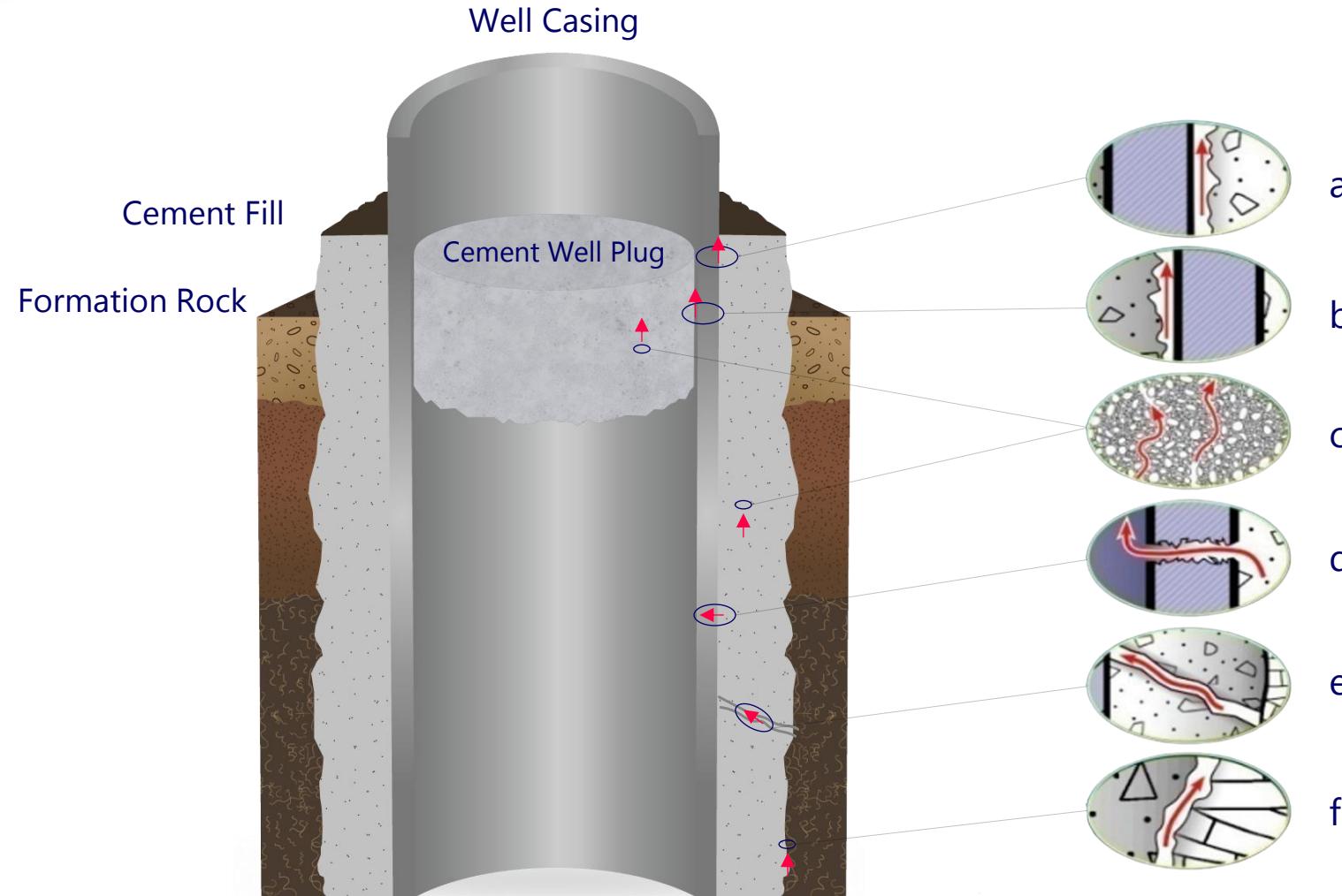
# Well Cementing Simulators

- Sources:
  - Service companies;
  - Independent specialized software companies.

# Well Cementing Simulators

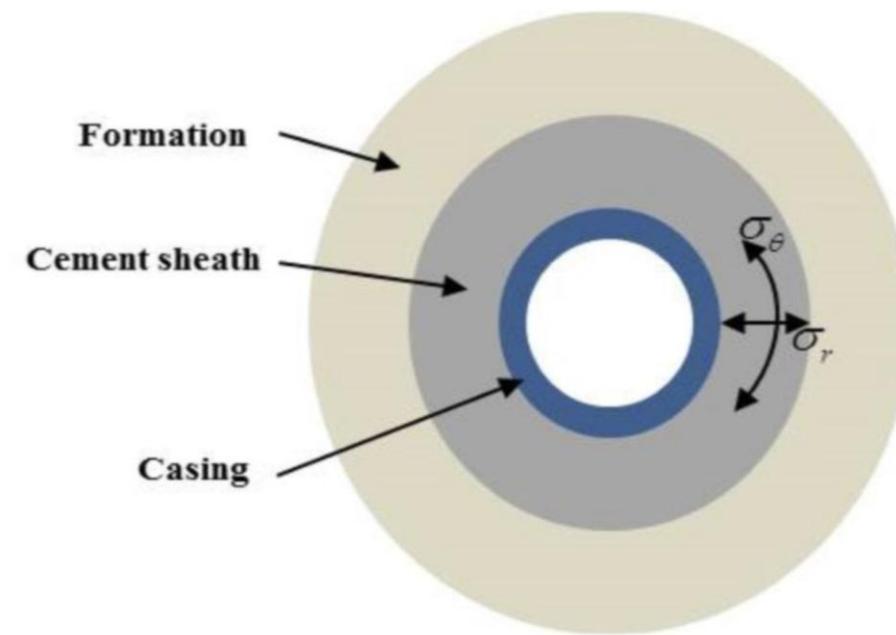
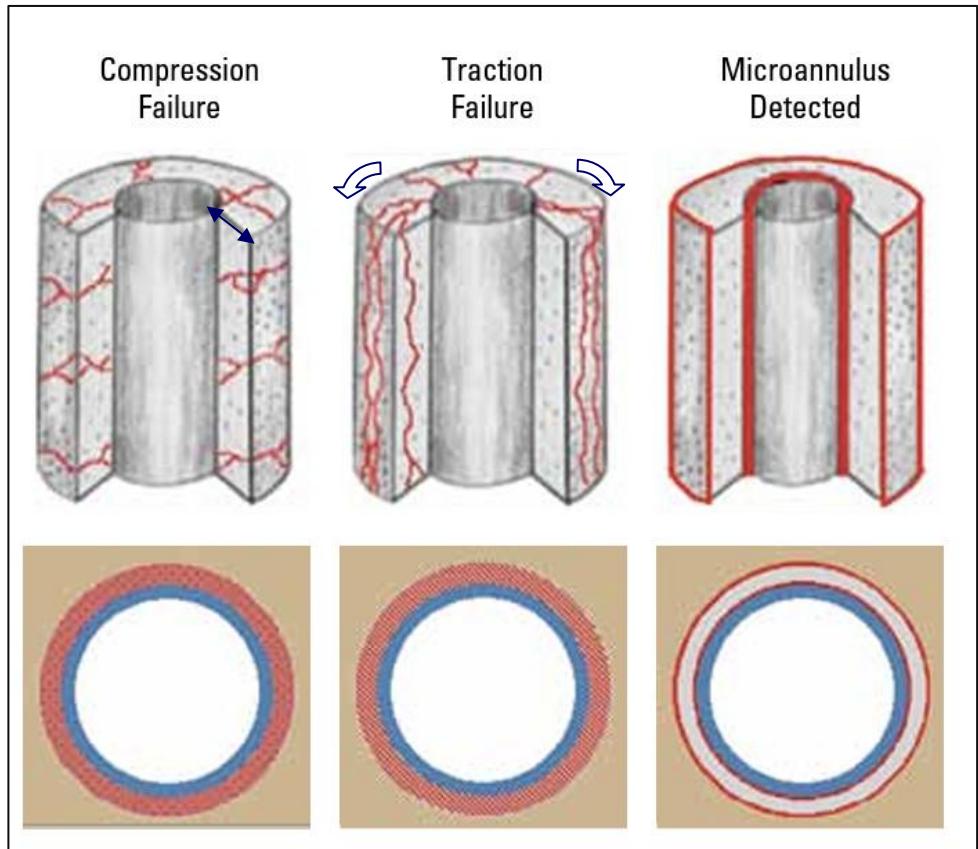


# Potential Leakage Pathways



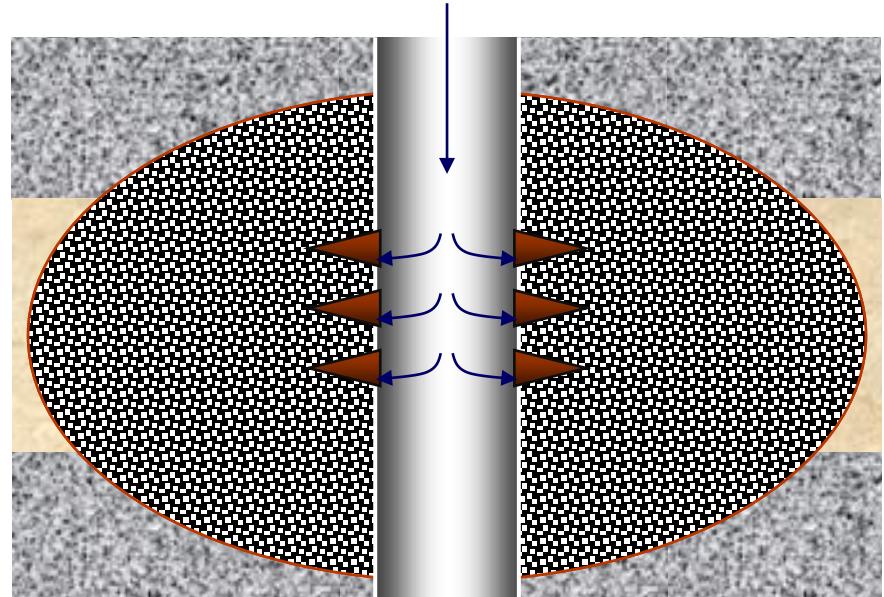
Gasda et al., 2004 and 2005

# Factors Impacting Cement Integrity

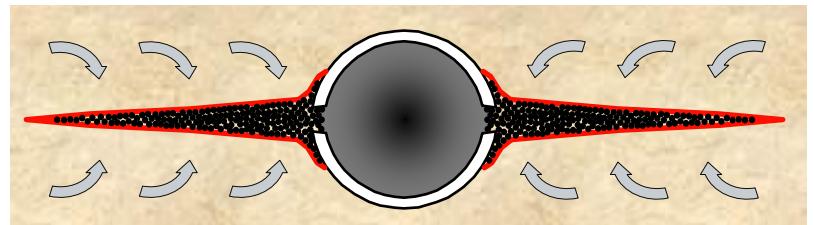


# Hydraulic Fracturing

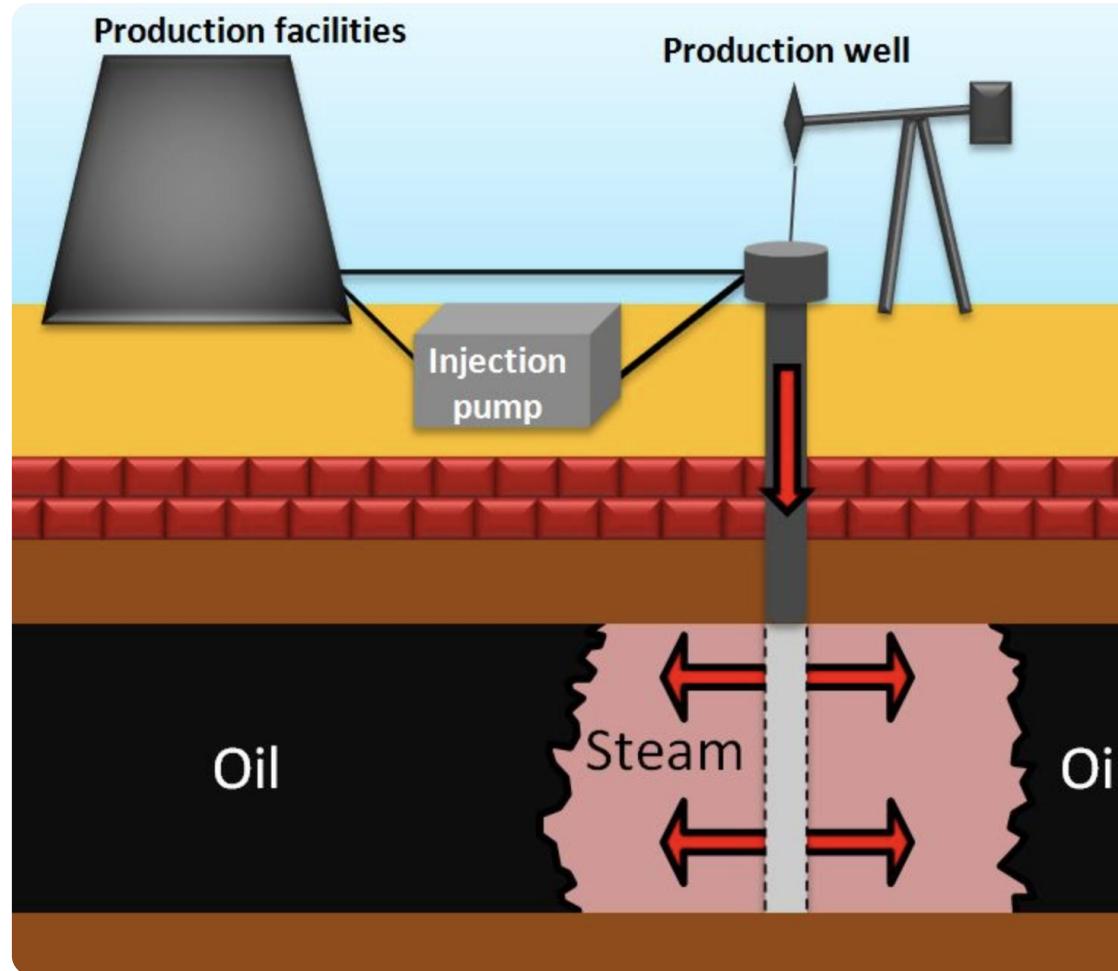
- High rate and high pressure pumping, injecting frac fluids into the formation, creating fractures...
- After the fractures are created, sustaining agents, also called proppants, are pumped in...
- The fracture is filled in by proppants, at the end of the pumping, in order to keep it open and to facilitate fluids from the reservoir to the well.



△  
P



# Steam Injection in Enhanced Oil Recovery



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**QUIZ TIME**

## **CO<sub>2</sub> Injection (EOR)**

In which likely scenario below do we have acid attacking set cement?

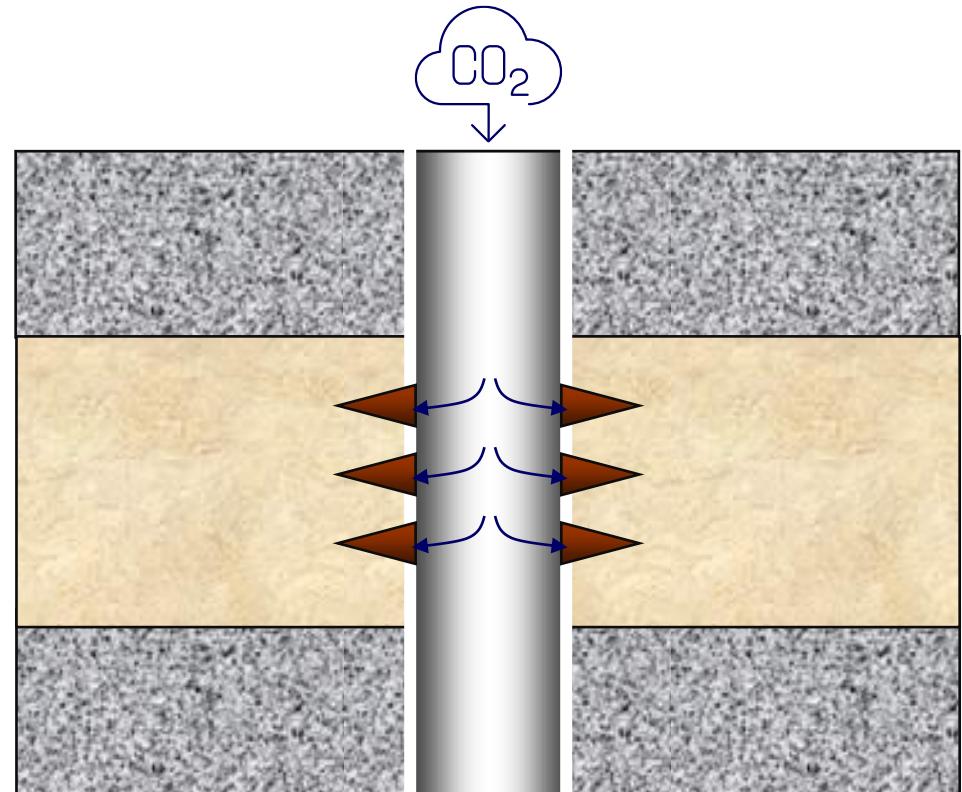
1 Raining over concrete skyscrapers

2 Fresh water over cemented floor

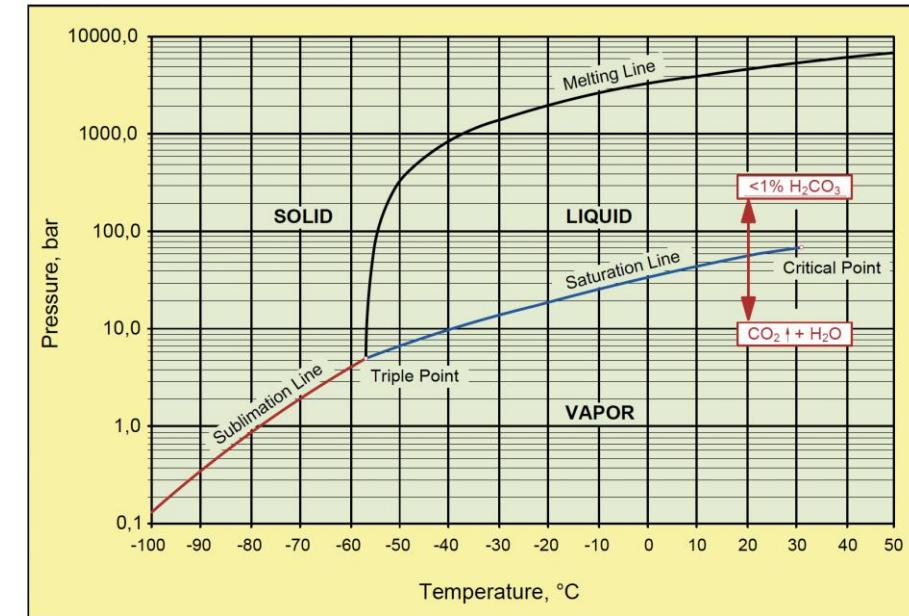
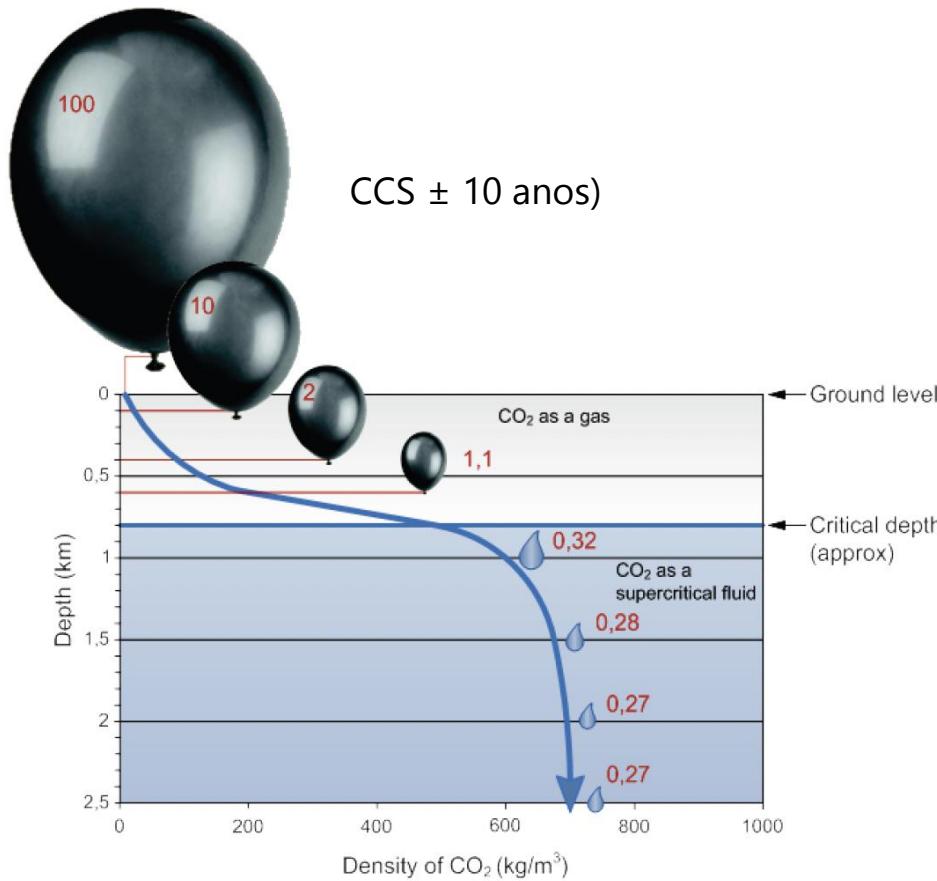
3 Paint over concrete walls

# CO<sub>2</sub> Injection (EOR)

- CO<sub>2</sub> injection is a proven EOR technique ( $\pm$  45 years);
- Injected CO<sub>2</sub> reduces oil viscosity and interfacial tension;
- Under high pressure, CO<sub>2</sub> becomes miscible with oil, improving recovery;
- It helps to keep reservoir pressure and improves oil sweep efficiency;
- Recovery increases by 10 to 20% or more in comparison with water injection;
- Captured industrial CO<sub>2</sub> can be reutilized, contributing to carbon management;
- Importance to set cement: wells should keep integrity when exposed to CO<sub>2</sub>.

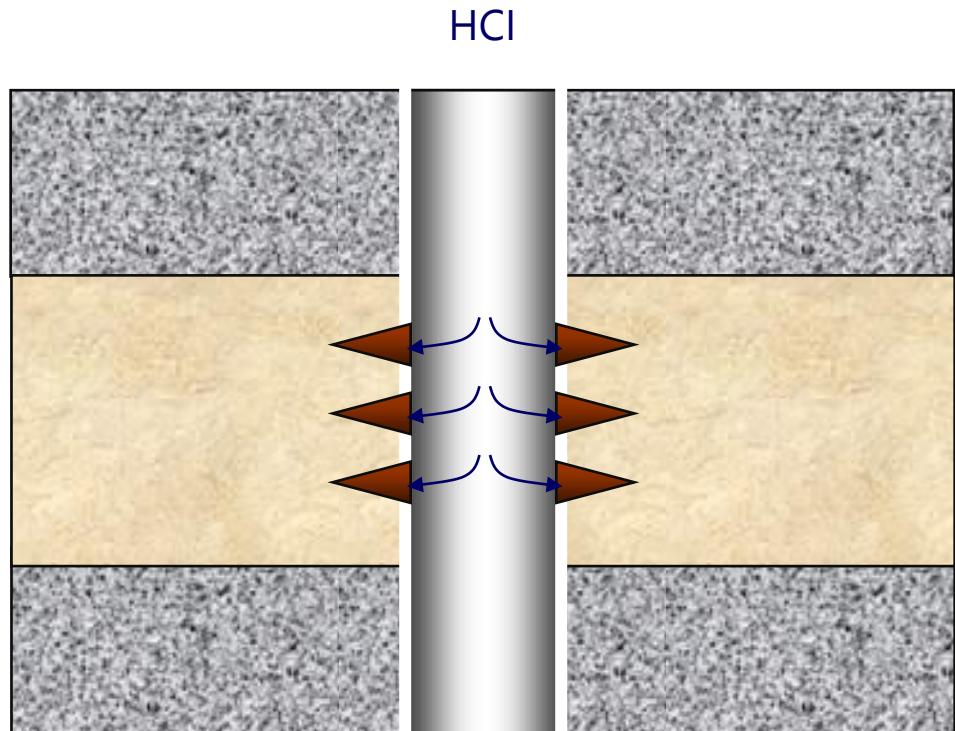


# CO<sub>2</sub> Injection (EOR)



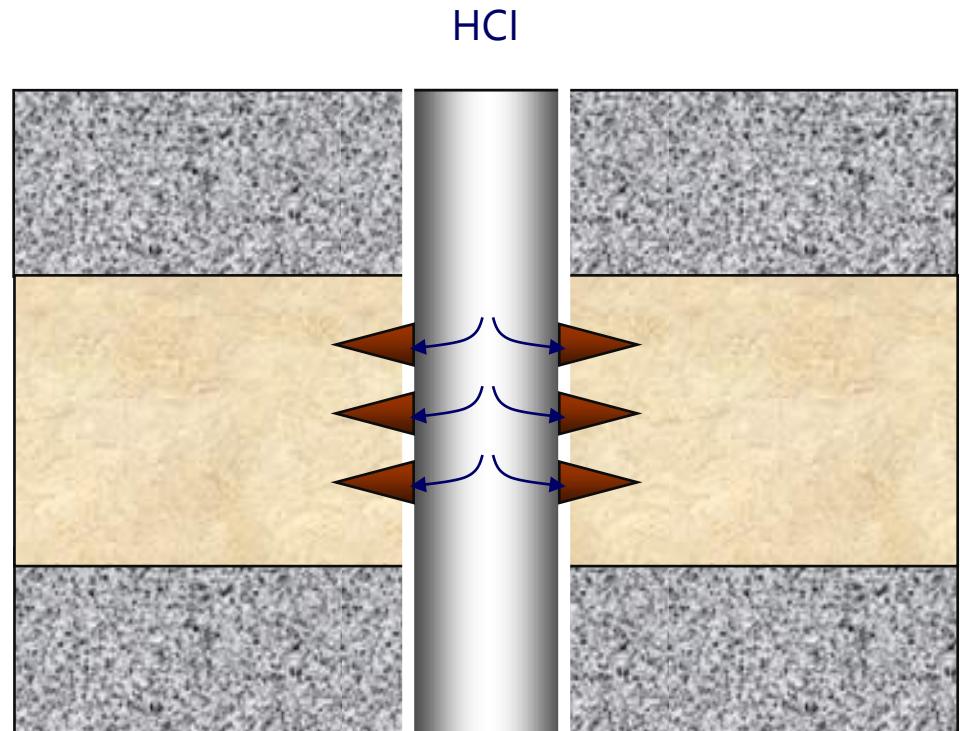
# HCl Injection (Stimulation)

- Acid stimulation fluids, especially hydrochloric acid (HCl), can cause serious damage to set cement if they come into contact with it. Here's what happens:
  - Dissolution of Cement Phases
    - HCl aggressively reacts with  $\text{Ca}(\text{OH})_2$  and other cement hydrates, such as calcium silicate hydrate (C-S-H), which are key to the strength of set cement.
    - This leads to decalcification, weakening the cement structure.
  - Increase in Porosity and Permeability
    - As acid dissolves cement compounds, it opens up the cement matrix, increasing porosity and permeability.
    - This compromises the sealing capability of the cement, potentially allowing fluid migration along the annulus.



# HCl Injection (Stimulation)

- Strength Loss
  - Progressive acid attack leads to loss of compressive strength, making the cement sheath unable to withstand pressure or mechanical loads.
- Zonal Isolation Failure
  - Damaged cement can lead to zonal isolation failure, resulting in crossflow between formation layers, gas migration, or sustained casing pressure (SCP).
- Risk of Well Integrity Compromise
  - In severe cases, acid-induced degradation of cement jeopardizes overall well integrity, requiring expensive remediation or re-cementing.



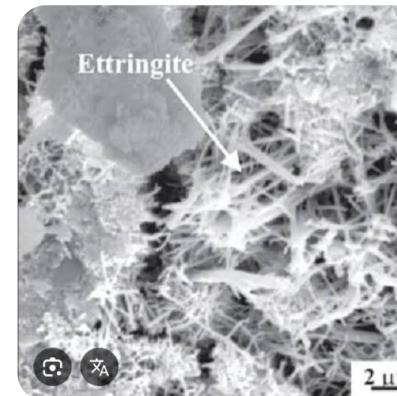
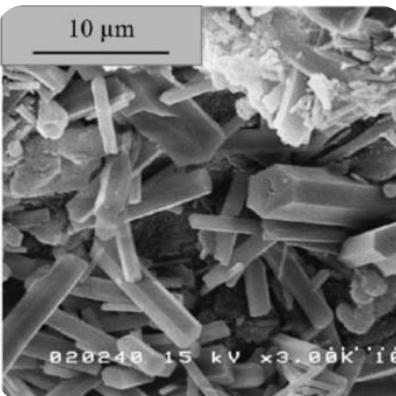
# What is set cement?

Ettringite is formed during the initial hydration of cement when C<sub>3</sub>A reacts with gypsum (CaSO<sub>4</sub>.2H<sub>2</sub>O) in the presence of water:

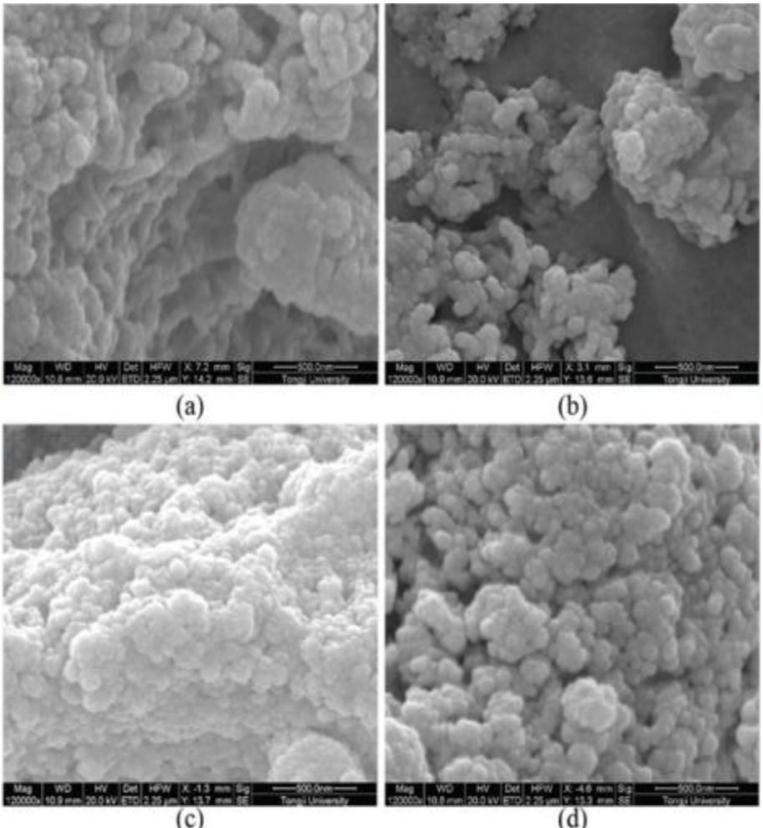


It controls thickening time and cement setting time.

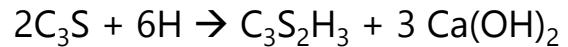
Compound	Chemical formula	Abbreviation	Typical Mass (%)	Contribution on performance
Tricalcium aluminate	3CaO·Al <sub>2</sub> O <sub>3</sub>	C <sub>3</sub> A	5 -12%	Durability and early setting



# What is set cement?



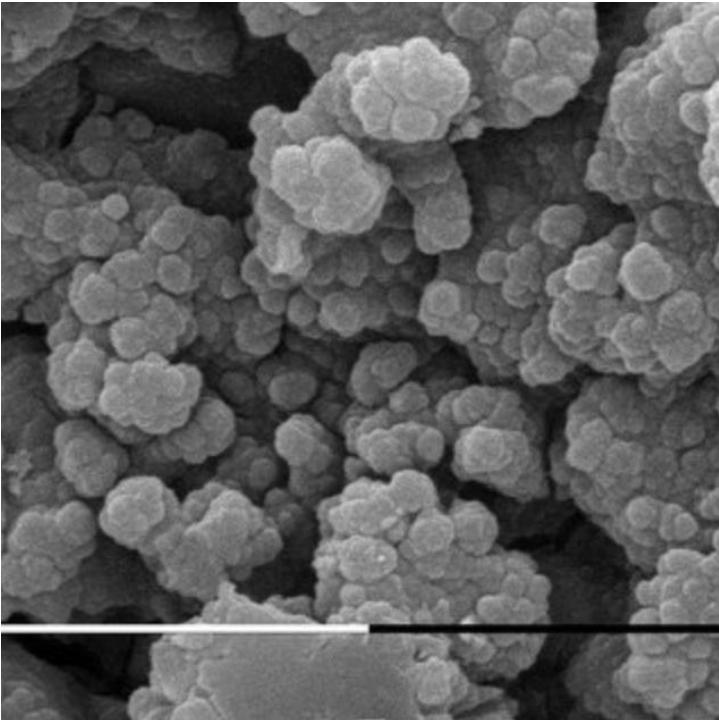
C-S-H (Calcium Silicate Hydrate) is the main phase which keeps the cement particles binded together, providing cohesion and resistance. It does not have a defined chemical formula and is amorphous. It is formed from the hydration of Portland cement silicate phases:



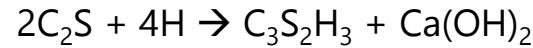
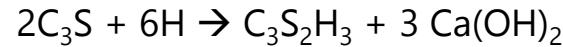
It controls cement permeability (gelled structure which fills the pore spaces), besides resisting to chemical attacks, and improve cement durability over cement long term life.

Compound	Abbreviation	Chemical Formula	Typical Mass (%)	Contribution on performance
Tricalcium silicate (Alite)	$\text{C}_3\text{S}$	$3\text{CaO}\cdot\text{SiO}_2$	45–60%	Durability and total resistance
Dicalcium silicate (Belite)	$\text{C}_2\text{S}$	$2\text{CaO}\cdot\text{SiO}_2$	15–30%	Long term durability

# What is set cement?



$\text{Ca(OH)}_2$  (Calcium Hydroxide) is byproduct of Portland cement silicate phases hydration:



It is also called hydrated lime or portlandite.

It provides alcalinity (high pH) to the pore solution, helping metal protection against corrosion in harmful environments. It is also one of the main reactants to  $\text{CO}_2$  attack (carbonation reaction).

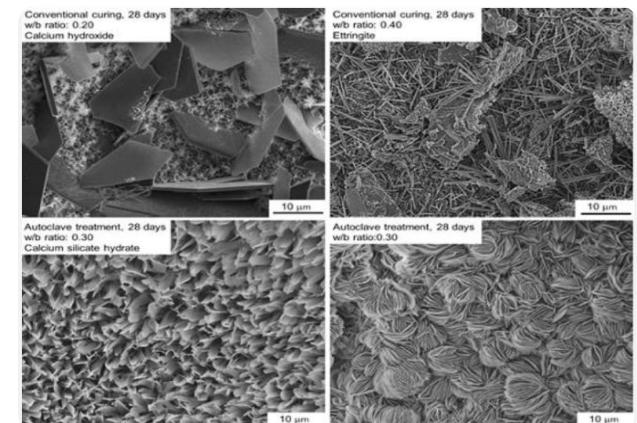
Compound	Abbreviation	Chemical Formula	Typical Mass (%)	Contribution on performance
Tricalcium silicate (Alite)	$\text{C}_3\text{S}$	$3\text{CaO}\cdot\text{SiO}_2$	45–60%	Durability and total resistance
Dicalcium silicate (Belite)	$\text{C}_2\text{S}$	$2\text{CaO}\cdot\text{SiO}_2$	15–30%	Long term durability

# What is set cement?

The main products generated by the cement hydration process are the Calcium Silicate Hydrate gel – CSH – and the Calcium Hydroxide –  $\text{Ca}(\text{OH})_2$ .

CSH is semi-amorphous material, similar to a gel, which make up approximately 70% in weight of hydrated cement and is the main particles binder.

$\text{Ca}(\text{OH})_2$  is crystalline and make up approximately 15 to 20% in weight of hydrated cement.

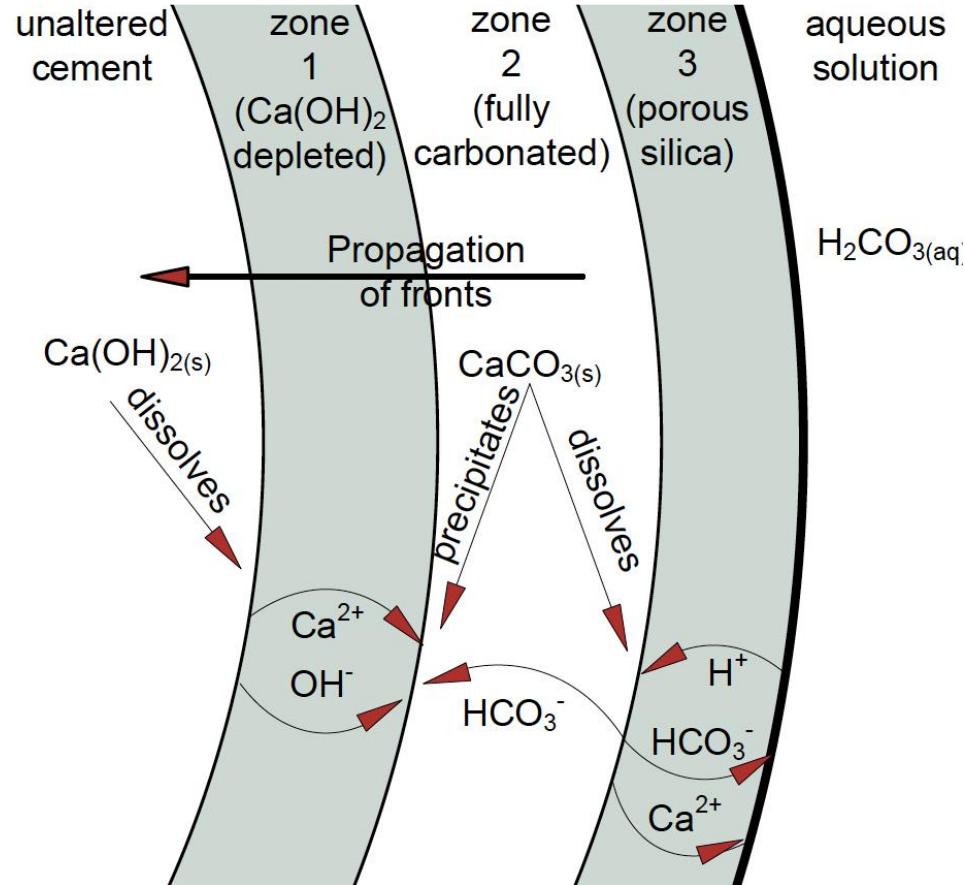


# Related Chemical Reactions ( $\text{CO}_2$ )

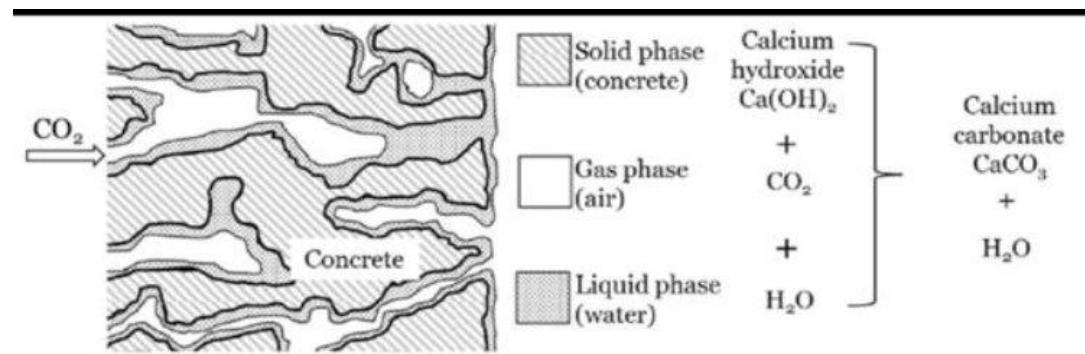
1.  $\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO}_3$  (carbonic acid)
2.  $\text{H}_2\text{CO}_3 + \text{Ca(OH)}_2 \rightarrow \text{CaCO}_3 + 2\text{H}_2\text{O}$
3. C-S-H and/or crystalline phases +  $\text{H}_2\text{CO}_3 \rightarrow \text{CaCO}_3 + \text{SiO}_2$   
(gel) +  $\text{H}_2\text{O}$
4.  $\text{CaCO}_3 + \text{H}_2\text{CO}_3 \rightarrow \text{Ca}(\text{HCO}_3)_2$



# Related Chemical Reactions ( $\text{CO}_2$ )

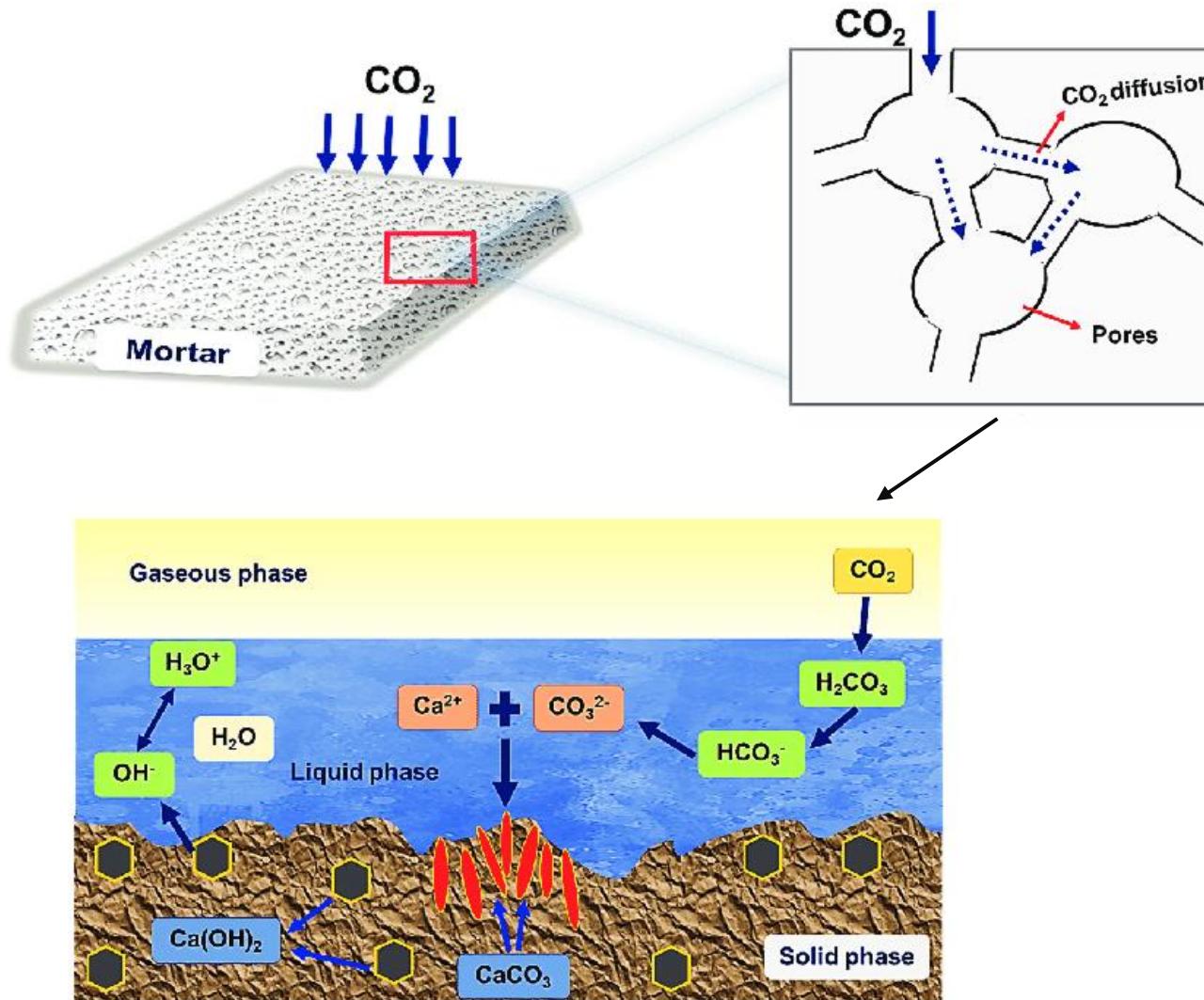


The dissolution and calcium migration and formation of distinct zones in the set cement.



Step 1:	Step 2:	Step 3:
Diffusion inwards of $\text{CO}_2$	Reaction between $\text{CO}_2$ and water molecules	Reaction between resultant $\text{H}_2\text{CO}_3$ and the $\text{Ca}(\text{OH})_2$ of concrete resulting in calcium carbonate $\text{CaCO}_3$ and water

# Related Chemical Reactions ( $\text{CO}_2$ )

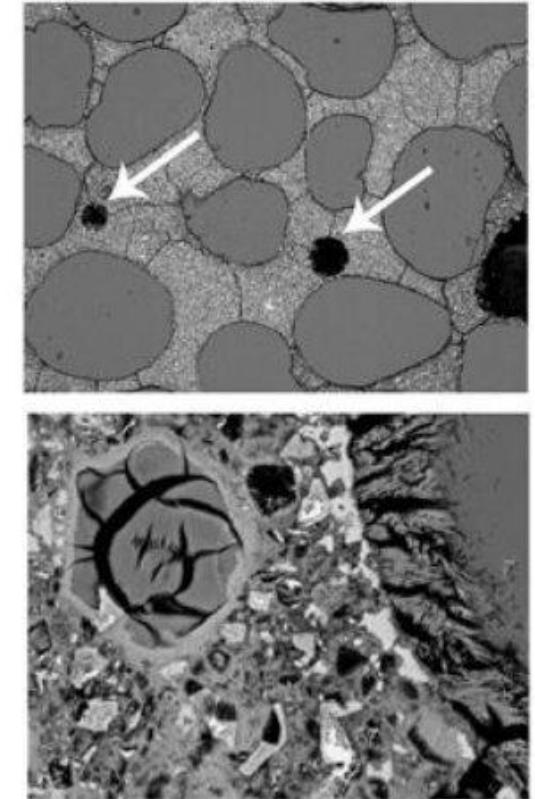
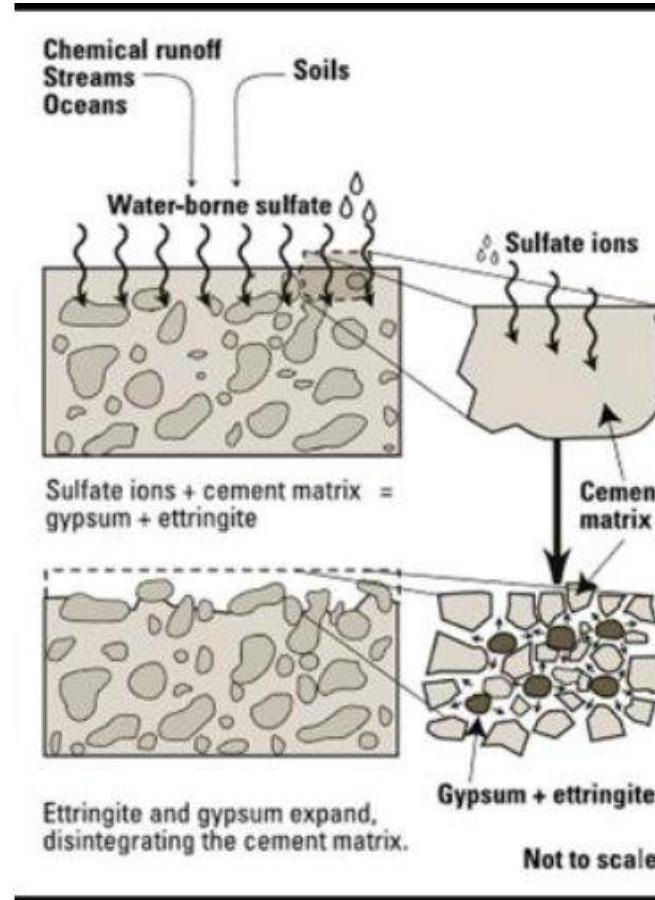
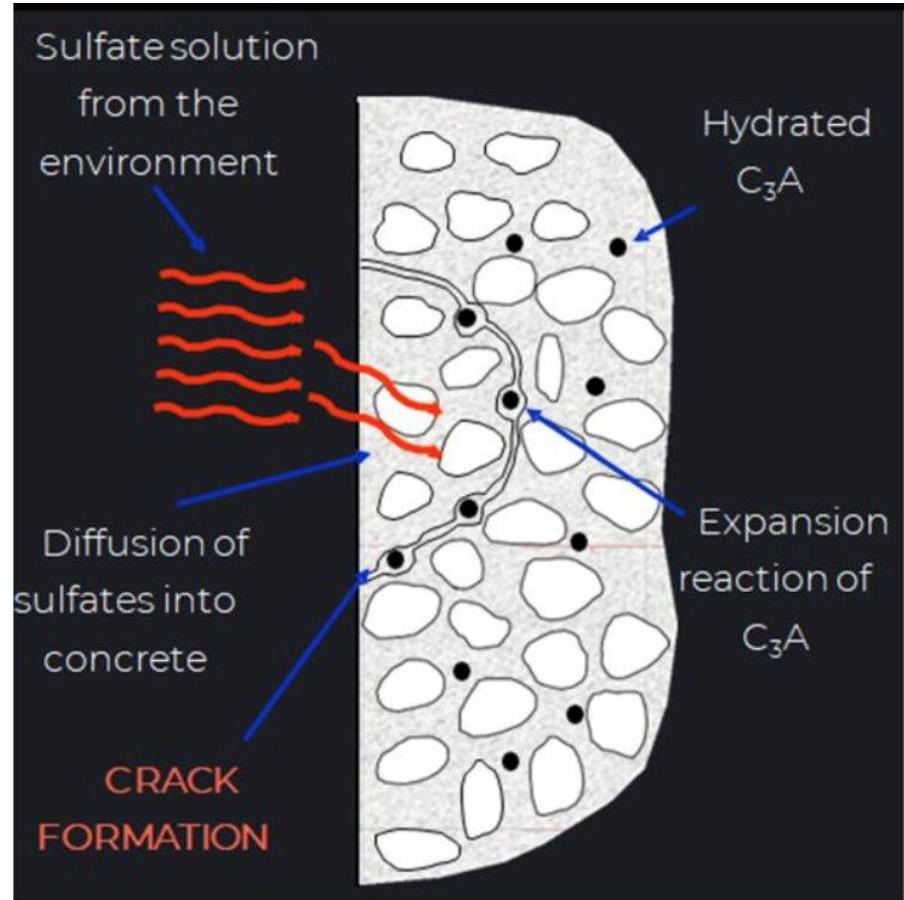


# Related Chemical Reactions ( $\text{H}_2\text{S}$ )

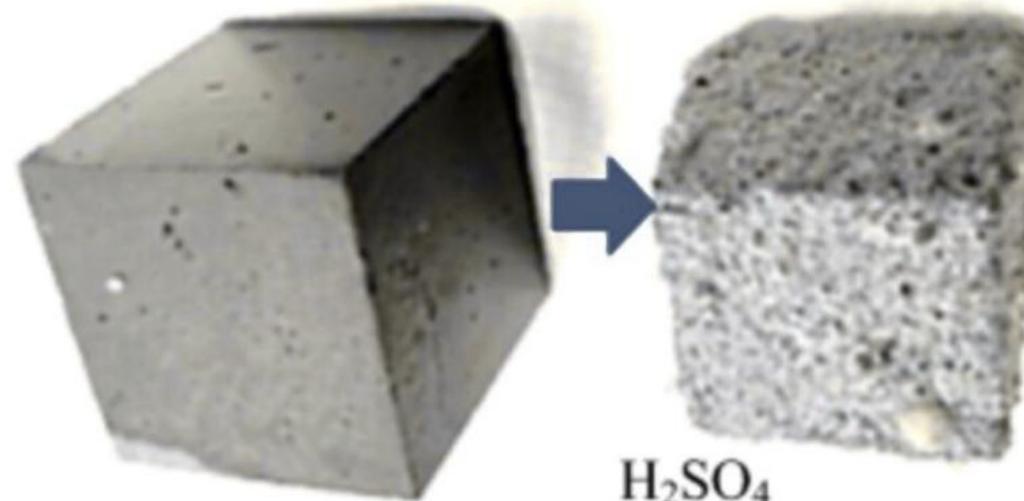
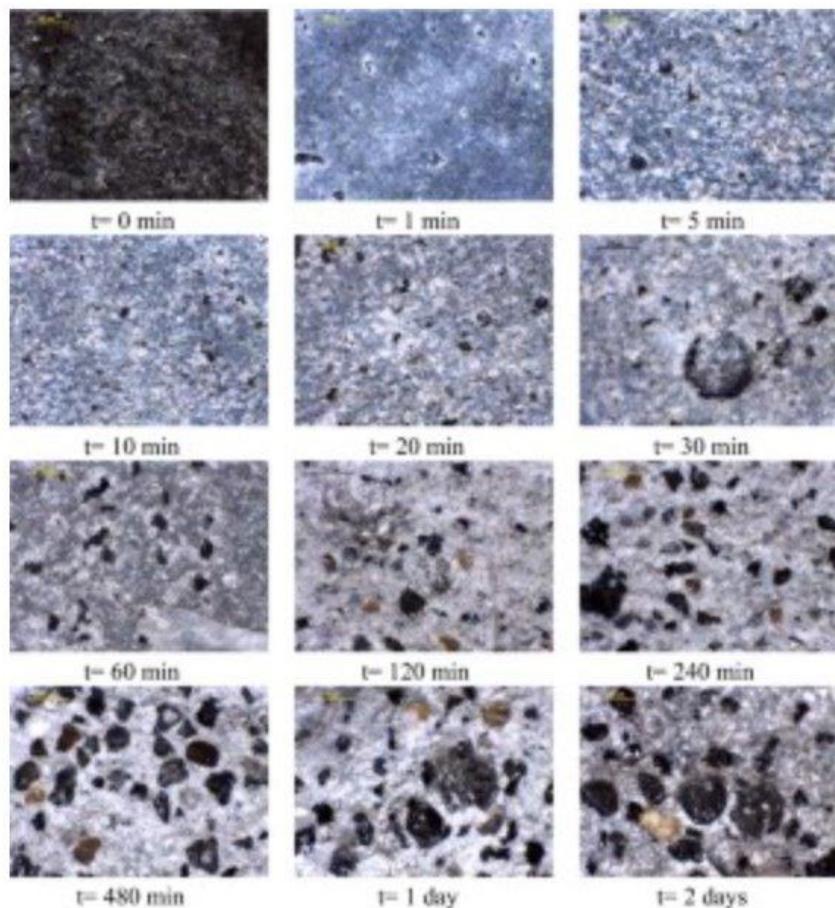
1.  $\text{H}_2\text{S} + \text{Ca}(\text{OH})_2 \rightarrow \text{CaS} + 2\text{H}_2\text{O}$
2.  $\text{CaS} + 2\text{H}_2\text{O} + \text{CO}_2 \rightarrow \text{CaCO}_3 + \text{H}_2\text{S}\uparrow$
3. Monosulfates react with  $\text{C}_3\text{A}$ , forming expansive crystals:
  - Ettringite:  
$$\text{C}_3\text{A} + 3(\text{CaSO}_4 \cdot 2\text{H}_2\text{O}) + 26\text{H}_2\text{O} \rightarrow \text{C}_6\text{A}\ddot{\text{S}}_3\text{H}_{32}$$
  
$$(3\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot \text{CaSO}_4 \cdot 12\text{H}_2\text{O})$$
  - Gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ):  
Can also form if excess sulfate reacts with calcium hydroxide (portlandite)



# Related Chemical Reactions ( $H_2S$ )



# Related Chemical Reactions ( $\text{H}_2\text{S}$ )



Before testing



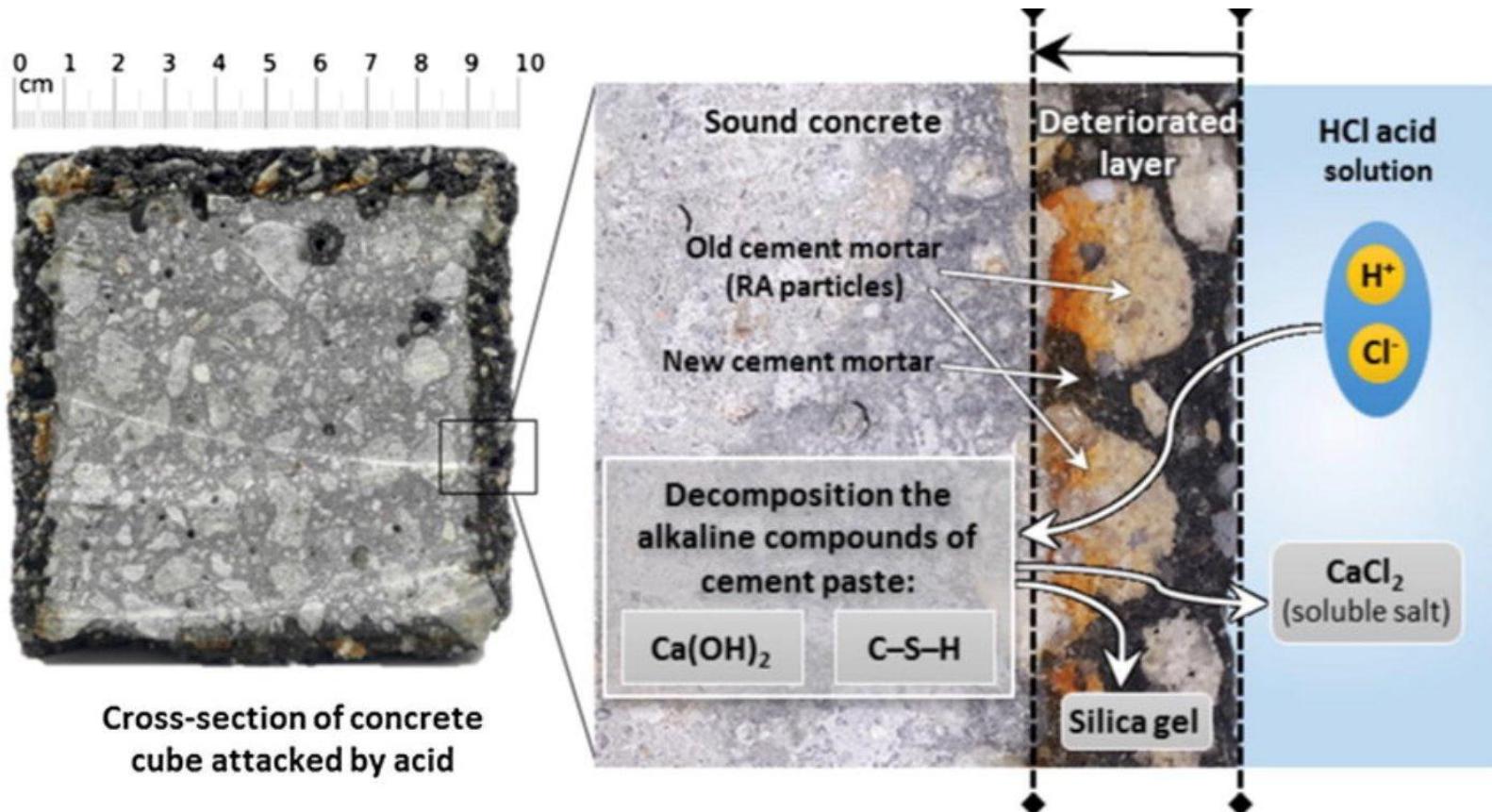
After testing

# Related Chemical Reactions (HCl)

1.  $2\text{HCl} + \text{Ca}(\text{OH})_2 \rightarrow \text{CaCl}_2 + 2\text{H}_2\text{O}$
2.  $\text{CSH} + 2\text{HCl} \rightarrow \text{SiO}_2 \cdot x\text{H}_2\text{O}$  (gel) +  $\text{CaCl}_2$
3. Reaction with Ettringite :  
 $\text{C}_6\text{A}\ddot{\text{S}}_3\text{H}_{32} + 12\text{HCl} \rightarrow \text{AlCl}_3 + \text{CaCl}_2 + \text{byproducts}$
4.  $\text{CaCO}_3 + 2\text{HCl} \rightarrow \text{CaCl}_2 + \text{CO}_2\uparrow + \text{H}_2\text{O}$



# Related Chemical Reactions (HCl)



# Mechanisms of Cement Degradation

## Dissolution:

Loss of  $\text{Ca}(\text{OH})_2$  reduces alkalinity.

## Precipitation:

Formation of secondary minerals such as  $\text{CaCO}_3$  and  $\text{CaS}$ .

## Structural alterations in high temperature:

Increase of porosity and micro fissures reduce mechanical resistance.

# Effect of Temperature in Corrosion

## Temperature:

- Temperature increase accelerate chemical reactions;
- Corrosion at 90°C is higher than at 50°C, under the same time exposure.

## Time:

- The longer the exposure time, the greater the corrosion penetration;
- The corrosion depth grows rapidly in the first few days and tends to stabilize over time.

# Effect of Corrosion on Compressive Strength

1

Corrosion reduces the mechanical resistance of set cement.

2

Increase of porosity and formation of microcracks compromise the structural integrity of set cement.

# Effect of High Temperature ( $>110^{\circ}\text{C}$ ) on Mechanical Properties of Set Cement

1

$\text{C}_3\text{S}_2\text{H}_3$  becomes unstable and transforms itself in a hydrated  $\text{C}_2\text{S}$  of low resistance.

2

The crystallization degree of the hydrated byproducts is limited, and the dehydration of crystals further deteriorate the compressive strength of cement.

3

Increase of porosity and formation of microcracks compromise the structural integrity of set cement.

# Effect of High Temperature ( $>110^{\circ}\text{C}$ ) on Mechanical Properties of Set Cement

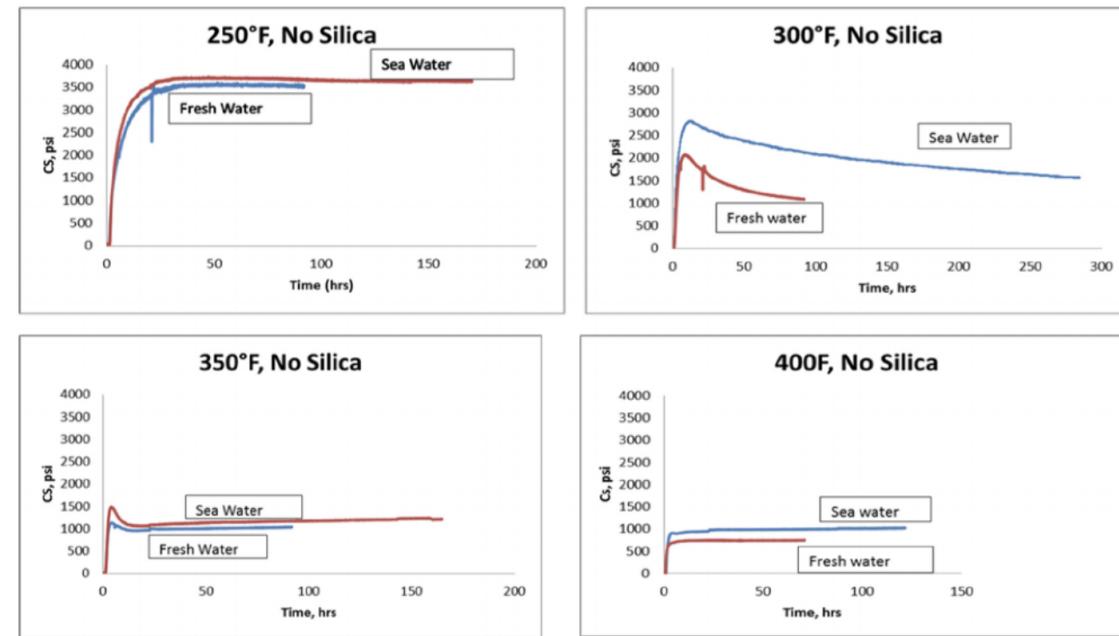
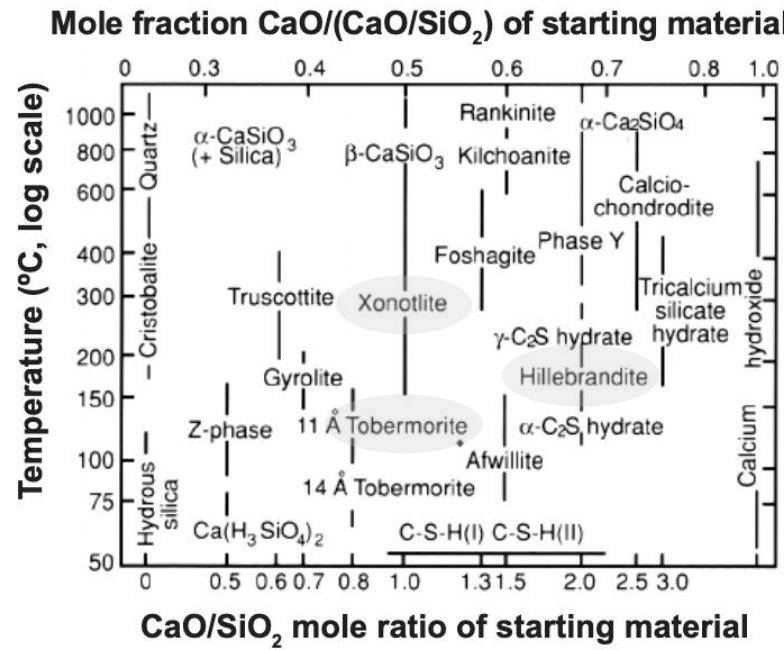
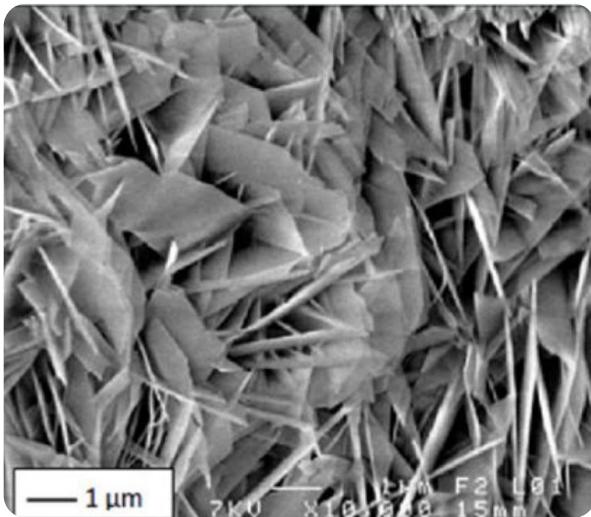


Figure 3—Early Strength development patterns for fresh and sea water formulations without silica flour

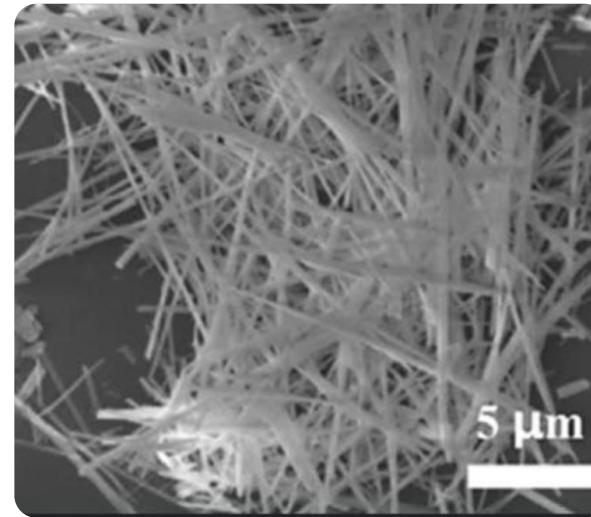
Figure 1: Phase changes in Portland cement submitted to elevated temperatures.

# Effect of High Temperature ( $>110^{\circ}\text{C}$ ) on Mechanical Properties of Set Cement

Tobermorite



Xonotlite



## QUIZ TIME

# Acid Attack

When does the acid attack produces a faster reaction:

1 Initial 7 days period

2 From 7 to 30 days (23 days period)

## QUIZ TIME

# Compressive strength

Which property is highly altered in this slide?

1 Core density

2 Core permeability

3 Core porosity

4 Core strength

# Mitigation Strategies

- Selection of corrosion resistance materials, such as pozzolanic cement and special anti-corrosion additives;
- Designs with more adequate materials for the maintenance of long term cement strength in high temperature environments.

# Example: specially formulated cement slurry

Composition of high-density cement slurries. Unit wt. %.

Density (kg/m <sup>3</sup> )	Cement	Water	Fluid Loss Reducer	Retarder	Dispersant	Slica Fume	Mn	Weighting Agent	Slag	Resin
2.0	100	41	7	2.5	2	35	16	16	20	8
2.1	100	42	7	2.5	3	35	32	32	18	8
2.2	100	44	6	2.2	4	35	52	52	18	8
2.3	100	45	6	2	4.5	35	79	79	16	10

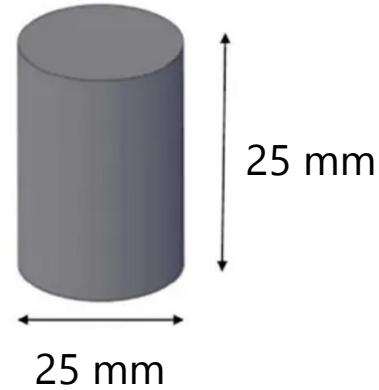
100 mesh: 150µm ; 300 mesh: 48µm

Material which replaces  
Portland cement, helping  
compaction

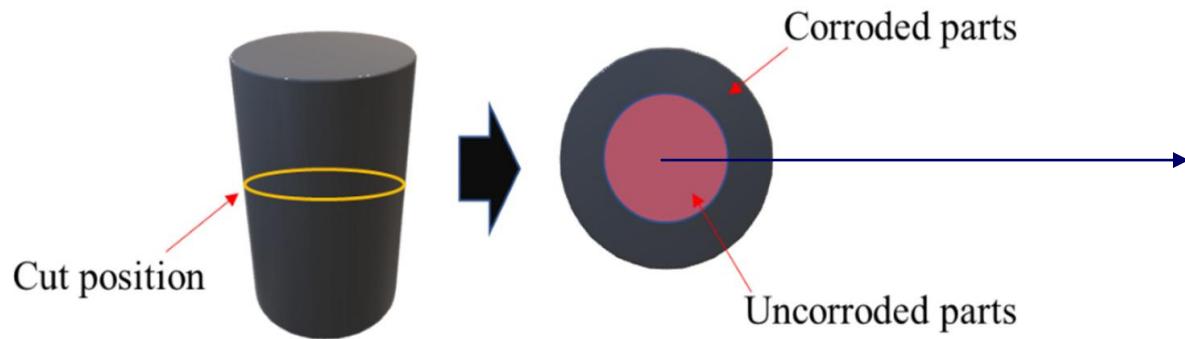
Added material which in high  
temperatures, reacts with cement  
hydrated silicates to generate  
tobermorite and xonotlite,  
reducing the ratio of C/S from 2  
to 3:1 to approximately 1:1

Material which  
protects cement  
matrix, mitigating  
corrosion

# Example: specially formulated cement slurry

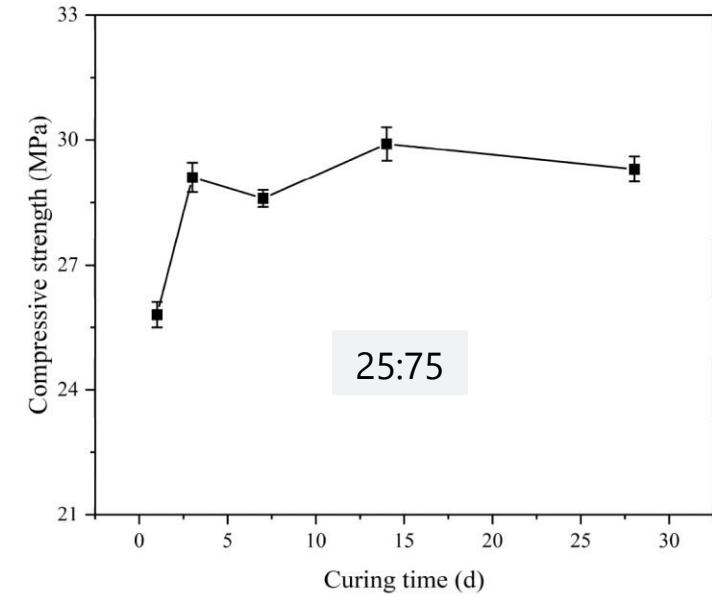
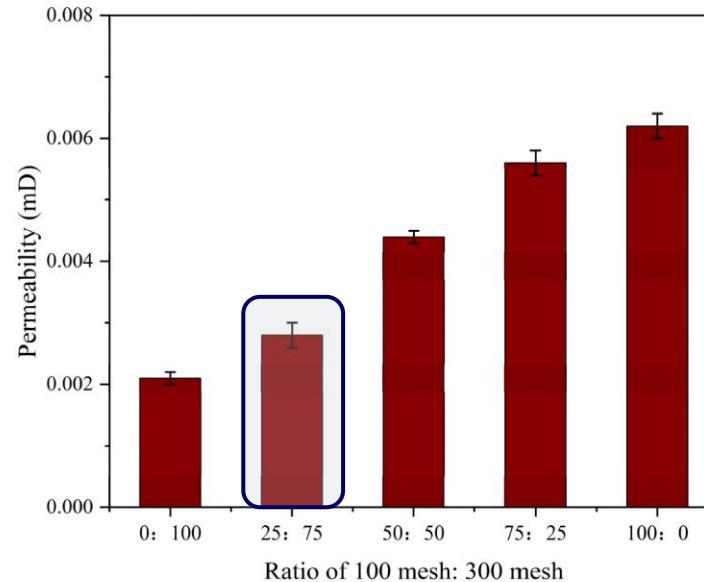
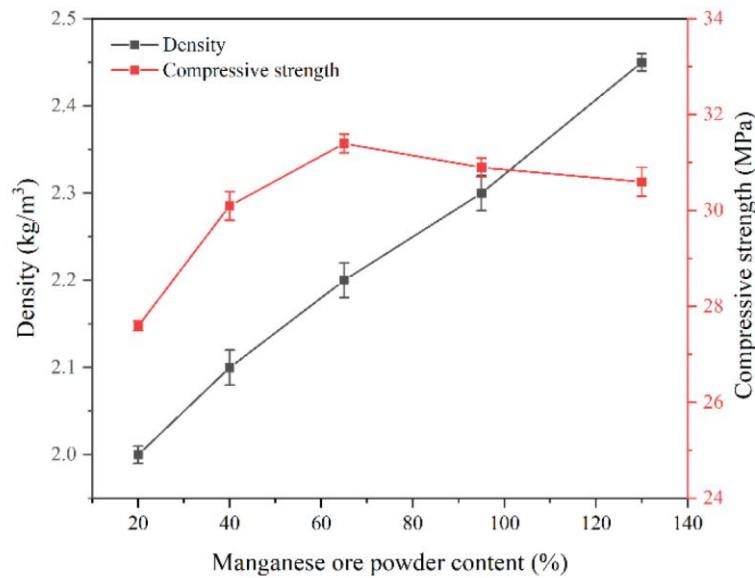


The cement cylinders were retrieved after 7 and 30 days for evaluation

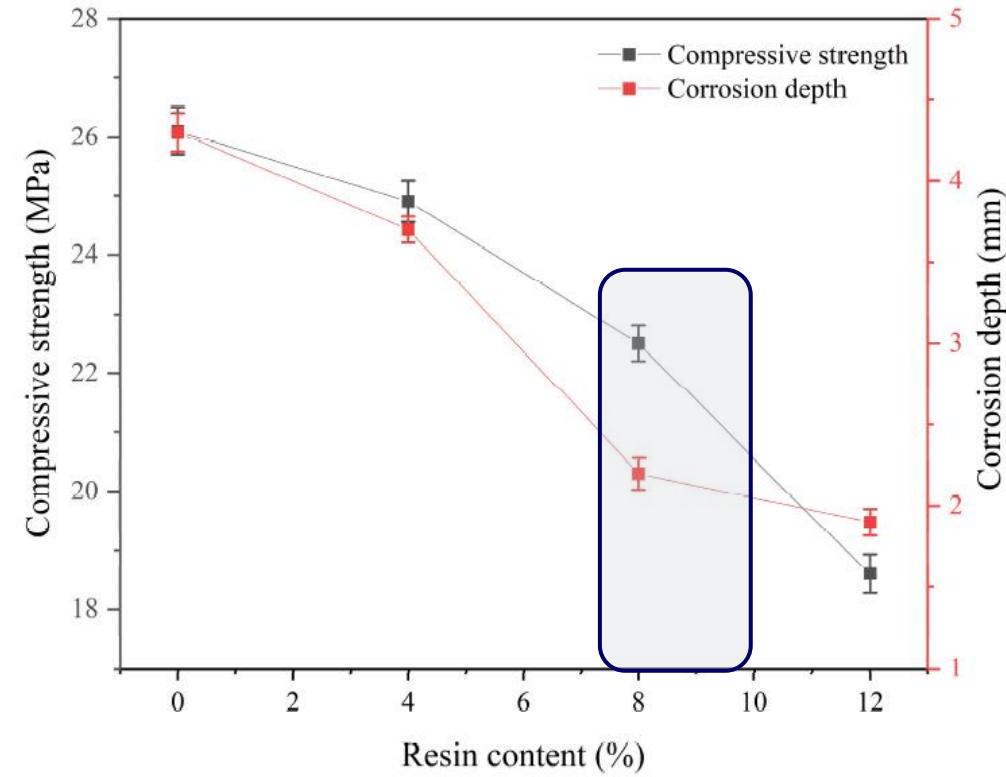
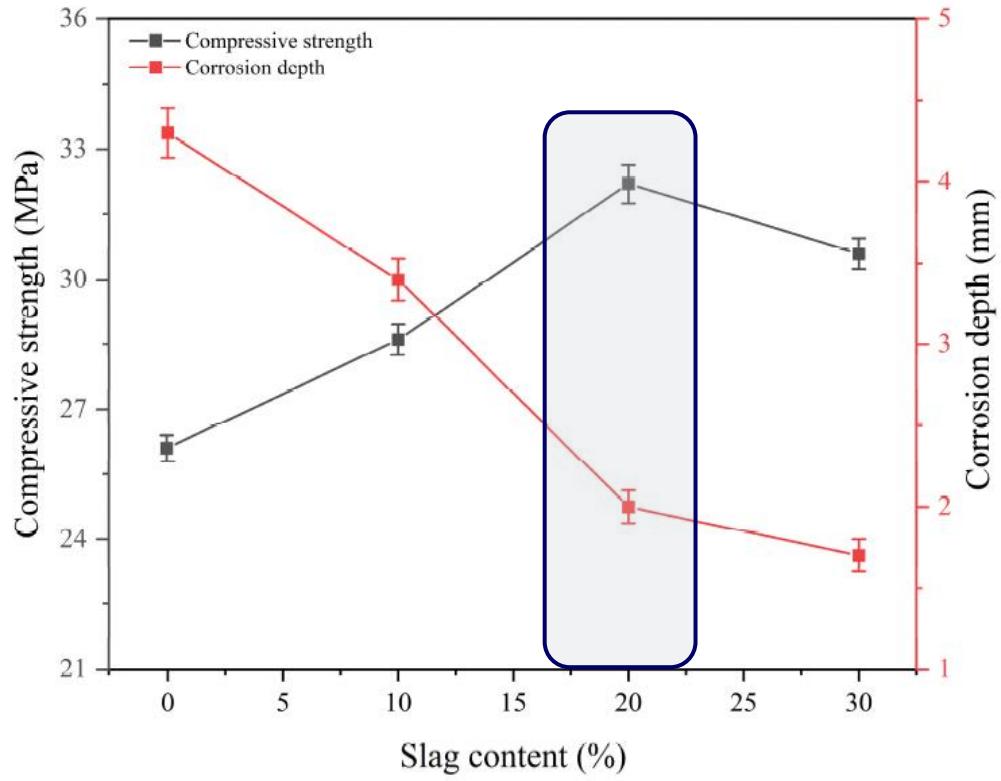


Most integral part = alkaline region (presence of Ca), indicated by phenolphthalein coloration (red)

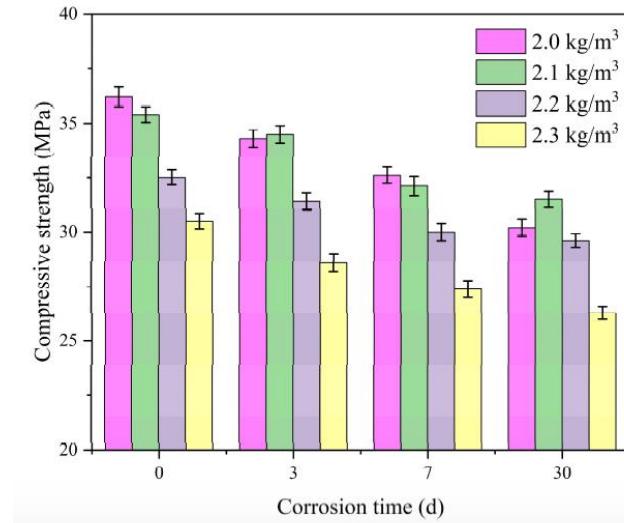
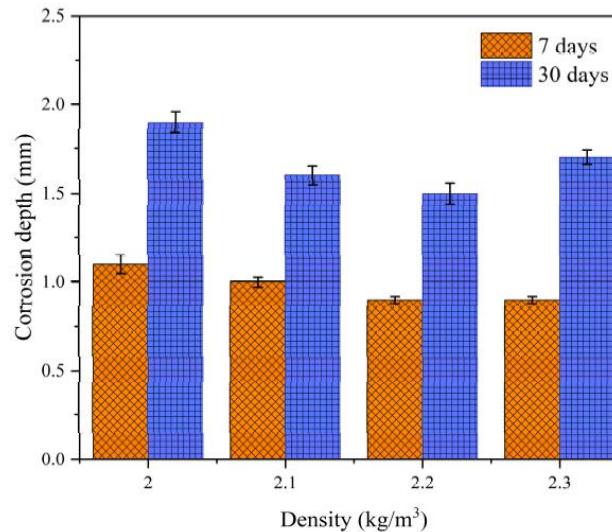
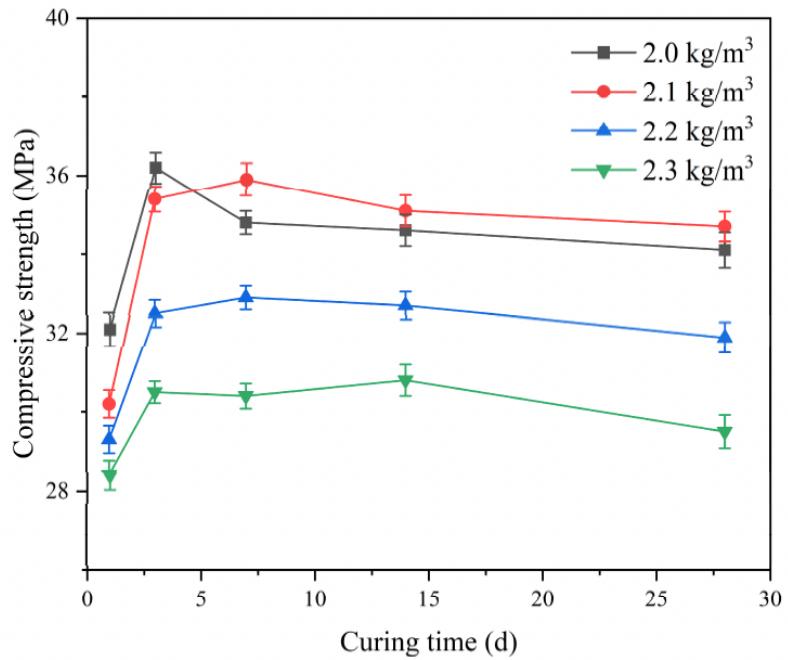
# Example: specially formulated cement slurry



# Example: specially formulated cement slurry



# Example: specially formulated cement slurry



# Example: specially formulated cement slurry

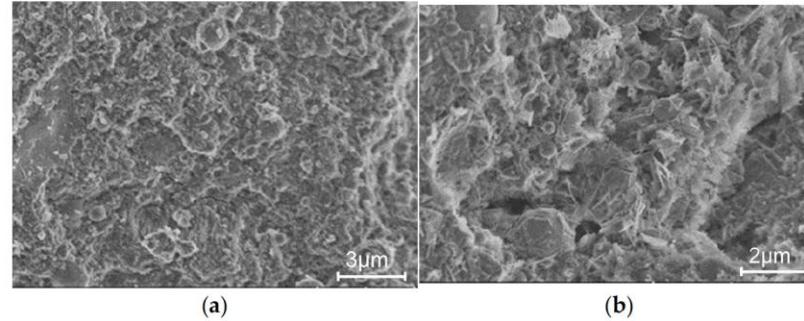


Figure 13. Morphology of  $2.0 \text{ kg/m}^3$  cement sample: (a) non-corroded; (b) corroded.

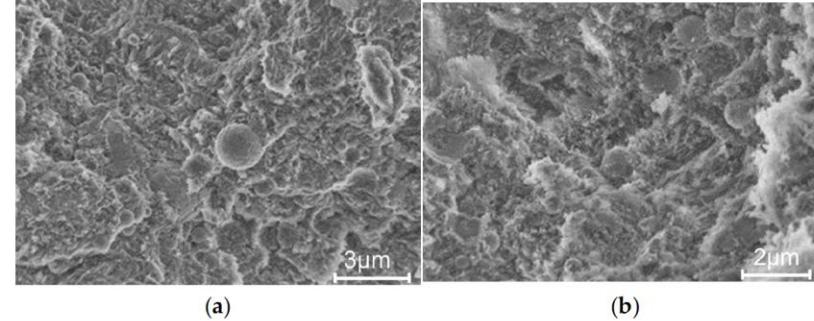


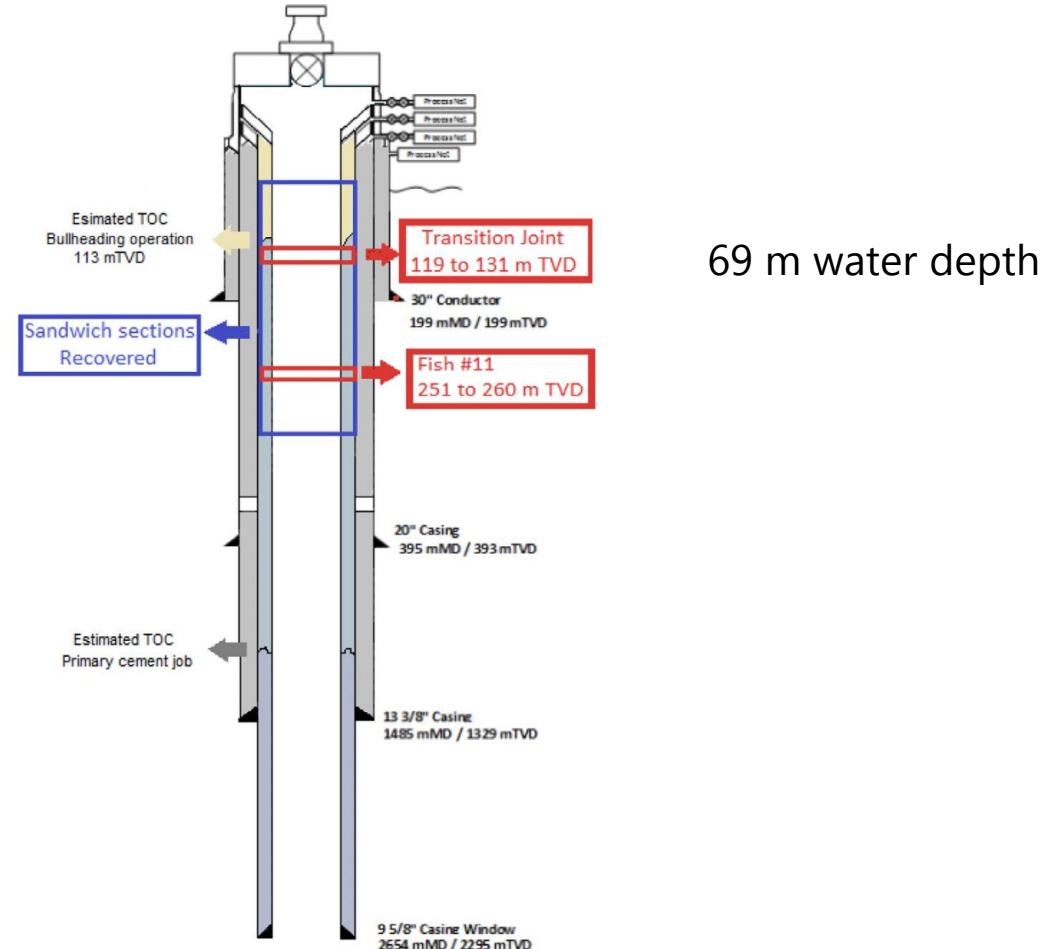
Figure 14. Morphology of  $2.3 \text{ kg/m}^3$  cement sample: (a) non-corroded; (b) corroded.

# Conclusion

- $\text{CO}_2$  ,  $\text{H}_2\text{S}$  and high temperature environments represent serious challenges to the durability of set cement in oil/gas wells;
- Well intervention events such as steam or  $\text{CO}_2$  injection, acid stimulation, hydraulic fracturing, well pressurization, or alike, may also negatively impact cement integrity
- Preventive strategies are essential to guarantee long term integrity of a well.

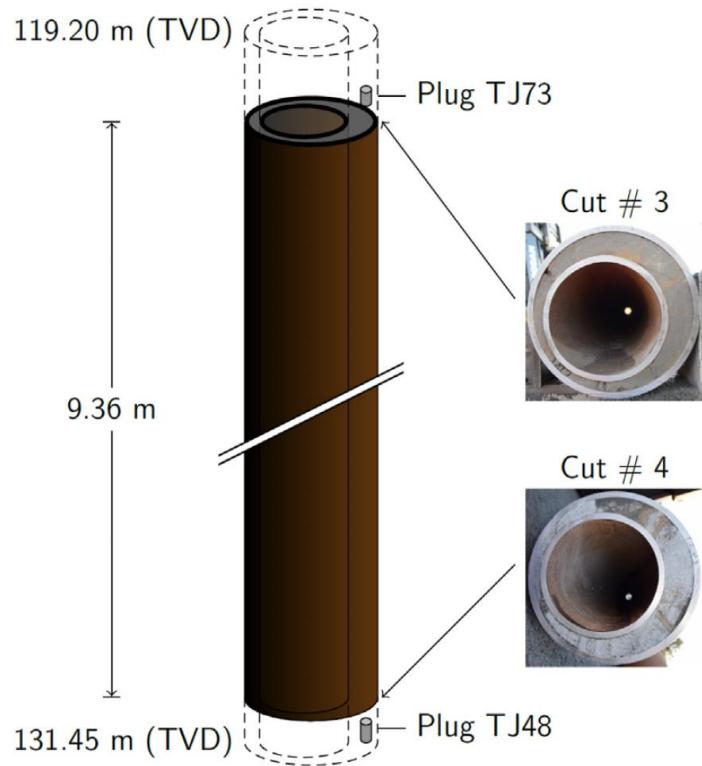


# Investigation of well integrity of a 33 years old offshore well in Norway

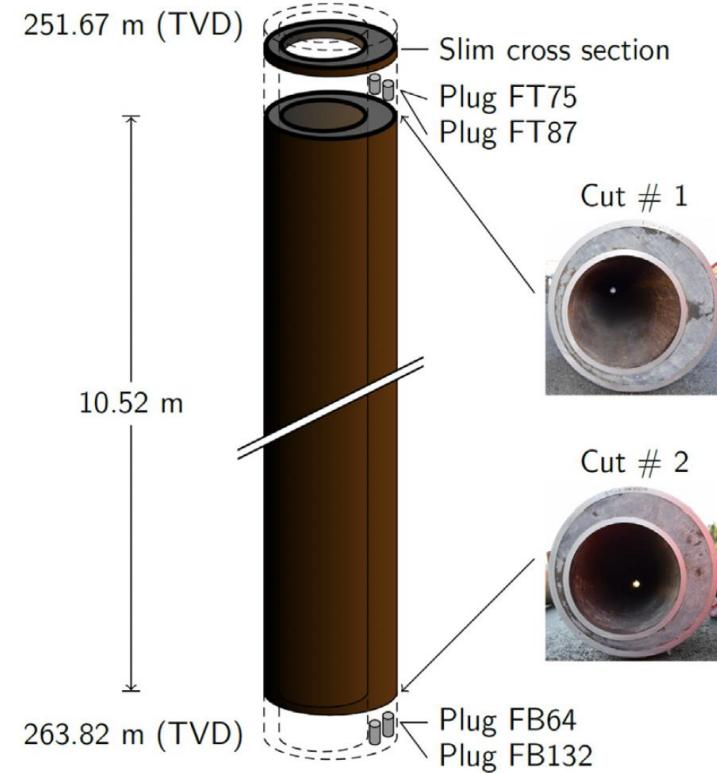


Well design showing the location of sections. In purple the twenty three recovered sections and in red the two sections, our object of study.

# Investigation of well integrity of a 33 years old offshore well in Norway



Transition Joint



Fish 11

Fig. 2. Transition Joint and Fish # 11 diagram including pictures of the ends (Bottom and Top).

# Investigation of well integrity of a 33 years old offshore well in Norway

Table 1 – Sandwich sections under study

	<b>Transition Joint</b>	<b>Fish # 11</b>
Well depth (m)	119.2-131-5	251.7-263.8
Final length (m)	9.36	10.56
Min. Sand off (m)	0.01057	0.01250
Max. Eccentricity %	70	64

Shallow depth (low temperature)

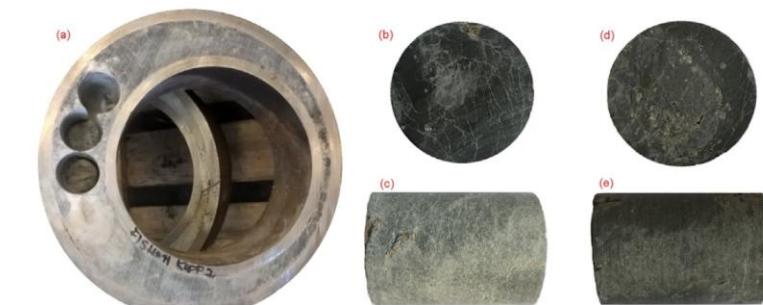
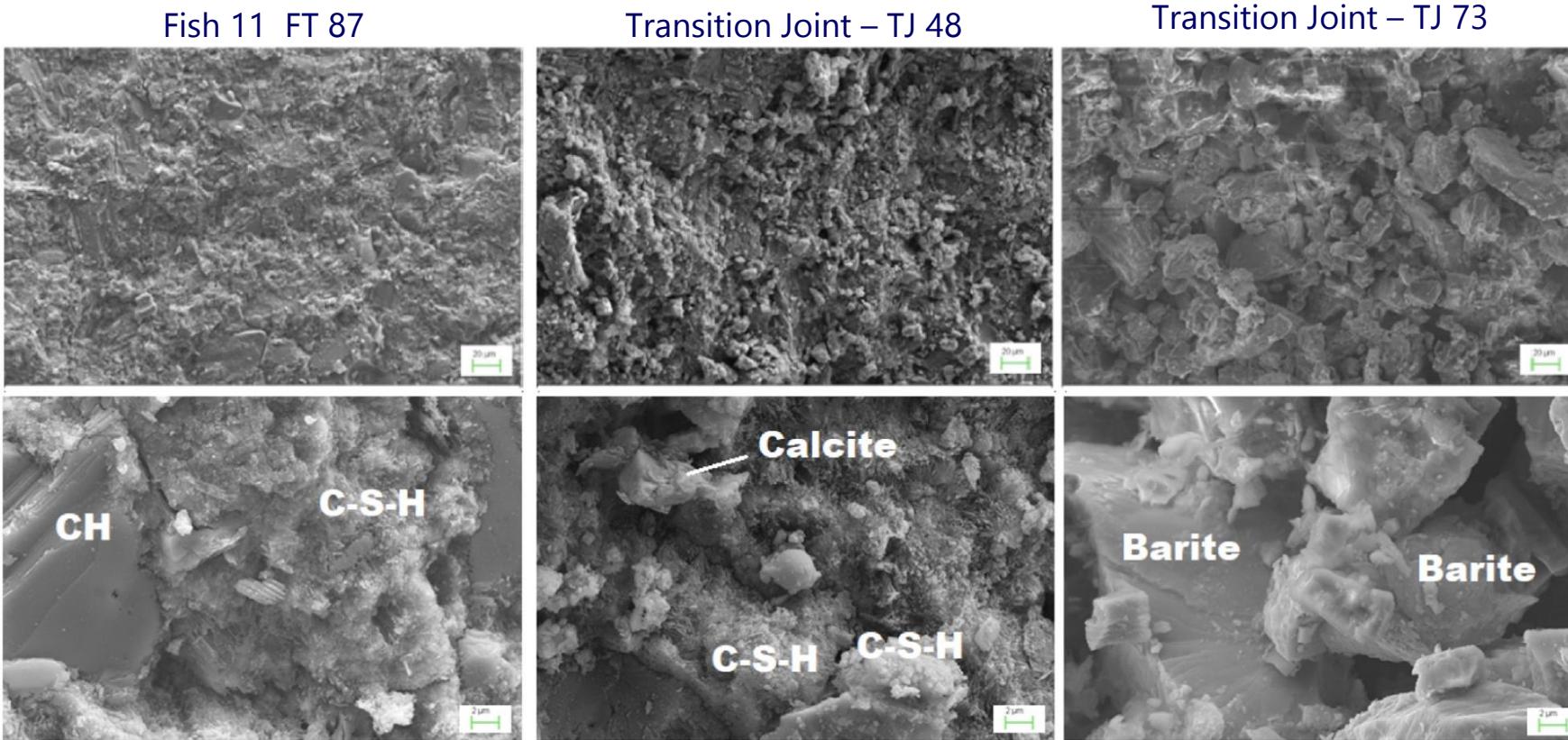


Fig. 3. Core plugs obtained from Fish 11 (Bottom). (a) Drilling of core plugs, (b) FB 64 top view, (c) FB 64 lateral view, (d) FB 132 top view and (e) FB 132 lateral view.

# Investigation of well integrity of a 33 years old offshore well in Norway

Selection name	Core Plug	Petrophysical Properties			Mechanical Properties		Compositional Analysis		
		Porosity	Permeability	CT scan	E	UCS	SEM-EDS	XRF	XRD
Transition Joint	TJ48 TJ73	✓ ✓	✓ ✓	✓ ✓	✓	✓	✓ ✓	✓ ✓	✓
Fish# 11	FT75 FT87 FB 64 FB132	✓ ✓ ✓ ✓	✓ ✓ ✓ ✓	✓ ✓ ✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓ ✓	✓

# Investigation of well integrity of a 33 years old offshore well in Norway



Comparison of SEM Images at magnifications 1.0 kX (upper panels) and 10.0 kX (lower panels) for material extracted from FT87, TJ47 and TJ 73 core plugs.



we are on it