

# Shale as natural barrier for well plugging and abandonment

Julien Eudes & Kun Su



**CFMR**  
COMITÉ FRANÇAIS  
DE MÉCANIQUE  
DES ROCHES

19/03/2026

# Question raised

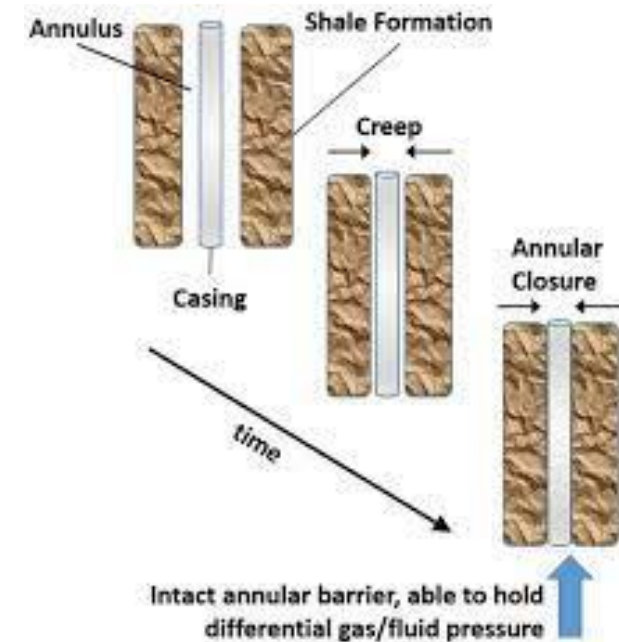
Can we predict the effective closure of the annulus rock/casing after 20-30 years for Plug and abandonment (P&A) operations ?

## Stakes:

Reduce the cost/time and CO<sub>2</sub> emissions of P&A operations

## Expected responses from Geomechanics:

Confirmation of use shale or salt as natural barrier in P&A



# The stakes for P&A projects & CCS



**Option 1 compliant Company rules**  
Milled or removed casing + cement plug

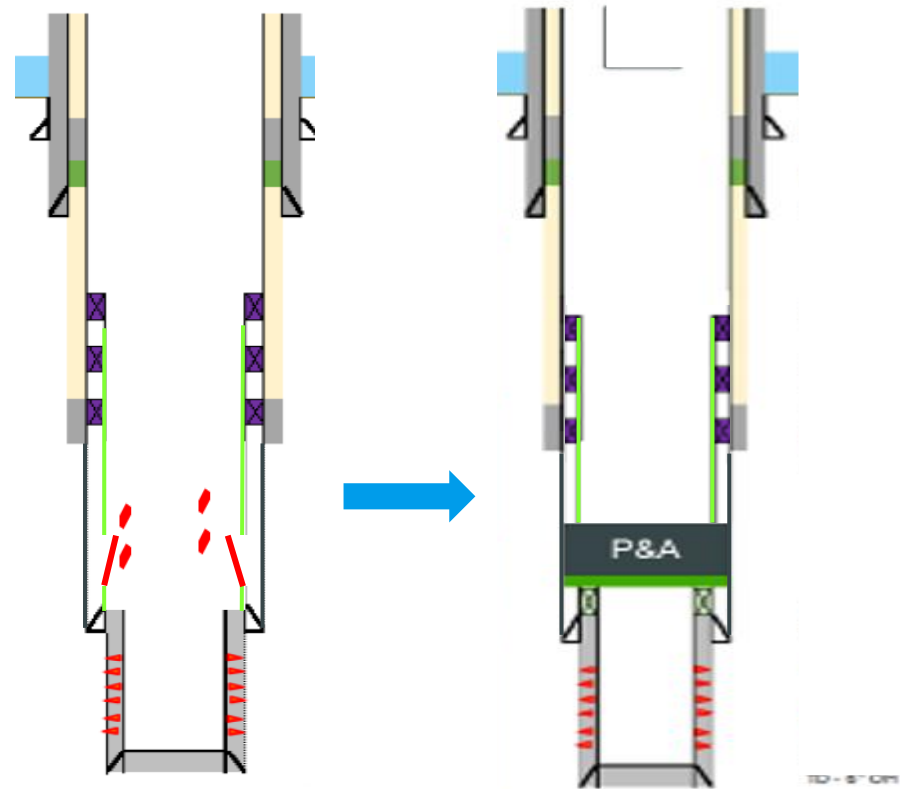
**Option 2: derogation TotalEnergies**  
Consider the shale as barrier

## Objectives

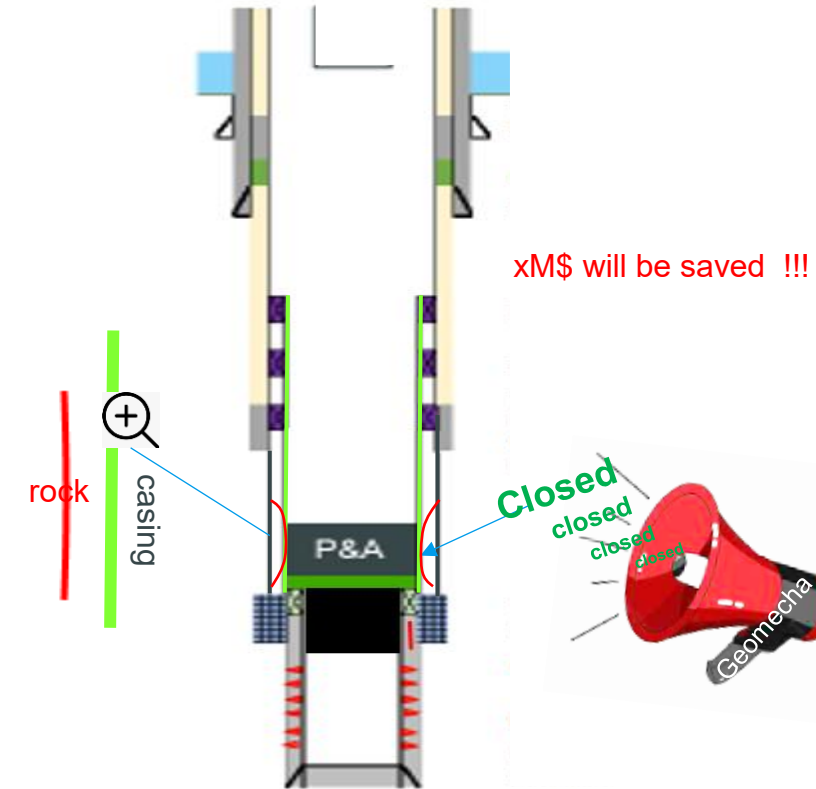
- Reduce CO<sub>2</sub> emissions & P&A cost

## Stakes

- TotalEnergies has **>5500 wells** to P&A worldwide
- Questions about the legacy wells & effects of repressurization in CO<sub>2</sub> storage project



Remove all scab liner  
+ Cement alongside borehole  
+ CR compliant  
- Timing  
- Uncertainties



+ Timing  
+ Easy  
- Cement alongside borehole  
- CR not compliant

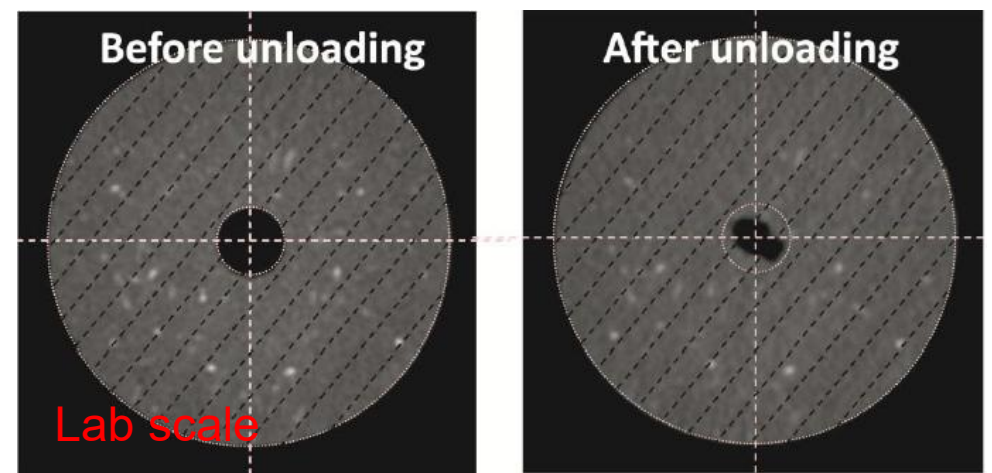
Option 2 divided the cost/time/CO<sub>2</sub> emission by 2

# What is the creep ?

Creep = deformation over the time; the material exhibits a fluid-like behavior

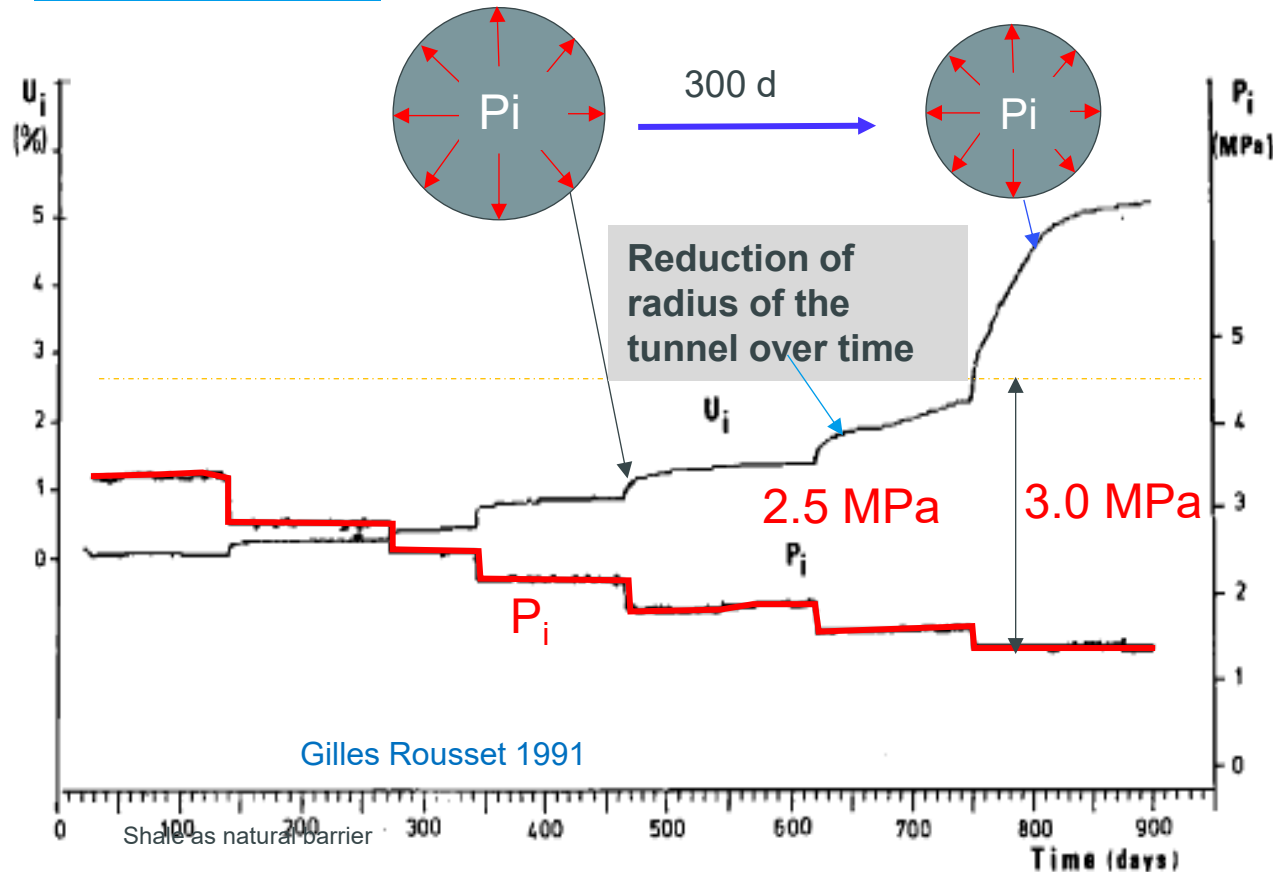
→ Progressive closure of hole

animation



Labouse et al 2013

## Shale \_ Clay

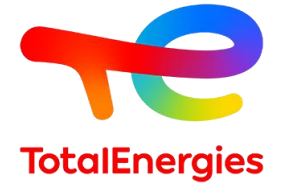


## In situ test



In situ test of wellbore closure versus time for difference radial stress exercised through a deformable jacket carried out in Boom Clay at 230 m depth, Belgium.

# The challenges and the method developed at TotalEnergies



## 1. Lab test

- on shale/salt plugs (Geomechanical Lab at TotalEnergies),
- on physical model at reduced scale: shale-casing test SAAB, thanks to R&D P&A project

## 2. In Situ observation and interpretation

- URL (Boom clay Belgium, Callovo-Oxfordien Argillites France, Opalinus Clay Switzerland, etc ...)
- Annulus closure recorded in our wells : Norway, UK, UAE, ....
- Correlation with formation properties:  $R_{hob}$ ,  $N_{phi}$ ,  $GR(Vcl)$ , ... from well Logs

## 3. Robust shale and salt creeping law calibrated on lab and in situ observation

- Synthesis of data, paper published in SPE conference (K. Su & A. Onaisi 2018)

## 4. Analytical model & Numerical modelling

- Analytical solutions, Finite Elements modeling
- Depth log of shale creeping capacity

10 heavy benches  
(+/- 300 tests/year)



Geomechanics  
core log



Petro-acoustic  
under stress



Elasticity and  
rupture of rocks

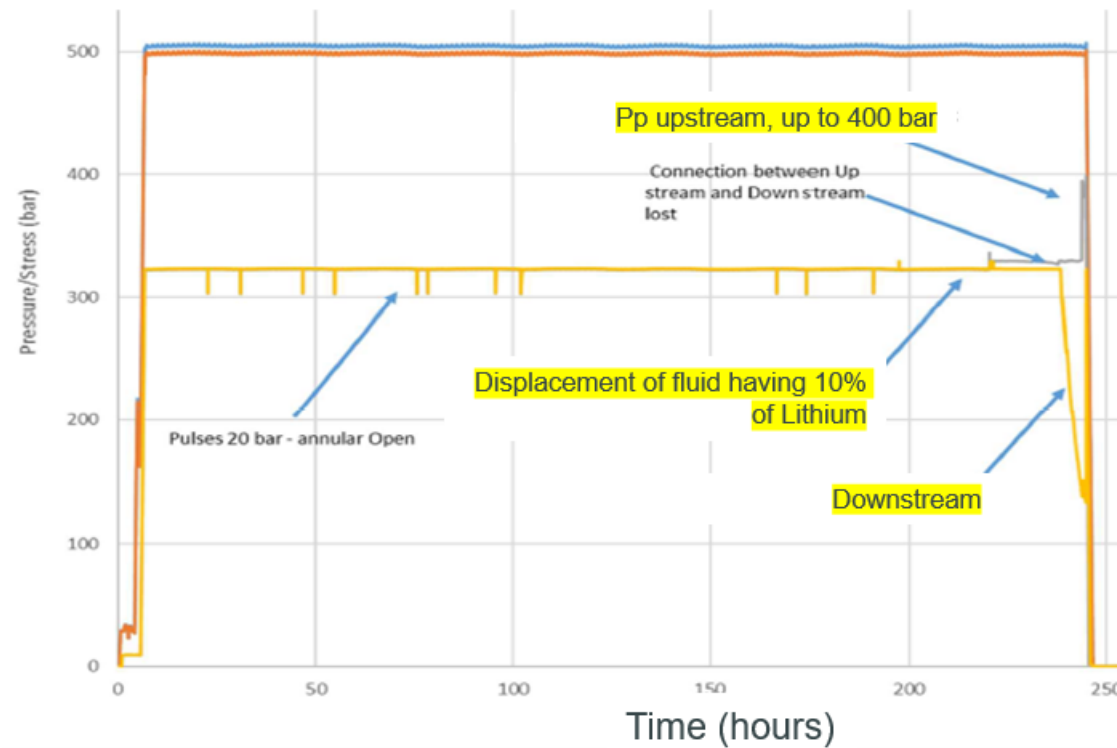
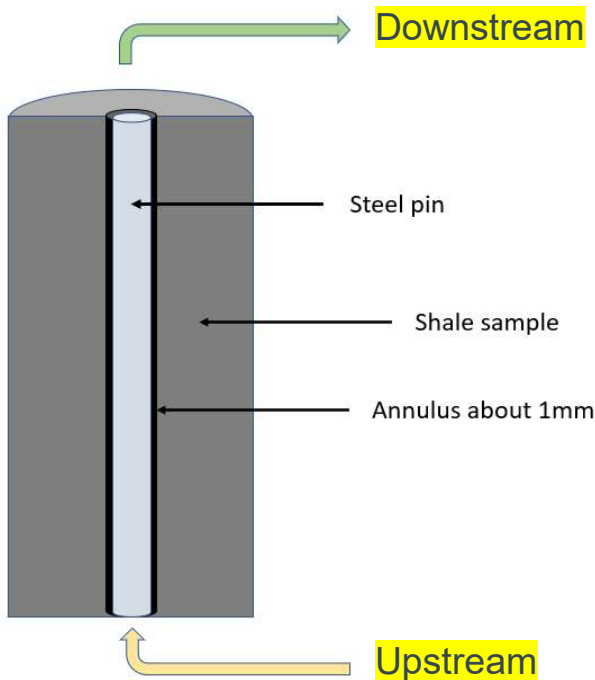
# Shale As A Barrier (SAAB) test



## Aim of the Test :

The aim of the SAAB test is to study the shale sensitivity to annular fluid chemistry as purpose to stimulate the shale to form a barrier.

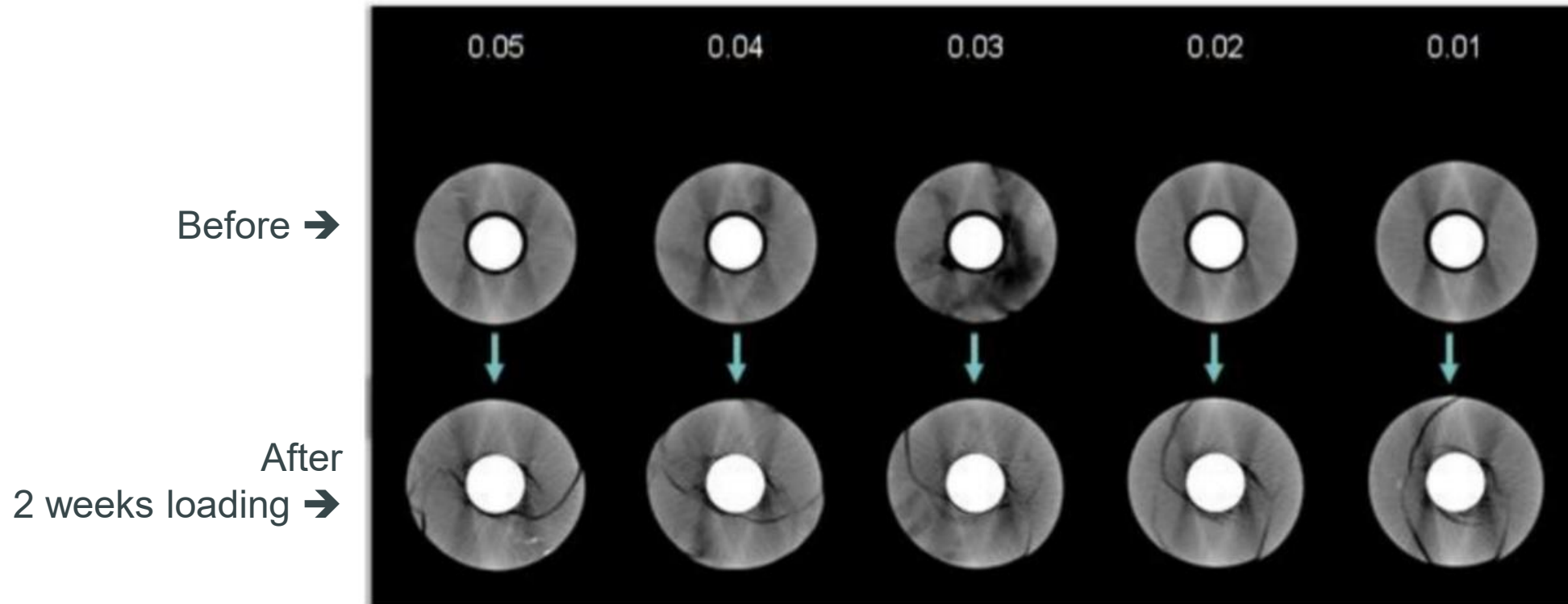
This barrier will can be used as cement substitute for Plug and abandon well.



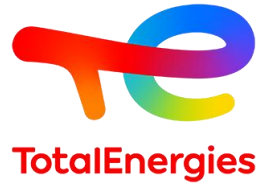
# Methods developed

## 1. Lab test

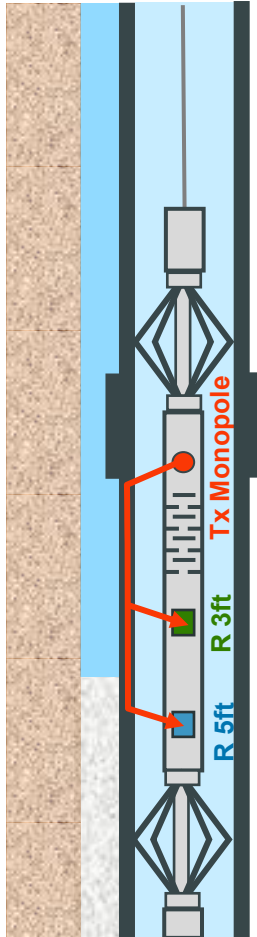
- on shale/salt plugs (Geomechanical Lab at D&W/LT\_GM & R&D JIP @ UTA, USA),
- on physical model at reduced scale: shale-casing test with monitoring of permeability



# CBL-VDL low frequencies (10-30kHz) & time domain



CBL-VDL



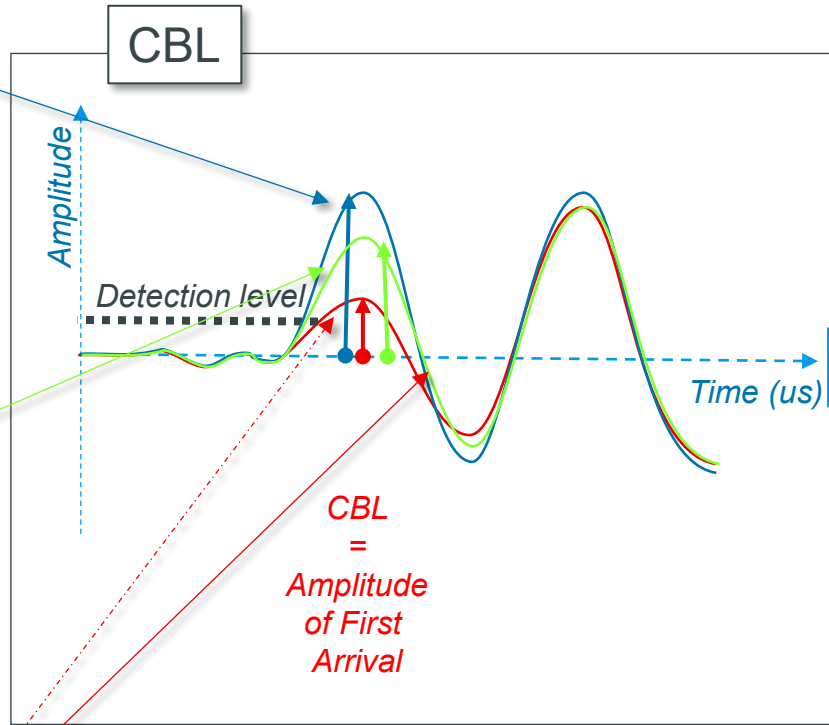
Free pipe



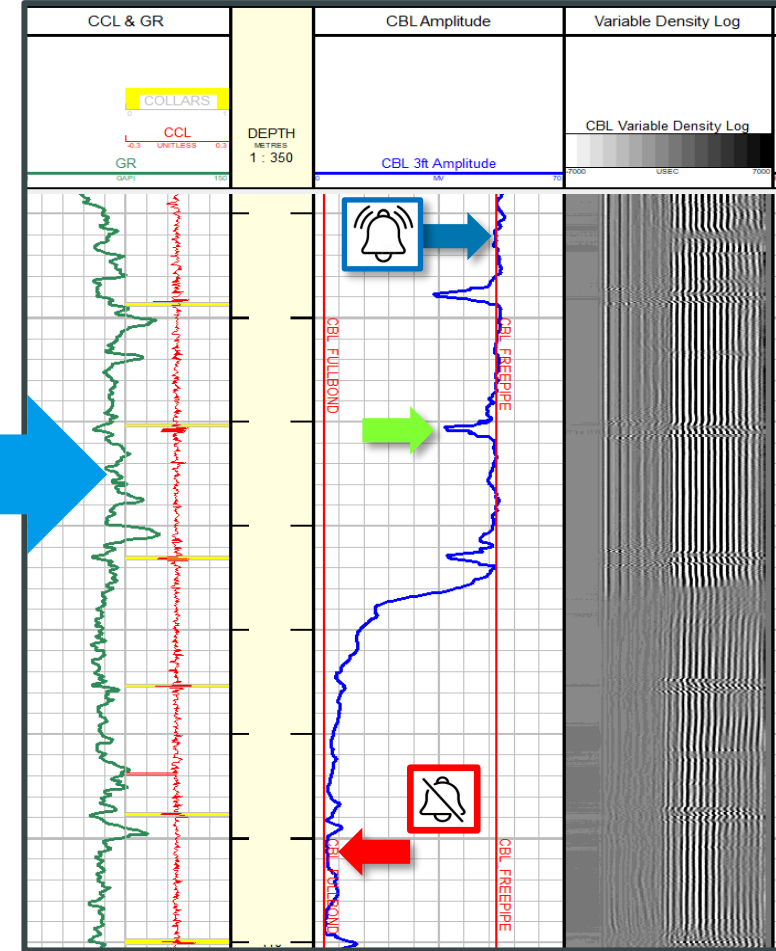
Free pipe + Tool joint



Fully cmted



For better visual and assimilation please shift the red arrow to show better the detection of good cement coverage amplitude



mV Normalization  
 Bound Index (0 to 100%)

# In Situ Observation Shale Creeping: North Sea & Africa



TotalEnergies

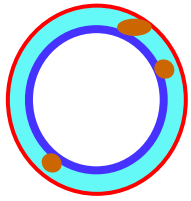
@ 1700 m depth, North Sea

@ 5300 m depth, West Africa  
2023, 17 months

02 Mar 2015 and 03 Mar 2015

4 months later: 11-Jul-2015

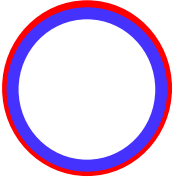
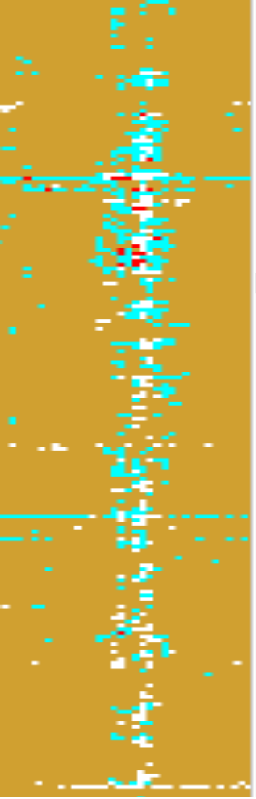
No contact



120 days

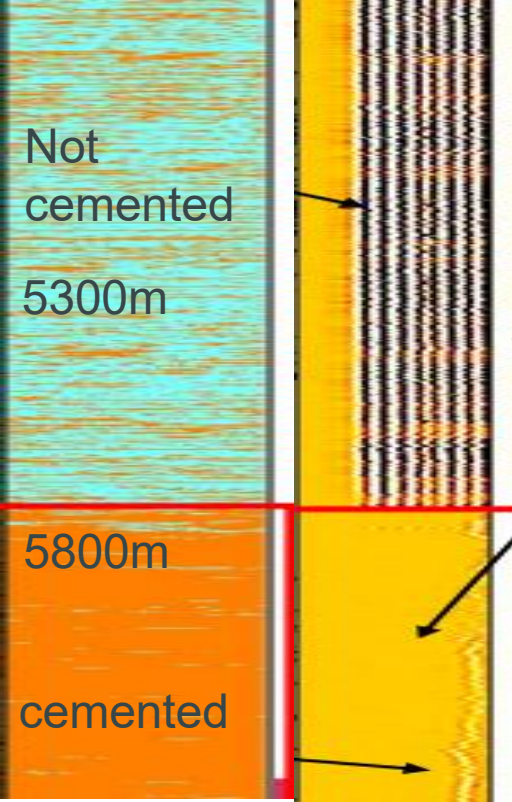


contact

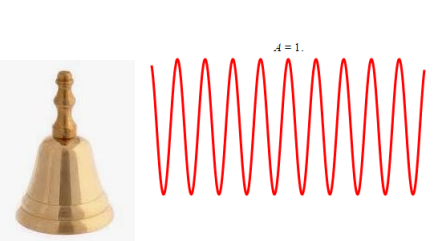


Nordaland shale high porosity (>25%)

Shale as natural barrier



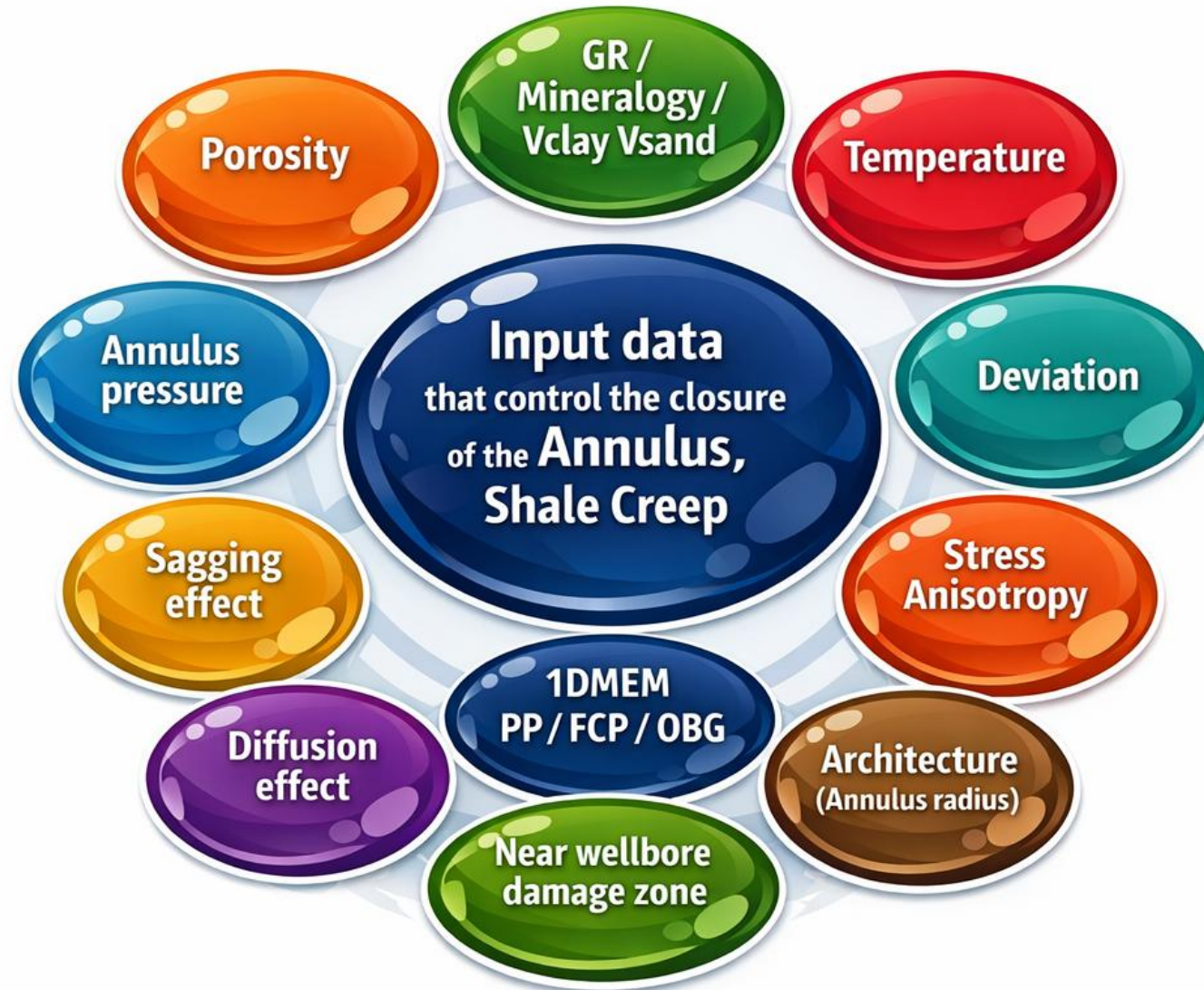
shale low porosity (<20%)



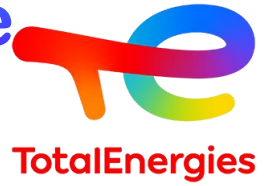
CBL : cement bond log

Methods developed

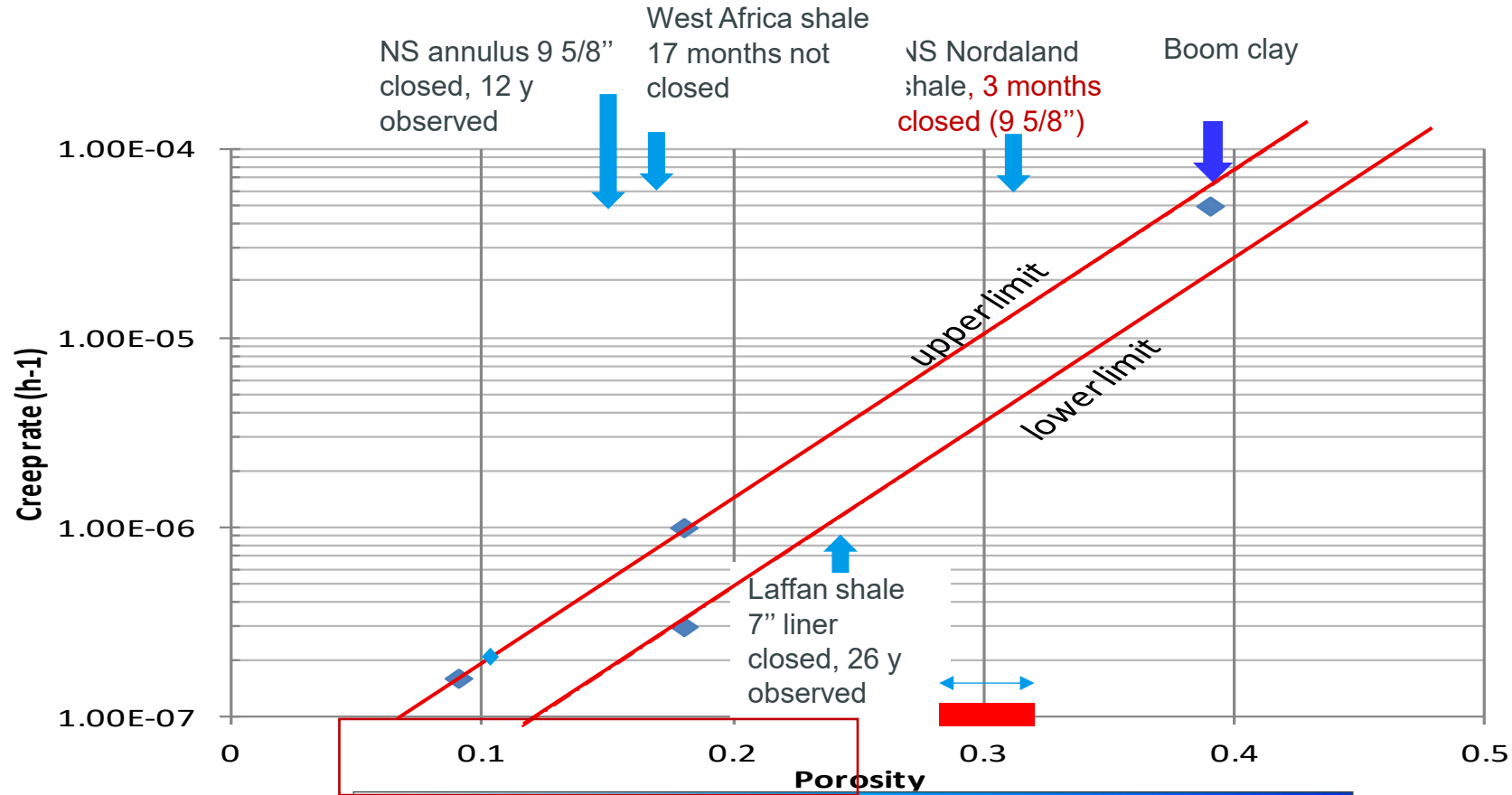
# Overview of concept



# Method to estimate the creeping capacity of cap rock shale



## → Review of creeping of shale



Porosity range 0.05 to 0.25 for late cretaceous in NNS (North North Sea)

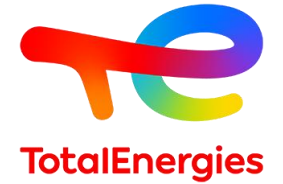
Very Consolidated

Consolidated

Unconsolidated

Kun SU & Atef Onaisi 2019

# Methodology for calculation of creep rate



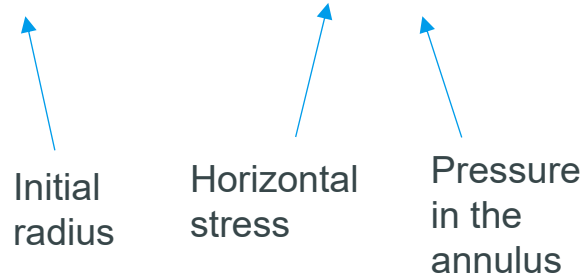
## Decreasing of hole diameter in case of an isotropic loading

$$R = R_0 \exp \left\{ -\frac{\sqrt{3}^{n+1}}{4n-2} A(\sigma_0 - P_w)^n \Delta t \right\}$$

Barker's solution (1994)

$$R = R_0 \exp \left\{ -\frac{\sqrt{3}^{n+1}}{2n^n} A(\sigma_0 - P_w)^n \Delta t \right\}$$

Liu's solution (2011)



$$\dot{\epsilon}^{VP} = 2.17 \cdot 10^{-15} \sigma_d^{1.1364 \cdot \phi + 1.1955} \text{ in h}^{-1} \text{ for } T = 80^\circ\text{C and } \phi = \sim 0.1 - 0.2 \quad (\text{equation 1})$$

$$\dot{\epsilon}^{VP} = 7.23 \cdot 10^{-15} \sigma_d^{1.65} \text{ in h}^{-1} \text{ for } T = 80^\circ\text{C and } \phi = \sim 0.4 \quad (\text{equation 2})$$

Where  $\sigma_d$  is the deviatoric stress in Pa.

Type of shale	Depth (m)	Rho g/cc	Porosity (%)	Clay (%)	Creep rate at ambient temperature (h <sup>-1</sup> )	Creep rate at 80° C (h <sup>-1</sup> )	E (MPa)	C (MPa)	Phi (°)
Boom clay	250	2.03	39%	23%-59%	4~5 x 10 <sup>-5</sup>	4~5 x 10 <sup>-4</sup> (at 50°C)	300	0.5-1.3	18-25
Opalinus clay	650	2.45	18%	49%	1.0x10 <sup>-6</sup>	2.9x10 <sup>-6</sup>	3000~6000	3	25
Calovo-Oxfordian argillite	490	2.45	18%	45%	0.2~0.4x10 <sup>-6</sup>	1.3x10 <sup>-6</sup>	5500	6	28
Tournemire	250	2.55	9.5%	55%	0.16x10 <sup>-6</sup>	-	9300 - 24000	6	28

Table 1 – Creep rate of different shales at ambient temperature and at ~80°C under a deviatoric stress of 2 to 5 MPa.

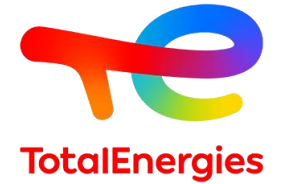
## In case of an anisotropic loading

New solution has been developed, not yet published

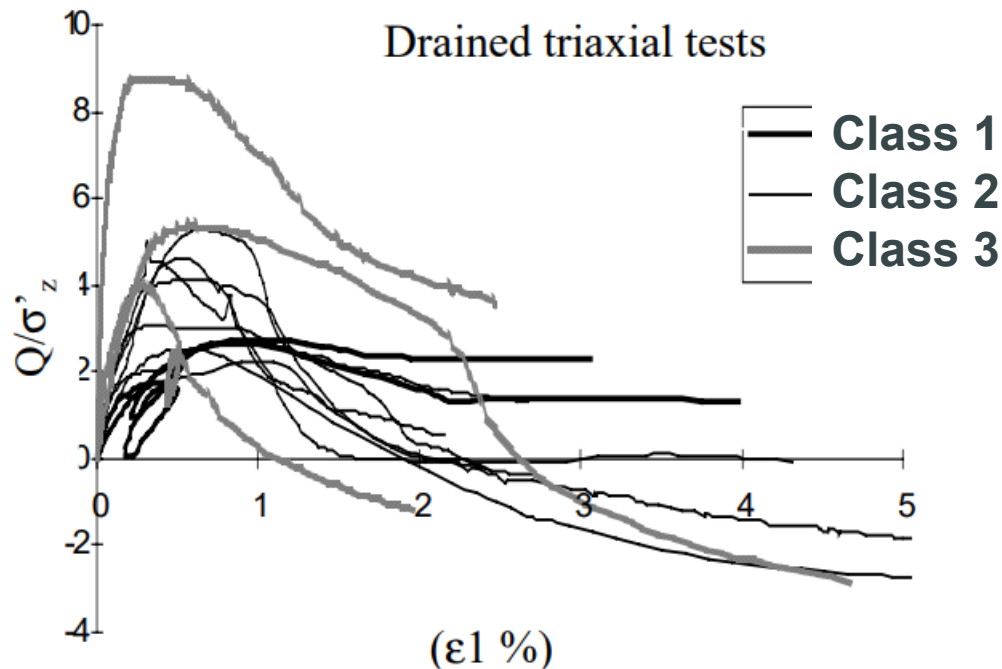
Shale studied generally at high temperature ( >80°C)

Kun SU & Atef Onaisi 2019

# Method to estimate the creeping capacity of cap rock shale



## → Mechanical behavior

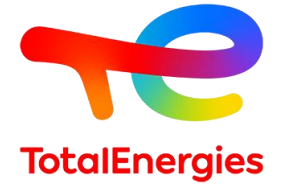


	Class 1	Class 2	Class 3
<b>Properties</b>	$\rho_d < 2,15\text{g/cm}^3$	$2,15 < \rho_d < 2,35\text{g/cm}^3$	$\rho_d > 2,35\text{g/cm}^3$
Wsat (%)	> 9,5	5,5 à 9,5	< 5,5
Porosity (%)	> 20	13 à 20	< 13
P-wave velocity (m/s)	< 2000	2000 à 3000	> 3000
Rc (MPa)	< 15	15 à 35	> 35
E (MPa)	< 3000	3000 à 10000	> 10000
Behaviour in triaxial test	ductile	ductile/brittle	brittle
Q/σ'z (for σ'c~σ'z) drained triaxial tests	< 2,5	2,5 à 3,5	> 3,5
Cc (at 50MPa)	> 0,15	0,05 à 0,15	< 0,05

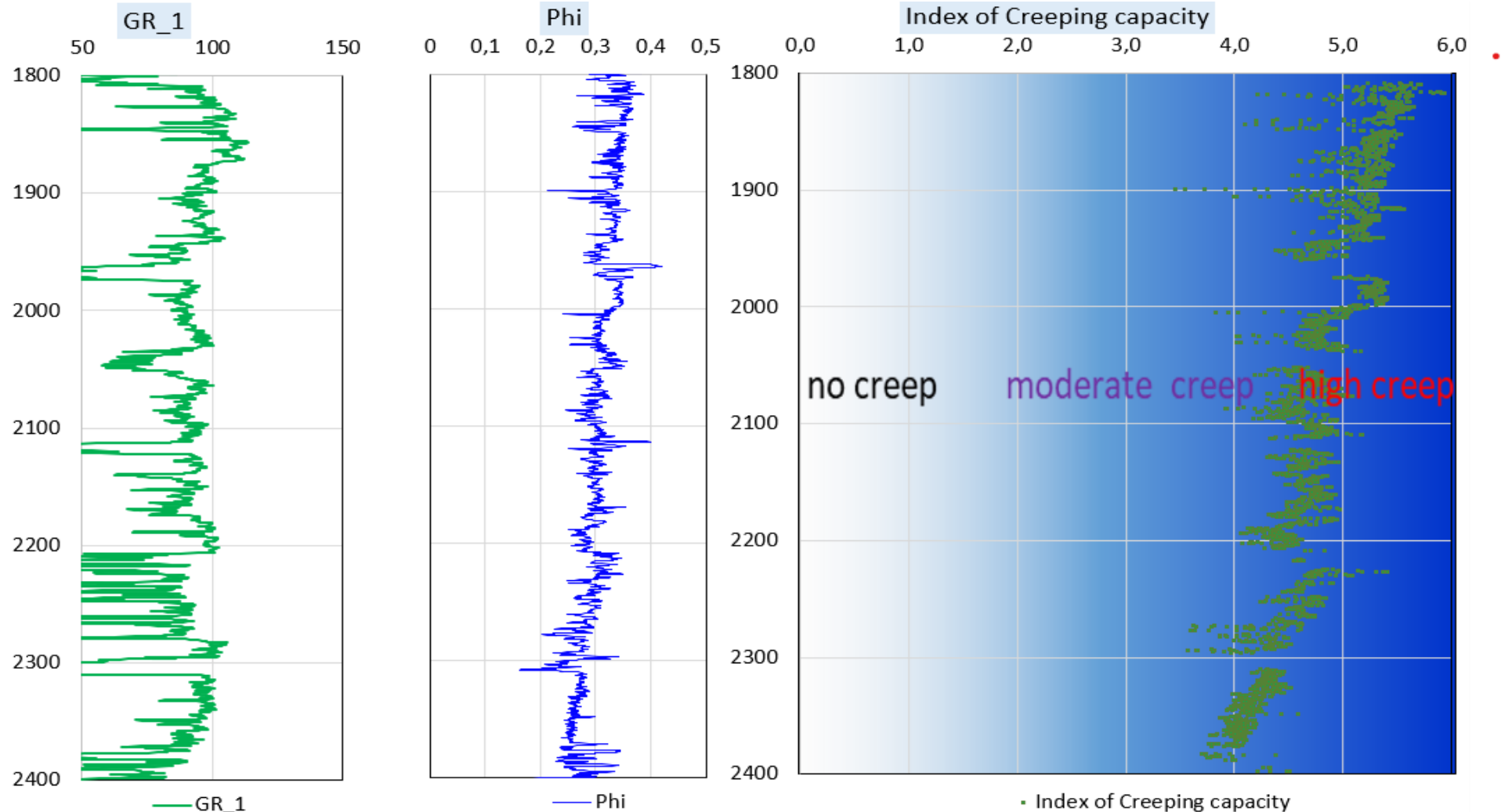
Table 1 – Characteristic values of the 3 classes of shale (from left to right : Class I, Class II and Class III) [2]

Hoteit N., Ozanam O., Su K. (1999) Geomechanical investigation of an argillaceous formation in the east of France - International Workshop on the rock mechanics of nuclear waste repositories, June 1999, Vail, Colorado, USA.

# Creeping index



Creeping capacity over an interval based on porosity and clay content

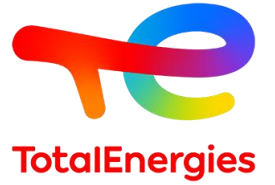
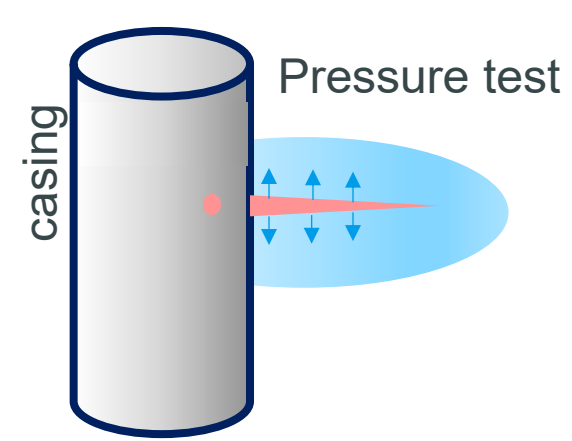


Quick way to identify the creeping capacity of a formation (GR, porosity) developed by KUN SU

# Case 1

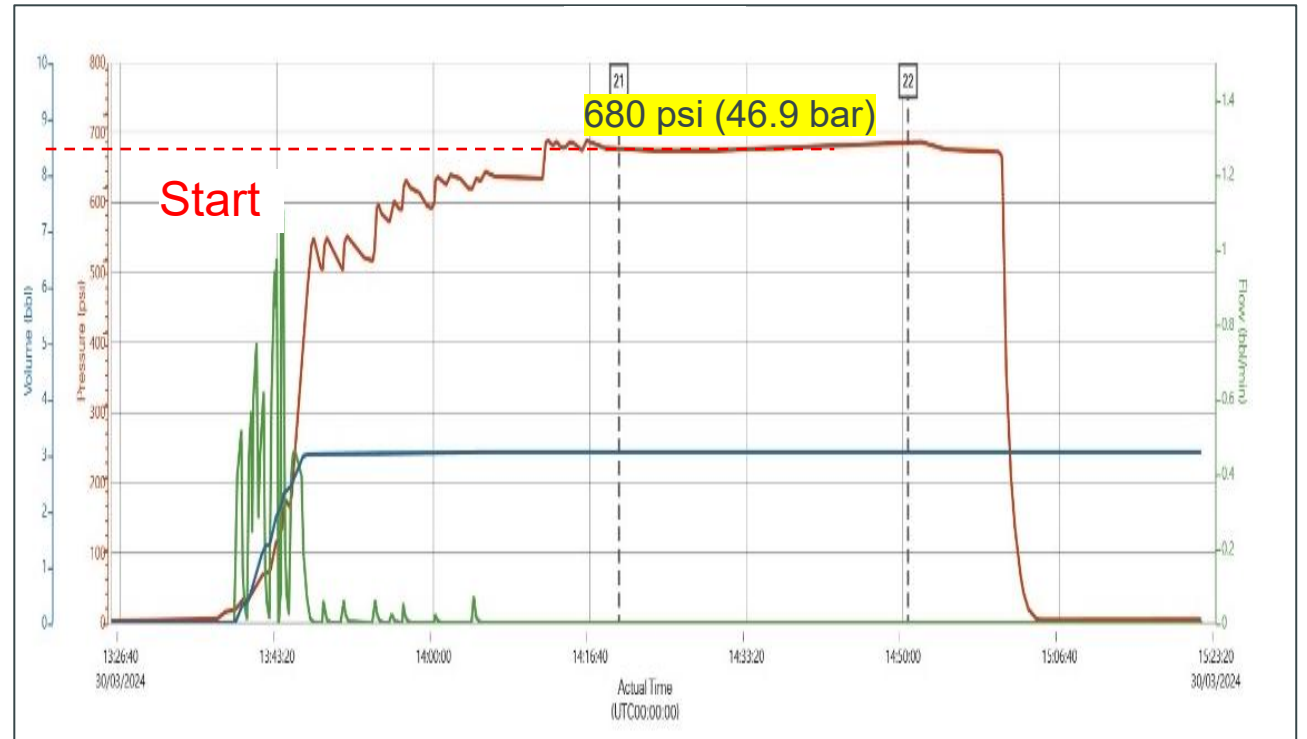
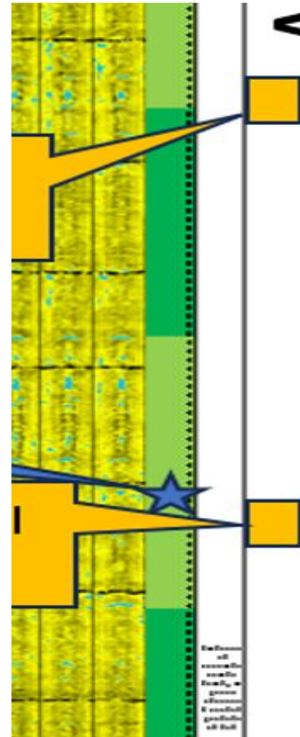
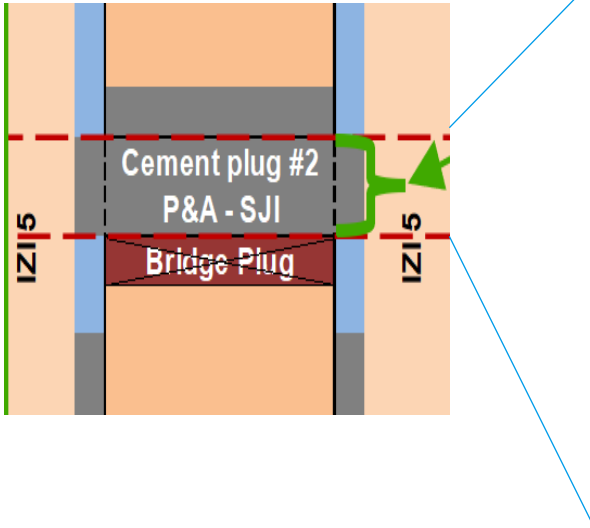
## P&A plan for a well in North Sea 2024

**Prediction from GM** : Even in the most pessimistic case of 15% shale porosity, the **12 years old** annulus should be closed at the P&A plug #2 interval and not closed for plug #3

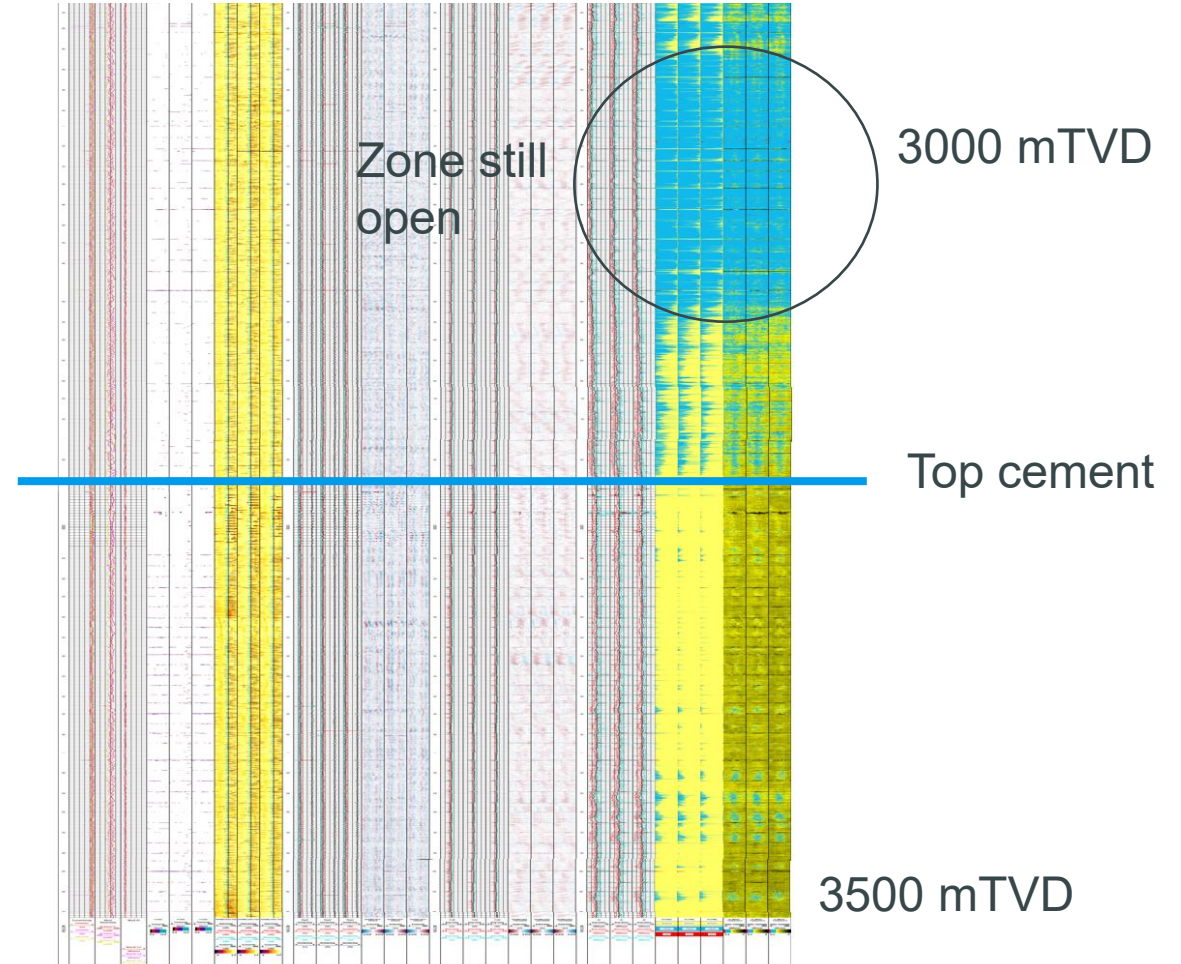
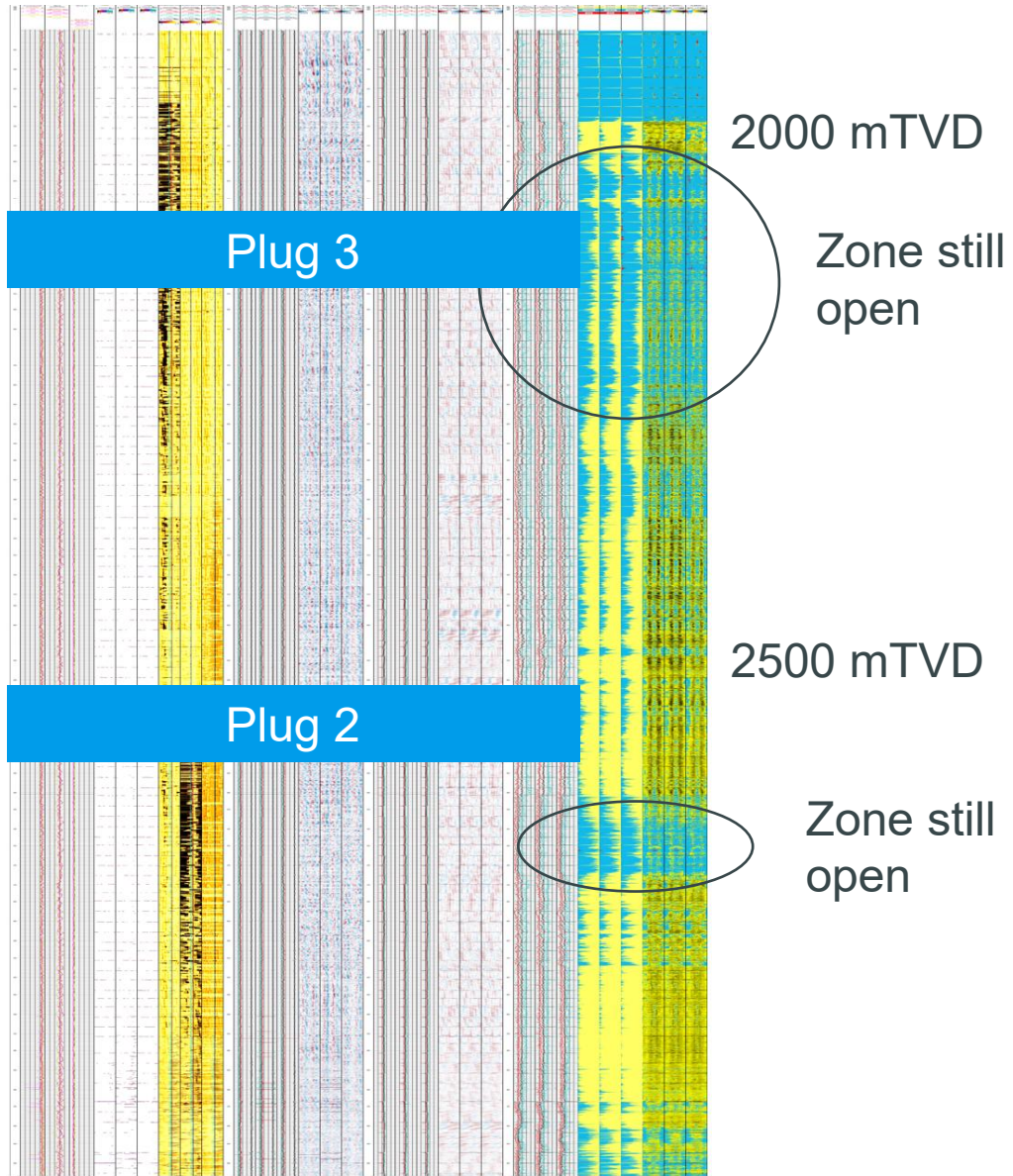
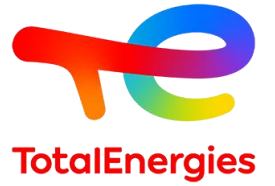


**Observation, sonic scan mandatory by CR**

**Observation: Pressure test mandatory by CR**

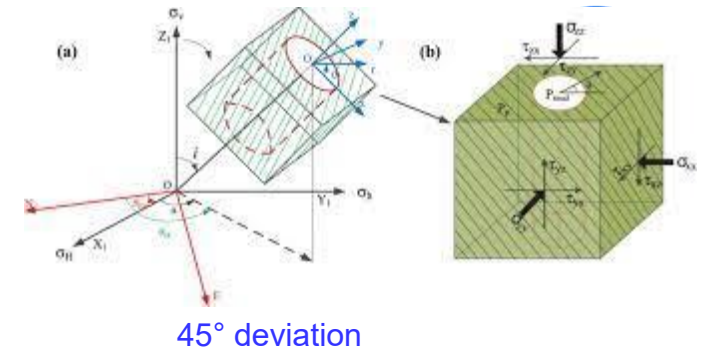
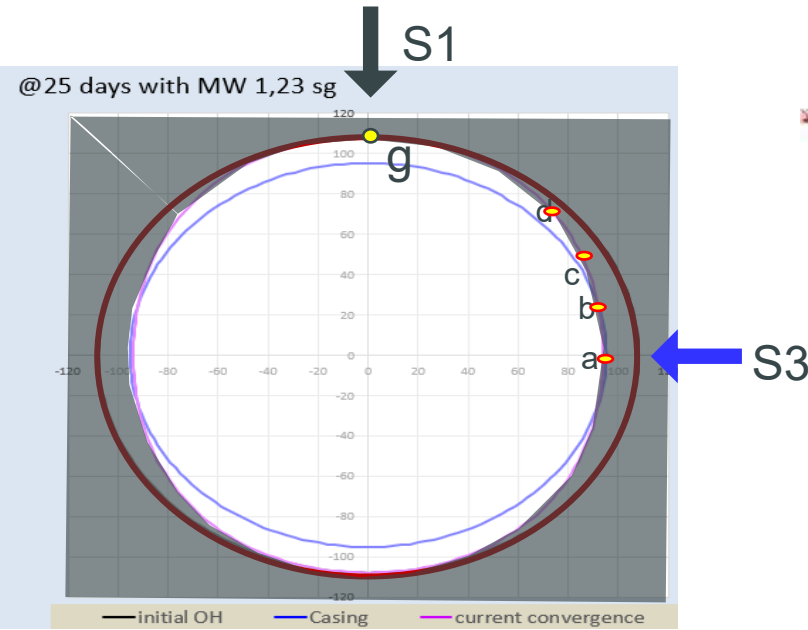
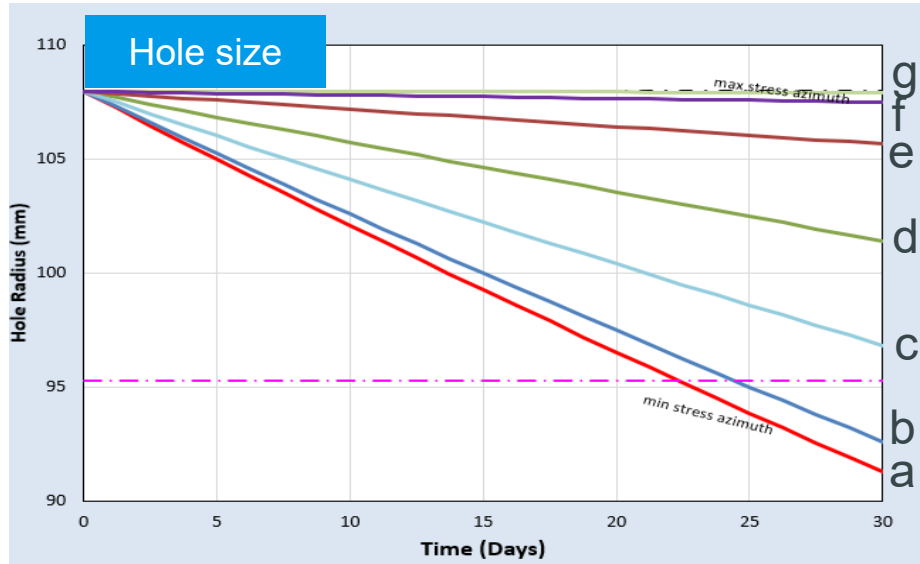


# Case 1 - CBL UK after 12 years

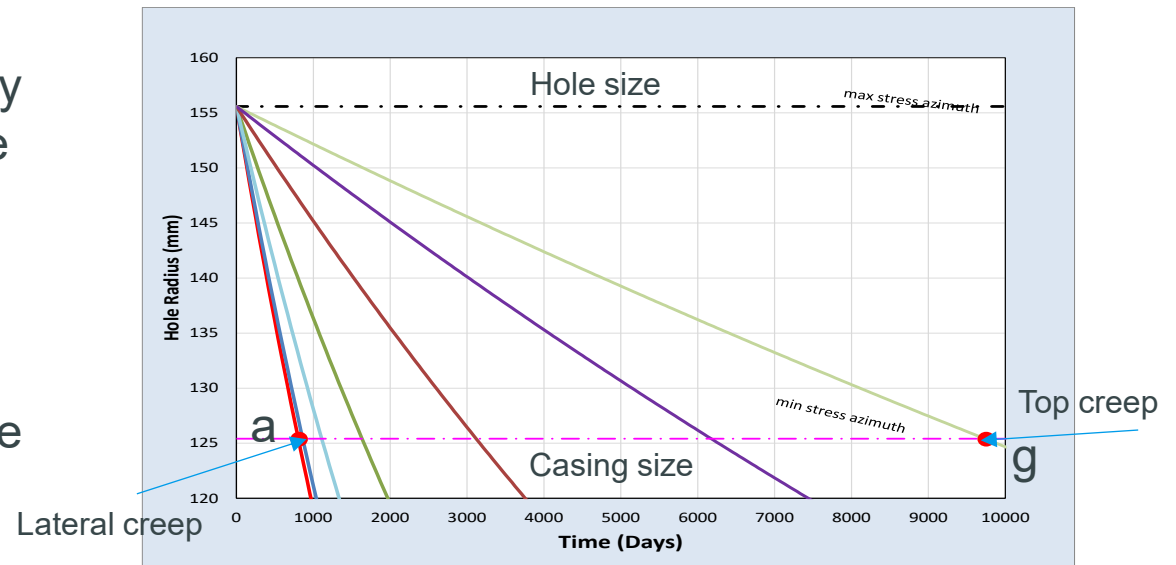


# Case 1 - Analytical and numerical modelling

Considering of anisotropic loading

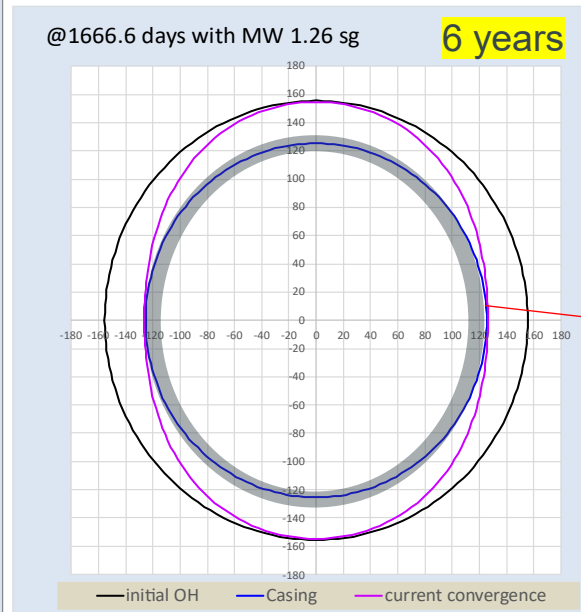
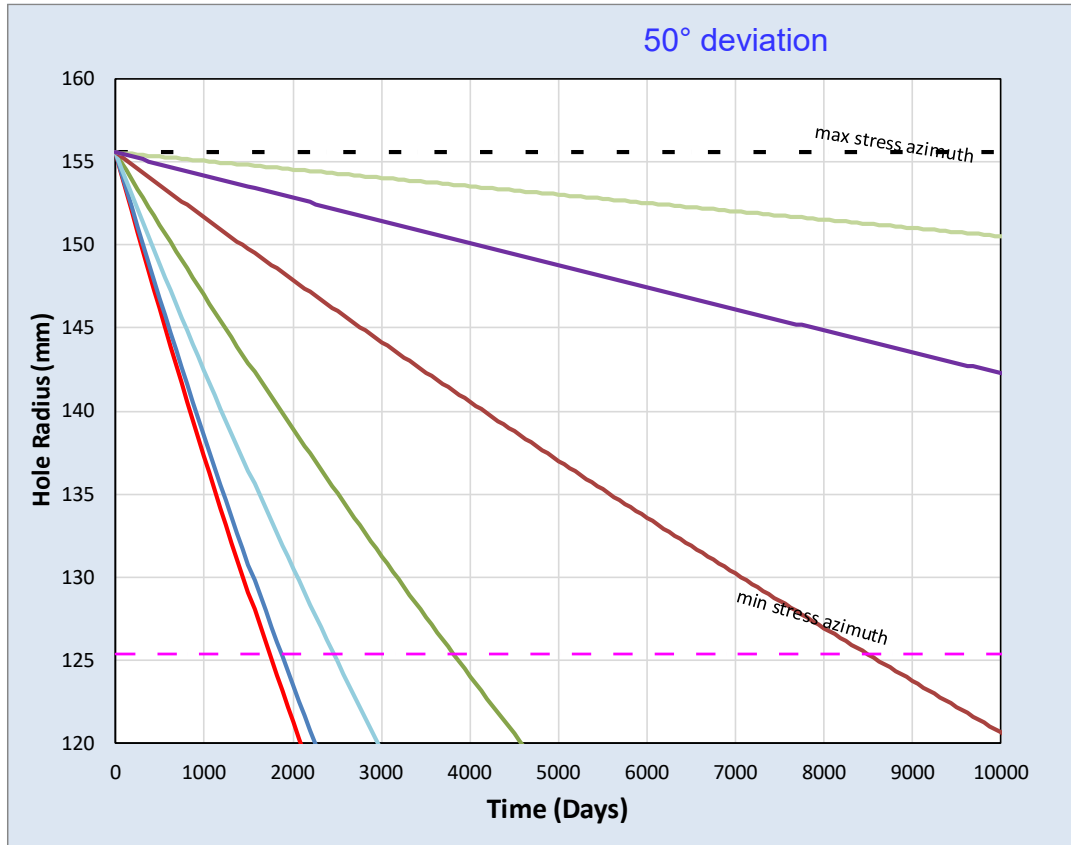


The analytical and numerical methods created by Kun Su, geomechanics Expert, illustrate how the creeping rate varies with changes in stress orientation. For specified depth and porosity, the model estimates the creeping rate at multiple locations around the wellbore (a, b, c, etc.). It demonstrates that the wellbore will begin to close laterally before other directions.

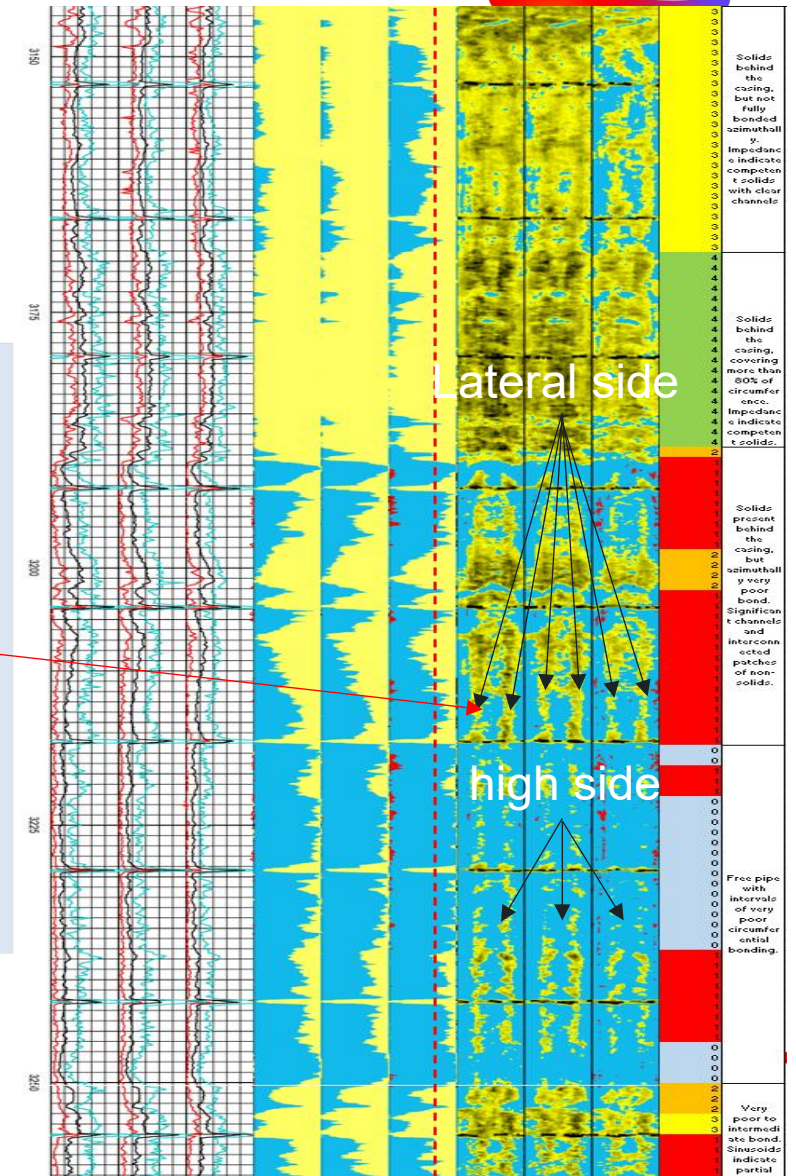


# Case 1 - UK postmortem @ plug 3 : 2110 mTVDRT

Hole size (R) mm	155.575	Shmin-MW	0.195	OBG (Sh max)	1.98
A (H-1)	2.17E-15	Depth TVD RT	2110	Shmin	1.455
n	1.30914	Porosité	0.1	MW	1.26
Radius to touch	125.4125			Sv-Shmin (Mpa)	10.86029412
Increment du temps	1500	4033823.529	40958823.5	30098529.41	26064705.88



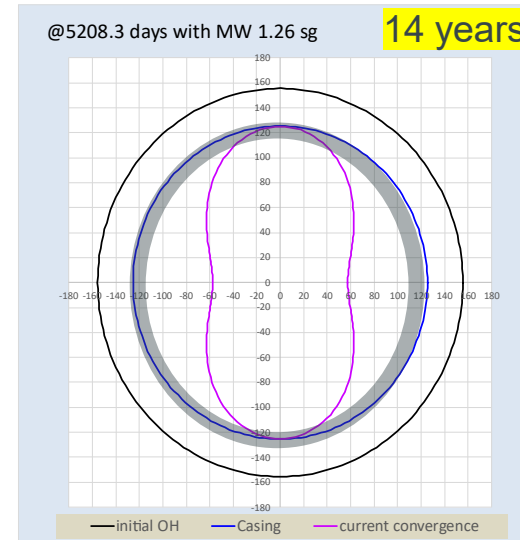
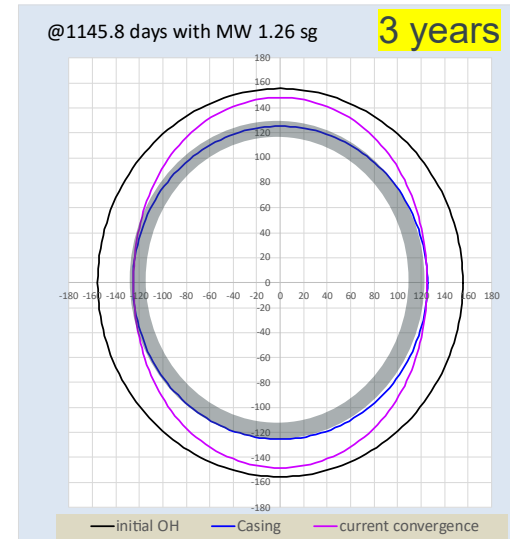
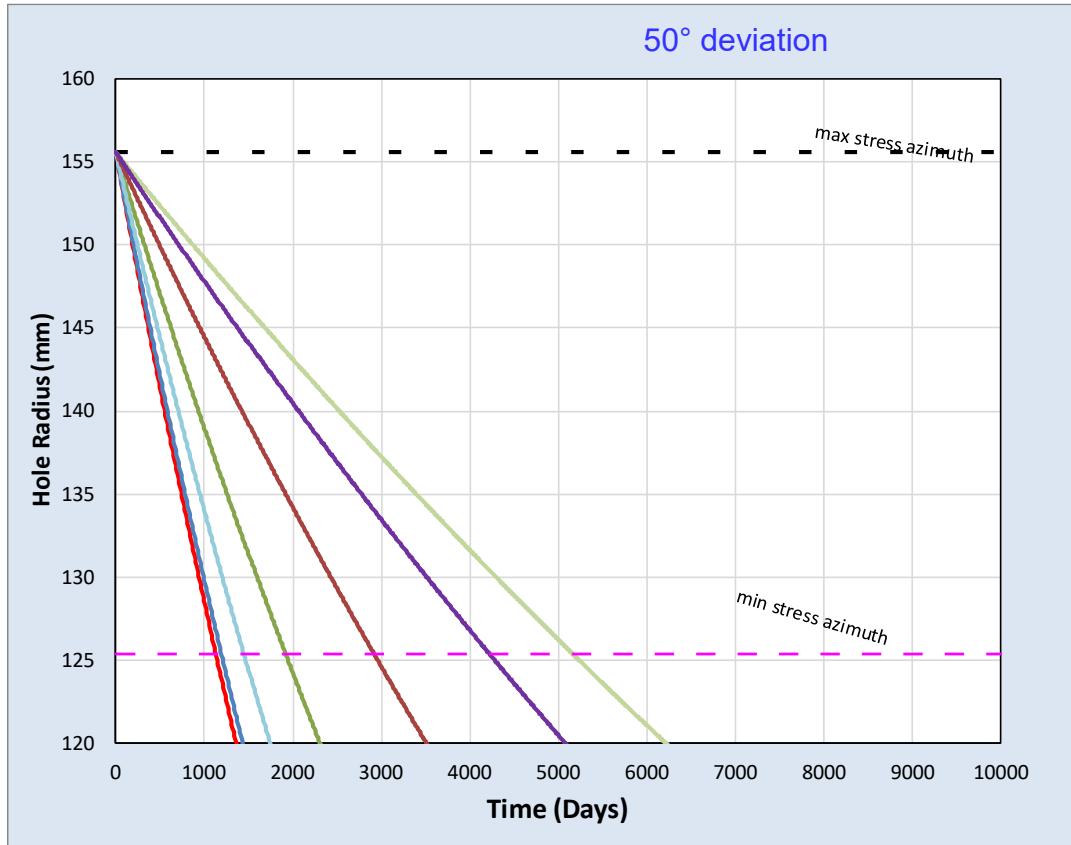
## CBL results after 12 years



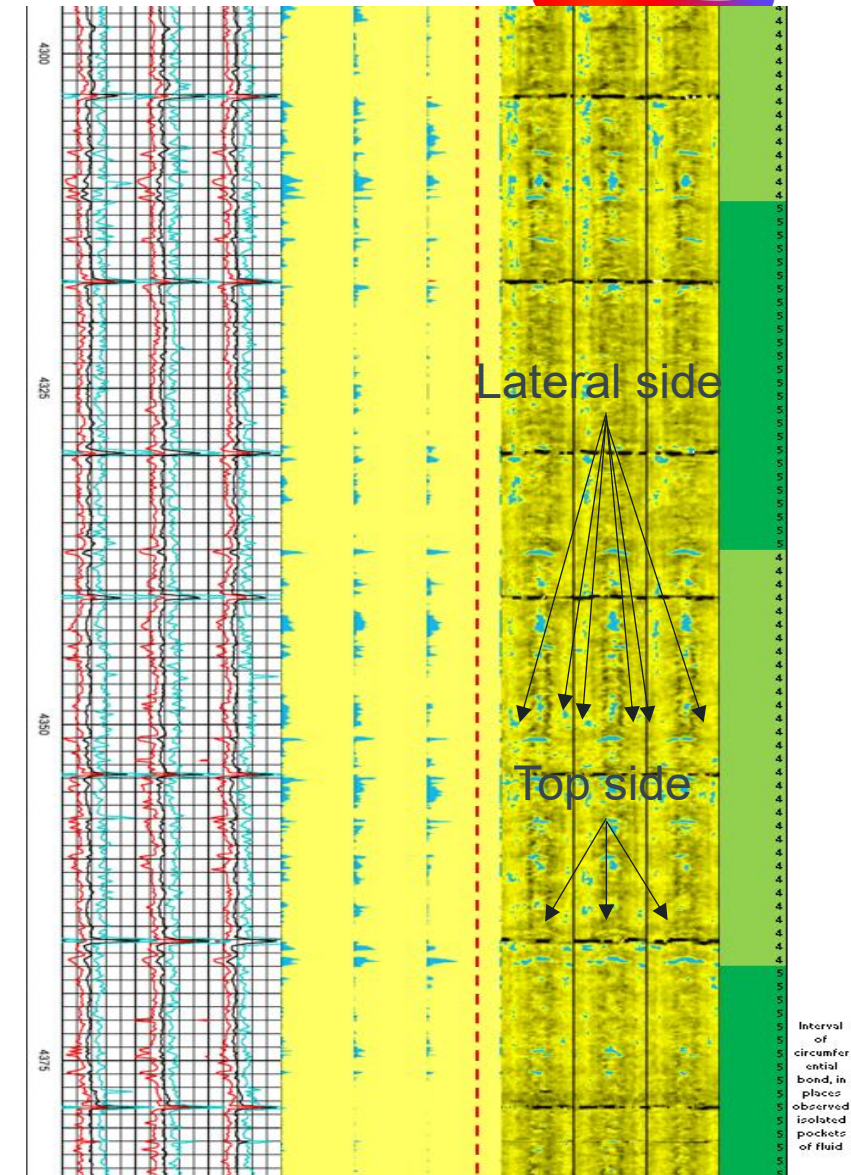
Simulation : Annulus starts to close laterally after 6 years and 180 years vertically / CBL results after 12 years show majority of lateral part closed and majority of high side sections are still open

# Case 1 - UK postmortem @ plug 2 : 2570 mTVDRT

Hole size (R) mm	155.575	Shmin-MW	0.36	OBG (Sh max)	2.06
A (H-1)	2.17E-15	Depth TVD RT	2550	Shmin	1.62
n	1.30914	Porosité	0.1	MW	1.26
Radius to touch	125.4125			Sv-Shmin (Mpa)	11
Increment du temps	250		9000000	51500000	40500000
					31500000



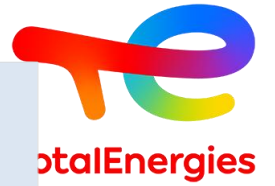
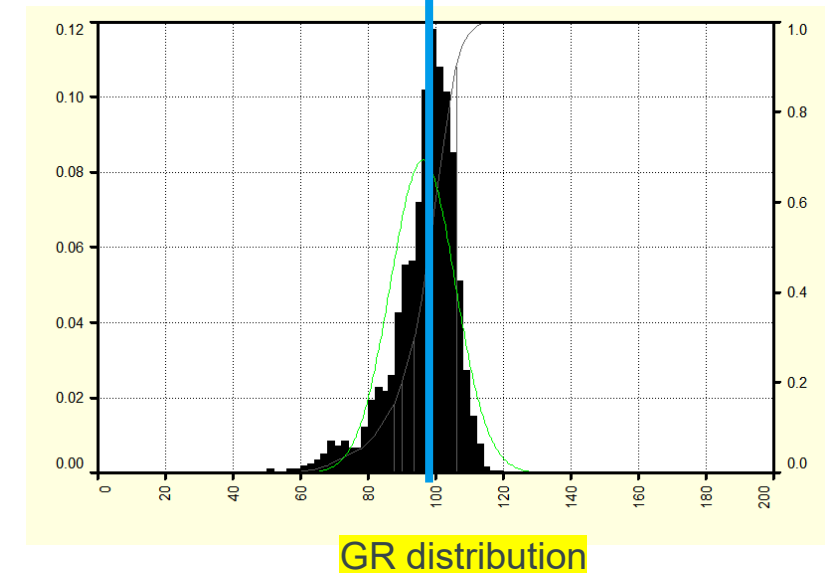
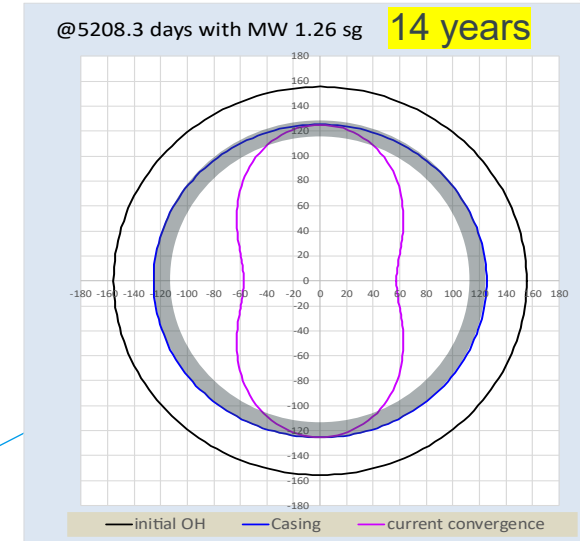
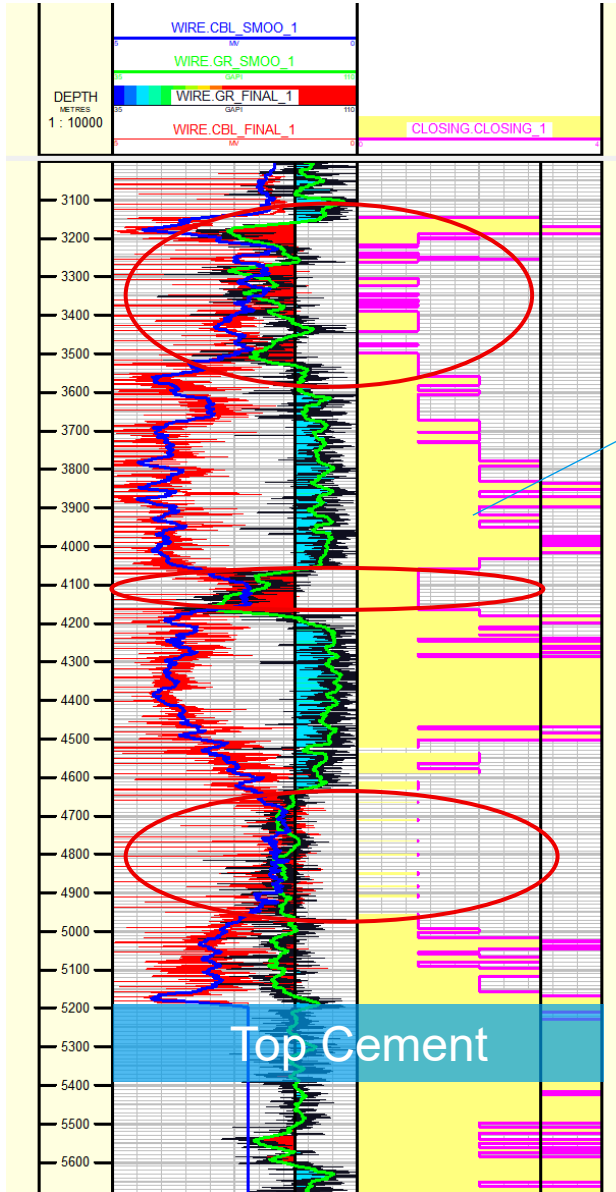
## CBL results after 12 years



Simulation : Annulus starts to close laterally after 3 years and vertically after 14 years / CBL results after 12 years show all lateral part closed and some high side sections are still open

# Case 1 - CBL vs GR over an interval

- Postmortem on CBL show a correlation between GR and the closure of the annulus
- The three zones that are not closed show a decrease in GR.
- Decrease of GR is related to decrease in Vclay and increase of quartz content.
- If GR above 90 – 91 GAPI the annulus is closed
- If Vclay total < 50% → no creep

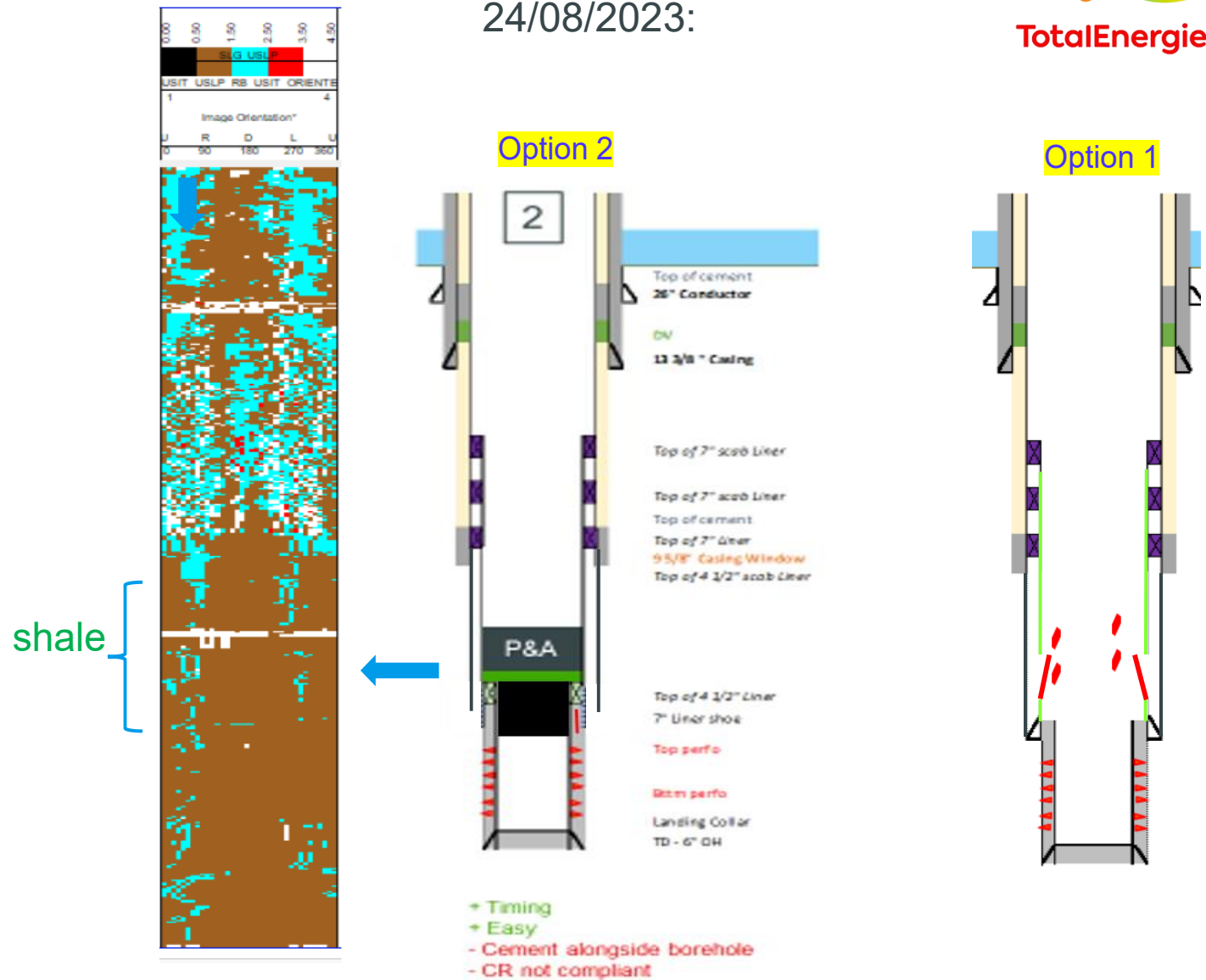
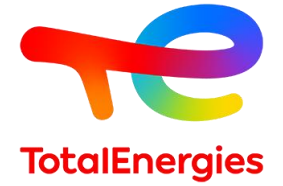


# Case 2: Middle East

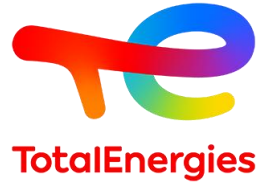
Prediction done @ 24/08/2023:

Yes, the annulus is closed thanks to the shale creeping over **25 years**, according to the model.

Yes, take the option n°2 as base case, which is ~3x less in cost time and CO2 emission compared to other option (3-4 million dollar to 8-11 million dollar)



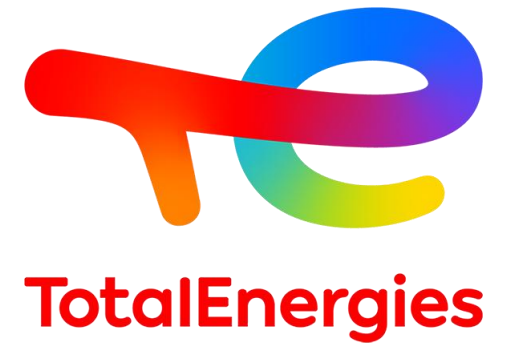
# Conclusion



- Both in situ data and modelling indicate that certain shales can mechanically and hydraulically close the annulus between rock and casing 20-30 years after drilling. The shale creeping forms an effective barrier and can be considered a natural barrier in permanent P&A operations.
- However, additional data and in situ experience are still required before widespread application for a given field.

## Way forward

- More in situ data acquisition
- Sharing in situ data between operators
  - UK Government developed collaborative dashboard monitoring shales evaluated as sealing barriers, organized per well and per interval (Offshore Energies UK)
- Consideration more parameters in the assessment of shale creeping ability
  - Mineralogical analysis from shale cuttings
  - Correlation with well logs
  - Correlation with drilling events



Thanks.