Activated creeping shale to remove the open annulus

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Standard completion methods leave long sections of the well with an open, uncemented annulus

However, cement bond logs from a number of wells indicate that the annulus is closed, presumably by creeping shale

Pressure tests confirm that the annulus has been sealed off
In situ stress
- drives the shale barrier forming process

Annulus pressure
- counteracts the shale barrier forming process
Shale Barrier Map

- Open gap
- Closed gap

**In situ stress**
- drives the shale barrier forming process

**Annulus pressure**
- counteracts the shale barrier forming process
While drilling.....

- In situ stress drives the shale barrier forming process.
- Borehole annulus pressure counteracts the shale barrier forming process.
After casing has been set......

In situ stress
- drives the shale barrier forming process

Annulus pressure
- counteracts the shale barrier forming process
The Shale Barrier Test

- Aluminum cylinder (representing casing)
- Confining pressure (representing in situ stress)
- Field core material
- Annulus pressure
The Shale Barrier Test

Field core material

Aluminum cylinder (representing casing)

Confining pressure (representing in situ stress)

Annulus pressure

Open gap

Closed gap

Annulus pressure

Confining pressure

Field core material
The Shale Barrier Test

- When does the gap close?

- If the gap is closed, is the annulus really sealed?

- "Annulus permeability" < 20 μD (↔ good quality cement) is OK

Monitoring stress on casing

Confining pressure (representing in situ stress)

Field core material

Periodic monitoring of flow along the annulus

Annulus pressure

Aluminum cylinder (representing casing)
Test on field core

Good quality cement

Confining pressure

Annulus pressure
Before the test

After the test
Hole diameter 12½", casing diameter is 9⁵/₆"  
\[ \Rightarrow \text{strain in the vicinity of the annulus: } 21\% \]
This is at least an order of magnitude larger than elastic deformation of soft shales

\[ \Rightarrow \text{A significant amount of plastic deformation is required in the vicinity of the hole, in order to establish a shale barrier.} \]
Some rocks are reluctant to form a barrier, despite massive persuasion.
Example of Activation and Verification of Shale Barrier During New Well Construction

Drilling sequence with drilling liner
(minor changes since 1993)

• Drilling and geo-stopping 5-8 m TVD over depleted reservoir
• Pick up drilling liner assembly and drill into depleted reservoir
• Goes on losses and the pressure drop rapidly in the annulus
• Stop losses on inside with a ball/plug, losses in annulus most often cure themselves
• Set liner top packer

Pressure drop in annulus equal to static mid weight in OB section minus fracture closure stress in depleted reservoir

Equipment and sequence for barrier verification

• Openhole annulus packer (OHAP)
• Wireless pressure sensors (PS)
• Port collars (PC)
G-9 Results

Operationally
- Went on increasing losses as we penetrated reservoir as predicted
- Pressure drop not as high as planned for (2000 psi +), but believed to be sufficient (around 1500 psi)
- The wireless gauge system did not work
  - Lost the ability to use pressure points along the wellbore and their pressure history with time to better understand the process
- A large volume (20 barrels +) XLOT (more than 10 times the volume we typically use) was pumped in 2nd cycle after a breakdown test

- Two linear pumpcycles, cycle two slightly stiffer
- Cycle one stopped prior to breakdown and fracture propagation
- Cycle two breakdown ~15.8, fracture propagation 15.76 - 15.9 ppg
- Closure pressure ~ 15.72 ppg
Very good barriers identified on bond logs at depth of deepest port collar where the XLOT was performed
Results from G-20

Cycle 1 peak pressure: 535 psi

Cycle 2 peak pressure: 328 psi

- No barrier based on XLOT
- No barrier based on bond log
Re-logged 19 days later

- Changes in bond log indicated over the 19 day period
- Most significantly the grey rectangle which is from the cement job through the port collar
  - This was a surprise to many
- Also more bonding in Lista is developing
- Some increased bonding in Horda 5 and 6 as well
- No verified barrier from log 19 days later
Summary

- Shale barriers are nature's own method to restore a perfect seal: robust, self-healing & durable
- Growing understanding of the mechanisms for shale barrier formation
- Field trials indicate that we can predict how barriers can be activated in the field based on laboratory experiments and numerical simulation
- P&A technology do also have applications in new well design