Effects of scCO$_2$ on permeability and viscoplastic properties of unconventional formations

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Samples

- Carb.: 4 – 71%
- “Clay + TOC”: 1-52%
- Diameter: 2.54 cm
- Length: 0.6 – 0.9 cm
- As-received, not dried
Experimental Set-up

Thermally-insulated

From Heller et al., 2014

Pulse-decay Method

Steady-state Method

Upstream pore pressure is held at a pre-scribed value.

Downstream pore pressure and inflow rate (from upstream side) are held at a pre-scribed value.
➢ CP = [20, 40, 20] MPa

➢ PP = 10 MPa

➢ 3 days of scCO₂ interaction

➢ Two argon cycles and one scCO₂ cycle

➢ Both pressure-dependency and hysteresis effects

➢ In C2 (scCO₂) cycle both recoverable and irrecoverable effects of scCO₂ on permeability are present

➢ In C3 (post-CO₂) cycle, only irrecoverable effects of scCO₂ are present

➢ Comparing the permeability cycles might give us some insights on the processes that affect permeability
Carbonate Dissolution

**Significant Irreversible Permeability Increase**

- **Carbonate Dissolution**
  - Graphs showing permeability changes under different conditions.
  - Comparison of Argon and scCO₂ permeabilities.
  - Effects of confining pressure and pore pressure.

**Mineralogy**
- Carb. 71%
- QFP 28%
- Clay + TOC 1%

**Mineralogy**
- Carb. 6%
- QFP 62%
- Clay + TOC 32%
SLIGHT RECOVERABLE PERMEABILITY DECREASE
GRADUAL DECREASE IN PERMEABILITY, REGARDLESS OF FLUID TYPE
Samples #1 and #2 have highest “Clay + TOC”

- Highest pressure dependency for Sample #1
- Lowest pressure dependency for Sample #2

Greater pressure dependency after interaction with scCO₂ for Samples #1 and #3

- Carbonate dissolution at pore and micro-crack scale
Time-dependent Dissolution

- **Net Change**: 50% dissolution-induced increase in permeability
- **When scCO₂ present**: 70% adsorption-induced decrease in permeability
- Significant permeability reduction after interaction with scCO₂
- Enhanced rate of permeability reduction under constant stress conditions
Mechanisms of Permeability Change

- Mineral composition is not the only factor determining scCO$_2$-induced changes in matrix permeability

- Dissolution of carbonate minerals causing irreversible permeability increase

- Adsorption causing reversible permeability decrease

- Weakening of the matrix leading to permanent enhanced compaction and decrease of permeability
Creep Experiments

- $CP = 40 \text{ MPa}$
- $PP = 10 \text{ MPa}$
- $DS = [10,20,30] \text{ MPa}$
- 7 days of scCO$_2$ interaction
- Comparison will be made between creep data with argon and scCO$_2$

- Power-law model will be used to model the axial strain data, as follows:
  \[
  \varepsilon = \sigma B t^n
  \]
  where $\varepsilon$ and $\sigma$ are axial strain and differential stress, respectively. $B$ and $n$ are empirical parameters.

- Higher values of $n$ imply higher ductility, while higher values of $B$ imply higher compliance.
Mechanical creep test

- Relatively constant Young’s modulus for argon and scCO₂ tests
- Higher n values for the scCO₂ test, so higher ductility

QFP: 62%
Carbonate: 8%
Clay+TOC: 30%
Conclusions

❖ **PERMEABILITY**

➢ *Short-term:*
  • Irreversible increase by carbonate dissolution
  • Reversible decrease by adsorption into clays and kerogen
  • Matrix weakening leading to enhanced compaction and decrease of permeability

➢ *Long-term:*
  • Exposure to scCO$_2$ (~80 days) shows considerable permeability loss in a sample with relatively low carbonate content (21%), apparently due to dissolution and compaction induced by matrix weakening

❖ **MECHANICAL CREEP**

• Enhanced ductility due to 7-day interaction with scCO$_2$, as evident from creep tests using argon and scCO$_2$
Future Work

❖ PERMEABILITY

➢ *Pore Size Estimation:*
  • Average pore size from Klinkenberg-type experiment and SEM imaging
  • Pore size distribution obtained from CO$_2$/N$_2$ adsorption isotherms

➢ *Dry vs Saturated Samples:*
  • Investigation of the effects of residual pore water on dissolution/adsorption

➢ *Continuing Long-term Tests:*
  • Studying the role of mineralogy on long-term permeability evolution

❖ MECHANICAL CREEP

• Conducting creep tests on a wider range of samples with concurrent measurements of permeability and ultrasonic velocities
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