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Water and CO_2 permeability of a shale sample core from Svalbard

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Abstract

Flow in tight shales is thought to be largely confined to fractures and similar features. Therefore, how open such features are under in-situ conditions has a major impact on shale permeability. We performed 43 permeability measurements on one shale core sample, both when it was intact and after it had fractured, using either water or supercritical CO_2 as the permeate. Our measurements show decreasing permeability with increasing confining pressure, due to both instantaneous and time-dependent, permanent compaction. Furthermore, our measurements show that under confinement, compaction may also eliminate the effect of a simple splitting fracture on shale permeability.

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Keywords: shale; pressure-dependent permeability; fluid flow; fracture flow; creep; CO_2

1. Introduction

In many geo-engineering practices, shales play an important role, as shale can act as source rock, caprock, or even reservoir rock. As a source rock, shale allows hydrocarbon-rich fluids to escape, whereas as a caprock shale forms a barrier to fluid flow. Hydraulic fracturing is often required to enhance fluid flow when producing hydrocarbons from shale reservoirs. The overlying caprock above many reservoirs targeted for CO_2-injection is shale.

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Previous experimental work has shown that shale permeability strongly depends on the applied effective confining pressure [1,2], as shale deforms elastically, plastically and by time-dependent viscous deformation [3]. Models suggest that due to shale deformability and the pressure-sensitivity of shale permeability, significant fluid fluxes are possible in shales (e.g., [4,5]). This is supported by laboratory experiments [6] and seismic observations indicating localized channels of increased fluid flow fluxes cutting through shales [7]. Therefore, it is of great importance to properly understand the flow of fluids through shale, as well as the possible interactions between shale and fluid that may influence this flow (i.e., mechanical effects, chemical effects [8,9], and swelling or shrinkage of clay minerals [10–12]).

To better understand fluid flow mechanisms in shales under in-situ stress conditions, we performed 43 permeability measurements on a single confined shale core plug from borehole DH7A in the Longyearbyen CO_2 well park in Adventdalen, on Svalbard's main island Spitsbergen on the northwestern margin of the Barents Sea Shelf [13]. These measurements have been carried out using either water or supercritical CO_2 as the permeate, to allow a comparison between water- and CO_2-permeability, under an effective isotropic confining pressure approximating sub-surface conditions relevant for CO_2-storage.

2. Method

2.1. Sample

The sample plug tested was drilled from a core that was retrieved on 23-06-2012 from borehole DH7A, from a depth of 375.25-375.47 m. Considering this depth and location, the sample originated from the Rurikfjellet formation (cf., [13]). Based on XRD analyses [14] on samples from borehole DH4, which was drilled in the same location, less than 100 m away, the main mineral phases present in our sample are illite, with only minor interlayered smectite, quartz, and plagioclase, with minor carbonates, kaolinite, and Fe-chlorite. The sample plug was drilled parallel to bedding, while keeping the shale under compression to prevent cracking. The core plug had a diameter of 25 mm and a thickness of 10 mm.

2.2. Apparatus and experimental method

All measurements reported here were carried out in a purpose-built transient pulse permeability apparatus, using a technique similar to that described in [15–17]. In our apparatus, a 25 mm diameter cylindrical sample is stacked between two hastelloy microporous plates, and two hastelloy pistons with grooved surfaces (to improve fluid flow distribution), and jacketed in a heat-shrink Fluorinated Ethylene Propylene (FEP) jacket, sealed to the pistons with steel wire tourniquets. For measurements performed with CO_2 as the pore fluid, aluminum foil is wrapped around the sample and pistons before sealing the assembly in its FEP jacket, as CO_2 diffuses through the FEP. The sample assembly is then placed inside a confining vessel, and the two pistons are each connected to an accurately calibrated volume. The confining pressure is applied using water as the confining medium. During the experiments performed at 40 °C, a temperature stability better than ± 0.1 °C is achieved by placing the apparatus inside a temperature-controlled cabinet (Termaks TS 8136), using an incandescent light bulb connected to a thyristor for precision control. The pore fluid pressure is maintained using an ISCO 100DX volumetric pump. Data is recorded at regular intervals (usually at 0.1 Hz) using an Agilent 34970A data acquisition/switch unit data logger connected to a PC. Data logs include temperature (K-type thermocouples), measured both inside the pressure vessel close to the sample, and in the temperature-controlled cabinet, pump pressure, pump piston position, and up- and downstream pore pressures and confining pressure (Unik 5000 pressure sensors with a range of 0-70 MPa and an accuracy of 0.1 % of full scale).

When setting up a series of measurements, the confining and pore fluid pressures are increased stepwise, such that the effective confining pressure is always kept below the desired value for the first measurement. Then, once the sample is stabilized at the desired confining and downstream pressures, a measurement is started by briefly opening the valve between the upstream volume and the ISCO pump, increasing the upstream pressure by 0.2 MPa. Once the valve is closed, pulse decay is monitored. Between measurements, the sample was kept under pressure.