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Research highlight

Characterization of mineral and pore evolution under CO_2-brine-rock interaction at in-situ conditions

Songtao Wu[1,2,3]*, Cong Yu[1,2,3], Xiaolin Hu[1], Zhichao Yu[1,2,3], Xiaohua Jiang[1,2,3]

[1] *Research Institute of Petroleum Exploration and Development, CNPC, Beijing 100083, P. R. China*

[2] *National Energy Tight Oil and Gas R&D Center, Beijing 100083, P. R. China*

[3] *CNPC Key Laboratory of Oil and Gas Reservoirs, Beijing 100083, P. R. China*

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Abstract:
Herein, a method of physical modeling of CO_2-brine-rock interaction and characterization of mineral and pore evolution at in-situ conditions is established. The nested preparation and installation of the same sample with different sizes could protect and keep the integrality of the millimeter-size sample in conventional high-temperature and high-pressure reactors. This paper establishes a procedure to obtain the three-dimensional comparison of minerals and pores before and after the reaction at in-situ conditions. The resolution is updated from 5-10 μm to 10 nm, which could be helpful for modeling CO_2-brine-rock interaction in unconventional tight reservoirs. This method could be applied to CO_2-enhanced oil recovery as well as CO_2 capture, utilization, and storage scientific research. Furthermore, it may shed light on the carbon sequestration schemes in the Chinese petroleum industry.

Greenhouse gases and their effects on the environment have attracted extensive attention worldwide. The injection of CO_2 into oil reservoirs is one of the most important strategies for enhanced oil recovery (EOR) and carbon storage, which is both of environmental significance and economic value. The CO_2-brine-rock reaction at in-situ conditions results in changes in both the minerals and their porosity, which is critical for flooding efficiency and oil production (Perrin et al., 2009). The means to capture these changes of both minerals and pores before and after the interaction have become crucial for the CO_2-brine-rock reaction in the lab. With the exploration targets turning to unconventional tight reservoirs, the storage space has transformed into micro/nanoscale pore-throat systems (Wu et al., 2019), and the microscale mineral evolution, especially the migration of clay minerals, is regarded as one of the most important factors for pore structure and oil flow. However, the current high-temperature high-pressure (HTHP) holder for the CO_2-brine-rock interaction is appropriated for plugs with diameters of 2.54 or 3.8 cm, and the resolution of computed tomography (CT) scanning for these samples is larger than 10-100 μm. In addition, there are few scanning electron microscopy (SEM) studies on the comparison of the states of the same mineral before and after the reaction (Yu et al., 2012; Dávila et al., 2016). Therefore, it is urgent to develop a new method that combines the conventional HTHP holder and the high-resolution characterization of mineral and pore evolution.

Our new method for the physical modeling and characterization of CO_2-brine-rock reaction at in-situ conditions in tight reservoirs was developed in the lab, including sample preparation and installation, mineral and pore comparison at in-situ conditions and fluid geochemical property evolution. Small plugs with diameters of 1 cm and 1 mm were drilled at the plug with a diameter of 2.54 cm. The 1-cm plug was ion-polished to obtain a flat surface for SEM analysis with no-carbon coating on the surface, for the carbon-coating would affect the CO_2-brine-rock reaction. The 1-mm plug was used for high-resolution CT scanning. The porosity, SEM, and CT

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*Corresponding author.
E-mail address: wust@petrochina.com.cn (S. Wu); yucong87@petrochina.com.cn (C. Yu); huxiaolin@petrochina.com.cn (X. Hu); yuzhichao@petrochina.com.cn (Z. Yu); jiangxiaohua69@petrochina.com.cn (X. Jiang).

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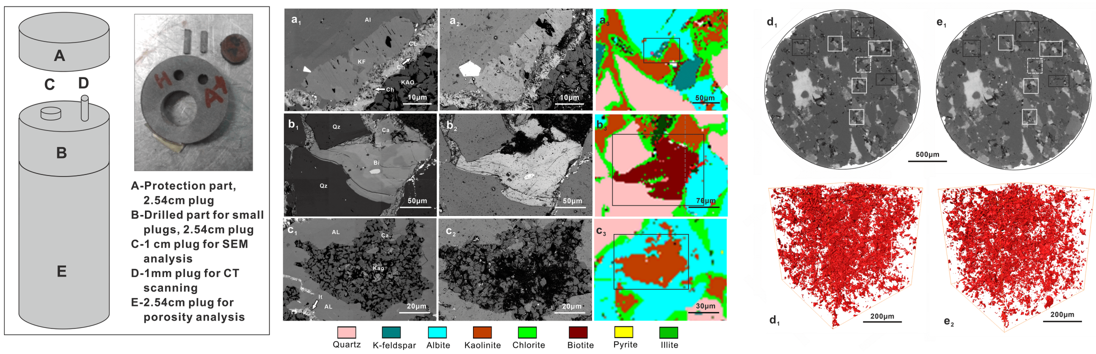

Fig. 1. Sample preparation method, mineral evolution and 3D porosity model of Triassic Chang 7 tight sandstones (modified after Wu et al., 2019). On the right side, Series a, b and c are the SEM images and Series d and e are the CT images. The subscripts 1, 2 and 3 denote the samples before the experiment, after the experiment, and the QEMSCAN results, respectively. Al-Albite, Qz-Quartz, KF-K-feldspar, Ca-Calcite, Kao-Kaolinite, It-Illite, Bi-Biotite.

analyses were carried out before the interaction, and then the small plugs were inserted into the plug with diameter of 2.54 cm and installed into the conventional HTHP holders. Such nested preparation and installation of the same sample with different sizes could protect and keep the integrality of the millimeter-size sample in the conventional HTHP reactors. Moreover, each group of three plugs was from the same sample, which could avoid the effect of heterogeneity. After the interaction, the porosity, SEM, CT, and quantitative evaluation of minerals by SEM (QEMSCAN) analyses were carried out at the same position, from which the three-dimensional (3D) mineral and pore model could be constructed after the interaction, and the resolution could be promoted from 5-10 μm to 10 nm (Fig. 1, left).

Taking tight sandstones from the Ordos Basin as an example, physical modeling revealed the dissolution and precipitation of minerals in Chang 7 tight sandstones, which varied among different minerals. K-feldspar, albite and calcite were the main non-clay minerals that went through dissolution. The dissolution, migration and precipitation of clay minerals were common processes. Chlorites were found to be the most dissolved clay minerals. Moreover, these were the precipitations of kaolinite and smectite, which have a significant influence on the pore structure. Ankerite, dawsonite and sidertite were found as the top three minerals for carbon storage (Fig. 1, right). During the reaction of supercritical CO_2, subsurface brine, hydrocarbon and minerals under high temperature and pressure, the distance from sandstones to CO_2 injection end, mineral composition, and original pore structure were found as the key to the evolution of sandstone physical properties. The nearer the sandstones were found from the CO_2 injection end, the more dissolution and clay mineral migration occurred, and the more obvious the enhancement of physical properties. The results showed that a higher clay mineral content leads to a greater probability of impaired physical properties after CO_2-brine-rock interaction. The top two minerals in the evolution of physical properties in sandstones were chlorite and kaolinite.

This work is a successful attempt at the characterization of mineral and pore structure evolution of lacustrine sandstones at in-situ conditions. A unique method was proposed for sample preparation and installation before and after the experiment of CO_2-brine-rock reaction and the optimization of SEM, QEMSCAN and CT combination process, which successfully resulted in the 3D pore-mineral characterization at high resolution at in-situ conditions. Nano-scaled pores and minerals could be accurately compared and evaluated, which could provide a firm foundation for the discussion of mineral evolution.

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Conflict of interest

The authors declare no competing interest.

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