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RESEARCH PAPER

Physical simulation and quantitative calculation of increased feldspar dissolution pores in deep reservoirs

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Abstract: The physical simulation of diagenesis was conducted for the Cretaceous Bashijiqike Formation deep sandstone reservoir in Kelasu structural belt of Kuqa Depression, Tarim Basin, and the dissolution rate and increased dissolution pores of feldspar matrix grains in such reservoirs were quantitatively calculated in the process from long-term shallow burial in early stage to quick deep burial in late stage. Through the field emission large-area SEM analysis, the dissolution rate and increased dissolution pores of feldspar matrix grains in core samples taken from Dabei and Keshen areas were quantitatively calculated. After the experimental data and the actual core data were cross-checked, the evolution model was established for increased feldspar dissolution pores in deep continental reservoirs with high content of feldspar matrix grains. According to the calculation results, the maximum increased feldspar dissolution pores in Keshen area during the process from long-term shallow burial in early stage to quick deep burial in late stage is by 0.86%–2.05%. The simulated sandstone reservoir with burial depth of more than 7 000 m reveals a larger quantity of increased feldspar dissolution pores, with the absolute error value of 0.23% after calibration. In Dabei area, calcite is the primary contributor to secondary dissolution pores, followed by feldspar. Quantitative calculation shows the maximum increased feldspar dissolution pores in Dabei area to be by 0.62%–1.48%. Similarly, the simulated sandstone reservoir with burial depth of more than 7 000 m reveals a larger quantity of increased feldspar dissolution pores, with the absolute error value of 0.15% after calibration. There are two causes of the experiment errors: One cause is that the simulation experiment uses ideal conditions and the simulation reservoirs are homogeneous; Another one is that deep reservoirs have strong heterogeneity and there are big differences in the dissolution within different areas.

Key words: Kuqa Depression; deep reservoir; feldspar dissolution; increased dissolution pore; physical simulation of diagenesis

Introduction

The existence of deep high quality reservoirs is often related to the development of a large number of secondary pores and microcracks. Studies include the cause and preservation mechanism of deep abnormal reservoirs, and the prediction of abnormal pore zones[1]. Reservoirs with a high content of feldspar skeleton particles are generally developed in Chinese continental sedimentary basins. The dissolution of feldspar skeleton particles forms secondary pores, which can improve the reservoir performance of sandstone, and is of great significance in low intergranular pore sandstone reservoirs[2]. The deep reservoirs of the Cretaceous Bashijiqike Formation in the Kuqa Depression have an average feldspar content of 25% in the Keshen area and 18% in the Dabei area. Under transformation during extrusion and dissolution in the reservoir in the Cretaceous Bashijiqike Formation (with a burial depth of more than 6 000 m) skeleton particles, such as feldspar, cuttings, and intergranular calcite and other cements have undergone significant dissolution. This process has enlarged pores; intragranular dissolution pores are important reservoir space types in the Dabei-Kei area[3–12]. Global research has been conducted on the feldspar, cuttings, and carbonate mineral dissolution, and the dissolution porosity increment of feldspar[13–22]. For example, Thomas et al.[20] used statistical analysis to obtain the dissolution porosity increment of feldspar in feldspar-rich marine sandstones in the Gulf of Mexico's Triassic, Miocene, and Eocene; the North China Sea's Permian and Triassic; the White Sea's Jurassic; and the West African Pleistocene; results showed values of 0.2%–4.8%.

At present, limited research has been conducted by Chinese scholars on the dissolution porosity increment of feldspar in reservoirs with a high content of feldspar skeleton particles within the continental sedimentary basins of China. Even fewer studies have been conducted on the evolutionary proc-

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esses and quantitative calculation of feldspar dissolution pores during the burial diagenesis of reservoirs. Therefore, using the deep reservoir of the Cretaceous Bashijiqike Formation in the Kelasu structural belt of the Kuqa Depression as an example, a diagenetic physical simulation experiment is conducted, and the dissolution rate and incremental porosity of the dissolution of feldspar skeleton particles in early long-term shallow burial–late rapid deep geological process is calculated in the sandstone of the Bashijiqike Formation. This study provides a basis for the evaluation and prediction of deep favorable reservoirs that have high feldspar skeleton particle contents in the continental basins of China.

1. Diagenetic physical simulation experiment

1.1. Experiments

The simulated target layer is the deep sandstone of the Cretaceous Bashijiqike Formation, which is dominated by quartz, followed by feldspar and cuttings[3] (the cuttings are mainly andesite, rhyolite, metamorphic quartz, and phyllite). In addition, intergranular matrix fillings are mud, and cements are mainly calcite and gypsum. This study calculates the type and content of quartz, feldspar, and cuttings in sandstone samples from the Bashijichike Formation in several drilling wells within the Keshen area. Simulated sandy samples are matched according to mineral species and content of actual core samples (Table 1), and fine sand with a grain size of 0.10–0.25 mm is selected. As the actual Cretaceous formation water is mainly calcium chloride, calcium chloride solution with a mass fraction of 2% is selected as the experimental fluid. At the end of the experiment, acetic acid solution with a mass fraction of 0.5% is added to simulate dissolution in the stratum after deep burial. In the experiment, the fluid is supplied under constant current mode with a velocity of 0.3 mL/min to each sample. After this fluid reaches 20% of each sample's total volume, the agitated reactor was closed. The fluid is firstly subjected to sufficient water-rock reaction using the sandy samples and then released for collection. This cycle continues until the end of the entire experiment.

Table 1. Simulation of mass fraction of clastic components of Cretaceous in Kuqa Depression

Clastic components	Mass fraction/%	Mineral species	Mass fraction/%
Quartzs	48	Quartz	48
Feldspars	25	Potash feldspar	17
		Plagioclase	8
Cuttings	27	Quartzite	9
		Phyllite	5
		Rhyolite	6
		Tuff	5
		Silicalite	1
		Dolomite	1

The Cretaceous sediments in the Kuqa Depression are about 130 Ma and the stratigraphic subsidence can be divided into two stages[23–25]: (1) an early long-term shallow burial stage from 23 Ma to 130 Ma, with the formation slowly settling to a depth of 2 000–3 000 m; and (2) a late rapid deep burial stage from 23 Ma to the present day, causing rapid settlement to about 8 000 m; fractures enabling the formation of acidic fluid occurred after deep burial of the formation, along with dissolution fractures.Based on this geological evolutionary process, the entire experimental process was designed to last for a period of 28 days. The experimental process was divided into four stages, as follows. (1) An early shallow burial stage with a simulated reservoir depth between 1 000 m and 3 000 m and conditions as follows: 1 000 m (simulated temperature: 250 °C, lithostatic pressure: 82.5 MPa), 2 000 m (simulated temperature: 300 °C, lithostatic pressure: 110 MPa), and 3 000 m (simulated temperature: 350 °C, lithostatic pressure: 137.5 MPa). The experimental diagenetic environment was consistent with that present during the actual geological evolutionary process and is a freshwater-brackish water environment; the simulated diagenetic fluid was calcium chloride solution with a mass fraction of 2%. (2) A transitional stage from shallow-burial to fast deep-burial, where the simulated reservoir depth was from 3500 m (simulated temperature: 362.5 °C, lithostatic pressure: 151.5 MPa) to 4500 m (simulated temperature: 387.5 °C, lithostatic pressure: 178.5 MPa). The simulated diagenetic environment gradually changes from a freshwater-brackish water environment to an acidic environment. The diagenetic fluid in the early period was a calcium chloride solution with a mass fraction of 2%; an acetic acid solution with a mass fraction of 0.5% was added in the late period. These first and second experimental stages lasted about 24 days and were followed by (3) an early deep burial stage, where the simulated reservoir rapidly settled from a depth of 5 000 m (simulated temperature: 400 °C, lithostatic pressure: 192.5 MPa) to 6 000 m deep (simulated temperature 425 °C, lithostatic pressure: 220 MPa), and (4) a late deep burial stage, where the simulated reservoir rapidly settled from a depth of 7 000 m (simulated temperature: 450 °C, lithostatic pressure: 247.5 MPa) to 8 000 m (simulated temperature: 475 °C, lithostatic pressure: 275 MPa). The third to fourth experimental stages lasted for about four days, the simulated diagenetic environment was acidic, and the diagenetic fluid was an acetic acid solution with a mass fraction of 0.5%. After completion of the diagenetic simulation experiment, loose sand was consolidated into sandstone and this laid the foundation for subsequent microcosmic analysis of the reservoir.

1.2. Basic characteristics of experimental sandstone samples

After obtaining simulated sandy diagenetic samples at dif-