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Comparative studies of microscopic pore throat characteristics of unconventional super-low permeability sandstone reservoirs: Examples of Chang 6 and Chang 8 reservoirs of Yanchang Formation in Ordos Basin, China

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ABSTRACT

It's difficult to evaluate the unconventional super-low permeability sandstone reservoir by conventional mercury injection test. In order to evaluate this kind of reservoir more efficiently, in this study, we mainly measure the microscopic pore throat characteristic parameters and the curves of the reservoir by constant-rate mercury injection test, such as the average pore radius, average throat radius, pore throat radius ratio, maximum throat radius and other parameters. The reservoir characteristic curves include the pore radius distribution, throat radius distribution, pore throat radius ratio, and capillary pressure.

Samples of tight sandstone in typical blocks from the Chang 6 and Chang 8 reservoirs were analyzed by a constant-rate mercury injection test to determine the differences in microscopic pore throat characteristics of unconventional super-low permeability sandstone oil reservoirs in the Yanchang formation of the Ordos Basin. According to the comprehensive classification results of PetroChina, a current super-low permeability reservoir can be classified as super-low permeability class I: 0.5 mD $\le K \le$ 1.0 mD, super-low permeability class II: 0.3 mD $\le K <$ 0.5 mD, and super-low permeability class III: 0.1 mD $\le K <$ 0.3 mD (Yang and Fu, 2012). Firstly, the results of a constant-rate mercury injection test in the study area are classified and compared. Secondly, for the same class of reservoirs, the differences of microscopic pore throat characteristics in different blocks of the reservoir groups are analyzed separately. Thirdly, the microscopic pore throat characteristics between the Chang 6 and Chang 8 reservoir of the same class are analyzed. The analysis of blocks belonging to the same class of reservoir shows that in the Chang 6 reservoir the Xin'anbian block is superior to the Huaqing block, and the Huaqing block is superior to the Heshui block. In the Chang 8 reservoir, the Xifeng block is superior to the Huaqing block in classes I and II, and the Jiyuan block is superior to the Heshui block in class III. Between the Chang 6 and Chang 8 reservoirs, we found that the Chang 8 reservoir is dominant in class I reservoirs; the Chang 6 reservoir is slightly superior to the Chang 8 reservoir in class II, and the Chang 8 reservoir is better than the Chang 6 reservoir in class III.

1. Introduction

Unconventional sandstone reservoirs with super-low permeability (0.1 mD $< K <$ 1 mD) have been extensively developed in China as an important component of unconventional resources. They are widespread in many large-scale sedimentary basins such as China's Ordos, Sichuan Basin, Bohai Bay, Songliao, and Junggar basins (Zou et al., 2014, 2015a; 2015b). Poor physical properties characterize super-low permeability sandstone reservoirs, some of which are strong heterogeneity, short-distance petroleum migration, and a complex formation pressure system (Pittman, 1992; Teige et al., 2005; Li et al., 2015; Zou et al., 2014; Deveugle et al., 2014; Wang et al., 2016). Each super-low permeability sandstone has unique characteristics, due to variations in the depositional environment and provenance, and its complex diagenetic evolution (Wescott, 1983; Morad et al., 2010; Zou et al., 2012; Feng et al., 2013; Macquaker et al., 2014; Saller et al., 2014; Jia, 2017; Şamil, 2017).

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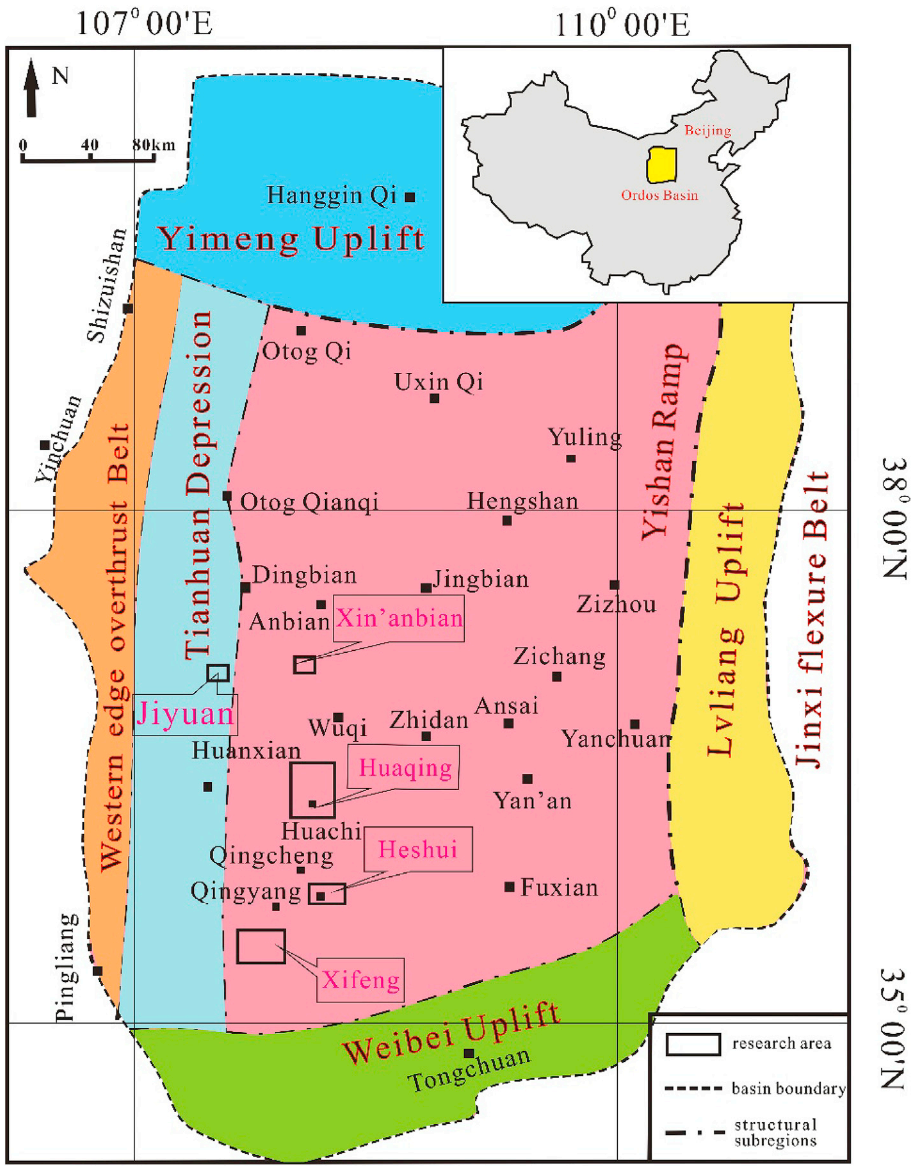

Fig. 1. Location of tectonic units and study areas in the Ordos Basin.

Table 1
Constant-rate mercury injection test of super-low permeability samples (by permeability classification).

Sample source	Super-low permeability class I	Super-low permeability class II	Super-low permeability class III
Chang 6	–	A2	A3, A4, H11, H12, H13, H14, H15, H16, H17, H18, H19, S11, S12
Chang 8	X32, H33, H34	X31, H32	J32, S31, S32

Note: Samples A, H, S, and X, represent Xin'anbian, Huaqing, Heshui, Xifeng blocks respectively (Fig. 1).

Reservoir characteristics are important to reservoir quality assessment, reservoir development, and enhanced oil recovery; the characteristics include inherent petrology, pore distribution, microscopic pore structure, and petrophysical properties, (Kilmer et al., 1987; Endres and Knight, 1991; Hayes, 1991; Aguilera, 2002; Shanley et al., 2004; Nehring, 2005; Nelson, 2009, 2011; Loucks et al., 2009; Dutton and Loucks, 2010; Guillaume et al., 2011; Loucks et al., 2012; Dai et al., 2012; Rivard et al., 2014; Wang, 2016).

Microscopic pore throat structure fine characterization of reservoirs is the core content of reservoir microphysics research, and a necessary link and relevant index of reservoir evaluation (Zhang et al., 2016; Zhou et al., 2016; Dai et al., 2016; Zhu et al., 2016). Much research has been carried out on the micropore structure of ultra-low permeability reservoirs (10 mD > K > 1.0 mD) (Desbois et al., 2011; Zhang et al., 2015; Meng et al., 2015; Ren et al., 2015; Li et al., 2016; Dou et al., 2016). However, a comparative study of microscopic pore throat characteristics is still relatively rare for super-low permeability sandstone reservoir (1.0 mD ≥ K > 0.1 mD) (Spencer, 1989; Wang, 2008; Wang et al., 2009, 2012a,b; Clarkson et al., 2012; Zhang and Yang, 2014). Spencer (1989) studied the relation between porosity and permeability, and the stress sensitivity of a low-permeability reservoir in the western United States. The research showed a likely trend of decreasing permeability with decreasing porosity. Wang et al (2009, 2012a,b) studied the micropore structure in a super-low permeability sandstone reservoir (10 mD > K > 1 mD) and the feature parameters of microscopic pore throats in a deeply buried low-permeability sandstone reservoir. Clarkson et al. (2012) identified the flow unit and studied the pore structure of the Lower Triassic Montney Formation tight gas reservoir in western Canada by N_2 adsorption. Guo et al. (2014) characterized a tight sandstone reservoir in