The distribution rule and seepage effect of the fractures in the ultra-low permeability sandstone reservoir in east Gansu Province, Ordos Basin

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To study the impact of the fractures on development in the ultra-low permeability sandstone reservoir of the Yangchang Formation of the Upper Triassic in the Ordos Basin, data on outcrops, cores, slices, well logging and experiments are utilized to analyze the cause of the formation of the fractures, their distribution rules and the control factors and discuss the seepage flow effect of the fractures. In the studied area developed chiefly high-angle tectonic fractures and horizontal bedding fractures, intergranular fractures and grain boundary fractures as well. Grain boundary fractures and intragranular fractures serve as vital channels linking intragranular pores and intergranular solution pores in the reservoir matrix, thus providing a good connectivity between the pores in the ultra-low permeability sandstone reservoir. The formation of fractures and their distribution are influenced by such external and internal factors as the palaeo-tectonic stress field, the reservoir lithological character, the thickness of the rock layer and the anisotropy of a layer. The present-day stress field influences the preservative state of fractures and their seepage flow effect. Under the tectonic effect of both the Yanshan and Himalayan periods, in this region four sets of fractures are distributed, respectively assuming the NE-SW, NW-SE, nearly E-W and nearly S-N orientations, but, due to the effect of the rock anisotropy of the rock formation, in some part of it two groups of nearly orthogonal fractures are chiefly distributed. Under the effect of the present-day stress field, the fractures that assume the NE-SW direction have a good connectivity, big apertures, a high permeability and a minimum starting pressure, all of which are main advantages of the seepage fractures in this region. With the development of oilfields, the permeability of the fractures of different directions will have a dynamic change.

fracture, genetic type, distribution characteristic, seepage flow effect, ultra-low permeability sandstone reservoir, Ordos Basin

The so-called low permeability reservoir refers usually to an oil-bearing reservoir with the permeability of the matrix less than $50 \times 10^{-3} \mu m^2$\textsuperscript{2}\textsuperscript{1}. In light of the average permeability of the reservoir matrix and of the micro porous structures of a reservoir and their development characteristic, low permeability reservoirs are generally divided into three types: conventional low-permeability reservoir with the permeability of the matrix being $50 \times 10^{-3} \text{–} 10 \times 10^{-3} \mu m^2$, ultra-low permeability reservoir with the permeability of the matrix being $10 \times 10^{-3} \text{–} 1 \times 10^{-3} \mu m^2$ and super-low permeability reservoir with the permeability of the matrix being $1 \times 10^{-3} \text{–} 0.1 \times 10^{-3} \mu m^2$. The ultra-low permeability sandstone reservoirs to

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be studied in this work include the second and third types, namely sandstone reservoirs with the permeability of the matrix less than $10 \times 10^{-3} \, \mu m^2$.

Chang 6 and Chang 8 oil reservoirs in the Yangchang Formation of the Upper Triassic are the chief reservoirs in east Gansu Province, southwest of the Ordos Basin. The Xifeng oil field being developed at present is located in this region. Their porosity is generally 10% or so, their permeability generally less than $10 \times 10^{-3} \, \mu m^2$ ($0.1 \times 10^{-3} - 2.0 \times 10^{-3} \, \mu m^2$ in the main), which indicates that they are typical ultra-low permeability sandstone reservoirs$^{[2,3]}$. Intense diagenesis and the structural effect in the later period endowed these ultra-low permeability reservoirs with such a remarkable heterogeneity that the natural fractures in them developed, thereby laying control of the seepage systems of such reservoirs and affecting their development plans and layout$^{[4,5]}$. Therefore, a study of the distribution rules of the fractures and of the seepage character is of much significance to a rational development of these ultra-low permeability sandstone reservoirs.

The Ordos Basin is one of the main regions in China, where ultra-low permeability sandstone reservoirs are distributed. Some basic research has been done on the distribution of the tectonic stress field, the time when the fractures in such reservoirs were formed, their genetic mechanism, and their distribution rules in the Mesozoic and Cenozoic of this basin$^{[6-11]}$. Since the discovery of the Xifeng oilfield, starting from sedimentation and diagenesis, oil geologists have done a lot of research on the characteristics of Chang 6 and Chang 8 ultra-low permeability sandstone reservoirs in the Yangchang Formation in east Gansu$^{[12-16]}$, but there is a lack of systematic studies of the distribution rules and seepage effects of the fractures in the above-mentioned reservoirs in this region. Therefore, a deep understanding of the fractures and their seepage effects is an important basis for making oil reservoir development plans in such reservoirs. Based on observations and analysis of the fractures in surface outcrops, cores and slices, in combination with data on logging and experiments, first made here is a study of the genetic types, distribution characteristics and law of development of the fractures in the ultra-low permeability sandstone reservoirs in the Yangchang Formation in east Gansu of the Ordos Basin, and then an analysis of the seepage effect of the fractures, which means much as a guide to the development of ultra-low permeability sandstone reservoirs in this region.

1 Geological setting

In the Ordos Basin, which is a basin of the Mesozoic sedimentation, formed through superimposition on the Craton plate of north China over a long-term evolution, there are three sedimentary overlying formations of the Paleozoic, Mesozoic and Cenozoic as well as petroliferous strata of both the Paleozoic marine and Mesozoic continental facies, of which the Mesozoic strata are important continental oil-bearing layers and the places where low-permeability sandstone reservoirs developed in this basin. In the Yanchang Formation of the Upper Triassic on the inland deltaic sedimentary system in particular, there are plenty of oil resources. The top of the Yanchang Formation is a flat monocline structure slanting slightly westward, the dip angle being less than 1°, upon which there developed a series of nose-like structural belts assuming nearly the E-W and NE-SW directions$^{[17]}$. Our studied area lies in the southwest of the Ordos Basin (Figure 1), and the stratum of the Yanchang Formation in it is 1000—1500 m thick, and it is again divided into 10 oil reservoir formations (Chang 1—Chang 10), of which Chang 6 and Chang 8 are the principal oil-bearing ones. Of these reservoirs here, which are mostly made of thickly-layered sandstone, most are of a half-deep lake and deep lake turbidite facies and consist of underwater distributary channel at the deltaic front, river mouth bars, natural levees and frontal sheet sandstones, of which fine and medium-sized lithic arkose is the principal, then fine and medium-sized feldspathic litharenite and feldspathic sandstone. The storage space is chiefly made up of the primary pores and secondary solution pores, including intergranular pores, feldspathic solution pores, lithic solution pores, zeolite solution pores, solution pores in the detrital matrix, intercrystalline pores and microfractures, controlled by sedimentary microfacies and diagenesis. The rocks in the reservoirs are compact and have high anisotropy and poor permeability and porosity, and in them developed fractures, affecting the water injection development of these oilfields.

2 Types of fractures

According to the data on the similar outcrops in Tong-