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RESEARCH PAPER

Natural fracture distribution and a new method predicting effective fractures in tight oil reservoirs in Ordos Basin, NW China

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Abstract: Based on core, imaging logging, and thin section data, the distribution features of natural fractures in the tight oil reservoirs of the Ordos Basin are examined. The tight reservoirs in the Ordos Basin are rich in natural fractures, the fractures are mainly high-angle structural shear fractures in continuous step arrangement. Affected by rock mechanical anisotropy and present stress field, the NE trending fractures are the dominating seepage flow direction. These fractures feature high angle, small cutting depth, small aperture and short extension, controlled by rock lithology and single layer thickness in development degree, natural fractures are most developed in fine siltstone, most undeveloped in mudstone. The thinner the single layer, the more developed the natural fractures will be. Based on distribution features of natural fractures and quantitative evaluation of natural fracture characteristic parameters, by using reservoir matrix and natural fracture geologic modeling, a comprehensive reservoir geologic model considering natural fractures was built, by using reservoir numerical simulation modeling inversion, the plane distribution of effective natural fractures was found out, and the contribution of natural fractures to single well production was quantitatively evaluated at around 30.0%–50.0%. The research results are of great significance for well-pattern deployment and optimization of development technical policies of similar reservoirs.

Key words: tight sandstone reservoir; natural fracture; distribution characteristic; effective natural fracture; Ordos Basin

Introduction

Tight oil exists extensively in lower Triassic Yanchang Formation in Ordos Basin, in delta plain, delta front and semi-deep-to-deep lake area. The tight oil reservoirs are mainly deep water gravity flow deposits, including sandy debris flow, slump and turbidite deposits. Controlled by sedimentary facies, sandbodies are pieced together in large area on the plane, but small in extension individually, and the sandstone is thick combined vertically, with rich interbeds. The major tight oil reservoirs, Chang4+5 to Chang8, have a permeability of less than 1×10^{-3} μm^2 and porosity from 4% to 12%. The reservoirs are small in grain size, tight, with an average fine sandstone content of 80.92%. Pores in the reservoirs tiny in throat, include dissolution pores, and mostly intergranular pores, original and secondary ones. Because of sedimentation, diagenesis and later tectonism, natural fractures are well-developed in the reservoirs, which improves reservoir permeability on one hand, but adds difficulty to waterflooding development on the other hand.

To date, researchers have done a lot of studies on distribution and evolution of structural stress field of Mesozoic and Cenozoic Ordos Basin, and tectonic fluid and thermal events affecting the Basin stress[1–10], and carried out some basic studies[11–16] on natural fracture distribution features and characterization with some parameters combined with production practice, reached some findings, but there are still some problems remained. The most popular method used in quantitative predicting of natural fractures is finite element method[13,17–20], but it doesn't combine the predicted natural fracture distribution with actual production characteristics. Moreover, there is no systematic and deep study on distribution features, development differences and origins of fractures in tight oil reservoirs from the whole basin perspective.

In this paper, the similarities and differences of natural fracture distribution features in different layers (Chang4+5 in Jiyuan, Chang6_3 in Huaqing, Chang7 in Xin'anbian, and Chang8 in Xifeng-Heshui) in Ordos Basin have been examined systematically, reservoir numerical simulation inversion technology has been used to combine actual production characteristics of injection and production wells with basic feature parameters

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and plane distribution of natural fractures, and contribution of natural fractures to the single well production has been evaluated preliminarily on the basis of recognizing natural fractures deeply.

1. Well-developed natural fractures in tight reservoirs

Data of core, thin section observation and image logging of Chang4+5 in Southern Buziwan Jiyuan, Chang6_3 in Huaqing, Chang7 in Xin'anbian and Chang8 in Xifeng-Heshui show out of the observed cores from 215 wells, fractures were found in cores from 181 wells (Table 1), accouting for 84.2%; out of the 993 thin sections observed, 664 had fractures, accounting for 69.9%; out of 84 wells with image logging, 80 have found fractures, accounting for 95.2%. Core, thin section observation and image logging all show that natural fractures are well-developed in tight reservoirs.

2. Basic features of natural fractures of tight reservoirs

2.1. Types of natural fractures

Fractures in tight oil reservoirs can be divided into structural fractures and diagenetic fractures according to origin[21], i.e., structural fractures formed under the structural stress field and diagenetic fractures formed in the process of reservoir sedimentation and diagenesis. Statistical core observation of 215 wells shows 181 of which have structural fractures, accounting for 84.2% (Table 2). Natural fractures were observed in six outcrop sections, including Yanhe in Yan'an, Anjiagou in Huangling, Jinsuoguan in Tongchuan, Cedi in Pingliang, Shanshuihe in Xunyi, and Ruishuihe in Chongxin, and the study shows structural fracture is the main type in the area. Structural fractures mainly existing in sandstone, are often filled with minerals, directional, regular in distribution and vertical to fractural plane (Fig. 1).

Mainly occurring on the lithology interfaces between sandstone, diagenetic fractures are characterized by intermittence, curving, pinchout and branching etc. Mainly in the form of bedding fracture, diagenetic fractures (Fig. 2) are poor in lateral connection, often close under overlying pressure, small in aperture, and low in permeability. Therefore, near-horizontal bedding fractures have small contribution to the total permeability of the reservoirs.

Structural fractures can be subdivided into three types according to their stress direction and propagation direction. Type A natural fracture is the tensional fracture formed under the action of tensional stress perpendicular to the direction of fractural plane and propagation. Type B is the shear fracture formed by shear stress parallel to the direction of fractural plane and propagation. Type C is the tension-shear fracture formed by the joint action of shear and tensional stress. Out of the cores taken from 215 wells, structural fractures were observed in cores from 181 wells, shear fractures were found in cores from 153 wells, that is the wells with shear fractures account for 84.5% of those with structural fractures (Table 2). Structural shear fracture is the main type in different zones. The shear fractures generally appear in continuous steps (Fig. 3), characterized by obvious striation on fracture surface, fracture terrace developed by mineral filling and shear stress, or mineral filling or fibrous mineral crystals are parallel to fracture plane or grow obliquely to fracture wall even bend. The shear fractures are stable in occurrence with straight and smooth fracture planes. Few in different zones (Table 2), with coarse and rough fracture planes, the tensional fractures are often open and filled by minerals, with mineral crystals perpendicular to fracture plane growing from two sides of the fracture to the center; and the fractures often have tree-shaped branches or almond-shaped loops at the tail end.

Table 1. Natural fracture data from core, thin section observation and image logging

Area	Layer	Core observation			Thin section observation			Image logging		
		Total wells/	Fractures/ well	Ratio/ %	Total samples/	Fractures/ sample	Ratio/ %	Total wells/	Fracture/ well	Ratio/%
S. Buziwan Jiyuan	Chang 4+5	46	33	71.7	96	72	75.0	7	7	100.0
Huaqing	Chang 6_3	36	33	91.7	65	45	69.2	29	25	86.2
Xin'anbian	Chang 7	60	47	78.3	40	27	67.5	40	40	100.0
Xifeng-Heshui	Chang 8	73	68	93.2	792	550	69.4	8	8	100.0
Total		215	181	84.2	993	694	69.9	84	80	95.2

Table 2. Ratio of structural fractures

Area	Layer	Shear fracture		Tension fracture	
		Wells	Ratio/%	Wells	Ratio/%
S. Buziwan Jiyuan	Chang 4+5	30	90.9	1	3.0
Huaqing	Chang 6_3	25	75.8	6	18.2
Xin'anbian	Chang 7	43	91.5	4	8.5
Xifeng-Heshui	Chang 8	55	80.9	11	16.2
Total		153	84.5	22	12.2