PETROLEUM EXPLORATION AND DEVELOPMENT
Volume 44, Issue 6, December 2017
Online English edition of the Chinese language journal

Available online at www.sciencedirect.com
ScienceDirect

Cite this article as: PETROL. EXPLOR. DEVELOP., 2017, 44(6): 972–982.

RESEARCH PAPER

Dynamic and static comprehensive prediction method of natural fractures in fractured oil reservoirs: A case study of Triassic Chang 6_3 reservoirs in Huaqing Oilfield, Ordos Basin, NW China

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Abstract: In consideration of the limited adaptability scope, low accuracy and high demand of great cost data of existent fracture prediction methods, a new fracture predicting method was advanced by implementing geological static data and production dynamic data from the Triassic Chang 6_3 reservoirs in the Huaqing Oilfield. Five constraints, lithology, sedimentary facies, thickness, rock rupture index and fracture intensity controlling the development of fractures were sorted out based on the static geological data. The multiple linear regression method was adopted to work out the quantitative relationships between the five constraints and fracture density, and the fracture density property of the whole area was calculated. Based on production dynamic data of well history, tracer, well interference test and intake profile test, the direction and distribution of fracture horizontally and vertically were figured out by reservoir engineering analysis method. The fracture density property was verified and quantitatively corrected with numerical simulation, and a 3D discrete fracture geological model in agreement with both geological cognition and dynamic production performance was built. The numerical simulation shows that the fracture model has higher fitting consistency, high reliability and adaptability.

Key words: fractured oil reservoir; natural fracture; fracture geological model; fracture prediction; Huaqing Oilfield; Ordos Basin

Introduction

In the development of fractured reservoirs, serious water channeling will impair waterflooding efficiency, which is one of the major factors affecting development effect. As crucial channels for oil and gas flow, fractures play a vital role in the development of low and ultra-low permeability reservoirs. But determining fracture distribution pattern and predicting fracture development degree quantitatively is a tricky issue in oil and gas exploration and development[1–2]. At present, natural fracture prediction methods can be divided into three types: The first type explores the relationship between the structure and fracture based on the architectural characteristics of the structure[3–4], and is mainly used to predict the associated fractures with faults or folds, for example, main curvature method, relationship analysis between fault and fracture, etc. The second type predicts the distribution of fractures by using tectonic stress finite element simulation and rupture criterion based on the tectonic origins of fractures[5–6]; but the predicted results have some discrepancy with the actual situation due to the limitation of mathematical model. The third type predicts fractures based on high resolution seismic data[7–11] by extracting fracture-related attributes, for example, seismic coherence cube method, multi-wave seismic method, ant tracking etc. This type of method can build accurate fracture model, and is the mainstream method currently. However, because of limited seismic data available and low resolution of seismic data, as well as human factors during interpretation, it is still hard to build a fracture model reflecting the actual reservoir situation.

Because of multiple controlling factors, fractures appear in high randomness and heterogeneity. The present methods of fracture prediction are mostly based on static geological data, but the geological data is limited, low in precision and high in acquisition cost, so the fracture model obtained usually has high uncertainty and inapplicability, and can't be used to

Received date: 26 Dec. 2016; **Revised date:** 18 Sep. 2017.
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Foundation item: Supported by the China National Science and Technology Major Project (2017ZX05013-002).

guide oilfield development, it is even more so in the regions with limited seismic data or few structures. In the view of the above problems, taking Chang 6_3 reservoir of Huaqing Oilfield in Ordos Basin as an example, various geological static data and production dynamic data were used to build the fracture model of the area based on the conventional fracture modeling method by considering multiple geological factors controlling fracture development, valuable experience of oilfield development situation and mutual constraining of multiple conditions. The model conforms to both geological cognition and production performance and provides a reliable basis for adjustment of water flooding in later stage.

1. Regional geological background

1.1. Regional structural features

The Huaqing Oilfield is located in the central south of Yishaan Slope in Ordos Basin (Fig. 1), and its structural evolution is closely related to the North China plate[12]. The basin inclines to the southwest regionally, due to the difference in stress intensity, the external edge of the basin has experienced frequent tectonic activities and strong stress, resulting in numerous faults and cracks, while the interior of basin is on the contrary. The study block is inside the basin with gentle terrain and less than one degree of inclination. The study area has relatively simple structure, few faults and folds, and nose-shape uplift tectonic belt in local parts[13].

1.2. Characteristics of stress field

According to the strength and occurrence time of tectonic movements, the main tectonic stress field in the Ordos Basin can be divided into four stages: Indosinian period, Yanshan period, Himalayan period and Neotectonic period[14]. The Yanshan period was a main period of fracture formation when fractures were generated due to squeezing action of the horizontal stress. During the Himalayan period, the tectonic movement mainly caused the uplift of the strata, reforming the fractures in the Yanchang Formation[15]. By implementing stereographic projection method[16], Liu Geyun et al. found that the direction of maximum principal stress of tectonic stress field was NWW-SEE in Yanshan period, the dominant direction of maximum principal stress was between 116 and 296 degrees, and the dominant direction of minimum principal stress was between 26 and 206 degrees; while in the Himalayan period, the direction of the maximum principal stress was NE-SW, the dominant direction of maximum principal stress was between 45 and 225 degrees, and the dominant direction of minimum principal stress was between 135 and 315 degrees.

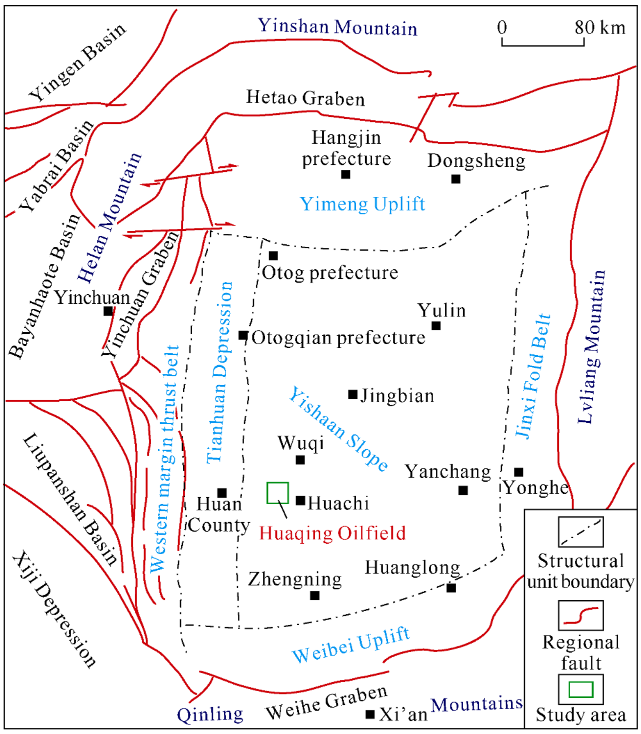

Fig. 1. Location map of Huaqing Oilfield.

1.3. Reservoir sedimentary characteristics and physical properties

The Chang 6 Member in Huaqing Oilfield can be divided into three submembers from top to bottom: Chang 6_3, Chang 6_2, and Chang 6_1. The three submembers have similar lithological composition of sandstone, siltstone and mudstone. The Chang 6_3, the main reservoir of exploration and development in Huaqing Oilfield, is dominated by sandy debris flow, accompanying with sedimentary system of gravity flow, including slide and turbidity deposits, and composed of largely silty-fine sandstone. The Chang 6_3 reservoir in the study area includes three kinds of sedimentary subfacies: sandy debris flow, turbidity and semi-deep-deep lake. For further study of the fracture development law, the sand debris flow subfacies is divided into the main body and edge according to the difference in thickness and physical properties in view of the wide distribution of sandy debris flow.

In general, the Chang 6_3 reservoir is characterized by poor sorting, strong heterogeneity, low porosity and low permeability, and wide distribution range of porosity and permeability. In the study area, the Chang 6_3 reservoir has a porosity range from 6 to 16%, on average 10.8%, an permeability range from 0.04 to 0.6×10^{-3} μm^2, on average 0.34×10^{-3} μm^2, representing ultra-low permeability reservoir.

1.4. Development features of natural fracture

Based on previous understanding[17–18], the observation of Yanhe outcrop and imaging logging data in the study area show that the dominant strikes of Chang 6_3 fractures are NEE and NE, and a few fractures are in nearly SN direction, which conform with the directions of paleostress fields when the fractures were formed.

Observation of cores from 66 wells in the study area shows that 60 wells out of them have natural fractures, and 90.9% of the cores have natural fractures. The fractures are 30 to 100 μm in aperture, on average 60 μm, representing small-micro