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Fine Analysis Renews Reservoir Understanding: Transforming Severely Waterflooded Zones into Profitable Development Areas

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ABSTRACT

Block D has maintained low-efficiency and low-rate development for more than 30 years, with an oil recovery factor of merely 8.4%. It is urgent to tap the production potential of this mature oilfield. Centered on detailed analysis of production and injection wells, this study achieves breakthroughs via refined sedimentary cognition, clarifies the distribution rules of oil-water contact, accurately characterizes faults to identify reservoir space, predicts remaining oil potential to define development directions, and finally realizes the deployment of profitable well locations. The integrated evaluation and overall edge potential tapping methodology for mature blocks proposed in this paper boasts broad application prospects, which can be extended to 14 mature oilfields including Shuguang Oilfield and Xinglongtai Oilfield.

KEYWORDS

Dual Sedimentary Provenances; Low-Resistivity Oil Layers; Reservoir-Controlling Faults; Remaining Oil Potential.

1. INTRODUCTION

Block D is a large-scale intact high-pour-point lithology-structural reservoir with abundant reserves and production, which is currently in a low-rate and high water-cut development stage. New potential growth points are urgently required. Through elaborate injection-production well analysis in the southwestern Block D, this research overturns the previous single-provenance cognition and proposes the reservoir-controlling theory of boundary faults. The study fully exploits remaining oil potential of small-scale geological bodies including minor faults, microstructures, thin reservoirs, single sand bodies and internal architectures. Severely waterflooded zones are successfully converted into profitable development areas, forming a typical demonstration block for oilfield production construction.

2. RESEARCH BACKGROUND

Block D is a typical medium-porosity and medium-permeability lithology-structural reservoir bearing high-pour-point crude oil. Its southwestern part suffers low-rate and high water-cut development with an oil recovery factor of only 8.4%, demanding urgent exploration of production potential within the mature block. Guided by the concept of "Five Inequalities", high overall water cut of the oilfield does not equal high water cut for every single well; high water cut of a production well does not mean all layers are water-bearing; high water saturation of an oil layer does not cover every position and orientation; elaborate geological research does not guarantee full recognition of all underground potential; refined development adjustment does not signify all blocks, wells and layers have been optimized.

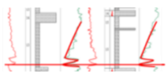
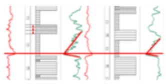
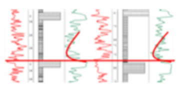
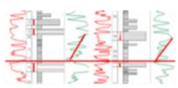
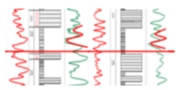
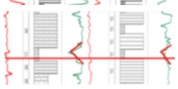
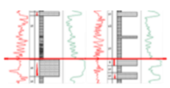
By re-examining three categories of historical data, potential intervals are newly identified inside the mature block. Well B was previously interpreted as water-bearing formation at the depth of 2467 m to 2596 m via well logging. However, core observation reveals gravel-bearing sandstone with oil-stained oil saturation, strong crude odor, yellowish-brown fluorescence under ultraviolet inspection, uniform oil distribution and semi-spherical non-permeable water droplets. It is preliminarily classified as oil layer, which opens up a new path for potential tapping in the study area.

3. APPLICATION OF INJECTION-PRODUCTION WELL ANALYSIS IN MATURE OILFIELD POTENTIAL TAPPING

3.1. Precise Fault Characterization to Tap Remaining Oil at Fault Corners

Marker beds, sedimentary cycles and electrical logging responses are combined to determine fault breakpoints. Newly processed 3D seismic data are adopted to accurately define fault geometries via breakpoint combination[1], and the reliability of boundary faults is verified with oil-water distribution data. As boundary faults serve as reservoir-controlling structures, the downthrown side is supposed to be water-bearing. Nevertheless, Well C has accumulated oil production of 12,000 tons, proving the well is located on the upthrown side of the fault. The actual fault trace shifts approximately 300 m southeastward compared with the original interpretation, expanding the planar space for well deployment in the mature oilfield — this marks the first transformation of the block's development understanding.

Table 1. Stratigraphic Correlation Markers of the Block

Marker Type	Correlation Marker	Legend	Electrical Characteristics
Standard Bed	S34I "Fish-mouth" Mudstone Member		Induction log: "fish-mouth" shape Interval transit time: micro-toothed shape
	S34II"Knife-shaped" Mudstone		Induction log: "knife" shape Interval transit time: micro-toothed shape
Marker Bed	S32"V-shaped" Mudstone and Silty Mudstone Member		Induction log: toothed "V" shape Interval transit time: serrated shape
	S33I2Ramp Mudstone and Silty Mudstone Member		Induction log: ramp toothed shape Interval transit time: serrated shape
	S33II"W-shaped" Mudstone Member		Induction log: "W" shape Interval transit time: serrated shape
	S33III "V-shaped" Mudstone		Induction log: "V" shape Interval transit time: micro-toothed shape
Auxiliary Marker Bed	Basal Mudstone and Silty Mudstone Member of S31		Induction log: micro-toothed high-amplitude induction Interval transit time: low-amplitude toothed shape

The well deployment concept shifts from avoiding faults to utilizing fault barriers. Given the gentle dip angle of the southwestern boundary fault, dual-target high-angle deviated well trajectories are designed to maximize remaining oil extraction at fault corners; the safe well-fault distance is reduced from the conventional 70 m to 30 m. After new wells are put into operation, the oil layer penetration rate rises by 23%.

3.2. Innovative Sedimentary Cognition to Unlock Lithologic Reservoir Potential

Core samples contain abundant unstable potassium feldspar, mixed sand-mud lithology with poor sorting, low ZTR index and high proportion of coarse-grained components, indicating near-source sedimentary features with low compositional and textural maturity.

The sedimentary characteristics match regional paleogeography, breaking the previous cognition of a single northeast provenance and proposing a new southeast secondary provenance — this forms the second major transformation of the block. The study area sits at the sedimentary convergence zone of two provenances[2].

Restricted by the sedimentary model of fan delta front subfacies, lithologic reservoirs dominated by single sand bodies are widely developed in this area. Updip pinch-out remaining oil is identified: crude oil accumulates at the updip termination of oil-bearing sand bodies where water injection cannot sweep the formation. Optimized well trajectories are designed to fully exploit remaining oil in lithologic traps.

3.3. Reconstructed Oil-Water Identification Charts to Tap Low-Resistivity Reservoir Potential

Based on the re-evaluation of the originally interpreted water layer in Well B, the four-property relationship research is carried out combining formation test and production data to define the lower limit of effective oil layer thickness. The standard lower limit of oil saturation is oil-stained grade, and the lithology cutoff is fine sandstone. Analysis of core physical properties defines the physical property thresholds for the Third Shahejie Formation: porosity ≥10% and permeability ≥30 mD with oil-stained saturation as the minimum standard.

Cross plots of deep lateral resistivity versus acoustic transit time are generated using formation test data, showing distinct electrical differences between oil layers and water layers. Controlled by dual sedimentary provenances, northern and southern sub-blocks present varied reservoir electrical thresholds: the northern area requires acoustic transit time $\geq 250\times10^{-3}$ μm² and resistivity ≥22 Ω·m, while the southern area requires acoustic transit time $\geq 245\times10^{-3}$ μm² and resistivity ≥16 Ω·m.

The conventionally recognized edge-water flooded zones are redefined as favorable well deployment targets — this completes the third transformation of reservoir cognition. Later drilled deep test wells discover a set of concealed low-resistivity oil layers in S34II interval[3], with resistivity ranging from 16 Ω·m to 24 Ω·m, close to water layer resistivity and much lower than conventional upper oil layers. A total of 14.5 m pay zones across 7 sublayers are perforated, yielding 9.1 tons of crude oil per day with cumulative production of 368.97 tons to date. This discovery extends the oil production depth limit of Block D downward by 170 m, further expanding vertical well deployment space in the mature oilfield.

4. CONCLUSION

Field practices demonstrate that dynamic injection-production well analysis lays the foundation for refined reservoir characterization and reservoir management improvement. Starting from single-well evaluation, guided by the philosophy of "Mature blocks still hold potentials, small zones still contain reserves", large-scale integrated mapping of hydrocarbon-rich belts is conducted to realize cognitive breakthroughs, technological innovations and potential expansion, strongly supporting the construction of millions-of-ton annual new production capacity for the oilfield.

The integrated evaluation and overall edge potential tapping framework for mature blocks possesses wide application prospects. Subsequent research will focus on reserve expansion and production construction at the junction of Jing'anpu and Qianjin structural belts. This methodology can also expand production capacity development in five hydrocarbon-rich belts including Huanshu and Xinglongtai, continuously injecting new momentum into reserve growth and production construction of mature oilfields.

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