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Research and Application Analysis of Single Sandbody Characterization Technology

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Abstract

As a critical field in geological studies, single sandbody characterization plays a vital role in oil and gas exploration and development. Detailed characterization of single sandbodies enables an in-depth understanding of reservoir internal structures, fluid distribution, and remaining oil potential, providing scientific foundations for mid-to-late-stage oilfield development strategies. This paper reviews recent advancements and applications of single sandbody characterization technologies, including sedimentary microfacies analysis, well log correlation, and geological modeling. The practical effectiveness and challenges of these methods in oilfield development are discussed. Through comprehensive analysis, this study aims to provide references for the further development and application of single sandbody characterization technologies.

Keywords

Single Sandbody Characterization; Sedimentary Microfacies; Well Log Correlation; Geological Modeling; Oilfield Development.

1. Introduction

Single sandbodies, as fundamental units of reservoirs, are central to refined hydrocarbon reservoir development. Quantitative characterization of their geometry, stacking patterns, and heterogeneity provides essential geological insights for optimizing oilfield development plans. As hydrocarbon fields transition into mid-to-late development stages, precise delineation of single sandbodies has become pivotal for addressing uneven remaining oil distribution and enhancing recovery rates. Recent demands for exploiting low-permeability, tight sandstone reservoirs, and residual oil in mature fields have driven the evolution of single sandbody characterization from macroscopic reservoir descriptions to microscopic architectural analyses. These advancements integrate geology, geophysics, and dynamic monitoring, yielding significant achievements.

2. Recent Advances in Single Sandbody Characterization Technologies

2.1. Multi-source Data Integration and Dynamic Analysis

2.1.1. Dense Well Network and Tracer-assisted Modeling

Sun et al. (2024) constructed a 3D architectural model of shallow-water delta single sandbodies in the Shengtuo Oilfield (Dongying Sag) using dense well network data combined with interwell tracer tracking, significantly improving resolution and revealing lateral migration patterns of distributary channels [1]. Cao (2023) proposed a "dynamic production data-constrained + electrofacies analysis" method for channel sandbody characterization in the Daqing Placanticline periphery, demonstrating enhanced accuracy in boundary identification through injector-producer response inversion[2].

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2.1.2. High-resolution Sequence Stratigraphy

In the Quling Block of Tuha Oilfield, base-level cycle analysis identified cyclic boundaries at multiple scales, establishing a genetic stratigraphic framework for single sandbodies. This approach clarified vertical connectivity and provided insights into remaining oil distribution.

2.2. Sedimentary Architecture Analysis

2.2.1. Fluvial Sandbody Patterns

Li et al. (2023) identified braided river sandbody boundaries using core facies markers and well log morphologies (e.g., box-bell combinations), revealing remaining oil enrichment in isolated sandbody flanks . Su (2023) quantified braided river sandbody spatial characteristics using fractal theory, improving modeling efficiency through seismic attribute integration [3].

2.2.2. Delta and Fan-delta Architectures

For shallow-water delta fronts, Li et al. (2023) developed criteria for refined sandbody characterization, achieving precise thickness estimation[4].Ma et al. (2024) proposed a model for fan-delta fronts in the Nanpu Sag, demonstrating the influence of lateral accretion angles on sandbody stacking patterns and their implications for horizontal well trajectories [5].

2.3. Intelligent Modeling and Numerical Simulation

2.3.1. Machine Learning-assisted Prediction

Yang (2023) applied convolutional neural networks (CNNs) to predict single sandbody distribution in the Hujianshan area (Ordos Basin), significantly reducing prediction errors through seismic attribute analysis[6].

2.3.2. 3D Geological Modeling Optimization

Wang (2023) employed sequential indicator simulation (SISIM) with seismic attributes and microfacies data, enhancing porosity prediction accuracy [7].

3. Methodologies for Single Sandbody Characterization

3.1. Geological Methods

3.1.1. Core Observation and Analysis

Core data provide direct evidence for single sandbody studies. Detailed lithological, sedimentary structure, and grain size analyses enable boundary identification. For example, in Yuancheng’s Fuxian Formation, core observations revealed depositional microfacies and sandbody architecture (Fig.1).

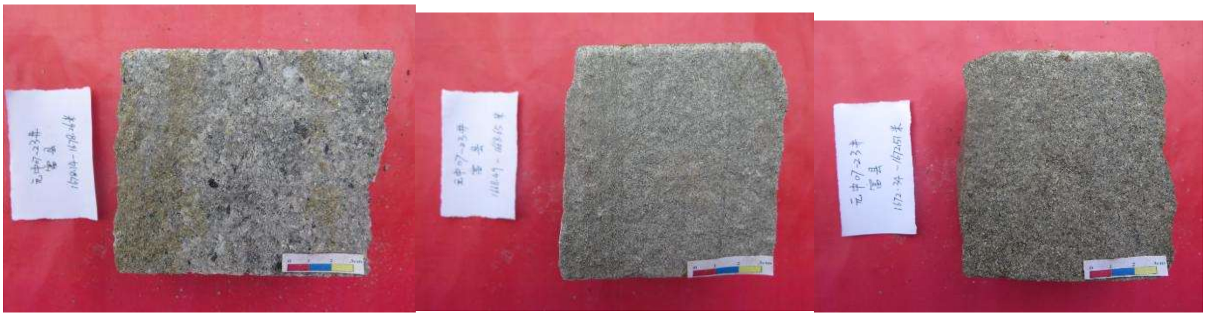

Fig. 1 Core Photograph of the Oil-bearing Interval in Fuxian Formation, Yuancheng Area

3.1.2. Well Log Analysis

Well log curves (spontaneous potential, resistivity, acoustic) enable continuous stratigraphic interpretation. In Hujianshan’s Chang 4+5 reservoir, log morphology and cross-plots differentiated sandbody types and established electrofacies models (Figure 2).

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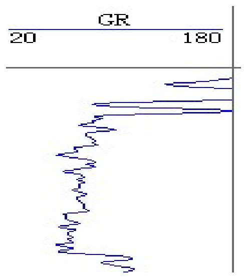
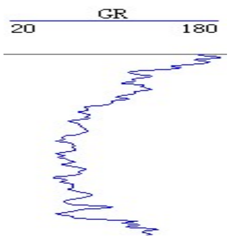
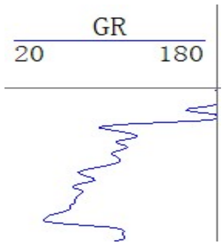
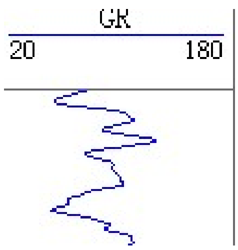
Table 1. Classification of Log Curve Morphology and Single Sandbody Identification

Sandbody Structure Type	Log Curve Morphology	Vertical Sequence	Thickness Characteristics
Composite Box Shape		Normal Rhythm or Composite Normal Rhythm	>10m
Toothed Bell Shape		Normal Rhythm	>8m
Isolated Box Shape		Normal Rhythm	2m < Thickness <5m
Isolated Finger-like Shape		No Obvious Rhythm Characteristics	<2m

3.1.3. Sedimentary Microfacies Analysis

Integration of regional depositional settings, provenance, and seismic data reconstructs microfacies. In L158 Block (Huanjiang Oilfield), microfacies analysis clarified sandbody stacking patterns and remaining oil distribution (Table 1).

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Table 2. Table of Lithological Characteristics, Log Responses and Typical Sedimentary Structures of Sedimentary Microfacies

Lithological Characteristics	Log Response (Spontaneous Potential/Resistivity)	Typical Sedimentary Structures
Medium-fine sandstone, containing mud gravel, moderate sorting	High-amplitude box-shaped/bell-shaped curves, obvious serration	Large-scale cross-bedding, scouring surface, parallel bedding
Dominated by fine sandstone, good sorting, low shale content	Funnel-shaped curves, abrupt contact at the bottom	Parallel bedding, wave ripples, small-scale cross-bedding
Mudstone interbedded with thin-bedded siltstone, containing carbonaceous materials or plant debris	Low-amplitude straight curves, occasional small peaks	Horizontal bedding, plant root fossils, homogeneous massive structure
Silt-fine sandstone, relatively good sorting	Medium-low amplitude bell-shaped/funnel-shaped curves, moderate amplitude	Small-scale cross-bedding, climbing ripple bedding
Siltstone, stable lateral distribution	Low-amplitude finger-like curves, straight baseline	Horizontal bedding, bioturbation structures

3.2. Geophysical Methods

3.2.1. Seismic Inversion

Impedance inversion delineates sandbody geometry. Pre-stack inversion in Pearl River Mouth Basin's E Oilfield improved lithological parameter accuracy.

3.2.2. 3D Seismic Attribute Analysis

Amplitude, frequency, and coherence attributes identified sandbody boundaries in Yan'an Gas Field's X Block.

3.3. Dynamic Monitoring

3.3.1. Interwell Tracer Monitoring

Tracer data in Shengtuo Oilfield revealed sandbody connectivity and informed waterflood optimization [1].

3.3.2. Production Data Analysis

Dynamic data (production rates, pressure) in Jiyuan's G83 Reservoir identified underutilized sandbodies for infill drilling[8].

4. Application Cases

4.1. Oilfield Development

In Ansai's Heishanliang Block, integrated characterization optimized well patterns and enhanced recovery[9]. Precision fracturing in low-permeability reservoirs achieved efficient sandbody development.

4.2. Geological Research

Wujiaoxi's Chang 6 study (Ordos Basin) advanced understanding of sandbody stacking heterogeneity, offering insights for rift-basin reservoirs[10].

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5. Challenges and Future Directions

5.1. Challenges

Limitations include low seismic resolution in deep reservoirs, subtle petrophysical contrasts in thin beds, and insufficient multi-disciplinary data integration.

5.2. Solutions

Strengthen fundamental geological research.Optimize well log interpretation.Develop high-precision modeling with geostatistics and machine learning.Enhance multi-disciplinary collaboration.

5.3. Future Perspectives

5.3.1. Technology Integration:

Combine seismic dispersion attributes, microseismic monitoring, and dynamic data.

5.3.2. Geomechanical Integration:

Develop coupled "architecture-stress-fracture" models for hydraulic fracturing.

5.3.3. Heterogeneity Quantification:

Apply digital rock physics (CT scanning, pore-network modeling) to characterize permeability anisotropy.

6. Conclusion

Single sandbody characterization has evolved from qualitative descriptions to quantitative models, significantly improving recovery rates. Future advancements in multi-disciplinary integration and intelligent technologies will bridge "static geometry" and "dynamic flow regulation," supporting unconventional resource development.

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