Open Journal of Applied Sciences, 2023, 13, 813-822
https://www.scirp.org/journal/ojapps
ISSN Online: 2165-3925
ISSN Print: 2165-3917

Study on Quantitative Prediction Method of Interlayer Based on Seismic Waveform

Jianmin Zhang, Xijie Wang, Pengfei Mu, Liande Zhou, Yuanpeng Jiang

Bohai Oilfield Research Institute, Tianjin Branch of CNOOC Ltd., Tianjin, China
Email: 75657043@qq.com

How to cite this paper: Zhang, J.M., Wang, X.J., Mu, P.F., Zhou, L.D. and Jiang, Y.P. (2023) Study on Quantitative Prediction Method of Interlayer Based on Seismic Waveform. *Open Journal of Applied Sciences*, **13**, 813-822.
https://doi.org/10.4236/ojapps.2023.136065

Received: March 30, 2023
Accepted: June 11, 2023
Published: June 14, 2023

Abstract

Taking the fluvial reservoir of the Neogene Minghuazhen Formation in Bozhong S oilfield in China as an example, a detailed study of the interlayer in the reservoir was conducted. From the perspective of sedimentary genesis of the interlayer, three types of genesis of the interlayer are summarized and analyzed, namely, fine grain sediment in the inter peak channel, suspended sediment in the post flood channel, and abandoned channel sediment. At the same time, combined with seismic waveform analysis, the distribution characteristics and morphology of the interlayer in complex fluvial facies oilfield are carefully depicted, and the horizontal well optimization implementation is guided based on the planar and three-dimensional spatial distribution characteristics of the interlayer. This method enriches the characterization technology of interlayer in offshore oilfields, and has important guiding significance for the overall evaluation and development research of complex fluvial facies oilfields.

Keywords

Fluvial Facies, Interlayer, Genetic Analysis, Seismic Waveform

1. Introduction

The interlayer is a non-permeable barrier layer developed within the reservoir, with significant differences in physical properties from the reservoir, and has a significant impact on fluid during oilfield development [1]. The interlayer of fluvial facies reservoir can be divided into two major categories from the perspective of genesis: interlayer formed by sedimentation and interlayer formed by diagenesis [2] [3]. The distribution of interlayer within the range of injection production well group has a significant impact on oil water movement and final recovery factor [4]. Interlayer research is a crucial basic work in the process of oilfield development, because the distribution of interlayer at different levels determines the division and spatial connectivity of oil formations or reservoirs [5] [6], and has a direct impact on the work at various stages of oilfield evaluation, design, and implementation [7]. If we cannot scientifically evaluate and establish a three-dimensional distribution geological model of the interlayer, we cannot reasonably conduct research work such as horizontal well deployment, program implementation, and perforation [8]. On the basis of a clear understanding of single sand body, the main work is aimed to conduct vertical and planar distribution rules of the interlayer within the single sand body, in other words, to conduct research on the distribution of sedimentary microfacies and heterogeneity of interlayer at different levels [9], thus determining the identification method of interlayer, establishing a quantitative geological knowledge base and three-dimensional geological model of interlayer, clarifying its macroscopic distribution rules [10], and preparing a perforation plan for horizontal well implementation to provide reliable geological basis for development effect evaluation [11] [12].

Bozhong S oilfield is located in the central structural ridge of the Huanghekou depression in the Bohai Bay, with good conditions for oil and gas accumulation and accumulation (**Figure 1**). The main oil bearing horizon is fluvial facies deposits of the Neogene Minghuazhen Formation. From the actual drilling information of development wells, the main sand body interlayer in the oilfield is relatively developed, and affects the productivity of development wells and oilfield adjustment. Taking the A sand body in S oilfield as an example, this paper quantitatively predicts and analyzes the distribution and spatial distribution characteristics of the interlayer based on identifying the interlayer using well point data and combining seismic waveform information from seismic data.

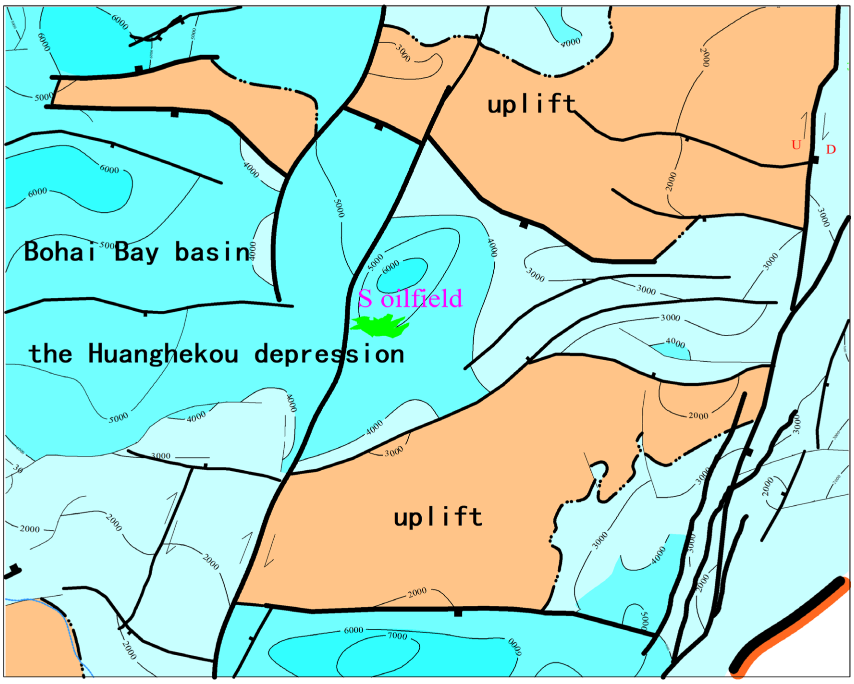

Figure 1. The regional location of S oilfield.

2. Genetic Analysis of Interlayer

The distribution of interlayer in Bozhong S Oilfield is mainly controlled by sedimentary microfacies, and the main genetic types of interlayer formation are the lateral accumulation layer of meandering river point bar microfacies, overbank sedimentation, underwater distributary channel inter channel, suspension sedimentation in flood channel after flood, and fine grain sedimentation in flood peak inter channel.

2.1. Fine Sediment in the Inter Peak Channel

The fine grain deposition in the inter flood peak channel is the difference in particle size, sorting, and reservoir physical properties caused by the differences in climate, provenance, and sand transportation in underwater distributary channels, generally forming a physical property interlayer vertically (**Figure 2**).

2.2. Suspended Sediment in Channel Sand

There are two main causes of suspended sediment in channel sand in Bozhong S Oilfield. One is the lateral mudstone within the point dam, which generally intersects the bedding plane and is arranged in an imbricate shape, tending to point towards the abandoned channel. The lateral accretion interlayer plays a certain role in shielding fluid migration within the point dam, resulting in enhanced heterogeneity of the point dam sand body. The other is the sediment formed by suspended load after the flood peak of meandering river channels and underwater distributary channels, mainly composed of argillaceous and silty sands, with unstable distribution, and the interlayer type is mostly argillaceous interlayer (**Figure 3**).

2.3. Abandoned Channel Sedimentation

For underground reservoirs, both the abandoned and end-stage meandering river channels will eventually be abandoned, and their interiors will be filled with low-permeability mudstone, silty mudstone, or argillaceous siltstone, forming physical and muddy intercalations that are laterally shielded, resulting in weak or disconnected connections between points and dams on both sides of the abandoned river channel and between underwater distributary channels (**Figure 4**).

3. Methods and Results

The ultimate goal of describing the interlayer is to reflect its distribution characteristics, thereby studying the impact of the interlayer on reservoir heterogeneity and development effectiveness. When the interlayer in the reservoir is relatively developed, there will be differences in the waveform, amplitude, frequency, and phase characteristics of seismic reflection waves, which will cause corresponding changes in seismic attributes. It can be seen that some seismic attributes are closely related to the interlayer, which can indirectly reflect the development degree of the interlayer, and can serve as an important basis for quantitative prediction of the interlayer.

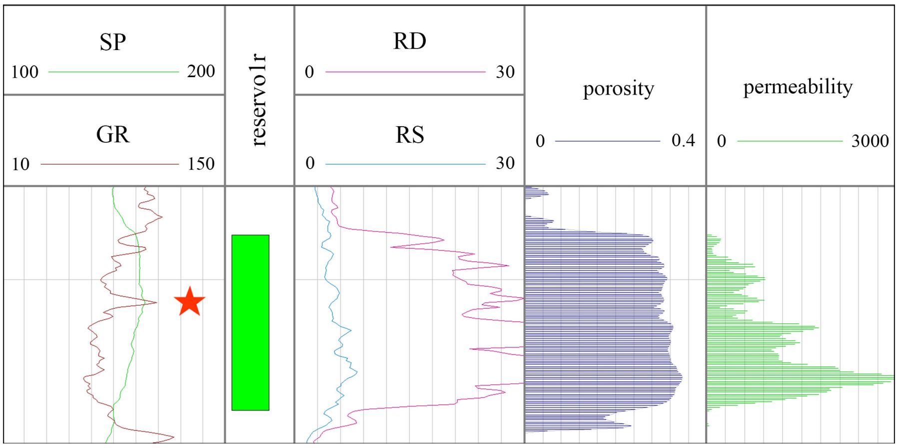

Figure 2. Fine sediment in the inter peak channel.

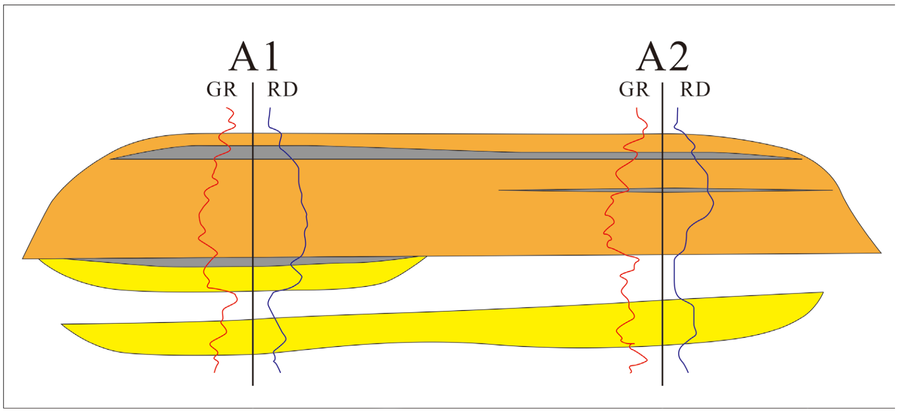

Figure 3. Suspended sediment profile in underwater diversion channel after flood.

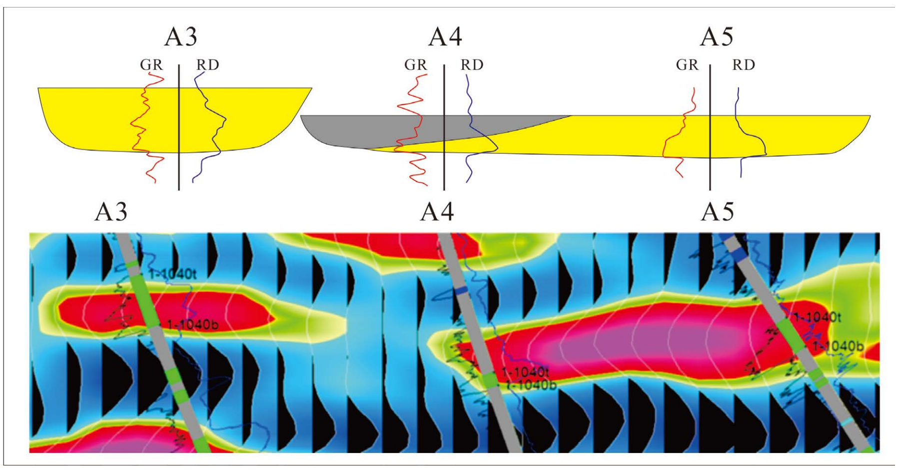

Figure 4. Sedimentary profile of abandoned river channel.

The presence or absence of interlayer development features can be identified from the reflection characteristics of seismic waveforms. For reservoir sand bodies without interlayer development, when the formation thickness is greater than the wavelength, the top and bottom reflection energy can be clearly separated, and the formation thickness can be determined based on the time difference between the two sets of reflection; When the thickness of the formation approaches 1/2 wavelength, the reflected wave has obvious interference, presenting a composite waveform; When the thickness approaches 1/4 - 1/8 wavelength, the waveform becomes simple, similar to the single wave form. When the interlayer is developed in the reservoir sand body, the seismic reflection characteristics change, which is related to the combination characteristics such as the development degree, interlayer thickness, and distribution density of the interlayer in the reservoir. When there are interlayer development in the reservoir, it often causes the seismic reflection waveform to become "fat" or complex. From the perspective of frequency response, it is frequency reduction. Through comprehensive analysis, it is believed that the combination characteristics of the interlayer in the reservoir and their corresponding seismic response characteristics can be divided into six types (**Figure 5**):

1) The thickness of the interlayer is between 1/4 - 1/8 wavelength, and the interlayer is located in the middle and upper part of the reservoir. The waveform becomes "fat", presenting an asymmetric single wave shape that is gentle upward and steep downward.

2) The thickness of the interlayer is between 1/4 - 1/8 wavelength, and the interlayer is located at the lower part of the reservoir. The waveform becomes "fat", presenting an asymmetric single wave shape with a gentle downward slope and a steep upward slope.

3) The thickness of the interlayer is between 1/4 - 1/8 wavelength, and the interlayer is distributed in the upper and lower parts of the reservoir, with a waveform similar to a box shaped complex wave shape.

4) The thickness of the reservoir is relatively large, with interlayer development, and the waveform is similar to box shaped complex wave shape.

5) The thickness of the interlayer is large, and the waveform appears as a separable complex wave shape.

6) Multiple interlayer with relatively large thickness, randomly distributed in the reservoir, with irregular complex wave shape.

Macroscopic control, microscopic analysis, and drilling calibration adjustment techniques are used to characterize the interlayer. Macro control is based on the seismic frequency attribute to divide the low frequency and normal frequency as well as the high frequency distribution range on the plane. Generally speaking, the low frequency distribution area is the main distribution range of the interlayer; Micro analysis refers to taking the frequency distribution zone as the macro control, analyzing the characteristics of seismic waveform through the seismic profile displayed by waveform, and determining the distribution range of different waveform feature categories; Drilling calibration adjustment refers to locally adjusting the well seismic inconsistency within the determined distribution range of different waveform characteristic categories based on the reservoir interlayer conditions revealed by drilling, so as to effectively and accurately reflect the distribution law of the interlayer.

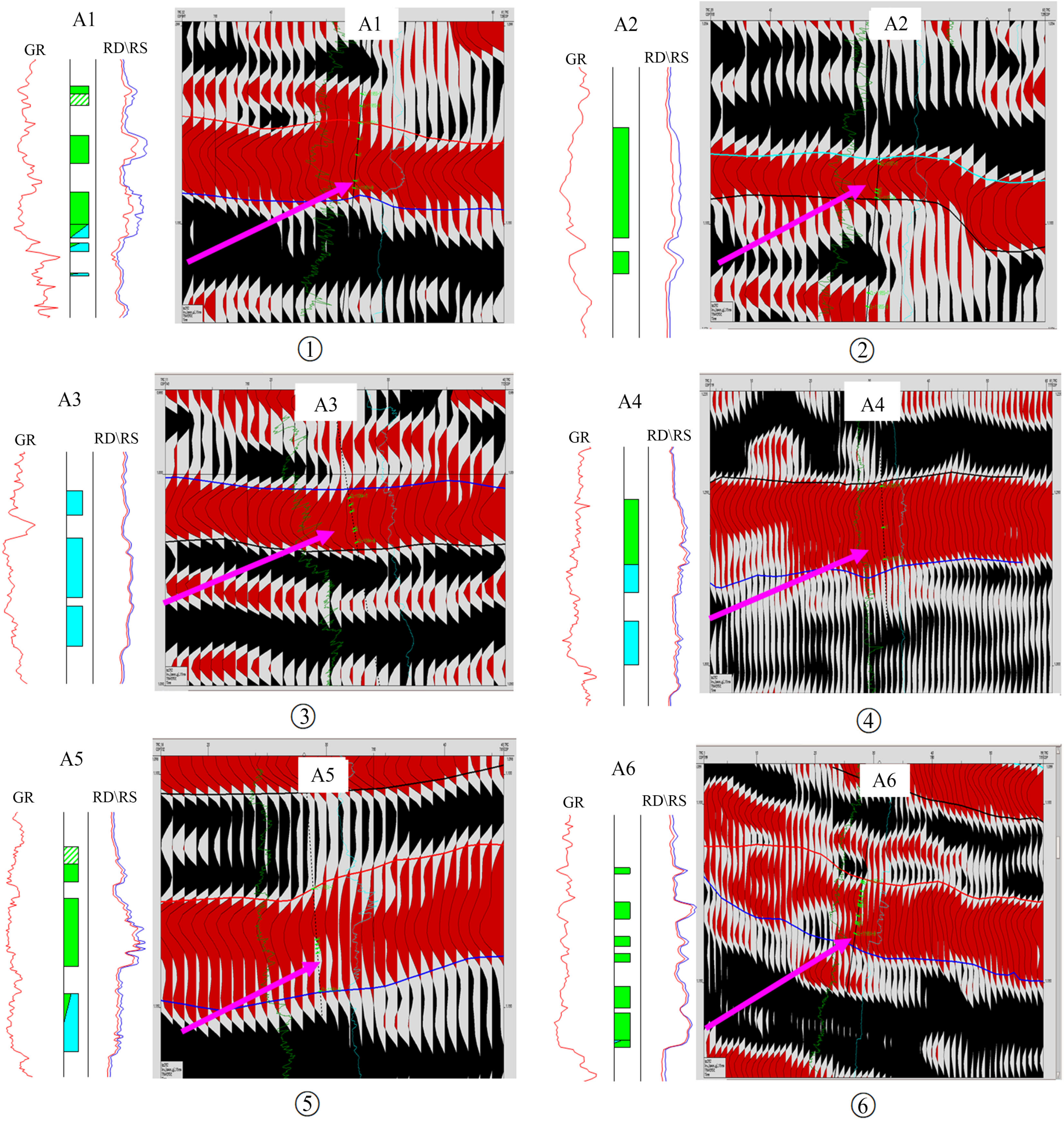

Figure 5. Development characteristics of interlayer in reservoir and corresponding seismic response characteristics.

4. Research Results

Based on the statistical analysis of the interlayer types and seismic waveform characteristics of A sand body encountered during drilling, it can be concluded that the symmetric single wave is a seismic response without interlayer. The lower gentle and upper steep single wave is the seismic response of the lower interlayer development. The upper gentle and lower steep single wave is the seismic response of the upper interlayer development. The quasi separated complex waves are mostly seismic responses with larger interlayer thickness. The seismic response of the near box shaped complex wave is relatively complex, which reflects a large reservoir thickness (about 20 m in thickness) and a development of interlayer in the upper middle or middle lower part.

As can be seen from **Figure 6**, the seismic waveform of sand body A can be divided into five types, namely, symmetrical single wave, downwardly gentle and upwardly steep single wave, upwardly gentle and downwardly steep single wave, near-box complex wave, and quasi separated complex wave. In order to quantitatively characterize the development degree of the interlayer, the ratio of the total thickness of the interlayer in the target interval to the total thickness of the reservoir is defined as the interlayer density. Through intersection analysis, the instantaneous frequency attribute that has the best correlation with the interlayer density is found and the quantitative relationship between the two is established (**Figure 7**). Then, under the constraint of this seismic attribute, the interlayer density contour map of the A sand body is obtained (**Figure 8**).

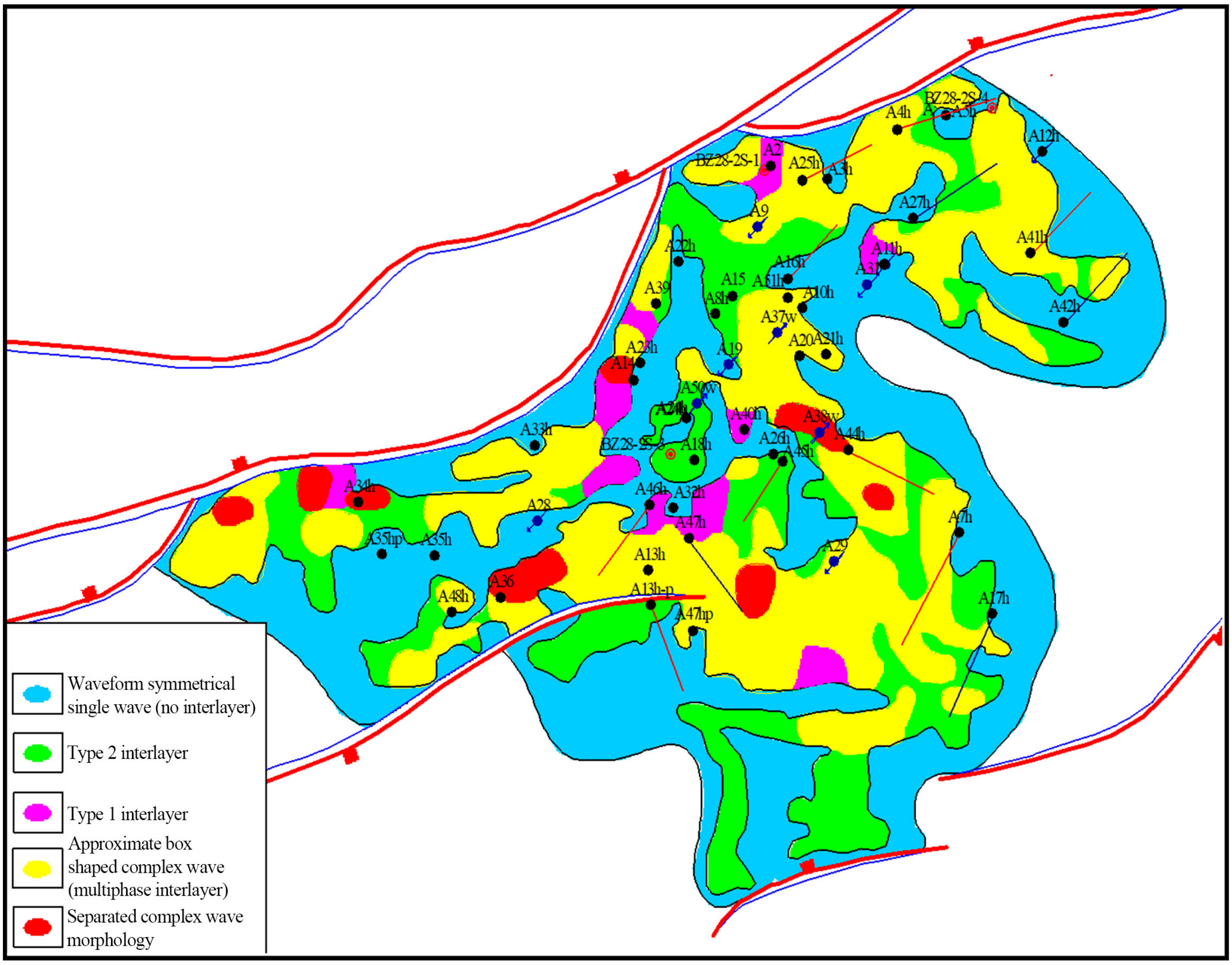

Figure 6. Seismic waveform type distribution of sand body A.

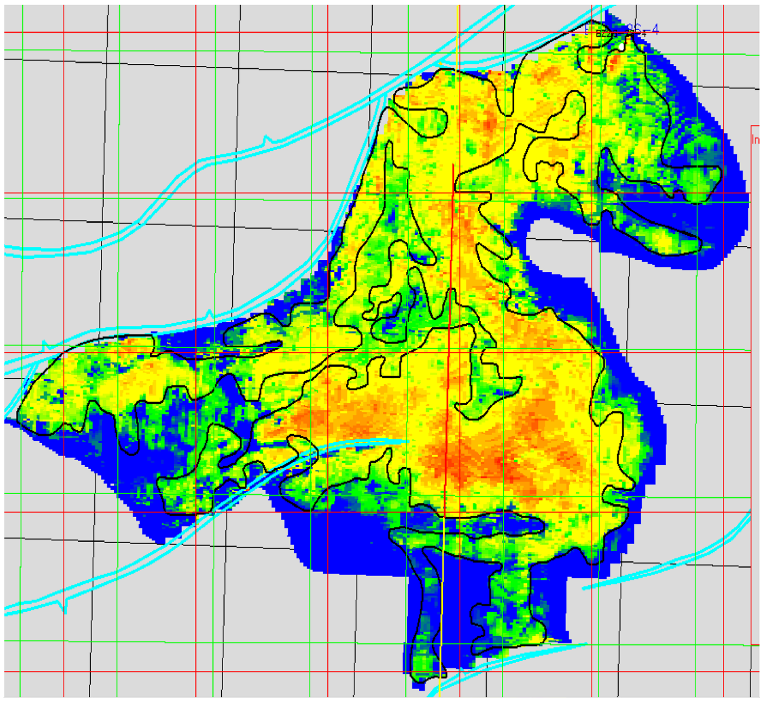

Figure 7. Instantaneous frequency attribute of sand body A.

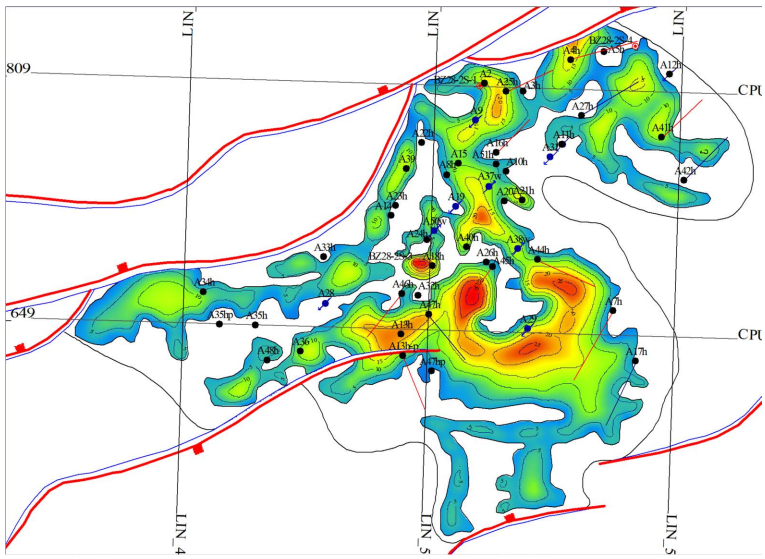

Figure 8. Density contour of sand body interlayer A.

5. Conclusions

1) From the perspective of sedimentary genesis of the interlayer, three types of interlayer genesis are summarized and analyzed, including fine grain deposition in the inter flood peak channel, suspended deposition in the post flood channel, and abandoned river channel deposition.

2) The characteristics of seismic waveform changes during the development of interlayer in reservoir sand bodies are summarized, mainly reflected in the changes in complex wave morphology caused by the vertical development position of the

interlayer; At the same time, the instantaneous frequency attribute that has the best correlation with the density of the interlayer is found through intersection analysis, and the quantitative relationship between the two is established, and the contour map of the density of the interlayer is obtained; Finally, combined with waveform characteristics and interlayer density, quantitative characterization of interlayer was achieved. This research technology mainly relies on seismic data and has certain requirements for the resolution and signal-to-noise ratio of seismic data.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Geehan, G.W. (1986) Geologic Prediction of Shale Continuity Prudhoe Bay Field. In: Lake, L.W. and Carroll Jr., H.B., Eds., *Reservoir Characterization*, Academic Press Inc., Cambridge, 162-168. https://doi.org/10.1016/B978-0-12-434065-7.50009-5

[2] Lv, X.G., Ma, F.S. and Tian, D.H. (1994) A Study of Lithology, Petrophysical of Barriers and Their Distribution Properties. *Petroleum Exploration and Development*, **21**, 80-87.

[3] He, X.X. (2012) Identification on Interbedded Layers among Donghe Sandstones in Hadexun District with Well Logging Data. *Offshore Oil*, **32**, 70-74.

[4] Bridge, J.S. and Tye, R.S. (2000) Interpreting the Dimensions of Ancient Fluvial Channel Bars, Channels, and Channel Belts from Wireline-Logs and Cores. *AAPG Bulletin*, **84**, 1205-1228. https://doi.org/10.1306/A9673C84-1738-11D7-8645000102C1865D

[5] Kelly, S. (2006) Scaling and Hierarchy in Braided Rivers and Their Deposits: Examples and Implications for Reservoir Modelling. In: Smith, G.H.S., Best, J.L., Bristow, C.S., *et al.*, Eds., *Braided Rivers*: *Process*, *Deposits*, *Ecology and Management*, International Association of Sedimentologists, Oxford, 75-106. https://doi.org/10.1002/9781444304374.ch4

[6] Wang, Y., Liu, J. and Wang, J.G. (2015) Major Controlling Factors for the Formation of Inter-Layer of Donghe Sandstone of Donghe1 Reservoir in Tarim Basin and Its Fluid Source. *Acta Petrolei Sinica*, **36**, 174-181.

[7] Feng, X., Meng, P. and Guo, J.M. (2020) Prediction Method of Thin Mudstone-Conglomerate Interlayer in Braided River with Sparse Well Pattern in Offshore Oilfield. *China Offshore Oil and Gas*, **32**, 95-102.

[8] Ma, C.L. (2018) Interlayer Identification in Ultra-Thick Heavy Oil Reservoir. *Special Oil & Gas Reservoirs*, **25**, 111-115.

[9] Yu, Y.C., Xu, H.M. and Wang, C. (2017) Dynamic-Static Integrated Prediction Method of Interlayer Distribution in Bottom Water Reservoir—A Case Study of Southeast Region in Hadeson Oilfield. *Geological Review*, **63**, 109-110.

[10] Li, W.L., Xu, H.M. and Wang, C. (2016) Spatial Distribution Prediction of Interlayers Based on Dynamic Evaluation: A Case of Donghe Sandstone in Donghetang Oil Field, Tarim Basin. *Journal of Northwest University* (*Natural Science Edition*), **46**, 877-886.

[11] Huang, S.J., Song, Q.L. and Cheng, L.S. (2018) Study on Interlayer Parameters of Bottom Water Heavy Oil Reservoir under Single-Well Condition. *Journal of Southwest Petroleum University* (*Science & Technology Edition*), **40**, 130-140.

[12] Best, J.L., Ashworth, P.J., Bristow, C.S., *et al*. (2003) Three-Dimensional Sedimentary Architecture of a Large, Mid-Channel Sand Braid Bar, Jamuna River, Bangladesh. *Journal of Sedimentary Research*, **73**, 516-530.
https://doi.org/10.1306/010603730516