Prediction of Sedimentary Reservoir in Dayangshu Basin

Jin-xin Han(✉)

Exploration and Development Research Institute of Daqing Oilfield, Daqing, Heilongjiang, China
810507545@qq.com

Abstract. Dayangshu basin is a volcanic rock covered basin from late Jurassic to early Cretaceous. Sedimentary rock reservoirs and volcanic rock strata are overlapped. Traditional sparse pulse inversion and geostatistical inversion methods are difficult to distinguish between volcanic rocks and sedimentary rocks. For this reason, firstly, analyze the physical characteristics of the sedimentary rock reservoir in the region through the actual drilling core data and experimental analysis, and study the matching relationship between lithology, logging and seismic facies by combining with seismic and logging data; Then use waveform indication inversion to realize high-resolution reservoir prediction. This method uses vertical well data and horizontal seismic waveform changes to characterize the spatial variability of the reservoir, and selects sensitive curves that can reflect lithology to participate in simulation, which improves the accuracy of reservoir prediction. The inversion results show that the superimposition relationship between sedimentary rock and volcanic rock is clear, the prediction of sedimentary rock is consistent with the actual drilling data, and the post test well coincidence rate is high.

Keywords: Volcanic Rock Cover · Sensitive Curve · Waveform Indication Inversion · Reservoir Prediction

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1 Introduction

The study area is located in Dayangshu Basin, where the oil and gas show of sedimentary rock reservoir of Jiufengshan Formation is very active. Well YC1 obtained low production oil flow, and well Y3 completed in 2018 obtained industrial oil flow, showing good oil and gas exploration prospects in Dayangshu Basin. Because of the interactive distribution of sedimentary rocks and volcanic rocks in the basin, it is difficult to identify them by conventional inversion methods, so it is urgent to find an effective method to identify sedimentary rocks and volcanic rocks to solve this problem. In this study, waveform indicator simulation method is used to better distinguish sedimentary rock and volcanic rock, determine the distribution of sedimentary rock reservoirs, and provide support for oil and gas exploration.

2 Regional Overview

Dayangshu basin belongs to Inner Mongolia Xing'anling fold system in regional structure. It is located in the south of Xing'anling fold belt and is a NNE trending fault basin. Dayangshu basin is the product of the combined action of mantle hot spot and sinistral stress field, and the late fault activity caused a large range of volcanic eruption. Based on the analysis of strata, structures and magmatic activities in Dayangshu basin and its surrounding areas, Dayangshu basin is a late Jurassic rift basin developed on the basis of pre late Jurassic folds [1]. The developed strata include Longjiang formation, Jiufengshan formation and Ganhe formation. The Nanping formation of Middle Jurassic developed under the Longjiang formation in the surrounding area is a pre rift Intermountain basin deposit. According to the characteristics of strata, structure and magmatic activity, the geological development history of Dayangshu rift basin can be divided into: (1) the stage of strong volcanic eruption accompanied by rapid accumulation of coarse clasts in the early stage of fault depression; (2) In the middle stage of fault depression, the volcanic eruption is weak and the sedimentary stage is stable; (3) In the late stage of fault depression, the volcano erupted strongly; (4) The whole uplift and denudation stage after fault depression. There were two strong volcanic activities before and after the stable deposition of Jiufengshan formation [2]. The tight volcanic rocks of Longjiang formation and Ganhe formation were developed as caprocks, and only a small part of oil and gas entered the upper and lower caprocks through fractures, mainly generated and stored in Jiufengshan formation. Jiufengshan formation is distributed in the whole basin, which is a set of volcanic clastic rock, intermediate basic lava and sedimentary rock interbedding [3]. In the southern depression, the maximum stratum thickness of Jiufengshan formation can reach more than 800 m. The taipingchuan and yulintun sub depressions in the central depression are thicker, generally 400–800 m thick, and the Liuhe sub depression is generally 100–400 m thick [4]. It is in conformity or pseudoconformity contact with the underlying Longjiang formation. Jiufengshan formation is divided into five members according to the interbedding of volcanic rocks and sedimentary rocks, in which three sets of sedimentary rocks are intercalated with two sets of volcanic rocks (see Fig. 1).

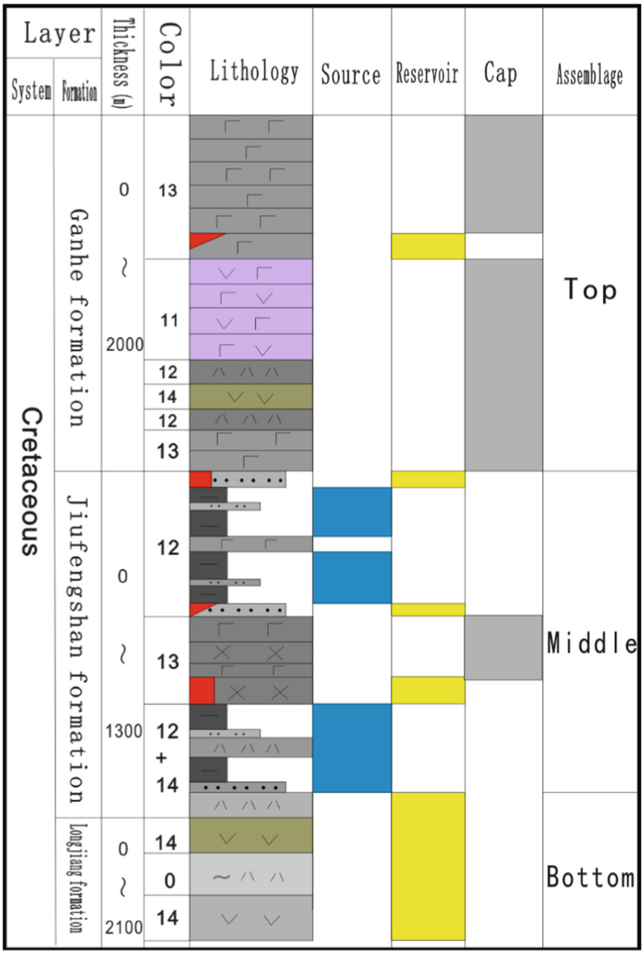

Fig. 1. Source reservoir cap rock assemblage of Dayangshu Basin

3 Characteristics of Sedimentary Reservoir

During the sedimentary period of Jiufengshan formation in Dayangshu basin, volcanic activity weakened, and sedimentation and volcanism interacted, forming a special lithologic combination mode of “binary structure”. The sedimentary rocks are mainly distributed in the lower and upper parts of Jiufengshan formation, with complete sedimentary cycle characteristics [5]. The lower part of Jiufengshan formation is deposited in lowstand domain, developed shore shallow lacustrine sedimentary rocks, generally containing volcanic ash, with limited distribution; After the eruption of a set of large-scale basic basalts, a set of transgressive domain mudstone and a set of highstand domain sedimentary rocks were deposited in the upper part (see Fig. 2).

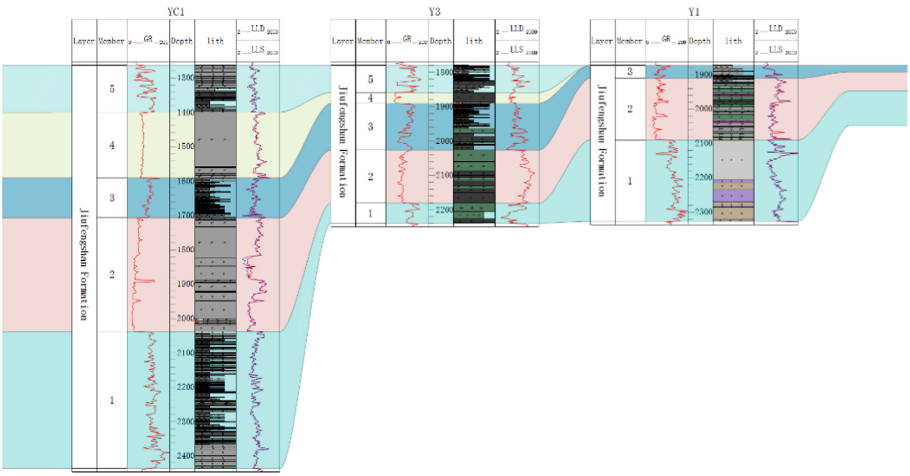

Fig. 2. A figure caption is always placed

3.1 Physical Properties of Sedimentary Reservoir

The sandstone reservoirs encountered in Jiufengshan formation are mainly medium fine sandstone, tuffaceous siltstone, argillaceous siltstone and glutenite. The sandstones are mainly lithic arkose and arkose [6] (see Table 1).The main grain size range of sandstone is 0.03–1.8 mm. The medium and fine-grained sandstones are moderately well sorted, while the unequal grained sandstones are poorly sorted. The rounded sandstones are sub round to sub angular, and the grains are in point to line contact relationship. The cementation types are pore film cementation and pore cementation.

Table 1. Statistical table of sandstone thickness of Jiufengshan formation

Well name	Thickness of sedimentary rock/m	Thickness of sandstone/m	Thickness ratio of sandstone to sedimentary rock/%
Y3	183.9	72.38	39.4%
YC1	360.79	102.99	28.5%
Y1	265.4	245	92.3%

The porosity of Jiufengshan Formation clastic rocks is 1.01–15.1%, with an average of 5.15%, and the permeability is 0.01–7.95 mD, with an average of 0.47 mD. The samples with porosity less than 10% account for 64–90%, and the samples with porosity 10–15% account for 10–32%; The samples with permeability less than 0.1 mD account for 50–67%, and the samples with permeability of 0.1–1.0 mD account for 21–46%; The porosity of sandstone in Y3 well is 0.7–15.1%, with an average of 6.2%, and the permeability is 0.014–11.4 mD, with an average of 0.69 mD. The porosity of clastic rock in YC1 well is 1.01–11.5%, with an average of 2.98%, and the permeability is 0.01–5.51

mD, with an average of 0.42 mD (see Fig. 3 and Fig. 4). The physical property of clastic rock in Jiufengshan formation of well Y3 is better than that of well YC1.

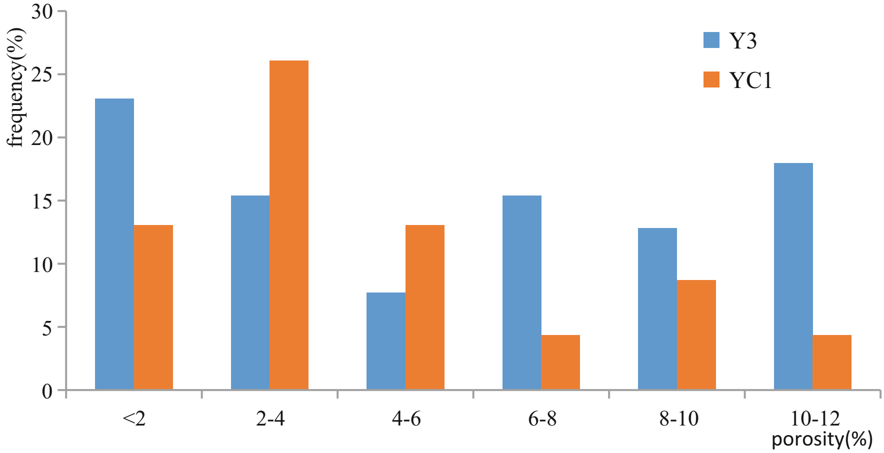

Fig. 3. Frequency histogram of porosity distribution of sedimentary rocks in Jiufengshan formation

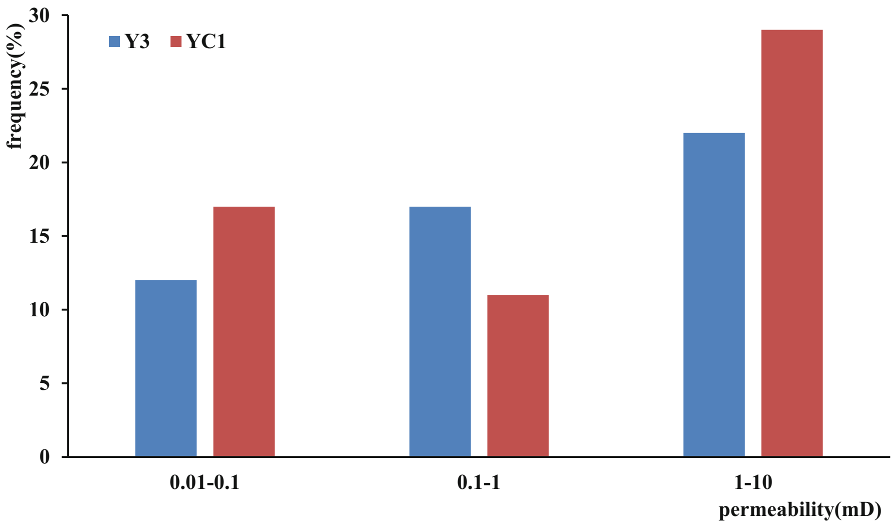

Fig. 4. Permeability histogram of sedimentary rock of Jiufengshan formation

The clastic sedimentary facies in Dayangshu basin mainly include fan delta facies, shore shallow lake facies, deep lake semi deep lake facies and volcanic sedimentary facies [7]. The physical properties of fan delta facies and volcanic sedimentary facies are relatively good. Fan delta facies is mainly developed in well Y3, volcanic sedimentary facies is mainly developed in well Yc1, and the other two sedimentary facies are developed in two wells. The porosity of fan delta facies is 8.5–12.4%, with an average of

10.6%, and the permeability is 0.04–0.58 md, with an average of 0.29 md; The porosity of volcanic sedimentary facies is 1.0–11.5%, with an average of 4.9%, and the permeability is 0.001–1.94 md, with an average of 0.27 md (see Fig. 5 and Fig. 6). According to the analysis of the relationship between clastic sedimentary facies and physical properties, the reservoirs with good physical properties are mainly developed in the fan delta facies, and vertically developed in the upper Jiufengshan formation.

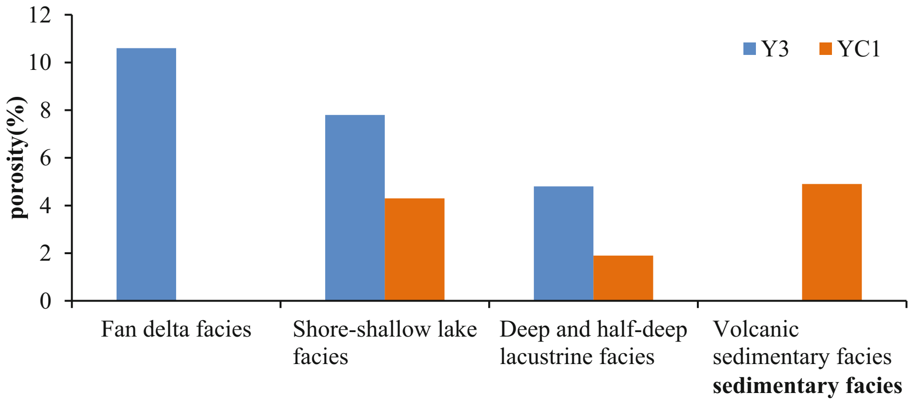

Fig. 5. Porosity comparison of different sedimentary facies of clastic rocks in Jiufengshan formation

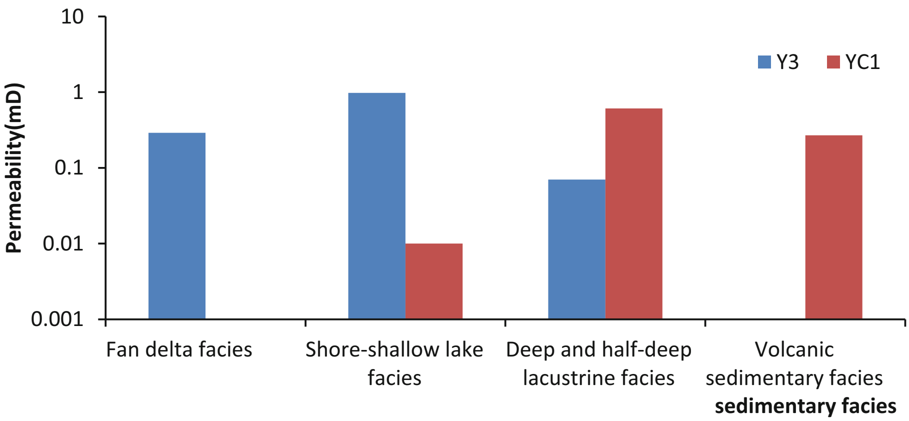

Fig. 6. Comparison Diagram of Permeability of Different Sedimentary Facies of Clastic Rock in Jiufengshan formation

By means of core observation and description, rock thin section and cast thin section identification, scanning electron microscope analysis and imaging logging analysis, the sedimentary rock reservoir of Jiufengshan formation in Dayangshu basin has strong compaction, and the pore type is mainly secondary pore. Jiufengshan formation sandstone contains tuffaceous, so the pore structure is generally developed, mainly intragranular dissolution pore and intergranular dissolution pore [8].

3.2 Electrical Properties and Seismic Response Characteristics of Sedimentary Reservoir

Jiufengshan formation sedimentary reservoir is subdivided into three sections, with two sets of volcanic rocks in the middle. From the electric property curve, Jiufengshan formation basalt is characterized by low gamma, high impedance and high density, while Jiufengshan formation sedimentary rock is characterized by relatively high gamma value in electric property, and there is no obvious corresponding relationship between other curves, such as resistance, acoustic wave and density [9] (see Fig. 7).

According to the characteristics of seismic response (see Fig. 8 and Fig. 9), the sedimentary strata developed in the Jiufengshan formation in Dayangshu basin are affected by the volcanic rocks of the Ganhe formation, and the amplitude is relatively weak [10]. By comparing the lithologic characteristics of the corresponding sections of the existing exploration wells and the analysis of the "phase surface method", it is found that the sedimentary rock development area generally presents the blank reflection characteristics of weak amplitude, while the amplitude of the sandstone in the sedimentary rock is stronger than that of the mudstone, It is characterized by weak continuous hillock and progradation [11].

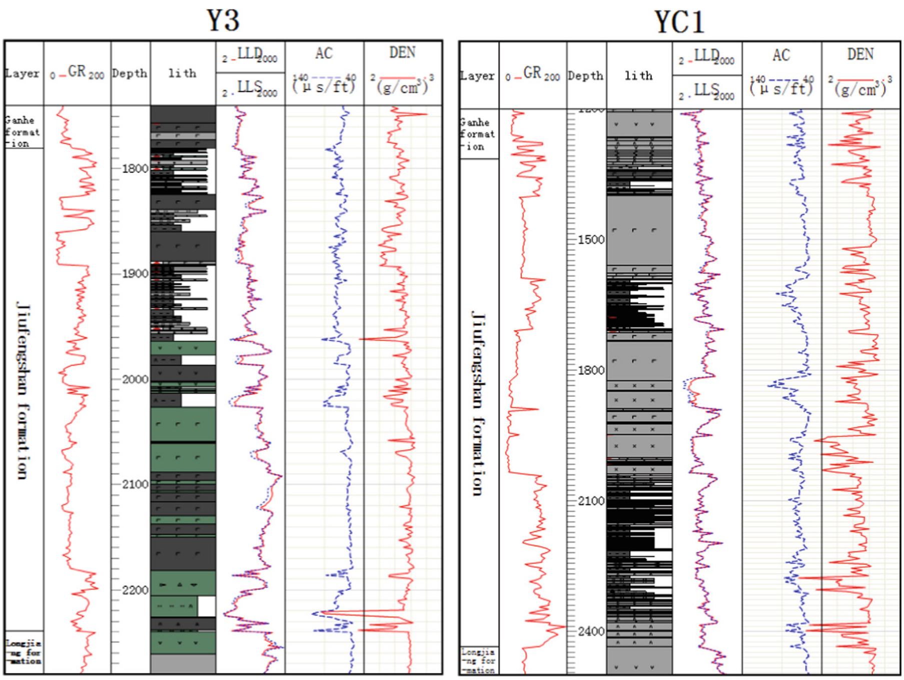

Fig. 7. Electrical characteristics of well Y3 and YC1

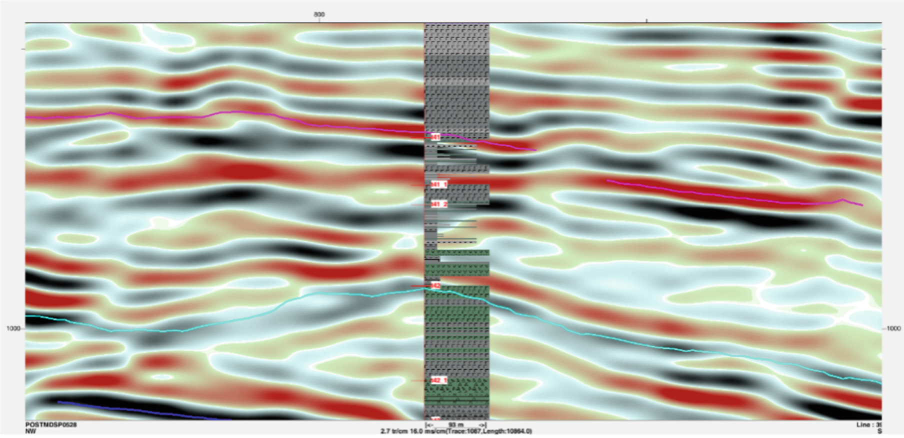

Fig. 8. Seismic Profile of Well Y3

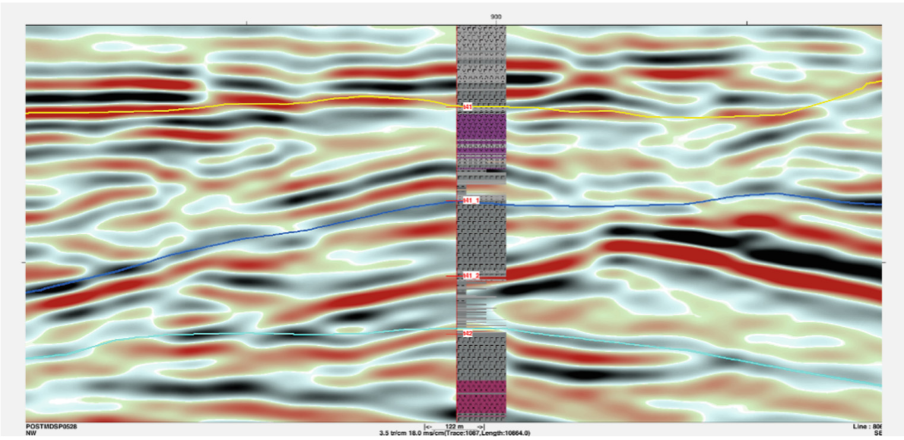

Fig. 9. Seismic Profile of Well YC1

4 Sedimentary Reservoir Prediction

4.1 Waveform Indication Inversion

Jiufengshan formation, the target reservoir in Dayangshu basin, is under the cover of volcanic rocks, and intermittent volcanic activities are also mixed in the deposition process of Jiufengshan formation [12]. The distribution of volcanic rocks is not as smooth and uniform as sedimentary rocks, which belongs to block plane distribution, and there are local violent tectonic movements in the deposition process. From the seismic data, the same phase axis is disordered and discontinuous. There are extra thick volcanic rocks in the overlying Ganhe formation, which form a strong shielding effect on the Jiufengshan formation reservoir. The seismic response characteristics of Jiufengshan formation are relatively complex, including medium strong amplitude continuous sedimentary rocks, broken volcanic rock explosion facies and strong reflection overflow facies. By comparing the lithologic characteristics of the corresponding sections of the existing exploration wells and the analysis of "facies surface method", it is found that the sedimentary rock development areas generally show good continuity of medium and weak amplitude, and some of them show blank reflection characteristics, while the amplitude of the sandstone in the sedimentary rock is stronger than that of the mudstone, showing the characteristics of weak continuous mound and progradation [13].

The above describes the electrical characteristics of Jiufengshan formation sedimentary rocks. It can be found that it is difficult to distinguish sedimentary rocks and volcanic rocks according to wave impedance [14]. Moreover, Dayangshu seismic bandwidth is less than 40 Hz, and the lateral continuity is poor. The traditional statistical inversion is essentially disconnected from the seismic data [15], and only the well data is used in the high-frequency part, but no seismic information is used [16].

Therefore, the waveform indication inversion method is considered. Waveform indication inversion regards seismic data as a series of structured data with spatial distribution [17]. Different lithologic sequence combinations correspond to various changes of seismic waveform. Referring to the two factors of waveform and distance, the well samples are optimized and the characteristic curve is analyzed, and then the optimal estimation is made according to the spatial distribution of sample wells (see Fig. 10).

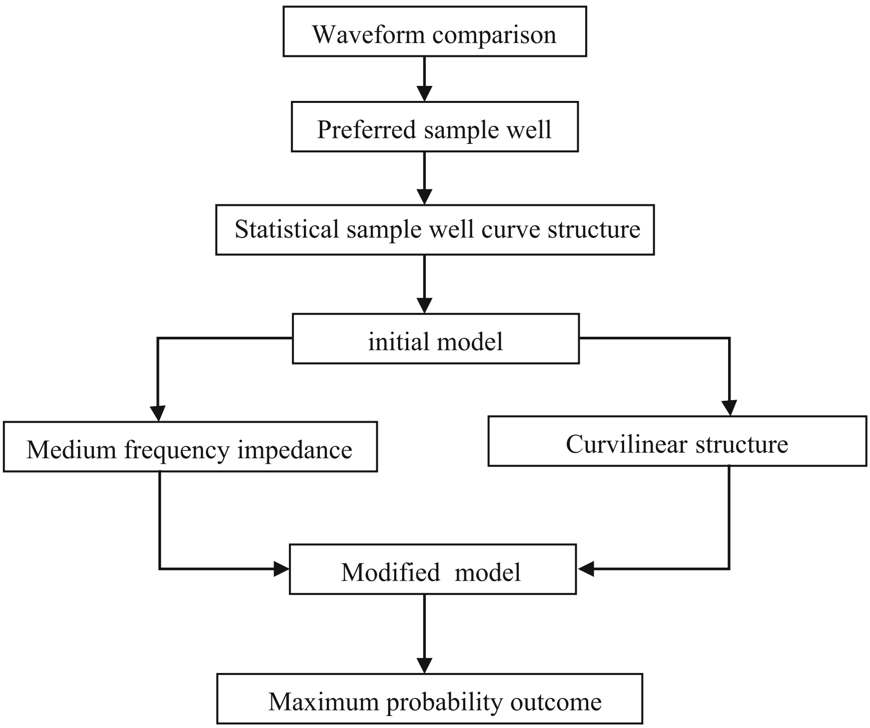

Fig. 10. Waveform indication inversion process

4.2 Analysis of Sensitive Parameters and Construction of Characteristic Curve

Because there are many kinds of volcanic rocks and their electrical characteristics are disordered (see Fig. 11 and Fig. 12 and Fig. 13), it is not ideal to analyze the lithologic sensitivity of the drilled gamma ray and acoustic logging data alone in the work area [18]. It is impossible to distinguish volcanic rocks and sedimentary rocks by using a single curve. In order to find the lithologic characteristic curve, firstly study the logging parameter characteristics of sedimentary rocks in the work area, and then cross analyze the logging curves [19], The multi parameter boundary between volcanic rock and sedimentary rock is found, and the lithologic characteristic curve is formed by fitting, which can be used to predict sedimentary rock (see Fig. 14).

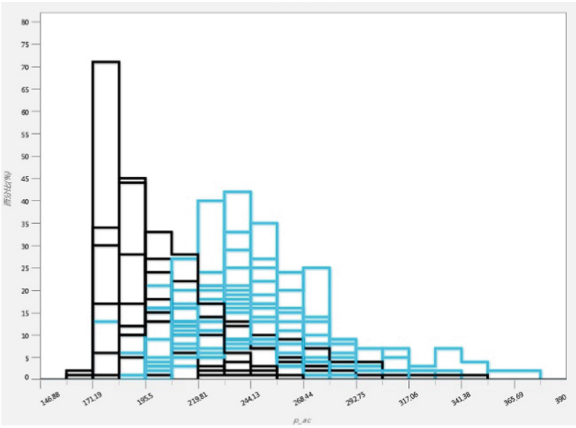

Fig. 11. Relationship between acoustic wave (AC) and lithology

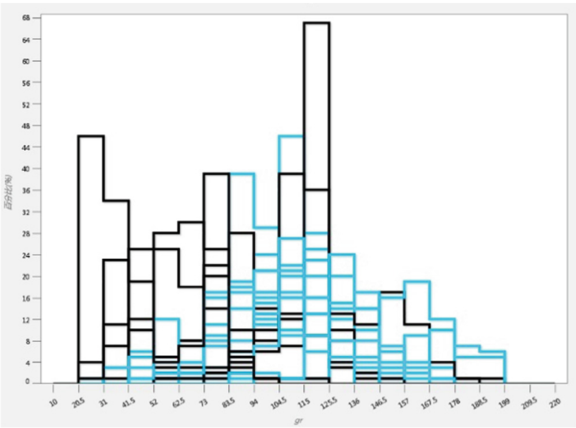

Fig. 12. Relationship between gamma (GR) and lithology

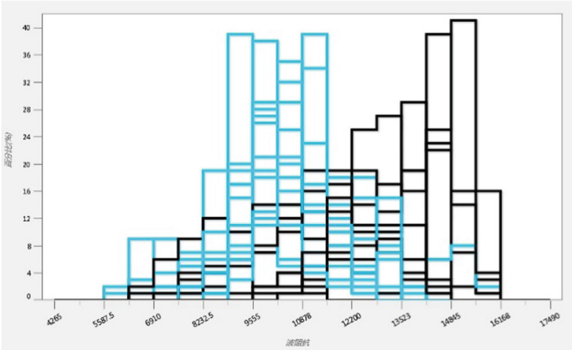

Fig. 13. Relationship between wave impedance (IMP) and lithology

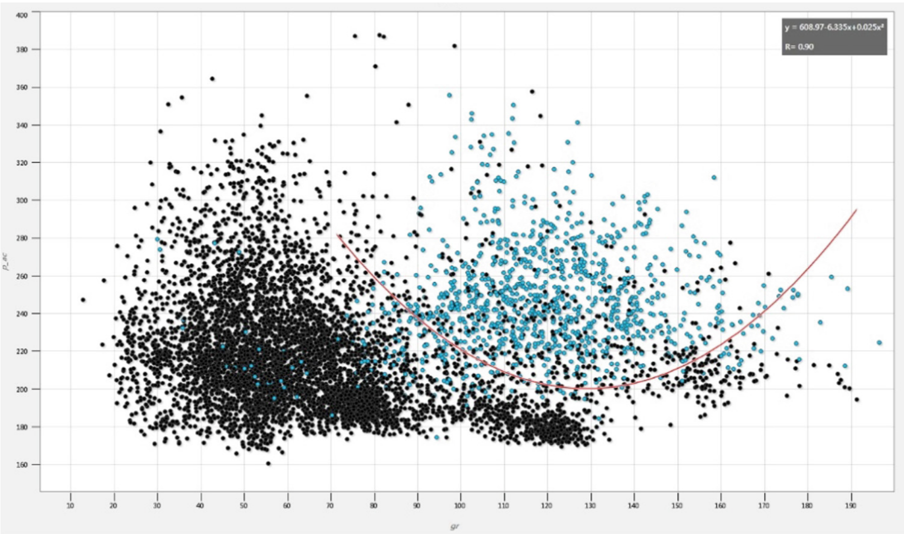

Fig. 14. Cross plot of acoustic wave (AC) and gamma (GR) ray

Through the intersection analysis of a variety of electrical curves and lithology, it can be seen that it is difficult to distinguish sedimentary rock and volcanic rock by a single curve [20]. Using the intersection of acoustic wave and gamma ray, and then establishing the fitting curve, sedimentary rock can be well distinguished. Fitting curve formula:

$$F = 608.97 - 6.335GR + 0.025GR^2 - AC \tag{1}$$

4.3 Application Effect Analysis

After analyzing the sensitive parameters of well data, using GR and AC curves, according to the above fitting formula, the characteristic curve of each well is established. When

F < 0, it is judged as sedimentary reservoir. Taking the characteristic curve as the input, the waveform indication inversion is carried out, and the inversion results show that the sedimentary rocks and volcanic rocks of Jiufengshan formation can be distinguished (see Fig. 15).

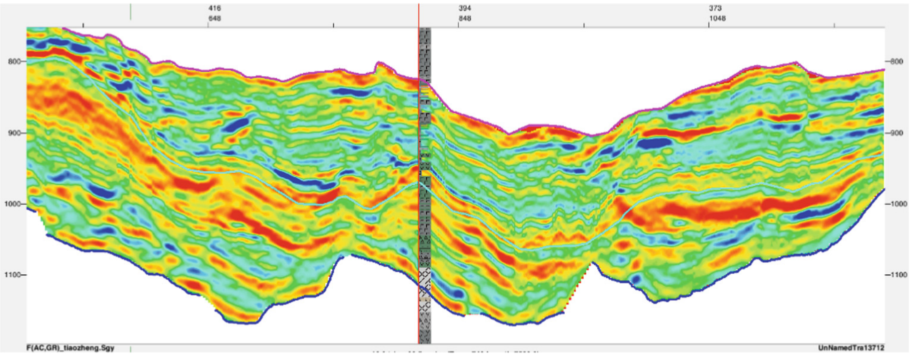

Fig. 15. Waveform indication inversion effect profile of Y3 well

In order to test the accuracy of inversion, we can take the wells not involved in the calculation as the posterior wells to test the inversion effect. We can see that for the posterior wells, the distribution of sedimentary rocks obtained by waveform indication inversion is well consistent with the actual drilling lithology (see Fig. 16).

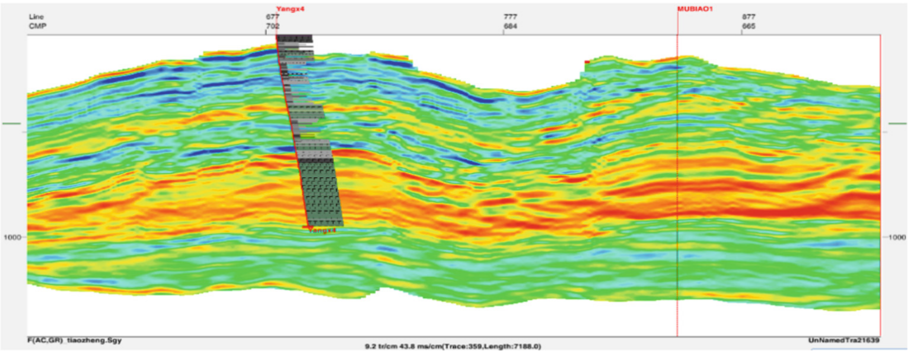

Fig. 16. Inversion effect profile of well YX4

5 Conclusion

(1) Jiufengshan formation sedimentary rock reservoir is developed in Dayangshu basin. The special "binary structure" lithologic combination mode caused by sedimentation and volcanic eruption has formed self generating and self storing oil and gas reservoir.

(2) Jiufengshan formation sedimentary rock reservoir has low porosity and poor permeability, which belongs to low porosity and low permeability reservoir.
(3) For the areas covered by volcanic rocks, poor quality of seismic data, complex seismic response characteristics, and difficult to distinguish reservoir by traditional wave impedance method, high-resolution waveform indication inversion technology is used to construct sensitive parameter curve, which can better predict reservoir.

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