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Fine Division of Internal Cycles of Glutenite based on INPEFA Technology and Wavelet Transform

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Abstract

In order to study the internal cycle characteristics of glutenite reservoirs, this study conducted high-resolution sequence division of glutenite based on INPEFA technology and wavelet transform technology. In this paper, the basic principles of INPEFA technology and wavelet transform technology are introduced in detail, and the differences and advantages and disadvantages of the two methods in high-resolution sequence division are compared. Taking Jilantai oilfield as an example, combined with INPEFA technology and wavelet transform technology, INPEFA processing and wavelet processing are innovatively carried out based on acoustic time difference curve, and the accuracy is verified by each other. On this basis, combined with logging, seismic, lithology and other data, the top and bottom interfaces of the third-order sequence of the K1g1 in the study area were identified, and on this basis, K1g1 was further divided into two oil groups, a total of eight layers.

Keywords

INPEFA; Wavelet Transform; Sand Conglomerate Reservoir; Hetao Basin.

1. Introduction

Logging technology has developed rapidly since the 1970s. Logging sequence is one of the three supporting points of sequence stratigraphic research. Logging data play an increasingly important role in sequence stratigraphic research with its advantages of high resolution, vertical continuity and multi-parameter. At present, logging data are also the most quantitative sequence stratigraphic analysis data that can be achieved in the basin coverage area. That is to say, logging data are one of the most basic and important basic data in the study of sequence stratigraphy. Logging curves endowed with geological content can be used for stratigraphic sequence analysis in different dimension domains.

According to the research results of Vail et al., the sedimentary sequences are divided into six grades. Among them, the I-III grade sequences are caused by tectonic origin or global sea level change, while the IV-VI grade sequences are caused by local action process and distributed in a small range. There are many controlling factors and influencing factors for the development of middle sequence in continental strata, with short development time and thin thickness.

In recent years, with the deepening of the exploration and development of oil and gas reservoir resources, the exploitation of oil and gas reservoir resources has decreased year by year, but the human demand for energy has been increasing, so the attention of glutenite reservoirs is getting higher and higher. The pore structure of glutenite reservoir is complex, the heterogeneity is strong, and the lithology changes greatly, which makes it difficult to divide the glutenite reservoir [1]. The identification and division of stratigraphic sequence is the basis for accurate identification of glutenite reservoirs. Therefore, it is of great significance to carry out

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high-resolution sequence stratigraphic correlation and division for the division of glutenite reservoirs in Jilantai area.

2. Regional Geological Profiles

The Hetao Basin is located in the central part of the Inner Mongolia Autonomous Region (Fig.1a [2]). It is a Cenozoic fault-depression basin. It is about 600Km in length from east to west, and about 30Km-90Km in width from north to south. It is an arc-shaped distribution with an area of about 4 × 104Km2. The Hetao Basin is located in the northwestern part of the North China Plate. It is connected to the Yinshan Arc Mountains and the Bayanwula Mountains in the north, and to the Yimeng Uplift of the Ordos Basin bounded by the hidden faults of the Yellow River in the south.

The Lower Cretaceous Guyang Formation of the Lower Cretaceous is the bottom sedimentary cover, which is in angular unconformity contact with the Palaeozoic. According to its lithological characteristics, the predecessors divided it into three sections, showing a ' red-black-red ' change sequence. The E1l1 in the lower part of the Linhe Formation is mainly red, and the lithology is obviously thicker than that of the second member of the Linhe Formation. The development of brownish red, light gray siltstone and mudstone shows the characteristics of ' red ' and ' coarse '. E1l2 in the central part of the basin is the deposition of the stable subsidence stage of the lake basin. It is the most important source rock section of the Cenozoic, and develops fine-grained gray-black and black mudstone.

The Paleogene Eocene Wulate Formation (E2w) is mainly composed of sandy sediments, with thin layers of pebbly sandstone and dolomite. The Oligocene Linhe Formation (E3l) has an integrated contact relationship with the underlying strata, and the sedimentary thickness is large. According to the lithology combination and cycle characteristics, it can be divided into three sections. Vertically, it has the cycle characteristics of ' coarse-fine-coarse ' and ' red-black-red ' from bottom to top[3].

The target horizon of this study is the first member of Guyang Formation. The first member of Guyang Formation is mainly composed of light gray sandstone and gray-black mudstone, which is the main oil-generating interval.

The relevant data of more than 100 wells in the study area (Fig.1b) are selected as the research object. According to the development of the bottom layer and the distribution of sandstone in the study area, the whole K1g1 can be regarded as a third-order sequence, and the oil group and sand group are finely divided.

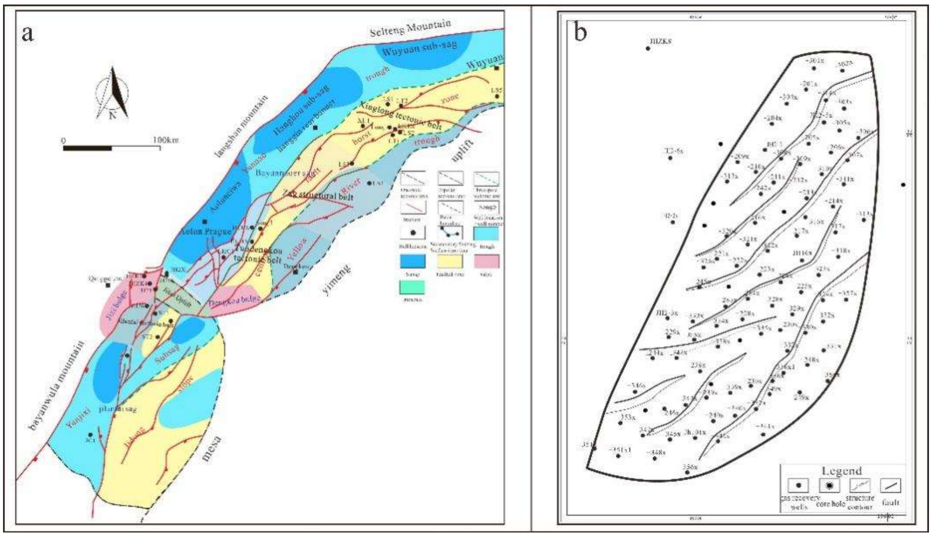

Fig. 1 Structure distribution map of Jilantai oilfield

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3. Technical Principle

3.1. The Basic Principle of INPEFA Technology

The INPEFA technique was first proposed by S.D.Nio et al.in 2005. The technique identifies sequence boundaries of different orders by reconstructing geological information hidden in conventional logging curves [4]. The INPEFA curve can identify the sequence boundary hidden in the conventional logging curve, because it is more obvious than the conventional logging curve to reflect the cyclic change of the deposition [5,6].

INPEFA technology first carries on the spectrum analysis, through the maximum entropy spectrum analysis processing logging curve, to calculate the maximum entropy spectrum analysis estimate (MESA), in with the corresponding logging curve true value (RV) minus the maximum entropy spectrum analysis estimate data difference (PEFA = RV-MESA) [7], namely the spectrum attribute, its larger positive or larger negative value is discontinuous point, may be formation discontinuous point or cycle interface (table 1). The INPEFA curve is obtained by integrating the PEFA curve, which can show the cyclic characteristics and cyclic interface of the strata (Fig.2).

According to logging geology, different logging curves can reflect different geological characteristics. Through the investigation of previous studies, the maximum entropy spectrum analysis is mainly carried out by natural gamma curve (GR) in high resolution bottom recognition. However, after synthesizing and comparing different logging curves of multiple wells in the study area, it is found that in clastic rock reservoirs, the change trend of acoustic time difference curve (AC) is more obvious. Therefore, this study uses acoustic time difference curve for analysis.

Table 1. Characteristics and rhe Meaning of INPEFA [8]

INPEFA characteristics	Mathematical meaning	Geological meaning
Negative trend	Logging response value decreasing	The process of water retreat
Positive infection point	Logging response value reaches minimum ralue	Sequence boundary
Positive trend	Logging response value increasing	The process of water retreat
Negative infection point	Logging response value reaches minimum value	Possible flooding surface

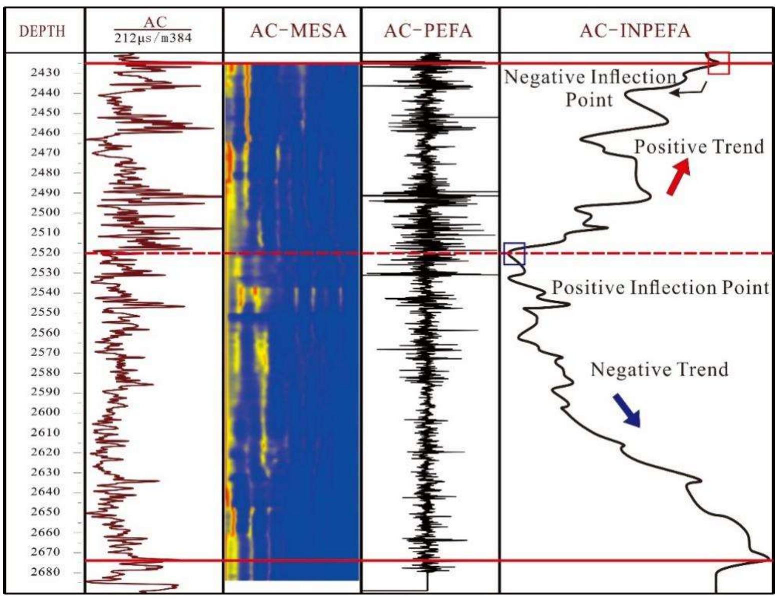

Fig. 2 Analysis chart of synthetic prediction error filtering for well JH2-312x

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3.2. Basic Principle of Wavelet Transform

Wavelet transform is mainly used as a tool for multi-scale analysis and time-frequency analysis in stratigraphic division and correlation. It can transform one-dimensional logging signal into two-dimensional deep frequency domain, and extract the information of small layers such as horizon, thickness and lithology in logging curve, which is convenient for subsequent comparative study.

A square integrable function ψ (t) satisfying the condition.

$$\int_{-\infty}^{+\infty}|\psi(\omega)|^2|\omega|^{-1}d\omega<\infty \tag{1}$$

is defined as a basic wavelet or wavelet generating function. where ψ (ω) is the Fourier spectrum of ψ (t). Let:

$$\Psi_{a,b}(t)=|a|^{-\frac{1}{2}}\psi\left(\frac{t-b}{a}\right)(a,b\in R\text{ and }a\neq 0) \tag{2}$$

be a continuous wavelet generated by the generating function ψ, which depends on the parameters a and b. Where a is a scaling function and b is a time shift function, then the wavelet transform of the signal f (t) is defined as:

$$C_f(a,b)=|a|^{-\frac{1}{2}}\int_{-\infty}^{+\infty}f(t)\Psi\left(\frac{t-b}{a}\right)\mathrm{d}t \tag{3}$$

According to the basic principle of wavelet transform, Morlet wavelet is selected in this study. The steps of one-dimensional continuous continuous wavelet transform are as follows(Fig 3) [9~13].

1) Select a complete layer of well, for its target layer, given the initial wavelet scale factor of a;

2) As shown in Fig.4 (A), the wavelet is compared with the initial segment of the original signal;

3) By calculating the wavelet coefficient C (the similarity between the initial segment signal and the wavelet, the two are positively correlated);

4) As shown in Figure 4 (B), move the wavelet to the right and repeat the above steps until the signal support interval is completely covered;

5) As shown in Figure 4 (C), the scale parameter a is adjusted and the above steps are repeated;

6) Repeat the above steps until all the scales of the wavelet transform coefficients are calculated to get the wavelet transform video energy map.

After the logging curve is transformed by one-dimensional continuous wavelet transform, a series of wavelet transform values corresponding to scale and depth are obtained. By observing the changes of local energy groups in wavelet time-frequency energy map and the periodic oscillation characteristics of various stretching scales, the cyclicity of strata can be analyzed and the corresponding relationship with sequence boundaries at all levels can be established by logging curves superimposed by multiple sedimentary cycles of different periods [14].

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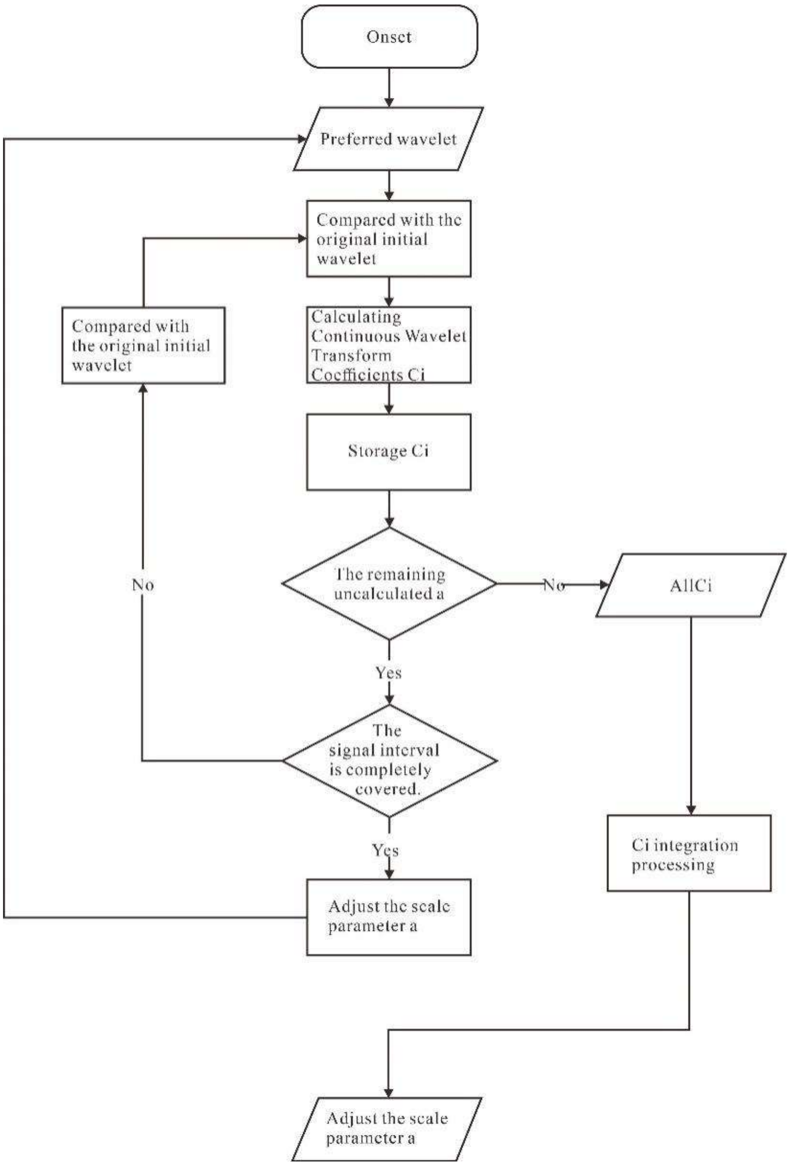

Fig. 3 Wavelet transform flow chart

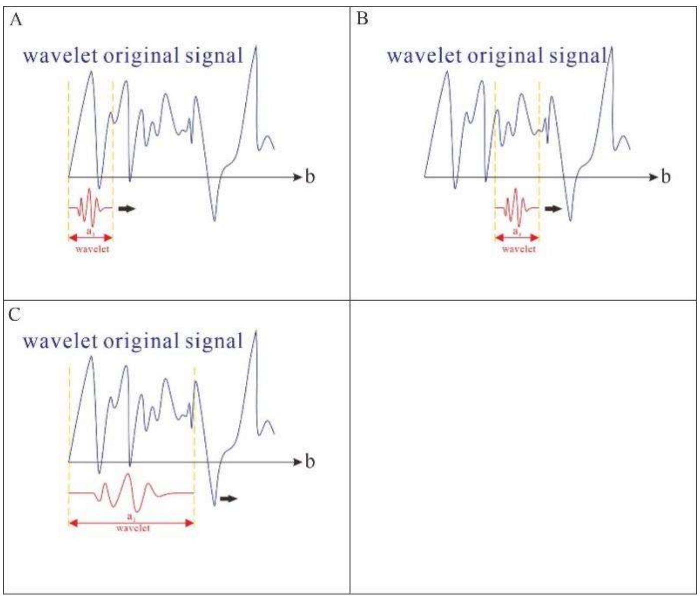

Fig. 4 Schematic diagram of wavelet transform

3.3. This Research Process

The INPEFA curve after the maximum entropy spectrum analysis is localized. In the relatively short sequence interface, the curve potential is obvious, which can well identify the characteristics of sedimentary cycles. Based on the completion of higher-order sequence identification, this study can clearly observe the third-order and fourth-order sequences by using INPEFA curve and supplemented by seismic and core data. Because the curve trend of the fifth-order sequence is not obvious in a very short period of time, the INPEFA curve can not be used as the basis for sequence division, but it can play a supporting and verifying role [15].

In this study, the first section of the study area was divided by the method of well-seismic combination, and then the fourth-order sequence was divided by INPEFA technology combined with core. Finally, the fifth-order sequence was divided by wavelet transform technology and verified by INPEFA technology. This study takes the formation, seismic, logging, core and other data of JH2-312 x as an example.

4. Sequence Division

4.1. Identification of Third-order Sequence Boundary based on Seismic Characteristics

Using seismic interface to identify sequence has the advantages of good continuity, obvious relief relationship between bottom layers and wide identification range. The reflection interface is relatively isochronous [16]. On the basis of re-seismic interface identification, the maximum entropy spectrum analysis and core characteristics are used to assist in verifying the accuracy of the sequence of seismic interface identification.

The seismic reflection surface observed in this study can clearly identify the seismic interface of the top and bottom of the target section K1g1. From the seismic profile, it can be observed that the K1g1 section of JH2-312x well is roughly located at 2526 ~ 2767 m. From the core section, it is observed that the mudstone layer with sandy conglomerate is developed at the top of the K1g1, and the bottom of the K1g1 is a thick mudstone layer. Combined with the lithology of the top and bottom interface of the core of the corresponding section of 10 coring wells in the study area, it is basically consistent with the well, so as to determine the division of the third-order sequence.

4.2. Based on INPEFA Technology, the Fourth-order Sequence is Divided.

The well JH2-312 x with complete formation development and obvious logging characteristics in the study area is selected for division, and the acoustic logging curve (AC) and natural gamma curve (GR) are selected for maximum entropy spectrum analysis (Fig.5). By observing and comparing the original curve and INPEFA curve of JH2-214 x well, it can be found that for the response of glutenite reservoir, whether it is the original curve or INPEFA curve, the fluctuation range of GR curve and GR-INPEFA curve is not obvious. It can be seen that the most commonly used GR curve in the study of re-sequence strata is not applicable in this study area. Therefore, this study is mainly based on AC curve, supplemented by other curves for identification.

The whole of K1g1 is sandy conglomerate with a thickness of 50 ~ 200 m. A relatively stable thin mudstone can be identified in the interior, which is preliminarily used as a sign for the division of I and II oil groups. The logging curve is observed. The thin mudstone corresponds to the negative inflection point on the AC-INPEFA curve. The AC curve has a high value point, and the GR and SP curves have a low value point, which is characterized by a sharp peak. Therefore, the thin mudstone can be used as the boundary between the I and II oil groups of K1g1, and finally the first member of the Guyang Formation can be divided into two fourth-order sequences, K1g1I and K1g1II.

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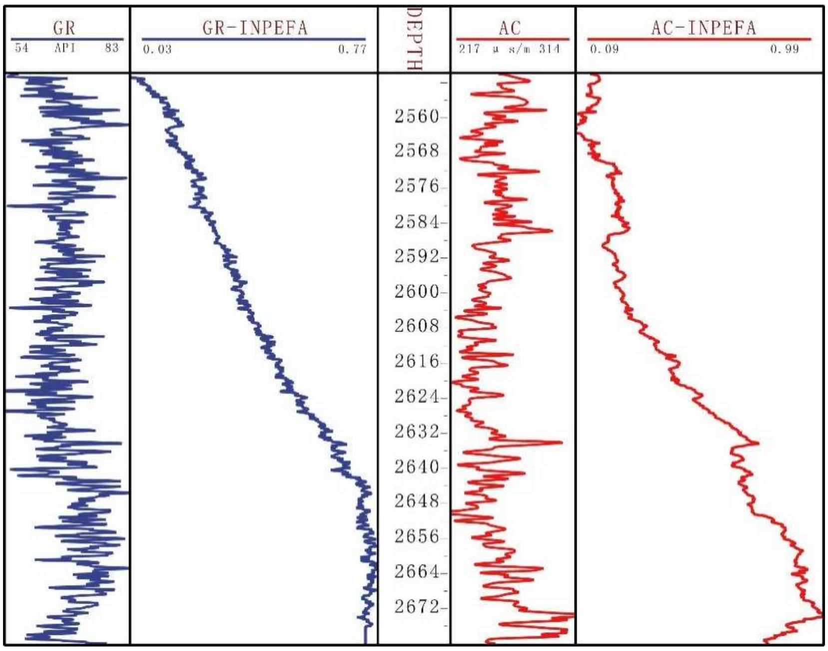

Fig. 5 Comparison diagram of GR curve and AC curve of JH2-312x well

4.3. Based on INPEFA Technology and Core Data, the Fifth-order Sequence is Divided.

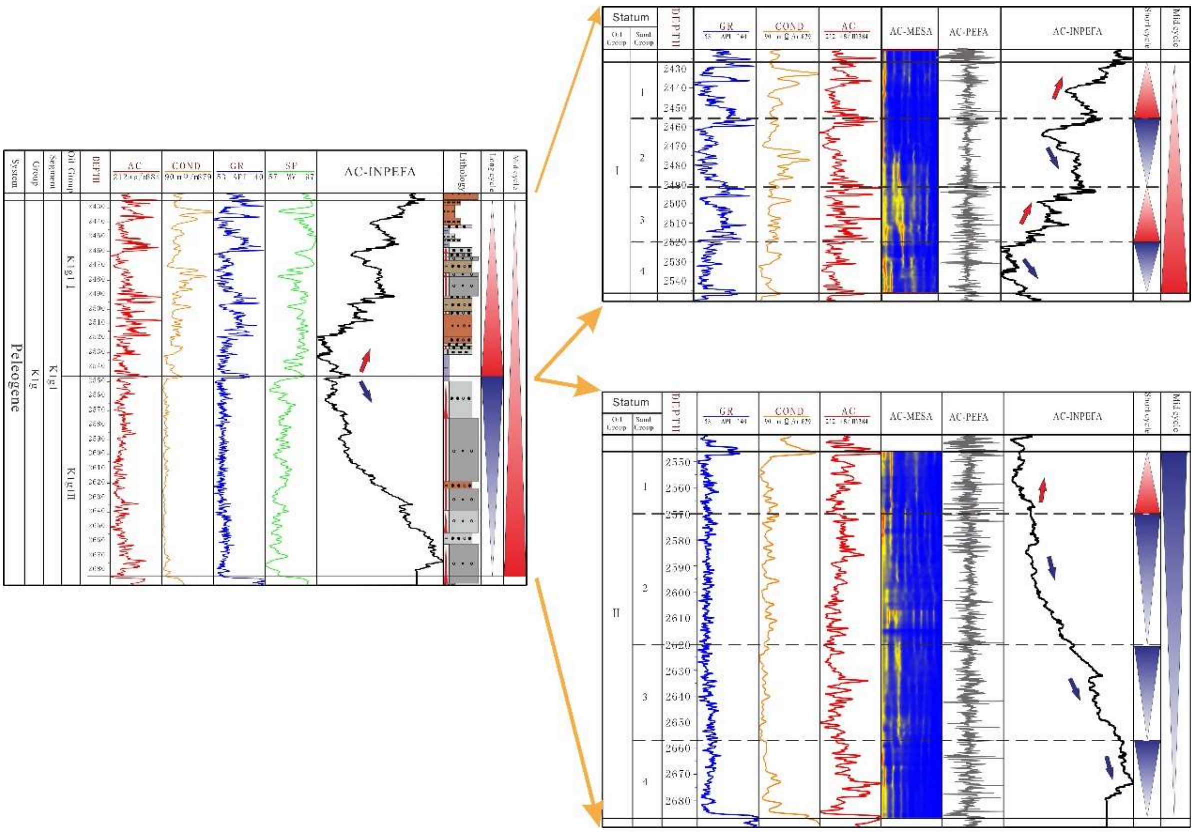

Fig. 6 The fifth-order sequence is divided by INPEFA technique

The curve trend of the fifth-order sequence is not obvious enough in a very short period of time. Therefore, for the identification of the fifth-order sequence, the INPEFA curve can only play a role in assisting the search and verification. Core observation is often used to find lithology, grain size and color mutation surface as the marker layer for the division of the interface of the

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small layer [15]. This study will divide K1g1II into five-order sequences on the basis of higher-order sequences.

For example, taking the second oil group of well JH2-312 x as an example, combined with the cores of many wells, the dense layer of fine gravel coarse sandstone at 2570 m is taken as the bottom interface of the first sand group, and the logging curve has the characteristics of high GR value and low COND value, and the AC-INPEFA curve is located at the inflection point. The lithology with high shale content at 2615 m is taken as the bottom interface of the second sand group. Combined with the logging curve, it has the characteristics of low GR and low COND, and the AC-INPEFA curve is located at the inflection point. The physical interlayer of oil-free glutenite at 2656 m is taken as the bottom interface of the three sand groups, combined with the characteristics of high GR value and high COND value of logging curve, and the AC-INPEFA curve is located at the inflection point (Fig.6).

Finally, based on the core, original logging curve and INPEFA curve, K1g1 is divided into one long-term cycle, two medium-term cycles and eight short-term cycles.

4.4. Sequence Division based on Wavelet Transform

K1g1 in Jilantai area is selected as the research layer, and JH2-312 x well is selected as the research well. The research well section is 2425.41 ~ 2686.13 m, and the thickness of the target layer is 260.72 m. The study area is a glutenite reservoir, and the sensitivity of various logging sequences to the response of sedimentary characteristics is different, so it will have a certain impact on the effect of wavelet transform to divide the sedimentary secondary. In general, for glutenite sedimentary bodies, due to the influence of near-source deposition and parent rock properties, the natural gamma logging has a vague response to lithology, and the overall change range of natural potential is small. Therefore, these two curves are not suitable for wavelet transform. The acoustic time difference curve and the compensated neutron curve are less affected by the composition of the rock skeleton. At the same time, the difference of the porosity of the sandstone and mudstone can also reflect the difference of the sedimentary characteristics of the reservoir, and the overall variation of the two curves is relatively large [17]. These two kinds of logging curves are very suitable for wavelet transform, and the amplitude and morphological changes of the two are very similar. Therefore, this study continues to select the acoustic time difference curve for wavelet transform, and the sequence division of the glutenite reservoir in the study area.

Taking well JH2-312x as an example, based on the third-order sequence, the fourth-order and fifth-order sequences will be divided by wavelet transform. Firstly, the logging curve is denoised by computer [18,19](Fig.7), and the wavelet coefficient curves of different scales are obtained after processing.

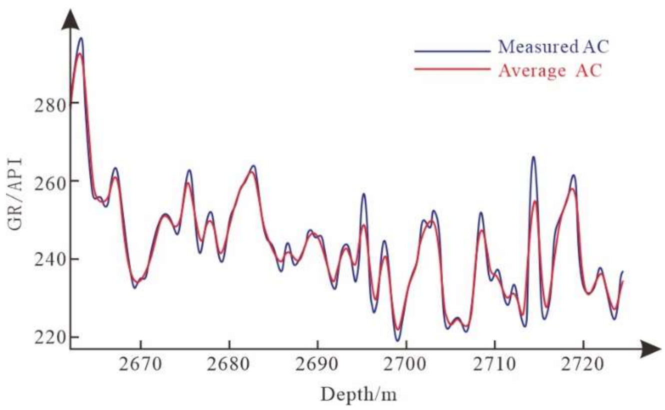

Fig. 7 Noise processing

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Figure 8 is the wavelet transform coefficient time-frequency chromatogram obtained by Morlet wavelet transform. The longitudinal axis is the scale factor and the transverse axis is the depth displacement axis. It can be seen that the shale content in the formation is positively correlated with the AC value. The higher the color brightness in the chromatogram, the higher the wavelet coefficient [20]. It can be observed that the color brightness of the upper and lower parts of the time-frequency chromatogram is significantly different, representing K1g1I and K1g1II, respectively.

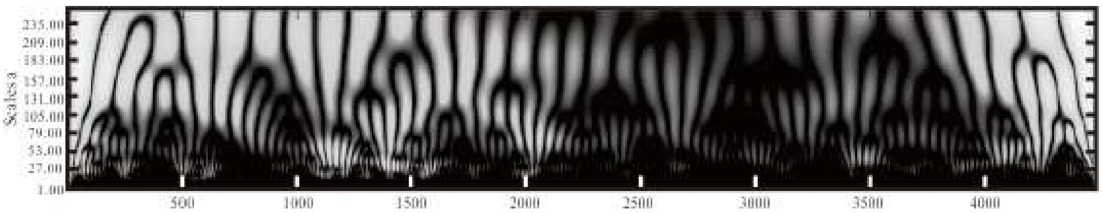

Fig. 8 Time-frequency chromatograms

Through the Morlet wavelet scale factor selection method, the peak value of the variance of the wavelet coefficient is identified, the corresponding scale is output, and the average value of the AC curve at different scales is made, and then the average value components are compared [21]. Finally, the best scales for dividing the oil group and the small layer interface are 105,203 and 235 (Figure 9). The wavelet coefficient variation maps were made on the scales of 105,203 and 235, respectively, and the sequence division was carried out by combining the time-frequency chromatogram (Fig. 10). It can be seen that the oscillation trend of the wavelet curve is related to the size of the scale factor. The larger the scale factor, the smoother the curve.

It can be observed that when the scale factor is 189, there are two boundaries showing abnormal obvious oscillation, which can be used as the top and bottom interface of K1g1; when the scale factor is 154, the oscillation amplitude of the whole K1g1 is significantly different, and K1g1 is divided into two oil groups : K1g1 I and K1g1 II. When the scale factor is 85, on the basis of the obvious difference of oscillation amplitude between the curves of the first and second oil groups, it can be clearly observed that there are four abnormal obvious oscillations in each of the two oil groups. According to this, K1g1I and K1g1II are divided into four sand groups.

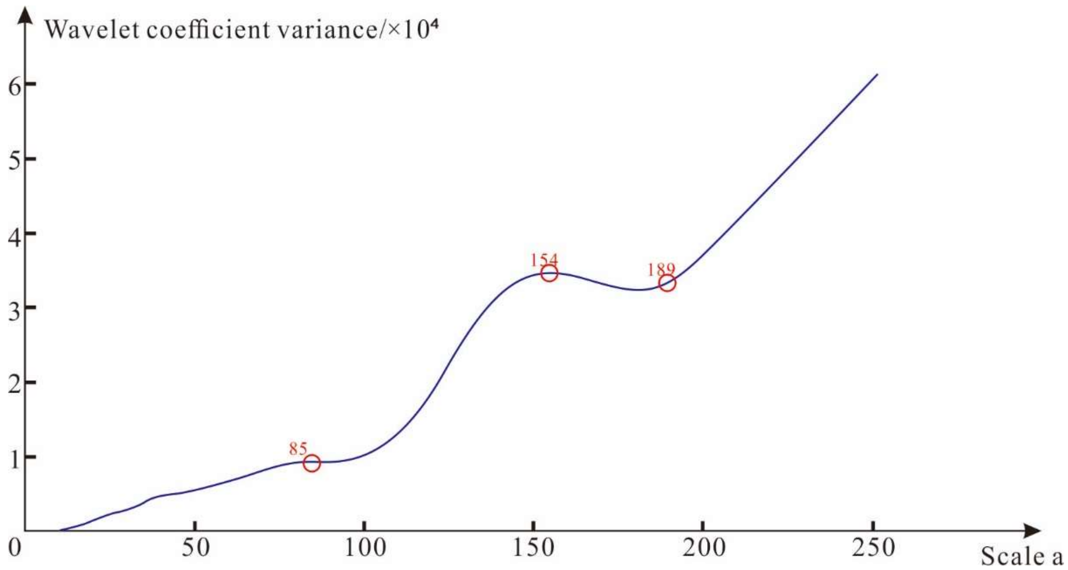

Fig. 9 The average value of AC curve modulus at different scales

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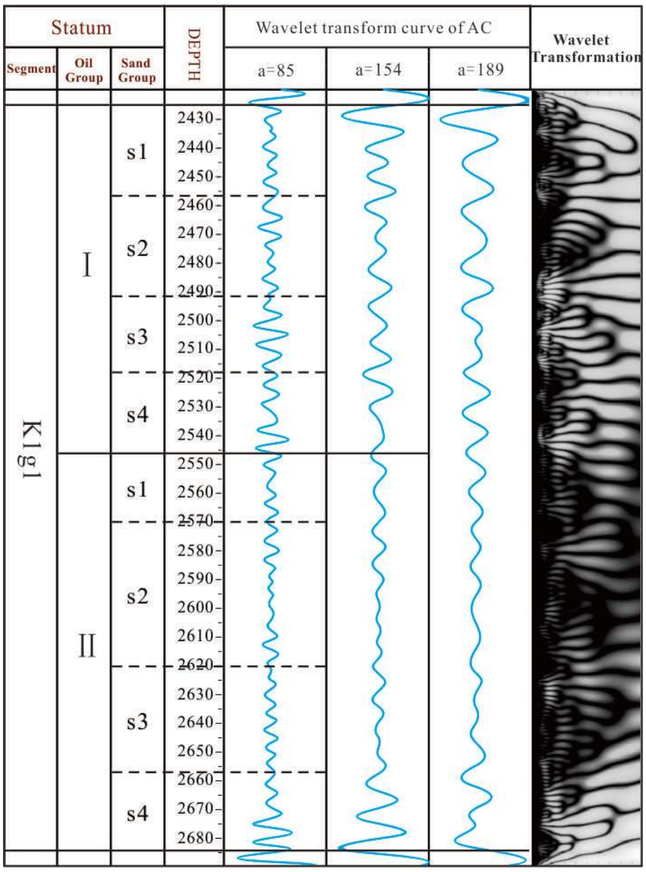

Fig. 10 Sequence division of JH2-312x well based on wavelet

Finally, based on the basic principle of wavelet transform, the top and bottom interfaces of K1g1 are identified. In general, the two oil groups of K1g1 are identified, and the sand groups of K1g1 I and K1g1 II are finely divided. Finally, K1g1 is divided into two oil groups with a total of 8 small layers. The division results are consistent with the high-resolution sequence division results based on INPEFA technology.

4.5. Discussion

The division of sequence stratigraphy is the basis of oil and gas geology research. The research of sequence stratigraphy is mainly based on natural gamma ray, acoustic time difference and other logging curves, combined with seismic and core data. Through the processing of INPEFA, wavelet transform and other techniques, the trend of logging curve can be more obvious [22]. However, both methods have certain limitations, so this study applies these two methods at the same time, and finally achieves the effect of mutual verification.

According to the above two methods, the strata of K1g1 are finely divided, and the results are shown in figure 1. In this study, K1g1 is divided into a long-term cycle by INPEFA technology, and further divided into two medium-term cycles and a total of 8 short-term cycles by combining lithology, seismic and core data. The top and bottom interfaces of K1g1 are identified by wavelet transform. K1g1 is divided into two oil groups : K1g1I and K1g1II, and further refined into a total of 8 sand groups, which correspond to the 8 short-term cycles divided by INPEFA technology. Within the allowable range of error, the same results were obtained by two methods for the stratigraphic sequence division of K1g1, indicating that the results of this study have high accuracy.

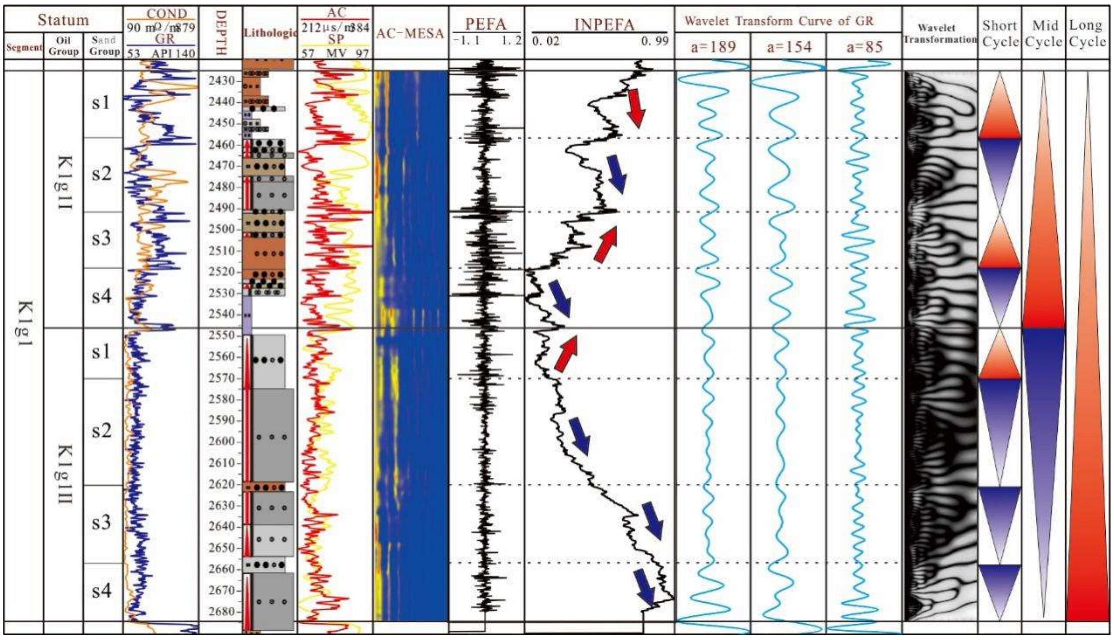

Fig. 11 JH2-312x well sequence division comprehensive histogram

5. Conclusion

1) Using INPEFA technology and wavelet change to divide stratigraphic sequence has its own advantages and disadvantages. INPEFA technology has obvious characteristics in the identification of lower-order sequences (such as third and fourth-order sequences), which can clearly reflect the changes of sequence boundaries and water intrusion and water regression. However, it is difficult to identify higher-order sequences, and core data are needed. The wavelet transform can identify the internal cycles of the curve through different scales, and can clearly divide the scope of the small layers, but can not define the boundaries between the small layers. Therefore, when performing high-resolution underlying recognition, it is best to combine these two methods to improve accuracy and verify accuracy with each other.

2) In this study, the high-resolution sequence division of the first member of Guyang Formation in Jilantai Oilfield was carried out by combining INPEFA technology and wavelet transform technology. The top-bottom interface of the third-order sequence is identified, and on this basis, the fourth and fifth-order sequences are divided. Finally, the first member of Guyang Formation is divided into two oil groups with a total of 8 small layers.

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