REVIEW PAPER-EXPLORATION GEOLOGY

Comparison of INPEFA technology and wavelet transform in sequence stratigraphic division of mixed reservoir: a case study of lower Es₃ of KL oilfield in Laizhouwan Sag

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Abstract

Sequence identification and division is an important basis for oil and gas exploration research. In view of the complex sedimentary environment, based on the previous element logging correction lithology, through the combination of logging curve and lithology data, in this paper, two methods of maximum entropy spectrum analysis and wavelet transform are used to identify the logging curve and divide the interface, and the high-resolution sequence identification of migmatite in the study area was completed. Compared with AC and SP logging curves, the overall and local trend inflection points of INPEFA-GR curve can improve the accuracy of medium-term and short-term cycle interface identification; wavelet transform and time–frequency spectrum analysis of different scale factors can realize the identification and comparison of medium-term and short-term cycle interfaces. The results show that maximum entropy spectrum analysis is more suitable for determining the third-level and fourth-level sequence interfaces. Wavelet transform is more suitable for the division of fifth-level sequences. By comparing and adjusting the two methods, the lower Es3 of KL Oilfield in Laizhouwan Sag can be divided into 1 long-term base-level cycle, 3 medium-term base-level cycle and 8 short-term base-level cycle. This study has certain reference significance for the construction of sequence stratigraphic framework in migmatite area and helps to better describe the reservoir.

Keywords Migmatite · Sequence division and correlation · Maximum entropy spectrum analysis · Wavelet transform · Laizhouwan Sag

Introduction

Sequence analysis the basic method of sequence stratigraphy is based on outcrop and core data analysis combined with seismic and logging data (Zhu 1998; Chi et al. 2001). Well logging data contain abundant geological information, which is characterized by good continuity and high resolution. With the progress of science and technology, logging technology and equipment become more mature, logging data are more widely used in sequence stratigraphy research. Log data have a unique advantage in identifying multilevel formation cycles because it can provide a variety of petrophysical parameters of the associated formation (Ou 1992). In recent years, the method of maximum entropy spectrum analysis or wavelet transform is mainly used to classify sequence stratigraphy based on logging data: processing logging data, extracting spectral data features, identifying sequence interface, and completing sequence stratigraphy division. However, there is a lack of systematic and comprehensive research on sequence stratigraphy division of mixed rocks. The study area is the KL Oilfield in Laizhouwan Sag, Bohai Bay Basin, which is in the early stage of exploration. It has the characteristics of high-frequency variation of sedimentary environment and lithofacies, complex lithology and frequent interbedding. During oil and gas exploration, the sequence stratigraphy of the target interval should be divided first, so as to lay a foundation for the subsequent study of

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sedimentary microfacies identification, mixed sedimentary model analysis and control factors of mixed sedimentation (Wang et al. 2020).

In view of the poor quality of seismic data and incomplete core data in the study area, it is more effective to use maximum entropy spectrum analysis or wavelet transform to identify logging data to divide sequence stratigraphy on the basis of correcting the lithology of mixed rock by formation element logging. Mixed rock is a kind of transitional lithology formed in complex sedimentary environment, and its composition and logging response characteristics are complex and diverse. Mixed rocks with different rock components often overlap in logging response, and the logging response characteristics of a single logging curve are not obvious (Zhang et al. 2019). In order to improve the sand under the three period of sequence stratigraphic classification accuracy, the GR log curves are processed by maximum entropy spectrum analysis and wavelet transform, respectively, judge the change of sedimentary environment and determine the sequence boundary, realize high-resolution sequence division and correlation, and provide technical support for the exploration and development of migmatite oil and gas.

Methodology

INPEFA technology and principle

The first step of INPEFA technology is spectrum analysis. Through the maximum entropy spectrum transformation, the value of the next point can be calculated from the value of the known point under the principle of maximum entropy, which is the maximum entropy spectrum analysis estimate (Zoukaneri et al. 2015). Then, the prediction error filter analysis (PEFA) curve can be obtained by subtracting the maximum entropy spectrum estimated value from the actual logging value, larger positive or negative values that are discontinuous points, which may be stratigraphic discontinuous points or cycle interfaces, and spikes of different sizes represent isochronous interfaces of different sizes. Integrated prediction error filtering analysis (INPEFA) curve was obtained by specific integral processing of PEFA curve (Liu et al. 2013; Li et al. 2019; Wang et al. 2016) (Fig. 1). INPEFA can be applied to sequence division (Rui et al. 2018).

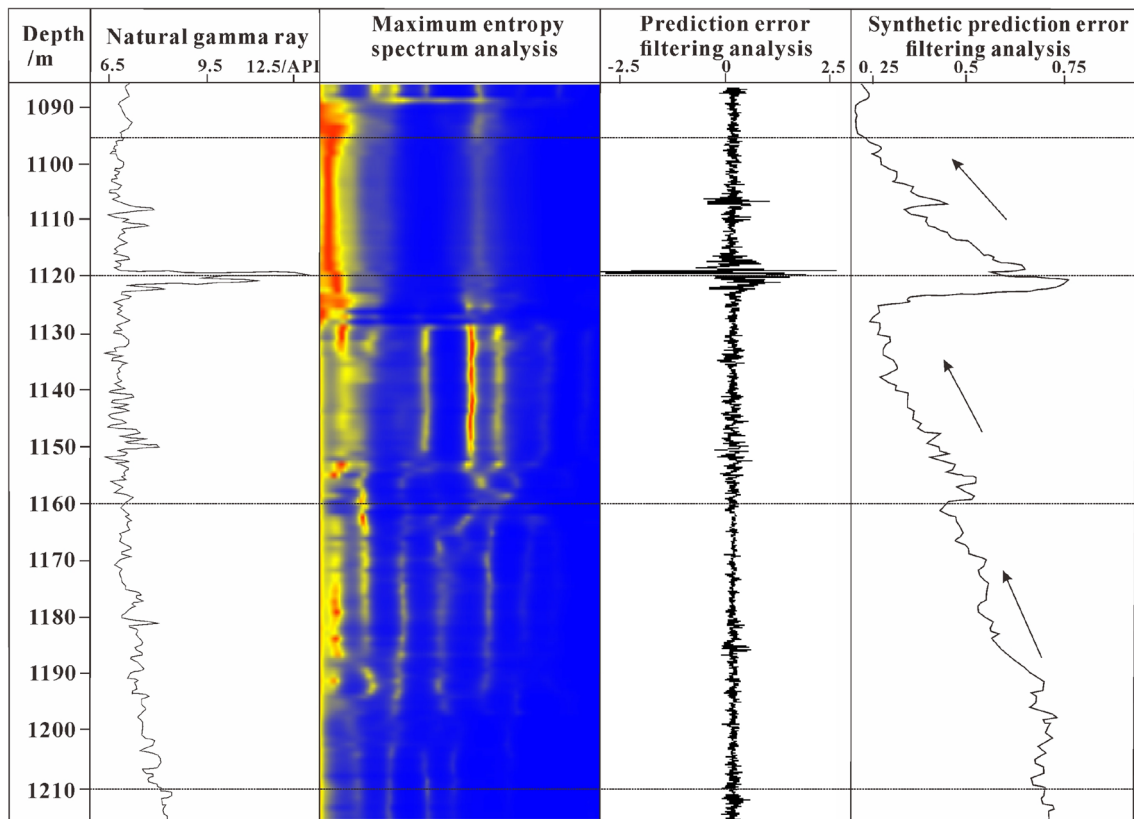INPEFA curve can identify the hidden sequence interface in conventional logging curves because its cyclicality

Fig. 1 INPEFA-GR curve synthesis diagram of well KL-2

changes to deposition are more obvious than that of conventional logging curves (Li 2013; Yuan et al. 2018). The different trends of INPEFA curve represent different geological significance (Soua 2012). INPEFA curve has two forms: positive trend and negative trend. The positive trend represents the process of increasing the argillaceous content, and the A/S value increases accordingly. The base level shows an upward semi-cycle, indicating that the argillaceous content is in the stage of diluvial or water inflow. The negative trend indicates that with the increase in sandstone and the decrease in mudstone, the A/S value decreases with it (Shehata et al. 2018, 2021). The base level shows A descending semi-cycle and is in the stage of water retreat. The position of the turning point represents the possible flood surface or sequence interface; the negative inflection point when the curve changes from a positive trend to a negative trend in most cases represents the flood surface; the positive inflection point when the curve changes from a negative trend to a positive trend represents the sequence interface (Yuan et al. 2018; Xue et al. 2015; Shehata et al. 2019). Sequence stratigraphic boundary and flood surface are the key interfaces for isochronous correlation of sequence stratigraphy; different variation amplitudes of INPEFA curve correspond to different levels of cycles.

The wavelet transform

The basic principle

Wavelet transform is a local transform process of time and frequency (Baka et al. 2017). By processing the independent variable t of the wavelet generating function $\psi(t)$, making the independent variable t close to the signal $f(t)$ after stretching (a) and shifting (b), the information extracted from the signal can be effectively multi-scale refined and analyzed (Srivardhan 2016; Tang 2006; Fang et al. 2007; Hassan et al. 2022). The continuous wavelet transform function $WT_f(a, b)$ of $f(t)$ is defined as:

$$WT_f(a,b) = |a^{\frac{1}{2}}| \int_{-\infty}^{\infty} f(t)\psi\left(\frac{t-b}{a}\right)dt \quad a \neq 0$$

The steps of wavelet transform (Liu et al. 2010; Ren et al. 2013) are as follows:

(1) Take a wavelet a_1 and compare it with the beginning segment of the original signal;
(2) Calculate $WT_f(a, b)$, as shown in (Fig. 2a), which represents the degree of correlation. between the starting signal and the selected wavelet. The larger $WT_f(a, b)$ is, the more similar they are.
(3) Translate the wavelet to the right and repeat (1) and (2) until all signals are covered, as shown in (Fig. 2b);
(4) Extend the wavelet a1 to a2 and repeat (1) ~ (3), as shown in (Fig. 2c).
(5) Repeat (1) ~ (4) for all scales a to obtain all $WT_f(a, b)$.

It can be seen from (Fig. 2) that continuous wavelet transform has the characteristic that time–frequency window can be harmonized and localized. It solves the contradiction between time and frequency resolution by changing the shape of time–frequency window, extracts information of different scales from it, and then divides the hierarchical interface of different levels (Shucong et al. 2014).

Basis of stratigraphic interface division

After wavelet multi-scale transformation of logging data, a series of wavelet transform coefficient values matching depth and scale can be obtained (Yan et al. 2009). The basis of dividing sequence stratigraphy by wavelet transform is: if the logging curve is superimposed by multiple cycles with different sedimentary cycles, there will be local energy mass changes on the wavelet time–frequency chromatogram, and periodic oscillations will occur under different scales of expansion and contraction. Through analyzing the cyclicity of strata, the corresponding relationship with sequence
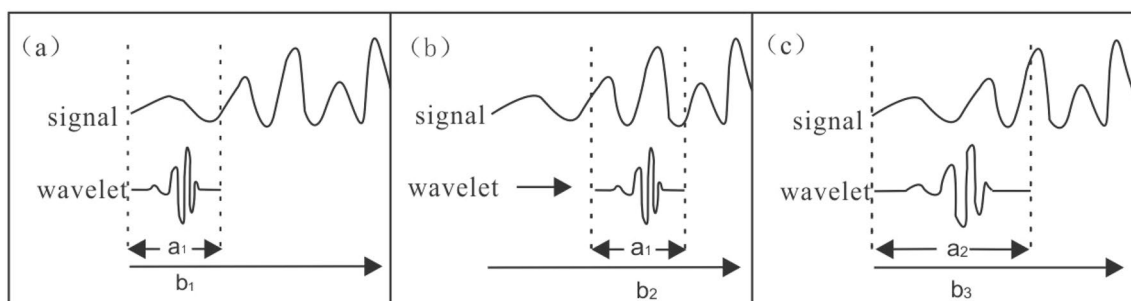

Fig. 2 General steps of wavelet transform

boundaries at all levels can be established (Chen et al. 2007). The scale factor a is positively correlated with the periodic component of the corresponding signal: the larger the scale value a is, the longer the periodic component is, and the larger the observation window is, indicating that the corresponding stratum has a large cycle thickness and a long deposition period, which are used to divide the sequence. On the contrary, when the scale is hour a, the corresponding strata with small cycle thickness and short deposition period can be used to classify the quasi-stratigraphic sequence and the base-level cycle (Xun et al. 2017; Li 2008).

The example analysis

Overview of the research area

Located in the east and south of North China, Bohai Bay Basin is one of the most important continental basins with oil and gas enrichment. KL Oilfield is located in the high part of the southern slope zone of Laizhouwan Sag in the southern Bohai Bay Basin. It is adjacent to the North Sag of Laizhouwan Sag in the north, the Weibei Uplift in the south, the South sub Sag of Laizhouwan Sag in the East, and the Tan Lu Fault zone in the West (Xin et al. 2013). It is controlled by strike slip faults and reverse depression controlling faults. Structural traps are developed and the trap shape is good (Fig. 3a). The strata revealed by drilling in the southern area of Laizhouwan Sag are quaternary Plain formation, Neogene Minghuazhen formation, Guantao formation, paleogene Dongying formation, Shahejie formation, and Kongdian formation from top to bottom (Duan et al. 2020a, b). Among them, Guantao formation and the lower Es_3 are the main oil-bearing strata, and the lower Es_3 are the target strata of this study. After the lithology of each well in the study area is corrected by using the element logging data, the

mixed sediments of the lower Es_3 in the south of Laizhouwan Sag are mainly carbonate-terrigenous clastic rocks, followed by terrigenous clastic rocks – carbonate rocks (Duan et al. 2020a, b). The clastic rocks mainly include mudstone, siltstone, argillaceous siltstone, fine sandstone and pebbled fine sandstone (Zhang et al. 2019) (Fig. 4).

Sequence division based on INPEFA -technique

The positive and negative inflection points of the INPEFA curve have a good correspondence with different sequence interfaces, and the level of sequence interfaces can also be clearly reflected on the INPEFA curve (Wang et al 2016). According to the principle of logging geology, different logging curves reflect different geological characteristics.

In view of the current situation that the lithology types of migmatites in the study area are diverse and the logging response characteristics of different lithology are complex, the INPEFA technology analysis is carried out on the spontaneous potential and acoustic curves to verify whether they are suitable for the division of sequence stratigraphy of migmatites in the study area. As shown in the figure, only the INPEFA-SP curves of well 2 and well 8 (Fig. 5) have good correspondence with the sequence stratigraphic division results in the study area, corresponding to the long-term base level decline half-cycle of the lower sub member of Es_3 member; for INPEFA-AC curve (Fig. 6), the logging response trend is complex, which is not applicable to the sequence stratigraphic division of migmatite in the lower Es_3 member of Laizhouwan Sag.

Compared with other logging curves, natural gamma curve is more sensitive to the change of shale content in the formation, and GR curve is selected to classify the stratigraphic sequence with the most accurate result (Lu et al. 2007; Adbel-Fattah et al. 2022). Therefore, GR curve was selected
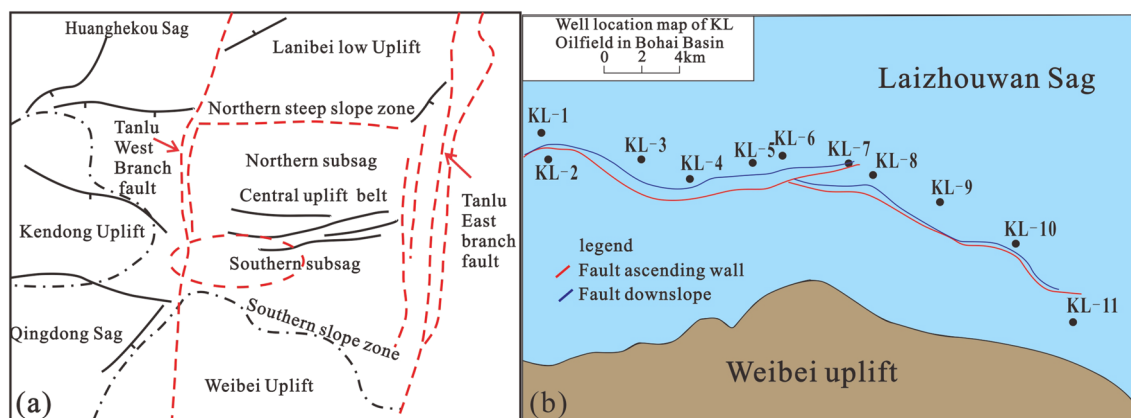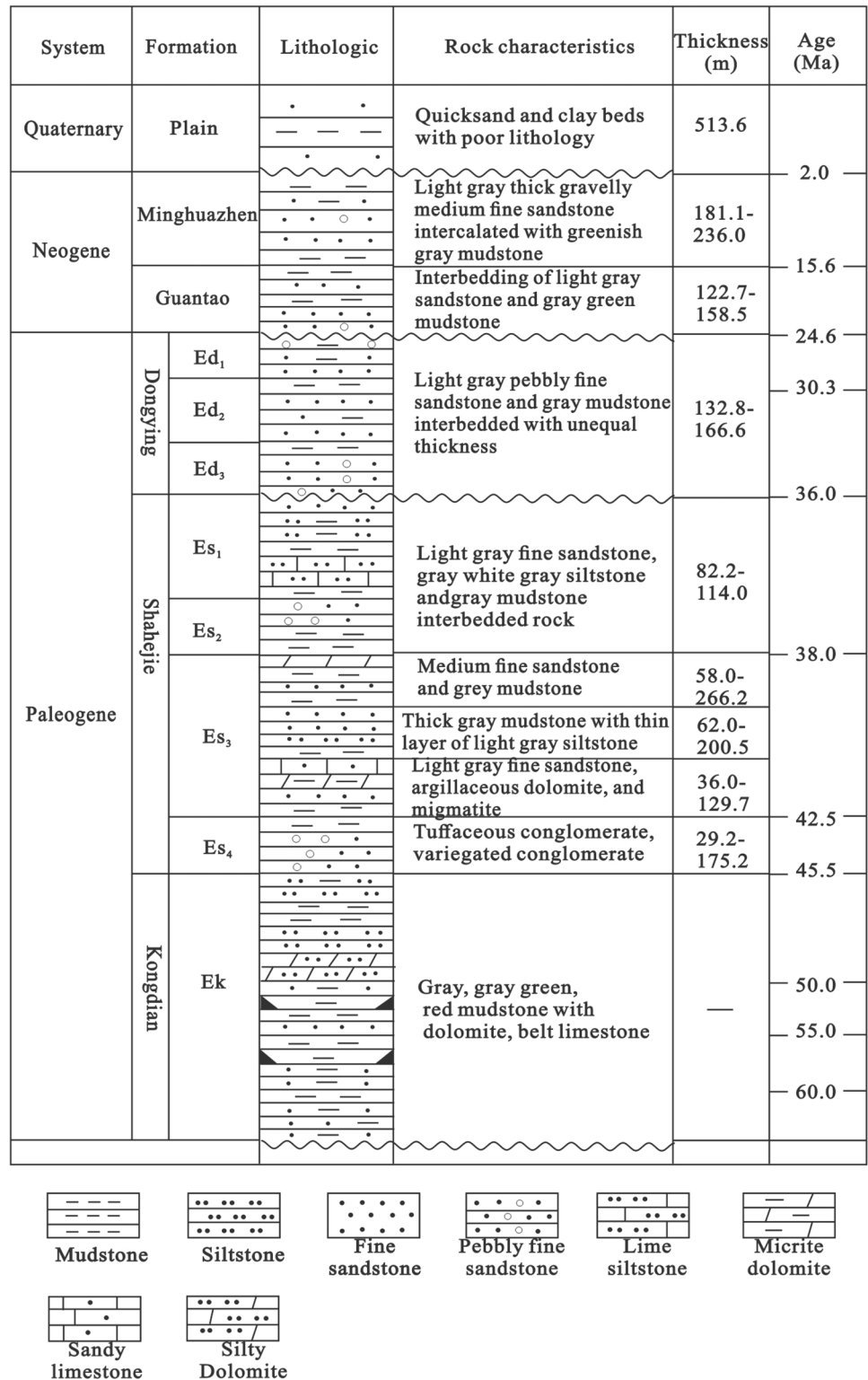

Fig. 3 Regional structural location map of KL Oilfield in Laizhouwan Sag and well location map of KL Oilfield **a** is the regional tectonic background map of KL Oilfield; **b** is the well location map of KL Oilfield

Fig. 4 Lithostratigraphy of the Laizhouwan Sag

System	Formation			Lithologic	Rock characteristics	Thickness (m)	Age (Ma)
Quaternary	Plain				Quicksand and clay beds with poor lithology	513.6	
Neogene	Minghuazhen				Light gray thick gravelly medium fine sandstone intercalated with greenish gray mudstone	181.1-236.0	2.0
	Guantao				Interbedding of light gray sandstone and gray green mudstone	122.7-158.5	15.6
Paleogene	Dongying	Ed₁			Light gray pebbly fine sandstone and gray mudstone interbedded with unequal thickness	132.8-166.6	24.6 30.3
		Ed₂					
		Ed₃					36.0
	Shahejie	Es₁			Light gray fine sandstone, gray white gray siltstone andgray mudstone interbedded rock	82.2-114.0	
		Es₂					38.0
		Es₃			Medium fine sandstone and grey mudstone	58.0-266.2	
					Thick gray mudstone with thin layer of light gray siltstone	62.0-200.5	
					Light gray fine sandstone, argillaceous dolomite, and migmatite	36.0-129.7	42.5
		Es₄			Tuffaceous conglomerate, variegated conglomerate	29.2-175.2	45.5
	Kongdian	Ek			Gray, gray green, red mudstone with dolomite, belt limestone	—	50.0 55.0 60.0

Legend: Mudstone, Siltstone, Fine sandstone, Pebbly fine sandstone, Lime siltstone, Micrite dolomite, Sandy limestone, Silty Dolomite

in this paper to analyze the variation trend of INPEFA curve and identify the sequence interface of the lower Es₃ by combining core and logging data.

Third-level sequence interface recognition

The Lower Es₃ in the study area of the southern gentle slope belt of Laizhouwan Sag can be regarded as a third-level sequence on the whole, which is equivalent to a long-term
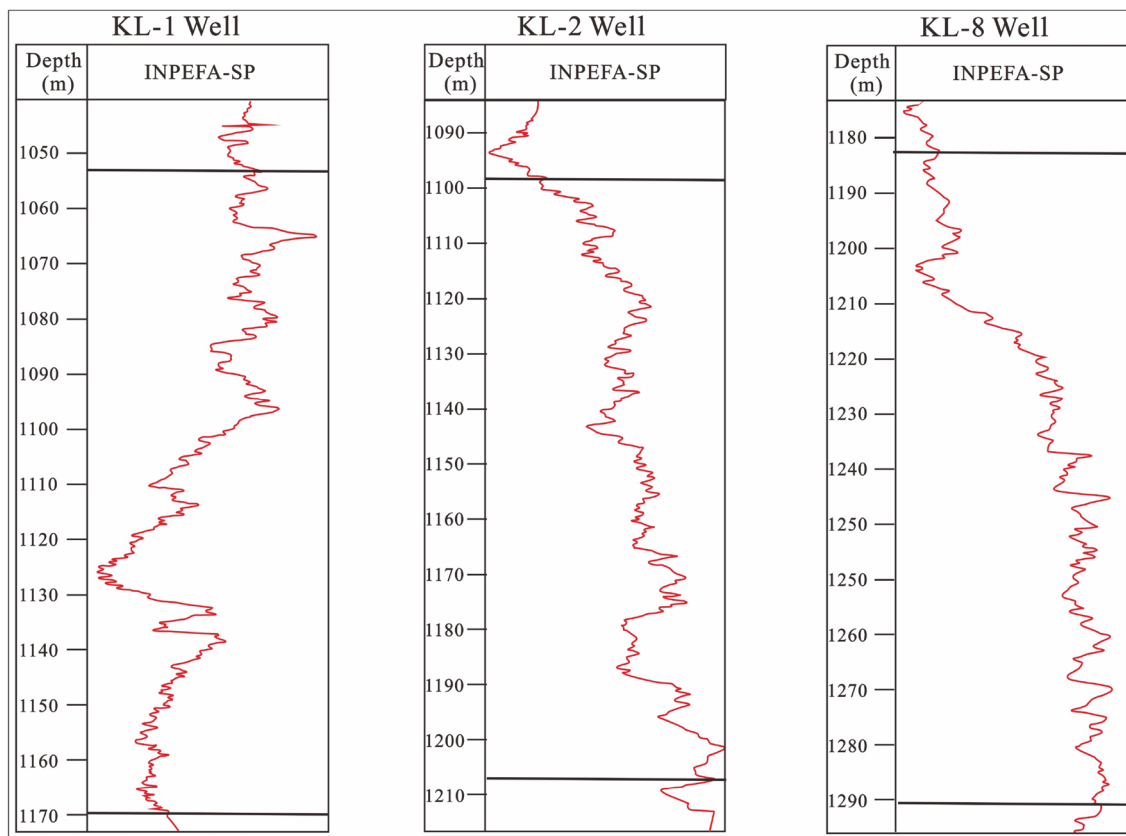
Fig. 5 Sequence interface recognition based on INPEFA-SP curve

base-level decline semi-cycle. In the study area, the bottom and lower strata of Es₃ lower sub member are identified by seismic data (Fig. 6). The bottom interface SB1 of the lower member of Es₃ in the southern gentle slope zone of Laizhouwan Sag shows the characteristics of micro-angle unconformity on the seismic profile. The seismic reflection T6 marker layer corresponds to SB1, which is a relatively continuous strong phase reflection traceable in the whole region. The top boundary SB2 of the third-level sequence of the lower Es₃ sub member is in micro-angle integrated contact with the middle Es₃ sub member overlying the large mudstone layer. The reflection T5 marker layer corresponds to SB2, and T5 reflects a relatively continuous strong phase reflection traceable in the whole region (Wang et al. 2020).

Above the top interface SB2 of the lower sub member of Es₃ in the study area is a thick mudstone (Fig. 7a) with a thin layer of light gray siltstone (Fig. 7b) at the bottom of the middle sub member of Es₃. The base value of the mudstone of the natural gamma curve is relatively low, which is easy to identify in the whole area. The bottom interface SB1 is the sedimentary discontinuity of the lower sub member of Es₃ and Es₄. A large section of reddish brown or brown pebbly fine sandstone is developed in the lower part (Fig. 7c), and most of the upper part is calcareous continental carbonate

rocks (Fig. 7d) that show high natural gamma value and low spontaneous potential value on logging. INPEFA-GR curve turns from ascending half-cycle to descending half-cycle, and it is a negative trend inflection point at the bottom interface (Fig. 8).

Fourth-level and fifth-level sequence interface recognition

The INPEFA curve based on maximum entropy spectrum analysis can better reflect the short-term sedimentary environment change process of grade IV and V. On the basis of the research of third-level sequence interface, the fourth-level and fifth-level sequence interface are identified by INPEFA technology. The inflection point of INPEFA curve indicates the change of sedimentary environment. Wells KL-1, KL-2 and KL-8 in the study area were selected for INPEFA curve analysis of their natural gamma ray curves (GR), with complete formation development, obvious logging curve characteristics and no drilled fault. As can be seen from (Fig. 9): (1) The overall trend of INPEFA curve of 4 wells is a water regression process, which corresponds to the long-term base level decline half-cycle of lower Es₃ sub member; (2) each inflection point and corresponding trend are obviously consistent, corresponding to one layer,
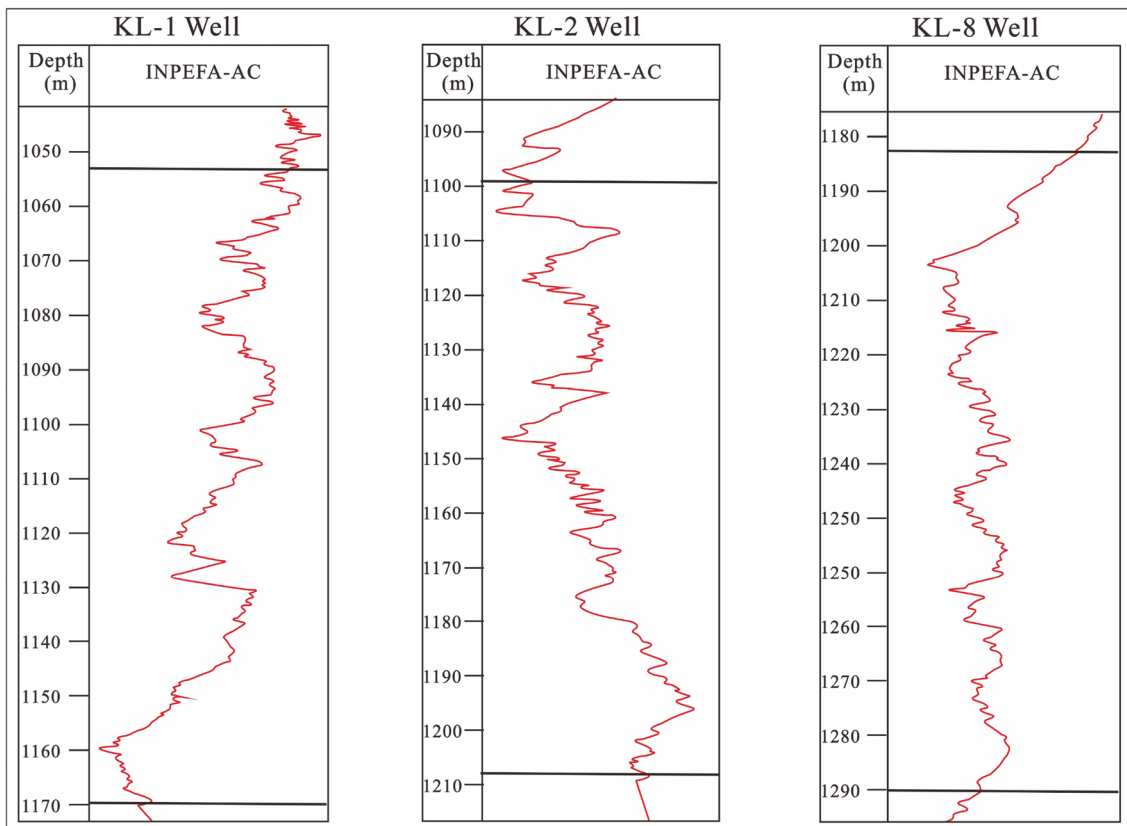
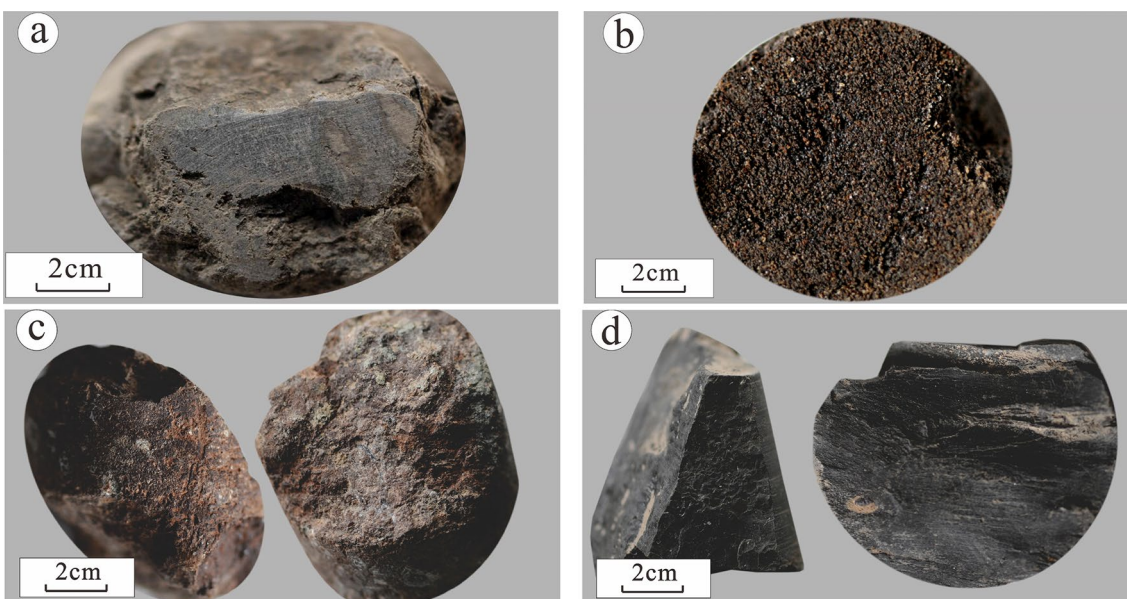**Fig. 6** Sequence interface recognition based on INPEFA-AC curve

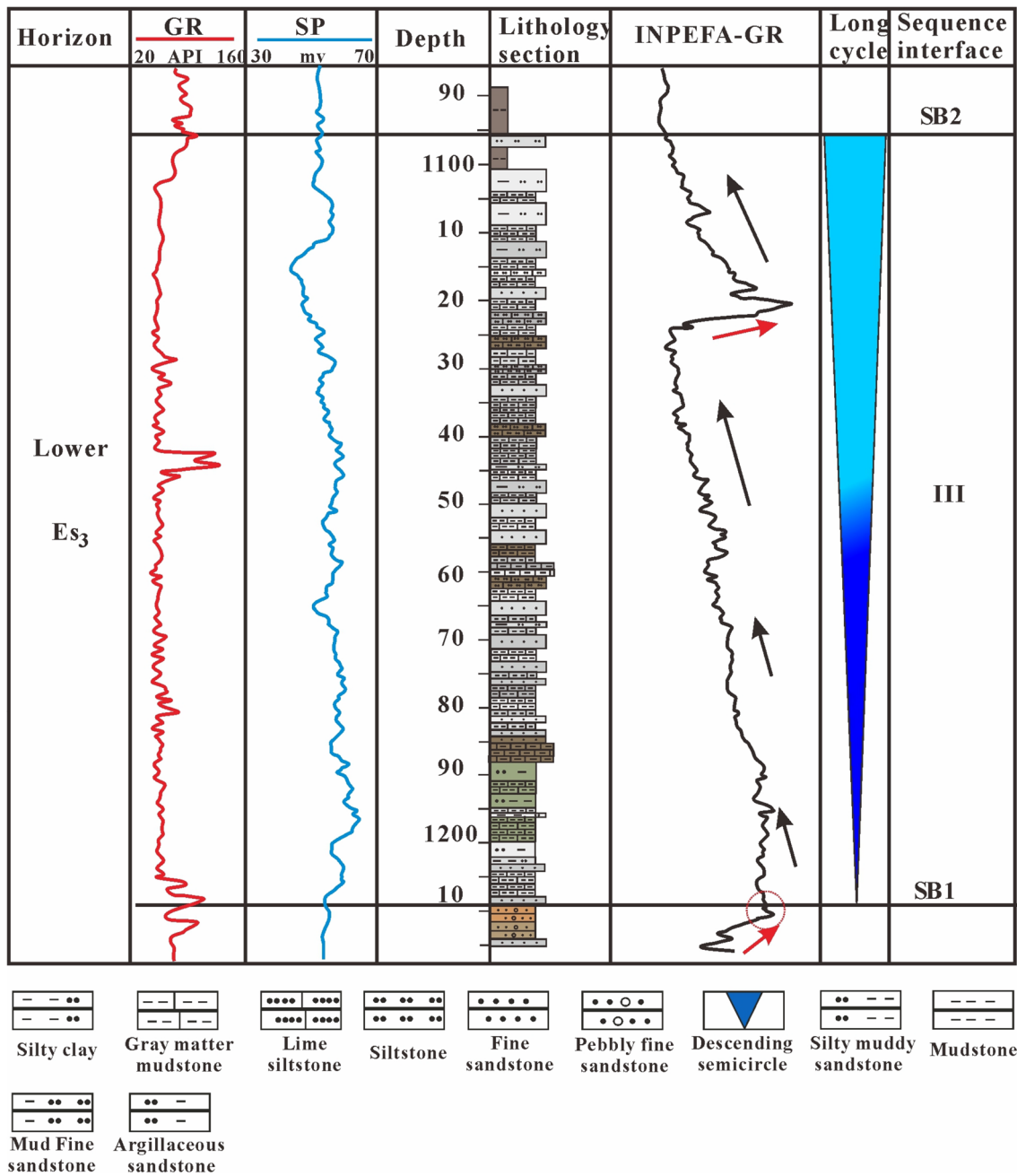**Fig. 7** Top and bottom core of research well section

Fig. 8 Well KL-2 top–bottom interface logging—Lithologic feature map of the third-level sequence

respectively. The sequence boundary and change trend of each layer are consistent, and the inflection point corresponding to the sequence boundary is very clear; (3) each layer of the four wells is marked with lines. The negative inflection point corresponds to the possible flood surface, and the positive inflection point corresponds to the possible sequence boundary. A total of two negative inflection points with the same trend are identified and divided into three fourth-level sequence: I, II and III.

On the basis of the fourth-level sequence interface recognition in INPEFA, five fifth-level sequence interfaces were identified and the lower Es_3 was divided into nine small layers. It can be seen that the internal cycle is not stable, and some inflection points at the interface are prominent and easy to distinguish: the II-1 and III-1 layers in well KL-1, and III-2 layers in well KL-8, etc. However, some interfaces cannot be accurately judged according to the trend of INPEFA curve.
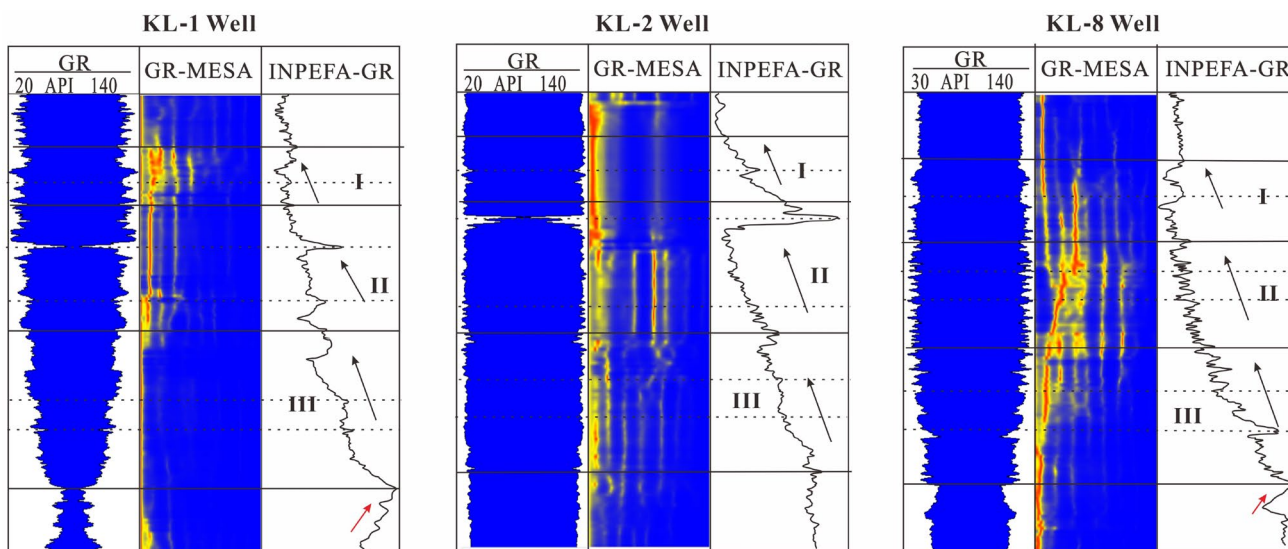
Fig. 9 Comparison grid for fourth-level sequence interface recognition based on INPEFA technology

Sequence division based on wavelet transform

The lower Es_3 in the study area of the south gentle slope belt of Laizhouwan Sag is selected as the research object. Well KL-1 was selected as the study well, and the study well segment was 1049–1165.8 m, and the formation thickness of the target layer was 116.8 m. In this study, the maximum scale of Morlet wavelet is 64, and GR curve is selected for the stratification. After the wavelet multi-scale transformation, the frequency structure in the natural gamma curve will become very obvious, and the abrupt point and abrupt block between each frequency segment will be detected, which represents the abrupt change in the formation environment geologically (Li et al. 2005).

Figure 10a is the original GR curve. The abscissa is the depth value, which increases from left to right. The coordinate value is the ordinal number of sampling points.

The ordinate is GR logging value. Figure 10b shows the time–frequency chromatogram of the wavelet transform coefficient obtained after Morlet wavelet transform. The horizontal axis is the depth displacement axis b that is the ordinal number of sampling points, and the vertical axis is the scale factor a. The higher the GR value is, the higher the shale content is. The higher the color brightness in the chromatogram, the higher the wavelet coefficient value. After the wavelet transform, the logging curve becomes a function in the two-dimensional depth-scale domain, and different scales and depth domains show different periodic changes (He 2010). What needs special explanation is that the wavelet transform has boundary effect, that is, the coefficient value at the boundary is abnormally large, which will lead to obvious bright color at the left and right boundary of the chromatogram.
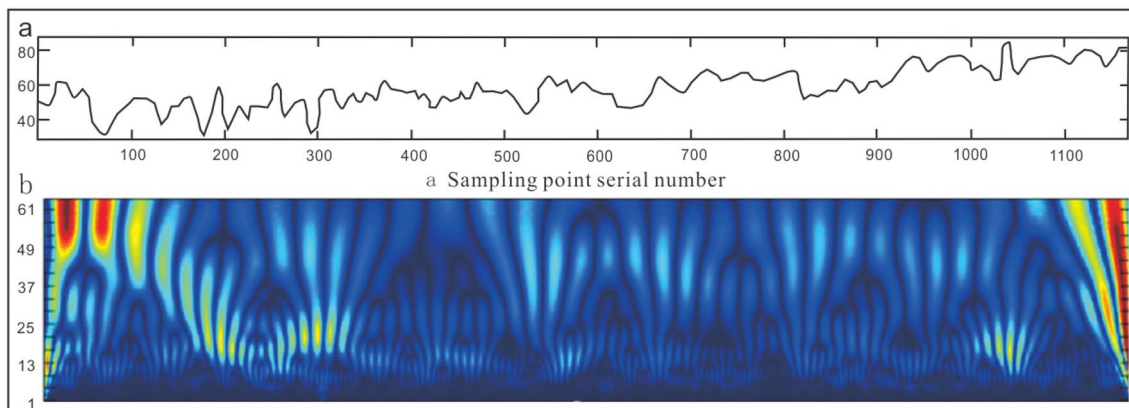

Fig. 10 Continuous wavelet transform diagram of well logging signals in well KL-1

Large-scale sedimentary cycle interface, that is, sequence or quasi-sequence group interface, corresponds to the position of large-scale bright color in chromatogram. Many small-scale sedimentary cycles, or quasi-sequences, are nested inside large-scale cycles (Li et al. 2006). The periodic variation characteristics of time–frequency chromatography of wavelet were compared with the sedimentary cycle characteristics of well KL-1. When the scale factor A was in the range of 50–71, the brightness position had a good correspondence with the third-level sequence interface. The periodic variation of the small-scale factor between 25 and 37 has good correspondence with the short- and medium-term cycle, which can be used for the identification of fourth-level sequence interface. The small-scale factor between 6 and 14 can be applied to the identification of fifth-level sequence interface. The maximum value is calculated according to the modulus average of GR curve on different scales. According to the position of the maximum value, the optimal scale factor a corresponding to different frequency components in the signal can be determined.

Figure 11 shows the wavelet coefficient curve when the scale factor a of well KL-1 is equal to 64, 32 and 8. It can be seen that the oscillation trend characteristics of the wavelet curve are different with different scale factors. The larger the scale factor, the smoother the wavelet curve. The Morlet wavelet scale factor selection method was used to make the modulus average of GR curves on different scales, and then, the mean component was compared. Finally, the scale factors with scales of 32 and 8 are selected as the best scale to divide the interface of fourth-level and fifth-level sequence interface (Zeng 2008) (Fig. 12). Generally, the place where the wavelet coefficient curve oscillates violently corresponds to the place where the sandstone is developed, and the place where the oscillation is gentle is the place where the mudstone is relatively developed. Therefore, according to the periodic oscillation trend of wavelet coefficient curve, the sequence can be divided.

As can be seen from Fig. 11, when the scale of wavelet transform a = 32, there are two obvious periodic cycle interfaces corresponding to the fourth-level sequence interface, that is, the number of sampling points on the horizontal axis
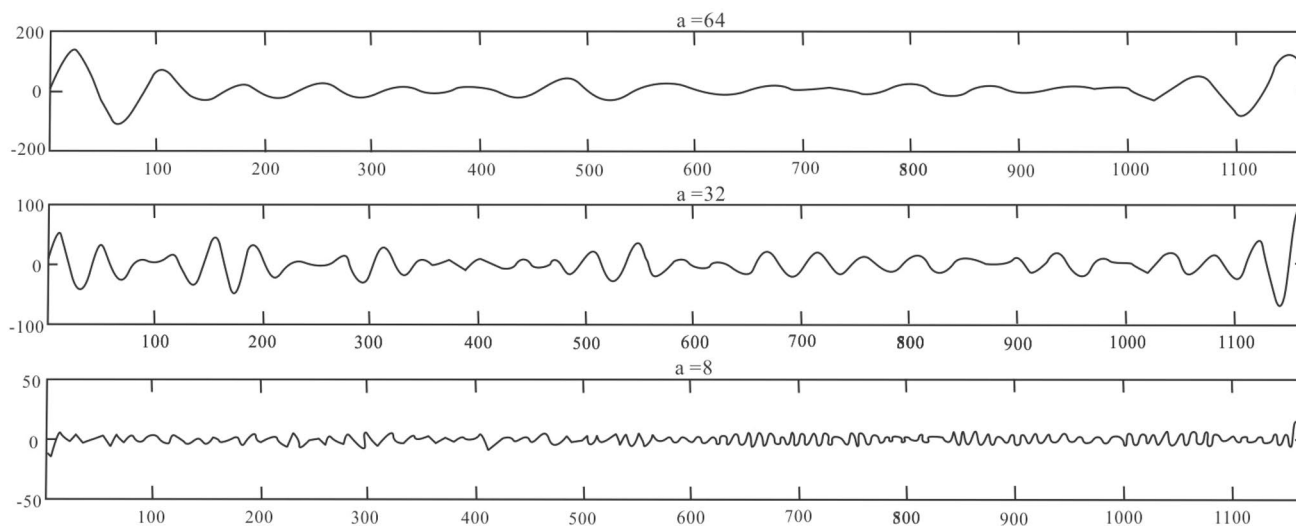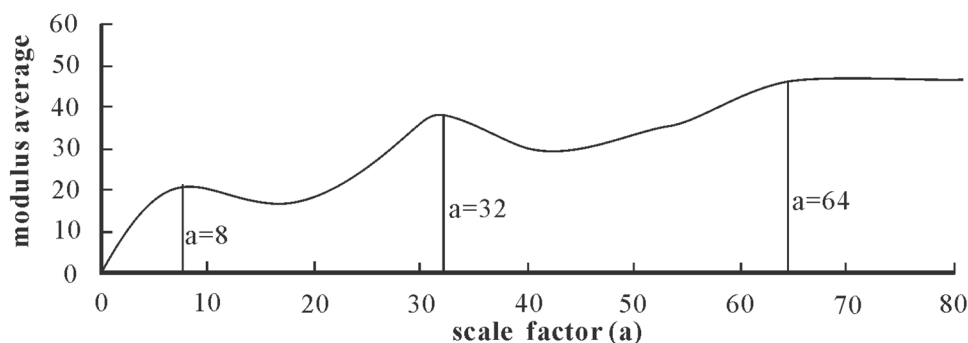

Fig. 11 Wavelet coefficient curves of well KL-1 under different scale factors

Fig. 12 Curve of Average Value of Wavelet Coefficient Scale Absolute Value

ranging from 200 (1070.02 m) to 635 (1114.30 m) layer segment wavelet curve is significantly different from the upper and lower two segments, so the whole target segment can be divided into three parts. It should be pointed out that the interface of wavelet coefficient division at different scales needs to be combined with traditional division methods to achieve better results.

Discussion

Sequence stratigraphic division is the basis of oil and gas geological research. When the seismic and core data are incomplete, the sequence can be divided by GR curve. The logging data can be processed by using INPEFA technology, wavelet transform and other methods, so that the trend of the processed logging curve is more obvious. However, these two methods are largely affected by human factors, and the core and other data are incomplete. The single use of a certain technical method cannot meet the requirements of high-resolution sequence stratigraphic division. Both INPEFA technology and wavelet transform can process GR curve, and the cycle trend of GR curve after processing is more obvious. The combination of INPEFA technology and wavelet transform can more clearly reflect the change trend of sedimentary cycle in the stratum, reduce the interference of human factors to a great extent, and meet the requirements of high-resolution sequence stratigraphic division.

Based on the differences between the above two sequence stratigraphic classification methods, with comprehensive reference to lithology, logging and other data, this paper comprehensively applies the above two methods to identify sequence interface. The specific classification method is as follows:

(1) Both INPEFA and wavelet transform can divide the target interval of the study area into three fourth-level sequence, which reflects the effectiveness of the two methods in sequence stratigraphic division. Because the oscillation of the wavelet transform curve cannot accurately identify the sequence interface, the sequence interface can be determined by using the obvious trend inflection point of the INPEFA curve, and the sequence interface determined by the INPEFA curve can be compared to whether the sequence interface is within the oscillation region of the wavelet curve.

(2) When using INPEFA technology to divide the small layers, some of the trends are not obvious due to the small thickness and short deposition time of the small layers. Therefore, on the basis of the subdivision of small layers by INPEFA technology, the results of the subdivision of INPEFA are compared and verified according to the stability of the internal cycles of the wavelet coefficient curve, so as to ensure the accuracy of the subdivision of small layers.

According to the above method, On the basis of referring to the stratification of other wells and combined with INPEFA technology, the natural gamma curve is processed. Two inflection points are identified as the fourth-level sequence boundary within 1068.02–1109.30 m of Es_3 lower sub member of well KL-1. Therefore, according to these two boundaries, well KL-1 is divided into three fourth-level sequence. Based on the identification of the fourth-level sequence boundary that is divided by INPEFA division of small layers, using the wavelet coefficient curve and the obvious fourth-level sequence interface when the scale factor $a = 32$. The results are consistent. Then, the fifth-level sequence is divided when the scale factor $a = 8$. Compared with INPEFA division results, most cases are consistent, and a few cases need to be adjusted slightly. II-2 is a large section of dark gray marl, adjusted from 1110.62 to 1097 m. This is exactly the lithology change surface (Fig. 13).

The natural gamma ray curve was processed by using INPEFA technology and wavelet transform comprehensively. According to its cycle trend, the lower Es_3 in Laizhouwan Sag was divided into 1 long-term cycle, 3 medium-term cycles and 8 short-term cycles. In the process of sequence interface identification and division, both of them have their own advantages and disadvantages. When INPEFA technology determines the sequence interface according to the curve trend, it has a high resolution in the identification of the third-level and fourth-level sequence interface. The positive and negative trends of the curve change significantly and the inflection points are prominent. When the fifth-level sequence is identified, that is, the interface of small layers is identified, the local analysis of INPEFA curve shows that the trend changes of some curves are not obvious (Fig. 13). Wavelet transform method is more suitable to analyze the cyclicity of logging curve, change of wavelet coefficient curve can get a different levels of base-level cycle, especially in the small layers interface recognition, its internal cycle more stability, its shortcoming is relative to the INPEFA technology, in the low resolution of sequence interface recognition, when determining the sequence interface need to adjust according to the seismic and core data.

In view of the characteristics of many small layers in the study area and the lack of comparison of previous studies, the two methods should be combined in the division of sequence stratigraphy, which is helpful to divide the high-frequency cyclic sequence stratigraphy of mixed sedimentary strata in the study area, and then establish the high-frequency isochronous level related stratigraphic framework. Based on the division of high-resolution strata, the study of mixed sedimentary facies is more accurate, which can be more accurate for the intervals of favorable reservoirs, and finally helps the fine description of oil and gas accumulation in the study area and other migmatite blocks.
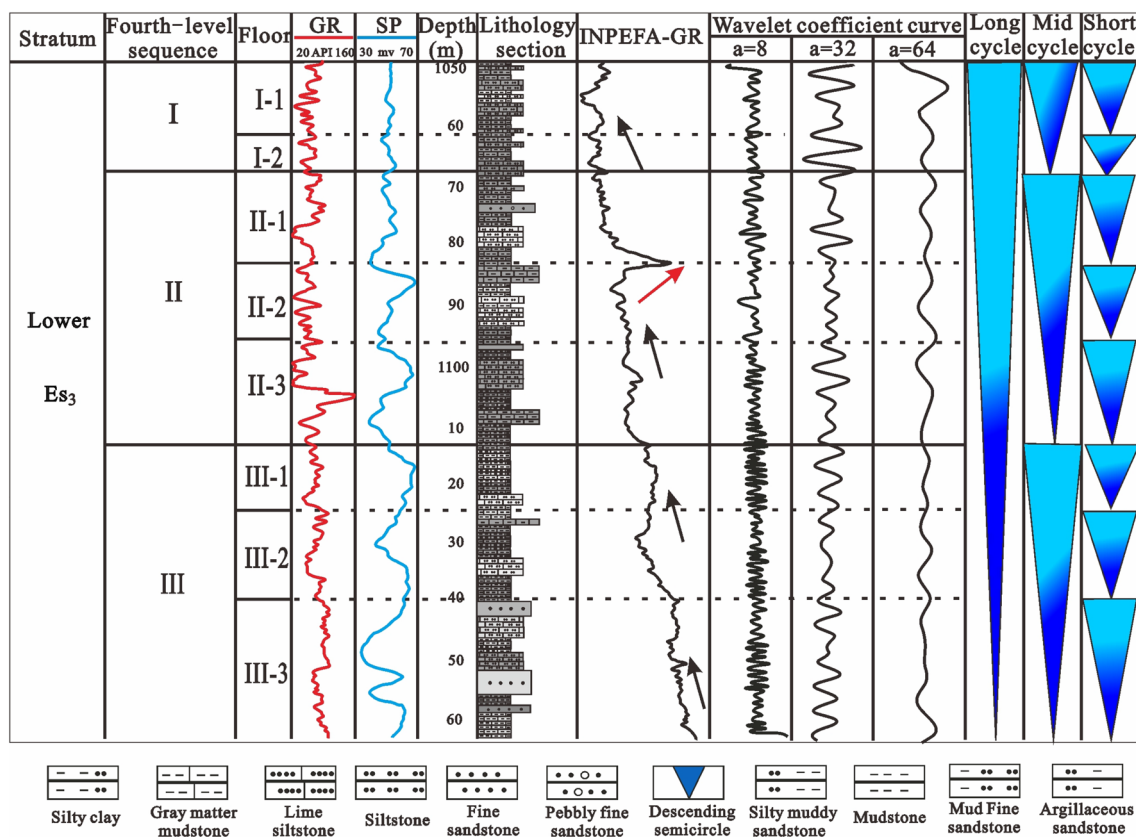
Fig. 13 KL-1 Comprehensive chart of sequence stratigraphic division

Conclusion

(1) Both INPEFA technology and wavelet transform can be applied to sequence stratigraphic division to identify the changing trend and abrupt surface of logging information. The two methods can be mutually verified in sequence stratigraphic division. In view of the current situation that the lithology types of migmatite in the study area are diverse and the logging response characteristics of different lithology are complex, a combination of the two methods is adopted in sequence stratigraphic division. The sequence boundary is determined by INPEFA technology and the internal cyclicity is analyzed by wavelet transform, the lower Es_3 member in Laizhouwan Sag is divided into 1 long-term cycle, 3 medium-term cycles and 8 short-term cycles, which makes the sequence stratigraphic division of the lower Es_3 member more accurate.

(2) Applying INPEFA and wavelet transform to sequence division of the GR curve is highly applicable in the lower Es_3 of Laizhouwan Sag, while SP and AC curves are not applicable to the sequence stratigraphic division of the study area.

(3) In the logging curve is used to analyze the sequence stratigraphy division, it is better to put the two methods, the combination of INPEFA technology to identify the sequence interface, realize the division of three or four class sequence, on the basis of the wavelet transform method for 5 sequence division, to improve the reliability of sequence stratigraphic classification, accuracy.

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