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Study of sedimentary sequence cycles by well-seismic calibration

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Abstract: In order to solve the problems of the fine division of sedimentary sequence cycles and their change in two-dimensional space as well as lateral extension contrast, we developed a method of wavelet depth-frequency analysis. The single signal and composite signal of different Milankovitch cycles are obtained by numerical simulation. The simulated composite signal can be separated into single signals of a single frequency cycle. We also develop a well-seismic calibration insertion technology which helps to realize the calibration from the spectrum characteristics of a single well to the seismic profile. And then we determine the change and distribution characteristics of spectrum cycles in the two-dimensional space. It points out the direction in determining the variations of the regional sedimentary sequence cycles, underground strata structure and the contact relationship.

Key words: Sedimentary sequence cycles, wavelet depth-frequency analysis, well-seismic calibration, spectrum cycles, well logging

1 Introduction

Sedimentary strata are not only characterized by layered properties, but also cyclicity. The complicated periodic motions are mostly the superimposition of simple periodic motions with different periods in nature. Sedimentary cycles are the periodic repeating of sedimentary events (Mitchum and Van Wagoner, 1991; Wang et al, 2002; Rudman and Lankston, 1973). Though many experts and scholars have done a lot of research to separate these complex strata with multistage superimposition into single stratum of a single period by using Fourier transforms, short-time Fourier transforms, Periodogram methods and wavelet transform algorithms to solve problems of sedimentary cycles (Goldhammer et al, 1993; 1990; Doveton, 1994). These algorithms only extract the spectrum characteristics to analyze the variations in sedimentary cycles by simply processing a list of seismic data or well logging data, and both the accuracy and precision of sedimentary cycle analysis need to be further improved. All in all, the problems of frequency cycle variations in two-dimensional space remain unsolved. Moreover, the mechanism of analyzing sedimentary cycles by these mathematical algorithms is not clear yet.

Based on the current situation and above problems, this paper develops the method of wavelet depth-frequency analysis. The typical cycle—Milankovitch period cycle is obtained by a numerical simulation method (Meyers et al, 2008; Zheng et al, 2007), and the simulated composite signals have been separated into single signals of singe frequency cycle. This paper also develops the well-seismic calibration insertion technique which helps to realize the calibration from the spectrum characteristics of a single well to the seismic profiles. And then we determine the two-dimensional continuation properties of spectrum cycles. Hence it indicates the direction on the variations of the regional sedimentary sequence cycles.

2 Wavelet depth-frequency analysis method and numerical simulation of sedimentary sequence cycles

2.1 Wavelet depth-frequency analysis method

The wavelet depth-frequency analysis method is based on time-frequency analysis, and it uses a one-dimensional wavelet transform algorithm. The data at different depths are processed by using new methods of "frequency division

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process along layer (FDPAL) multi-scale automatic processing" and "high resolution reconstruction of the frequency division sections (HRRFDS)", finally the depth-frequency profiles are gradually unfolded in the order of frequency from high to low. The geological features are reflected by this profile and the geological targets are one-to-one mapping, and this profile reflects and portrays the characteristics of high frequency sequence cycles particularly. This method mainly processes the well logging data to extract the characteristics of spectrum cycles. It also can be used to process seismic, electrical, and gravity data to extract the characteristics of spectrum cycles. The decomposition and reconstruction of logging data are the foundations of depth-frequency analysis. Both the decomposition of a single logging curve or the coupling curve of multiple logging curves and reconstruction of them into frequency-division sections with different frequency bands are based on the decomposition of the wavelet. It is assumed that the well logging signal or reflection coefficient is $f(t)$, then its continuous wavelet transform (Li and Liu, 2002; Xu et al, 2009) is:

$$W_{\Psi}^{f}(a,b)=\frac{1}{\sqrt{c_{\Psi}}}\frac{1}{\sqrt{|a|}}\int\Psi(\frac{b-\tau}{a})f(t)\mathrm{d}t \tag{1}$$

where

$$c_{\Psi}=2\pi\int\frac{\left|\overline{\psi}(\omega)\right|^{2}}{|\omega|}\mathrm{d}\omega \tag{2}$$

$$\overline{\psi}(\omega)=\frac{1}{\sqrt{2\pi}}\int\Psi(t)\mathrm{e}^{-i\omega t}\mathrm{d}t \tag{3}$$

In Eq. (1), $W_{\Psi}^{f}(a,b)$ is the analyzing wavelet or continuous wavelet, and is the wavelet coefficient values in practical processing, dimension a, location b, translation point τ, signal factor t, admissibility condition c_{Ψ}, and mother wavelet $\Psi(t)$, the Morlet wavelet was used in this paper. $\overline{\psi}(\omega)$ is spectrum of $\Psi(t)$, and it reflects the characteristics of cycles. It is noted that the above parameters are all scalars with no units. We call it the reconstruction of $f(t)$ or reverse wavelet transform when we get $f(t)$ from $W_{\Psi}^{f}(a,b)$ and wavelet function $\Psi(t)$.

$$f(t)=\frac{1}{\sqrt{c_{\Psi}}}\iint|a|^{-\frac{1}{2}}\Psi(\frac{t-b}{a})W_{\Psi}^{f}(a,b)\frac{\mathrm{d}a\mathrm{d}b}{a^{2}} \tag{4}$$

In Eq. (4), the energy conservation and isomorphism between $f(t)$ and $W_{\Psi}^{f}(a,b)$ are ensured to some degree.

The main function of the method: 1) Improving the vertical and horizontal resolution, extracting the response characteristics of spectrum cycles, and it should truly reflect and portray the sedimentary sequence cycles. In addition, it is a one-to-one relationship between extracted spectrum cycles and the underground sedimentary sequence cycles, and we can also invert some other sedimentary characteristics; 2) A high anti-interference ability; 3) The cycle interfaces are shown clearly, and spectrum cycles of different frequency can be used to divide sedimentary cycles of different levels.

2.2 Numerical simulation of sedimentary sequence cycles

Sedimentary sequence cycles are characterized by periodicity, rhythmicity, and cyclicity (Van Wagoner et al, 1990; Berger, 1988; Kemp, 1982; Xu et al, 2009), and how can we extract these characteristics or reduce complex sedimentary sequence cycles into a single period cycle? How can we use numerical methods or geophysical methods to describe and calibrate single or complex sedimentary sequence cycles? Based on these problems, we choose a typical type of sedimentary sequence cycles—the Milankovitch cycle as the object of numerical simulation in order to calibrate the characteristics of sedimentary cycles. The Milankovitch cycle is generally acknowledged as a high frequency sequence cycle, and is controlled by eccentricity, precession, and obliquity, which are three period parameters of the earth orbital motion. The periodic variations of the three period parameters of the earth orbital motion contribute to the periodic superimposition succession of the sedimentary strata, and the Milankovitch sequence cycle is formed in this way (Shanley and McCabe, 1994; Galloway, 1989). Numerical simulation methods are used to simulate the single signal and composite signals of the three periodic parameters of earth motion: eccentricity, precession, and obliquity, then we analyze the spectrum of these signals and the characteristics of the Milankovitch cycle. In this way we can find out the characteristics of the sedimentary sequence cycles. According to the results of the simulation, we can focus on the research of the sedimentary sequence cycles of actual strata (well logging or seismic signals).

Fig. 1 is the simulation of the three periodic parameters of earth motion (eccentricity, precession, and obliquity), and the five single sine signals are the respective simulations of the five earth movement periodic parameters: the long eccentricity (M413ka), the short eccentricity (M100ka), the precession (M40ka), the long obliquity (M22.5ka), and the short obliquity (M19ka). The superimposition of these five single signals forms a composite signal. Suppose in Fig. 1 it is a set of strata 180 m thick, this stratum is the superimposition of five stratigraphic units with different frequency, and all information of the stratum is contained in the composite signal. The composite signal is composed of five single signals of different frequency, and there are 3 long eccentricity cycles, 14 short eccentricity cycles, 35 obliquity cycles, 63 long precession cycles and 75 short precession cycles. The above information is the simulation result of typical sedimentary sequence cycles (Milankovitch cycle), and it can be seen directly from Fig. 1.

When it comes to the research into the division of real strata, at first we do not know how many stratigraphic units are included in the strata, and the level, thickness, and deposition time of each stratigraphic unit remain unknown. By the present research methods, what can we get are only

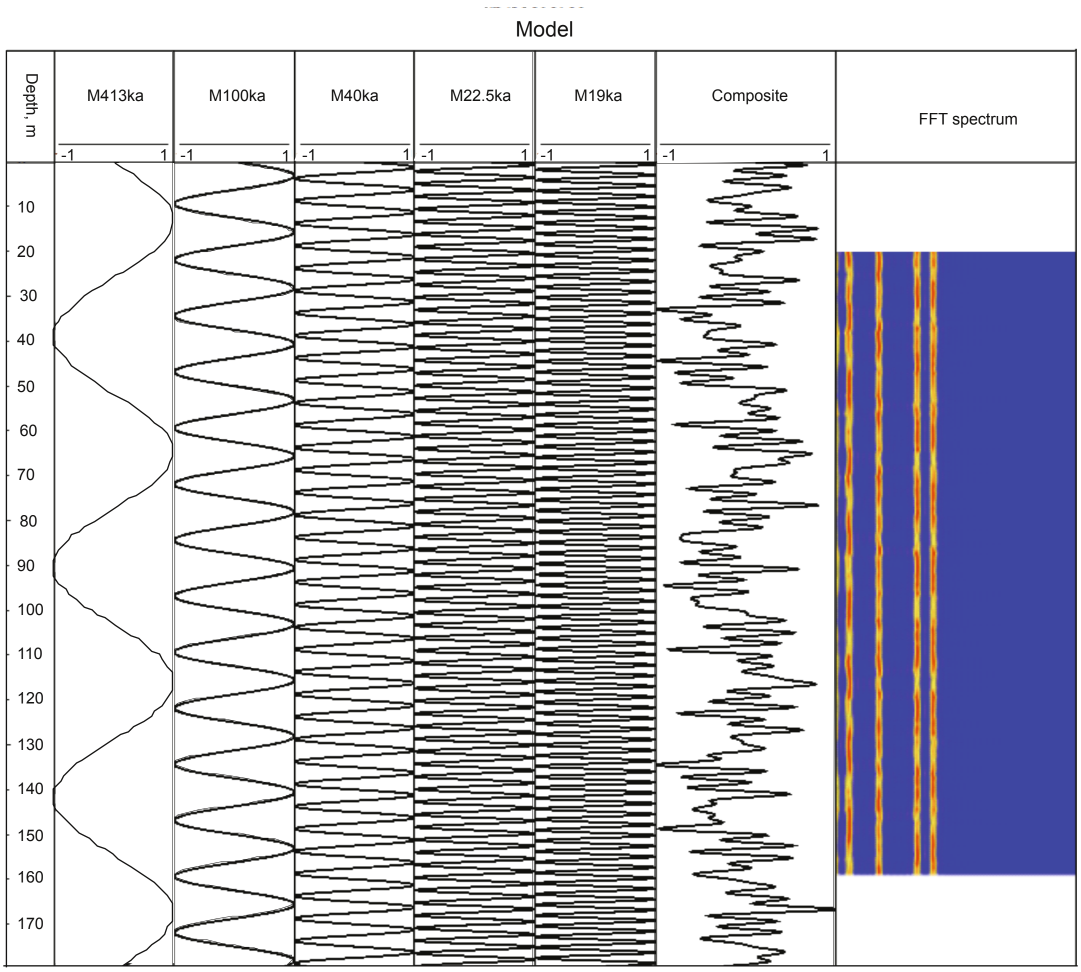

Fig. 1 The numerical simulation results of the sedimentary sequence cycles—Milankovitch cycles

the stratigraphic units or boundaries at a high level. Hence there are many differences existing in determining the number, level, and thickness of small stratigraphic units as well as recognizing the boundaries. Although in the actual formation research, the most powerful material is the division of stratigraphic units according to seismic profiles and well-logging curves, there are many different division results. Hence there are always multiple solutions and there are no uniform international standards yet. The second column on the right in Fig. 1 is the composite signal, which is the superimposition of the numerical simulated single signals. The composite signal contains all kinds of information of the strata, and it is equivalent to the well-logging signal of the actual strata. The last column on the right in Fig. 1 is the frequency information figure which is transformed and picked up from composite signals by fast Fourier transform (FFT). We can see that the composite signals contain five different frequencies, that is to say, the composite signals can be separated into five single signals of different frequencies. Every single signal corresponds to a certain parameter of the earth orbit motion, and every parameter corresponds to a certain sedimentary sequence cycle. So five different frequency components reflect five sedimentary cycles with different sedimentary thickness and different deposition time. It means this set of strata is composed of five stratigraphic units with different sedimentary cycles.

Fig. 2 is the amplitude spectrum diagram extracted from the analysis of the composite signals, and it is the spectrogram of wavelength and amplitude. We can see that this spectrogram contains five different wavelengths, every wavelength corresponds to a main frequency, so it has five main frequencies. Every wavelength (main frequency) corresponds to a deposition period, and there are five deposition periods, 413ka, 100ka, 41ka, 23ka and 19ka. These five deposition periods correspond to five orbit parameters respectively. It points out that this set of strata not only includes the Milankovitch sequence cycle, but also the superimposition succession with five different deposition periods.

2.3 Analysis of the response characteristics of numerical simulation

According to the analysis above, the composite signals of a set of strata can be separated into single signals of different frequencies, and the frequency spectrum of each single signal corresponds to a stratigraphic unit of a certain deposition period. However, the number of stratigraphic units in a deposition period is unknown. That is to say, what is the number of stratigraphic units with the long eccentricity (M413ka), the number of stratigraphic units with the short

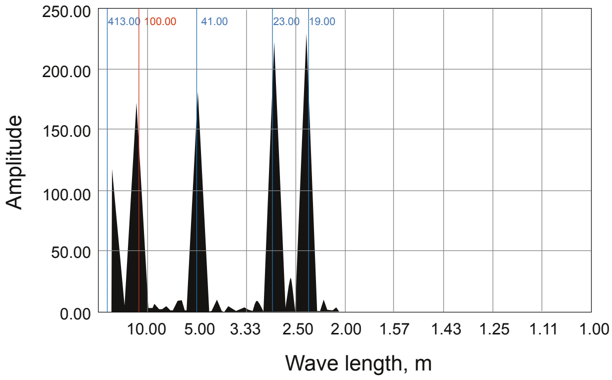

Fig. 2 Amplitude spectrum

eccentricity (M100ka), the number of stratigraphic units with the precession (M41ka), the number of stratigraphic units with the long obliquity (M22.5ka), and the number of stratigraphic units with the short obliquity (M19ka)? The number of stratigraphic units included in each kind of period remains unknown, as is the boundary.

From this we can ascertain, it is impossible to solve the problems above by Fourier transform alone, so we did a lot of research and developed the wavelet depth-frequency analysis method. Two single signals (413ka and 100ka) are used to simulate the characteristics of sedimentary sequence first, as shown in Fig. 3. In Fig. 3, the first three columns are the depth, long eccentricity (M413ka) and short eccentricity (M100ka) respectively, the fourth column on the left is the composite signals Com413-100 of the former two signals, the fifth column is analysis lines of the frequency trend. The sixth column on the left is the wavelet depth-frequency analysis profile of the composite signals. Adding geological significance to the analysis lines of the frequency trend (the second column on the right in Fig. 3), we can conclude that: 1) This set of strata contains three large and integral frequency trend variation periods, and each big frequency trend variation contains four small frequency trend variation periods. 2) Each big frequency trend variation period corresponds to the long eccentricity (M413ka), and the boundary matches perfectly. Each small frequency trend variation period corresponds to the short eccentricity (M100ka), and the boundary matches perfectly too. 3) This set of strata contains two stratigraphic units of different sedimentary cycles, one is the stratigraphic unit with the long eccentricity—big stratigraphic unit, and the other is the stratigraphic unit with the short eccentricity—small stratigraphic unit. 4) This set of strata contains three stratigraphic units with long periods (long eccentricity) and 14 stratigraphic units (the middle 12 plus the two on the top and bottom) with short periods (short eccentricity).

Adding geological significance to the response characteristics of the wavelet depth-frequency (the first column on the right in Fig. 3), we can conclude that: 1) The wavelet depth-frequency diagram is divided into three parts: the middle and two sides. And both sides are symmetrical about the middle line. From both sides to the middle, the frequency changes from high to low. 2) The wavelet depth-frequency profile is the superimposition of red and blue energy groups of the frequency spectrum. The red energy group of the frequency spectrum represents the rock matrix of the formation, while the blue energy group of the frequency spectrum represents the non-matrix of the formation, and it is the layer deposited in static water which can reflect the formation boundary. 3) The low frequency part in the middle includes three integral and large red energy groups of the frequency spectrum, while the high frequency part (except the top and bottom) includes 12 integral and small blue energy groups of the frequency spectrum. Each large red energy group of the frequency spectrum contains four small red energy groups of the frequency spectrum. 4) There is a large blue energy group of the frequency spectrum contained in every two large red energy groups of the frequency spectrum. The blue energy group of the frequency spectrum is always the reflection of non-matrix of the formation, and it reflects the characteristics of the boundaries. Thus, the large red energy group of the frequency spectrum corresponds to the long eccentricity (M413ka), and the boundary of the large red energy group of the frequency spectrum just corresponds to the blue energy group of the frequency spectrum, at the same time, it matches the boundary of the long eccentricity (M413ka) perfectly. The small red energy group of the frequency spectrum corresponds to the short eccentricity (M100ka), and the boundary of the small red energy group of the frequency spectrum corresponds to the boundary of the short eccentricity (M100ka). 5) This set of strata contains two stratigraphic units with different deposition periods. One is the stratigraphic unit with the long eccentricity, and it is a big stratigraphic unit which corresponds to the red energy group of the frequency spectrum with low frequency parts. The other is the stratigraphic unit with the short eccentricity, and it is a small stratigraphic unit which corresponds to the small red energy group of the frequency spectrum. 6) This set of strata contains three stratigraphic units with long periods (long eccentricity), 14 stratigraphic units (the middle 12 plus two on the top and bottom) with short periods (short eccentricity).

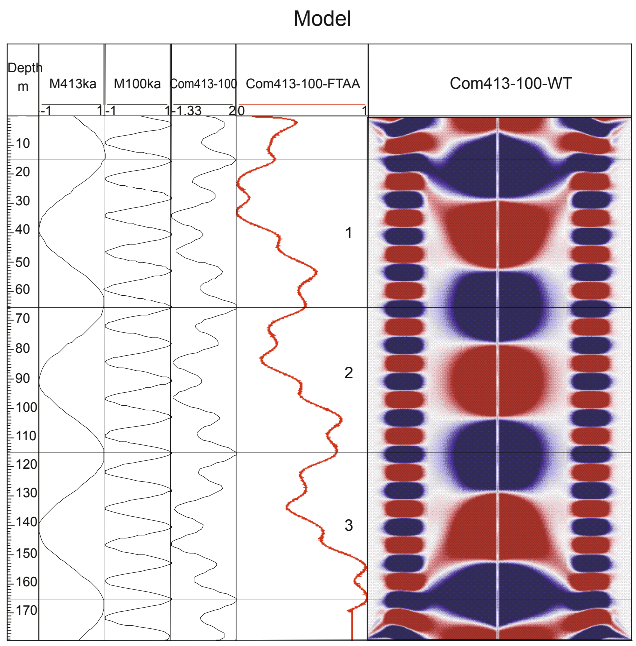

Fig. 3 Response characteristics of combination of the two single signals

Therefore, the method of wavelet depth-frequency analysis not only breaks down the composite signals (logging or seismic signals) into single signals with different frequency, but also extracts the depth-frequency profiles which can reflect and calibrate the sedimentary sequence cycles of different levels. The geological significance corresponding to the response characteristics of the wavelet depth-frequency profile and the geological significance of the frequency trend lines match closely, which verifies the accuracy of the numerical simulation, and the validation of the wavelet depth-frequency analysis method.

3 The foundation of the well-seismic calibration using the wavelet depth-frequency analysis method

As is well known, seismic data are very abundant, and the horizontal range we can identify is wide. The seismic data are often used to interpret sedimentary sequence, structure, and the contact relationship of formations. However, the vertical resolution of the seismic data is low, and the geological objects or sequences we can identify in the vertical direction are rough. So it can only be used to recognize the high level sequence cycles, while it is not suitable for fine research. On the contrary, the vertical resolution of well-logging data is high, and the sedimentary cycles, structure, and reservoir characteristics reflected in the vertical direction are very fine. However, the horizontal resolution is low, and it is limited in the borehole range. In order to make up the shortcomings of well logging and seismic data and make full use of their respective advantages, we apply the method of well-seismic calibration joint interpretation. At present, well-seismic calibration joint interpretation mainly calibrates the well logging data into a seismic profile by software through the synthesis records to obtain a relatively accurate recognition of the formation characteristics. Due to the high resolution of the well logging data, when it is calibrated to the seismic profile, there is not a good match between the seismic and well logging data. The well logging curve was condensed, so the fine characteristics of the sedimentary cycles are not reflected or reflected unclearly. In order to solve the problems above, to achieve well-seismic calibration in the true sense, we developed a calibration method and a processing module—the well-seismic calibration insertion technology.

The well-seismic calibration insertion technology mainly used the principle of depth-time conversion, according to the formation velocity or acoustic logging data, the borehole information of the depth domain is transformed into the time domain. By data format conversion, the data are merged into the seismic profiles, and the wavelet depth-frequency analysis method is used to process well-logging data, the depth-frequency profiles of different scales can divide the sequences into different levels. By experimental analysis and previous research results, in a third-order sequence (thickness is about 500-600 m), the depth-frequency profiles of 512 scales are usually used to divide the third-order sequence, which is corresponding to sequence. The depth-frequency profiles of 256 scales are usually used to divide fourth-order sequence, which is corresponding to parasequence set. The depth-frequency profiles of 128 scales are usually used to divide fifth-order sequence, which is corresponding to parasequence. The depth-frequency profiles of 64 scales are usually used to divide sixth-order sequence, which is corresponding to small layers. The well-seismic calibration insertion technology is achieved, and this method makes the well logging data match the seismic data well.

We insert borehole information into the seismic profile directly through the processing module, and then we can do the well-seismic calibration joint interpretation which plays an important role in recognizing sedimentary sequence, structure, reservoir space, petrophysical facies, and reservoir description. According to the numerical simulation results and response characteristics of sedimentary sequence cycles, we use the wavelet depth-frequency analysis method to make the spectrum cycles processed from GR data calibrated into the seismic profiles. This achieves well-seismic calibration in the true sense to interpret the superimposition characteristics and horizontal continuation property of sedimentary sequence cycles mainly by the time-depth conversion well-seismic calibration method. There is a basic model of sedimentary sequence cycle analysis by the well-seismic calibration insertion technology in Fig. 4.

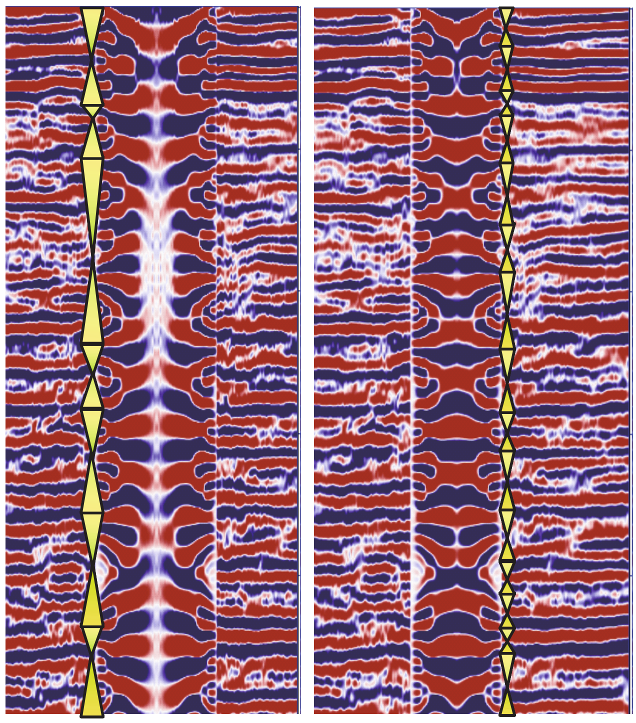

Fig. 4 The theoretical model of well-seismic calibration joint interpretation

Fig. 4 adopts the well-seismic calibration insertion technology to insert the wavelet depth-frequency profile into the seismic profile, forming a theoretical model of well-seismic calibration joint interpretation. If we add the geological significance in Fig. 4, then we can conclude that: 1) The blue energy groups are the responses of the non-matrix parts in the formation, the transport of the red energy groups represents the cyclicity of the formation, the boundary between the blue and red energy groups reflects the sequence boundary of different levels. The blue and red represent the rhythmicity and periodicity of sedimentary strata. The number of migrations of blue and red energy groups of the frequency spectrum corresponds to the number of sedimentary sequence cycles of the same level. 2) The wavelet depth-frequency profile on the left is the result extracted from the 128 scales processing, while the wavelet depth-frequency profile on the right is the result extracted from the 64 scales processing. The depth-frequency profile on the left reflects the cycle structure of formation, and the level of sequence or the amplitude of energy transport are both bigger than those of the right profile. This shows that the left reflects the high level sequence units, while the right reflects the low level sequence units. 3) When calibrating the large scale depth-frequency profile (128 scales processing) into seismic profiles, the depth-frequency profile can be divided into seven parasequences, which cannot be realized by seismic data alone. If the depth-frequency profile of small scale (64 scales processing) is calibrated into the seismic profiles, then 14 small layers can be divided, which cannot be realized by seismic data alone. 4) When the depth-frequency profiles of different scales are calibrated into seismic profiles, the sequences of various levels can be recognized, furthermore we can determine the level of sequence cycles, the number of cycles and superimposition sequences, realizing the division of sequences of various levels. The difficult problems which cannot be solved by seismic data alone are solved. 5) The accuracy and precision of sequence division can be improved by the well-seismic calibration technology, and the well-seismic calibration joint interpretation can be truly realized. 6) The isochronous correlation of sand bodies or strata can be done by well-seismic calibration, which lays the foundation of delineating the distribution range of the oil & gas reservoirs.

4 Examples of studying sedimentary sequence cycles by well-seismic calibration joint interpretation

The theoretical foundations and patterns of calibrating the wavelet depth-frequency into seismic profiles for joint interpretation have been worked out, which helps explain the significances of calibrations. On this basis, in order to further study the application of well-seismic calibration in analyzing the sedimentary sequence cycles, we apply the well-seismic calibration insertion technology in the Dagang Oilfield to testify its accuracy and precision. Here Fig. 5 is an example of inserting the depth-frequency profiles of the three wells into the survey line dg001 in the Dagang Oilfield using the well-seismic calibration insertion technology.

We can conclude from Fig. 5 that : 1) The three depth-frequency profiles are all extracted by 64 scales processing, the sedimentary cycle structure, sequence level, boundary of the sequence and the superimposition of strata reflected in the depth-frequency profiles are very clear. The seismic profile (survey line dg001) in the figure is the comprehensive response of reflection characteristics of the seismic event whose traveling time is between 1 s and 2 s. 2) The three depth-frequency profiles are inserted into the seismic profiles, the transport of the red energy groups of the frequency spectrum and the boundary of the blue-red frequency spectrum match the characteristics of seismic events well, that is to say, an integral migration of a red frequency spectrum constitutes a sequence cycle. In other words, a sequence unit, if we calibrate it into the seismic profile, matches the boundary of seismic events, thus making the well-seismic calibration joint interpretation come true. 3) When the depth-frequency profile of 64 scales was calibrated into seismic profiles, the sixth-grade sequence—small layer units can be divided. Not only can the stratigraphic units be divided in

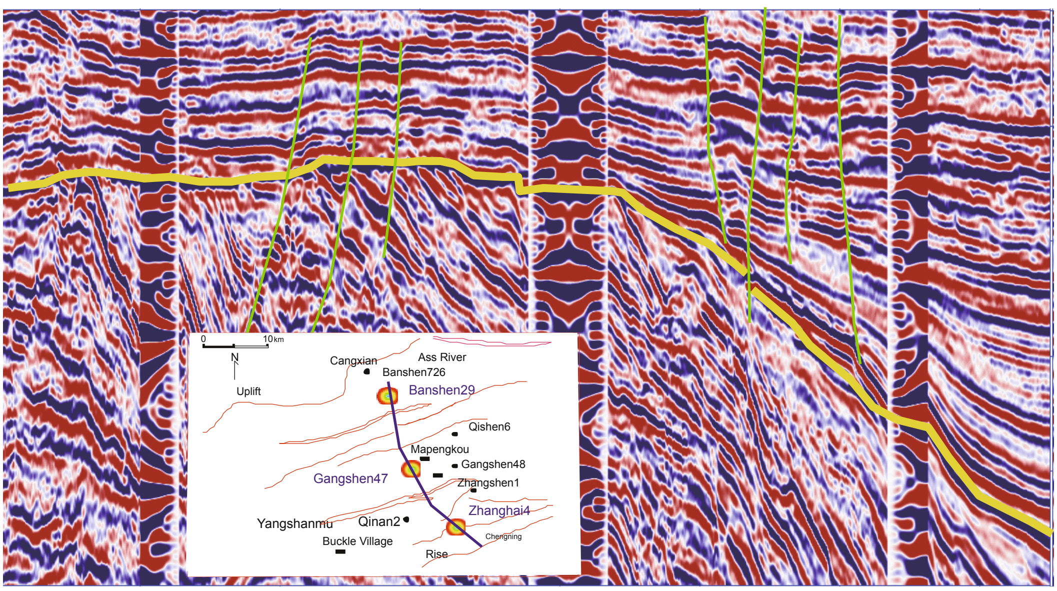

Fig. 5 Well-seismic calibration insertion technique used in the dg001 survey line in the Dagang Oilfield (64 scales)

detail in the vertical direction, but also they can be extended to other well areas. 4) The yellow line in the figure is a clear sequence boundary—the bottom boundary of the Guantao Formation. There are four migrations of red energy groups of the frequency spectrum in the first well on the left above the yellow line, and there are also four migrations of red energy groups of the frequency spectrum in the middle well. The seismic events between the two wells are continuous, so the stratigraphic units between the two wells were deposited at the same time and had the same sedimentary environments and similar thickness. There are nine migrations of red energy groups of the frequency spectrum in the right well above the yellow line. Big differences exist between this well and the former two. With the correlation of the cycle structure of the red frequency spectrum, the number of cycles, and the seismic events between the two wells, we can analyze the deletion, fault depression, and thickness differences of the formation, thus laying the foundation of stratigraphic correlation. 5) By using the well-seismic calibration insertion technology, we do the well-seismic calibration joint interpretation in the true sense, and the effect is significant and precise.

In order to check the validity and accuracy of the well-seismic calibration insertion technique, we expand the scale, insert the depth-frequency profile of 128 scales into the seismic profile (survey line dg001 in Fig. 6). Fig. 6 shows the sample inserting the depth-frequency profile of 128 scales of three wells into survey line dg001 with seismic event between 1-2 s in the Dagang oil province using the well-seismic calibration insertion method. It is shown that: 1) Sedimentary cycles, structure, level of sequence, sequence boundary and strata superimposition series that the depth-frequency profile of 128 scales reflects are clear. 2) The three depth-frequency profiles are inserted into the seismic profiles. The transport of the red energy groups of the frequency spectrum and the boundary of the blue-red frequency spectrum match the characteristics of seismic events perfectly. That is to say, an integral migration of a red frequency spectrum constitutes a sequence cycle. A sequence unit, if we calibrate it into the seismic profile, matches the boundary of seismic events. However, the number of integral red energy groups of the frequency spectrum of 128 scales is bigger than that of 64 scales. So in this way we can interpret the sequences of different levels by well-seismic calibration. 3) It realizes the division of the fifth-grade sequence or parasequence units. Not only can the stratigraphic units be closely divided in the vertical direction, but also they can be horizontally extended to other well areas. 4) The yellow line in the figure is a clear sequence boundary—the bottom boundary of the Guantao Formation. There are three migrations of the red energy groups of the frequency spectrum in the first well on the left above the yellow line, and there are also three migrations of the red energy groups of the frequency spectrum in the middle well (one less than that of 64 scales). The seismic events between the two wells are continuous, so the stratigraphic units between the two wells were deposited at the same time and had the same sedimentary environments and similar thickness. There are seven migrations of the red energy groups of the frequency spectrum in the right well above the yellow line (two less than that of 64 scales). There are big differences between this well and the former two. With the correlation of the cycle structure of the red frequency spectrum, the number of cycles, and the seismic events between the two wells, we can analyze the deletion, fault depression, and thickness differences of the formation, thus laying the foundation of stratigraphic correlation. 5) Through the contrast between Fig. 5 and Fig. 6 we can conclude that depth-frequency profile of different scales can be used to divide the cycle structure and sequence units of different levels, the divided sequence boundary, superimposition sequence and seismic

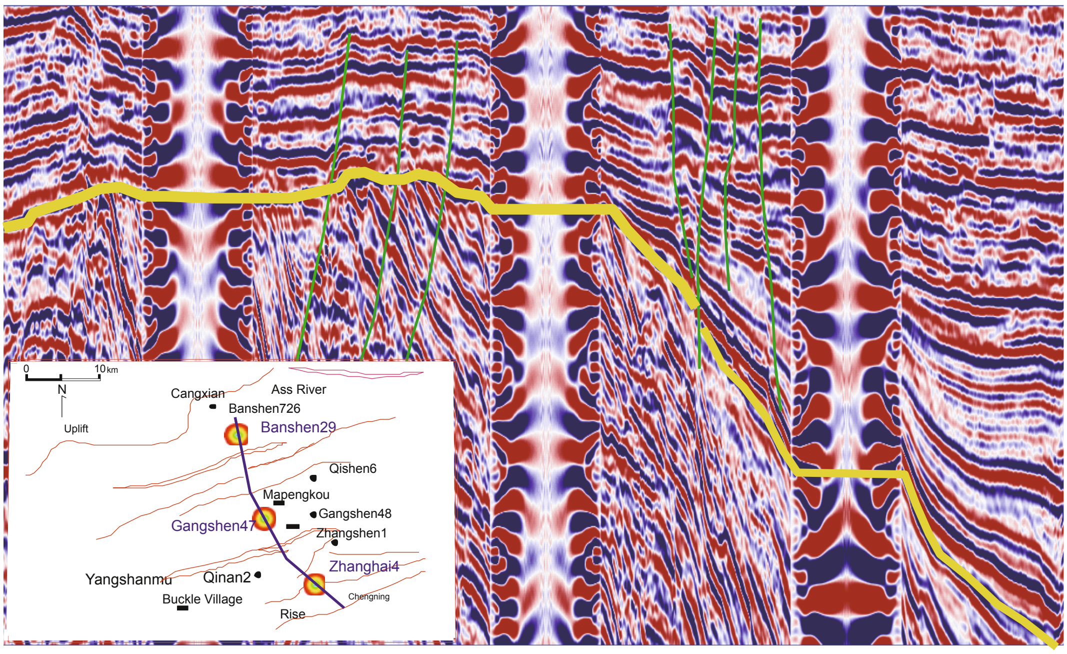

Fig. 6 Well-seismic calibration insertion method used in the dg001 survey line in the Dagang Oilfield (128 scales)

events of three wells in each figure have a good match. This proves the validity and accuracy of the proposed method.

5 Conclusions

1) The wavelet depth-frequency analysis is developed, and the composite signal can be separated into single signals of different frequencies. Every spectrum cycle of a single signal can reflect and characterize the sedimentary sequence cycle of a certain level.

2) Through numerical simulation, we can get five single and composite signals of the Milankovitch cycle, and we extract the characteristics of their sedimentary sequence cycles and build the model and typical significances of sedimentary sequence cycles with different levels calibrated by spectrum cycles with different frequencies. From this model we can obtain the types, the boundaries and the numbers of spectrum cycles which are all corresponding with those of sedimentary sequence cycles. This paper realized calibrating the sedimentary sequence cycles by mathematical and geophysical methods and established a theoretical basis for the well-seismic calibration joint interpretation.

3) We developed the well-seismic calibration method which inserts the borehole information into seismic profiles. Through the well-seismic calibration, we divide the structures of sedimentary cycles with different levels, the sequence units, the sequence boundaries and superimposition sequences and analyze the horizontal continuation property. Finally, we have truly achieved well-seismic calibration joint interpretation.

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