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Applications of geophysical technology in natural gas hydrate prediction of LW21-1-1 well area

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Abstract. A method of prediction of natural gas hydrate in sea deposits of oil and gas is proposed. It is found that three instantaneous processing and colored inversion can respectively mark out the natural gas hydrate characteristics of natural gas hydrate and amplitude of blanking zone, lithology, and provide a scientific basis for the prediction of natural gas hydrate. In this paper, natural gas hydrate of the Well LW21-1-1 zone is predicted by three instantaneous processing and colored inversion, which may represent a reference to drilling of other blocks.

Key words. Natural gas hydrate, deepwater drilling, three instantaneous profiles, colored inversion.

1. Introduction

Well LW21-1-1 is China National Offshore Oil Corporation in the South China Sea and Asia's first hit deep wells. The water depth is about 2460 m. According to the experience at home and abroad in deepwater drilling, drilling should be done before the well area geological disaster prediction, in order to prevent disasters and accidents. Geological disaster types usually appear in the sites where are the main submarine gas hydrate, shallow gas and shallow water flow.

Natural gas hydrate is a kind of solid crystals with domination of methane, which is composed from hydrocarbon gas molecules and water molecules. Its formation is controlled by temperature and pressure. Since the discovery that the natural gas hydrate can be connected with fuel energy, people have been paying more and more attention to it. But with the development of research, it was found that the possibility of gas hydrate formation to cause shallow geological disasters in the bottom of the sea is very large, and this kind of disaster environment for engineering activities at sea brought certain difficulties, especially for offshore drilling. Many domestic and foreign offshore drilling accidents display that it is easy to cause a major accident when natural gas hydrate is drilled.

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1.1. Lead to collapse of seabed

Shallow sediments of deep water basin [1] and continental slope usually contain natural gas hydrate [2]. Affected by change of pressure and temperature, the occurrence of natural gas hydrate can easily be subjected to change, the stability zone of natural gas hydrate can partially or even entirely disappear. When the sea level drops, the bottom of the stability zone of natural gas hydrate (GHSZ) in seabed sediments will become unstable and begin to decompose, which will make GHSZ change. As GHSZ band [3] starts to break down, water and gas begin to enrich. The resulting pressure will reach abnormal excess hydrostatic pressure, low-density gas and mud may penetrate through the natural gas hydrate layer, which can lead to geological disasters and even spray the surface threatening to drilling platforms. Meanwhile, the liquefied GHSZ can form a downward slide, along the sliding surface of bulk gas hydrate cementation wedge will be downward movement evolved into large-scale submarine landslide. Sea levels have changed so that these events repeated, eventually it will form a chaotic sediment landslide with a certain thickness in the lower slope. Therefore, in the environment of high pressure and low temperature, the natural gas hydrate is stable, change of pressure and temperature will lead to release amounts of gas, which may cause landslide and other major seabed disasters (see Fig. 1).

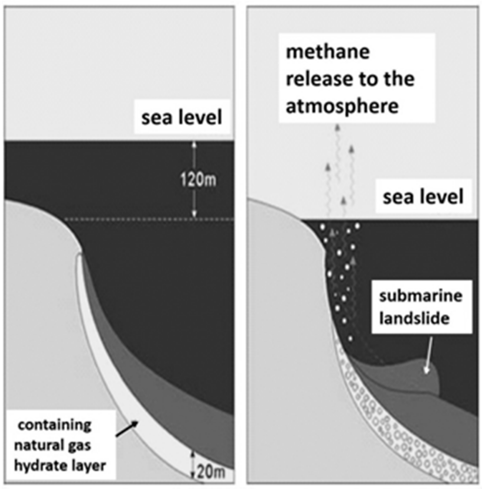

Fig. 1. Natural gas hydrate caused landslide

1.2. Threat of drilling security

Geological tectonism, sedimentation and maritime activities can also cause change of external conditions such as pressure and temperature in the continental slope and shallow sediments in deep water basin, and result in decomposition of natural gas hydrate. The movement of sediment and mudslide also can be triggered by outside activities (such as drilling or seismic work in this horizon, etc.), then landslide and diapir phenomenon will occur, under the effect of high pressure for a long time, the high-pressure airbag will squeeze weaknesses of the upper layer, which will be a great threat to is its range operation drilling ships and oil platforms. At the same time, in the case of a large number of natural gas hydrate decomposing, amounts of methane will overflow the stratum and dissolve in seawater, so that the density of seawater will be reduced, and result in drilling ships and oil platforms sinking because of buoyancy sudden decrease.

2. Prediction of natural gas hydrate

Through these theories such as the previous analysis of the sensitivity of the characteristics of the natural gas hydrate development zone to various geophysical responses, study of seismic attribute analysis, AVO analysis, the establishment of the inversion velocity field in the formation of steep dip angle, geophysical prediction technique for pseudo well constrained wave impedance inversion. After analyzing the geological characteristics of the LW21-1-1 well, we think that this area is more sensitive to seismic instantaneous attributes, using the two geophysical methods to predict the natural gas hydrate by using three instantaneous profile and colored inversion.

2.1. Three instantaneous processing of seismic data

Three instantaneous profile is the instantaneous attributes extracted by Hilbert transform, namely the three instantaneous attributes, including instantaneous amplitude, instantaneous phase and instantaneous frequency and its corresponding properties. Instantaneous feature refer to concise information about horizon, using the instantaneous attributes need to be analyzed with the angle of the amplitude information, the decomposing process does not make any change for the basic information, but it gets different attribute profiles. Instantaneous profiles carrying a large number of information associated with oil and gas features, such as amplitude, lithology, frequency and phase, which can show geophysical phenomena which are different from conventional seismic profiles.

Three instantaneous attributes is established in the Hilbert transform and complex seismic trace analysis technology. When studying underground lithological change and stratigraphic structure, the Hilbert attribute extraction can be used. For a seismic signal, firstly calculate its Hilbert transform, the transformed result is deemed as the imaginary part, seismic signal is considered as the corresponding real part, they can compose complex seismic trace[4], then the instantaneous attributes of complex seismic trace are calculated. Three instantaneous attributes are on the base of Hilbert transform and complex seismic trace, so we can start from the collected seismic signals $s(t)$, its analytical signal as follows:

$$z(t) = s(t) + i\frac{1}{\pi t} * s(t)\,, \tag{1}$$

where $*$ denotes the convolution, and imaginary part of $z(t)$ in the form $\widetilde{s}(t) = i/(\pi t) * s(t)$ is the Hilbert transform of $s(t)$. Then the instantaneous amplitude, the instantaneous phase, the instantaneous frequency of the signal $s(t)$ can be denoted, respectively, as follows:

$$a(t) = \sqrt{s^2(t) + \widetilde{s}(t)}\,, \tag{2}$$

$$\theta(t) = \arctan \frac{\widetilde{s}(t)}{s(t)}\,, \tag{3}$$

$$\omega(t) = \frac{\mathrm{d}}{\mathrm{d}t}\left[\arctan \frac{\widetilde{s}(t)}{s(t)}\right]. \tag{4}$$

Three instantaneous attributes can be used to locate underground lithologic change and fluid properties. The instantaneous amplitude is the intensity of earthquake wave size [5], instantaneous frequency is the mapping of a dielectric absorption properties, while the instantaneous phase can reflect the change of lithology stratigraphic sequence. In the gas hydrate bearing strata, as the earthquake wave speed increases which leads to increasing the reflection coefficient between the underlying strata, the corresponding strong reflection interface appears in the seismic profile. And if there is contained natural gas hydrate above the stratum, because sediment pores are filled and cemented by hydrate making the stratum become uniform, in the seismic reflection profile there usually appears a weak reflection or amplitude blanking zone. Natural gas hydrate in the seismic section forms usually a strong reflected wave roughly parallel with seabed, and the reflected layer like seabed is called BSR for short. According to seismic response of natural gas hydrate and corresponding characteristics of BSR, the instantaneous amplitude profile can clearly reflect characteristics of amplitude blank zone. The instantaneous phase profile can display the intersected state between the reflection of BSR and true reflection of the stratum better, while abnormal BSR area can be displayed on the instantaneous frequency profile [6]. Seismic profile combines with three instantaneous profiles and BSR reflection interface of natural gas hydrate can be roughly identified.

As shown in Fig. 2, the South China Sea of a crossline instantaneous amplitude profile, showing the suspected gas hydrate distribution area.

In the study, the profile of the LW21-1-1 well is processed. As shown in Fig. 3, there is no amplitude space, so the possibility of occurrence of gas hydrate is lower.

Instantaneous phase is a momentary phase at selected points within each seismic trace, which is a reflection of the phase of dominant frequency of seismic data. When the seismic wave is spread in different physical stratum, its phase can be changed. Instantaneous phase and reflection intensity are independent, not affected by the intensity of energy, and, therefore, they can be used to enhance the in-phase axis within the deep reservoir (seismic wave energy is weak in the depth). Instantaneous phase is a measure of the phase axis continuity in seismic profile. Instantaneous phase profile can more clearly represent the intersected phenomenon between BSR reflection and reflection of the real stratum. An instantaneous phase profile of a

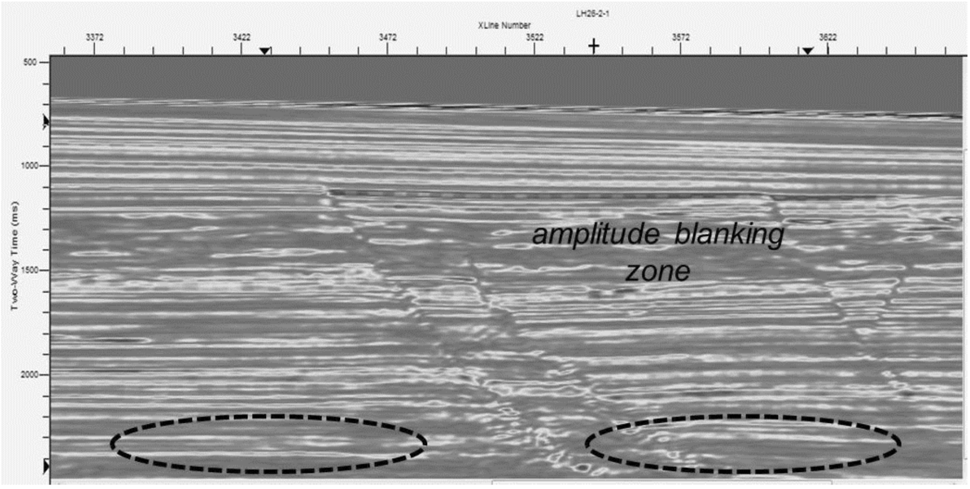

Fig. 2. Instantaneous amplitude profile of the South China Sea

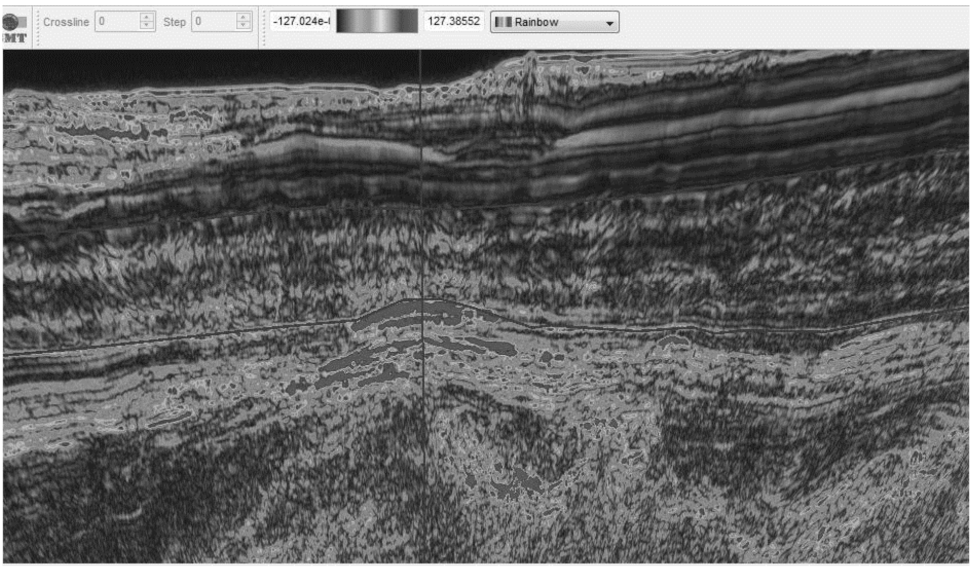

Fig. 3. Instantaneous amplitude profile of LW21-1-1 on crossline 2528

crossline in the South China Sea is depicted in Fig. 4. In Fig. 5, the study area on the phase anomaly is not obvious.

Instantaneous frequency is the time derivative of phase, and can reflect absorption and attenuation characteristics of the stratum. It can be advantageous for analyzing the lithologic changes. Instantaneous frequency is the time rate of change of phase and a reflection of dielectric absorption characteristics. The instantaneous frequency

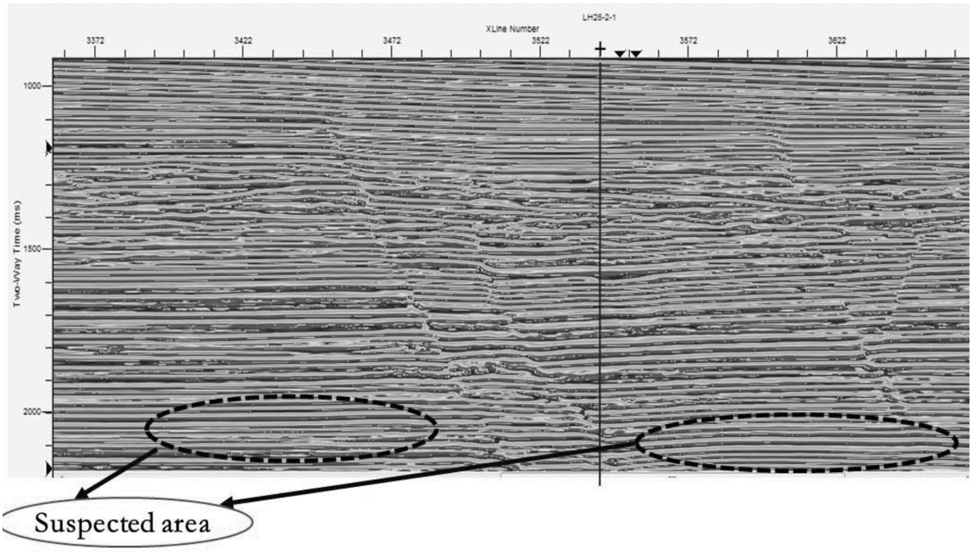

Fig. 4. Instantaneous phase profile of a crossline in the South China Sea

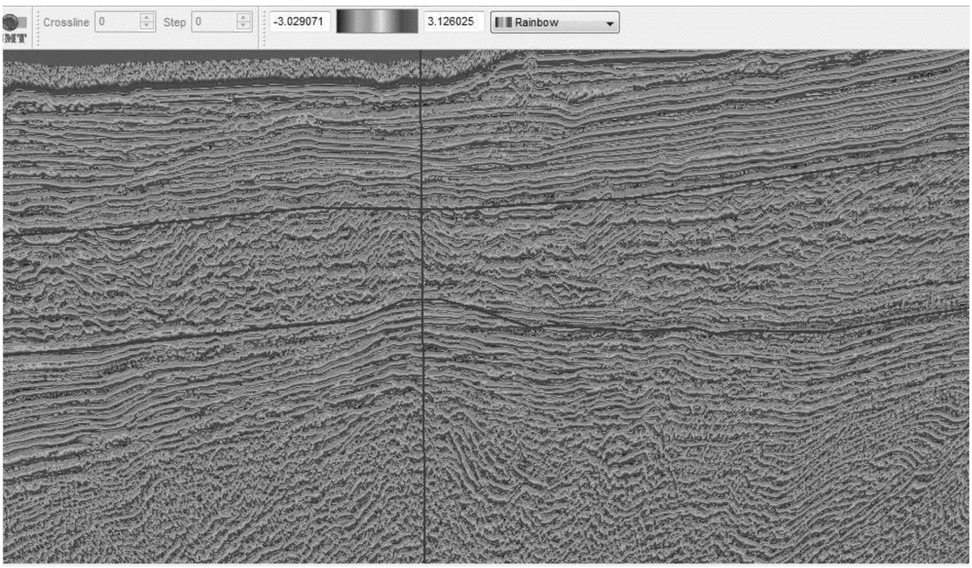

Fig. 5. Instantaneous phase profile of LW21-1-1 on line 2528

profile can reveal the BSR area, see Fig. 6.

In Fig. 7, the instantaneous frequency profile in the area does not show any abnormal BSR region. Instantaneous phase profile can more clearly represent the intersected phenomenon between BSR reflection and reflection of the real stratum,

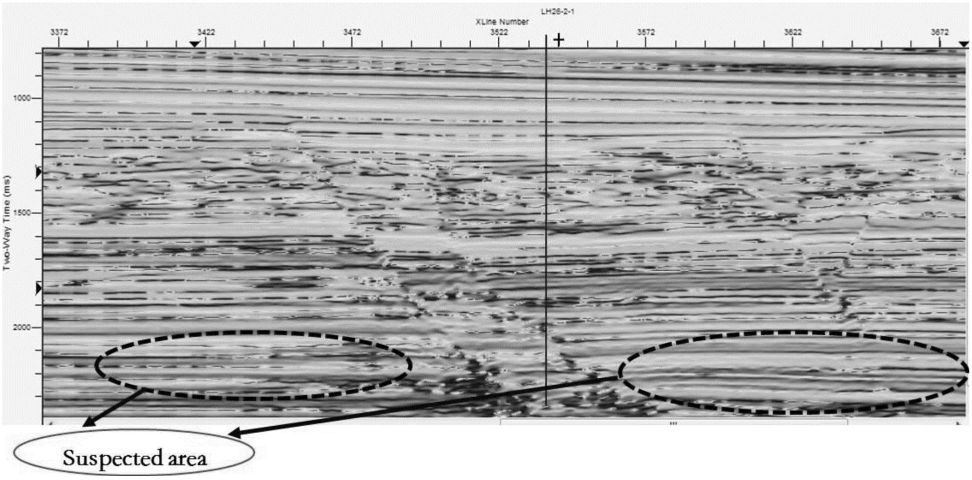

Fig. 6. Instantaneous frequency profile of a crossline in the South China Sea

and instantaneous amplitude profile can clearly reflect BSR interface and characteristics of amplitude blank zone. Instantaneous frequency profile can reveal abnormal BSR area. By the analysis, the study area shows no significant BSR interface and abnormal BSR region, based on three instantaneous profiles combined with seismic profile. We can roughly exclude BSR reflection interface of natural gas hydrate. Through analyzing three instantaneous profiles, it is concluded that there is little chance of natural gas water compounds in LW21-1-1 well area.

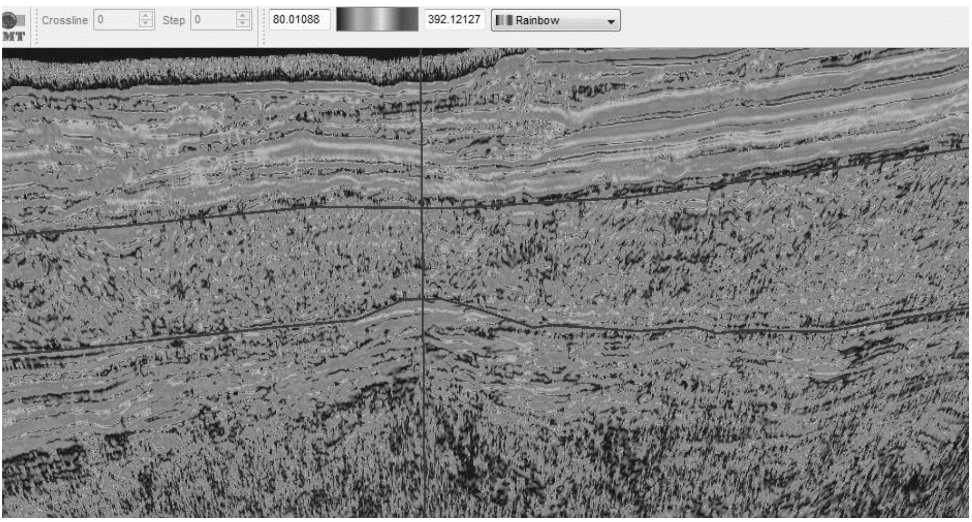

Fig. 7. Instantaneous frequency profile of LW21-1-1 on line 2528

2.2. Seismic colored inversion (SCI)

Inversion is based on a measured data to infer the original geological model. Color inversion is a kind of inversion [7] which uses well log data to constrain the wave impedance inversion in the frequency domain. The core is matching of wave impedance spectroscopy and seismic spectrum to complete inversion. This method does not have a wavelet extraction process, and also does not have to set the initial model to constraint. Its longitudinal resolution is higher than the sparse spike inversion, but lower than the model inversion. It is characterized by lower degree of dependence on the well, global optimization, better eliminating the interference of human analysis factors, so it can objectively reflect the geological phenomenon. The analysis formulae of the colored inversion follow.

The convolution model of seismic records is

$$s_i(t) = r_i(t) * \omega(t)\,, \tag{5}$$

where $s_i(t)$, $i = 1, 2, \ldots, n$ denotes the seismic record, $r_i(t)$, $i = 1, 2, \ldots, n$ denotes the reflection coefficient, n is the number of traces, and $\omega(t)$ denotes the seismic wavelet. The convolution model is transformed to the frequency domain, and then

$$S_i(\omega)\mathrm{e}^{-\mathrm{j}\phi_i(\omega)} = [R_i(\omega)\mathrm{e}^{\mathrm{j}\Psi_i(\omega)}][W_i(\omega)\mathrm{e}^{-\mathrm{j}\varphi_i(\omega)}]\,, \tag{6}$$

where $R_i(\omega)$ denotes the reflection coefficient amplitude spectrum, $W_i(\omega)$ denotes the wavelet amplitude spectrum, $\Psi_i(\omega)$ denotes the reflection coefficient phase spectrum and $\varphi_i(\omega)$ denotes wavelet phase spectrum. Then we can write

$$\left\{ \begin{array}{c} S_i(\omega) = R_i(\omega)W_i(\omega) \\ \phi_i(\omega) = \Psi_i(\omega) + \varphi_i(\omega) \end{array} \right\}. \tag{7}$$

and, therefore:

$$\ln S_i(\omega) = \ln R_i(\omega) \ln W_i(\omega)\,. \tag{8}$$

Assuming that impedance of each trace $Z_i(t)$, $i = 1, 2, \ldots, n$ is transformed to the frequency domain, we get

$$Z_i(\mathrm{j}\omega) = Z_i(\omega)\mathrm{e}^{-\mathrm{j}\Omega_i(\omega)}\,. \tag{9}$$

Among them $\Omega_i(\omega)$ denotes the wave impedance phase spectrum and$Z_i(\omega)$ denotes the wave impedance amplitude spectrum. According to the relation between the wave impedance and reflection coefficient we obtain

$$R_i = \frac{(Z_{i+1} - Z_i)}{(Z_{i+1} - Z_i)}\,. \tag{10}$$

Therefore, the reflection coefficient sequences can be obtained from the impedance sequences, in other words $R_i(\omega)$ can be obtained using $Z_i(\omega)$. The result is then substituted into (8) and in this way we can get the matched operator $W_i(\omega)$ in the frequency domain.

Notably, when the gap of the energy between the amplitude spectrum of seismic records and wave impedance spectrum of wells is large, before any inversion, the equalization process must be carried out for the wave impedance spectrum energy and amplitude spectrum energy of seismic records of each track on wells.

The colored inversion technique is an inversion method which is not directly dependent on the well data. When this method defines inversion operator in the frequency domain, well data only play the contrast effect for the desired results in the inversion operator estimation. The inversion is the deconvolution process, therefore, the inversion result is impedance, and the amplitude keeps good lateral changes.

The colored inversion process is schematically indicated in Fig. 8:

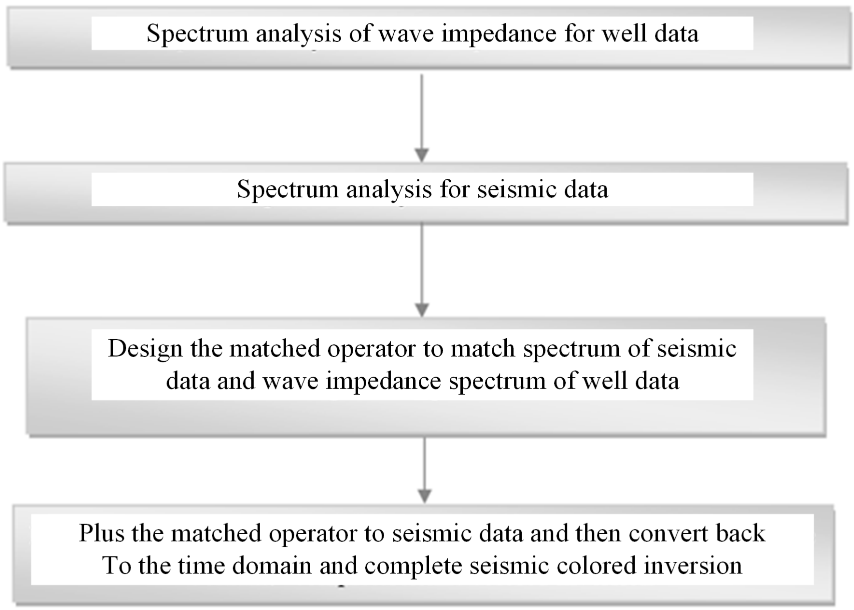

Fig. 8. Process of color inversion

This technology has the following characteristics: 1) no obvious wavelet extraction process; 2) no constraints of the initial model; 3) it can keep the lateral changes of amplitude and is conducive to the planar sedimentary imaging. Therefore, the results of colored inversion completely retain seismic data whose numerical magnitude is close to well data on the whole. This can be considered an attribute with inversion significance, that meets requirements of the seismic lithologic body [8–11].

Figure 9 depicts the impedance inversion section of the South China Sea.

Finally, Fig. 10 mainly shows inversion profiles of colored inversion about well LW21-1-1 and neighboring well LW3-1-1.

As can be seen from Fig. 10, as the phase axes of impedance of cross well profile are continuous and stable and do not exhibit any large impedance discontinuities,

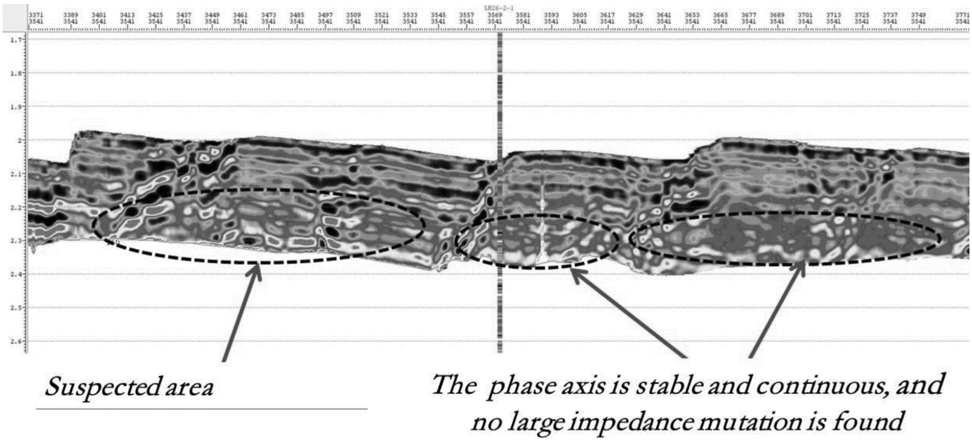

Fig. 9. Impedance inversion profile of the South China Sea

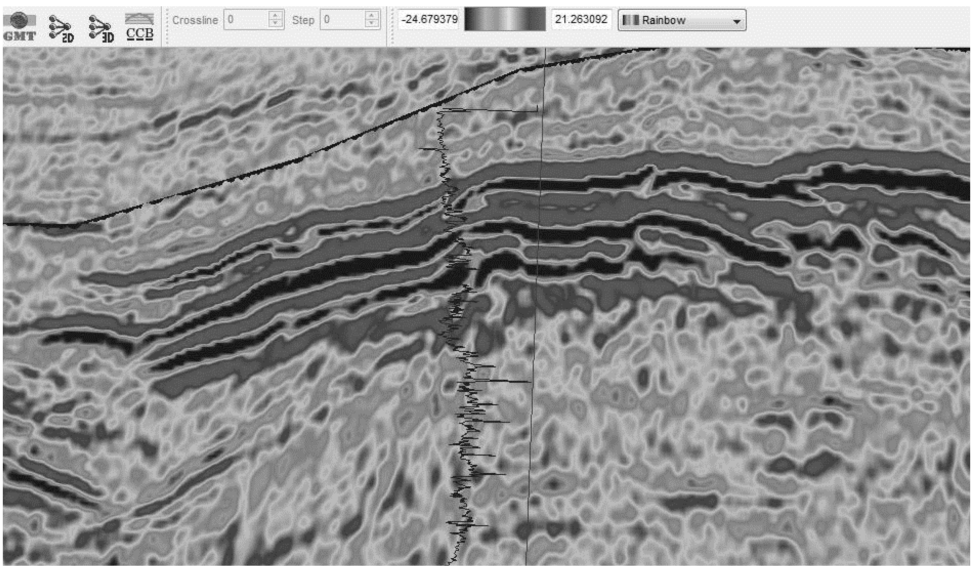

Fig. 10. 1569 line colored inversion profile of LW3-1-1

the figure suggests that the media is basically isotropic around the well and shows no evidence of gas hydrates occur.

The correct rate of pre-drilling shallow geologic disaster forecast depends largely on the selection of prediction methods, so that the correct method of disaster identification is very important. Choice of a correct approach must understand that parameters of shallow disasters we had studied have relationships and are most closely associated one to another. Researching natural gas hydrate can also use speed and other attribute parameters of seismic wave, and generally, there are many ways to predict shallow disasters, improving the accuracy of recognition [12-14], which make the results more convincing.

3. Discussion

1. After a lot of research and field practice, we found that the research method also has some limitations. For some complex structure areas, the accuracy of a single technologies must still to be improved. To improve the accuracy of recognition we try to use a variety of methods, which will improve the accuracy of forecast and make the results more convincing.

2. Because of the lack of more detail of the deepwater seismic and logging data, it is difficult to get a better prediction results. But with the development of deepwater drilling technology, we will get more and more reliable data, so that the prediction accuracy will be better and better in the future.

3. The result in natural gas hydrate prediction of LW21-1-1 well area is correct. It means that our method is reliable.

4. Conclusion

The main results following from the research may be divided as follows:

- Three instantaneous profiles refer to instantaneous amplitude, instantaneous phase and instantaneous frequency. They respectively reflect the intensity of seismic wave, event connection and the time rate of change of phase. According to seismic response of natural gas hydrate layer and BSR characteristics, the process of three instantaneous attributes can reflect changes of reflected characteristics from another angle. BSR characteristic of amplitude blanking zone can be better reflected in the instantaneous amplitude profile. Intersected state between BSR reflection and reflection of the real stratum can be better reflected in the instantaneous phase profile. Instantaneous frequency is a reflection of dielectric absorption characteristic and abnormal BSR zone can be shown in the instantaneous frequency profile.

- Colored inversion technique of seismic data is an inversion method of direct conversion, fully established on the basis of seismic data. It retains basic characteristics of reflection on seismic data such as fault, occurrence, speed and so on. There also does not exist multiplicity based on the model inversion method. This method excludes interference of artificial analysis and can reflect the spatial change of the lithology obviously and objectively. It can also better reflect changes of physical properties of reservoirs based on stable condition of lithology. In addition, the inversion process does not require complex modeling, therefore it greatly improves the speed of inversion; on the other hand, it can remove inversion errors that impedance models are not allowed to bring.

- Analysis of the after-drilled data of well LW21-1-1 confirmed that the prediction was correct. Thus, it indicates that the application of technology of three instantaneous profile processes and colored inversion technique to predict natural gas hydrate is feasible.

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