ABSTRACTS

First break picking method based on artificial intelligence and apparent velocity constraint. David COVA[1,3], LIU Yang[1,2,3], DING Chengzhen[4], WEI Chenglin[4], HU Fei[4], and LI Yunzhu[4]. Oil Geophysical Prospecting, 2021, 56(3): 419-435.

Picking seismic first breaks is an important step for correcting near-surface long-wavelength static anomalies. Nowadays, dense acquisition brings exponentially increasing seismic data, so that it is necessary to find a new method to pick first breaks. Conventional methods rely on manual picking and quality control, which is inefficient for large datasets. Compared with conventional methods, deep learning can greatly improve picking efficiency. Among the deep learning algorithms for picking first breaks, Fully Convolutional Networks (FCNs) have outstanding advantages in semantic segmentation, they can process data with variable sizes and perform high-resolution pixel classification. However, such segmentation has shortcomings in locating accuracy. U-Net is a variant of FCN that can solve the problem of first break picking. Although it is characterized by easy implementation, the accuracy decreases when the signal-to-noise ratio is low. In order to eliminate the limitation, this paper proposes four key points: (1) Design a workflow to balance the amplitude of samples, thus improving the network accuracy; (2) Compare three state-of-the-art U-Net variants with varying complexity, including Wide U-Net, UNet++, and Attention U-Net; (3) Optimize the network's hyperparameters with categorical loss and improved activation functions; (4) Use apparent velocity to constrain and improve the segmentation accuracy. Comparison of U-Net and its variants with different complexity has shown that U-Net has the best accuracy and efficiency. Finally, the results over a land dataset are promising.

Keywords: first break picking, apparent velocity, deep learning, convolutional neural network, image segmentation

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A fault detection method of seismic data based on MultiResU-Net. TANG Jie[1], MENG Tao[1], HAN Shengyuan[1], and CHEN Xueguo[2]. Oil Geophysical Prospecting, 2021, 56(3): 436-445.

Fault detection is significant for seismic data interpretation. Conventional fault detection methods based on coherent volume and curvature are not intuitive enough. Using manual operation, it is impossible to deal with big seismic data in actual production. Deep learning is widely used in seismic interpretation in recent years because of its powerful ability of feature extraction and expression. This paper proposes a fault detection method based on Multiresolution U-net. It can enhance the multiscale fault detection ability on network models by introducing multi-resolution blocks, and reduce the semantic difference between concatenate feature maps by using a residual path instead of an ordinary skip connection. The trained network model has higher accuracy than the conventional U-net. The Jacard index and the Dice coefficient were increased by 0.027 and 0.136 respectively, and the fault detection error rate was reduced by 0.094. Through visual analysis of the interlayer in the network, the feature extraction and expression process was displayed intuitively. When the network is extended to 3D, and combined with transfer learning, satisfactory fault detection in raw 3D seismic data can be obtained. It is of great significance to realizing efficient and automatic fault detection in actual production work.

Keywords: fault detection, deep learning, convolutional neural network, MultiResU-Net, transfer learning

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An approach of sensor parameters measuring in field. WEI Jidong[1], CAO Guobin[1], and LIU Bin[1]. Oil Geophysical Prospecting, 2021, 56(3): 446-461.

From the viewpoint of signal and system, high-speed seismic waves shot by dynamite offer a very coincident input to the system designed specifically, an array of sensors spaced approximate 20 cm and located within an area of 1m×1m. Different outputs characterize different properties of the sensors. By analyzing the output data, some parameters of the sensors, such as sensitivity, ultra-low-frequency distortion and tolerance, could be evaluated. This paper describes the basic principles and practical application of the above idea, and

proposes two new concepts (Lowest Faithful Frequency and General Consistency) to analyze the recording ability for low-frequency and general reliability of some sensors, both of which are significant to imaging subsurface media, and concludes that the performance of the sensors is more quantified and complete. The method, termed Micro Box Wave Test, can be applied in two scenarios: to quickly find unqualified sensors before large-scale field acquisition, and to calibrate the parameters of new sensors in field.

Keywords: sensor, specifications, calibrating, lowest faithful frequency, micro box wave test, general consistency

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Anti-harmonics sweep based on discrete cosine transform (DCT). LUO Fei[1], WEI Tie[1], ZHANG Mugang[1], DONG Liequan[1], and WANG Ze[1]. Oil Geophysical Prospecting, 2021, 56(3): 462-467.

Seismic signals are excited by a controlling vibration system for sweeping signals in vibroseis seismic exploration. It is very common that there exists distortion between swept signals and output signals. For the technology for vibrator distortion correction, the hardware solution is realized by real-time control of a servo valve to obtain the correction amount through nonlinear quadratic fitting of hammer signals and plate signals, so as to improve response accuracy and reduce distortion. The software solution is realized by using the difference fitting between plate signals and hammer signals. This paper introduces a method to calibrate swept signals with the difference between force signals and preset swept signals in harmonic domain. The difference function is directly obtained by analyzing the harmonic component of the force signals and the preset swept signals. The harmonic interference is harmonic, so the algorithm reflects the changes caused by harmonic distortions more directly. It is realized by software correction, and it is convenient and fast, and has a good initial application effect.

Keywords: signal distortion, discrete cosine transform (DCT), force signal, harmonic spectrum, harmonic differential function, anti-homonics sweep (AHS)

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A Kalman seismic iterative filtering method based on lateral and vertical combination. CHEN Gang[1,2], QI Hongyan[2], LI Wei[2], ZHANG Rong[2], XIAN Chenggang[1], and WANG Zhenlin[1,2]. Oil Geophysical Prospecting, 2021, 56(3): 468-475.

Low signal-to-noise ratio and lateral continuity of seismic data result in multiple solutions of horizon tracking and fault characterization in seismic interpretation. To improve the lateral continuity and signal to noise ratio of seismic data, this paper puts forward an effective Kalman seismic filtering method based on lateral and vertical combination. This method proposes an alternate iterative optimization model in space and time and obtains a formula of lateral and vertical combination for filtering seismic data. Specifically, $4N$ times of modified lateral Kalman seismic filtering is firstly performed in the seismic trace direction, then N times of modified vertical Kalman seismic filtering is performed in the time direction. and finally, multiple rounds of combined filtering are performed based on the ratio of lateral and vertical filtering times. Compared with smooth filtering and lateral or vertical kalman filter, our method can greatly improve the signal-to-noise ratio and lateral continuity of seismic data. Numerical test and a field data example have proved that our method is feasible and effective.

Keywords: Kalman filtering, lateral continuity, signal-to-noise ratio, lateral and vertical combination

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Research and application of mixed sources high-precision matching processing technology in the complex obstacle area in western China. ZENG Huahui[1], WANG Xiaowei[1], SU Qin[1], YONG Yundong[1], LIU Huan[1], and MENG Huijie[1]. Oil Geophysical Prospecting, 2021, 56(3): 476-484.

In some areas with complicated surface conditions, such as mountain, town, and reservoir nature reserves. Dynamite is prohibited in seismic acquisition. Although a variable recording system can provide full coverage on the prohibited zone, without shallow or near-offset data, great impacts may occur on near-surface velocity model inversion, velocity analysis and imaging. Therefore, it is necessary to use matching process technology in the seismic data which acquisited by dynamite combinate with vibroseis. However, the wavelets, amplitudes, frequency and phases of shots by mixed sources are inconsistent, which could cause illusion of fine interpretation. This paper proposes a high-precision matching processing method which can overcome the shortcomings of conventional matching filtering processing methods, which don't consider the influence of noise and the signal-to-noise ratio. This method removes the inconsistency

of the data collected by using mixed sources, eliminates the differences caused by different shooting methods, and improves the S/N ratio and imaging quality of seismic data. Actual processing results show that the high-precision matching processing method with mixed sources is effective to remove data inconsistency and can be applied to merged seismic data processing.

Keywords: mixed sources, high-precision matching, average amplitude spectrum, phase matching processing, residual time correction

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Gaussian-type weighted hybrid absorbing boundary for elastic wave simulation and its acceleration on GPU. WANG Shaowen[1], SONG Peng[1,2,3], TAN Jun[1,2,3], XIE Chuang[1], MAO Shibo[1], and WANG Qianqian[1]. Oil Geophysical Prospecting, 2021, 56(3): 485-495.

Usually, hybrid absorbing boundary conditions (HABC) in simulating elastic wave based on elastic wave equation use linear or exponential weighted coefficient. It is hard to get excellent absorbing effect in both inner and outer boundaries, and the boundary difference scheme is not suitable for efficient acceleration of GPU. This study proposes a HABC method based on a Gaussian-type weighted coefficient to achieve better absorption, and a finite-difference scheme of HABC based on the first-order Higdon absorbing boundary conditions to realize GPU acceleration. Numerical simulation has demonstrated that the HABC based on a Gaussian-type hybrid weighted coefficient can achieve better absorbing effect in both inner and outer boundaries than the HABC based on a linear and exponential hybrid weighted coefficient. In addition, the application of the finite-difference scheme can improve GPU acceleration efficiency, making more suitable for large-scale numerical simulation on elastic wave field based on a complex model.

Keywords: elastic wave equation, simulation, hybrid absorbing boundary condition, Gaussian-type, GPU

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Approximate 3D phase and group velocities for elastic wave in TTI media based on an approximate match method. SUN Shangrao[1], LIANG Kai[1], YIN Xingyao[1], Cao Danping[1], and LI Kun[1]. Oil Geophysical Prospecting, 2021, 56(3): 496-504, 518.

The phase velocities of elastic wave in TTI media can be obtained by solving the Christtoffel equation. But the exact equations are complicated and difficult to use. Starting from the 3D exact expression of phase velocities of elastic wave in TTI media characterized by Thomsen anisotropic parameters, the 3D approximation of qP- and qSV-wave phase velocities in TTI media is derived by an approximate match method. Substituting the approximation into the Berryman's group velocity equation, we can obtain the approximation of qP- and qSV-group velocity. Theoretical analysis and numerical calculations show that the approximation of phase and group velocities based on the approximate match method are in good agreement with the exact value within some ranges, and can be applied to the conditions of moderated and strong anisotropy. The closer the ε and δ are, the higher the approximation accuracy is. Meanwhile, the relative error along the symmetric axis and the vertical symmetric axis of the TTI media is the smallest, but increases near the direction at 45° to the symmetric axis. The relative error of approximate phase and group velocities of qP wave are smaller than qSV wave when the anisotropy is similar.

Keywords: TTI media, phase velocity, group velocity, approximate match method

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First-order velocity-stress equation forward modeling and two-way wave illumination in two-phase viscoelastic VTI media. Worral QURMET[1], QU Yingming[1], LI Zhenchun[1], WANG Yuting[1], JU Fengjiang[1], and LIU Chang[1]. Oil Geophysical Prospecting, 2021, 56(3): 505-518.

Rock has such properties as anisotropy, viscoelasticity and two-phase. To understand the propagation characteristics of seismic waves in complex media and interpret raw seismic data, it is of great practical significance to establish a more accurate model and study the propagation theory of seismic waves in subsurface media. This paper derives the first-order velocity-stress equation of two-phase viscoelastic VTI media and performs forward modeling based on a viscoelastic GSLS model. Compared with single-phase elastic isotropic media, seismic waves propagating in two-phase viscoelastic VTI media are more significantly attenuated and the wave fronts become elliptical, and slow qP waves appears. Analysis of two-way seismic wave illumination of two-dimensional two-phase viscoelastic VTI media shows that the viscoelasticity of the media attenuates seismic wave

energy, the anisotropy of the media causes seismic velocity to vary with direction, and the slow qP wave caused by the two phases of the medium complicates the energy distribution of seismic waves. According to the illumination result, the observation system was optimized.

Keywords: forward modeling, viscoelastic medium, two-phase, anisotropy, standard linear solid model, two-way illumination analysis

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Elastic wave equation for porous media saturated with non-Newtonian fluid. SUN Weitao[1,2], XIONG Fansheng[2], CAO Hong[3], YANG Zhifang[3], and LU Minghui[3]. Oil Geophysical Prospecting, 2021, 56(3): 519-527.

Non-Newtonian fluids like heavy oil, polymer and fracturing fluid are common in oil and gas exploration and development. The Biot theory ignores the nonlinear changes in the fluid viscosity coefficient and shear stress. Although it can be used to describe the interaction between fully saturated solids and classical Newtonian fluids under the action of wave field, it is not correct for the pore filling of non-Newtonian fluids. After establishing a fractional order derivative Maxwell model of non-Newtonian fluid, we found that there was a significant difference in the features of wave field propagation between regular wave equation and elastic wave equations in porous media saturated with non-Newtonian fluid. Resonance phenomenon exists in wave dispersion and attenuation. Such special effects have not been found in wave field dispersion and attenuation in porous media saturated with Newtonian fluid. At the same time, the rheological parameters and fractional derivatives of the constitutive relations of non-Newtonian fluids have obvious effects on the fluid-solid coupling. Numerical results show that the wave equation with non-Newtonian fluid effect is more accurate to predict the P wave velocity of heavy oil sandstone. Non-Newtonian constitutive relation brings new changes to fluid-solid coupling mechanism, which cannot be ignored for the influence on wave field dispersion and attenuation. This study explored the petrophysical model for field seismic survey. The results are useful to other related fields, such as seismic exploration of dense oil reservoir, and micro seismic simulation in cracked reservoirs filled with fracturing fluid.

Keywords: non-Newtonian fluid, porous medium, elastic wave equation

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Rock physics modeling method of natural gas hydrate based on equivalent medium theory. YANG Wenqiang[1], ZONG Zhaoyun[1,2], JIANG Man[1], and LIU Xinxin[2,3]. Oil Geophysical Prospecting, 2021, 56(3): 528-535.

Seismic rock-physics modelling is a bridge used to quantitively convert observed seismic information into the physical properties of reservoir. A reasonable rock-physics model is an important theoretical basis for seismic response analysis, saturation prediction and pre-stack seismic inversion of gas hydrate reservoir. However, gas hydrate can be either a part of rock matrix or a pore-filler, and this complicated composition may cause uncertainty and errors. Based on the equivalent medium theory, this paper presents a rock-physics model, which considers the shear modulus of hydrates and hydrates stored in pores and matrix at the same time. Particularly, the ratio between hydrates stored in pores and matrix is dynamic and can be updated by an iterative process constrained by P-wave velocity form well logging data. This model can be used to support for the prediction of S-wave velocity and saturation in gas hydrate layers, and has been validated by real logging data from well SH2 in a sea area.

Keywords: gas hydrate, equivalent medium theory, rock-physics model, prediction of S-wave velocity, Gassmann equation

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Volumetric edge detection of seismic data based on arbitrarily rotated windowed Hilbert transform. XU He[1], CHEN Xuehua[1,2], LYU Bingnan[2], LI Kangyi[2], and XU Bin[2]. Oil Geophysical Prospecting, 2021, 56(3): 536-542.

The edge detection algorithm based on Hilbert transform usually extracts comprehensive fracture information from real seismic data. The information is very complicated and may weaken some effective information, making difficult to distinguish data characteristics in a particular direction, and unconducive to analyzing fracture orientation. This paper proposes a volumetric edge detection algorithm based on fracture directionality. It uses a

Gaussian window to process the Hilbert operator, and then rotates the operator counterclockwise at any angle on a direction detecting template. An arbitrarily rotated windowed Hilbert transform (AR-WHT) edge detection operator is constructed. It can extract effective edges in any specific direction. The algorithm is used for volumetric edge detection of 3D seismic data. It can not only extract discontinuous features in any direction of seismic data, but also highlight local abnormal information and reduce the influence of noises, so as to obtain a more accurate trend and distribution of reservoir fractures. Applications on model and raw data have proved that the algorithm has the following characteristics. For large faults with known strike or fracture systems with similar orientation, in order to strengthen the discontinuous information of the strike or orientation, the operator perpendicular to the strike or orientation should be selected. For complex fracture systems containing information in various directions, more angles should be selected to extract edge information for fusion, so as to display more effective information. This is conducive to fine seismic interpretation.

Keywords: Hilbert transform, 3D seismic data, edge detection operator, rotation, fracture identification, volumetric edge detection

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Monte Carlo-Markov Chain stochastic inversion constrained by seismic waveform. ZHOU Shuangshuang[1,2], YIN Xingyao[1,2], PEI Song[1,2], and YANG Yaming[1,2]. Oil Geophysical Prospecting 2021, 56(3): 543-554,592.

The resolution of seismic stochastic inversion based on geostatistics and logging data is higher than that of conventional deterministic inversion, so the former is quickly and widely used, but it is difficult to improve calculation efficiency and eliminate randomness. This paper proposes a Monte Carlo-Markov Chain (MCMC) stochastic inversion method based on the constraint of seismic waveform. By making full use of the geophysical mapping relationship between seismic data and parameters to be inversed, and a correlation coefficient to guide pseudo ordinary Kriging interpolation to well data according to the similarity of known seismic waveforms, an initial model is established; then the posterior probability density distribution is constructed under the constraints of seismic data and logging data on the Bayesian framework, and the initial model which can indicate seismic waveforms is randomly simulated multiple times by using the Metropolis-Hastings sampling algorithm. The posterior mean value is the optimal solution to the model parameters. This method effectively improves inversion stability and lateral continuity, reduces randomness, effectively weakens the impact of seismic noises on inversion results, and greatly accelerates the convergence of the Markov chain, which effectively improves computing efficiency and estimation accuracy. Applications on model and real data have proved the MCMC stochastic inversion method constrained by seismic waveforms has good noise resistance, can effectively improve inversion accuracy, and are advantageous in identifying thin reservoirs within a tuning scale. It improves both vertical resolution and horizontal resolution.

Keywords: seismic stochastic inversion, initial model, seismic waveform constraint, Metropolis-Hastings algorithm, posterior probability density distribution

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Reservoir fracture prediction method and application based on structure-oriented filtering and coherent attributes of gradient structure tensor. CUI Zhengwei[1,2], CHENG Bingjie[1,2], XU Tianji[3], and NIU Shuangcheng[1,2]. Oil Geophysical Prospecting, 2021, 56(3):555-563.

Gradient structure tensor (GST) coherence and structure-oriented filtering have their own advantages in fault interpretation, but there are few examples that combine them. This paper proposes a reservoir fracture prediction method based on the coherent attributes of GST and structure-oriented filtering. Firstly, the structure-oriented filtering method is used to compensate the anisotropy of seismic data, which can improve the signal-to-noise ratio and highlight the fault and fracture features. Then, using the optimized seismic data to extract the formation dip, azimuth, etc. to obtain basic data for calculating faults and fractures. Finally, based on the dip, azimuth, amplitude and other data, construct the directional derivative vector and GST. By calculating the eigenvalue and eigenvector of GST, the GST coherence highlighting the structural features of seismic data are extracted to realize fine identification of reservoir fractures. The reservoir fracture prediction method based on

the coherent attributes of structure-oriented filtering and GST accurately predicted the fractures in the carbonate reservoirs in the upper Lei 4th member in western Sichuan Basin. The results show that the faults and fractures are mainly distributed below the T6 layer, which has continuous reflection and stable formation, and is a good caprock. Small and medium-scale faults and fractures (mainly structural fractures) are relatively developed in the upper Lei 4th member. They are natural channels for gas migration and spaces for gas accumulation.

Keywords: structure-oriented filtering, gradient structure tensor, coherent attribute, fractures, dip, azimuth

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Seismic motion simulation for horizontal well drilling in Fuyu reservoirs. XIE Chunlin[1], LI Yongyi[1], CHEN Zhide[1], HU Jiuzhan[1], TIAN Meng[2], and WANG Xiaoyang[3]. Oil Geophysical Prospecting, 2021, 56(3):564-573.

The geologic and geophysical characteristics of Fuyu reservoirs are as follows: ① The reservoirs are thin and superposed; ② Their seismic resolution is low and T_2 events (strong top reflections) shield the reservoirs; ③ Both the velocity and the density of the sandstone are higher than that of the mudstone, but the difference is tiny; ④ The corresponding relationship between the impedance and the sandstone is not obvious due to the tuning effect of thin interbedded sandstone and mudstone; ⑤ Gamma ray (GR) and resistivity logging curves can distinguish the sandstone from the mudstone. Finally, GR logging curves were chosen as the characteristic curves used in the seismic motion simulation (SMS) process. The basic ideas of seismic motion simulation are that, constrained by sequence stratigraphic framework, the lateral changes of seismic waveform instead of variation function is used to express the spatial variation of reservoir; constrained by the Bayesian framework, and considering seismic, geological and logging information, a frequency-divided inversion strategy is taken to gradually improve the resolution of inversion results, namely to calculate the low frequency components through logging interpolation, conduct seismic spectrum simulation inversion to obtain intermediate frequency components, and run waveform controlled simulation and random simulation to provide deterministic high-frequency components and random high-frequency components. The reasonable high-frequency components help greatly improve the vertical resolution of the reservoir prediction result. The application of this method to real data shows that: ① SMS can improve both vertical resolution and lateral resolution; GR SMS results have so high resolution that they can predict single sand bodies more than 2.4 m thick. However, there are multiple solutions and it is hard to select the best solution. Drilling data should be used to select, and only the solution selected can be used to predict geologic sweet points for future deployment and drilling of horizontal wells; ② Effective samples and the best cut-off frequency, two important parameters of SMS, which decide the quality of inversion, should be chosen through repeated tests.

Keywords: Fuyu reservoir, channel sandstone, seismic motion simulation, frequency-divided inversion, effective samples, best cut-off frequency

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A fault enhancing method based on dynamic time warping. DONG Lin[1], SONG Weiqi[1], HU Jianlin[1], ZENG Chao[1], ZHAO Baoyin[2], and GAO Wenzhong[2]. Oil Geophysical Prospecting, 2021, 56(3):574-582.

Seismic attributes can reflect the spatial characteristics of faults to a certain extent, but they are very sensitive to noises, resulting in less effective detection of complex faults. The conventional fault enhancing algorithm first calculates the fault direction according to the fault attribute, then enhances the fault information along the fault direction and suppresses other information along the non-fault direction, but the calculation accuracy depends on the calculation accuracy of the fault direction. This paper proposes a fault enhancing method based on dynamic time warping (DTW) by assuming that faults are linear in plane and planar in space. This method uses DTW to calculate optimal fault lines, and uses nonlinear smoothing, forward and reverse tracking to effectively improve the accuracy of the optimal fault lines. So the non-fault information in the fault attribute is completely removed, the faults are more continuous and

clearer, the fault distribution and extension features are more obvious, and at the same time some nonlinear local features in seismic images are removed too. Complex faults are divided into simple faults within local windows, and then the optimal fault lines are calculated within the local windows. Final enhanced complex faults are obtained by integrating the local optimal fault lines. Applications on model and field data have proved that the proposed method can suppress the non-fault information on fault images, and provide more continuous and clearer faults after enhancing processing, and it has good robustness and applicability.

Keywords: dynamic time wrapping, fault attribute, fault enhancing, seed points, optimal fault lines

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Fusion of multiple data for predicting complex carbonate reservoirs and its application: A case study on Ordovician of Qianmiqiao buried hills. YAN Jiawei[1], WANG Wenqing[1], LYU Fangfang[2], ZHU Guijuan[2], FU Hui[1], and LI Zhenyong[1]. Oil Geophysical Prospecting, 2021, 56(3):583-592.

Reservoir prediction by a single method is limited, because it is controlled by multiple factors in special areas. By referring to previous researches on geological characteristic of the Ordovician carbonate reservoirs in Qianmiqiao buried hills, we established a multiple-data fusion technique which utilizes seismic waveform parameter inversion and sensitive seismic attributes to characterize complex fractured-vug reservoirs controlled by lateral dissolved pores and fractures. Relieable lateral dissolved pore prediction was achieved by seismic waveform parameter inversion and impedance rebuilting from sensitive logging data. Fractured reservoir identification was realized by optimizing fracture sensitive seismic attributes, such as curvature and ant volume, under the constraint of FMI. On the geological model, seismic inversion was fused with fracture prediction using the method based on support vector machine. The result can guarantee the precision of lateral dissolved pore predicion and reflect the connectivity of fractures. Field application shows that favorable reservoirs are developed along the major fault belt at a large scale. Wells drilled in the predicted favorable reservoir zone have good production, and the accuracy is close to 89%. The results is helpful to locating development wells, increasing reserves and production.

Keywords: carbonate reservoirs, Qianmiqiao buried hill, multiple-data fusion, seismic waveform parameter inversion, seismic attributes, well log rebuilt, support vector machine

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Wide-azimuth Young's modulus inversion and fracture prediction: An example of H structure in Bozhong sag. WANG Jianhua[1,2], ZHANG Jinmiao[1,2], and WU Guochen[3]. Oil Geophysical Prospecting, 2020, 56(3):593-602.

Buried hill structures are widely distributed in the Bohai Sea and the South China Sea. Affected by both structural stress and weathering corrosion, fractures are relatively developed in buried hills. As an important space for oil and gas storage and migration, fracture zones are key targets of oil and gas exploration in buried hills. Traditional fracture prediction based on seismic attributes has low accuracy due to the difference in AVO attributes between top and bottom layers. In this study, first based on the first-order perturbation approximation equation of HTI media and the relationships among elastic parameters, an azimuthal elastic impedance equation was derived, which is characterized by Young's modulus, Poisson's ratio and anisotropic parameters. Then the azimuthal elastic impedance inversion method was constructed according to the Bayesian theory, which avoids the influence of different AVO attributes on top and bottom layers. The reliability of inversion can be improved, and fracture prediction can be realized by combining anisotropic inversion with azimuthal Young's modulus fitting. Finally, the method was used to predict the fracture development intensity and direction in the buried hills in the H structure of Bozhong sag. The data used is the first wide-azimuth data acquired offshore in China. The result has proved that the fracture prediction method is accurate and rational.

Keywords: buried hill, azimuthal Young's modulus, fracture prediction, anisotropy

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Practice and understanding of double controlled geological modeling technology: A case study on SZ36-1 Oilfield in the Bohai Bay Basin. ZHANG Haixiang[1,2,3], LI Zhandong[1,2,4], LI Yang[5], ZHAO Jiabin[3], PANG Hong[3], and JIANG Hongfu[6]. Oil Geophysical Prospecting, 2021, 56 (3): 603-611.

At present, most offshore oilfields, especially in the Bohai Bay Basin, have entered into development stage with high water cut. This paper proposes a constrained modeling technology based on seismic inversion and sedimentary microfacies. Taking the SZ36-1 Oilfield in the Bohai Bay Basin as an example, a porosity model is built by using synthetic seismic records as a bridge, sedimentary microfacies as a "hard constraint" and seismic inversion as a "soft constraint". The method has technical advantages as follows: ① The geological model based on double constraints is consistent with actual geological understanding. The model hasn't the "trace" of the hard constraint. It is not only conformed to the development of sandstone lithofacies, but also can predict inter-well development. ②The model has higher accuracy and the average coincidence rate of posterior wells is up to 92.51%. In addition, it can reduce the uncertainty and the limitations of a geological model . The model based on double constraints is helpful to provide strong technical support for improving waterflooding oil recovery.

Keywords: Seismic inversion, geological modeling, reservoir numerical simulation, remained oil, SZ36-1 Oilfield

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A method of predicting T_2 cutoffs from NMR logging data of tight glutenite reservoirs based on normal distribution simulation. ZHU Ming[1], JIA Chunming[1], MU Yuqing[2], LI Jing[1], and HU Tingting[1]. Oil Geophysical Prospecting, 2021, 56(3): 612-621.

T_2 cutoff value is an important input for interpretation and evaluation of NMR (nuclear magnetic resonance) logging data. The existing method of determining T_2 cutoff is deficient, and brings a great challenge to the NMR interpretation of complicated reservoirs. A new method for calculating T_2 cutoff value was proposed. Firstly, 21 core samples are classified into five types according to the morphological difference of NMR T_2 spectra under full brine saturation. The morphological characteristics of the NMR T_2 spectra in the states of full brine saturation and centrifugal irreducible water are analyzed. Then the normal distribution function is used to fit the NMR T_2 spectrum of centrifugal irreducible water or movable water in macropores. The simulated T_2 distributions are used to replace the experimental results of core samples to get the variable T_2 cutoff value. Then calculate irreducible water saturation (S_{wi}) and permeability. The advantage of the proposed method is that the T_2 cutoff can be directly acquired from the NMR T_2 distribution of full brine saturated condition. The actual data processing results show that the absolute error between the T_2 cutoff value determined by this method and the core-derived results is less than 2.0ms. The absolute error between the corresponding estimated S_{wi} and the core-derived results is less than 5.0%. Meanwhile, the predicted permeability is also in good agreement with the core-derived results. The method makes the applicability of NMR logging technique much improved.

Keywords: NMR logging data, T_2 cutoff, irreducible water saturation (S_{wi}), normal distribution simulation

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3D CSAMT infinite-element forward modeling based on equivalent source. ZHANG Lincheng[1,2], HU Hongling[3], TANG Jingtian[2], XIAO Weichu[1], XIAO Xiao[2], and YUAN Yuan[4]. Oil Geophysical Prospecting, 2021, 56(3): 622-630.

Traditional 3D CSAMT forward modeling has disadvantages such as source singularity and infinite boundaries. This paper proposes a 3D CSAMT forward modeling algorithm based on an equivalent source. It is fast and accurate for forward modeling of electric dipole sources. Firstly, accurately simulate the horizontal electric dipole source by calculating the electromagnetic field at the grid nodes in a certain range near the source. Secondly, replace the traditional cut-off boundaries with infinite elements, and implement finite element-infinite element coupling and paralleling to directly get fast and accurate 3D CSAMT solutions on an equivalent field source. The algorithm has been proved correct on a uniform half-space model. Finally, the optimal range of source equivalent

simulation was studied based on the skin depth formula. Numerical results show that the best equivalent range of source shouldn't be less than 1.5 times of the skin depth.

Keywords: equivalent source, infinite element, direct solution by parallelling, skin depth

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Study on the influence and correction method of coast effect on magnetotelluric responses. LI Yongbo[1,2,3], WU Qiong[1,2,3], WANG Gang[1,2,3], ZHANG Zhenyu[1,2,3], WANG Shumin[1,2,3], and XI Yongzai[1,2,3]. Oil Geophysical Prospecting, 2021, 56(3): 631-644.

Influenced by coast effect, distortions occur on land-side magnetotelluric (MT) data when the distance from coastline is less than the skin depth of target-related frequency. In this study, the variation of coast effect on various types of electrical structures were analyzed and summarized via magnetotelluric three-dimensional (3D) forward modeling, and the coast effect was quantified by a mean-square-relative-error(MSRE). An iterative correction method was used to correct the coast effect. Coast effect typically depends on the distance from coastline and the resistivity of subsurface layers. It decreases with the increase of the distance, and increases with the increase of the layer resistivity. The intensity of coast effect typically depends on the distance from coastline, sea water depth and the resistivity of deep layers. It decreases with the increase of the distance, and increases with the increase of sea depth. When the distance from coastline is approximately less than 50km, coast effect increases with decreasing resistivity of deep layers in a transverse magnetic(TM) mode, which is on the contrary in a transverse electric(TE) mode. When the distance from coastline is approximately more than 50 to 100km, coast effect is weak, and the smaller the resistivity of deep layers, the weaker the coast effect. Additionally, coast effect in TM mode is sensitive to conductive asthenosphere, and the shallower the asthenosphere, the stronger the coast effect. Modeling results indicate that the coast effect in an offshore area should be corrected, the inversion model can be selected based on the coast effect in the area far from the coastline, and the iterative correction method can be better able to eliminate the coast effect. In this paper, the study on the variation and correction methods of coast effect provides a basis for MT data correction and inversion in offshore areas.

Keywords: coast effect, magnetotelluric, three-dimensional forward modeling, iterative correction method

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An iterative algorithm for calculating component ΔT_{Pro} from magnetic anomaly ΔT. HU Zhengwang[1,2], DU Jinsong[1,2,3], SUN Shida[4], and CHEN Chao[1,2]. Oil Geophysical Prospecting, 2021, 56(3): 645-658.

Total magnetic intensity anomaly(ΔT) is intrinsically different from the projected component (ΔT_{Pro}) of the magnetic vector anomaly(T_a) on the direction of the main field (T_0), and this difference is very obvious in a highly magnetic environment. Traditionally, to simplify computation, ΔT is always treated as ΔT_{Pro} approximately. This may cause a large error in quantitative interpretation. This paper proposes an efficiently iterative algorithm for fast calculating ΔT_{Pro} from ΔT by utilizing the theoretical difference formula between ΔT and ΔT_{Pro}. First, the factors influencing the validity, convergence rate and calculating accuracy, and computational efficiency are analyzed successively by serial model tests. Then using field data, related problems which need to be paid attention and the difference between the results from our method and a traditional method are discussed. Both model and field applications have verified the reliability and stability of our method. Furthermore, compared with other methods, our method requires a little amount of computation and computer memory. It is effective and practical, and worth being promoted in the field application.

Keywords: total magnetic intensity anomaly, magnetic anomaly processing, transform of magnetic field component, iterative algorithm, highly magnetic environment

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Contact-type induced polarization and its application for detecting leakage. LI Jinghe[1], HE Zhanxiang[2,3], YANG Jun[1], and RAN Mengkun[1]. Oil Geophysical Prospecting, 2021, 56(3): 659-669.

Heavy metal pollution and oil/gas leakage are major sources of pollution in mining areas and industrial sites. Such environmental pollution caused by heavy metal pollution and leakage seriously affects our life and national economy. How to develop a new monitoring technology for detecting wastewater with heavy metal and oil/gas leakage is a very challenging task if considering monitoring cost, efficiency and accuracy. This paper describes contact-type induced polarization and its application. Two kinds of observation systems (contact power supply and ground observation; contact power supply and direct observation) are proposed, which can reduce the limitations in a complex construction environment, and improve the strength and accuracy of observed signals. Then the mechanism of microscopic polarization effect of contact-type heavy metal pollution is discussed in details, the content of heavy metal elements in contaminated samples is determined by emission spectrometry, and the polarizability of the samples is determined by a dipole-dipole method. In the study, two physically simulated soil tank tests were designed for simulating the initial state and diffusion state of heavy metal pollution, and the results were compared with the traditional induced polarization method to verify the existence of the contact-type induced polarization effect of heavy metal contaminated soil and its feasibility in detecting oil/gas leakage. The results provide an effective reference to detecting heavy metal pollution, oil leakages from oil tanks and underground oil/gas reservoirs.

Keywords: Contact-type induced polarization, leakages, polarization mechanism, abnormal pattern, physical simulation

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Technique and application of joint magnetotelluric and seismic modeling and constrained inversion based on clustering and multivariate geostatistics. YANG Bo[1], ZHANG Xiangguo[2], LIU Zhan[1], and XU Kaijun[1]. Oil Geophysical Prospecting, 2021, 56(3): 670-677.

With more and more complex and deeper geological bodies, the one-sidedness and limitation of a single geophysical method have become more and more prominent, and comprehensive utilization of multiple geophysical technologies and data has become an inevitable trend. This paper proposes cross-variogram in multivariate geostatistics to establish the petrophysical relationship between velocity and resistivity. Based on the relationship, the guided fuzzy C-means clustering algorithm in machine learning is used to conduct multi-constraint inversion and realize MT-seismic joint modeling. Application to real data recorded from the southern depression of the Dayangshu Basin has proved that the MT-seismic joint modeling and multi-constraint inversion can gradually reduce the ambiguity of a single geophysical method and improve the ability to identify target geological bodies. The results of MT and seismic methods are verified each other, demonstrating that the joint modeling and multi-constraint inversion technology is potential in field application.

Keywords: cluster analysis, multivariate geostatistics, joint modeling and multi-constraint inversion

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