ABSTRACTS

A dual-vessel broadband seismic acquisition experiment. Li Fuyuan[1,2], Wei Chenglong[1,2], Hu Jiafu[1,2], Deng Guilin[1,2], Yi Hai[1,2] and Zhong Guangjian[1,2]. OGP, 2018, 53(5):887-895.

With dual-vessel towing streamers, we can deploy flexible seismic acquisition geometry. This acquisition geometry has various advantages such as larger offset, higher common mid-point (CMP) folds, dual-azimuth illumination (split spread), etc. At the same time, the large volume broadband source can be used in the seismic acquisition, and variable depth towed-streamers will help de-ghosting during the data processing. All these will greatly improve deep target imaging. So we have carried out a dual vessel seismic broadband acquisition experiment. Final seismic sections show better imaging and higher resolution on both shallow layers and deep targets. This confirms the effectiveness of the proposed acquisition approach and it is worth to use in complex subsurface areas.

Keywords: dual-vessel towed streamer, broadband source, variable depth towed streamer, de-ghosting, band expansion, synthetic processing

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Residual static corrections with the niche genetic algorithm based on Poisson disk sampling. Zhou Qiang[1,3], Cao Linyu[2] and Chen Aiping[1,3]. OGP, 2018, 53(5):896-902.

For residual static corrections, linear methods are easy to fall into local solutions and lead to poor seismic imaging in complex mountain areas. Therefore we propose in this paper a new approach with a niche genetic algorithm based on the Poisson disk sampling. First based on cnventional residual static corrections, real number codes are calculated with the Poisson disk sampling to increase the uniformity of the initial solution. Then multi-populations of niches are constructed with multi-threads to estimate residual statics based on "marriage" operation. Multi-core parallel calculations of machines can quickly search optimal residual statics within the multi-populations and their "marriage". Both theoretical model tests and real data applications confirm that the proposed residual statics approach can increase the event continuity and improve low signal-to-noise ratio (SNR) data imaging.

Keywords: residual static correction, genetic algorithms, Poisson disk sampling, multi-populations, niche, multi-threads

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Absorption effects in nearly perfectly matched layers and damping factor improvement. Luo Yuqin[1] and Liu Cai[1]. OGP, 2018, 53(5):903-913.

There are two kinds of problems in perfectly matched layers (PML) introduced in the seismic wave field simulation: one is how to reduce the extra storage capacity in the practical boundary application and enhance the calculation speed; the other is how to absorb incident wave more quickly and make the absorption better. The first problem is well solved with a few advanced non-split perfectly matched layer approaches. For this issue, we adopt a newly-developed non-split perfectly matched layer approach, which transforms directly the wavefield, and will not change wavefield form and use convolution. For the second issue, there is not much progress in boundary absorption enhancement due to the discrepancy complexity caused by discretization. Currently, we decrease the discretization discrepancy by adding the number of layers. In this paper, we analyze the property of damping term and design a new attenuation function which can improve the absorption effect. The function could weaken the reflection amplitude value by 20%～60% when the number of layers is 5～10 compared with conventional attenuation function.

Keywords: perfectly matched layer (PML), damping factor, seismic wavefield simulation

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Joint absorbing boundary in the staggered-grid finite difference forward modeling simulation. Hu Jianlin[1], Song weiqi[1], Zhang Jiankun[2], Xing Wenjun[2] and Xu Wenhui[2]. OGP, 2018, 53(5):914-920.

The boundary condition is one of the key issues discussed in the simulation of the staggered-grid finite difference of the 3D acoustic equations. The perfectly matched layer absorbing boundary (PML) is stable and effective, but it needs a certain boundary thickness to make perfectly absorption which makes the model bigger and requires a huge computation. Higdon absorbing boundary condition can stably eliminate the incident wave at any angle on the boundary, but it becomes very complex after discretization when the higher order condition used. Based on the plane wave propagation in a PML medium, we obtain a new Higdon absorbing operator in the PML, and then get joint absorbing boundary conditions. In the test of the joint absorbing conditions, it is found that the joint absorbing conditions are effective with a thinner PML layer

and smaller computation.

Keywords: 3D acoustic equation, staggered finite-difference, forward modeling, PML boundary condition, Higdon boundary condition, joint absorbing boundary

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Simultaneous inversion for velocity and reflector geometry using multi-phase travel-times in 3-D tetrahedral cell model. He Leiyu[1], Yan Xing[2] and Bai Chaoying[1,3]. OGP, 2018, 53(5): 921-931.

To conduct forward modeling and simultaneous inversion for a complex geological model with an irregular topography, or irregular reflectors, or irregular velocity anomaly, we propose in this paper simultaneous inversion using multi-phase travel-times in 3-D tetrahedral cell model. First we realize a multi-phase arrival tracking with a multi-stage modified shortest-path method, develop calculation formula of partial derivative of reflection depth about travel-times under a tetrahedral cell model. Then we solve a constrained-damped least-squares inversion with a conjugated gradient method to simultaneously invert the velocity model and reflector geometry with multi-phase arrival time information. Finally we normalize the different Jacobi elements in the simultaneous inversion to eliminate undulated reflector scattering, which causes over-high ray density and over-updated velocity issues. Numerical simulation results show that with the tetrahedral cell model parameterization, it is possible to maintain a high computational accuracy for forward modeling in the complex velocity model, and capture the irregular velocity anomaly and reflector geometry in the simultaneous inversion. Therefore, the proposed simultaneous travel-time inversion has a wide application in real problems.

Keywords: tetrahedral cell, multi-phase arrival tracking, joint inversion, simultaneous inversion, travel-time tomography

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Structure-constrained plane-wave least-squares FFD prestack depth migration for VTI media. Zhu Feng[1,2], Huang Jianping[1,2], Li Zhenchun[1,2] and Li Qingyang[1,2,3]. OGP, 2018, 53(5): 932-944.

For most of the sedimentary strata in the central and eastern China, seismic wave velocity is determined by both the underground position and the spread direction. It is important to develop migration methods for anisotropic media to improve seismic imaging. With the high order Fourier finite difference (FFD) operator to the linear inversion imaging, we propose a VTI least-squares FFD prestack depth migration method (VTI-LSFFD). Based on the accomplishment of VTI-LSFFD, optimization strategies are adopted to solve some key problems of the least-squares migration such as heavy computation cost and sensitivity to coherent imaging noises. First, the plane-wave encoding strategy is used to reduce the amount of seismic data and improve computation efficiency. Then common imaging gathers (CIG) are extracted and plane-wave construction (PWC) operators are applied to the CIGs, the coherent imaging noise is suppressed and the signal-to-noise ratio (SNR) is improved. Based on our numerical experiments on the modified anisotropy Marmousi 2 model, the following advantages of the proposed method are found: this method is suitable for strong horizontal velocity variation; it has both high computation efficiency and low coherent imaging noises sensitivity; and with the plane-wave encoding strategy, it achieves better near-surface imaging than the one-way wave migration methods.

Keywords: VTI media, plane-wave, least-squares migration (LSM), Fourier finite difference (FFD), plane-wave construction (PWC)

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Focal mechanism inversion with single-well microseismic wave energy. Zhao Wei[1], Xin Wei[2], Mao Zhonghua[3], Zhai Shang[1], Hu Tianyue[1] and He Chuan[1]. OGP, 2018, 53(5): 945-953, 968.

The microseismic focal mechanism contains important information about reservoirs and fractures, which makes it critical to evaluate the reservoir production. Conventional methods that utilize S/P amplitude ratios to determine the focal mechanism are not applicable for the cases where the observation aperture is limited. Studies have shown that the wave energy is sensitive to the focal mechanism. For this reason, we propose a method to invert the focal mechanism with wave energy. Before the inversion, the velocity model, source location, and scalar seismic moment are calculated in advance. We select P- and S-wave windows to calculate wave energy for waveforms after the seismic moment normalization. Using the weighted K nearest neighbor prediction method, the strike, dip, and rake of fault plane are resolved. Synthetic data test shows that the accuracy of inversion results is

greater than 97% under the noise free condition. Tests with different noise levels indicate that the proposed method is more stable than the amplitude ratio method and can improve the inversion accuracy. Finally, real data tests in an oil field show that the proposed method achieves good results in application.

Keywords: downhole microseismic monitoring system, focal mechanism, wave energy, grid search

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Strong tolerance random forest algorithm in seismic reservoir prediction. Song Jianguo[1,2], Yang Lu[1], Gao Qiangshan[3] and Liu Jong[4]. OGP, 2018, 53(5): 954-960.

Since it is difficult to effectively define noise and signal on seismic and logging data, seismic reservoir prediction needs good noise tolerance algorithms. The random forest (RF) algorithm with strong noise tolerance is proved by adding noise to training samples. However this does not mean RF has good noise tolerance in seismic reservoir prediction as well. First we extract noise samples from original seismic data with strong noise in the Survey F3, and extract denoised samples from the data processed by the dip-steered median filter. Then we establish random forest regression models between seismic attributes and the porosity parameter. After processing the original seismic data and the filtered seismic data with the noise sample model and denosied sample model, we estimate four different porosity parameter cubic data. The results reveal that the two data sets obtained with the noise model are more disturbed by noise, and the other two data sets obtained with the denoised model are much less affected by noise. On these data sets, reservoir geological characteristics can be effectively characterized which proves the random forest model has strong robustness and perfect tolerance to abnormal data differing from the sample data. The key issue in the application of the random forest algorithm to seismic reservoir prediction is that the training data does not contain noise. In other words, the input variable of sample data being denoised is much more significant, whereas whether seismic data were denoised or not has less effects on the prediction result.

Keywords: seismic attribute, random forest algorithm, noise tolerance, reservoir prediction, noise

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Seismic sparse spike inversion based on L_0 norm approximation. Liu Baihong[1], Li Jianhua[2] and Zheng Silian[1]. OGP, 2018, 53(5): 961-968.

Under the assumption that the reflectivity is a series of sparse spike, a sparse spike inversion for seismic reflection coefficients is proposed. First the inversion is accomplished by minimizing an objective function which includes a quadratic error term (L_2 norm) combined with a sparseness-inducing regularization term (L_0 norm). Then the L_0 norm is approximated by a smoothing function, so that the L_0 penalty becomes differentiable, and the minimization algorithm for continuous functions based on derivative is used to solve the problems. The proposed method is tested on both model data and real field data, and the results show this method is feasible.

Keywords: seismic exploration, reflectivity, impedance, sparse spike inversion, L_0 norm

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AVO types discrimination based on a proximal support vector machine. Li Wenxiu[1,2,3], Wen Xiaotao[1,2], Li Tian[3], Li Leihao[1], Liu Songming[1] and Yang Jixin[1]. OGP, 2018, 53(5): 969-974.

AVO is an important approach for reservoir oil and gas analysis. It can qualitatively describe oil reservoirs. The AVO conventional classification depends mainly on human discrimination so that the discrimination result is often inaccurate and the workload is heavy. In this paper, we extract feature parameters from four types of AVO curves as a training set, and introduce the proximal support vector machine method to AVO types discrimination. Based on the shape of four types of gas AVO curves, taking the morphological features of prestack seismic data as input parameters, AVO types of the reservoir in a survey area are obtained. This method is applied to the automatic identification of AVO types in a clastic-rock gas field in the South China Sea, and more accurate results are obtained. The proposed method provides a reliable and convenient tool for AVO types discrimination in reservoirs.

Keywords: proximal support vector machine, AVO types, classification, reservoir analysis

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Comparison of linear and nonlinear time-frequency analysis on seismic signals. Huang Yucheng[1], Zheng Xiaodong[1], Luan Yi[2] and Yang Tingqiang[1]. OGP, 2018, 53(5): 975-989.

In this paper, we discuss the resolution, computational efficiency, and robustness of currently used seismic time-frequency analysis methods based on synthetic signals and real seismic data. In synthetic signal analysis, the time-frequency energy concentration of linear methods are generally weak, yet they are preferred in the low signal-to-noise (SNR) situation for their high computational efficiency, among which the continuous wavelet transform (CWT) is considerably robust; nonlinear methods are unstable with noisy data except for smoothed pseudo Wigner-Ville distribution (SPWVD) and general linear Chirplet transform (GLCT). However, nonlinear methods may reach much higher time-frequency resolution with high SNR. Thin-beds and the distribution of geologic features could be clearly identified using these methods. In real seismic data analysis, compared with linear methods like short time Fourier transform and CWT, reservoir reflection interfaces and sedimentary facies belts are better delineated on common frequency sections and time slices obtained by robust nonlinear methods like SPWVD and GLCT.

Keywords: seismic signal, time-frequency analysis, resolution, computational efficiency, robustness

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Application of zero-offset VSP data transformation to bridge calibration in high-dip structure areas. Cai Zhidong[1,2], Wang Chong[2], Chen Ce[2], Wang Yang[2], Jiang Zhongcheng[3] and Tian Wenhui[2]. OGP, 2018, 53(5): 990-996.

The bridge calibration of vertical seismic profile (VSP) is one of the key approaches to bridging surface seismic, logging, and lithology data. However for high-dip structure areas, this bridge calibration cannot achieve horizon analysis because the up-going wave field is not flatted. Therefore we propose in this paper a new approach of bridge calibration for zero-offset VSP data. For the zero-offset VSP data transformation, up-going waves after NMO are classified and listed as sub-matrix. Then horizons are calibrated on this data. This approach calibrates horizons directly on the transformed data rather than on VSP corridor stacked data. So calibrated results are more intuitional, more reliable, and better for seismic and geology analysis. An application example in Tarim Basin demonstrates the effectiveness of the proposed approach.

Keywords: high-dip structure, vertical seismic profile (VSP), bridge calibration, corridor stack, data transformation

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Well-to-seismic calibration in the depth domain using dynamic depth warping. Luo Hongmei[1,2], Wang Changjiang[1], Liu Shuhui[1], Mu Xing[1], Zhang Zhijing[1,2] and Zheng Wenzhao[1]. OGP, 2018, 53(5): 997-1005.

Prestack depth migration seismic data play an important role in the geologic integrated research with its unique advantage, but depth errors between well logging and seismic data caused by low-frequency migration velocity model limit its wide application in the petroleum exploration and development. The depth correction is the premise and the key in better applications of the data. Although it is impossible to be completely consistent in all aspects due to the different formation mechanism of seismic and well logging data, they should be almost the same in terms of the depth of the formation interface. So in this paper we put forward a well-to-seismic calibration method with high-precision based on dynamic depth warping (DDW) algorithm. First the similarity between observed seismic traces at well locations and synthetic seismogram is analyzed in the depth domain. Then a distance-like quantity between the sampling points is obtained by calculating amplitude, wave number, and time-frequency features based on the forward dynamic programming (DP) algorithm. Finally errors between each seismic layer depth and the true depth can be obtained, and depth calibration can be further performed with the correction value. The proposed method is verified on a theoretical model and real seismic data, and the feasibility and reliability are clearly proved by the results.

Keywords: depth domain, dynamic depth warping (DDW), well-to-seismic calibration, error correction value, 3D Kriging interpolation

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Application of segmented-frequency-band fusion inversion in Chunguang prospect area. Zhang Xinchao[1], Li Feng[1], Yan YongXin[1], Wang Yong[1], Zhang Chi[1] and Yue Xinxin[1]. OGP, 2018, 53(5): 1006-1013.

The Chunguang prospect area located in the west of the Junggar Basin is characterized by thin-thickness, small-scale, and rapid-lateral-variation reservoirs. However, conventional high-resolution

inversion methods are not completely applicable for the reservoir prediction in the area. Therefore, we propose in this paper a segmented-frequency-band fusion inversion to predict these special reservoirs. Conventional model inversion results are used as initial model, and high frequency seismic data is processed with high-resolution inversion algorithms. With log-constraint model inversion, this method can improve both the vertical resolution and the lateral accuracy. And the high resolution seismic inversion with tuning-frequency constraints can reduce the uncertainty of horizontal interpolation of high-frequency logging data. The application proves the effectiveness of the proposed method.

Keywords: Chunguang prospect area, thin reservoir, segmented-frequency-band fusion inversion, reservoir prediction

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Dim spot subtle trap identification in Yinggehai Basin. Pan Guangchao[1], Deng Yong[1], Fan Caiwei[1], Zhu Peiyuan[1] and Wu Tao[1]. OGP, 2018, 53(5): 1014-1021, 1030.

Deep strata in Yinggehai Basin have good hydrocarbon potentials. Seismic reflection characteristics of gas reservoir and dim spot targets in deep high-temperature and ultra-high pressure are clarified based on rock physics analysis and seismic forward modeling. Difficulties in dim spot target identification are also discussed. Based on our mentioned research, we propose a three-step approach of dim spot target identification. The first step is dim spot identification. Weak reflection bodies with AVO type 2 anomaly on stack sections are considered as dim spots based on FN attribute. The second step is lithology identification. The reservoir identification is achieved with v_P/v_S differences between sandstone and mudstone, and false FN attribute anormalies caused by other lithology are eliminated. The third step is physical properties prediction, which is achieved with the linear relationship between sandstone porosity and P- and S-wave impedances, and sweep spots are identified at the same time. The proposed approach is applied to the Block Ledong and Ledong 10-X dim spot is identified. The latest drilling proves the feasibility and effectiveness.

Keywords: Yinggehai Basin, bright spot, dim spot, deep high-temperature and ultra-high-pressure, subtle trap, low porosity and low permeability

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Key characterization techniques for traps controlled by low order unconformity: A case study of the south slope belt in the Dongying Sag. Liu Shuhui[1], Cai Juhong[2], Guan Xiaoyan[1] and Chen Tao[1]. OGP, 2018, 53(5): 1022-1030.

Low order unconformities were well developed in the Eogene in the south slope belt of the Dongying Sag in Jiyang Depression, and they provided favorable conditions to form stratigraphic traps and reservoirs. Due to a very short geologic period, there are little difference in form and petrology of strata beneath and above the unconformities, and there is also little difference between conventional logging and seismic data. This causes difficulties in pinch-out identification along the unconformities in this area. To overcome these difficulties, we propose a comprehensive layered curve method based on optimal segmentation of ordered series, and combine with high-resolution seismic time-frequency analysis. So an approach of low order unconformity identification is developed. Seismic data is converted into character expressions, and establish strata pattern "gene". Automatic search in the character domain is feasible to realize refined characterization of pinch-outs. The proposed approach has been applied to the south slope belt in the Dongying Sag and good results are achieved.

Keywords: lower-order unconformity, comprehensive layered curve, time-frequency analysis, seismic "DNA" detection, pinch-out

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Residual oil prediction on seismic data in a deep sand reservoir, Tarim Basin: A case study of the Reservoir Donghe 1. Ling Dongming[1,2], Du Qizhen[1], Cui Yongping[3], Tian Jun[2], Yao Xianzhou[2] and Han Yaozu[2]. OGP, 2018, 53(5): 1031-1040, 1094.

Deep burial reservoirs in Tarim Basin went through long-period shallow buried and rapid deep burial. This two-stage burial process forms three unique geological conditions: ①Physical properties of deep buried sand reservoirs are well kept with medium or good porosity; ②The velocity and density of mudstone are obviously increased, generally larger than sandstone; ③Reservoirs have large internal pressure and good anti-compression ability, they are not easy to be deformed. All these constitute an important geological foundation for the residual oil prediction in deep burial sand reservoirs in Tarim Basin on seismic data. Based on available data of Donghe 1, geological models of sand reservoirs are reconstructed, and a seismic quantitative prediction is carried out. The following understandings are obtained: ①Both water saturation increase and shale content decrease can weaken of seismic amplitude, and the influence of water saturation variation in the range of 0～100% is equivalent to that of the shale content variation in the range of 10%～0; ②The porosity increase can strengthen the amplitude, and the influence of porosity variation in the range of 14%～24% is ten times more than that of shale content variation in the range of

10%～0; ③Under the assumption of this article, the porosity increase and the shale content decrease form a symbiotic relationship, and their influence on the amplitude appears at the same time but in the opposite direction, the overall response is mainly caused by the porosity variation. Based on a newly acquired 3D seismic data associated with the position of injection wells and high water-cut production wells, target plots are characterized by distinct amplitude blocks. So we can distinguish response areas of reservoir physical orientation change from that of oil-water replacement caused by long-term water flooding, and then confirm the main effective direction of water injection and the approximate boundary shape of the water flooding front. Remaining oil enrichment areas are located outside. Such observations are proved by newly drilled wells in the Donghe 1 Area.

Keywords: Tarim Basin, deep layer, Donghe sandstone reservoir, passive geological reconstruction, remaining oil, seismic prediction

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Lateral migration hydrocarbon identification in fault-sand configuration. Zhang Jiao[1], Fu Guang[1] and Song Dailei[1]. OGP, 2018, 53(5): 1041-1048.

Hydrocarbon accumulations have a law of the lower-generation and upper-accumulation source-rock-reservoir-caprock pattern. Based on the analysis of influence factors, fault-sand configuration hydrocarbon vertical migration evaluation index (T_c) and fault-sand configuration hydrocarbon lateral migration evaluation index (T_d) are obtained. Based on the relation between the ratio of the index T_c to the index T_d and hydrocarbon column height, an approach to identify fault-sand hydrocarbon lateral migration is established. This approach is used to the Dongying Formation, Nanpu Sag, and the following understandings are obtained: ①For 67 known fault-sand configurations, the minimum T_c/T_d is 1. If T_c/T_d is greater than 1, it is a lateral migration, if not, vertical migration; ②For 11 unknown fault-sand configurations at Well NP1-5, the T_c/T_d of the configurations 1-6 and 8 are greater than 1, so they are lateral migration, which are favorable for hydrocarbon accumulation. The T_c/T_d of the configurations 7 and 9-11 are less than 1, they are vertical migration, which are not favorable for hydrocarbon accumulation. The latest drilling proves that the proposed approach is feasible and effective.

Keywords: fault-sand configuration, lateral migration, hydrocarbon migration, identification

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Fluvial facies inter-bedded sand reservoir prediction with seismic multi-attributes. Jing Yongquan[1], Luan Dongxiao[1], Zhang Yuqing[1], Chen Fei[1], Fan Ting'en[1] and Hu Guangyi[1]. OGP, 2018, 53(5): 1049-1058.

Based on the ratio of sediment supply to accommodation space, we divide Neogene meander fluvial facies sedimentary sand bodies in the target area into the following inter-bedded types: superposition type, side-superposition type, and isolated type. Then we compare seismic response characteristics of the different type sand bodies with well-seismic calibration and substratum correlation. Finally we conduct the seismic attribute clustering analysis of these type sand bodies with 7 sensitive seismic attributes: RMS amplitude, various amplitude, mean amplitude, effective bandwidth, arc length, peak frequency, and energy half time. So we obtain RMS amplitude and a seismic attribute clustering plan of the Layer Nm Ⅱ-3. The logging data proves that our approach can accurately predict this kind of fluvial facies inter-bedded sand reservoirs.

Keywords: fluvial facies, sand reservoir, inter-bedded sand, seismic attribute, forward modeling

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Sweet spot prediction for fine-grain sediment reservoirs in the Cangdong Sag. Li Yuetong[1], Lu Zongsheng[1], Wu Zhendong[2], Li Yuhai[2], Li Bingling[2] and Wang Renkang[2]. OGP, 2018, 53(5): 1059-1066.

Ek_2 in the Cangdong Sag, a fine-grained tight and thin reservoir, is characterized by horizontally rapid change, complex lithology, and low resolution on seismic data, so it is very difficult to use conventional methods to predict it. Therefore we propose a stripping step-by-step strategy. First seismic response characteristics of different sweet spot segments are classified by single-well rock-electrical characteristics and forward modeling. Amplitude and frequency characteristics of the different lithofacies are analyzed on well-seismic data. And lithology prediction is carried out with amplitude and frequency attribute fusion. Then sweet spots are predicted with the sensitive signature log inversion. This approach is applied to Ek_2 in the Cangdong Sag; the sweet spot distribution is successful achieved. The total area of predicted sweet spots in Xiaoji, Guanxi low slope and Kongxi low slope is 185km^2. The increased drilling success rate after our prediction proves that the proposed approach is effective and practical.

Keywords: fine-grained sediments, sweet spot prediction, reservoir prediction, forward modeling, attribute fusion

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Structure characteristics and its control to reservoir in the southern slope of Laizhouwan Sag. Niu Chengmin[1], Chen Lei[1,2], Yang Bo[1], Zhang Bingliang[1], Wang Siquan[1] and Guo Xuan[1]. OGP, 2018, 53(5): 1067-1074.

Laizhouwan Sag, a Cenozoic marginal sag located in the southeast of Bohai Sea, is characterized by complex hydrocarbon accumulation. In order to solve the diversity and complexity of hydrocarbon accumulation, tectonic evolution characteristics are studied based on the analysis of fault system and trap characteristics, and reservoir control effects are defined. Based on our research, KL16-A structure went through four evolutionary stages: early faulted stage of $E_{1-2}k \sim E_2s_4$, strong faulted stage of E_2s_3, fault-depression stage of $E_3s_{1-2} \sim E_3d$, and depression and Neotectonics stage of N～Q. The imbalance subsidence in periods led to the different evolution of the eastern, central and western blocks, the development of strike-slip and extensional fault systems, and the obvious different residual thickness of Paleogene. The different tectonic evolution controlled reservoir characteristics including the development and migration of hydrocarbon generating center, trap formation and type, sedimentary type and reservoir distribution, and hydrocarbon accumulation model.

Keywords: Laizhouwan Sag, Structure KL16-A, tectonic evolution, fault system, hydrocarbon characteristics, accumulation model

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Geological significances of typical seismic facies of volcanic rocks of the rifted period in Songliao Basin, NE China. Tang Huafeng[1], Hu Jia[2], Li Jianhua[1], Chen Meifu[2] and Gao Youfeng[1]. OGP, 2018, 53(5): 1075-1084.

Based on seismic and borehole data, we discuss typical facies types and geological significances of volcanic rocks of Yingcheng Formation and Huoshiling Formation in Songliao Basin. The seismic facies can be divided into 4 types: moundy/lenticular shape-subparallel (M/L-SP), platy/sheet/shield shape-parallel/subparallel (P/S/Sh-P/SP), dome/moundy shape-vacant/disordered (D/M-V/D), and mushroom shape-disordered (M-D). The M/L-SP is correlated to rhyolitic or basaltic rocks, and corresponds to interbedding effusive facies and eruptive facies. This type facies has middle-good porosity, abundant vesicles, intergranular pores, and fractures, and favorable reservoirs might probably be developed, which are thick in the center of seismic facies unit and are thin in the distal part. The P/S/Sh-P/SP is correlated to basaltic lava or rhyolitic pyroclastic rocks, and corresponds to effusive facies interbedded with eruptive facies. With good-excellent porosity, abundant vesicles, intergranular pores, and fractures, several thick favorable reservoirs might be developed. The D/M-V/D is correlated to dacite or trachyandensite, and corresponds to intrusive facies and effusive facies. With fair-good porosity and abundant fractures, only one reservoir might probably be developed. The M-D is correlated to rhyolitic tuff, rhyolite or trachyandensite, and corresponds to interbedding eruptive facies and effusive facies. With good-fair porosity, abundant vesicles, dissolution pores, and fractures, several favorable reservoirs might be developed.

Keywords: volcanic rock, seismic facies, lithofacies, reservoir distribution partner, Yingcheng Formation, Huoshiling Formation, Songliao Basin

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Logging resistivity correction under the strong extrusion stress condition in the Kuqa Foreland Basin. Yuan Long[1], Zhang Haining[1], Li Guoli[1], Han Chuang[2], Zhang Wen[3] and Wang Qian[1]. OGP, 2018, 53(5): 1085-1094.

The crustal stress in the Kuqa Foreland Basin often causes an abnormal increase of formation resistivity due to high-pressure and strong-extrusion condition. Resistivity curves of water layers look like that of high-resistivity gas beds, which results in inaccurate identification of reservoir fluid property in the resistivity logging data interpretation. Therefore we propose in this paper a resistivity correction method for the influence of strong compressive stress condition. This resistivity correction method is tested on theoretical analysis and experimental data simulations. The saturation comparison between the Function J calculation of mercury injection data and the corrected resistivity verifies the reliability of the resistivity correction method. The results show that the resistivity corrected by the proposed method reflects more authentically formation electrical characteristics, and further enhances the logging data interpretation of deep-fracture sandstone reservoirs in the study area.

Keywords: foreland basin, strong extrusion stress, resistivity correction, Function J, fractured sandstone

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Application of low-frequency magnetotelluric detection in coalbed methane enrichment areas. Chen Li[1,2], Qin Qiming[3], Wang Nan[4], Zhao Shanshan[3], Zhang Chengye[3] and Hui Jian[3]. OGP, 2018, 53(5): 1095-1102.

A field experiment of low-frequency magneto-

telluric detection was designed and conducted in Hudi, Qinshui Basin. Based on the processed multi-source electromagnetic data of this survey, the geological evaluation and coalbed parameter analysis are carried out in order to detect the coalbed methane (CBM). The following understandings are obtained: A. Different lithologic layers and coalbeds can be effectively identified on super-low frequency (SLF) electromagnetic data; B. Collapse pillars and faults can be extracted from 2D apparent resistivity inversion of audio frequency electromagnetic (AMT) data and they are consistent with that of seismic data. And subtle beds are also identified; C. The anomaly center depth, anomaly scope, and its average magnitude of SLF data have good correlation respectively with the buried depth, thickness, and gas content of coal reservoirs. The prediction accuracy of gas content is 87.33% with a coalbed methane evaluation model supported by vector machines, and the average error is only 0.17m^3/t. Our research proves that the low-frequency magnetotelluric detection is effective in the CBM exploration.

Keywords: audio frequency magnetotelluric (AMT), super-low frequency (SLF) electromagnetic prospection, coalbed methane (CBM) enrichment area, fractured structure, reservoir parameter evaluation

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Influence factors of frequency-dependent coefficient with GEMTIP model. Chang Yanjun[1], Tohniyaz Tunyaz[1] and Wang Hanyu[2]. OGP, 2018, 53(5): 1103-1109.

We use the generalized effective-medium theory of induced polarization (GEMTIP) model to analyze theoretically the frequency characteristics of the complex resistivity of rocks and ores filled with a variety of polarized grains, and then to study the main physical influence factors of frequency-dependent coefficient. The following understandings are obtained: A. When the shape and size of polarized particles are different, the spectral curve of complex resistivity becomes smooth and the frequency-dependent coefficient becomes smaller with the increase of the range of the polarized particles; B. When rocks and ores contain multi-type polarized grains with different polarization, the frequency-dependent coefficient also becomes smaller; C. When the polarization characteristics of polarized particles in rocks and ores are similar each other, the frequency-dependent coefficient mainly reflects the shape and size of the mineral particles. The understandings have important significances for the anomaly interpretation and the identification of polarized bodies based on the relative magnitude of the frequency-dependent coefficient.

Keywords: frequency-dependent coefficient, generalized effective-medium theory of induced polarization (GEMTIP) model, complex resistivity

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Reservoir petrophysical parameter estimation with joint inversion of MCSEM and seismic AVA data. Peng Guomin[1,2], Xu Kaijun[1,2], Du Runlin[2,3] and Liu Zhan[1,2]. OGP, 2018, 53(5): 1110-1116.

Seismic survey is the major approach to oil and gas exploration and development, but the ambiguity exists during estimating reservoir petrophysical parameters such as hydrocarbon saturation only with seismic data. Marine controlled-source electromagnetic (MCSEM) data is sensitive to resistive hydrocarbon reservoirs and thus aids seismic survey to increase the well drilling success rate. Therefore, the joint inversion of MCSEM and seismic data contributes to more reliable estimation of reservoir petrophysical parameters. This paper proposes an approach to estimate petrophysical parameters with MCSEM and seismic amplitude variation with angle of incidence (AVA) data. The approach utilizes Archie's equation and Gassmann's equations to relate reservoir petrophysical parameters to the conductivity and seismic wave velocities as well as density, and adopts simulated annealing (SA) optimization algorithm to minimize the joint inversion objective function. Numerical experiments show that the joint inversion could estimate more reliable reservoir petrophysical parameters compared with only MCSEM or seismic AVA data inversion. Compared to the Occam method based on descent gradient, this inversion is independent from an initial guess.

Keywords: joint inversion, marine controlled-source electromagnetic (MCSEM), amplitude variation with angle of incidence (seismic AVA), reservoir petrophysical parameter, simulated annealing (SA)

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