ABSTRACTS

Vibroseis dynamic sweep. XIAO Hu[1], TANG Donglei[1], YANG Guoping[1], WANG Jingfu[1], WU Yongguo[2], and FAN Ping[3]. Oil Geophysical Prospecting, 2019, 54(3):493-499.

The flip-flop sweep, the slip sweep, and the distance separated simultaneous sweep (DS3) are the three most commonly used ways of high-productivity vibroseis technology. Because of their difference in technical characteristics, operation organization, and equipment resource demand, usually only one of them is used independently in the past operation, which limits their application areas and affects the production. In order to solve this problem, a new approach, dynamic sweep, is developed. This approach not only considers the time domain change as in the past, but also adopts the concept of the space domain, and combines them by establishing the time-space relations rules. Thus the flip-flop sweep, the slip sweep, and the DS3 are integrated together. According to the pre-set time-space rule, recording systems can freely group vibrators and switch the sweep modes. The proposed vibroseis dynamic sweep can adapt to more terrain conditions and achieve further higher production.

Keywords: vibroseis, dynamic sweep, time-distance rule, slip sweep with variable interval, slip sweep with fixed interval, simultaneous sweep

1. Acquisition Technique Center, BGP Inc., CNPC, Zhuozhou, Hebei 072751, China
2. Qinghai Geophysical Department, BGP Inc., CNPC, Dunhuang, Gansu 736202, China
3. Liaohe Geophysical Department, BGP Inc., CNPC, Panjin, Liaoning 124000, China

A numerical investigation on wide-line seismic data acquisition and processing. HE Baoqing[1,2], and XIE Xiaobi[2]. Oil Geophysical Prospecting, 2019, 54(3): 500-511.

The wide-line is a way between 2D and 3D seismic survey. In this paper, we investigate the wide-line seismic method with both theoretical analysis and numerical simulations. Response functions of a wide-line acquisition system for both monotonic signals and broad band signals are calculated for different parameters commonly used in the acquisition. To numerically simulate the entire process including the acquisition and data processing, we generate synthetic 3D narrow azimuth data using the full-wave finite-difference method, conduct wide-line processing, and finally use the 2D reverse time migration to generate the depth image. Horizontal structures, dipping structures, and a near-surface scattering layer are built into a 3D model to study the advantages of the wide-line method. Benefitted from the flexibility of the numerical calculation, we can adjust acquisition geometry parameters in a large range and test their effects on the image results. In particular, we investigate the mechanisms how various wide-line parameters, including line spacing, number of lines, aperture, and signal frequency band, will affect the migration image. Based on our analysis, a geometry with 120～200m aperture and 3～5 receiver lines is most advantageous for suppressing lateral interference. Our study may provide a reliable basis for more efficient use of wide-line seismic method.

Keywords: seismic wide-line acquisition, near-surface scattering, scattering noise attenuation, seismic imaging, numerical simulation

1. Acquisition Technique Center, BGP Inc, CNPC, Zhuozhou, Hebei 072751, China
2. Institute of Geophysics and Planetary Physics, University of California, Santa Cruz, CA 95064, U S A

Source signature extraction from marine seismic direct waves. LI Fuyuan[1,2], WEI Chenglong[1,2], DENG Guilin[1,2], ZHANG Baojin[1,2], ZHANG Heng[1,2], and YANG Li[1,2]. Oil Geophysical Prospecting, 2019, 54(3):512-521.

The signature generated by an array of marine seismic source is an important input to many processing algorithms. Not much attention is given to direct wave arrivals in marine seismic data that are closely related to source signatures. In this paper, we process these direct arrivals to accurately estimate source signatures. By deducing the time-distance equation of direct wave arrivals, considering source-receiver pattern, and combining with bubble oscillation theory, the relation between direct wave and signature is obtained; and the solution of source far-field wavelet calculation with direct wave in the frequency domain is given. When the receiver position meets the far-field condition of source array, it is of great practical significance to estimate the source far-field wavelet with the direct wave of seismic data. The proposed method provides a new idea, which is avoiding the influence on seismic wavelet extraction from reflection information. The direct wave is separated beforehand from seismic data, and then the source far-field wavelet

is extracted by the accurate formula. The feasibility of the proposed method is verified with synthetic and real data tests. Finally, an application example is given to illustrate that the proposed method is characterized by high efficiency and high precision in seismic data processing.

Keywords: source signature, wavelet estimation, direct arrivals, far-field wavelet, source/receiver ghosts, geophone array, debubble

1. Key Laboratory of Marine Mineral Resources, Ministry of Natural resources, Guangzhou, Guangdong 510760, China
2. Guangzhou Marine Geological Survey, Ministry of Natural resources, Guangzhou, Guangdong 510760, China

3D anisotropic Laplacian filtering based random seismic noise suppression. LIU Hongjie[1], MAO Haibo[1], YANG Xiaohai[1], LI Wenjie[1], and JIANG Li[1]. Oil Geophysical Prospecting, 2019, 54(3): 522-528.

The 3D random noise attenuation (3D-RNA) is a spatial prediction filtering, which is widely applied to poststack seismic data in the Junggar Basin. With the linearity assumption of events in a short distance, this method improves strong energy signal-to-noise ratio (SNR), but it damages weak energy signals and blurs signals which are relative to faults and cracks. Therefore, a denoising method based on 3D anisotropic Laplacian filtering is proposed to solve these problems. Tests on model and real seismic data show that the proposed method is better than 3D-RNA in random noise suppression. Not only seismic data SNR is improved, but also weak signals are preserved. Meanwhile, geological-body edge characteristics become clearer and better fault imaging is achieved. The proposed method has been successfully applied in different areas in the Junggar Basin. This research provides a solid foundation for further reservoir inversion and seismic interpretation.

Keywords: anisotropic, Laplacian filtering, random noise suppression, signal-to-noise ratio (SNR), 3D random noise attenuation (3D-RNA)

1. Geophysical Department, Research Institute of Exploration and Development, Xinjiang Oilfield Company, PetroChina, Urumqi, Xinjiang 830013, China

Finite-difference numerical modeling with variable mechanisms for viscoacoustic wave equation. CAI Ruiqian[1,2], SUN Chengyu[1,2], WU Dunshi[3], and LI Shizhong[1,2]. Oil Geophysical Prospecting, 2019, 54(3): 529-538.

Subsurface media are generally not elastic but viscoelastic, and the viscoelasticity is normally depicted by a dimensionless quantity, i. e., quality factor Q. Within the frequency band of seismic exploration, Q is widely considered frequency-independent, which can be properly characterized by the generalized standard linear solid (GSLS) model. Thus, the GSLS model has become the mainstream while viscoelastic seismic wave modeling. However, when GSLS model has been chosen, the current modeling schemes commonly adopt a fixed number of relaxation mechanisms, which leads to a shortcoming, not being able to integrate the computational efficiency and precision. In this paper, we propose a finite difference viscoelastic seismic-wave modeling scheme with variable mechanisms based on GSLS model. More precisely, we use different number of mechanisms to approximate the Q in different areas of earth model, thereby integrating both computational efficiency and precision. We compare our results with the analytical solution, and analyze the relation between the precision and the number of mechanisms, and Q and the traveling distance to determine the appropriate applicable range of different mechanisms. We also compare the precision and efficiency of variable mechanisms with those of a fixed number of mechanisms, and analyze the applicability of the proposed method. The results indicate some merits of the proposed scheme: wider applicability, higher computational precision, and more efficient simulation.

Keywords: viscoelasticity, generalized standard linear solid (GSLS) model, variable mechanisms, wave field simulation

1. School of Geosciences, China University of Petroleum (East China), Qingdao, Shandong 266580, China
2. Laboratory for Marine Mineral Resources, Qingdao National Laboratory for Marine Science and Technology, Qingdao, Shandong 266071, China
3. Northwest Branch, Research Institute of Petroleum Exploration & Development, PetroChina, Lanzhou, Gansu 730020, China

Elastic wavefield forward modeling in heterogeneous media based on the quasi-regular grid high-order finite difference. LI Qingyang[1,2], WU Guochen[1,2], and DUAN Peiran[1]. Oil Geophysical Prospecting, 2019, 54(3): 539-550.

In this paper, we propose a quasi-regular grid high-order finite-difference seismic forward modeling to accurately describe elastic wave propagation in heterogeneous media. The quasi-regular grid strategy is to stagger the displacement component

of the elastic wave equation and make a new center difference operator for displacement, while the simulation accuracy and stability are the same as those of the staggered grid. But the memory usage of the quasi-regular grid is reduced by 60% in 2D and 66.7% in 3D compared to the staggered grid. Then the equivalence between the quasi-regular grid and staggered grid is mathematically demonstrated, and the source loading, boundary conditions and stability are analyzed. A numerical test is carried out on a layered model to validate the accuracy of the quasi-regular grid method by comparing with staggered grid and regular grid methods. Finally, a test on Marmousi-2 model proves the applicability and stability of the proposed method.

Keywords: seismic forward modeling, finite difference, quasi-regular grid, heterogeneous media, elastic wave

1. School of Geosciences, China University of Petroleum (East China), Qingdao, Shandong 266580, China
2. Laboratory for Marine Mineral Resources, Qingdao National Laboratory for Marine Science and Technology, Qingdao, Shandong 266071, China

Kirchhoff prestack time migration for ocean bottom seismic data. WANG Shihu[1], QIAN Zhongping[1], WANG Chengxiang[1], ZHAO Changhai[1], KOU Qin[1], and ZHANG Jianlei[1]. Oil Geophysical Prospecting, 2019, 54(3): 551-557.

The ocean bottom seismic (OBS) acquisition includes two ways of acquisition, i.e. ocean bottom cable (OBC) and ocean bottom node (OBN). Because shot points are located in the sea surface and receivers are placed in the sea bottom, the assumptions of traditional seismic imaging, which is based on the same datum, is no longer adapt to the OBS data. So we propose in the paper the Kirchhoff prestack time migration for ocean bottom seismic data. First the calculation formula of the travel of down-going and up-going waves from reflection points are derived, and graphs show directly the coverage range of their respective common-receiver-point gathers data. Then using the mirror imaging theory as a guidance, the calculation formulas of travel time of down-going and up-going waves for Kirchhoff time migration are given, and conversion methods between imaging time corrections and RMS velocity in the formulas are clearly specified. Finally, the calculation formula of OBS seismic prestack time migration weighted function is described.

Keywords: ocean bottom seismic (OBS), ocean bottom cable (OBC), ocean bottom node (OBN), up-going wave, down-going wave, mirror image

1. Research and Development Center, BGP Inc., CNPC, Zhuozhou, Hebei 072751, China

Ray-tracing equation-based first-arrival traveltime tomography and eikonal equation-based first-arrival traveltime tomography. GUO Zhenbo[1], SUN Pengyuan[1], LI Peiming[1], REN Xiaoqiao[1], QIAN Zhongping[1], and TANG Bowen[1]. Oil Geophysical Prospecting, 2019, 54(3): 558-564, 576.

The first-arrival traveltime tomographic inversion is the most widely used near-surface modeling method. According to the forward modeling operator in the inversion, the tomographic inversion based on the ray theory can be divided into two kinds of methods: based on the ray-tracing equation and based on the eikonal equation. In this paper, a detailed contrastive analysis of the two methods in terms of inversion accuracy and computational efficiency are carried out respectively in theory and numerical tests. The following observations are obtained: ①The two methods can be deduced from the unified inversion framework. The main differences between the two methods are caused by the differences of the forward-modeling operators in the inversion; ② The two methods have similar inversion accuracy. The kernel function of the second method is band-limited, so it is more stable in complex areas; ③The computational efficiency of the first method depends on the number of receivers and the second method depends on the size of the model. So the first method is preferable when receivers are sparse. Otherwise, the second method is preferred; ④The first method has lots of quality controls such as ray density, while the second method lacks similar quality controls.

Keywords: tomography, ray tracing, eikonal equation, near-surface modeling, seismic inversion

1. Research & Development Center, BGP Inc, CNPC, Zhuozhou, Hebei 072751, China

The practices and effects of 3D development seismic in Shengli Oilfield. SU Chaoguang[1], SONG Liang[1], MENG Yang[2], SHANG Xinmin[1], and GUAN Jian[1]. Oil Geophysical Prospecting, 2019, 54(3): 565-576.

Since the Project K71 conducted in 2005, Shengli Oilfield Branch Co., SINOPEC has completed 7 projects of 3D development seismic, 4 of which were carried out in the 12th Five-Year Plan. Thanks to these projects, great progress was achieved. For instance, an integrated model for seismic data acquisition, processing, interpretation, and

reservoir updating-evaluation were established. The 3D seismic deployment location were optimized, and point receiving strategy is realized rather than array receiving. As results, the 3D development seismic achieves higher data resolution, better amplitude-preserved, better fault imaging, and better geological target identification. Lots of achievements of 3D development seismic are made not only in new exploration areas, but also in some mature oilfields, which provides a strong geophysical technology support for the exploration and development of Shengli Oilfield.

Keywords: 3D development seismic, integrated model, the principle of survey-deployment location selection, seismic geometry design, point-receiving high-density acquisition, Shengli Oilfield

1. Geophysical Research Institute, Shengli Oilfield Branch Co., SINOPEC, Dongying, Shandong 257022, China

2. Oil and Gas Development Management Center, Shengli Oilfield Branch Co., SINOPEC, Dongying, Shandong 257001, China

The Xu-White model linearized approximation and inversion based on lithofacies constraint. LING Dongming[1,2], DU Qizhen[1], TIAN Jun[2], WANG Guizhong[3], CHENG Suo[4], and WANG Jixun[2]. Oil Geophysical Prospecting, 2019, 54(3): 577-586.

The Xu-White model is a strong nonlinear model, and linearized approximation and inversion of this model cannot be directly achieved. The Xu-White forward model demonstrates that the size of clay volume is the key of the model nonlinear strength. Therefore we propose a linearized approximation based on lithofacies constraint to realize the Xu-White model linearized approximation and inversion for petrophysical property. The procedure of the proposed approach includes four steps: ① lithofacies model building with logging data, ②model linearized approximation on each facies with first-order Taylor series expansion, ③ petrophysical property inversion objective function establishment based on Bayesian theory, and the porosity, clay volume, and water saturation obtained with least-squares optimization algorithm, and ④the reliability of the inversion results verification with the uncertainty analysis. Model and real data tests show the feasibility of the proposed approach, which delivers accurate results for reservoir characterization and fluid prediction.

Keywords: Xu-White model, lithofacies constraint, linearized approximation, Taylor series expansion, Bayesian theory, petrophysical inversion

1. School of Geosciences, China University of Petroleum (East China), Qingdao, Shandong 266580, China

2. Korla Branch, GRI, BGP Inc., CNPC, Korla, Xinjiang 841001, China

3. GRI, BGP Inc., CNPC, Zhuozhou, Hebei 072751, China

4. Research Institute of Exploration and Development, Tarim Oilfield Company, PetroChina, Korla, Xinjiang 841000, China

Strong reflection identification and separation based on the local-frequency-constrained dynamic matching pursuit. XU Lu[1,2], WU Xiaohe[3], ZHANG Mingzhen[3], YIN Xingyao[1,2], and ZONG Zhaoyun[1,2]. Oil Geophysical Prospecting, 2019, 54(3): 587-593.

When there are high impedence layer above and below a reservoir, strong reflections will shield reservoir reflection information on seismic sections. Therefore, we propose in this paper a dynamic matching pursuit method based on local frequency constraints to identify and separate strong reflections. Considering the "negative frequency" phenomenon of instantaneous frequency, we introduce local frequency to constrain the search range of the optimal atom of the dynamic matching pursuit algorithm. The local frequency is reasonable for the signal calculation, which can be used to identify the seismic wavelet that matches best the strong reflection. Using the local frequency and instantaneous phase information at the strong reflection position as a priori information, a dynamic waveform library is constructed to search for the wavelet that matches best the strong reflection. The strong reflection suppression coefficient is determined by signal tests to ensure that the equilibrium energy is consistent with the background energy after stripping strong reflection. This is helpful for picking up the reflection information of reservoirs and achieving reservoir characterization. The feasibility of the proposed method is verified by constructing model data with high impedence layer. Finally, the proposed method is applied to field data, which weakens strong reflection interference and highlights weak reflection.

Keywords: local frequency, matching pursuit, strong reflection, instantaneous frequency, dynamic atomic library

1. School of Geosciences, China University of Petroleum (East China), Qingdao, Shandong 266580, China

2. Laboratory for Marine Mineral Resources, Qingdao National Laboratory for Marine Science and

Technology, Qingdao, Shandong 266580, China
3. Geophysical Research Institute, Shengli Oil Field Branch Co., SINOPEC, Dongying, Shandong 257022, China

Seismic data phase reconstruction. YANG Peijie[1], LUO Hongmei[1], and WANG Jinduo[1]. Oil Geophysical Prospecting, 2019, 54(3): 594-599.

How to extract and analyze phase spectrum information from seismic data effectively will be a hot and difficult point in the frequency domain seismic data processing. We propose in this paper a novel phase reconstruction method based on time-frequency analysis. Firstly, seismic trace time-frequency analysis is carried out. Secondly, seismic trace amplitude and phase information is extracted point by point using windows function. Ater that, phase values to be reconstructed and phase tolerance in [−180°, 180°] are set. Finally, phase reconstructed traces can be obtained after Fourier inverse transform. Model and practical application show tnat the proposed algorithm is accurate and efficient, and beneficial for further applications.

Keywords: spectral estimation, phase decomposition, phase reconstruction, phase gather, phase tolerance

1. Research Institute of Exploration and Development, Shengli Oilfield Branch Co., SINOPEC, Dongying, Shandong 257015, China

Seismic fine depiction of the thin sand distribution of the Putaohua Reservoir in the Well C51 Area. CHEN Hongzhu[1], WANG Yanchun[1], and GAO Yang[2]. Oil Geophysical Prospecting, 2019, 54(3): 600-607, 633.

The Putaohua Reservoir in the Well C51 Area is of delta-front facies, and 2 sand groups (PⅠ1 and PⅠ2) are vertically developed with the average thicknesses 2m and 5m respectively. Although these sand groups are clearly distinguished on the well drilling data, their distribution cannot be identified on seismic data due to its low resolution. To solve the problem, seismic information and attributes are selected based on the sand groups of 18 wells. Sand group reflections are determined at wells and traced along horizons on seismic slices. Then seismic attributes of sand groups are extracted and optimized. After that, the attributes are conversed to sedimentary micro-facies, and the constrained sedimentary micro-facies geo-statistical inversion is carried out to increase the vertical resolution. Finally, the distribution of 2 sand groups is predicted. According to our prediction, PⅠ2 is thicker, and is suitable for gas base building.

Keywords: Putaohua Reservoir, delta-front, sedimentary micro-facies, slice, geo-statistical inversion

1. School of Geophysics and Information Technology, China University of Geosciences (Beijing), Beijing 100083, China
2. Key Laboratory of Coal Resources Exploration and Comprehensive Utilization, Ministry of Natural Resources of the People's Republic of China, Xi'an, Shaanxi 710021, China

Multi-technique combination for the complex-fault elaborate interpretation. HU Bin[1]. Oil Geophysical Prospecting, 2019, 54(3): 608-616.

The fault system in the study area features high complexity, and it is characterized by high-density faults, short extend length, small displacement, and complicated relationship between faults. Thus, conventional seismic interpretation methods are not adequate to describe this fault system due to very complicated fault planar connections. For this reason, we propose a multi-technique combination for this complex fault system interpretation. This technology portfolio consists of structure-oriented filtering, horizon-fault interaction interpretation, discrete frequency coherency multi-scale fault imaging, weak signal enhancement, and multi-attribute and multi-information fusion. The process of the technology portfolio includes poststack interpretative processing, preliminary fault interpretation, elaborate fault characterization, achievement verification, and output. The technology portfolio is applied in complex faults of the area M. The results are very encouraging: 30 traps confirmed, 90% drilling success ratio achieved based on proposed 20 wells, and 4 commercial oilfields discovered, which proves the validity of the proposed technology portfolio.

Keywords: complex faults, structure-oriented filtering, horizon-fault interactive interpretation, discrete frequency coherency multi-scale fault imaging, weak signal enhancing, multi-attribute and multi-information fusion, multi-technique combination

1. CNOOC Research Institute, Beijing 100028, China

Reservoir fluid mobility extraction based on the deconvolution generalized S-transform. LIU Jie[1,2], ZHANG Yijiang[3,4], WANG Xiuling[2], ZENG Shaogang[2], and ZHANG Wenzhu[2]. Oil Geophysical Prospecting, 2019, 54(3): 617-623.

In the calculation of fluid attributes, the resolution of fluid mobility attribute profiles obtained by time-frequency analysis methods are different, which affects the accuracy of reservoir prediction,

and in this calculation, it is difficult to obtain key parameters of rock physics (such as the bulk modulus of rock matrix). Therefore, the deconvolution generalized S-transform and linear regression method (LRM) are introduced to extract the fluid mobility attribute. The realization of the method is as follows: the bulk modulus of matrix is calculated by LRM, the peak frequency is calculated by Silin's formula of peak frequency of fast P-wave reflection resonance, and the reservoir fluid mobility is obtained by the relationship between fluid mobility attribute and derivative of amplitude to frequency; then the deconvolution generalized S-transform is used to improve the resolution of fluid mobility attributes profile. Results of the simulation test and case analysis show that the proposed approach has high time-frequency resolution and a strong ability to distinguish different signal components in non-stationary signals, which is more suitable for fluid mobility attribute calculation of non-stationary seismic signals. LRM provides a method for determining the bulk modulus of rock matrix.

Keywords: time-frequency analysis, fluid mobility, bulk modulus of rock matrix, linear regression method (LRM), deconvolution generalized S-transform

1. School of Geosciences, China University of Petroleum (East China), Qingdao, Shandong 266580, China
2. Shenzhen Branch, CNOOC, Shenzhen, Guangdong 518067, China
3. State Key Laboratory of Oil and Gas Reservoir Geology and Exploitation, Chengdu, Sichuan 610059, China
4. Geophysical Institute, Chengdu University of Technology, Chengdu, Sichuan 610059, China

Prestack AVAZ fracture prediction applied in Chepaizi Uplift. YU Xiaodong[1,2], GUI Zhixian[1,2], WANG Yong[1,2], and WANG Jingling[3]. Oil Geophysical Prospecting, 2019, 54(3): 624-633.

In recent years, more and more attention has been paid to fractured oil and gas reservoirs. Carboniferous volcanic fractured reservoirs were well developed in the east part of Chepaizi Uplift. Conventional methods can hardly predict this kind of reservoirs. We demonstrate in this paper our prediction with the amplitude variation with azimuth (AVAZ) to solve the problem. First the anisotropy of reflection coefficient of prestack P-wave is analyzed. Then the forward modeling of seismic response of fractures is carried out in combination with characteristics of the working area. On this basis, azimuth gathers of prestack seismic data are divided. Finally the fracture spatial distribution characteristics is predicted with AVAZ. The predicted fracture density and direction are in good agreement with logging data in the study area, which lays a foundation for the future exploration and development in this area, and also provides technical references for the fracture reservoir prediction in similar areas.

Keywords: forward modeling, amplitude variation with azimuth (AVAZ), fracture prediction

1. Key Laboratory of Exploration Technologies for Oil and Gas Resources, Ministry of Education, Yangtze University, Wuhan, Hubei 430100, China
2. College of Geophysics and Petroleum Resources, Yangtze University, Wuhan, Hubei 430100, China
3. Unconventional Petroleum Research Institute, China University of Petroleum (Beijing), Beijing 102249, China

Reminding gas potential study based on quasi time-lapse seismic. LIAO Yi[1], ZHOU Jiaxiong[1], LIU Wei[1], MA Guangke[1], YIN Xiuxing[1], and ZHANG Kunkun[1]. Oil Geophysical Prospecting, 2019, 54(3): 634-640.

As a hydrocarbon reservoir monitoring approach, the time-lapse seismic is not widely used due to its high cost and high risks and time-lapse seismic data is not enough for reminding resource potential study. Therefore we conduct a reminding gas potential study based on quasi time-lapse seismic data. We use 2D seismic data (surveyed in 2001) as basic data and 3D seismic data (surveyed in 2015) as monitoring data in a later-stage gasfield, South China Sea. We analyze the relationship between water and gas and predict water invasion mode on the quasi time-lapse seismic data. According to frequency-segmented attributes and production information, we build a dynamic reservoir model, and then obtain reminding gas potential. Based on our study, as high and medium permeability barriers, the northwest part of the gas-field has limited reminding potential due to strong water approaching; while the southeast part has great reminding potential with argillaceous and stable barrier, which is a favourable zone for the later deployment. Our application proves that the proposed quasi time-lapse seismic might play an important role in the reminding resource potential study.

Keywords: time-lapse seismic, reservoir monitoring, consistency, water flooding model, reminding gas, sensitive attribute

1. Zhanjiang Branch, CNOOC, Zhanjiang, Guangdong 524057, China

Design and implementation of the PetroV distributed file system based on geographic meshing and geological information coding. SHENG Xiujie[1], JIN Zhijun[1], PENG Cheng[1], and JING Yan[1]. Oil Geophysical Prospecting, 2019, 54(3): 641-649.

Because of the key software architecture requirements of middleware in the field of geological intelligence in big data, big computing, and big models, this paper designs and implements a new petroleum valuation distributed file system (PetroV DFS). PetroV DFS adopts a two-level data storage mechanism including local spatial database storage under ST-based KIDA metadata modeling and distributed data chunk file storage based on geographic meshing and geological information coding. The storage kinds of distributed chunk file include spatial index chunk for basin-level geological mapping (two-dimensional digital cores), octree branch chunk for three-dimensional volume data (seismic data, three-dimensional digital cores), and spatial key-value pairs for conventional, imaging log data storage. Following the geographical mesh subdivision algorithm, PetroV DFS supports the storage of different data types from the global geographic scale to single well or even smaller scales, and there is no upper allocation limits on the number of data chunk files. Especially, if there are no any constraints in the case of scale-out inexpensive servers from different regions (e.g., different local data center), it is no upper limits on the amount of data stored. PetroV DFS ensures that "geographically close and storage location close", namely, data from the same geographic area are stored in the same rack of the same data center. For the segmentation of 440G prestack seismic data files and the calculation of the full-time frequency-amplitude attributes, the generic programming of PetroV DFS can be effectively deployed on the commodity computers, and gets almost the same calculation effects preserved ever by high-performance computers in addition to significantly improving the professional data management.

Keywords: geological intelligence, geographic meshing, octree brunch chunk, spatial key-value pairs, petroleum valuation distributed file system (PetroV DFS)

1. Research Institute of Petroleum Exploration and Development, SINOPEC, Beijing 100086, China

Comprehensive evaluation of fault vertical sealing ability with mudstone caprocks. JIANG Zhenhai[1]. Oil Geophysical Prospecting, 2019, 54(3): 650-655.

The fault vertical sealing hydrocarbon ability with mudstone caprocks is mainly influenced by the displacement pressure of fault rocks, the caprock-fault juxtaposition thickness, and the hydrocarbon residual pressure in underlying reservoirs. The greater of displacement pressure of fault rocks, the thicker of caprock-fault juxtaposition thickness, and the smaller of hydrocarbon residual pressure in underlying reservoirs, the stronger of fault vertical sealing hydrocarbon ability with mudstone caprocks, and vice versa. A comprehensive evaluation of fault vertical sealing hydrocarbon ability with mudstone caprocks is proposed in the paper based on the displacement pressure of fault rock, the caprock-fault juxtaposition thickness, the hydrocarbon residual pressure in underlying reservoirs, and hydrocarbon permeation and dissipation velocity within mudstone caprocks. The proposed comprehensive evaluation is applied to the structures of Huhe and Nuoren in Hailar Basin. The permeation and dissipation velocity at 14 measuring points within mudstone caprocks are less than 0, which indicates that the vertical sealing hydrocarbon ability is relatively strong and it is conducive to the hydrocarbon accumulation. These evaluation results are coincident with the hydrocarbon discovery in the area and prove the validity of the proposed approach.

Keywords: mudstone caprock, fault, vertical sealing ability, displacement pressure of fault-rock, caprock-fault juxtaposition thickness, hydrocarbon residual pressure in underlying reservoirs

1. No. 3 Oil Production Plant, Daqing Oilfield Company, PetroChina, Daqing, Heilongjiang 163113, China

Palaeo-geomorphology restoration with double-interface seismic layer leveling: an example of Tianhuan Depression in Ordos Basin. LIU Yongtao[1,2], LIU Chiyang[1], ZHOU Yijun[2], HUANG Lei[1], BI Mingbo[2], and WANG Xiuzhen[2]. Oil Geophysical Prospecting, 2019, 54(3): 656-666.

In order to identify the palaeogeomorphology and study the relationship between the hydrocarbon accumulation and the palaeo-geomorphology, a new approach for palaeo-geomorphology restoration in the critical period of hydrocarbon generation with double-interface seismic layer leveling is proposed. The approach includes four steps. First, the applicability of seismic layer leveling technology is analyzed, and the seismic layers in the critical period of hydrocarbon generation and the end period of filling-leveling up are determined. Second, in order to eliminate the influence of late tectonic deformation on the palaeo-geomorphology, the seismic lay-

er of the critical period is flattened, then the stratum thickness between the seismic leveling layer and the seismic layer representing the end period of filling-leveling up is calculated. Third, the seismic layer representing the end period of filling-leveling up is flattened in order to restore the palaeo-geomorphology of this period, and the stratum thickness between the two seismic leveling layers is calculated. Finally, by adding up the above the two strata thickness values, the palaeo-geomorphology at the critical period of hydrocarbon generation is described. The proposed approach is applied to restore the pre-Jurassic palaeo-geomorphology in the middle part of Tianhuan Depression, Ordos Basin, and the accuracy of palaeo-geomorphology restoration is improved. At the same time, the Jurassic reservoir-forming regularity in this area is found out, that is, relatively gentle structures of palaeo-geomorphology at the end period of filling-leveling up control the oil migration direction, and the local uplift of palaeo-geomorphology in the critical period of hydrocarbon generation is the favorable part of oil accumulation. This proposed approach may provide a reference in the study of palaeo-geomorphology in similar areas.

Keywords: palaeo-geomorphology, seismic layer leveling, critical period of hydrocarbon generation, palaeo-structure, Ordos Basin

1. State Key Laboratory of Continental Dynamics, Northwest University, Xi'an, Shaanxi 710069, China
2. Changqing Branch, GRI, BGP Inc., CNPC, Xi'an, Shaanxi 710021, China

Application of kernel principal component analysis in well logging turbidite lithology identification. ZHOU You[1,2], ZHANG Guangzhi[1,2], GAO Gang[3,4], ZHAO Wei[3,4], YI Yuanping[5], and WEI Hongmei[6]. Oil Geophysical Prospecting, 2019, 54(3): 667-675.

It is difficult to identify the lithology on well-logging data in the evaluation of complex lithologic reservoirs. Due to complexity of turbidite reservoirs in Dongji Sag, Dongying Depression, conventional cross-plot and principal component analysis methods fail to identify their lithology. In order to solve this problem, based on particle swarm optimization and kernel function theory and combining with log response characteristics of the area, an improved principal component analysis method is used to establish a new principal component calculation. Five principal component variables are constructed with measured natural gamma-ray logging (GR), acoustic logging (AC), compensated neutron porosity logging (CNL), density logging (DEN), and virgin zone resistivity (RT) of reservoirs. The accumulate contribution rate of the first two principal component variables reached 93.83%, which can effectively replace the original multi-dimensional logging information. The proposed method is tested in the study area. Based on our application results, this proposed method can effectively identify the lithology of turbidite reservoirs, and its identification rate reaches up to 90%.

Keywords: turbidite, principal component analysis, kernel function, lithology identification, particle-swarm algorithm

1. School of Geosciences, China University of Petroleum (East China), Qingdao, Shandong 266580, China
2. Laboratory for Marine Mineral Resources, Qingdao National Laboratory for Marine Science and Technology, Qingdao, Shandong 266071, China
3. Key Laboratory of Exploration Technologies for Oil and Gas Resources, Ministry of Education, Wuhan, Hubei 430100, China
4. College of Geophysics & Oil Resources, Yangtze University, Wuhan, Hubei 430100, China
5. Wuhan Surveying-Geotechnical Research Institute Co. Ltd., MCC, Wuhan, Hubei 430080, China
6. Research Institute of Geophysics, Shengli Oilfield Branch Co., SINOPEC, Dongying, Shandong 257022, China

Numerical simulation of the geo-steering electromagnetic wave measurement while drilling in inclined wells. XIE Xicao[1], WU Jie[1], and GAO Jianshen[1]. Oil Geophysical Prospecting, 2019, 54(3): 676-684, 699.

The electromagnetic wave measurement while drilling tool in the directional well mining identifies the drilled formation and the formation to be drilled, and ensures the bit in a right tracjectory, so the oil and gas recovery will be greatly improved. We conduct a study on the electromagnetic wave measurement while drilling tool in inclined wells. The following understandings are obtained: ①The distance from the surrounding rock layer to the target can be judged by the positive or negative of the directional response signal; ②The influence of formation inclination and formation anisotropy on the directional response can be reduced or eliminated with symmetric coil arrangement for measurement. The directional measurements of two pairs of single emissing and single receiving coil system should be superimposed together. When the tool is located near the formation boundary, the directional response signal is only sensitive to the inclination, and when the tool is far from the formation boundary, the directional response signal is less af-

fected by anisotropy and inclination, and the directional response curve is simple; ③A numerical simulation for the directional measurement response of formation dip angle less than 20° is carried out. If the target thickness is less 6m, the geosteering signals are very sensitive to well dip angle. The proposed method has a high real-time measurement accuracy and compensates the shortage of the current borehole imaging.

Keywords: directional electromagnetic wave measurement while drilling, directional response signal, single-sided arranged coil system, symmetrical arranged coil system

1. School of Electronic Engineering, Xi'an Shiyou University, Xi'an, Shaanxi 710065, China

3D magnetic data interpretation based on improved tilt angle. WANG Yanguo[1], LUO Xiao[1], DENG Juzhi[1], YANG Yaxin[1], WANG Cheng[2], and ZHANG Jin[1]. Oil Geophysical Prospecting, 2019, 54(3): 685-691.

The delineation of magnetic anomaly and the division of structure are the important contents of the magnetic exploration. There is often no correspondence between the magnetic anomaly and the geologic body because of the influence of magnetization direction. At present, most methods for 3D magnetic interpretation require the magnetic anomaly reduced to the pole beforehand. However, it is difficult to achieve satisfactory results by reduction to the pole when a study area is relatively large or magnetic anomaly contains remanence. In addition, magnetic reduction to the pole may bring errors, which results in the failure of exploration. This paper proposes a 3D magnetic interpretation technique that can be directly used without reduced to the pole of magnetic anomaly. The proposed method is based on improved tilt angle, which can highlight the information of magnetic sources in the x and y directions. Model tests show that the proposed method can effectively identify the horizontal positions of the boundaries of prisms and sphere's centroid. Furthermore, the proposed method achieves better resolution and better identification of magnetic anomaly compared to other methods. The proposed method is applied to aeromagnetic data from Tamusu of Inner Mongolia, North China, and obtains detailed information of magnetic sources. The results have good correspondence with the geological data and seismic interpretation. In addition, the calculation results of the proposed method provide guides for delineation of hidden magnetic sources in the study area.

Keywords: magnetic anomaly, 3D data interpretation, improved tilt angle, accuracy

1. Key Laboratory of Fundamental Science on Radioactive Geology and Exploration Technology, East China University of Technology, Nanchang, Jiangxi 330013, China
2. Xi'an Research Institute of China Coal Technology and Engineering Group, Xi'an, Shaanxi 710077, China

Underground small target recognition using magnetic gradient tensor. ZHENG Jianyong[1], FAN Hongbo[1], ZHANG Qi[2], and LI Zhining[1]. Oil Geophysical Prospecting, 2019, 54(3): 692-699.

An underground small target recognition based on magnetic gradient tensor and support vector machine (SVM) is proposed in the paper. Firstly, underground target magnetic anomaly models with different shapes and different attitudes are used to build a magnetic gradient sample database. Then, nine attribute parameters of the magnetic gradient tensor matrix are analyzed and selected to construct eigenvectors to be used for the support vector machine. Finally, a support vector machine (QPSO-SVM) classification model based on quantum particle swarm optimization is established based on the test data. Simulations and experiments prove that the method can effectively identify the shape of underground small targets, and the accuracy of classification is up to 90%.

Keywords: magnetic gradient tensor, shape recognition, underground small target, particle-swarm support vector machine

1. Shijiazhuang Campus, Army Engineering University, Shijiazhuang, Hebei 050003, China
2. Force Unit 94019, the Chinese People's Liberation Army, Hetian, Xinjiang 848000, China

Gravity data inversion using high-order polynomial function of density contrast varying with depth. LIU Jie[1], ZHANG Jianzhong[1,2], JIANG Li[1], WAN Li[1], and HU Jiashan[3]. Oil Geophysical Prospecting, 2019, 54(3): 700-708.

The gravity inversion is one of the geophysical means for depicting the spatial distribution of mass bodies with density contrast. Conventional inversion methods directly invert density contrast values of each cell through both horizontal and vertical meshes. In this paper, complex density variations are approximated by polynomial functions, and a new method is proposed to determine density contrasts by inverting the coefficients of polynomial density functions. Different from the conventional

inversion methods, this method can invert complex density contrasts without partitioning vertically cells. To some extent, it eases the contradiction between the quantity of mesh, memory occupancy, and inversion precision. Theoretical model tests show that polynomial coefficient inversion combined with multiple constraints can clearly highlight the position, scale and boundary information of local masses, and is superior to the conventional L2-norm inversion results. This proposed method is successfully applied to the identification of buried hills and sags in the Jiyang Depression. The boundaries of different lithologic bodies are roughly determined by density contrasts inverted, which makes up the gap of buried hill distributions showing on seismic sections.

Keywords: polynomial function, variable density, residual gravity anomaly, gravity data inversion, meshing

1. Key Laboratory of Submarine Geosciences and Prospecting Techniques, Ministry of Education, College of Marine Geosciences, Ocean University of China, Qingdao, Shandong 266100, China
2. Laboratory for Marine Mineral Resources, Qingdao National Laboratory for Marine Science and Technology, Qingdao, Shandong 266061, China
3. Research Institute of Exploration and Production, Shengli Oilfield Branch Co., SINOPEC, Dongying, Shandong 257015, China

Magnetotelluric data 2D forward modeling based on quadtree grid. WANG Peijie[1], HU Hua[2,3], XU Fei[3,4], GUO Huo[3,4], and CHEN Lianmu[3,4]. Oil Geophysical Prospecting, 2019, 54(3): 709-718.

A finite difference algorithm for forward modeling of magnetotelluric (MT) data based on quadtree gridding is proposed in this paper. First the model is gridded based on the quadtree data structure. Then finite difference formulas for different nodes of the mesh are derived with the method of undetermined coefficient, and the magnetotelluric responses are finally obtained by solving difference equations of nodes. The proposed algorithm is tested on several models with reliefs and its validity is proved by the comparison of conventional finite difference and finite element methods. Based on our test results, the proposed algorithm achieves much better calculation efficiency with comparable accuracy.

Keywords: magnetotellurics (MT) response, 2D forward modeling, quadtree grid, finite difference method

1. Institute of Geology, China Earthquake Administration, Beijing 100029, China
2. School of Geosciences, Yangtze University, Wuhan, Hubei 430100, China
3. Key Laboratory of Exploration Technology for Oil and Gas Resources, Ministry of Education, Yangtze University, Wuhan, Hubei 430100, China
4. School of Geophysics and Petroleum Resources, Yangtze University, Wuhan, Hubei 430100, China

A novel technology: Reservoir Seepage Geophysics. ZHAO Pingqi[1], HAO Huimin[2], NI Tianlu[1], LI Hongge[2], TAO Ziqiang[1], and MA Yuehua[2]. Oil Geophysical Prospecting, 2019, 54(3): 719-728.

As old oilfields enter the stage of high watercut development, reservoir physical properties (porosity, permeability, and shale content) change with the increase of water injection multiple, which leads changes of reservoir seepage field. In this case, the reminding oil prediction and oil recovery improvement are much more difficult. Therefore, Reservoir Seepage Geophysics (RSG), a novel technology, is proposed. The feasibility of the reservoir seepage geophysics is proved with change analysis of reservoir porosity, shale content, and reminding oil saturation in different development stages. Based on rock physics experiments, multi-disciplinary information such as time-lapse seismic, time-lapse VSP, time-lapse electromagnetic surveys, and different well logging data are jointly used to study the reservoir seepage field. Finally a multi-dimensional reservoir seepage geological geophysical model is built, which shows reservoir seepage variations. The reservoir seepage geophysics is some continuation and improvement of reservoir geophysics, which will play an important role in the reservoir seepage field reconstruction and the oil recovery improvement of old oilfields.

Keywords: reservoir seepage geophysics, time-lapse VSP, time-lapse electromagnetic survey, reservoir geological model

1. Dagang Oilfied Company, PetroChina, Tianjin 300280, China
2. BGP Inc., CNPC, Zhuozhou, Hebei 072750, China