Advances in Geo-Energy Research

Vol. 9, No. 1, p. 1-4, 2023

Editorial

Recent advances in theory and technology of oil and gas geophysics

Yibo Wang[1,*], Yang Liu[2], Zhihui Zou[3], Qianzong Bao[4], Feng Zhang[5], Zhaoyun Zong[6]

[1]*Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 100029, P. R. China*

[2]*College of Geoexploration Science and Technology, Jilin University, Changchun 130026, P. R. China*

[3]*Key Lab of Submarine Geosciences and Prospecting Techniques MOE, College of Marine Geosciences, Ocean University of China, Qingdao 266100, China*

[4]*School of Geological Engineering and Geomatics, Chang'an University, Xi'an 710054, P. R. China*

[5]*College of Geophysics, China University of Petroleum, Beijing 102249, P. R. China*

[6]*College of Geosciences, China University of Petroleum (East China), Qingdao 266580, P. R. China*

Keywords:
Oil and gas geophysics
geophysical data processing
rock physics
reservoir characterization

Cited as:
Wang, Y., Liu, Y., Zou, Z., Bao, Q., Zhang, F., Zong, Z. Recent advances in theory and technology of oil and gas geophysics. Advances in Geo-Energy Research, 2023, 9(1): 1-4.
https://doi.org/10.46690/ager.2023.07.01

Abstract:
Oil and gas are important energy resources and industry materials. They are stored in pores and fractures of subsurface rocks over thousands of meters in depth, making the finding and distinguishing them to be a significant challenge. The geophysical methods, especially the seismic and well-logging methods, are the effective ways to identify the oil and gas reservoirs and are widely used in industry. Due to the complexity of near surface and subsurface structures of new exploration targets, the geophysical methods based on advanced computation methods and physical principles are continuously proposed to cope with the emerging challenges. Thus, some new advances in theory and technology of oil and gas geophysics are summarized in this editorial material, especially focusing on the geophysical data processing, numerical simulation technology, rock physics modeling, and reservoir characterization.

In the 6th National Youth Geological Conference held on June 9-11, 2023 in Wuhan, China, about 30 young geophysicists attended the session of Theory and Technology of Oil and Gas Geophysics. The new advances of oil and gas geophysics are discussed and exchanged, and the presented works are summarized as follows.

1. Geophysical data processing

Song Xu, from the Ocean University of China, delivered a presentation entitled "Highly accurate slowness processing for array acoustic logging data: Theory and application". A new signal processing technique based on the supervirtual interferometry theory was presented for logging while drilling acoustic data processing (Xu and Zou, 2023). Meanwhile, a new model-based dispersive processing method was presented to accurately determine wave slowness from the logging while drilling acoustic data, especially for the unconsolidated formations (Xu et al., 2022b). The reliability and accuracy of the methods is confirmed by synthetic data and real logging while drilling data. The acoustic-wave radiations of monopole and dual sources are also analyzed in the poorly bonded cased boreholes (Xu, 2023). The results provide a guideline for understanding and interpreting acoustic logging measurements.

In the lecture on "Research progress of pattern-based seislet transform in seismic data processing" given by Jiawei Chen from Jilin University, the velocity dependent seislet transform (Liu et al, 2015) was applied to seismic stacking. Synthetic and real-data tests showed that the proposed method

Yandy Scientific Press

*Corresponding author.
E-mail address: wangyibo@mail.iggcas.ac.cn (Y. Wang); yangliu1979@jlu.edu.cn (Y. Liu); zouzhihui@ouc.edu.cn (Z. Zou); qzbao@chd.edu.cn (Q. Bao); zhangfeng@cup.edu.cn (F. Zhang); zongzhaoyun@upc.edu.cn (Z. Zong).

Received June 15, 2023; revised June 22, 2023; accepted June 26, 2023; available online June 28, 2023.

can produce high-resolution and high signal-to-noise ratio stacking results. He proposed the shot continuation seislet by applying shot continuation theory (Fomel, 2003) to the seislet transform. This method outperformed the Fourier projections onto convex sets method in reconstructing data with irregularly missing shot records, resulting in the improved signal-to-noise ratio of stacking results.

Hongri Sun, from China University of Petroleum-Beijing, delivered a presentation entitled "Multiple types of noise suppression of seismic shear wave data". In this talk, a 2D seismic SS-wave dataset was acquired by using horizontal vibrator and three-component geophone in Qinghai Sanhu area, Qaidam Basin, China. The acquired shear waves have a similar bandwidth to the compressional waves (Zhang, 2021). The shear-wave dataset contains the linear noises, the monofrequency noises and the internal multiples at both near- and far- offsets, which seriously interfere with the information of effective waves. Median filtering and coherent noise suppression were used to remove monofrequency noises and linear noises. Frequency wave-number and the data-driven multiple suppression inversion internal multiple suppression method based on wave equation theory (Bao et al., 2021) is applied to suppress multiples at far- and near-offset, respectively. Applications to field data indicate that the combined processing method can effectively suppress noises in seismic shear wave data.

2. Numerical simulation

Munirdin Tohti, from the Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, delivered a talk entitled "Numerical simulation of seismoelectric signals in anisotropic poroelastic medium". The simulation of seismoelectric coupling in an electric isotropic and elastic anisotropic medium is developed using a primary-secondary formulation (Tohti et al., 2020). The anisotropy is of vertical transverse isotropy and orthorhombic type with only the poroelastic parameters is studied. The seismoelectric response to an explosive source is solved based on a finite difference time domain algorithm. The seismic wave fields are used as the primary field. The electric field is then considered as a secondary field and obtained by solving the Poisson equation for the electric potential. To test the numerical algorithm, seismoelectric numerical results are compared with analytical results obtained from Pride's equation. The comparison shows that the numerical solution gives a good approximation to the analytical solution. At last, the influence of medium parameters on the propagation of seismoelectric wavefields are simulated in several different models (Tohti et al., 2022).

Shigang Xu, from Chang'an University, presented a talk entitled "Numerical modeling of optimized pure viscoacoustic wave equation in complicated anisotropic media". To suppress the numerical noise and the instability of the conventional pseudoacoustic wave equations of anisotropic media, a pure-mode acoustic wave equation based on the Poisson algorithm is adopted firstly (Li and Zhu, 2018). Then, by considering that the attenuation media affect the amplitude and phase characteristic of seismic wave, a modified pure viscoacoustic wave equation by using standard linear solid theory is developed (Xu et al., 2022a). The numerical modeling examples show that the proposed equation can result in correct amplitude decay and phase dispersion in complicated anisotropic media.

3. Rock physics modeling

Shuheng Du, from Institute of Mechanics, Chinese Academy of Sciences, delivered a lecture on "New flow distinctions of tight oil reservoir considering quantitative dependence between minerals and spaces". A new classification scheme for seepage channels based on mineral types was developed after considering the differences in their geophysical and geological properties. The maximum flow velocity increases in a nonlinear way as the average diameter of each type of seepage channel increases. The comprehensive potential flow capability has almost no relationship with the type of space. A small space does not have a greater potential of exploitation than a large space (Du et al., 2023a). A new direction is presented for investigating the oil generation mechanism and enhancing unconventional oil recovery (Du et al., 2023b).

Han Bai, from Jilin University, delivered a presentation entitled "Modeling of nonlinear elastic constitutive relationship and numerical simulation of rocks based on the Preisach-Mayergoyz space model". The progress of experimental methods and theoretical models for the study of nonlinear elasticity of rocks is introduced (Feng et al., 2018; Feng et al., 2022). A new nonlinear elastic constitutive relation was constructed and a wave equation was derived too. The harmonic characteristics of classical nonlinear elastic waves are observed by numerical simulation using finite difference method. The nonlinear elastic mechanism of rock is explained qualitatively. This study is helpful to the evaluation of the nonlinear elastic characteristics of the Earth on a large scale.

Zuoxiu He, from the Chinese University of Petroleum-Beijing, delivered a presentation entitled "Rock physics modeling and AVO forward modeling for gas-hydrate reservoir in South China Sea". In his work, rock physics models suitable for hydrate-bearing reservoir in South China Sea were selected to carry out rock physics modeling (Li and Liu, 2017), and the frequency-dependent AVO (amplitude versus offset) forward modeling was carried out to obtain synthetic seismogram with attenuation (Guo et al., 2015), which was then compared with real seismogram and synthetic seismogram of convolution model. The rock physics modeling shows that the gas hydrate in South China Sea is most likely to be cemented or load-bearing hydrate. Moreover, P-wave quality factor is sensitive to hydrate saturation, frequency, the input parameter of White's model and gas saturation. The AVO modeling shows that the frequency-dependent AVO synthetic seismogram is close to real seismogram, and can improve the quality of well-to-seismic tie. The results can benefit the understanding of the petrophysical and AVO characteristics of hydrate-bearing reservoirs in South China Sea.

4. Reservoir characterization

In the lecture entitled "Quantitative description method and application of turbidite reservoir in NZ depression", Qiyun

Wang, from Geophysical Research Institute, Sinnopec Shengli Oilfield Company, proposed a technical sequence for quantitative description of turbidite reservoirs. Firstly, she used seismic data interpretation processing techniques to improve the resolution of seismic data. Secondly, on the basis of single well anatomy, she used logging cycle data to subdivide geological layer, and to establish a fine geological layer framework. Finally, she used the reorganized sand data and geological layer comparison data to optimize the sensitive seismic attributes, established a quantitative relationship between the predicted and the actual thickness of sand in turbidite reservoirs, and described the boundaries and thicknesses of different sand bodies. The above method was applied to predict the thickness of the reservoir in the N1 block of Shengli Oilfield. The results confirm that the presented method can effectively realize the high-precision quantitative description of turbidite sand bodies, and has guiding significance for the prediction of the same type of reservoir and the followed steps of the well location deployment.

Zhishui Liu, from Chang' An University, delivered a presentation entitled "A prediction method of in-situ stress in carbonate reservoir with complex pore structure". Due to the poor application result of equivalent depth method in the dense carbonate reservoir with complex pore structure, a poroelasticity theoretical model of pore pressure prediction was derived to characterize the quantitative relationship between pore pressure and rock elastic parameters based on the poroelasticity theory. A new differential effective media model for carbonate with complex pores is utilized to calculate the elastic properties. Various stress parameters, such as horizontal stress and fracture pressure, are calculated based on the predicted pore pressure. This method has been applied in the carbonate reservoir of Yingshan Formation of Ordovician in Shunbei Oilfield, Tarim Basin. The results show that the predicted pore pressure agrees well with the testing data, and the trend of the predicted pressure is consistent with the monitoring pressure while drilling. This verified the effectiveness of the proposed method in predicting in-situ stress of carbonate reservoir.

Tianjun Lan, from China University of Petroleum (East China), presented a lecture entitled "Prediction of fluid and engineering sweet spots in tight sandstone reservoirs using pre-stack seismic frequency-dependent AVO". The solid-liquid decoupling fluid factor that is most sensitive to fluid and the seismic frequency is selected to characterize the fluid in tight sandstone reservoirs (Zong et al., 2021; Lan et al., 2023). By investigating the relationship between solid-liquid decoupling fluid factor and brittleness index, a PP-wave reflection coefficient equation is derived by involving the solid-liquid decoupling fluid factor and the brittleness index. A pre-stack seismic frequency-dependent AVO inversion method is also developed to simultaneously invert for the frequency-dependent solid-liquid decoupled fluid factor and frequency-dependent brittleness index (Li et al., 2019). This method was tested on models and applied in tight sandstone reservoirs, and the predicted reservoir fluid and brittleness index show good agreement with well logging results. Based on the inversion results, predictions of fluid distribution in tight sandstone reservoirs and characterization of engineering sweet spots are conducted, enabling a comprehensive evaluation of fluid in tight sandstone reservoirs.

Weihua Jia, from the China University of Petroleum (East China), presented a talk entitled "Research on total organic carbon prediction method for hydrocarbon source rocks based on LightGBM". Given the superior performance of machine learning in handling nonlinear problems, he presented a semi-quantitative prediction scheme of hydrocarbon source rock total organic carbon based on well-logging curves and seismic attributes. Based on the well-logging curves, the sensitive parameters of total organic carbon of hydrocarbon source rock can be determined by cross-plot and correlation analysis (Jia et al., 2023). In addition, the LightGBM machine learning algorithm was employed to predict total organic carbon of hydrocarbon source rock. This method provides a novel approach for predicting the total organic carbon of hydrocarbon source rock.

Conflict of interest

The authors declare no competing interest.

References

Bao, P., Wang, X., Xie, J., et al. Internal multiple suppression method based on iterative inversion. Chinese Journal of Geophysics, 2021, 64(6): 2061-2072. (in Chinese)

Du, S., Jin, J., Shi, Y., et al. Complex flow in tight oil reservoirs impacted by heterogeneous minerals: A new mechanism. Marine and Petroleum Geology, 2023a, 150: 106095.

Du, S., Zhao, Y., Sun, F., et al. Estimations of the upper and lower depth limits for kerogen to generate oil/gas worldwide: A hypothesis. International Journal of Hydrogen Energy, 2023b, 48(34): 12661-12671.

Feng, X., Fehler, M., Brown, S., et al. Short-period nonlinear viscoelastic memory of rocks revealed by copropagating longitudinal acoustic waves. Journal of Geophysical Research: Solid Earth, 2018, 123(5): 3993-4006.

Feng, X., Fehler, M., Burns, D., et al. Effects of humidity and temperature on the non-linear elasticity of rocks. Geophysical Journal International, 2022, 231(3): 1823-1832.

Fomel, S. Seismic reflection data interpolation with differential offset and shot continuation. Geophysics, 2003, 68(2): 733-744.

Guo, Z., Liu, C., Li, X. Seismic signatures of reservoir permeability based on the patchy-saturation model. Applied Geophysics, 2015, 12: 187-198.

Jia, W., Zong, Z., Sun, H., et al. Seismic response analysis and distribution prediction of source rocks in a survey of the South China Sea. Interpretation, 2023, 11(2): T349-T360.

Lan, T., Zong, Z., Feng, Y. An improved seismic fluid identification method incorporating squirt flow and frequency-dependent fluid-solid inversion. Interpretation, 2023,

11(1): T117-T130.
Li, C., Liu, X. Seismic wave attenuation in hydrate-bearing sediments based on the patchy saturation model in the Shenhu area, South China Sea. Interpretation, 2017, 5(3): SM25-SM32.
Li, K., Yin, X., Zong, Z. Estimating frequency-dependent viscoleastic fluid indicator from pre-stack F-AVA inversion. Journal of China University of Petroleum, 2019, 43(1): 23-32. (in Chinese)
Li, X., Zhu, H. A finite-difference approach for solving pure quasi-P-wave equations in transversely isotropic and orthorhombic media. Geophysics, 2018, 83(4): C161-C172.
Liu, Y., Fomel, S., Liu, C. Signal and noise separation in prestack seismic data using velocity-dependent seislet transform. Geophysics, 2015, 80(6): WD117-WD128.
Tohti, M., Wang, Y., Slob, E., et al. Seismoelectric numerical simulation in 2D vertical transverse isotropic Poroelastic medium. Geophysical Prospecting, 2020, 68(6): 1927-1943.
Tohti, M., Wang, Y., Xiao, W., et al. Numerical simulation of seismoelectric wavefields in 3D orthorhombic poroelastic medium. Chinese Journal of Geophysics, 2022, 65(11): 4471-4487. (in Chinese)
Xu, S. Acoustic-Wave radiations of mono-and dual-sources in poorly bonded cased boreholes: Modeling and field applications. IEEE Transactions on Geoscience and Remote Sensing, 2023, 61: 5904610.
Xu, S., Bao, Q., Ren Z. A simplified pure visco-acoustic wave equation for 3D TTI media and its numerical simulation. Oil Geophysical Prospecting, 2022a, 57(2): 331-341. (in Chinese)
Xu, S., Zou, Z. Supervirtual interferometry as a tool for slowness estimation of logging-while-drilling multipole acoustic data. IEEE Transactions on Geoscience and Remote Sensing, 2023, 61: 5909416.
Xu, S., Zou, Z., Tang, X. Estimation of elastic wave velocity from logging-while-drilling measurement in unconsolidated formation of accretionary wedge in nankai trough. IEEE Transactions on Geoscience and Remote Sensing, 2022b, 60: 5922713.
Zhang, F. Simultaneous inversion for S-wave velocity and density from the SV-SV wave. Geophysics, 2021, 86(2): R187-R195.
Zong, Z., Feng, Y., Yin, X., et al. Fluid discrimination incorporating viscoelasticity and frequency-dependent amplitude variation with offsets inversion. Petroleum Science, 2021, 18(4): 1047-1058.