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Application of Seismic Anisotropy Analysis Technology in The Prediction of Volcanic Rock Fractures in Songliao Basin

Yong Xiao[1,*], Bingsong Yu[1]
[1]School of Earth Sciences and Resources, China University of Geosciences (Beijing), Beijing, China
[*]Corresponding author
E-mail: *x_y81@126.com, yubs@cugb.edu.cn*

Abstract

In recent years, volcanic rock reservoirs in the Songliao Basin in China have been important layers for deep petroleum exploration and development in the basin. However, the volcanic rocks in this area belong to low porosity-ultra-low porosity and ultra-low permeability reservoirs. Under the influence of a series of transformations during and after the formation of the volcanic rock, various types of pores and fracture storage spaces are formed inside the volcanic rock body, especially the fracture system is the main part to communicate the pore space and improve the permeability, which is the evaluation An important parameter for the effectiveness of volcanic reservoirs. The prediction of volcanic rock fractures is the bottleneck technology restricting deep oil and gas exploration in the Songliao Basin in recent years, and is the difficulty of oil and gas exploration research in this area. The current exploration technologies developed for fracture prediction include: shear wave exploration, P-S converted waves, multi-component seismic, multi-directional VSP, longitudinal wave AVAZ, etc. In this paper, based on the geology, drilling characteristics and seismic data of deep Cretaceous volcanic rock fractures in Songliao Basin, the seismic method is used to identify the spatial distribution characteristics of volcanic rock fractures, which provides technical support for the study of volcanic reservoir connectivity and has important research implications.

Keywords: Volcanic Rock; Crack Prediction; Seismic Anisotropy Analysis.

1. Introduction

Volcanic rocks are widely distributed in the basins of the world. In recent years, a number of volcanic reservoirs have been discovered in China's Songliao Basin, Junggar Basin, Erlian Basin, and Bohai Bay Basin. However, there are few research results that can be used for seismic prediction of volcanic rock fractures. Seismic prediction is a difficult problem in oil and gas exploration research worldwide. This is mainly manifested in: (1) the formation of fractures is controlled by many factors, its physical properties are complex, the lateral and vertical changes are large, and it shows strong anisotropy; (2) fractures are mostly generated late, unlike other oil and gas reservoirs that have corresponding Due to the characteristics of the sedimentary environment, fractured oil and gas reservoirs are more difficult to explore than conventional oil and gas reservoirs; (3) due to the complexity of fractures, the prediction of fracture direction and density between wells is difficult to rely on extrapolation of the results in the well; The change occurs with different azimuths, which is called azimuth anisotropy in earthquakes. With the increasing interest in volcanic oil and gas reservoirs in recent years, research on seismic identification of volcanic fractures at home and abroad has received increasing attention. How to effectively predict the spatial

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distribution and development law of volcanic rock fractures is of great significance for the study of volcanic oil and gas reservoirs.

2. Prestack Seismic AVAZ Analysis Technology

Among the seismic attributes, the attributes sensitive to fractures include amplitude, layer velocity, time difference, azimuth AVO gradient, azimuth layer frequency, layer frequency difference, superimposed amplitude and superimposed amplitude azimuth difference, etc. Studies have shown that in anisotropic media, the P-wave AVO gradient is quite different between parallel to the fracture direction and perpendicular to the fracture direction. This is the theoretical basis for detecting cracks with P waves. In these theories, the fractured oil and gas exploration technologies that have been developed are: shear wave exploration, P-S converted wave, multi-component seismic, multi-directional VSP, longitudinal wave AVO, AVAZ, etc., the most effective method should be the shear wave splitting technology. However, the cost of shear wave acquisition and processing is extremely high, and the investment risk in oil fields is large, so it is not a conventionally applied technology. Multi-component earthquakes, multi-azimuth VSP, and P-S converted wave technologies have good results, but either high exploration costs or unconventional seismic acquisition projects are difficult to apply widely in many areas.

AVAZ (or AVOZ) technology is the abbreviation of technology for detecting the relationship between the amplitude of 3D seismic data and the change of offset and azimuth. The theoretical research of AVAZ (or AVOZ) technology shows that the direction of the smaller AVO gradient is the fracture direction, and the direction of the largest gradient is the fracture normal direction, and the difference itself is proportional to the density of the fracture, so the density of the fracture can be calibrated. Experimental results also show that the relationship between AVO and azimuth (ie, AVO gradient) reflects the change in rock hardness. If the AVAZ analysis method is used to calculate the gradient value of each set of azimuth angles within 360 °, the maximum difference between the gradients calculated from the orthogonal azimuth angle range can be obtained, and the fracture direction can be determined based on this.

Theoretically, the longitudinal wave propagates perpendicular to the fracture zone will have obvious travel delay and attenuation, and the reflection intensity will decrease and the frequency will become lower. These different characteristics of longitudinal waves can be used to determine fractured reservoirs.

According to the theory of seismic scattering in fractured reservoirs, the attenuation of seismic frequency is related to the spatial variation of fracture density field. The frequency along the fracture direction decreases slowly with the offset, while the frequency along the vertical fracture direction decreases rapidly with the offset. The greater the fracture density, the faster the frequency decreases. Rock seismic model experiments were used to study the seismic wave response characteristics of fractured reservoirs. The results show that the propagation velocity of seismic P waves in the direction perpendicular to the fracture is faster than that in the direction parallel to the fracture. In addition, the dynamic characteristics of seismic waves such as amplitude, dominant frequency, and attenuation are more sensitive to changes in fracture characteristics than kinematic characteristics such as velocity. The above research results indicate that it is completely feasible to use pre-stack seismic data to extract azimuth seismic attributes such as amplitude, velocity, dominant frequency, attenuation, etc. to detect fractured reservoirs. The study of forward modeling of rock physics can help us establish a theoretical model of reservoir rock properties and theoretically the seismic anisotropy response characteristics generated by the model.

In the pre-stack forward simulation study, we have to establish a geological model and elastic medium model of the fractured reservoir. To build a rock physical model of a fractured rock, we need to know the rock's vertical and horizontal wave velocity and density. After obtaining the P-wave velocity and rock density data in the well, we need to calculate the elastic tensor and the anisotropy equivalent Thomsen index of the rock in the fractured reservoir section of the well according to the rock physical model to understand the influence of heterogeneous rock physical parameters. Based on the fracture anisotropy parameters obtained in the well, the response of the prestack seismic reflection at various azimuth angles is calculated, and the relationship between the anisotropic seismic reflection amplitude and the fracture direction is calculated.

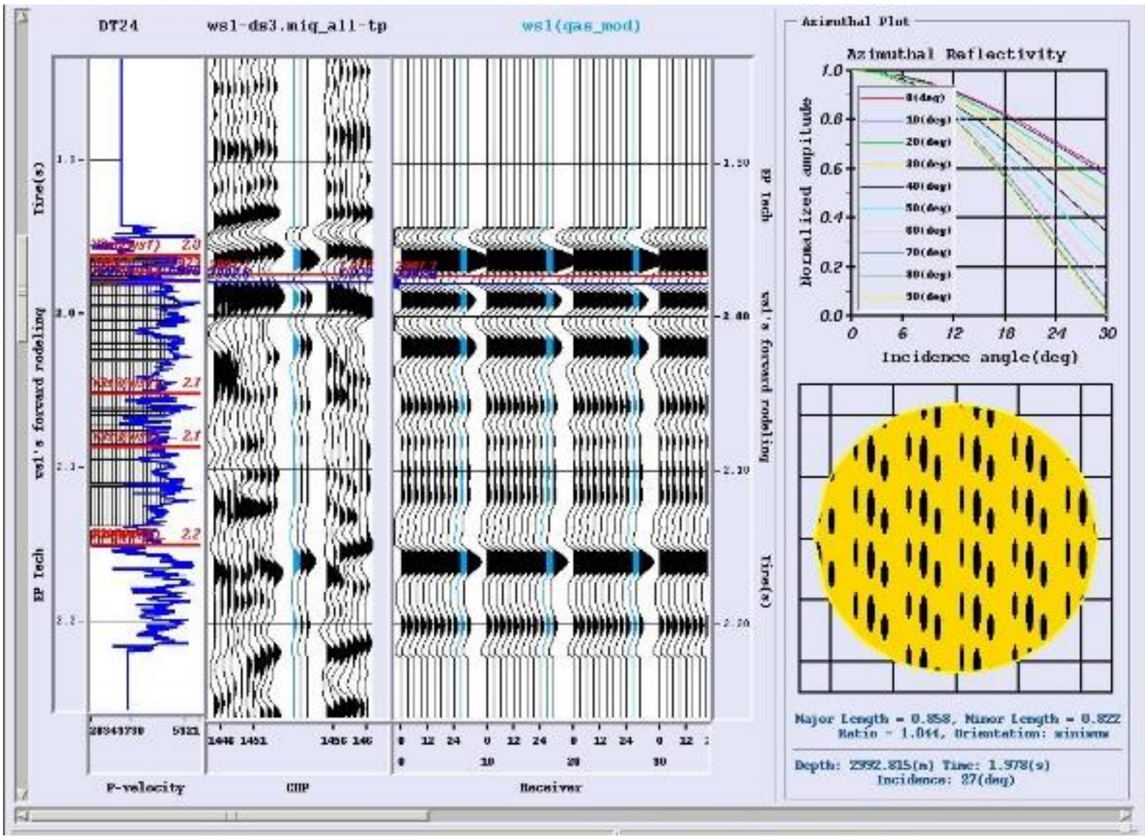

Fig. 1. Forward modeling of well D6 rock physics model (with gas)

Aiming at the deep volcanic rock reservoirs in the southern Songliao Basin, several wells were analyzed by pre-stack forward modeling (Fig. 1 and Fig. 2). The results of the forward modeling of the rock physical model can obtain the correspondence between the geological interface and seismic reflection, and the AVO characteristics of the seismic response on the geological interface. The normalized reflection amplitude with the AVO response of the incident angle is used to quantitatively describe the change characteristics of the azimuth amplitude caused by the fracture. To determine the direction of the crack.

The pre-stack forward simulation study of the well is helpful to better understand the geophysical response characteristics of volcanic rock fractures, and to clarify the relationship between azimuth amplitude change with offset and fracture properties. At the same time, it is obtained how the cracks with different fluids affect the change of the pre-stack amplitude with the offset. These studies are the basis for the subsequent prediction and interpretation of volcanic rock fractures.

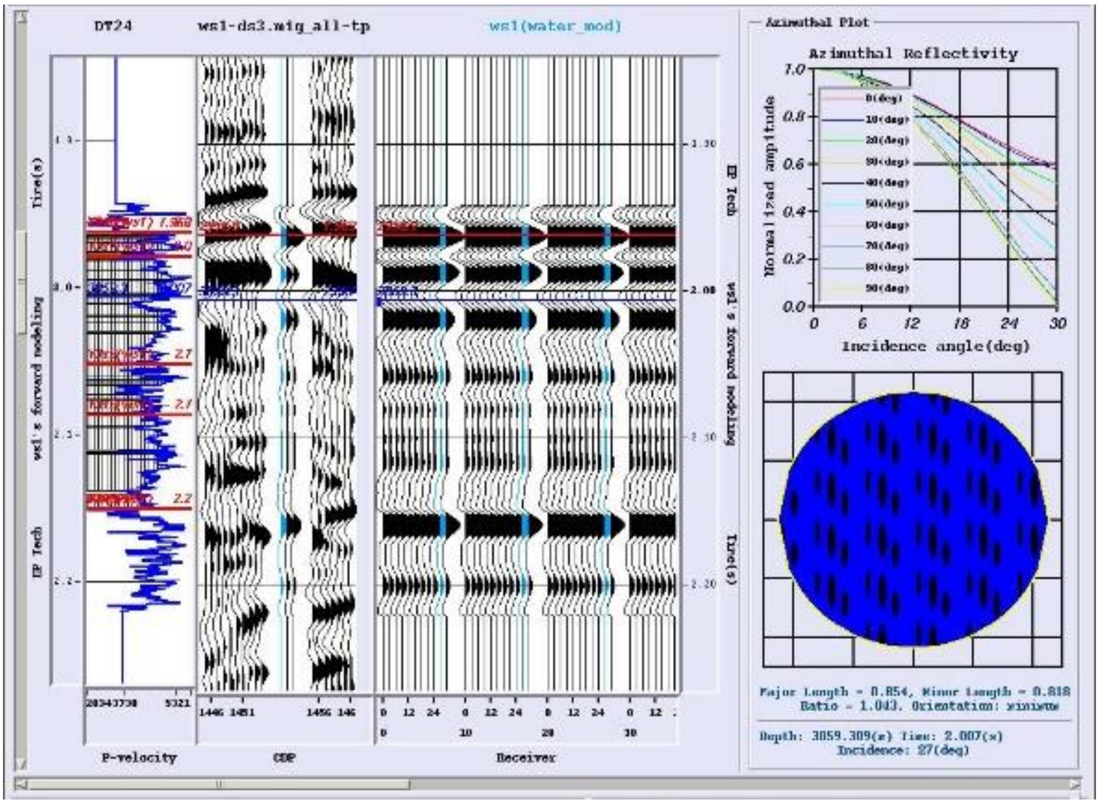

Fig. 2. Forward modeling of well D6 rock physics model (with water)

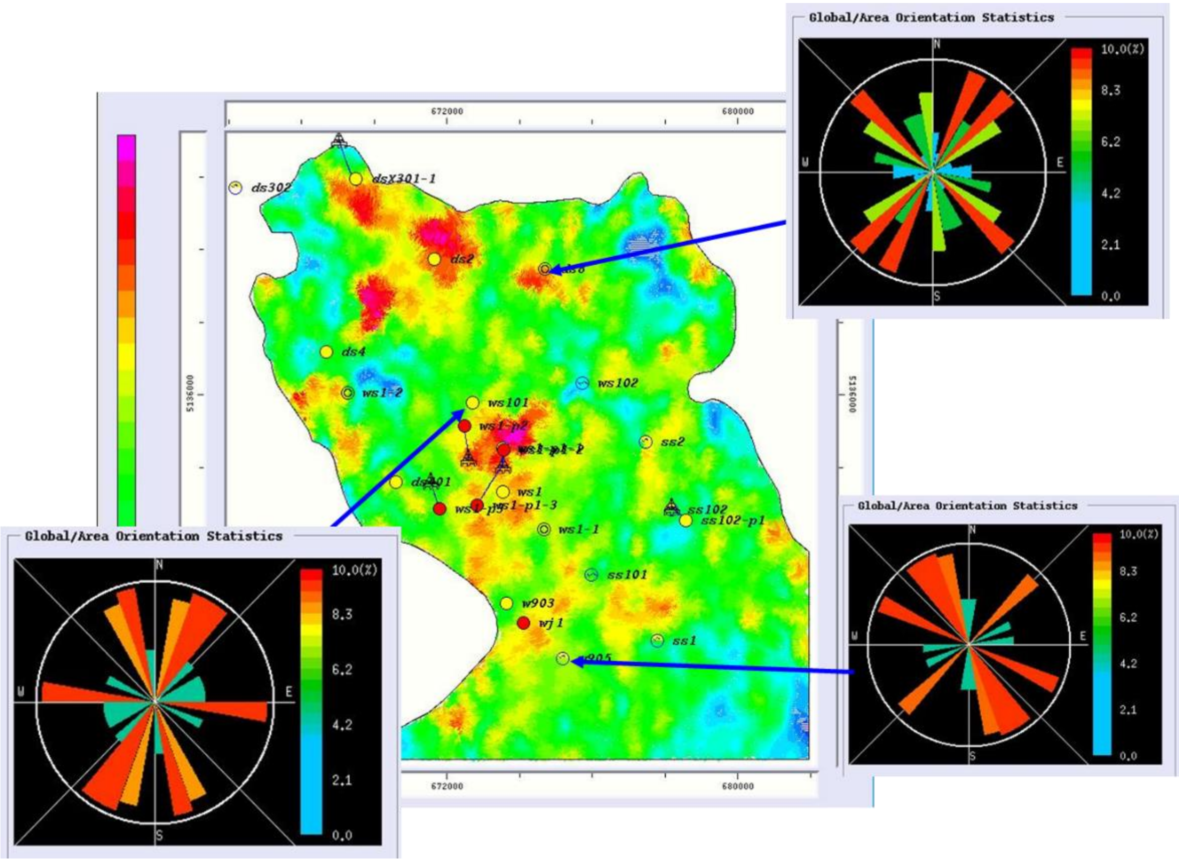

Fig. 3. The predicted fracture plane distribution and trend of a section of volcanic rock in the

southern Songliao Basin

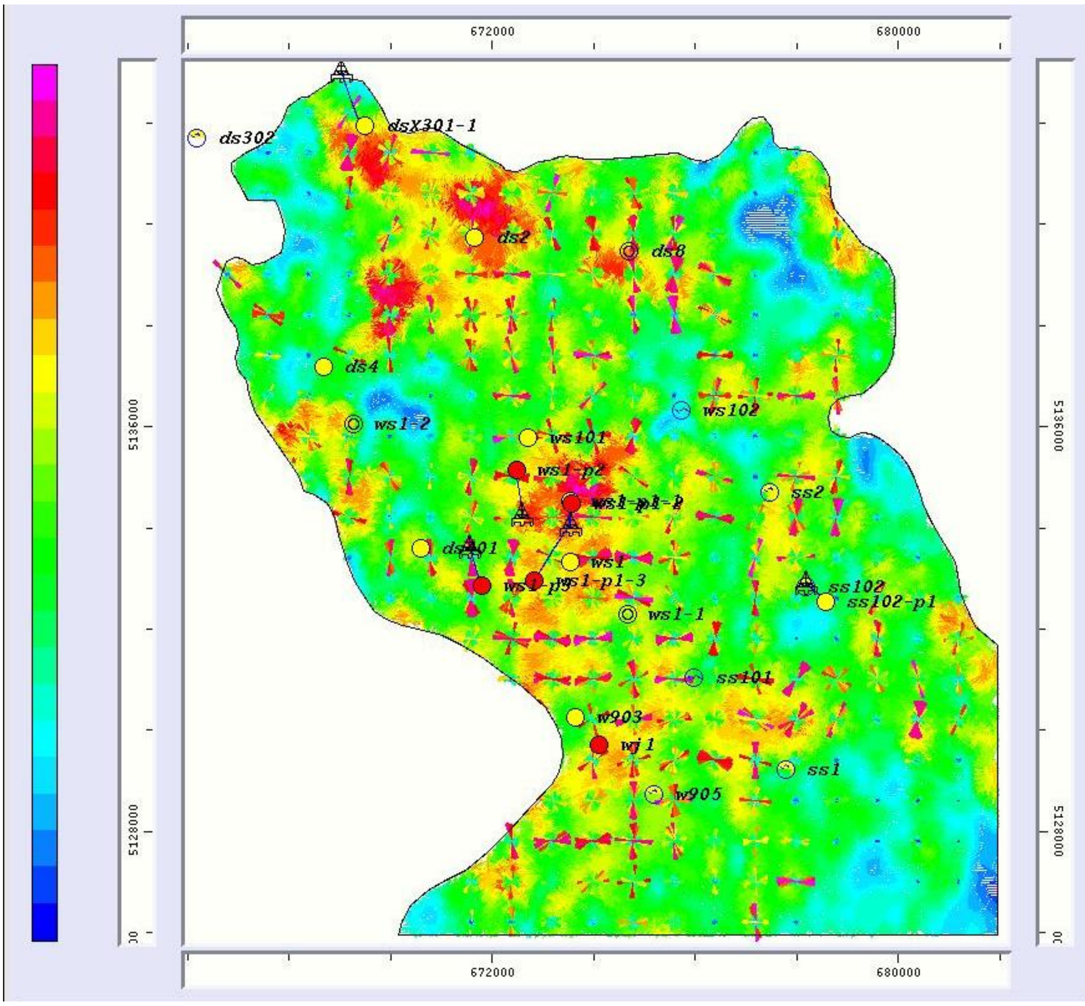

Fig. 4. Planned distribution of fracture trend predicted for a section of volcanic rocks in the southern Songliao Basin

3. Application Effect of Pre-Stack Seismic AVAZ Technology to Identify Cracks in Volcanic Rocks

The distribution of fractures is the main factor that controls production well productivity and underground fluid flow. In this study, the anisotropy analysis was mainly used to detect the characteristics of the fracture; while in the prestack anisotropy calculation, the analysis of the change of the prestack seismic amplitude and prestack attenuation properties with the azimuth angle, and the change The relationship with fractures, and then provide a geophysical basis for fracture interpretation. In fracture analysis, the orientation of the fracture is mainly determined by the change in amplitude with the azimuth angle; and the change in attenuation property with the azimuth angle is mainly used as one of the methods to determine the relative density of the fracture, especially the relative density of the crack.

According to the aforementioned forward modeling results, in volcanic reservoirs, if the seismic reflection amplitude anisotropy is caused by fractures. Therefore, the azimuthal amplitude ellipse short axis direction roughly indicates the statistical orientation of the fracture in space. The flatness of the amplitude ellipse is defined as the ratio of the long axis to the short axis. The magnitude of this value represents the anisotropic intensity of seismic reflection amplitude. The anisotropic strength of the amplitude is related to the density of the fracture. The greater the relative density of the fracture, the greater the strength of the anisotropic amplitude. Anisotropic strength is used to indicate crack density. The direction of the short axis of the anisotropic amplitude ellipse represents the crack direction, and the amplitude ellipse oblateness represents the anisotropic strength. In this way, through the change of amplitude with azimuth angle, the spatial direction of volcanic reservoir fractures and the intensity of seismic wave amplitude anisotropy are determined. However, to accurately describe the density distribution of fractures in the reservoir, comprehensive seismic attribute analysis is required under the constraints of fracture interpretation.

Through analysis of the change of amplitude with azimuth angle, the spatial distribution of seismic anisotropy characteristics can be obtained (shown in Fig. 3 and Fig. 4): In addition, the rose diagram of fracture direction at the statistical well point, the fracture predicted by anisotropy The direction is basically the same as the fracture direction counted by logging FMI.

In the deep volcanic rocks of the Yingcheng Group in the Songliao Basin, the fracture development direction is divided into two groups, mainly NW-SE direction and NNE-SSW direction; seismic analysis results with amplitude varying with azimuth angle indicate that the fracture direction is affected by The characteristics of fracture distribution and diagenesis after volcanic eruption are controlled. The direction and spatial distribution of fractures are controlled by the lithology of the reservoir and the lithology of the overlying strata and the spatial distribution and development of sedimentary facies and faults. It is related to the geological environment (diagenesis) and tectonism in the later period of the volcanic eruption in the study area.

4. Conclusions and Suggestions

Based on the above-mentioned plane distribution law of volcanic rock fractures and the prediction results of fracture trend, the pre-stack seismic AVAZ technology prediction research on volcanic rock fractures has achieved the following conclusions:

(1) Based on the pre-stack seismic AVAZ analysis technology, it has a good lateral resolution for the identification of fractures, and it has a good identification effect for the prediction of fracture direction, which is consistent with the interpretation results of the drilled FMI logs.

(2) The development of cracks on the plane is mainly concentrated near the main body of the volcano, and the degree of development of the cracks toward the periphery is weakening rapidly.

(3) The degree of development of deep volcanic fractures in the Songliao Basin is closely related to the fault activity and the main body of the volcanic rocks. Near the fault, the closer to the fault, the more developed the fracture; the intersection of the fault and the turning part of the fault are often where the fracture is most developed. It is consistent with the geological understanding of the distribution of volcanic rock fractures in this area.

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