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AVAZ/FAVAZ Analysis to Predict Permeable Fractured Terrigenous Reservoirs Using Full-Azimuth Seismic Data in Local Angle Domain

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Summary

This work presents the technology and results of applying full-azimuth seismic data processing in the Local Angle Domain (LAD) in order to study the frequency absorption of reflected signals versus azimuthal direction of incident and reflected rays, to assess fracture permeability zones in an oil field in Western Siberia. Terrigenous (sandstones) of the Jurassic reservoirs are located at great depths and have low porosity and permeability values. In addition, low-amplitude faults influence their distribution and properties, which are poorly allocated when using traditional processing technologies. On the positive side, terrigenous reservoirs of Jurassic age have dual porosity (fracturing plus grain porosity), which makes it possible to use new approaches to predict oil-saturated zones based on LAD processing. This work shows that by using LAD processing together with AVAZ/FAVAZ analysis, it is possible to predict zones of permeable (and as a rule, oil-saturated) fractures in terrigenous sediments. This increases reliability when predicting oil-saturated fractures compared to AVAZ analysis. This work also shows the effectiveness of using the results of AVAZ/FAVAZ analysis with an integrated interpretation of the seismic image and diffractor forming a structural-skeleton (SI-STS) to predict Jurassic terrigenous oil reservoirs.

Introduction

This work presents the technology and results of applying full-azimuth seismic data processing in the Local Angle Domain (LAD) in order to study the frequency absorption of reflected signals versus azimuthal direction of incident and reflected rays, to assess fracture permeability zones in an oil field in Western Siberia. Terrigenous (sandstones) of the Jurassic reservoirs of Western Siberia are located at great depths (over 3000 meters) and have low values of total porosity and permeability. In addition, low-amplitude faults have a great influence on the distribution and properties of the porosity and permeability of the reservoir, which are poorly allocated when using traditional processing technologies. On the positive side, terrigenous reservoirs of Jurassic age have dual porosity (fracturing plus grain porosity), which makes it possible to use new approaches to the detailing and prediction of oil-saturated zones based on LAD processing. The frequency absorption is primarily due to the presence of permeable fractures in the reservoirs, and fluid saturation and fluid movement in dual porosity reservoirs (e.g. fracturing plus grain porosity). The physical and theoretical background of such effects are described in Tomsen (1995), Goloshubin (2002) and Kozlov (2006). This work describes the process of full-azimuth processing in the Local Angle Domain (Koren and Ravve, 2011) plus Amplitude vs. Angle and Azimuth (AVAZ) analysis (Canning and Malkin, 2009) and Frequency Absorption versus Azimuth (FAVAZ) analysis (e.g., Inozemtsev et al., 2019), which was used for the first time to predict fractured permeable oil reservoirs of Jurassic age in Western Siberia. It is shown that by using LAD processing together with AVAZ/FAVAZ analysis, it is possible to predict zones of permeable (and as a rule, oil-saturated) fractures. This increases reliability when predicting oil-saturated fractures compared to AVAZ analysis, which registers the general effects of azimuthal anisotropy associated with both closed and open fractures. This paper also shows the effectiveness of using the results of AVAZ/FAVAZ analysis with an integrated interpretation of the seismic image and diffractor forming a structural-skeleton (SI-STS) to predict Jurassic terrigenous oil reservoirs.

Method and Technology

In order to study permeable fractures at an oil field in the Jurassic terrigenous sediments of Western Siberia, the following technology for processing and analysing full-azimuth seismic data was used: Depth processing in the Local Angle Domain followed by AVAZ and FAVAZ analysis according to the following workflow:

1. Full-azimuth time processing with preservation of amplitudes, spectrum and waveform.
2. Model-based 3D ray tracing to study the illumination of target depth objects, taking into account the anisotropy of velocities and an assessment of the reliability of data for full-azimuth studies.
3. LAD migration and processing to obtain full-azimuth Directional Gathers (DG) and Reflection Gathers (RG).
4. Separation of the wavefield in the DG domain into specular and diffraction components, based on the removal of the specular energy from the DG.
5. VVAZ (RG) analysis.
6. Interactive analysis of azimuth-dependent residual kinematics (RMOz).
7. Generalized Dix type inversion with sequential conversion of effective parameters of azimuthal anisotropy into interval parameters of azimuthal anisotropy.
8. Analysis of the azimuth-dependent amplitudes (AVAZ analysis and inversion) to obtain more accurate information from the amplitude variations about the azimuthal anisotropy intensity and the direction of its axis of symmetry.
9. Study of frequency absorption (FA) versus the azimuthal direction or FAVAZ analysis.
10. Estimation of the frequency absorption intensity (FAI) for predicting zones of permeable fractures.
11. Integrated interpretation of the results of LAD processing of DG/RG, and AVAZ/FAVAZ analysis to predict promising areas of permeable (oil-saturated) fracturing in terrigenous (sandstone) reservoirs in Jurassic sediments.

Results and Example Predictions

Figure 1 shows the results of FAVAZ analysis in different azimuth sectors, namely the joint seismic image and attribute - Instantaneous Frequency (FI). This attribute characterizes the change in the frequency spectrum vertically and laterally, in this case associated with the Frequency Absorption (FA) of the low frequency component of the effective part of the spectrum. The main direction of the axis of symmetry of the HTI anisotropy, determined according to AVAZ data, is in the azimuth sector of 0-45°. The time and depth interval of the analysis corresponds to terrigenous sediments of age J2 in a field in Western Siberia. The maximum low frequency absorption effect corresponds to the azimuth sector of the summation of seismograms 0–45° (Figure 1A), when the phase front of the wavefield is directed across the fracture. The minimum effect of low frequency absorption corresponds to the azimuth sector of the summation of seismograms 90-135° (along the fracture). Full-azimuth summation in the 0-360° sector gives an averaged absorption effect, which does not reflect the real picture. The intermediate value of the absorption effect is displayed in the 45-90° sector, which is inclined to the fracture.

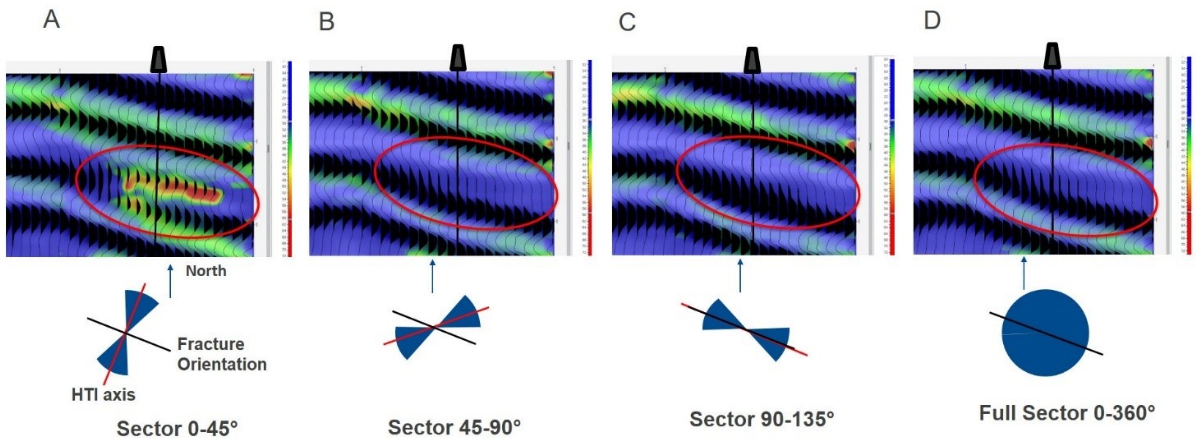

Figure 1 Structural hydrocarbon trap (pinching) in terrigenous sediments of age J2. FAVAZ analysis results for different azimuth sectors for studying permeable fractures in sandstone reservoirs of terrigenous sediments of J2 age. A - -the depth image of the attribute Instantaneous Frequency for the azimuth sector 0-45°; B - for sector 45-90°; C - for sector 90-135°; D - for the full sector 0-360°. The red line is the direction of the HTI axis of symmetry, the black line is the direction of fractures. The oval indicates the zone of change in the frequency of the reflected signal associated with the absorption of low frequencies.

Figure 2 shows a comprehensive analysis of the results of LAD processing and AVAZ/FAVAZ analysis for a longitudinal section passing through an oil-saturated and dry well.

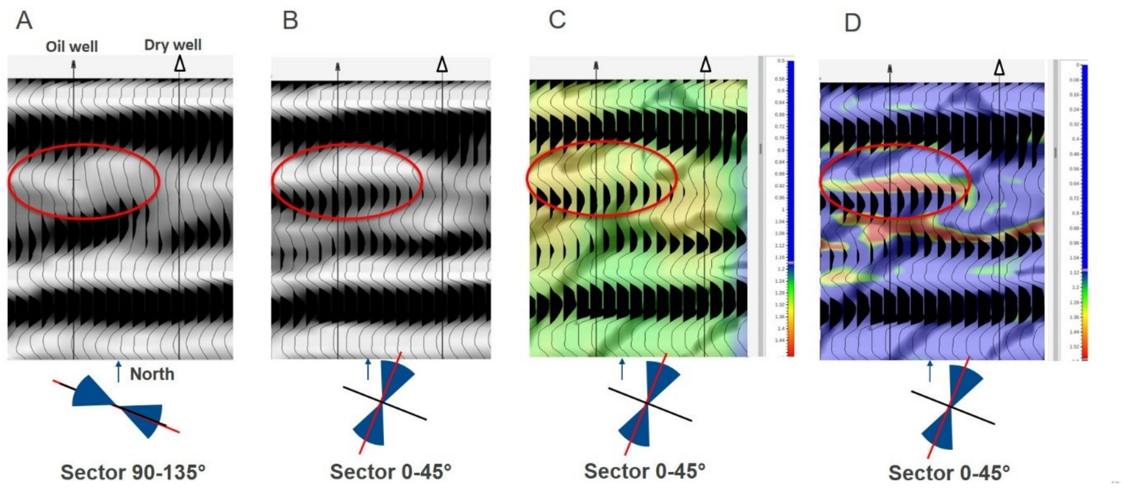

Figure 2 Structural-tectonic oil trap of hydrocarbons in terrigenous sediments of J2 age – the longitudinal section passes through the oil-saturated and dry wells. A - depth image for the azimuth sector 90-135°; B - depth image for the azimuth sector 0-45°; C - joint depth image and diffraction

image together with the attribute AVAZ Intensity of azimuthal anisotropy for sector 0-45°; D - joint depth image and diffraction image together with the attribute FAVAZ Frequency Absorption Intensity (FAI) for azimuth sector 0-45°.

From analyzing the results of Figure 2, it follows that the intensity of the azimuthal anisotropy and FAI intensity are generally correlated with each other, but not proportionately. FAI is more localized, as it is associated with permeable (often oil-saturated) fractures, while azimuthal anisotropy intensity is associated with both open and closed fractures. A higher fracture density estimated by HTI may correspond to a smaller number of permeable fractures estimated by FAI. It can also be seen that the faults identified by the Diffraction component also control the zones of elevated and reduced FAI values, creating a block structure of the oil field. SI-STS shows that the oil reservoir is associated with a structural oil trap - pinching.

Figure 3 shows a comparison between the 3D intensity distribution of azimuthal anisotropy and the intensity FAI of the absorption frequencies within SI-STS in the area surrounding a productive and unproductive well in a deep slice of an oil-saturated terrigenous reservoir. Figure 3 also gives a prediction of prospective zones associated with permeable (oil-saturated) fracturing, based on a cross-plot between the attributes of azimuthal anisotropy intensity and FAI intensity.

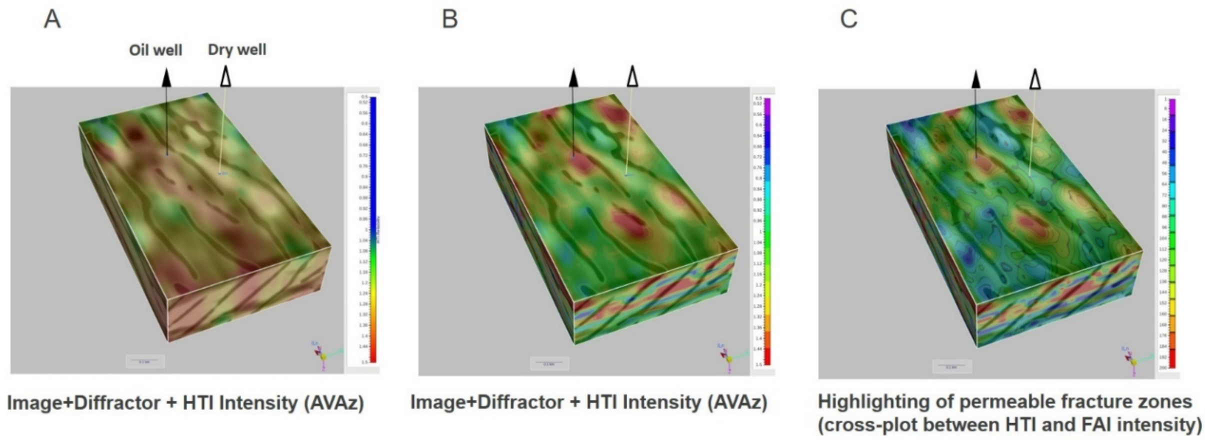

Figure 3. Comparison in 3D of the distribution of azimuthal anisotropy intensity (A) and FAI of the intensity of absorption of frequency (B) in SI-STS in the area surrounding the productive (black) and non-productive (yellow) well. Image (C) indicates prospective oil-saturated zones on the basis of a cross-float between the HTI and FAI intensity attributes.

A comparison of the intensity distribution of azimuthal anisotropy (AVAZ) and the intensity of FAI frequency absorption (FAVAZ) in the volume shows that the general correlation between the intensity of azimuthal anisotropy and FAI exists laterally. The zones of higher FAI values are also more localized and have a different shape and smaller size than the azimuthal anisotropy intensity. The fault in the center divides the values of FAI into a zone of high and a zone of low values. The productive (oil-saturated) well falls into the anomalous zone. A non-productive (dry) well is located on the other side of the fault, in the zone of low values of the FAI attribute. It is obvious that the fault between them played the role of a tectonic screen, dividing the fractured zone into two parts of different properties. The statistical prediction made it possible to contour the promising zones of permeable fracturing in order to plan new production wells or zones for the hydraulic creation of fractures. In this example, faults are shown to often control both zones with high permeability and zones with low permeability in the reservoir. The application of the approach described above in the conditions of West Siberia makes it possible to more reliably predict zones of permeable oil-saturated fracturing in fractured-porous terrigenous sediments of Jurassic age.

Conclusions

This paper first demonstrated new, practical capabilities of LAD processing together with AVAZ/FAVAZ analysis to predict permeable fractures in terrigenous sediments. The application of this approach in the conditions of West Siberia makes it possible to more reliably predict zones of permeable oil-saturated fracturing in fractured-porous terrigenous sediments of Jurassic age.

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