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# Estimating Seismic Anisotropy to Characterize Open Fractures in a Pre-Salt Reservoir of the Santos Basin

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## Abstract

The characterization of open fractures is a critical component of reservoir model development, as these features often serve as preferential flow paths during hydrocarbon production. Seismic data, especially when acquired with multi-azimuthal coverage, allows for the three-dimensional mapping of fracture networks. In Brazil's ultradeep offshore pre-salt province, a recent large-scale Ocean Bottom Node (OBN) seismic acquisition was conducted to address the illumination issues caused by a complex overburden, particularly the thick salt layers overlaying the reservoirs. The OBN technology, with its dense azimuthal sampling and high repeatability, significantly enhances seismic imaging and supports time-lapse reservoir monitoring. Furthermore, the dataset enables robust Amplitude Variation with Azimuth (AVAz) analysis, a key technique for evaluating seismic anisotropy and detecting aligned fracture systems, which are crucial for optimizing reservoir development strategies. In a porous medium containing open and vertically aligned fractures, the velocity of acoustic waves exhibits directional dependence. Waves propagating parallel to the fractures experience higher velocities compared to those traveling perpendicular to them. This directional variation reflects both the matrix porosity and the fractured porosity. The perpendicular direction influences the seismic response of both matrix and fractured porosity. Additionally, this anisotropy induces azimuthal variations in seismic amplitude, driven by contrasts in the elastic properties of the medium. To estimate fracture porosity from Full Azimuth (FAZ) datasets, one method involves identifying the azimuthal sector volume corresponding to a full angle range centered around the dominant fault direction and then subtracting the volume corresponding to the perpendicular sector. The resulting difference highlights anisotropy, as the fractures align with the fault directions, and these two volumes represent the maximum and minimum seismic amplitudes. An alternative approach involves analyzing amplitude variations across the full open dataset, incorporating all incident angles and azimuthal sectors. This method generates a surface that varies with both angle and azimuth, from which two key attributes can be derived: the azimuthal gradient and the reference azimuth. Interpretation of these results must be contextualized within the field's structural-stratigraphic model, well log data, and production history to yield meaningful insights into the fracture system. In this study, we analyzed two FAZ datasets from a mature Pre-salt field — one processed with Least-Squares Kirchhoff migration (LSKM) and the other with Least-Squares Reverse-Time Migration (LSRTM). Our goal was to evaluate whether the data align with anisotropy theory for Horizontally Transverse Isotropic (HTI) media and provide insights into reservoir fracture systems. The amplitudes extracted from the azimuthal sector near the main fault direction in the fractured reservoir were expected to show an elliptical variation, with the highest values in the fault direction and the lowest at the perpendicular direction. No significant variations were anticipated between the different migration methods. However, the seismic anisotropy maps revealed distinct differences between the two migration techniques. The LSKM data shows a clear energy concentration beneath the salt domes, particularly at the basal anhydrite top reflector, with a strong response in the azimuthal gradient attribute. The AVO gradient at the Common Reflection Point (CRP) closest to the well follows the theoretical sinusoidal model, aligning well with fault patterns observed in conventional amplitude data and the conceptual structural model. In contrast, the LSRTM data show a weaker correlation with the salt domes and are more aligned with the field's structural trends. However, the match with the theoretical curve at the CRP is less consistent and shows discrepancies with the structural model. This is unusual, as RTM typically outperforms Kirchhoff migration in complex geological environments. A potential explanation is that RTM migration may not yet adequately balance amplitude across azimuthal sectors, affecting anisotropy interpretation.