PARADIGM CUSTOMER STORY

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Imaging and Characterization of a Shale Reservoir Onshore Poland, Using Full-Azimuth Depth Imaging*

The Challenge

The exploration and development of shale plays in Europe have shown that the "statistical drilling" approach used in some basins cannot be extended to areas where local stress in rocks or fracture distribution varies both laterally and in depth. Moreover, drilling and fracturing practices confirm the presence of local geobodies resistant to hydraulic fracturing.

The Assessment

Paradigm, together with its client Geofizyka Torun (GT), decided to use a new technology, Paradigm EarthStudy 360® full-azimuth angle domain depth imaging. This innovative technology is particularly suitable to Poland, where conventional seismic migrations do not provide sufficient image quality and the resolution required to analyze fractured reservoirs.

The Solution

The EarthStudy 360 system was used to perform the seismic imaging and characterization. Using EarthStudy 360, it is possible to decompose the recorded seismic data into full-azimuth subsurface angle gathers, and build an accurate anisotropic model using full-azimuth tomography. EarthStudy 360 also provides an environment for interpretive AVAZ analysis.

Formation evaluation

Many measurements were logged in the wells, the most important of which were obtained using a crossed-dipole sonic tool and electrical micro-imager (XRMI). Data processing results indicated anisotropy in some parts of the Silurian and Ordovician sections. The general direction of anisotropy confirmed the direction estimated from seismic in the most interesting zone. A comparison between WaveSonic results and electrical imager data (XRMI) indicated that anisotropy was predominantly related to the presence of fractures; however, it may also be caused by carbonate or pyrite concretions inside shales.

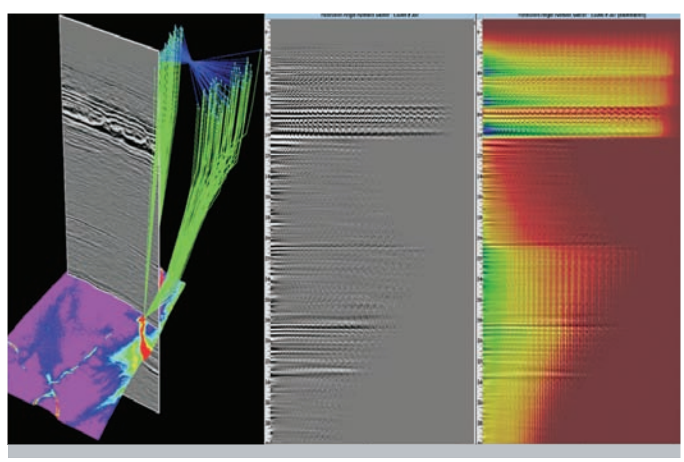
Seismic imaging

The first step in the depth imaging workflow was to estimate and compensate for polar anisotropy with vertical axis of symmetry (VTI), a prerequisite for estimating azimuthal anisotropy parameters. Estimating the VTI model parameters involved the application of full-azimuth tomography to separate velocity heterogeneities from azimuthal anisotropy. This was important for building a reliable background model of the overburden, and ensured a consistent estimation of azimuthally-dependent phenomena at target. The accuracy of the VTI model was confirmed when new drilling was completed, where the seismic-to-well ties reached an accuracy of +3 m.

To meet the challenges of high precision, conventional seismic imaging in depth was replaced by the new software package dedicated to full-azimuth, angle domain depth imaging. The full-azimuth depth imaging workflow offers numerous advantages, including:

- Wavelet stretch compensation in the angle domain, enabling the use of wide angles.
- Illumination compensation, which minimized the impact of acquisition, complex overburden, and velocity model on amplitude distribution.
- Full-azimuth tomography, which separated heterogeneities from azimuthal anisotropy, thereby allowing proper correction for overburden.
- Transformation of the effective, azimuthally varying residual moveouts measured along LAD depth gathers into local (interval) anisotropic velocity parameters.
- Decomposition of the seismic wavefield into specular and diffraction components., enhancing both structural continuity and small-scale discontinuities (faults or cracks).

All of these features revealed details in the subsurface of unconventional plays, and enabled better analysis of the azimuthal anisotropic effects on stress/fracture environments. The possibility for in situ expression of spatial relations between analyzed seismic events brings high precision to imaging.



▲ Compensation for irregular illumination: Ray fan filtered with real acquisition geometry (left), CRP gather (middle), CRP gather with illumination in color (right)

Moreover, in practice it was confirmed that such maps, provided by the full-azimuth prestack depth imaging technology, also predict which bodies are resistant to fracturing. In conclusion, 3D FAZ seismic is essential for success in these areas when drilling for shale gas.

More options: Diffraction images

In addition to improvements in image quality and estimate of azimuthal attributes using reflection data, the EarthStudy 360 full-azimuth depth imaging system can also use diffraction characteristics in the recorded data to enhance high-resolution discontinuous objects in both unconventional and conventional resources. The separation of two components of the recorded wavefield - reflection and diffraction energies - revealed subtle features related to small-scale, geologic discontinuities. Preliminary experience indicates that the use of diffraction imaging in some geologic environments can be even more useful than azimuthal analysis. It can reveal tiny features not seen by geologists using classical reflection images extracted from the same seismic data.

Seismic interpretation

Seismic interpretation was applied to seismic rich-azimuth data imaged using EarthStudy 360. The methodology was supplemented by both acoustic and elastic inversion. Inversion velocities and elastic impedances were extracted in specified intervals, related to particular formations. That workflow allowed comparison of the sector-oriented approach to full-azimuth technology. The latter definitely delivered higher precision.

The Results

Results obtained from analyzing the seismic data were in line with results of the geologic and geophysical analysis of the borehole data, as well as with information from microseismic monitoring of fracturing treatment. The technology delivered high-quality images of the reservoir and geomechanical characterization of rocks with the precision needed to steer horizontal drilling, detect sweet spots, and locate geobodies resistant to fracturing.

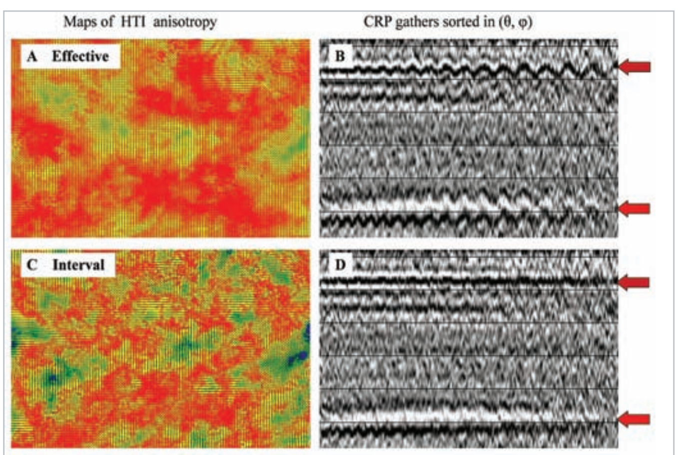
The Conclusions

From a seismic perspective: Full-azimuth seismic depth imaging is efficient in unconventional plays, such as shale gas, shale oil, tight gas, and geothermal projects. Compared to traditional time-domain, sectored imaging and data analysis, depth imaging in the local angle domain provides more reliable attributes for seismic characterization of reservoirs with azimuthal anisotropy. In areas where azimuthal anisotropy is weak and covered with complex overburden, application of full-azimuth depth imaging can be a condition for the economic success of the project.

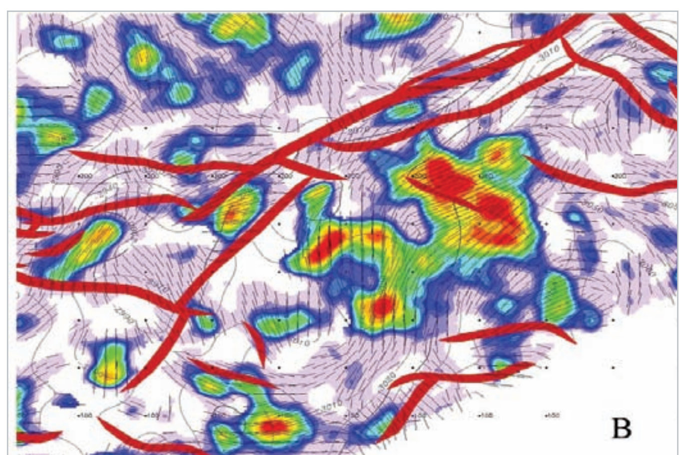
From a well log perspective: While regional stress may not be relevant to local prospecting, stress orientation predicted from seismic is compatible with an azimuth rose diagram seen in wells, and with information measured from microseismic monitoring during horizontal well fracturing.

From a geological perspective: Analysis of the lithostratigraphic formations of Ordovician and Silurian sections revealed significant anisotropy of their mechanical properties. This can be attributed to their original lithologic differentiation, and the later impact of tectonics, including the present field of stress. Identifying the relationship between core data (e.g. mechanical properties, deformations, fracture patterns), well logs, and seismic is essential to the creation of the local geomechanical model. Such a model is necessary for the correct planning and drilling of horizontal wells, as well as for hydraulic fracturing.

From a conventional prospecting perspective: The search for conventional traps in areas of complex geology can also profit from this method. Bottom-up ray tracing, the precise use of a 360° view of irregular surfaces, correction for illumination shadows (vertical and lateral), non-stretch NMO, and decomposition into reflection and diffraction components offer the potential to derive new images from archived 3D seismic shot over conventional geology, as well as high-resolution imaging of new, dedicated, rich-azimuth seismic data.



▲ (A) Map of effective HTI anisotropy for target (red arrow horizon). (B) HTI anisotropy at overburden bottom (brown arrow horizon) and target (red arrow horizon). (C) Map of interval HTI anisotropy estimated for interval between horizons marked by arrows. (D) Considerably reduced full-azimuth PreSDM RMO.



▲ Zoom on composite, azimuthal anisotropy map: Colors indicate intensity, and arrows - orientation of anisotropy. Faults are in red.

* This Customer Story is taken from an article of the same name that originally appeared in First Break, October 2014, authored by: Henryk Kowalski, Piotr Godlewski, Wojciech Kobusinski, Jakub Makarewicz, Michal Podolak - Geofizyka Torun S.A.; Aldona Nowicka, Zbigniew Mikolajewski - PGNiG S.A.; and David Chase, Raanan Dafni, Anat Canning, Zvi Koren - Paradigm