Full-Azimuth Angle Domain Seismic Depth Imaging – High Resolution, True Amplitude Practical Workflow

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Abstract

The new seismic data imaging method, called full-azimuth angle domain depth imaging, has been designed for work with rich-azimuth seismic data. Dedicated software delivers high-quality images for the reservoir and geomechanical characterization of rocks with the precision needed to steer horizontal drilling, detect sweet spots, and allows location of geobodies resistant to fracturing. However, practice of application proves this technology brings also new quality of seismic imaging of conventional resources, where deeper penetration under complex overburden, or imaging irregular-shape geobodies is the case. Recent experience with shale plays indicates that regularly sampled "blind drilling" to identify sweet spots yields low percentage of success. That becomes understood when examining HTI anisotropy maps estimated with the described method of full azimuth seismic imaging: only limited percentage of examined interval should be selected for drilling. The method provides cubes, and horizon maps of interval values of HTI anisotropy of kinematic (V, dip, ε, δ, Δα, φ) and dynamic (amplitude) attributes, which are easily related to geomechanical properties of rocks. Seismic estimation of geomechanical rock parameters requires maps of interval attributes. Formulae built in the discussed imaging method do effective-to-interval conversion for general media, with depth-variant VTI + HTI anisotropy. Examples of diffraction imaging are shown. This option is alternative and supplementary to reflection imaging. Discussed is also impact of acquisition geometry on reliability of amplitude and azimuthal estimations. Presentation underlines specific features of this new seismic method and deliver summary of comparison to characteristics of classical seismic technology.

Introduction

The novelty seismic imaging technology dedicated to process full or rich azimuth seismic data marks new level of precision in seismic characterization of subsurface. Developed originally for identification of shale gas sweet spots and characterization of the unconventional reservoirs, can be helpful in areas of classical seismic tasks, but remaining unsolved for complexity of geology.
Decision to reach for the full azimuth angle domain depth imaging (FAZADI) seismic technology had been based on several years' experience with simpler technique of azimuthal sectoring seismic data prepared with prestack time migration (PreSTM). Results obtained within those projects led to the belief about necessity of higher precision of imaging.
Since several decades, the ideas about correct processing account for various physical phenomena affecting seismic vibrations on their paths of propagation were discussed and relevant software solutions developed. When necessity of correction for the azimuthal anisotropy has been identified, it came to development of a new software tools. While the theory of the presented technology has been published in [1,2,3], development of practical implementation has been published in [4,5,6], here the focus is on possible different areas of application the FAZADI technology. Provided is summary of potential solutions it offers to seismic prospection for both: conventional and unconventional reservoirs. Practical experience is being cumulated as currently the fourth shale gas project is under processing with this technology.

Geologic setting and data acquisition

The area where current FAZADI projects are applied is Northern Poland, onshore. Sample image in Fig.1 comes from one of areas with shale gas in Poland. Zechstein interval, with anhydrite buildups and strong lateral velocity contrasts causes problems of imaging underlying horizons. This image was created with software dedicated to FAZADI technology applied to the full azimuth seismic.

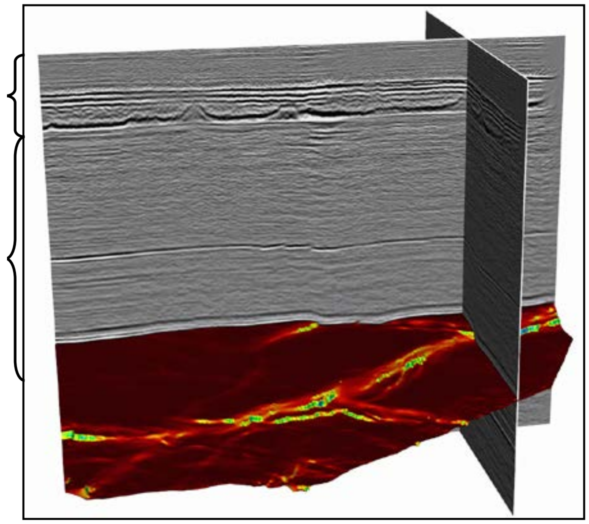

Fig.1. Example of seismic image from the area where the described technology was applied.

The acquisition geometry assumed stacking fold 160 to 190, depending on particular survey, maximum offset over 4 km, and bin size 20 x 20 m. The experience of the several full azimuth (active spread close to square) projects indicates that the stacking fold should be higher twice in both x and y directions, if reliable, high resolution result is required. That is more expensive, but reliability of result is much increased. Density of such survey removes harm with spatial aliasing.

Processing and Imaging workflow

Preparation of seismic data for the full azimuth depth imaging consists of all conventional elements, however changed to: preserve azimuthal distribution of seismic attributes, create data appropriate to solutions built in the dedicated software Earth Study 360®, and protect diffractions – the waves frequently disregarded. Specific features of the processing of data to be input to FAZADI imaging are summarized in the Table 1. To meet these requirements, the new component has been introduced into algorithms of surface-consistent processing: statics, decon, and amplitude balance, and into database operations on attributes. That is azimuth component. The respective algorithms work in so called 5D option.

The time domain preprocessing is ended with prestack time migration, usually in VTI anisotropy option, as VTI is present almost everywhere when sediments are layered. At this point the FAZADI imaging begins. Schematic workflow can be seen in Fig.2. Some pieces of the workflow are iterative: that is procedure of model building for prestack depth migration.

Seismic data should be corrected for	Cannot be corrected for
Instabilities of wavelet not related to geology	Azimuthal characteristics of the wavefield
Short wavelength statics	Spherical divergence of amplitude
LVL effects: statics, wavelet, amplitudes	Overburden geology
Noise and multiple reflections removed	Acquisition gaps (trace interpolation)
Diffractions preserved	Long wavelength statics

Table 1. What to do and what not to do during time domain preprocessing for the full azimuth imaging.

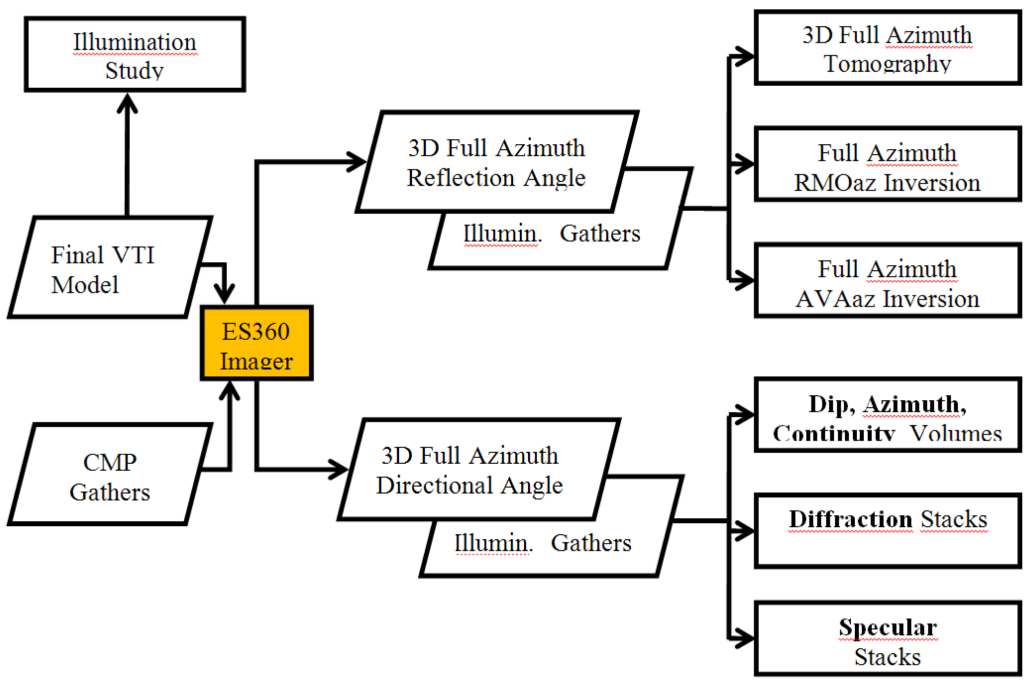

Fig.2. General workflow of the full azimuth depth imaging in angle domain. Input are CMP gathers, VTI model from PreSTM, and horizons interpreted from VTI PreSTM stack.

There are several datasets output from the FAZADI imaging (Fig.2). It resembles, in some aspects, the idea of generalized stacking (implemented under names of CRS, Multifocusing, or ECP): geologists get from seismic much more than just stack volume. *ES360 "Imager"* in Fig.2 stands for key engine of the Earth Study 360®: CRAM (Common Reflection Angle Migration) and Full Azimuth Tomography. Central engine of the full azimuth imaging performs multitask job. Brings new value to the data. It is capable to:

- regularize illumination, reduce greatly fault shadows,
- interpolate traces in acquisition gaps,
- estimate and correct for spherical divergence,
- work in angle domain (incidence angle, azimuth angle), so removes NMO stretch – see Fig.3,
- separate inhomogeneities from azimuthal anisotropy - key correction for overburden,
- work in LAD (Local Angle Domain) – follow depth/space variant azimuth – basis of precise conversion effective attributes into interval ones.

Therefore, several conventional limitations are no longer obstacles to get high resolution image.

High resolution seismic

Potential of high resolution of the full azimuth depth imaging in angle domain (FAZADI) comes from the numerous, abovementioned, novelty techniques built in the software. Perfectly flat migrated events (Fig.3) with geology-related amplitudes, corrected for depth- and spatially-variant changes of the azimuthal (HTI) anisotropy in LAD domain, bring precise, clear image of the subsurface – sample is in Fig.4.

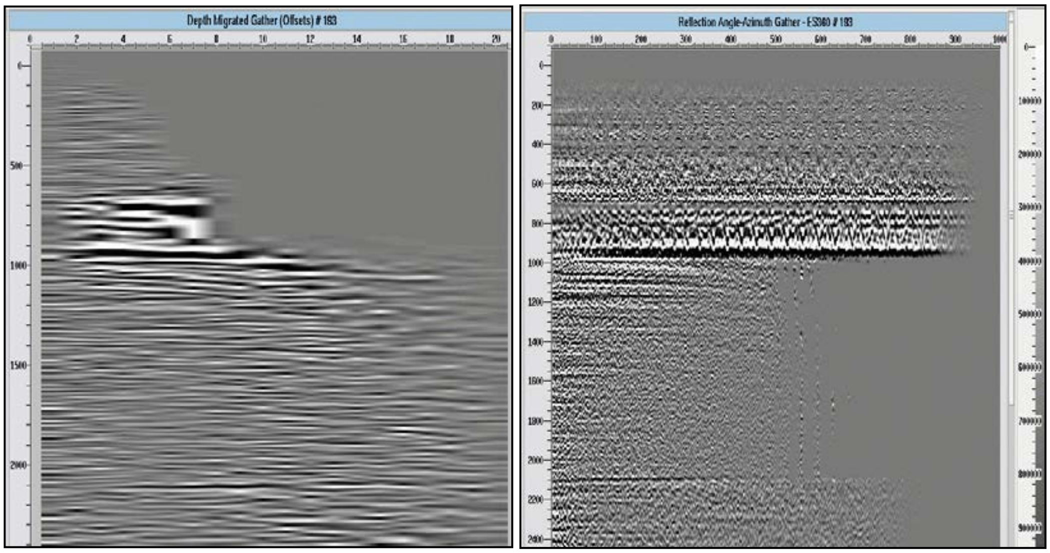

Fig.3. Sample migrated CRP gather: left – from Kirchhoff, right from ES360. NMO stretch is reduced.

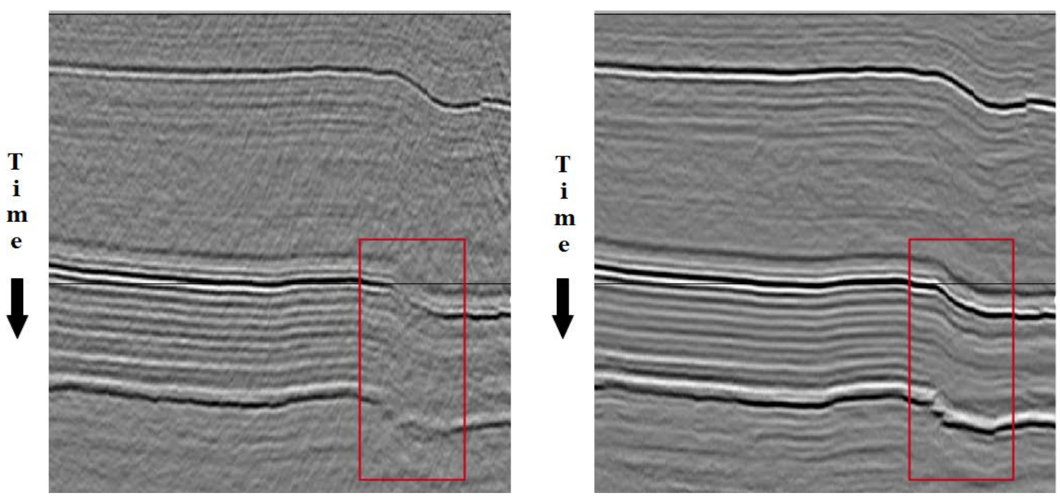

Fig.4. Comparison of images from classical (left) and full azimuth imaging (right). Deep target can be well seen on the right, opposite to the result of Kirchhoff algorithm (left).

Work of the FAZADI method in local angle domain, i.e. local system of coordinates following local changes of the multiattribute subsurface model (for VTI + HTI the model consists of 6 cubes: V, dip, ε, δ, Δα, φ) ensures advantage of precise estimation of local values of seismic attributes. That, in turn, yields high-resolution volumes of interval attributes ready for conversion into geomechanical parameters for reservoir characterization. Comparison, in Fig.5, of the conventional, PreSTM-based map of effective azimuthal anisotropy (left. arrows – orientation, colour – intensity) to the map of interval azimuthal anisotropy from FAZADI (right) reveals new level of precision brought by the novelty method. Comparison of seismic results to reference measurements from vertical and horizontal well data (Fig.6) proves their consistency.

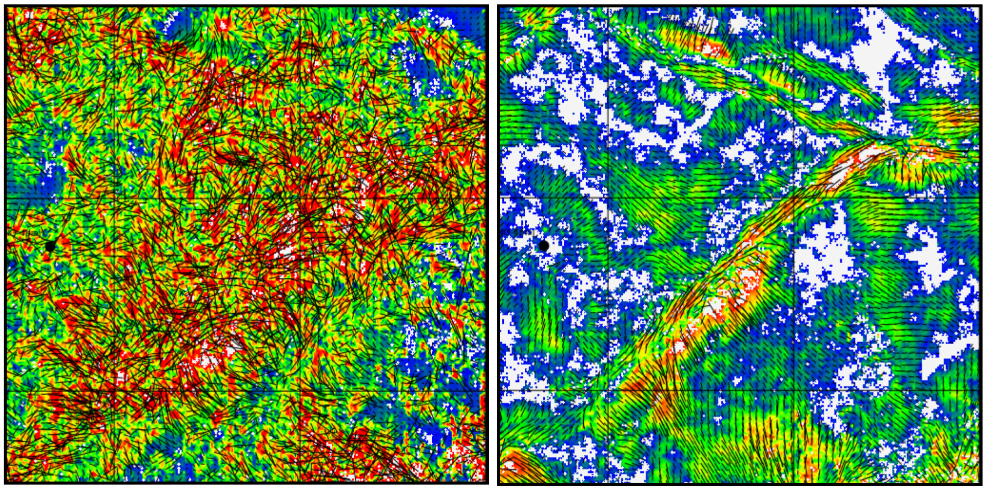

Fig.5. Comparison of HTI anisotropy maps: effective from sectored PreSTM (left) to interval one from FAZADI imaging (right).

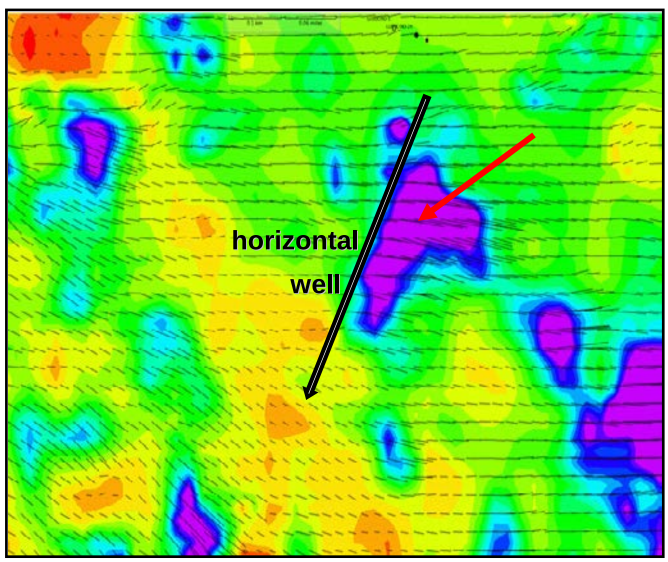

Fig.6. Azimuthal anisotropy map (colour for intensity; small arrows for orientation), derived from full azimuth seismic for target interval is consistent with HTI estimation from vertical well, indicates some sweet spots, and identifies bodies resistant to hydraulic fracturing (violet). Presence of the body marked with red arrow is consistent with observations from hydraulic fracturing.

Advantage of the FAZADI imaging to derive diffraction image from classical seismic data is illustrated in Fig.7. Diffractivity volume provides new geologic information, not available from classical methods.

Conclusions

When preliminary assessment of phenomena observed in the time-domain processed seismic data, and complexity of the overburden geology indicate that classical techniques are insufficient to solve defined

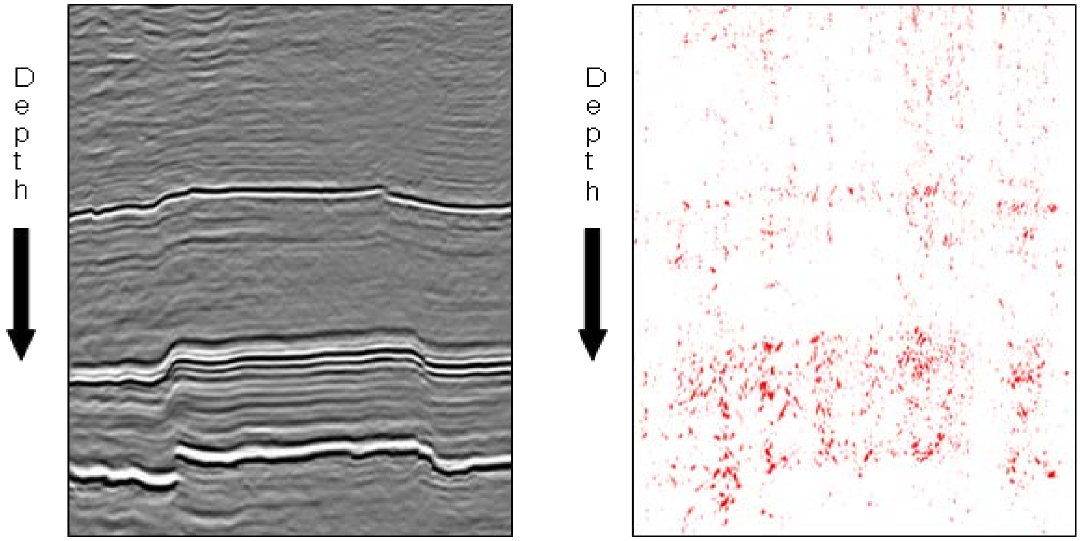

Fig.7. Example of two images (reflection component on the left, and diffraction component on the right) separated from one input seismic volume provides different, but complimentary information.

questions – it is time to consider full azimuth seismic and application of the FAZADI technology. It is relatively slow, expensive, and needs dedicated acquisition, but delivers added value of top quality images and seismic attributes precise enough for: unconventional or conventional reservoir characterization, steering horizontal drilling, and also imaging conventional geological targets: overthrusts, bodies of irregular surface, e.g. reefs, targets obscured by complex overburden.

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Earth Study 360® is the technology developed by Paradigm®.

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