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Diffraction Imaging in North-Western Poland, A 3D Land Seismic Case Study

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Summary

Seismic diffraction imaging (DI) is applied to a 3D seismic survey acquired in the Trzebiatow Faulted Zone of West Pomerania located in the Permian Basin, North-Western Poland. 3D seismic data underwent Kirchhoff Pre-Stack Depth Migration (PreSDM) in offset domain, then extended to angle-domain full-azimuth (FAZ) CRAM PreSDM, and finally DI applied as a development experiment on a 3D sub-volume. The DI was targeted to provide details of the complex network of faults. Another technical objective was the application of DI to increase structural resolution with respect to standard seismic imaging. Comparison of the novelty result and the standard images is discussed. Of the several advantages of the novelty imaging, a couple proved to be particularly valuable for geologists. Both, existence of faults, and positioning of events are key to the development assessment of the reservoir structure and were solved.

Introduction

A potential of higher resolution in seismic images, much higher than the λ/4 limit attributed to standard reflection processing was noticed several years ago (Khaidukov, Landa and Moser, 2004). That pioneered the modern interest in diffractions. A next milestone was marked when the full azimuth software, angle imaging in depth, was launched. In addition to improved reflection imaging, it opened the option to generate diffraction images. The relevant theory has been introduced by Koren, Ravve and Levy (2010), followed by practical applications (e.g. Kowalski et al., 2014), which focused on reflection full azimuth (FAZ) PreSDM. Although the idea of seismic imaging using diffraction had already been discussed since the early 1950s, the practical use of seismic diffraction came to the forefront with FAZ acquisition and imaging technology. The effectiveness of diffraction imaging (DI) was first recognized offshore, and it is now being applied routinely (Moser et al, 2020). Results of presented application of both reflective and diffractive components of the wave field suggest, it make an interpretation impact. Presented case shows evidences of such impact, seen for example in figures 3, 4, and 5.

The results presented here for land seismic DI case are of experimental nature. The idea was benefiting of production Kirchhoff depth migration, check ability of the diffraction technique based on CRAM, and essentially improve detailed imaging of complex faults' structures. Expectation to improve imaging of complex faulting pattern has been a permanent challenge of seismic processing projects performed in Permian Basin in Poland. Today, advances in processing, and availability of the appropriate software, make the job feasible even onshore. The complementary pieces of information from two components: reflection and diffraction, convey the full interpretation detail contained in the recorded P-wave seismic data. Examples of images brought by FAZ DI in depth, follow.

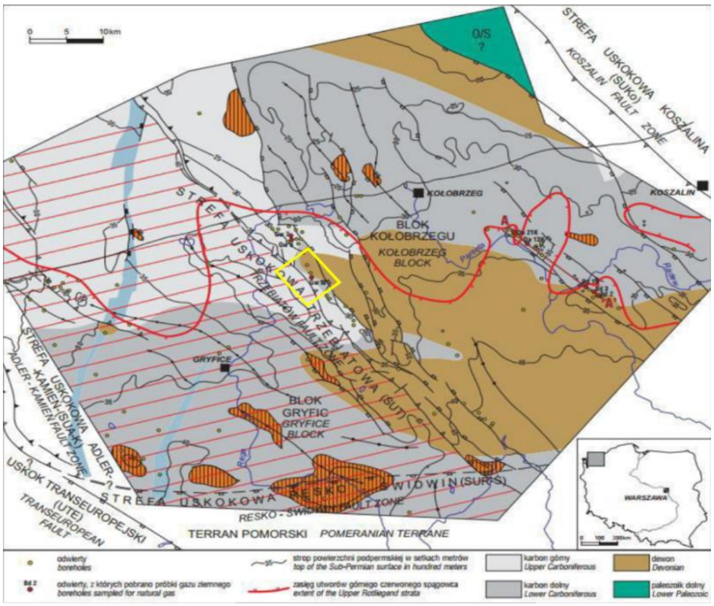

__Figure 1__ Location of the DI experiment (yellow rectangle) is in the Trzebiatow Faulted Zone, in West Pomerania. After: Pokorski, Modlinski, 2007. Geological Map of West Pomerania.

Geological setting

The area of discussed survey, shown in Figure 1, is located in Trzebiatow Fault Zone. The target interval is Zechstein, Rotliegendes, and Carboniferous, and is marked in Figure 2. The overburden and target, the both intervals feature complex structure: steep dip horizons, laterally and vertically developed fault structure with many of them being strike-slip faults. That sets serious imaging challenge for prestack depth migration. The existing archive images were obtained with isotropic time migration followed by vertical-stretch time to depth conversion. Therefore, the core of recent, production imaging was VTI Kirchhoff prestack depth migration. A sample of PreSDM compared to PreSTM can be seen in Figure 3, panels B and A respectively.

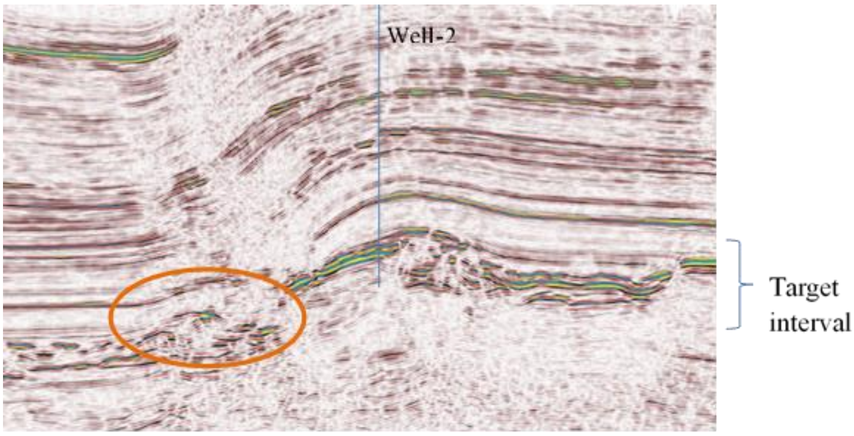

Figure 2 *VTI Kirchhoff time-migrated, SW-NE section of the Trzebiatow Faulted Zone confirms presence of numerous steep dip horizons, faults, or breccias (oval area), and widespread evidence of fractures and discontinuities caused by these factors.*

Among main geological tasks to be solved are: (1) getting improved imaging with continuity gaps filed up, (2) detailed positioning of the critical faults to explain reservoir characteristics observed in existing wells, (3) improved resolution of seismic image. To meet these expectations, beside the VTI Kirchhoff PreSDM based on model from FAZ tomography, the new technology of diffraction imaging (DI) was applied as an extra, research work. The motivation for the presented work, were the results of recent applications of DI to other land seismic surveys (e.g. Quintero et al., 2020).

Methodology: time domain processing, reflection depth imaging, and diffraction imaging

The time-domain processing, preceding depth domain imaging was guided by log data available from several wells. Especially, the recently logged Well-2 marked in Figure 2, represents high quality data, and served as reliable reference for processing in both time and depth. This helps to establish optimal focusing of the standard migration image, as well as the subsequent diffraction images. Up-to-date processing methods have been applied: denoising based on advanced techniques, wavelet standardization and shaping, spiking deconvolution with parameters selected from tests of matching to synthetic seismograms, reconstruction of amplitude relations, multiples' removal with adaptive subtraction of model estimated in tau-p domain (this step was confined to velocity analyses to avoid attenuation of diffraction contents), synthetic seismograms-based guidance to *iterative separation statics-velocities*. Furthermore, VTI model building for depth imaging went through an iterative procedure before entering the DI stage. The standard, i.e. reflection PreSDM compared to legacy PreSTM brought improved positioning of events, as shown in Figure 3. Analysis of core data from Well-2 indicates that it is crossing the down thrown wing of fault as imaged by PreSDM (Fig.3B). The PreSDM used the VTI model, then used for DI.

The DI workflow consisted of the following steps outlined in (Kowalski et al., 2014), and implemented by (Pelissier et al., 2017): 1. extraction of reflector local dip and reflector local azimuth from the VTI Kirchhoff PreSDM (least squares dip estimation method), 2. FAZ CRAM PreSDM with migration output sorted into directional gathers. This step involves specific choices of parameters in order to obtain an optimal preservation of diffraction content, 3. Tapering and stacking of specularity gathers. The specularity taper design involves a careful sampling of the Fresnel zone and selecting which part of the Fresnel zone should enter into the diffraction image. Two characteristics make diffraction waves an efficient wavefield component to image complex tectonics: enhancement of image resolution, and full azimuth illumination of the imaged target. Generation of diffraction waves does not need a large piece of reflector, comparable to size of a Fresnel zone. Down in Earth they are created locally, at small pieces of even very steep discontinuities. Opposite to the classic output of the FAZ reflection PreSDM: 2D CIGs in (offset-depth) domain, the DI output contains directional gathers having 3D structure (angle, azimuth, depth).

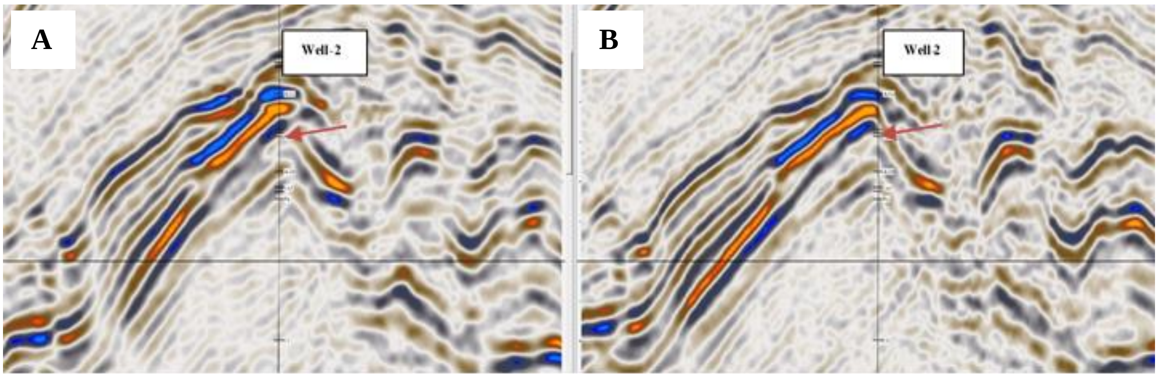

Figure 3 *Comparison of Well 2 position plotted on: (A) PreSTM vs (B) PreSDM.*

A representative comparison of the specular (4A, best P-wave reflection) migration image with the diffraction image (4B) is provided in Figure 4.

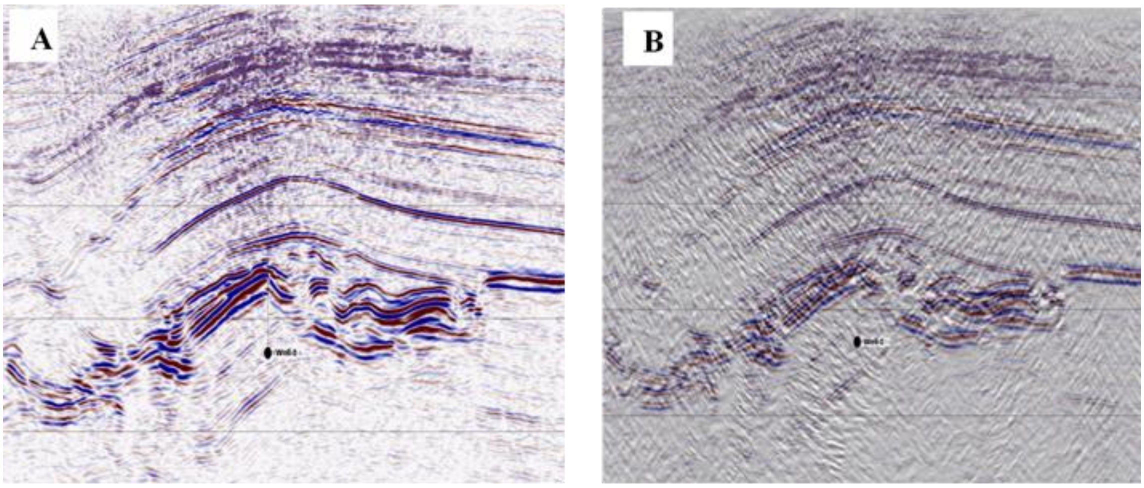

Figure 4 *Specular image (A) of selected vertical section, compared to diffraction image (B) superimposed on specular image background.*

Summary and Conclusions

The demonstrated DI experimental work was an extension of the ongoing reflection imaging project. It demonstrated that the result of classical interpretation, based on azimuth-blind, offset-domain PreSDM can be upgraded with FAZ, angle-domain PreSDM. The next level of advancement DI brings even further, significant interpretive value to geologists. The scope of the Part 1 of the DI experiment was limited to generation of the raw diffraction cube (section seen in Fig.5B). Part 2 of this experiment is intended to involve advanced customization to interpretation (CTI), which is capable to deliver images refined by exploitation of azimuthal variability of diffraction.

Recent projects provide more examples of land DI, (for example Quintero et al., 2020), while for details on CTI refer to (Moser et al., 2020). Interpretation of the reflection component, obtained from standard offset-domain Kirchhoff PreSDM, brought documentation of extensive faulting and folding tectonics in the area of the Trzebiatow Faulted Zone. The DI extension delivers much more detailed images (Figure 5B) of discontinuities than reflection images do, therefore enables reliably solve important geological puzzles of this area, and better image the reservoir in particular. Currently, the interpretation of the results of DI method requires considerable time. However, emerging machine learning solutions are capable to make interpretation process of the diffraction component faster and more objective . The presented DI application confirms usefulness of DI method to reduce intrinsic risk of the exploration decisions. Possible onshore-specific constrains need further investigation.

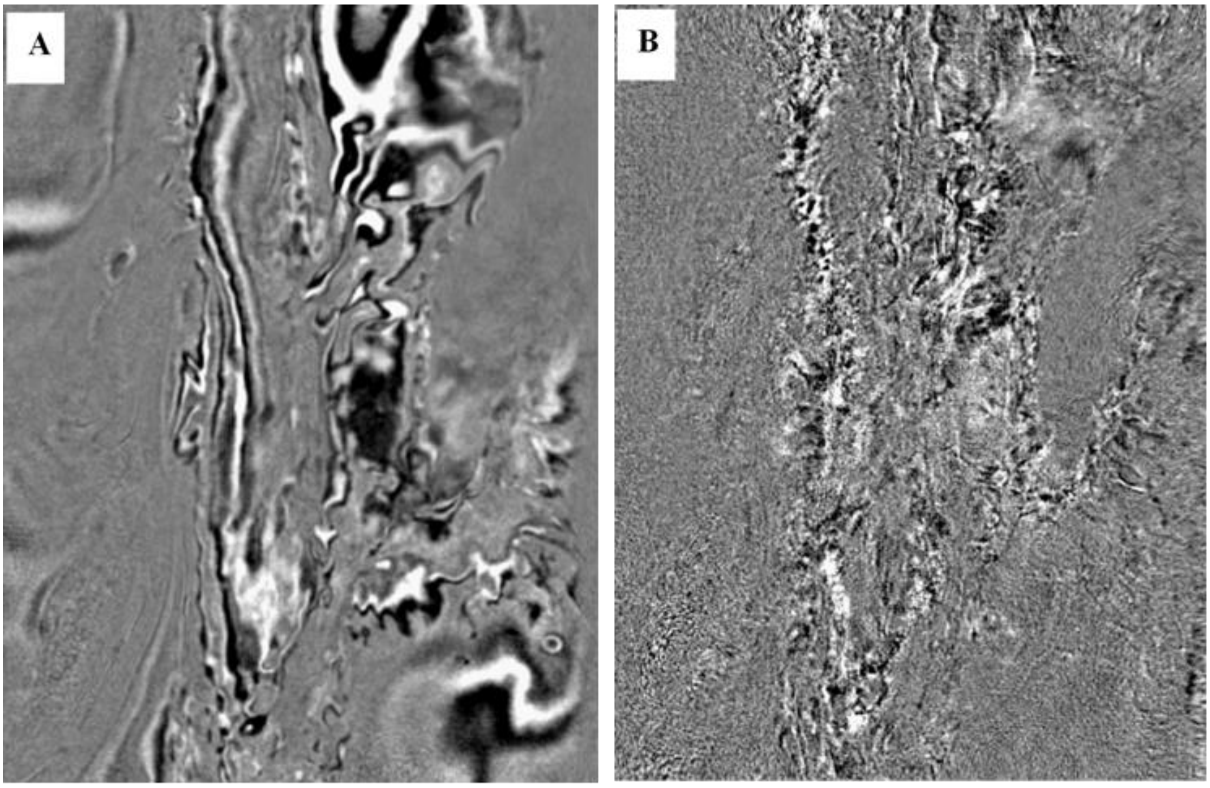

Figure 5 *Depth slice of the raw diffraction images. Comparison of specular (A) and diffraction (B) components. Detailed tracks of small size discontinuities are visible in panel B.*

Acknowledgements

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