PARIS 2017

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Diffraction Imaging and Well Planning – A Case Study in the Dutch North Sea

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Summary

Diffraction imaging provides a powerful addition to the standard processing suite normally available to the seismic interpreter. Based on a case study from the Dutch offshore we demonstrate that diffraction imaging allows the interpreter to significantly improve the accuracy and uncertainty of fault positions and better define the outline of gas pools.

Introduction

Diffractions are created at discontinuities such as faults, channel edges, pinch-outs (stratigraphic, hydrocarbon wedge zones) and fractures. Unlike reflections, diffractions do not satisfy Snell's law. During processing, diffractions usually are suppressed and reflections enhanced. The DI (diffraction image) data cube is created by doing the opposite and thus with relatively limited additional effort and at limited cost can be obtained in addition to the standard processing sequence. DI results in significantly enhanced positioning accuracy and reduced uncertainty because of the zero-width Fresnel zone at target depth and favourable tuning properties. In addition, DI provides superior illumination of the subsurface targets. It should be noted that the improvements from DI are not obtained using classical discontinuity attributes (e.g. variance, coherency), since DI operates pre-stack and pre-migration, rather than post-stack/migration (see Veenhof et al. 2014, Sturzu et al. 2014, Pelissier et al. 2015 and Moser et al. 2016a, where further references are found). Moser et al. (2016b) apply diffraction imaging to the monitoring of well drilling.

The case study presented is about a narrow elongated gas pool in the Dutch offshore. For definition of drilling targets and volumetric estimates, precise definition of the crest of the structure is essential. The crest is defined by a boundary fault, the imaging of which on the available PSDM processed seismic is hampered by the complex tectonics. The resulting interpretation uncertainty adds to the inherent lateral uncertainty from the Fresnel zone. Classical discontinuity attributes are shown not to enhance the accuracy of the interpretation of the fault. DI and its derived attributes however do significantly enhance accuracy and have been confirmed by the drill bit. In addition, the characteristics of the DI attribute suggest that in this particular case it may constitute a hydrocarbon indicator, tentatively labeled as D(H)I.

Diffraction Imaging

Diffraction imaging is a process similar to pre-stack depth migration, with the difference that contributions to specular reflection are suppressed in the innermost migration loop. The benefits of diffraction images are twofold: enhanced resolution (or even super-resolution) of small-scale structural details and superior illumination. This is illustrated by the diagram in Figure 1. For reflections (Figure 1, left), the Fresnel zone is typically at its widest at the reflecting interface and hence detail is smeared out. In addition, the illumination of the reflector depends critically on the data acquisition parameters. In contrast, for diffractions (Figure 1, right) the Fresnel zone is smallest at the diffracting point and hence image resolution optimally preserved; moreover since diffractions are scattered in all directions, the imaging of diffractions is less sensitive to acquisition limitations.

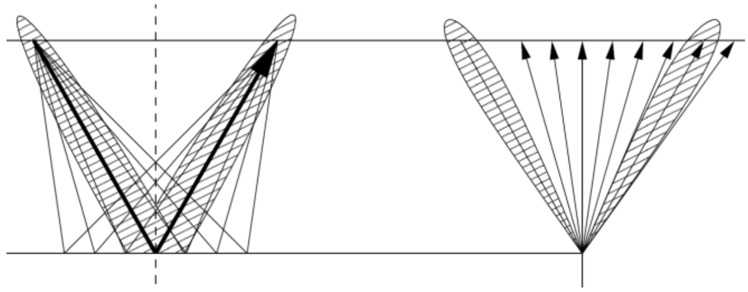

Figure 1 *Ray paths and Fresnel zones (hatched areas) of reflection and diffraction (left/right).*

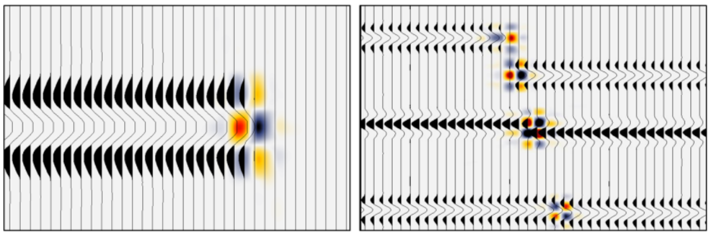

Figure 2 *Reflection and diffraction image (wiggles/colour) of a single edge (left) and fault system with decreasing throw (right). Note the multipole character of the diffraction image (left), its tuning properties and ability to image small throws (right).*

A particular property of diffractions and diffraction images is the polarity reversal at reflector edges. This is illustrated in Figure 2. The standard PSDM reflection image occurs along the impedance contrast and terminates at the edge, while the diffraction indicates the egde location by a multipole image consisting of side lobes with alternating polarity (Figure 2, left). With ever decreasing throw (Figure 2, right) the fault becomes subseismic and the interpreter will at best interpret a flexure. The DI proves the presence of fault throw, and accurately positions the fault free from the lateral inaccuracy due to the Fresnel zone affecting the wiggle trace.

The simple pinch-out model of Figure 3 illustrates another useful application of the high-resolution of the diffraction image. For the regular PSDM image, the uncertainty in the location of the pinch-out (denoted by the red bar) is considerable due to tuning, for the diffraction image it is dramatically reduced.

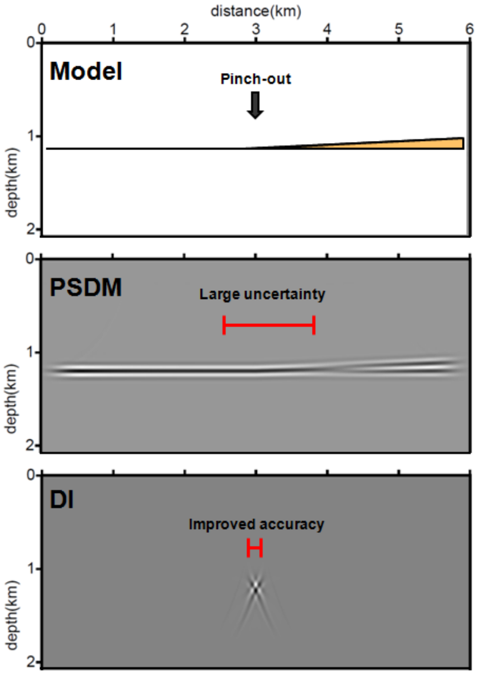

Figure 3 *Pinch out, model, PSDM and diffraction image. Note the improved accuracy of the pinch-out location on the diffraction image.*

Case study

The case study presented is about a gas pool contained in a narrow elongated (~300 by ~2500 m) footwall fault/dip closure. Given the limited width of the gas pool, reducing any uncertainty associated with the boundary fault is important in view of the narrow areal drilling window and the significant impact of the fault position on volumetrics. The gas pool is covered by a 3D data set that has been recently reprocessed, including pre-stack time and depth migration (PSTM/PSDM). From the latter a DI cube is available.

Definition of the crest of the gas pool - as defined by the boundary fault - is hampered by complex tectonics with several phases of faulting including transpression (Figure 4). This complexity does not allow full capture of the fault details in the PSDM image and thus leaves room for considerable interpretation freedom. The lateral spread of the alternative fault interpretations amounts to some 200 metres. In addition, the inherent lateral uncertainty of the PSDM (Fresnel zone) should be taken into account which adds another 50-75 metres for the depth and velocity range under investigation. Prior to embarking on the DI route, we investigated classical discontinuity attributes (e.g. variance, coherency) and observed that these do not allow accurate fault positioning (Figure 5, left).

At the intersection of the boundary fault with the gas bearing reservoir, juxtaposition against shales occurs. Here a strong diffraction effect is expected from the contrast between the gas reservoir and the shales. Indeed a strong diffraction is observed, a diffraction that precisely defines the very crest of the gas pool (Figure 4). In map view, these strong diffractions can be seen to line up coherently providing a sharp outline of the intersection of the boundary fault and gas reservoir (Figure 5, right). This highly accurate image of the gas pool's crest is seen to be positioned at the very edge of the most conservative (most structurally inbound) fault interpretation from PSDM and has been confirmed by drilling results (Figure 4).

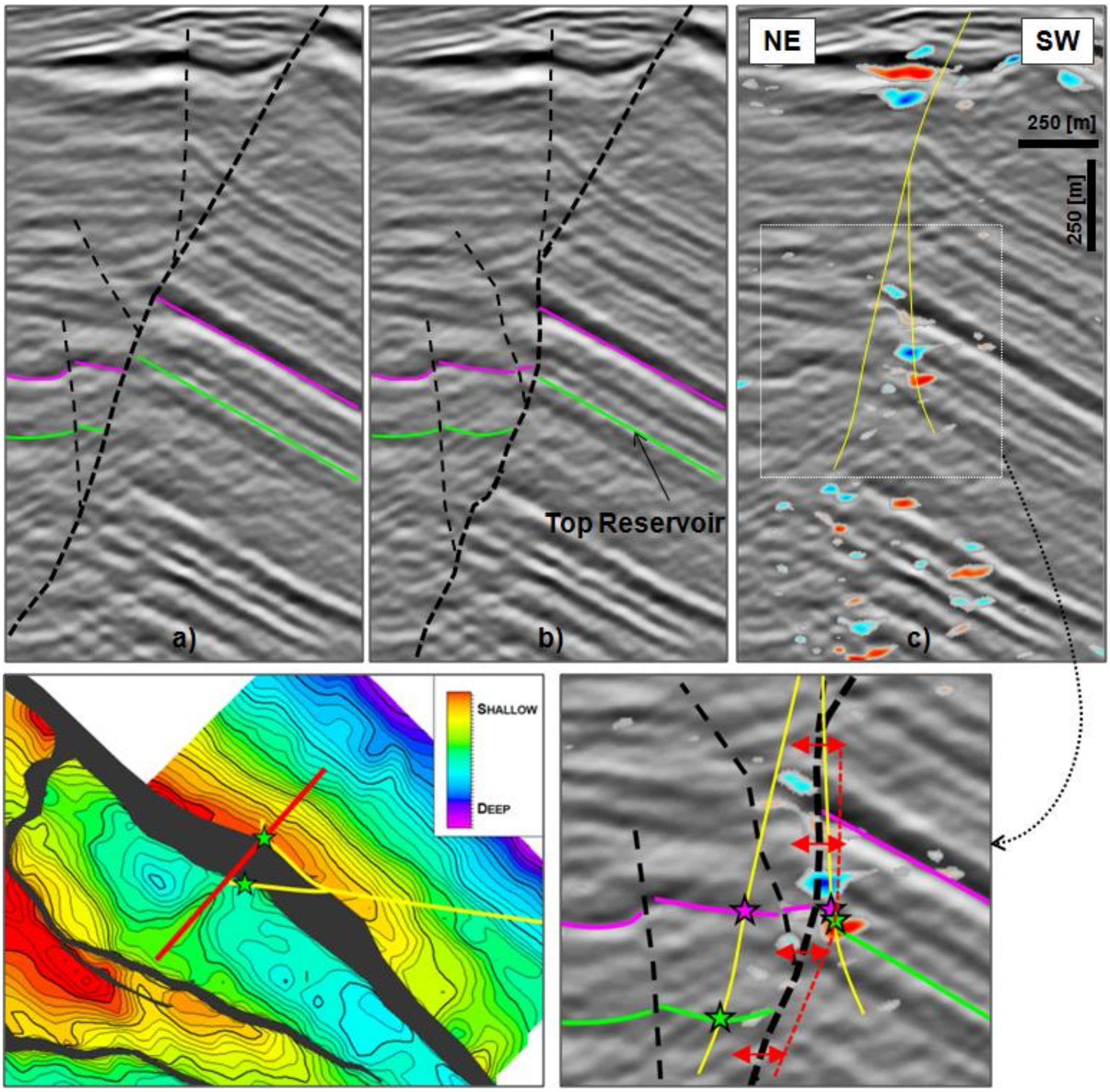

Figure 4 *PSDM sections across gas pool with alternative interpretations (a and b) and with DI overlay (c). Note that well results show that the boundary fault is accurately depicted by DI and occurs at the very inboard edge of the fault interpretation b) aggregated with Fresnel zone. Legend: green = top reservoir, purple = regional marker, stars = well penetrations (colours as for markers), dashed black = extreme fault interpretations, dashed red with arrows= Fresnel zone, yellow = well track. For DI: red = positive, blue = negative. For PSDM: black = trough = AI increase.*

The dimming of the DI attribute along strike towards the south-east is tentatively attributed to reaching the water leg. This is where one would expect the contrast between reservoir and juxtaposed shale to be less. It appears that DI data in this case could constitute a powerful direct hydrocarbon indicator – D(H)I – that further aids in fine tuning GIIP estimates. Similar dimming towards the north-west is probably influenced by data edge effects and therefore might be an artifact. The potential use of DI as a direct hydrocarbon indicator deserves further investigation and deployment.

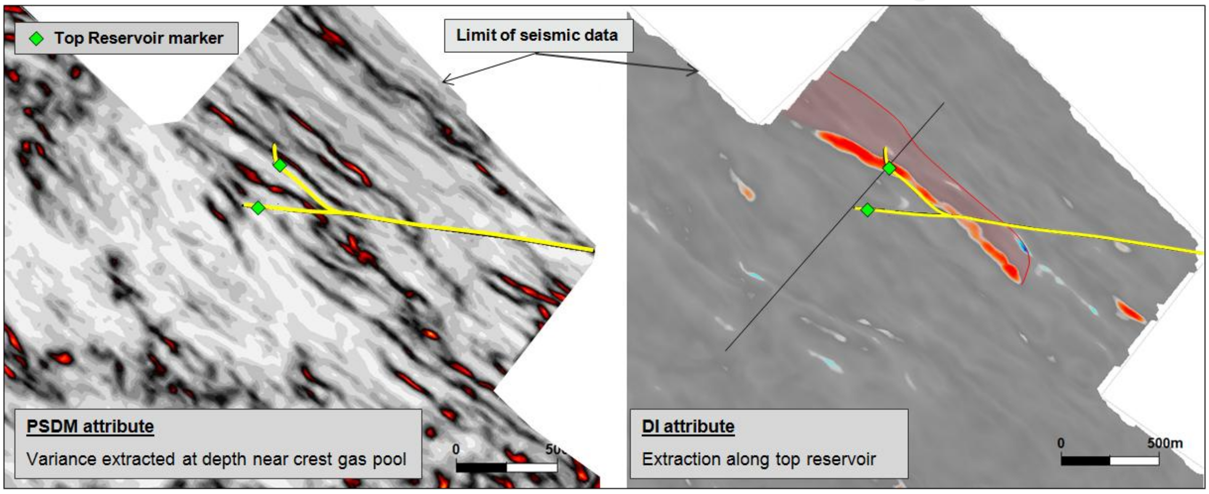

Figure 5 *Comparison of PSDM attribute (variance) and DI attribute. Boundary fault along crest of gas pool is clearly defined on DI attribute where the gas bearing sandstone is offset against shale in the hanging wall. The dimming of the DI attribute towards the south-east is tentatively attributed to reaching the water leg. Similar dimming towards the north-west could be influenced by data edge effects. Legend: Black line = location of section in Figure 4. Yellow line = well track. DI attribute: red = positive, blue = negative. Red contour is possible extent of gas as suggested by DI attribute and structural map at top reservoir.*

Conclusions

In a case study from the Dutch North Sea, the super-resolution of DI has been confirmed by drilling results. Use of DI for fault delineation allows fine tuning of drilling windows and more accurate structural definition resulting in the reduction of exploration risks and more precise volumetrics. The presented case study shows that DI under certain conditions can serve as a direct hydrocarbon indicator, tentatively labeled as D(H)I.

Acknowledgements

We wish to thank Z-Terra staff for the processing of the seismic data (Devon Dowell, Alexander Mihai Popovici, Ioan Sturzu).

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