Structural and Stratigraphic Diffraction Imaging - applications on the Zhao Dong field, Bohai Bay, China

T.J. Moser, MGS, M.A. Pelissier, C. Yu, Dagang Zhaodong Oil Company of PetroChina, A.M. Popovici, I. Sturzu, Z-Terra Inc.*

SUMMARY

We present structural and stratigraphic diffraction imaging and show how both are beneficial to development of the Zhao Dong field. Structural diffraction imaging enhances the details of the complex faulting at both the fault block and reservoir scales. Stratigraphic diffraction imaging resolves the internal geometries of a channel system better than regular reflection imaging. Volcanic features are also better resolved by diffraction imaging.

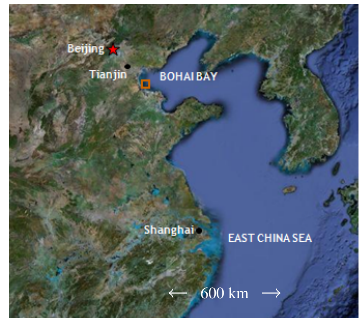

Figure 1: Location map of Bohai Bay and Zhao Dong field in East China Sea.

INTRODUCTION

Zhao Dong is a mature oil field located in the northwest of China's Bohai Bay (see location map, Figure 1). The petroleum geology of Bohai Bay has been extensively documented. Castellanos (2007) provides an in-depth study of the tectonic history and stratigraphy of the Zhaodong field and Bohai Bay and provides ample references. The field is structurally compartmentalized into various fault blocks associated with a strike slip and oblique slip faulting (Figure 2). The field is also highly compartmentalized stratigraphically, resulting in over 80 productive pools. These pools occur over a range of stratigraphic intervals in the Cenozoic and Mesozoic. The depositional environments range from fluvial to lacustrine and deltaic. At each stratigraphic level, the pools are typically separated by structural and/or stratigraphic barriers. The seismic data are used for well planning and real time geosteering in drilling horizontal producers. The fine detail of the sand body geometry and connectivity has important implications for development and production. Many pools are beyond the conventional resolution limit, with the reservoir thickness less than the tuning thickness. Our approach involves extending the resolving power of the seismic value by using diffraction imaging to complement the conventional reflection imaging. We demonstrate that the diffraction imaging brings an additional level of detail for both the stratigraphic and structural features in Zhao Dong.

DIFFRACTION IMAGING WORK FLOW

Seismic diffractions are the response of subsurface discontinuities. Unlike reflections, which follow Snell's law and are subject to illumination constraints, edge and tip diffractions are generated by line and point sources, without constraints on illumination. In addition, diffractions allows very high, or even super-, resolution imaging of structural details not normally visible on regular pre-stack depth migration (PSDM) images. This makes them a good candidate to image the faults, fractures, channel systems and volcanic features present in Zhao Dong. The work-flow for diffraction imaging used here is basically similar to the one presented in Moser and Howard (2008) and consists of the following steps. First, the standard depth imaging and migration velocity building process is completed to obtain a high-quality regular (PSDM) image. Second, from this regular PSDM image a reflector dip is extracted. In the third step, the migration is repeated with the same velocity and input data, but with a migration kernel modified to suppress specular reflections. A key ingredient in the diffraction imaging is the specularity tapering (Sturzu et al., 2013), which allows to generate diffraction images with different degree of structural detail. The specularity taper is specified by a percentage: the closer to 100 %, the weaker the taper, and the closer the resulting diffraction image resembles the original regular PSDM. Following Pelissier et al. (2015), in this paper we study the interpretation impact of ultra-weak taper diffraction images, which have subtle but essential differences compared to the regular PSDM.

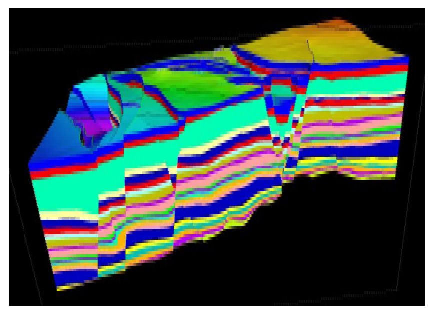

Figure 2: Zhao Dong geomodel.

FAULTS AND FRACTURES

A seismic section illustrating the flower structure typical of Zhao Dong is shown on the PSDM and diffraction images in

Figure 3. The corresponding depth slices are shown in Figure 4. The diffraction imaging provides a clear benefit in the resolution of the fine detail of the faulting on the depth slices. The boundaries of the flower structure and the dense faulting within it are more clearly imaged by applying the various specularity tapers. (Note that in all these displays, gridlines represent 2500 m in/cross-line increments and 1000m depth increment.)

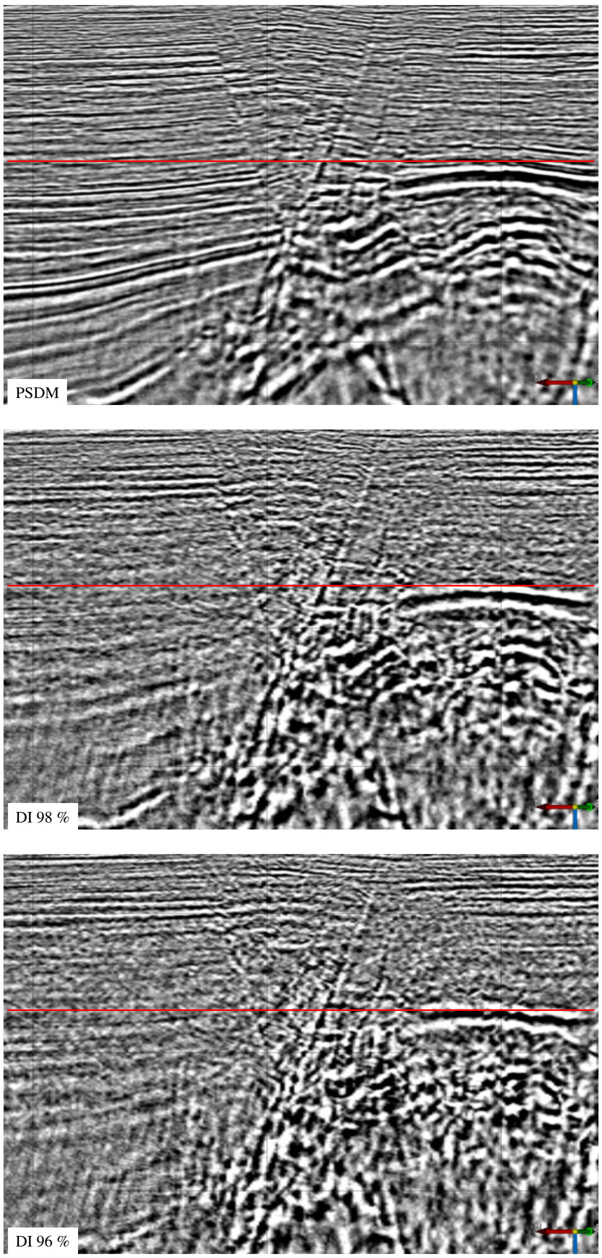

Figure 3: Inline section showing negative flower structure on PSDM and diffraction images. The red line indicates the depth of the depth slices shown in Figure 4.

For the deeper reservoirs, in the Mesozoic, fracture porosity is a critical factor in production. The ability of the diffraction imaging to detect very small scale faults and fractures is

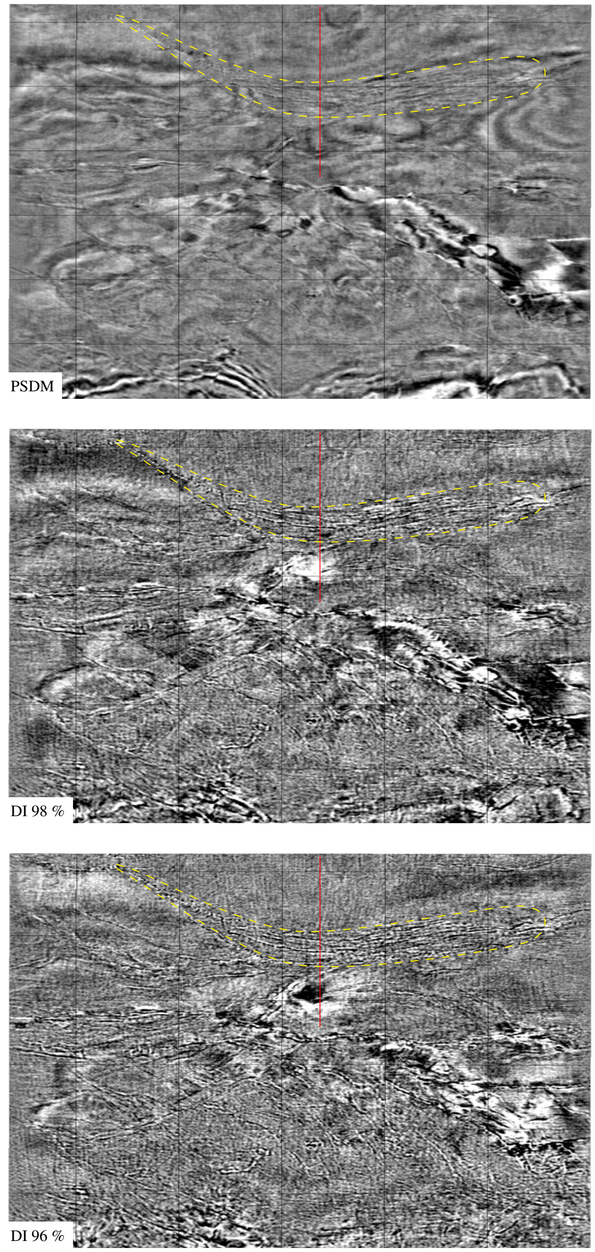

Figure 4: Depth slices for PSDM and diffraction images. Position of inline shown in Figure 3 indicated by the red line. The flower structure is outlined in yellow.

illustrated by comparing the PSDM with a diffraction image produced using a mild specularity taper (Figure 5).

VOLCANIC PIPES

The various periods of rifting in the tectonic history of Bohai Bay were associated with extensive volcanic activity (Liu et al., 2012, Wu et al. 2010). The Zhao Dong dataset includes several examples of volcanic features. Several publications (Løseth et al. 2011, Grasmueck et al. 2015, Moser et al.

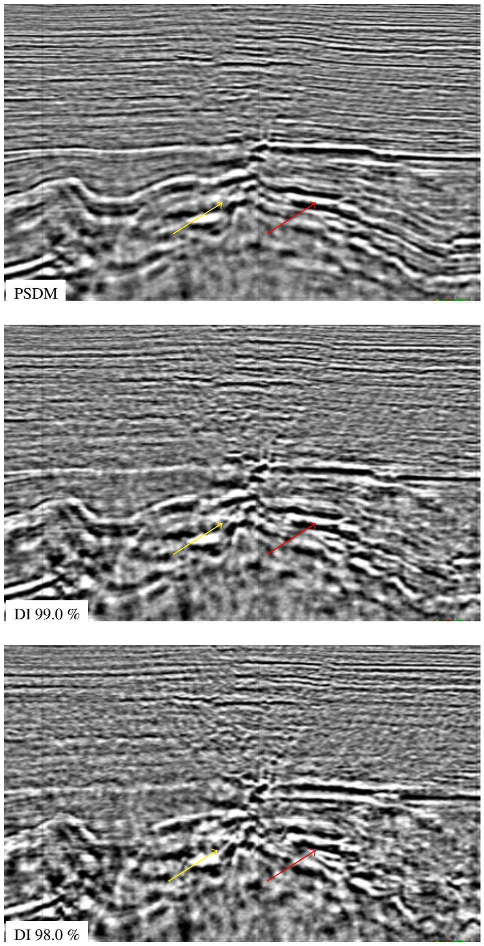

Figure 5: PSDM and diffraction images at 99 % and 98 % of a crossline, showing densely faulted/fractured Mesozoic reservoir (yellow) and continuous reflector (red).

2016) have pointed out that vertical intrusions, like injectites, karst pipes and volcanic pipes, have a prominent diffraction response, while their geometry is unfavorable for regular reflection processing. The reason is the lack of coherent reflection response and, due to the vertical orientation, illumination issues with respect to normal surface acquisition.

CHANNELS

Although diffraction imaging is most commonly associated with the imaging of faults and fractures, this technology has great potential for imaging the fine detail of depositional systems. This is especially true of channel systems. There are several reasons for this. Firstly, the channel edges give rise to diffractions; a channel edge is a type of pinchout and is therefore associated with an edge diffraction. Moreover when the channel is meandering it gives rise to curved edge diffraction. Secondly, sub-wavelength channel features give rise to diffractions. In this case, the conceptual model is that of a line diffractor. Finally, the specularity tapering process can accentuate the differential compaction associated with channel systems. A mild taper preserves the reflection energy but magnifies small differences in travel time.

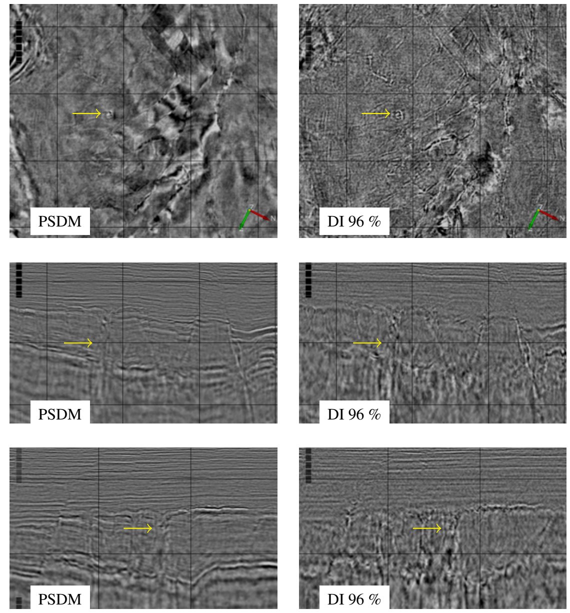

Figure 6: Volcanic pipe, indicated by yellow arrow. Top to bottom: depth slice, in- and crossline section. Left: PSDM, right: DI 96%.

The proof of concept for stratigraphic diffraction imaging is illustrated by Fomel, Landa and Taner (2007) using numerical modeling and subsequent diffraction imaging of a channel system. The diffraction image presented by them clearly slows the migration pattern (swing and sweep) of the channel system, whereas this is ambiguous in the conventional imaging. A real data example illustrating the stratigraphic resolution of diffraction imaging was given by Tyiasning et al. (2016).

The stratigraphic resolution of diffraction imaging for Zhao Dong is illustrated in Figure 7a-d. The channel feature was detected using the Thalweg tracker method detailed in Pelissier et al. (2016). The results presented in this work represent the early phase of a pilot workflow for the characterization of stratigraphic features using the PSDM and a range of diffraction image volumes with various specularity tapers. Figure 7a is the horizon amplitude of a channel feature on the PSDM. The feature is located on a tilted fault block; the dip is indicated by the structural contours. Figure 7b shows the horizon amplitude following the application of a very mild specularity taper of 99.95%. Here it can be seen, in the area highlighted, that the main channel consists of two elementary channels. This level of extra detail is important in horizontal well planning and seismic assisted geosteering; we can expect a change in facies and an additional risk of sand exit in a well drilled across the two elementary channels. Figure 7c shows the response of a slightly stronger taper of 99.50%. In both Figures 7b and 7c we observe the increased resolution of small channel features on the flanks of the main channel. It is clear from these examples that diffraction imaging can help to define the internal geometry and connectivity of dispositional systems.

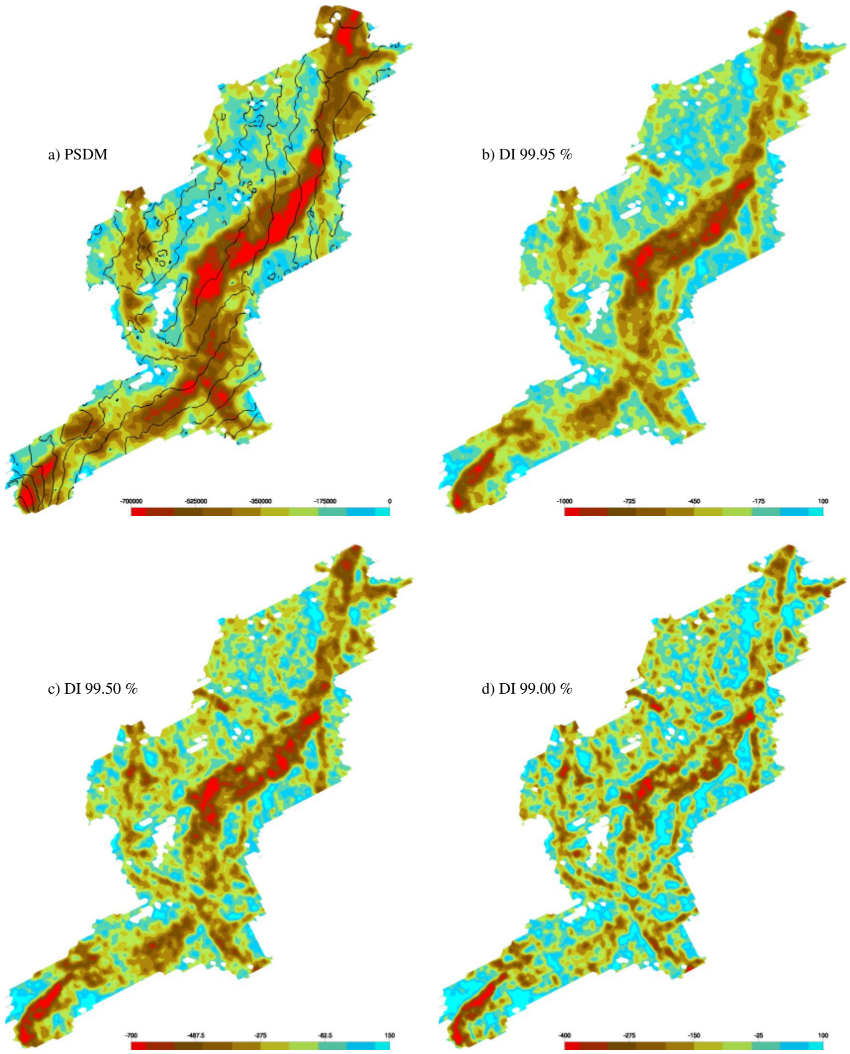

Figure 7: Channel images. Regular PSDM (a, with 10 m depth contours) and diffraction images with different specularity tapers, as indicated by percentages (b-d).

For reference, we include a diffraction imaging with a relatively stronger taper of 99 % (Figure 7d).

CONCLUSIONS AND OUTLOOK

We have demonstrated that structural as well as stratigraphic diffraction imaging is effective in Zhao Dong. The structural imaging enhances the details of the complex faulting at both the fault block and reservoir scales. The volcanic features in Zhao Dong are also better resolved by diffraction imaging. We have illustrated the potential of stratigraphic imaging to resolve the internal geometries of a channel systems. Taken together, the structural and stratigraphic diffraction imaging has the potential to benefit the field development of Zhao Dong and other Bohai Bay fields. The improved resolution is obtained from the diffracted wavefield arising from sub-wavelength subsurface features. From first principles, this method has greater resolving power than attributes derived from post-processing on the conventional PSDM.

Our future work will focus on further developing workflows for the simultaneous interpretation of PSDM data along with suites of diffraction images taken over a range of specularity tapers, and application of these workflows in field delineation and development.

ACKNOWLEDGEMENTS

We would like to thank the Dagang Zhaodong Oil Company of PetroChina for permission to show the Bohai Bay seismic data.

EDITED REFERENCES

Note: This reference list is a copyedited version of the reference list submitted by the author. Reference lists for the 2016 SEG Technical Program Expanded Abstracts have been copyedited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

REFERENCES

Castellanos, H. A., 2007, Sequence stratigraphy and tectonics of the Guantao and Minghuazhen formations, Zhao Dong Field, Bohai Bay, Eastern China: Ph.D. thesis, University of Texas at Austin.

Fomel, S., E. Landa, and M. T. Taner, 2007, Poststack velocity analysis by separation and imaging of seismic diffractions: Geophysics, **72**, no. 6, U89–U94, http://dx.doi.org/10.1190/1.2781533.

Grasmueck, M., T. J. Moser, M. A. Pelissier, J. Pajchel, and K. Pomar, 2015, Diffraction signatures of fracture intersections, Interpretation, **3**, SF55–SF68, http://dx.doi.org/10.1190/INT-2014-0086.1.

Liu, J., P. Wang, Y. Zhang, W. Bian, Y. Huang, H. Tang, and X. Chen, 2012, Volcanic rock-hosted natural hydrocarbon resources: A review, *in* K. Nemethm, ed., Updates in volcanology — New advances in understanding volcanic systems: InTech.

Løseth, H., L. Wensaas, B. Arntsen, N. M. Hanken, C. Basire, and K. Graue, 2011, 1000 m long gas blow-out pipes: Marine and Petroleum Geology, **28**, 1047–1060, http://dx.doi.org/10.1016/j.marpetgeo.2010.10.001.

Moser, T. J., B. Arntsen, S. Johansen, E. B. Raknes, and S. Sangesland, 2016, Seismic diffraction response from boreholes: 78th Annual International Conference and Exhibition, EAGE, Extended Abstracts.

Moser, T. J., and C. B. Howard, 2008, Diffraction imaging in depth: Geophysical Prospecting, **56**, 627–641, http://dx.doi.org/10.1111/j.1365-2478.2007.00718.x.

Pelissier, M. A., T. J. Moser, L. Jing, P. de Groot, A. Sirazhiev, I. Sturzu, and A. M. Popovici, 2015, Diffraction imaging of the Zhao Dong Field, Bohai Bay, China: 77th Annual International Conference and Exhibition, EAGE, Extended Abstracts.

Pelissier, M.A., C. Yu, R. Singh, F. Qayyum, and P. de Groot, 2016, Thalweg tracker: A voxel-based auto-tracker to map channels and associated margins: 78th Annual International Conference and Exhibition, EAGE, Extended Abstracts.

Sturzu, I., A. M. Popovici, N. Tanushev, I. Musat, M. A. Pelissier, and T. J. Moser, 2013, Specularity gathers for diffraction imaging: 75th Annual International Conference and Exhibition, EAGE, Extended Abstracts.

Tyiasning, S., D. Merzlikin, D. Cooke, and S. Fomel, 2016, A comparison of diffraction imaging to incoherence and curvature: The Leading Edge, **35**, http://dx.doi.org/10.1190/tle35010086.1.