Introduction

In this paper we apply the seismic diffraction imaging method (Moser and Howard, 2008) to a 3D data set in the southern Malay Basin. This Tertiary petroleum province is structurally complex, comprised of a series of half-grabens that were inverted in the Miocene. The structural evolution of the basins has been detailed by Kong (1997) and Tjia (1998, 2014). The inversion resulted in flower structures and en échelon Riedel shears. As noted by Ghosh et al. (2010), exploration and production in this relatively mature basin faces a number of challenges, with thin reservoir sands and complicated reservoir compartmentalization.

The reservoirs are located in the Oligocene-Miocene sequence which includes fluvial sandstones, ranging from alluvial plain environment in the Oligocene, and a coastal plain environment in the Miocene (Bishop 2002, Mansor et al. 2014). The Paleocene-Eocene clastics are dominated by laterites overlaying the basement and overlain by a sequence of alluvial fans. The fractured basement reservoirs are a key emerging play in the Malay Basin (Madon et al. 2015, Alai et al. 2019).

Structural diffraction imaging

Diffraction imaging (DI) provides significant improvement in the definition of the fault system in both the high and low reflectivity/continuity strata. As shown in the depth slice in Figure 1, diffraction imaging significantly improves the definition of the distinctive type en échelon pattern documented by Riedel (1929). The similarity attribute lacks the resolution of the diffracted wavefield.

Figure 1. Depth slice for a) PSDM b) DI with 97% specularity taper c) similarity.

In the deeper, lower reflectivity section and in the basement, the diffraction image helps to bring out main structural features as well as small scale faulting, as shown in Figure 2. On the PSDM (Pre-Stack Depth Migration), the faulting is especially poorly defined in the low reflectivity section, which is also of low coherence. On the diffraction image of Figure 2b and the composite display of Figure 2c, we can see the continuation of the flower structures at depth.

Figure 2. Small scale faulting a) PSDM b) DI with 92.5% specularity taper c) PSDM with semitransparent DI overlay.
Basement fractures can be expected to have a significant diffraction response. One of the defining characteristics of basement fractures is roughness (Amitrano and Schmittbuhl, 2002), and this gives rise to diffraction. Basement fractures will also have numerous intersections with each other. As noted by Grasmueck et al. (2015), fracture intersections have a distinct diffraction response. Finally, steeply dipping fractures will be difficult to illuminate with reflection, whereas diffraction does not have any illumination restriction. In Figure 3 we compare the PSDM to a diffraction image, demonstrating a clear improvement of the basement fracture definition in the latter.

**Figure 3.** Basement fracture. a) PSDM b) DI with 92.5% specularity taper.

Alai et al. (2014) demonstrate the application of post-stack attributes on conventional seismic images to basement fracture characterization. Here we extend this approach to include the seismic diffraction image, as illustrated in Figure 4. The basement fracture attribute is the equivalent the fault attribute detailed by Hale (2013) for formations with low reflectivity coherence.

**Figure 4.** Basement fracture properties derived from 92.5% specularity taper a) overlay of fracture likelihood on diffraction image b) corresponding basement fracture strike.

**Stratigraphic diffraction imaging**

The application of diffraction imaging to channel systems is illustrated by the conceptual modelling shown in Figure 5. As noted by Zavalishin (1982), a deposit edge can be represented by a simple reflection coefficient discontinuity, and such a discontinuity produces a diffraction response arising from two edge diffractors. In our example we use reflection coefficients of equal amplitude and opposite signs to represent the discontinuity for channels of various widths.

**Figure 5.** Channel modelling. a) PSDM and b) diffraction image for channel features of varying widths represented by reflection coefficient discontinuities.
From the modelled diffraction image, we can make two observations. Firstly, the channel edges are marked by imaged diffraction events. Each event includes a polarity reversal which occurs precisely at the channel edge. Secondly, as the channel width decreases, the diffraction events from opposite edges interfere. Tuning will occur at a certain width when the interference becomes constructive. Below tuning, the composite amplitude will decrease in proportion to the channel width. This property implies that diffraction imaging can be used to detect stringer sands, which will behave as line diffractors in 3D. The detection of narrow channel features is illustrated in Figure 6 using very weak specularity tapers.

**Figure 6.** Isolated channel a) PSDM and b) specularity taper 99.5% c) specularity taper 98.5%.

In Figure 7 we illustrate that diffraction imaging cannot only detect isolated channels, but also break down larger channel systems into elementary channels. Note that one property of diffraction imaging is to amplify the vertical difference between edge diffraction events. This effect is similar to that of small throw faults discussed by Pelissier et al. (2016). In both cases, pairs of edge diffractors are the basic geological building blocks of the diffraction image.

**Figure 7.** Various comparisons of PSDM (top) with DI 97% taper (bottom).

In Figure 8, we compare a depth slice from the PSDM to DI and similarity derived from the PSDM. Note that on the diffraction image, we see amplitudes of opposite polarities about the channel edge. This is associated with the polarity reversal of edge diffraction that we observe in the above modelling (Figure 5). As in the case of structural diffraction imaging, the stratigraphic diffraction image provides a higher resolution image than similarity.

**Conclusions**

Diffraction imaging has a wide range of applicability to both structural and stratigraphic targets in the Malay Basin. In the Tertiary section, diffraction imaging helps to resolve small scale faulting, inclusion the en echelon faulting. At the same time, diffraction imaging assists the overall structural interpretation in both high and low reflectivity formations. Isolated small scale channel features can be identified, as well as the internal architecture of channel complexes. Seismic diffraction provides superior illumination and definition of basement fractures. The basement fracture network can be characterized by the basement fracture attribute. Based on these results, we conclude that diffraction
imaging can reduce development risks for channel sand reservoirs in the Malay Basin, and provide an advantage in the development of the basement fracture play.

Figure 8. Channel depth slice for a) PSDM b) DI with 97% specularity taper c) Similarity of PSDM.

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References


