Investigating the impact of acquisition design on the problem of imaging below shallow gas

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SUMMARY

The problem of shallow, highly absorptive zones negatively affecting the quality of the seismic image at target depth is widespread across the Malay Basin. Whilst developments in processing regimes have lead to considerable improvements in the compensation of amplitudes below these areas of high absorption, the issue of improving the seismic image, and subsequently, our confidence in exploration decisions within affected fields remains a key challenge for operators in this region.

This study investigates the impact that acquisition geometry and design can have on the problem of imaging below shallow gas. Using advanced ray-based modeling techniques, we take a detailed look at the improvements in sub-gas amplitudes afforded by adopting non-conventional acquisition geometries; including, but not limited to, the large-offset (approx. 14 km), full-azimuth, dual coil shooting approach recently used in the Gulf of Mexico and broad-bandwidth acquisition techniques.

In addition to the illumination and amplitude characteristics associated with each design, we also investigate the improvements in resolution by simulating 3D prestack depth migration (PSDM) cubes at key areas of interest to try to understand the additional benefits afforded by adopting a non-conventional approach to acquisition.

Through the use of forward modeling, we provide a comprehensive insight into whether non-conventional acquisition techniques have a role to play in addressing the problem of imaging below zones of high absorption located in the overburden.

Key words: Shallow gas, seismic acquisition, forward modelling, illumination studies, survey evaluation and design.

INTRODUCTION

The aim of this paper is to investigate the impact that seismic acquisition design can have on imaging below shallow gas. Whilst we use the term shallow gas, this study applies to all scenarios where a shallow anomalous body is present in the overburden and has the undesired effect of highly attenuating the amplitudes of the seismic image across target horizons in our reservoir zone.

Seismic data processing obviously has an important role to play in overcoming the problem of imaging below shallow gas, with recently introduced technologies such as overburden compensation and Q-tomography. However, these approaches aim to compensate for inherent deficiencies within the original seismic data. It is the remit of this paper to consider the possibility of designing a seismic survey that can mitigate the problems of high attenuation in the overburden such that the acquired seismic data do not suffer from extreme cases of seismic data wipe-out or dimming.

MODEL

The model used for this study is synthetic and inspired by the geology of the Malay Basin. The target horizon is at a depth of approximately 4 km and shows pronounced topographic variation including large syncline trends across the centre of the model (Figure 1). Above this target, we created a number of anomalous areas in the overburden. These lie at a depth of between 1 km and 2 km and vary in size and shape. These anomalous areas share the same velocity and density characteristics of the rest of the model, but have been assigned an anomalously low Q value relating to relatively high earth attenuation with the intention of representing pockets of shallow gas.

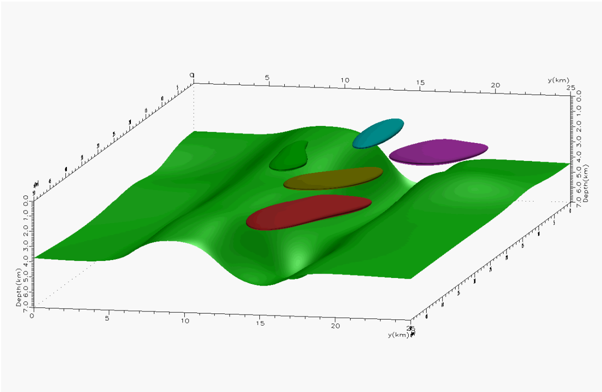

Figure 1. The 3D model used in the study. The target horizon is represented by the green plane that lies at a depth of approximately 4 km.

Why do we think we can design our way out of this problem? Well, if we look at Figure 2, we can see that, for a single shot from a coil survey, the recorded long offsets are not affected by the anomalous body. Whilst this might also be true for a conventional survey at this shot location (within this model), it is this observation that lead us to believe that non-conventional seismic acquisition designs that include increased azimuth and large-offset sampling, such as wide azimuth, coil shooting and dual coil shooting, may provide a significantly better image of the reservoir within complex areas affected by shallow gas. The coil shooting technique uses a conventional streamer spread, but acquires data in large circles (approx 7-km radius), as opposed to a straight line as in a conventional seismic survey. Dual coil shooting extends the techniques of circular shooting by including two streamer vessels at opposite sides of the circle and two additional source vessels located at the end of each spread. As both receiver spreads are live for each shot, offsets of up to 14 km can be recorded. For a more detailed explanation of the coil shooting technique and its success, see Ross (2008). Moldoveanu and Kapoor introduced the dual coil shooting technique in their SEG paper, "What is the next step after WAZ for exploration in the Gulf of Mexico?" (2009).

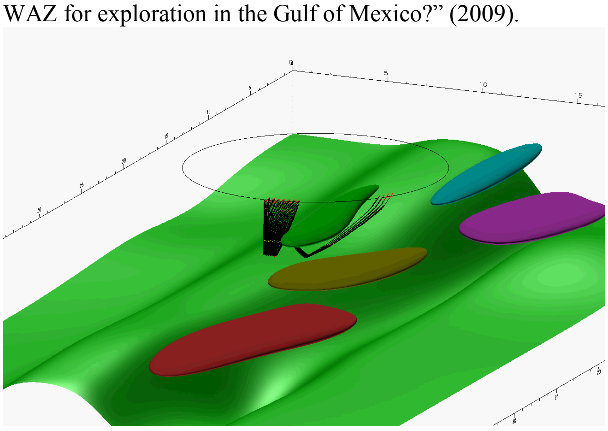

Figure 2. A snapshot showing the results from a single shot during a coil survey. The ray code was designed such that only rays that have not passed through the anomalous area are displayed.

With that in mind, we simulated results for narrow azimuth acquisition in the strike direction of the syncline, narrow azimuth in the dip direction of the syncline, singular coil shooting, and dual coil shooting. The output from these acquisitions was also compared with ocean-bottom node acquisition.

METHOD

Using the ray-based survey design methodology described by Zuhlsdorff et al. (2010), we investigate the possibility of designing a seismic acquisition program that minimizes the effect that shallow bodies of high earth attenuation can have on our seismic data.

To summarize the approach, we are able to accurately determine the impact that a certain acquisition geometry has on a specific exploration problem by running a series of forward modelling tests. These tests break down into four key steps

- Illumination analysis
- Offset and azimuth analysis
- Dip and azimuth analysis
- Resolution and imaging analysis

Illumination Analysis

By using ray-tracing technology, we are able to simulate migration amplitudes across the target horizon. This process is a target orientated, Kirchhoff migration of synthetic data around the reflection points using the local paraxial approximation of the two-way traveltime field on the target horizon (Laurain et al., 2004). For the purpose of this study, this process allows us to rapidly and accurately quantify the target response to the various acquisition geometries that we simulate, giving us a clear indication of which geometries best overcome the challenges in the overburden.

By varying the source wavelet used in the process of simulating the migration amplitudes across the target horizon, we can also make progress in addressing the question as to whether a broadband signal would give a better amplitude response.

In addition, using the functionality within the ray tracer, we can design ray codes that are killed if they encounter a certain area within the overburden. By doing so, we can generate attribute maps for our target horizon that have contributions from only those rays that have not travelled through the anomalous area in the overburden. This approach not only makes it visually easier to distinguish the relative merits of the various acquisition geometries, but it also allows us to optimise our designs to maximise the coverage of unaffected rays.

Offset and Azimuth Analysis

Offset and azimuth analysis is a survey-independent methodology that enables the geophysicist to better understand the illumination of the target horizon by determining which offsets, azimuths, and recording times are required to illuminate particular points (common reflection point nodes) across the target horizon. This approach can be particularly useful when the overburden contains features such as salt bodies or pockets of free gas as it allows the designer to better understand which offsets and azimuths are affected by travelling through these features and which to record to avoid them.

Dip and Azimuth Analysis

Dip and azimuth analysis is a methodology that allows the designer to determine the range of dips that the proposed survey can image. In this case, the modeling is independent of the target horizon, and instead, analyses the combination of the survey geometry and overburden to establish the angle and azimuth of all structures that could potentially be imaged by a particular survey. It is a useful extension to standard illumination analysis as it demonstrates the potential benefits of an advanced design in addition to the effectiveness of that design to image a known horizon. This analysis helps quantify the robustness of a proposed survey and its ability to image unknown structures such as steeply dipping faults within a compartmentalised reservoir.

Resolution and Imaging Analysis

Using a local prestack imaging method (Lecomte and Kashwich, 2008), we can rapidly simulate 3D prestack depth migration (PSDM) cubes that include the illumination effects of the survey, the overburden, and the properties within the reservoir for a specific area of interest. The method is rapid and cost efficient, allowing for multiscenario analysis, e.g., the comparison of multiple acquisition designs or 4D seismic feasibility analyses.

As the survey and overburden information is included in the study, the synthetic data accurately represents the 3D resolution and illumination of the area of interest (both lateral and vertical). Analysis of the benefits of different acquisition approaches can be made to establish the potential image quality within the area of interest, e.g., will steeply dipping faults be imaged within the reservoir? The simulated synthetic data are equivalent to a fully processed PSDM cube for the local area of interest.

Combining this analysis with the output from the dip and azimuth analysis allows us to quantify the resolution and imaging improvements that a specific acquisition geometry might have in addition to the illumination improvements across the target horizon. For more information of this type of analysis, see Lecomte (2008).

RESULTS

The results from the first stage of the modelling are laid out in Figures 3 through 6. Figure 3 shows the migration amplitudes that we would record from a narrow-azimuth survey with no attenuation in the overburden. It can be seen that the distribution of amplitudes is uniform and high. However, when we introduce anomalous areas of high earth attenuation into the overburden, it has a dramatic impact on the amplitudes across our target horizon. Figure 4 shows significant areas of zero amplitude located beneath the areas in the overburden. In effect, we are visualising the same data wipe-out that we see in our acquired seismic data.

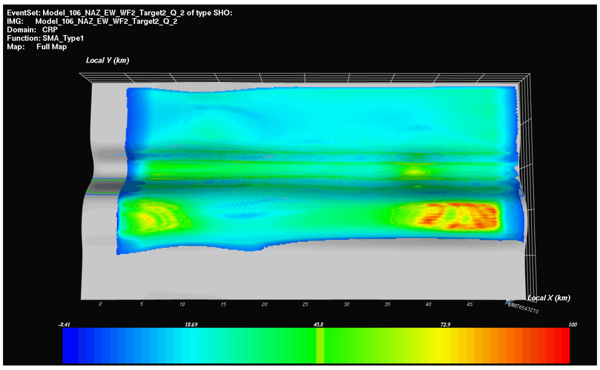

Figure 3. An attribute map showing the distribution of migration amplitudes across the target horizon for a narrow-azimuth survey acquired in the strike direction of the trench. Attenuation was not included in the model.

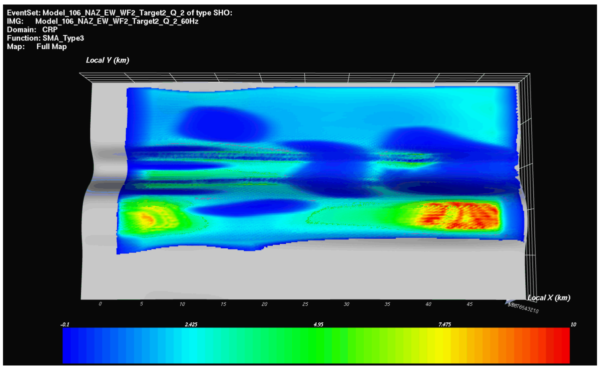

Figure 4. An attribute map showing the distribution of migration amplitudes across the target horizon for the same survey as Figure 4. In this case, however, earth attenuation is included in the model.

Figure 5 shows the amplitudes recorded from a coil survey. The colour bar was kept the same as Figure 4 for easy comparison; however, doing so leads to the saturation of the colour bar and the pronounced footprint in the data. The results show a significant increase in amplitudes across the entire horizon. Most notably, an increase can be seen in the areas not directly beneath the anomalous bodies, but perhaps more importantly, the areas beneath the anomalous bodies now have a better amplitude response and the areas of zero amplitude are limited to beneath those bodies with greater lateral extent and higher values of earth attenuation.

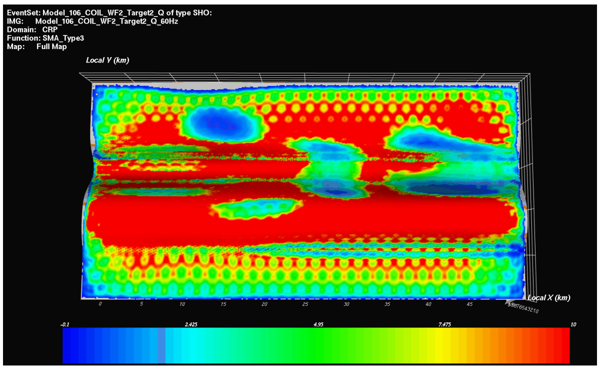

Figure 5. An attribute map showing the distribution of migration amplitudes across the target horizon for a coil survey. In this case, earth attenuation is included.

Figure 6 shows the amplitudes recorded from a dual coil survey. Again, the colour bar was kept constant so that direct comparisons between Figures 4, 5, and 6 can be made easily. Whilst the restriction of the color bar has masked all subtle features within the data set, it can be seen that the target horizon no longer suffers from any region of zero amplitude. Not only that, but the amplitude response from the entire horizon is 10 to 15 times greater than that experienced by the narrow-azimuth survey.

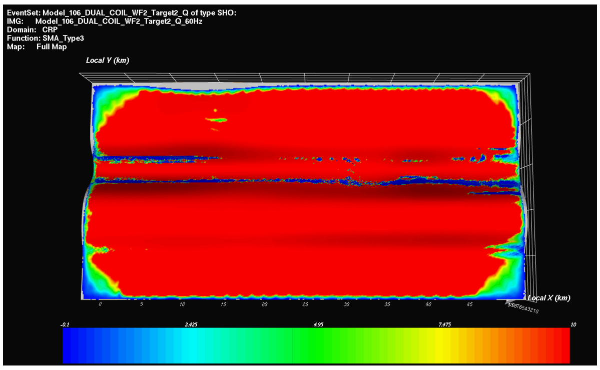

Figure 6. An attribute map showing the distribution of migration amplitudes across the target horizon for a dual coil survey. In this case, earth attenuation is included.

Extending this to look at attribute maps created by using only those rays that have not passed through the anomalous bodies in the overburden further reaffirms the success in the circular shooting approach in sampling the target horizon.

In fact, the dual coil results show that a near-uniform coverage of the target horizon can be achieved with rays that have not passed through the anomalous areas, and have, therefore, not suffered from the attenuating effects of the shallow gas.

The offset and azimuth analysis shows that the success of the dual coil approach is a result of the large offsets afforded by this technique. The analysis shows that to undershoot the larger anomalous bodies, offsets of up to 12 km are required. The dual coil design used can record offsets of up to 14 km.

The dip and resolution analysis helps us take the study one step further and quantifies the additional benefits associated with each acquisition design. Whilst the illumination analysis showed us which design illuminates the known structure best, the dip and resolution analysis showed, in quantifiable terms, what impact the design will have on our ability to image unknown structures and the quality of our final 3D PSDM image.

CONCLUSIONS

The issue of shallow, anomalous areas in the overburden, such as shallow gas, affecting the quality of our seismic data is a common problem in this region. Whilst processing techniques provide many very good solutions, they all try to overcome inherent deficiencies within the acquired seismic data.

We believe that, in areas of extreme data wipe-out or data dimming, a solution can be achieved through the application of a rigorous survey evaluation and design study. This synthetic case study demonstrated that significant benefits in target illumination, structural imaging, and data resolution can be achieved by implementing a more advanced acquisition design such as coil shooting.

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