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Illumination Analysis from Coil Survey Design and Acquisition to Coil Processing Solution

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SUMMARY

A narrow azimuth survey and an overlapping Coil survey were acquired and processed for TOTAL offshore Angola. After fast track processing, a direct comparison showed that at a specific location a sub-salt steeply dipping event was better defined on narrow azimuth image than on the Coil image. This case study illustrates how illumination analysis can be used to make critical survey design, acquisition and processing decisions. The initial flower plot analysis helps determine the survey design requirements to illuminate target horizons, and will fully justify the need for a full azimuth design. Then, an acquisition illumination analysis complements the previous analysis by creating offset and azimuth illumination maps for chosen design. This identifies illumination and shadow zones on the target horizon. This can be directly related to the seismic data and used to design an appropriate processing solution. Finally, during the processing phase, the specific azimuth contributions identified from illumination analysis need to be separated into azimuthal images. These are intelligently stacked to create the final image, using an intelligent stacking method, designed to retain azimuth specific contribution. To use the full benefit of Coil Acquisition, this two-steps processing strategy derived from the illumination analysis, is essential.
Introduction

In 2011, two surveys were acquired and processed for Total over Block 33 in Angola (Khaled et al. 2012), (Zamboni et al. 2012): a large narrow-azimuth survey (NATS) shot on 90° azimuth and an overlapping coil survey centred on the main target area. The target structure consists of subsalt horizons dipping upwards towards the salt and potentially closing on the base salt. This structure extends all around the main salt dome and is illustrated in Figure 1.

After fast-track processing, reverse time migration (RTM) images of the target area were produced with both the narrow-azimuth and the coil surveys, allowing for a direct comparison.

However, at a specific target location (Figure 2), identified later in this abstract as location A, the full-azimuth acquisition coil RTM image showed a poorer definition of the subsalt steeply dipping events when compared to the NATS survey image,

To understand the underlying cause of this observation, a detailed illumination analysis was performed. The objective was to determine if this was due to an acquisition issue or a processing issue, and to design an appropriate solution.

Illumination analysis

The illumination analysis was divided into two steps:

- The first step was to analyse the target horizon and determine which azimuth and offset illuminate the target.
- The second step was to check if the target horizon had effectively been illuminated during the acquisition.

Flower plot analysis

In the first part of this illumination analysis, a series of analysis points were defined on the steeply dipping target horizon around the salt structure. For each location, ray tracing was performed from the target point to a carpet of receivers on the surface. Pairs of rays that verify Snell’s laws at the horizon were created and recorded as a function of the source-to-receiver distance and azimuth. The results were displayed in flower (offset / azimuth) plots, representing the number of ray pairs for each defined offset-azimuth bin.

A small selection of the flower plots are displayed in Figure 3. As the target location moves on the dipping horizon around the salt structure, the range of offsets and azimuths required for illumination varies significantly and rapidly (within a few kilometres). Some locations are only illuminated by a very restricted range of offsets (several hundred metres) or a very restricted range of azimuths (a few tens of degrees).
The conclusions reached from this flower plot illumination analysis are:

- Varying restricted azimuth ranges are required to illuminate the target horizon all around the salt structure. A narrow-azimuth acquisition configuration will correctly illuminate only a small part of the dipping target. This justifies the need for a full-azimuth configuration.

- Target location A is illuminated only by far offsets (larger than 3.5 km) and azimuths between 60° and 110° (Figure 4).

Finally, this flower plot analysis is an efficient survey design tool to analyse the acquisition requirements to illuminate a specific target.

**Acquisition illumination analysis**

The second part of the analysis is focussed on illumination of the acquired coil survey design. Using the actual coil acquisition navigation data, illumination hit maps are created using 3D ray tracing to the target horizons. These illumination maps are then subdivided to obtain illumination maps by offset ranges, as well as illumination maps by azimuth ranges.

Shadow and illumination zones are identified on each offset and azimuth illumination map and can be related to the seismic data. Offset images were created using beam migration and azimuth images using Gaussian packet migration (GPM).

**Figure 5** Illumination maps and comparison with coil GPM section at location A for 2° azimuth ranges: 0-10° (left) and 90-100° (right). The steeply dipping events have been recorded, but only within a restricted azimuth range.
The conclusions from this illumination analysis are:

- The observations on seismic data confirm the shadow and illumination zones predicted by the illumination maps (Figure 5).
- At target location A, the dipping events have only been recorded on offsets larger than 3.5 km and a restricted azimuth range – 60 to 120° (Figure 5).

This acquisition illumination analysis enables identification of the offset and azimuth ranges of the recorded energy for various parts of the target horizons. This is a key analysis to check the validity of the acquisition geometry and to enable the design of an appropriate processing solution.

**Processing implications**

The previous illumination analysis showed that, at location A, the dipping events were recorded on a small portion of the data corresponding to large offsets and a restricted azimuth range centred on 90°. This explains the initial comparison between the coil and NATS survey RTM images. The NATS survey is centred on the perfect azimuth to illuminate location A; whereas, in the coil survey the information is stacked destructively with the other azimuths, thus leading to a poorer definition of the dipping events. Note, however, that at a different location around the salt, the required illumination azimuth range will be different from the narrow-azimuth survey azimuth and, hence, the NATS image will not contain the target events, whereas they would have been recorded in part of the coil data.

To avoid destructive stacking and take full benefit of the recorded full-azimuth data, the following processing solution was designed.

**Azimuth-sectored RTM**

Firstly, azimuth- (and optionally, offset-) sectored images are created. Depending on the illuminating azimuth ranges, the target events will appear in one or several azimuthal images, but the energy will not stack destructively because it has been separated.

A solution is to define a shot azimuth (for example, by taking the average azimuth of a user-defined offset range) and separate the input shots into several azimuth sectors. Each azimuth sector is then migrated separately using RTM. This solution has no impact on the cost of RTM. Four reciprocal 45° azimuth sectors were defined. As expected from the illumination analysis, at location A the steep dips are mainly imaged by azimuth sector 57.5 to 112.5°.

**Iterative optimum weighted stack**

Once the energy has been separated in azimuth- (offset-) sectored images, an intelligent stacking strategy is required to create the final image without destructively stacking the different azimuth contributions. The iterative optimum weighted stack workflow compares each azimuthal image with a reference stack and derives depth- and spatially variant weights to apply to each azimuthal image before stacking. The weights are derived such that each azimuth-specific contribution is weighted up; whereas, the use of a reference stack prevents boosting noise. The initial reference stack can be, for example, a straight stack of either several or all azimuth images. The process is iterated using the optimum stack from the previous iteration as the reference for the next iteration. Experience has shown that the process converges after a few (three to six) iterations.

One of the advantages of this method is that the weights can be QC’d and edited before application and can also constitute an additional valuable deliverable product. One of the limitations of the method is that converted waves are reinforced in the final images. Although the final weighted stack cube provides a significant uplift compared to straight stacking, a multicube interpretation is also necessary.

Examples of the uplift obtained by using this azimuth-sectored RTM method with iterative optimum weighted stack are displayed in Figures 6 and 7.
Figure 6 Comparison between NATS survey, fast-track coil, and final coil RTM (Example 1).
Figure 7 Comparison between NATS survey, fast-track coil, and final coil RTM (Example 2).

Conclusion

Figures 6 and 7 show final comparisons between the NATS survey RTM image and the final coil RTM image. The illumination analysis enabled us to understand the geometry of how the energy was recorded and to design a processing solution to extract maximum benefit from the acquired data. The final coil RTM shows an overall better imaging of the target horizons compared to the NATS survey RTM, with striking improvements between the initial and final RTM images.

This specific case study illustrates how illumination analysis can be used to make critical survey design, acquisition, and processing decisions.

- The flower plot analysis helps determine the survey design requirements to illuminate specific target horizons, and fully justifies the need for full-azimuth data acquisition.
- The acquisition illumination analysis complements the previous flower plot analysis by creating offset- and azimuth-specific illumination maps from the navigation data of the chosen design. This clearly identifies illumination and shadow zones on the target horizon within user-defined offset and azimuth ranges. This can be directly related to the seismic data and used to design an appropriate processing solution.
- The specific azimuth contributions identified from illumination analysis must be separated into azimuthal images. For reverse time migration, a zero-cost solution is to separate the input shots based on a user-defined shot azimuth.
- Finally, intelligent stacking of the azimuthally sectored images is required to create the final image. The iterative optimum weighted stack is designed to retain any azimuth-specific contribution, whilst avoiding boosting noise.
- To extract the full benefit of coil acquisition, the processing strategy based upon illumination analysis is essential.

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