Infill decisions through real time seismic illumination modeling

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Abstract

Real time seismic illumination modeling with the intent of enhancing infill decisions was performed for the first time in the industry on a non-exclusive 3D survey over block BMS-31 in the Santos basin offshore Brasil. The goal was to prioritize regular infill on the basis of subsurface coverage at the target horizon. Ultimately, an off-angle boat pass was recorded to improve the coverage on the target horizon in an area between a key well and new exploration objectives. The resulting subsurface fold was enhanced and the project has reached its intended goal of ensuring that real time modeling results can be available on a daily basis to enhance infill decisions. At the time of writing this expanded abstract the processing of the survey is in the early stages and possible improvements on the processed data still need to be evaluated.

Introduction

Several modern deepwater 3D seismic surveys exhibit clear examples of amplitude shadows (low reflectivity) at the flanks of salt induced structures (See Figure 1). Extensive research and reporting of these phenomena has been undertaken (ref [1], [2], [3], [4]). It has been demonstrated that the shadows are related to a low number of ray paths illuminating these areas. This effect downgrades the reliability of the amplitudes in the dataset and the associated interpretation of those amplitudes, and also causes difficulties in the structural interpretation of the horizon itself.

3D datasets in deepwater settings offshore Brasil were inspected for similar problems and it was found that numerous datasets in areas with less complicated geologic structure show similar amplitude artifacts. The BMS-31 3D survey, located on the inner flanks of the Santos basin, is in an area where salt has mostly withdrawn leaving relatively gentle geologic structures at the exploration objectives (see Figure 2 for location map) Real time seismic illumination modeling was used on this survey to enhance infill decisions during the acquisition phase. The objectives of the illumination modeling were:

1.) To demonstrate that this technique could be performed in “real time”.

2.) To assess and prioritize regular infill both on surface coverage and subsurface coverage.

Both objectives were achieved on this survey. In this example, it was found that regular infill based on subsurface coverage was not significantly different from regular infill based on surface coverage criteria. Instead, it became obvious during the preparation stage, and during the acquisition stage, that more beneficial information could be gained by acquiring off angle lines targeting the subsurface where the illumination coverage was deficient.

Method

A methodology to accomplish real time illumination monitoring has been proposed (ref [5]), in which Long describes a basic process and points out potential obstacles for accomplishing the objective. In this experiment, these obstacles have been overcome.

The methodology for this experiment can be separated six distinct phases:

1.) Preparation of a 3D horizon and velocity model from 2D input. Both a Vp and Vs model was generated. A 3D density model was also created based on rock property estimates.

2.) An Illumination pre-study to investigate the suitability of the model and to predict the subsurface coverage for ideal survey layouts (dip vs. strike acquisition azimuth).

3.) Transfer of model data, QC, including repeat modeling to the acquisition departments. Only Vp and horizon data was transferred.

4.) Actual real time illumination modeling using P1/90 navigation data as acquired.

5.) Comparison of ideal subsurface coverage, subsurface coverage based on P1/90 navigation data and surface (midpoint) coverage.

6.) Decide on infill. Reverse modeling if needed.

3D horizon and velocity data were created from 2D seismic input. The model consisted of two surfaces (seabed and objective) and a gridded interval velocity model. Several intermediate horizons were used in the construction of the gridded velocity model. Figure 3 shows the resulting earth model.

To predict the subsurface coverage assuming ideal (i.e. no feather) conditions for the acquisition, an illumination technique that works in the CDP domain was used. First, a 3D offset de-migration was performed on the model data to determine the shot and receiver locations from the ideal marine geometry that would illuminate any given point on the target horizon. This was followed by an elasto-dynamic ray tracing using all model properties, providing an estimate of the amplitude of the rays as a measure of the illumination. This was done for both dip and strike recording. Additional products included maps of the de-migration distance, de-migration azimuth, and reflection incidence angle. These products could be used limit the streamer length to only what was needed to provide a useful incidence angle range at the target horizon with a high degree of confidence. This resulted in significant cost/time savings. The recording direction was also changed from dip to strike, based on operational criteria. The model data showed that this would not lead to significant changes in the subsurface illumination in this case.

Only the Vp and horizon model were used during the actual acquisition. This would not permit an estimate of the anticipated amplitudes at the objective horizon, but rather concentrate on the production of maps showing hit-count, reflection angle and offset distribution. These maps were compared with standard mid-point coverage maps to aid infill decisions. The data/work flows to accomplish this in real time are shown in Figure 4 and Figure 5.

Re-creating illumination maps using ray trace modeling has been accomplished on past occasions, but attempts to perform the re-creation as the data are being acquired have been hampered by several factors. Recent advances in the speed at which data can be transferred and improvements in the computational capabilities with the acquisition contractor have overcome these obstacles. This included the application of compression software, developed by Ødegaard, for transmission of the P1/90 data files. Additionally the data was decimated by a factor 4 (every 4th receiver was used in the modeling, resulting in a bin size of 25 x 25 m with the same fold as the acquisition fold).

The Nucleus/NORSAR3D modeling package was used to perform the real time modeling. Figure 5 shows the workflow that was followed from input data to modeled products. As a quality control, a flat layer was also modeled using a constant velocity overburden. The results were compared with the Census mid-point coverage plots and found identical, other than display issues. This exercise could not be performed at the start of the survey, since it required a substantial amount of data to be acquired first, so this QC was produced at an appropriate stage, before infill decisions based on any subsurface modeling were made.

The 3D earth model data was used in the ray tracing of incoming P1/90 data. Daily updates were performed by adding the newly received data to the existing results. In total, 90 sail lines were acquired on this survey (20 subsurface lines/sail line; line length ~ 45 km, total ~ 810,000 CMP line kilometers). The ray trace illumination modeling completed on the same day that the final navigation data was received.

Frequent viewing sessions were organized to fine tune infill decisions, aided by the use of a 3D visualization system (HoloSeis™).

Results

When comparing midpoint (surface) coverage with modeled (subsurface) coverage, it became clear that "normal" infill decisions would not be significantly different for this survey. That is, where midpoint coverage was deficient, the modeled subsurface coverage was also deficient to approximately the same extent. This is due primarily to the choice of survey area, which is devoid of complex geologic structure. This area was chosen specifically for this reason to ensure that the subsurface infill requirements would not be overly complicated. However, it was also obvious that "normal" infill targets areas that may be deficient in certain offset groups while other offset groups have sufficient coverage and hence, a large percentage of duplicate offsets are acquired when infilling these areas. It would clearly be much more beneficial to acquire lines specifically targeting near zero coverage on the subsurface illumination maps (Figure 6 explains).

Processing

At the time of this writing, processing of these data is in an early stage, however, it is hoped that it will be possible to demonstrate that the targeted infill did contribute effectively to ensure that proper amplitude behavior at the objective horizon was achieved. For this purpose, two processed seismic data volumes will be needed: one with the target infill, and one without the targeted infill".

Further issues that have been identified are:

1.) The accuracy of the model of the objective horizon. This horizon was crated from 2D seismic data. When the processed 3D data is available, new interpretations may indicate that the target is significantly different and possibly more complex. Should the target infill have been acquired at a different location?

2.) Integration of the "off-angle" line. While irregular acquisition geometries are handled routinely on land data, marine data processing is generally line oriented. Will the processing algorithms tolerate the irregular locations?

3.) Processing steps like offset rejection will have to be handled differently. Since duplicate offsets at the surface will map to different locations in the subsurface, traditional offset rejection will eliminate data that was intended to be included. The possible creation of a "subsurface P1/90 dataset" may be needed. Another possibility would be to split the data into azimuth consistent subsets and then perform the rejection in this domain.

4.) Anisotropic effects may require azimuth consistent stacking velocities to be derived. Will the off angle data merge well in this situation?

It is anticipated that, at the conference, some or all of the above will be solved, since the processing should be nearing completion by that time.

Conclusions

1.) Infill decisions through real time seismic illumination modeling was performed for the first time on the BMS-31 3D survey in the Santos basin, Brasil.

2.) The real time illumination modeling assisted operational decisions relating to infill.

3.) The original objective -prioritizing "normal" infill- did not prove useful in this example. Instead, it became evident that targeted infill based on the illumination modeling would generate more useful information at the objective level.

4.) A number of processing issues have been identified and are not clearly resolved yet. Those include anisotropic effects and duplicate offset rejection.

5.) Proof of usability of real time illumination modeling will only be available after the dataset has been processed.

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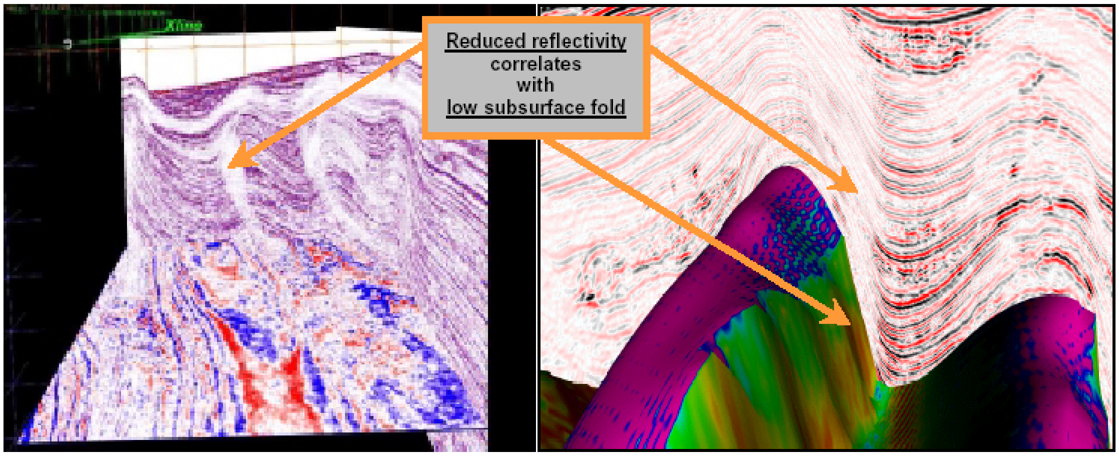

Figure 1: Perspective view of inline, cross-line and time slice of the processed data volume (left) and of the modeled target coverage, together with a seismic cross section (right). Blue to purple indicate high fold, and green to yellow low fold. (Source: Ref [1])

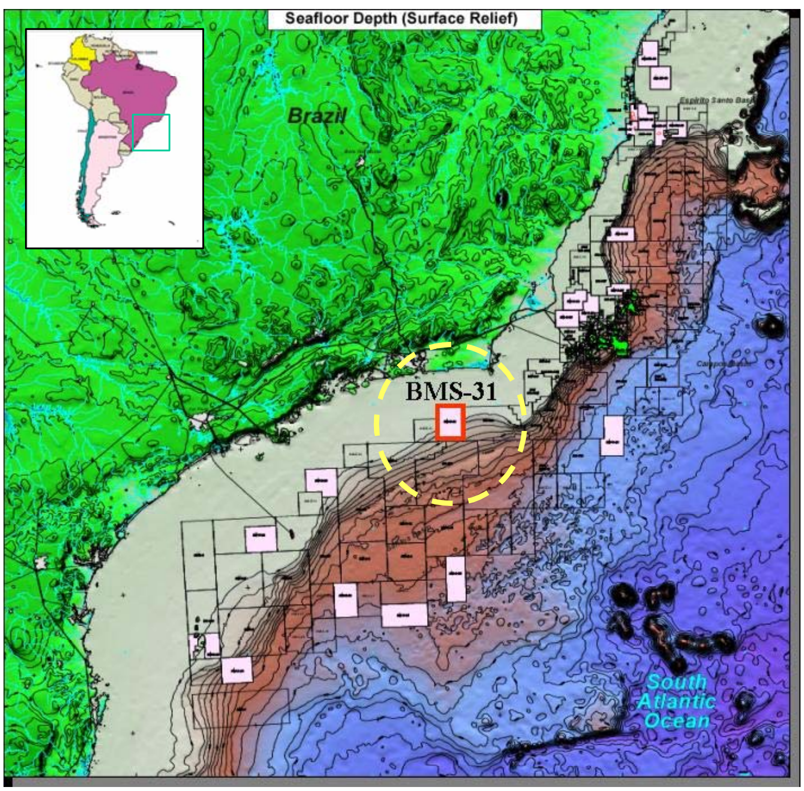

Figure 2: Location map showing the Brasil ANP round 4 blocks. Block BMS-31 is indicated in the yellow circle.

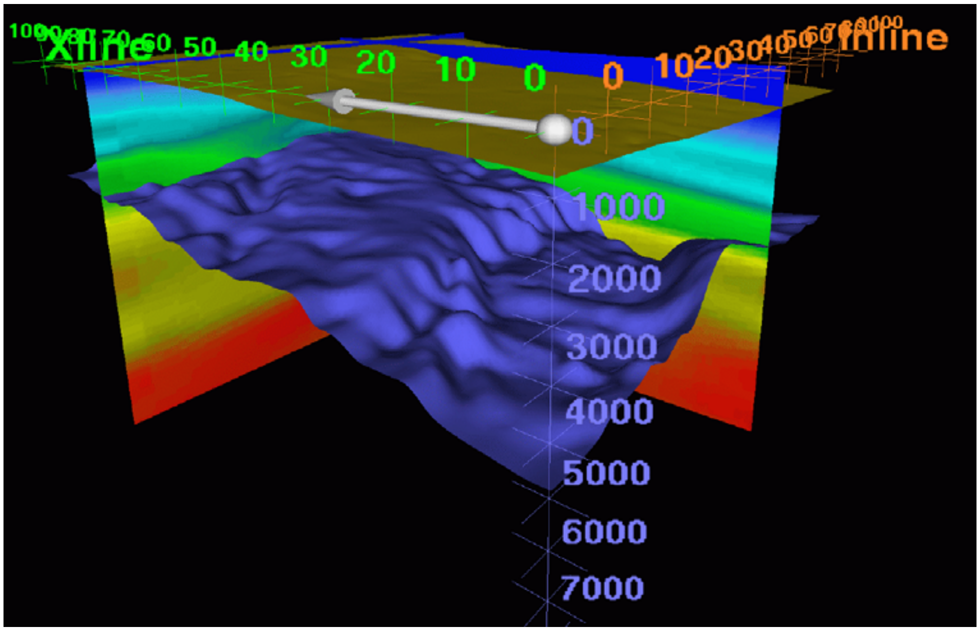

Figure 3: Velocity model displayed in depth (m) with seafloor and objective horizon.

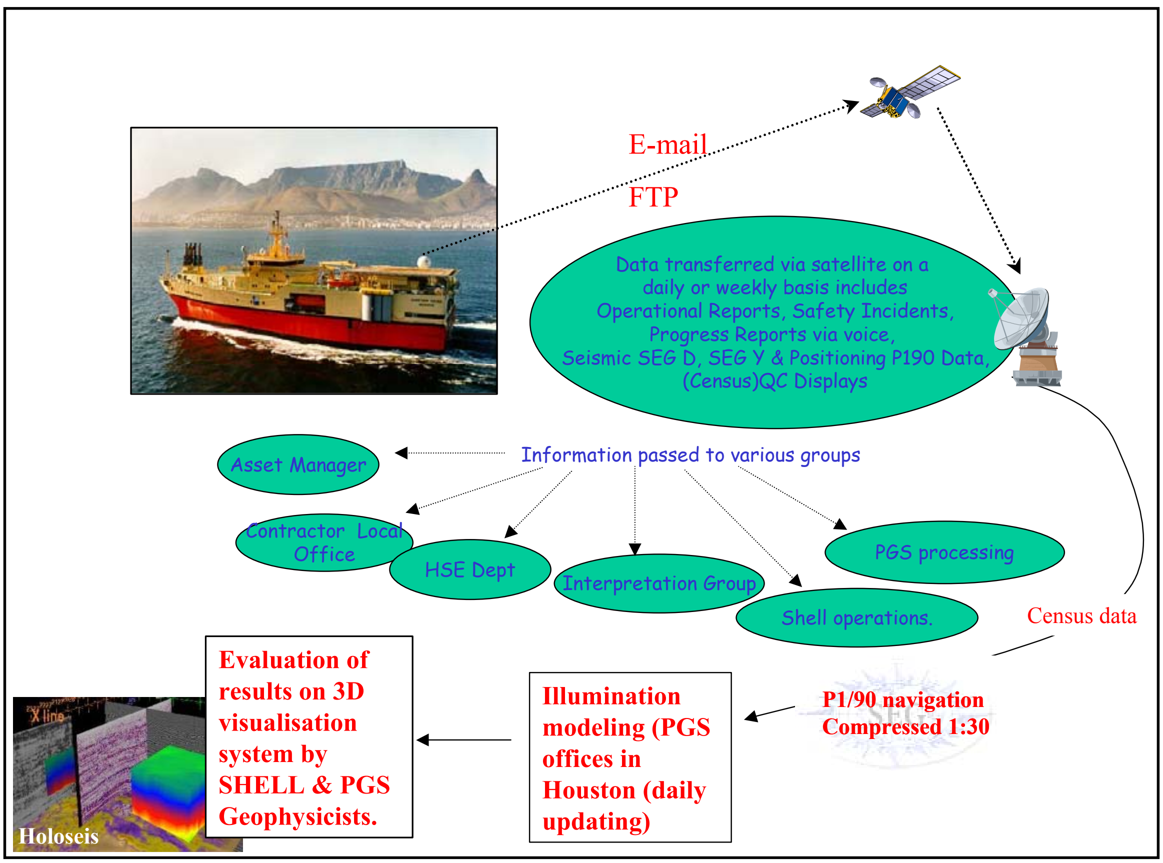

Figure 4 : Brasil BMS-31 3D survey. Illumination modeling dataflow.

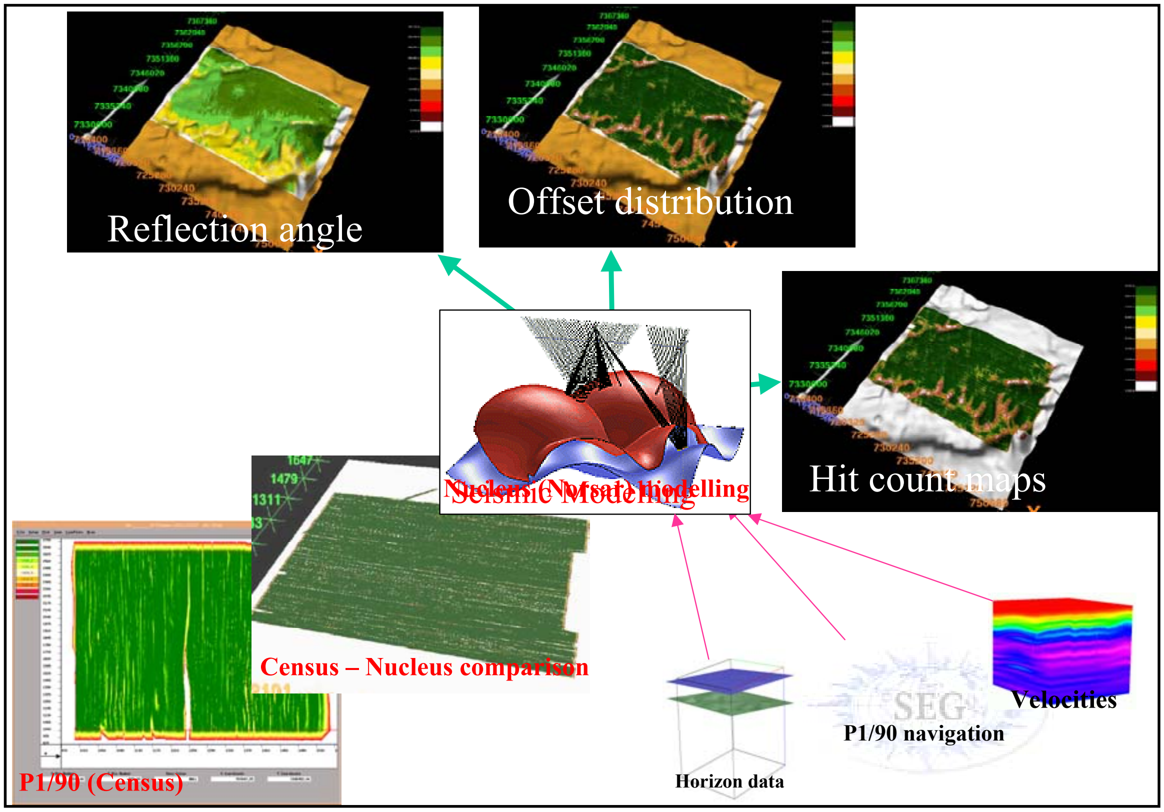

Figure 5: Illumination modeling workflow.

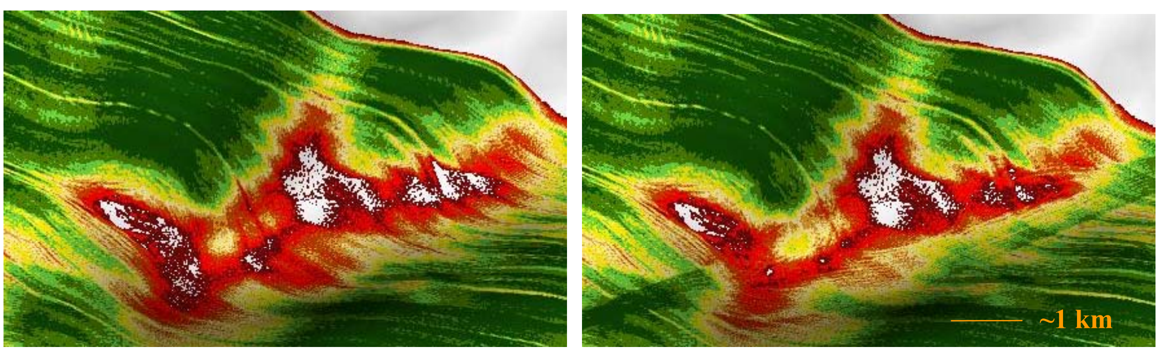

Figure 6: P1/90 coverage, projected on target horizon, before (left) and after (right) the acquisition of an off-angle boat pass. Whilst regular infill would target the lower fold stripes (yellow –28 to 32 fold, all offset groups) this off-angle line targeted the white areas (0 – 4 fold coverage). Clearly a second boat pass is needed to fill the white areas.