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A Survey Design Case History Using Complimentary Raytracing and Wavefield Extrapolation Techniques

P.J. Christian* (Maersk Oil), T. Pringle (Primeline Energy Holdings Inc.), L. Zühlsdorff (NORSAR), Å. Drottning (NORSAR), G. Brown (WesternGeco) & B. Webb (WesternGeco)

SUMMARY

We present a survey design and modelling case history showing how complimentary modelling techniques were used to optimize and de-risk a new marine seismic acquisition programme. A recent discovery sits close to a salt diaper and although not affected by the salt, the towed-streamer seismic exhibits a shadow zone. The aim of the study was to choose a new acquisition geometry and to demonstrate that acquired data could be successfully processed. In the first part of the study we used ray-tracing to assess subsurface illumination for a number of acquisition geometries including ocean-bottom cable (OBC). In the second part we used wavefield extrapolation modelling to create and process synthetic seismic datasets for the existing conventional (narrow-azimuth) data as well as the new OBC geometry. We show how the use of complimentary modelling techniques (raytracing and wavefield extrapolation) enabled a de-risking of the survey design. While the raytracing allowed us to model the optimum subsurface illumination and provide a multiple-free synthetic dataset, the wavefield extrapolation modelling provided the opportunity to predict the final image quality before and after multiple attenuation. We suggest that the approach adopted will be applicable to many potential surveys where improved imaging and multiple attenuation is required.
Introduction

We present the results from a survey design and modelling study. The aim of the study was to support a new seismic acquisition programme over a discovery. The discovery sits close to a salt diapir and although not affected by the salt itself, the towed-streamer seismic data does exhibit a shadow zone. This shadow zone affects our ability to map the possible extension of the discovery. The asset team was, therefore, interested in acquiring new seismic data to deliver a better image of the full area of the discovery and its immediate surroundings.

Our modelling study was based on a 3D earth model consisting of depth horizons, a V$_P$-velocity field, relationships to derive both V$_S$-velocity and density from V$_P$-velocity, a constant Q-factor to define attenuation, and Thomsen parameters to define VTI anisotropy. Key features of the model included the salt diapir above the reservoir’s area of interest, pronounced faulting beneath the salt diapir, and a pronounced high-velocity-layer between the salt and the reservoir that strongly affects seismic wave propagation in the overburden.

The study was divided into three parts: (1) A full illumination study and parameter selection for the upcoming seismic survey, (2) generation of synthetic seismic data for a chosen final setup, and (3) synthetic seismic processing and comparison to existing field data.

The philosophy behind the study was quite simple. Survey planning is about making as certain as possible that the acquired data will contain all the information required for carrying out a specific analysis or interpretation. In order to achieve that, a careful illumination study based on the best available model is required. Ray-based modelling allows for simulating seismic results either as seismic cubes (including shot gathers and stack simulation) or as parameter distributions (including flower plot analysis, fold maps, amplitude estimation at target level, and illumination vectors) (Gjøystdal et al. 2007, Zühlsdorff et al. 2010). Based on illumination vectors it is even possible to locally simulate prestack depth migration (PSDM) results and provide a measure of both vertical and lateral resolution (Lecomte, 2008).

However, in some cases a complete survey evaluation and design (SED) study must reach even further, as practical constraints may still limit the amount of information that can be extracted from a seismic data set, even if it in principle contains all required information. Such constraints include processing issues in general and de-noise and demultiple approaches more specifically. As ray-based modelling methods usually do not include noise, are target oriented in nature, and provide results that do not include the full wavefield, they are not ideally suited for investigating the potential effects of processing on interpretation results. The method to choose here would clearly be wavefield extrapolation modelling.

This paper describes how the results of our study can be optimized by combining the benefits of both raytracing and wavefield extrapolation modelling. Rather than considering the modelling approaches as competitive, we prefer to integrate them within a complementary setup, using the more flexible and efficient raytracing to find parameters for the most promising survey, to understand the results of this survey, and thus to set the ground for a computationally expensive wavefield extrapolation modelling run that provides a full seismic data set for processing and comparison to available field data.

Part 1: Illumination study and parameter selection (raytracing)

Raytracing is based on a high-frequency approximation to the full wave propagation equations and therefore is carried out in smooth macro models. The smallest detail in such models with regard to interface curvature, size of model features, or property inhomogeneities must be larger than the seismic wavelength, which usually is the case for studies as related to seismic exploration. Raytracing will not compute surface waves or diffracted waves, and the operator must use ray codes in order to specify which parts of the wavefield are to be generated. Many such ray codes can be run in parallel, e.g. to combine primary and multiple reflections, but the wavefield will never be complete.
This obviously is a disadvantage for the generation of complete sets of synthetic seismic data, but can also be considered as a major advantage for target-oriented studies. Raytracing on just two or three target interfaces is flexible and computationally very fast, even in 3D. Moreover, raytracing has no problems with boundary boxes and is generally robust and stable, especially if wavefront construction rather than classical raytracing is applied. However, the major advantage of raytracing is that the energy is labelled along the raypath and that, e.g., the location of reflection points is known. This makes raytracing perfectly suited for illumination studies, e.g. to generate fold and amplitude maps on the target, find the required offsets and recording time, study azimuth and angle relationships, get an estimate of the expected migration aperture, and to test a number of different survey templates for all these parameters efficiently.

In this case, narrow-azimuth (NAZ), wide-azimuth (WAZ), multi-azimuth (MAZ) and coil shooting streamer templates were tested in addition to different ocean-bottom cable (OBC) setups. Comparing results based on the initial NAZ field data with corresponding raytracing results indicated that the amplitude shadow zone as generated by the combination of salt and high-velocity layer in the overburden was consistent in both data sets and for both reservoir target horizons, providing high confidence in the raytracing model.

Raytracing results further indicated that the initial survey could have been improved by an extension of cable length to 8 km, a change in survey direction by 45-90°, and a change in the source array in order to provide more energy more efficiently. Even so, a NAZ survey does not provide sufficient fold and azimuthal coverage in some areas. With regard to the general trend, significant improvement was achieved by extending the NAZ to a MAZ survey, i.e. by adding two more survey directions. However, within the smaller core area of interest beneath the salt, only OBC provided satisfactory results. This was mainly decided based on two attributes: fold (Figure 1) and a measure of relative PSDM amplitude on the target as generated by migrating raytracing results along the target interface. Lateral and vertical resolution was not much affected by the different survey templates. Taking attenuation into account, the suggested source should be able to resolve about 30 m thick structures.

![Figure 1 Fold comparison, narrow-azimuth, multi-azimuth and ocean bottom cable. The grey area is a non-illuminated area due to very steep dips, while the shadow zone is a low hit-count area to the northwest of the grey area.](image)

It was thus decided to take an OBC template on for further testing. In general, OBC data can be expected to provide reasonable signal-to-noise ratio (due to quiet surroundings at the seafloor) and
larger bandwidth (as the low frequency spectrum is flatter due to a deep cable and dual sensors are able to partly compensate for ghosts). However, as the initial NAZ data were severely distorted by multiple reflections, effects of both multiple and noise suppression during processing had to be tested. As even advanced raytracing applications like Kirchhoff modelling do not provide the full wavefield, this had to be done by wavefield extrapolation modelling.

To reiterate, Part 2 and Part 3 (described in detail below) were aimed at using the synthetic shots to determine the effectiveness of the acquisition designs and to see if one of the templates gave an advantage when it came to the processing stage. It was also envisaged that with the optimum template it would be possible to look at decimation trials and how these results would affect a final image.

**Part 2: Generation of synthetic data (wavefield extrapolation modelling)**

A finite difference acoustic modelling algorithm was used to generate synthetic shot gathers by means of two-way wavefield extrapolation modelling. The output synthetic shot gathers contained direct arrivals, primaries, surface multiples, and interbed multiples. The input model was specified as a dense 3D grid of velocity Vp, anisotropy parameters (vertical transverse isotropy) and density. In general various source wavelets can be applied and any frequency bandwidth can be specified although higher frequencies have a significant impact on performance. In this instance we used a 15Hz peak frequency Ricker wavelet. For each geometry modeled, simple stacks (without any preprocessing or migration) were generated as part of the modelling QC. Each geometry gave clearly different results and these differences are partly the result of the different response to the earth model e.g. shooting direction and partly the result of the different trace sampling used for each acquisition geometry. We concluded that the combination of raytracing and wavefield extrapolation methods provided the following benefits:

- Raytracing provides the ability to generate a “primary only” dataset, which is very helpful during interpretation of results
- Finite difference modelling allows us to generate a primary plus multiple dataset without limiting the orders of multiples
- Synthetic shot gathers derived from finite difference modelling can be processed for the removal of multiples prior to final imaging

**Part 3: Seismic processing results**

Processing of each of the synthetic data sets followed a simple flow, keeping to the basic needs of the data. This consisted of first-arrival muting, a trace-by-trace deconvolution, binning and prestack depth migration. The velocity model for the migration came from the legacy streamer data PSDM project. The aim was to keep this flow simple in order to be able to see if one of the templates delivered superior results.

The NAZ result showed a noise zone that corresponded very closely to the area of poor image on the streamer data. The reflectivity of the deeper events was very similar between the legacy data and the NAZ model. The OBC modelled dataset (Figure 2) is currently being tested for improved de-multiple processing, but is expected to show a much-improved image compared to the NAZ with higher reflectivity under the salt with a good chance to map events continuously.
**Figure 2** Preliminary synthetic seismic sections (OBC) as generated by wavefield extrapolation (including multiples) and raytracing (including primaries only). The effect of attenuating multiples during processing is tested on the full-wavefield synthetic data, using raytracing results as multiple-free reference. The section shown has a thickness of about 4 km.

**Conclusions**

We demonstrate an example of a complete survey design and modelling study, which covers (1) analysis of existing survey results, (2) an extensive illumination study, and (3) testing of processing effects on a full set of synthetic seismic data. Both raytracing and wavefield extrapolation are used in a complementary manner: the raytracing results enable us to show that an OBC acquisition geometry would provide optimum sub-surface illumination, while the wavefield extrapolation modelling enables us to demonstrate the uplift in image quality over conventional (narrow-azimuth) acquisition. Consistent results were achieved when comparing field data and modelled data. In the future we believe there is a high potential to learn even more from this data set when the field OBC data are available for real benchmarking of our methods. This will be a unique data set with regard to its completeness.

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**References**

