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Separated Wavefield Imaging for Shallow Geohazard Analysis - An Ocean Bottom Study on a North Sea Dataset

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Summary

We present a method using separated wavefield imaging to mitigate risk associated with well drilling. In shallow water environments the process of geohazard assessment is challenging. Conventional acquisition processed for shallow hazard assessment is deficient in shallow reflectivity. This leads to appraisal difficulties. High resolution site surveys are often acquired and then processed, but incur additional costs. Imaging with separated wavefields uses up-going and down-going wavefields at the surface to deliver high-resolution images of the subsurface. It takes advantage of the extended illumination provided by surface-multiple energy. We present a feasibility study for using this technology on a shallow water ocean bottom cable acquisition, demonstrating the suitability of this technology to mitigate geohazard assessment.

Introduction

To mitigate risk associated with well drilling for field development, a geohazard assessment is performed. Typically this appraisal follows a two stage approach; a screening of the seismic data to detect outliers based on reflection strength, and an AVO analysis to predict the composite nature of those anomalies.

In shallow water environments this process is challenging. Conventional acquisition processed for shallow hazard assessment is deficient in shallow reflectivity, leading to appraisal difficulties. To accommodate this ‘so-called’ high resolution site surveys are often acquired and then processed. Surveys of this type attempt to mitigate the challenges of geohazard assessment in shallow water by modifying the acquisition geometry, however site surveys incur additional costs. This is often controlled by acquiring the site survey sparsely. In ocean-bottom data, imaging challenges can also exist because of the interplay between source and receiver sampling and the depths of near surface reflectivity.

Imaging with separated wavefields is an innovative imaging technology that uses up-going and down-going wavefields at the surface to deliver high-resolution images of the subsurface (Lu et al., 2015). It takes advantage of the extended illumination and angular diversity provided by surface-multiple energy, and thus, it exploits data that the seismic industry historically has treated as unwanted noise. The benefits of this process are represented in Figure 1.

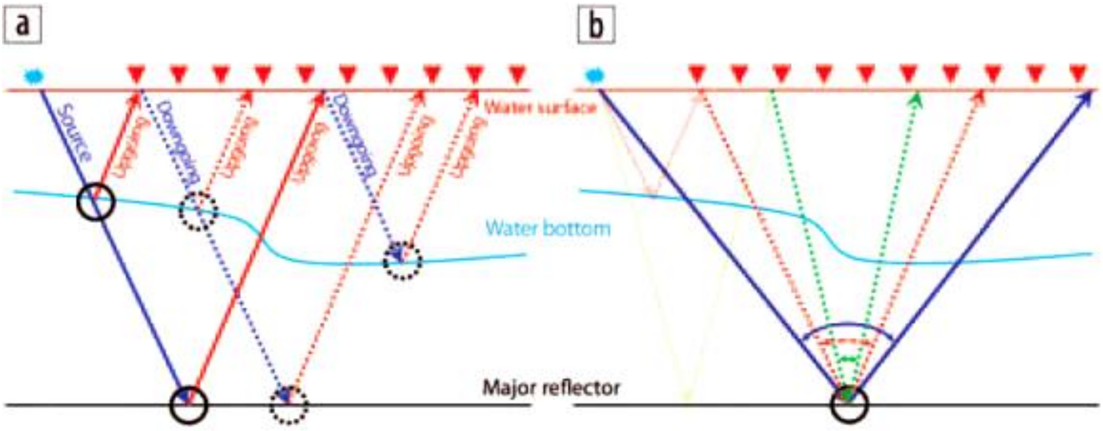

Figure 1. *Schematic diagram for primary (solid) and multiple (dashed) wavefield trajectories. 1a shows multiple reflection imaging points (dashed circles) illuminate more of the subsurface than primary (solid circles). 1b shows for a given sub-surface illumination point, the multiple contribution has greater angular diversity.*

We present an application of this imaging technique to an ocean-bottom acquisition dataset and make a comparison against conventional primary imaging and a high resolution site survey for geohazard assessment. We demonstrate the technology can produce a finely sampled, survey-wide dataset, with the same image quality as a high resolution site survey and mitigate the cost associated of performing a site survey acquisition.

Method

Geohazard assessment is often based on a two stage approach; firstly a seismic screening phase to detect anomalies based on the strength of reflectivity, and secondly an analysis phase to identify and classify the AVO response of the data (Paternoster et al., 2007). The second phase enables a more detailed understanding of near-surface hazards. In addition to this method, there are numerous other approaches that enable a more detailed geohazard evaluation, for example Pivot et al. (2014). In each method, the analysis requires access to meaningful data.

In shallow water environments, the interplay between acquisition geometry and sub-surface geology can inhibit effective illumination and angular diversity in the near-surface. To circumvent this high resolution site surveys are often acquired. For this the acquisition geometry is modified to optimize near surface reflectivity imaging. To reduce costs site surveys are often sparsely sampled. Processing algorithms are used to accommodate the sparse acquisition.

The principle behind separated wavefield imaging is the use of each receiver as a virtual source. This expands the surface coverage of the seismic experiment and enhances the subsurface illumination. To achieve this the down-going wavefield is used as the virtual areal source. This results in images with increased angular illumination. As a result, the use of multiples improves the extent of the subsurface image and its resolution. Significant near-surface image improvements are observed for all acquisition geometries. Lecerf et al., (2015) demonstrate for ocean bottom acquisition conventional imaging uses either the up-going or down-going wavefield (Figure 2a, 2b). For separated wavefield imaging, each receiver acts as a virtual source and allows the exploitation of both primary and sea-surface reflections (Figure 2c, 2d). This improves both illumination and angular diversity.

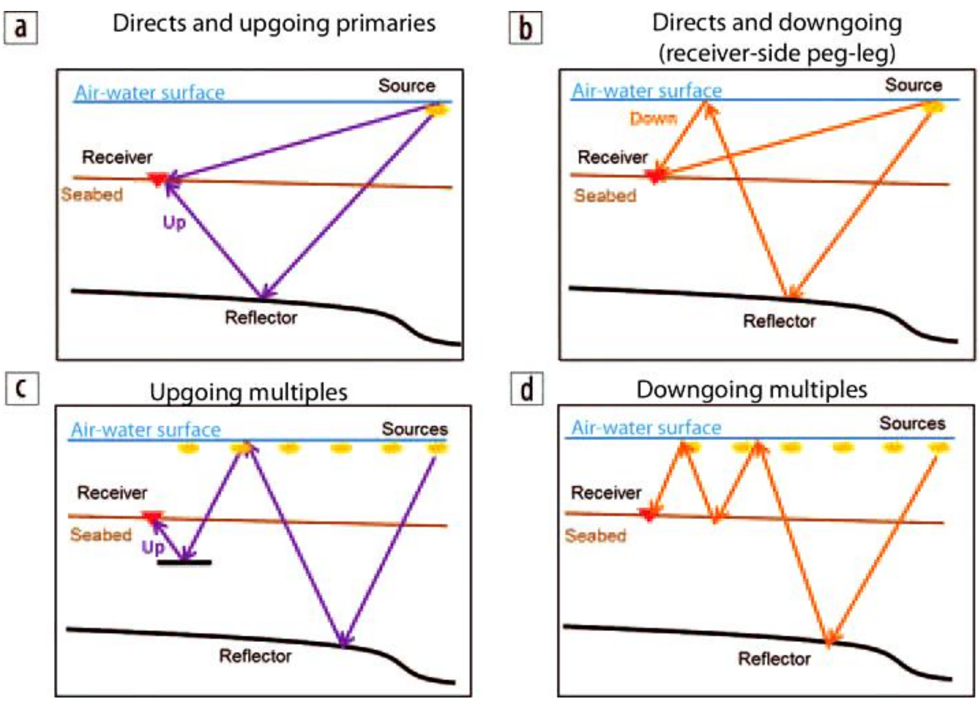

Figure 2. *Schematic showing conventional imaging of ocean-bottom data (2a/2b). The benefits of imaging with separated wavefields is demonstrated in 2c and 2d.*

Claerbout (1971) demonstrated that the reflectivity coefficient in shot record wavefield extrapolation migrations can be estimated by the deconvolution of the receiver wavefield by the source wavefield. In separated wavefield imaging the process of using the down-going wavefield as a virtual areal source can create cross-talk (Lu et al., 2015). Whitmore et al. (2010) demonstrate that this can be reduced by using a deconvolution imaging condition (Guitton et al., 2007) during migration:

$$R(\vec{x}) = \sum_{\vec{x}_s} \sum_{\omega} \frac{P_{\mathrm{up}}\left(\vec{x}_s, \vec{x}, \omega\right) P^{*}_{\mathrm{dwn}}(\vec{x}_s, \vec{x}, \omega)}{\langle P_{\mathrm{dwn}}(\vec{x}_s, \vec{x}, \omega) P^{*}_{\mathrm{dwn}}(\vec{x}_s, \vec{x}, \omega)\rangle_{\vec{x}} + \varepsilon(\vec{x}_s, \vec{x}, \omega)} \tag{1}$$

Where P_{up} and P_{dwn} are the respective up-going and down-going wavefield at an image point $\vec{x}$. The wavefields are using a common source $\vec{x}_s$ and that they are presented in the frequency domain (ω).

Remaining cross-talk can be eliminated by post-processing of the image data. In equation (2) using an extended imaging condition enables a pre-stack angle gather output $I(\vec{x}, \vec{h})$ (Whitmore et al 2010):

$$I(\vec{x},\vec{h}) = \sum_{\vec{x}_s}\sum_{\omega} \frac{P_{\text{up}}(\vec{x}_s, \vec{x}, \omega, \vec{x}+\vec{h}) P^*_{\text{dwn}}(\vec{x}_s, \vec{x}, \omega, \vec{x}-\vec{h})}{\langle P_{\text{dwn}}(\vec{x}_s, \vec{x}, \omega, \vec{x}-\vec{h}) P^*_{\text{dwn}}(\vec{x}_s, \vec{x}, \omega, \vec{x}-\vec{h})\rangle_{\vec{x}} + \varepsilon(\vec{x}_s, \vec{x}, \omega)} \qquad (2)$$

Where $\vec{h}$ is the source-receiver half offset. The resulting gathers are converted from sub-surface offset to angle using a radial transform (Rickett and Sava, 2002). Separated wavefield imaging can therefore be used on existing seismic acquisition for geohazard assessment, both for reflectivity screening and pre-stack AVO analysis.

Field example

We present an application of separated wavefield imaging for geohazard assessment over the Culzean field, located in approximately 120 m of water in the UKCS Quad 22 block. We compare a high resolution 2D site survey with a separated wavefield imaging application to a four component ocean bottom cable survey.

The ocean bottom survey was acquired in 2010. The survey was broken down into two swaths each with six receiver lines, each 350 m apart with 25 m between receivers. 188 source lines were shot each 100 m apart and shooting 25 m flip-flop. Acquisition was done in patch mode.

The interplay between water depth and ocean bottom acquisition geometry makes interrogation of the near surface reflectivity very challenging for conventional imaging. To mitigate overburden geohazards, a site survey was acquired in 2013 consisting of 85 lines covering a survey area measuring 4.8 km x 4.3 km. All lines were acquired with a two second record length using a 48 trace streamer with 12.5 m groups, an inline spacing of 50 m and a 6.25 m shot interval.

Conventional processing of the ocean bottom cable data was compared to the processing product from the 2D site survey; a separated wavefield imaging application to the ocean bottom cable.

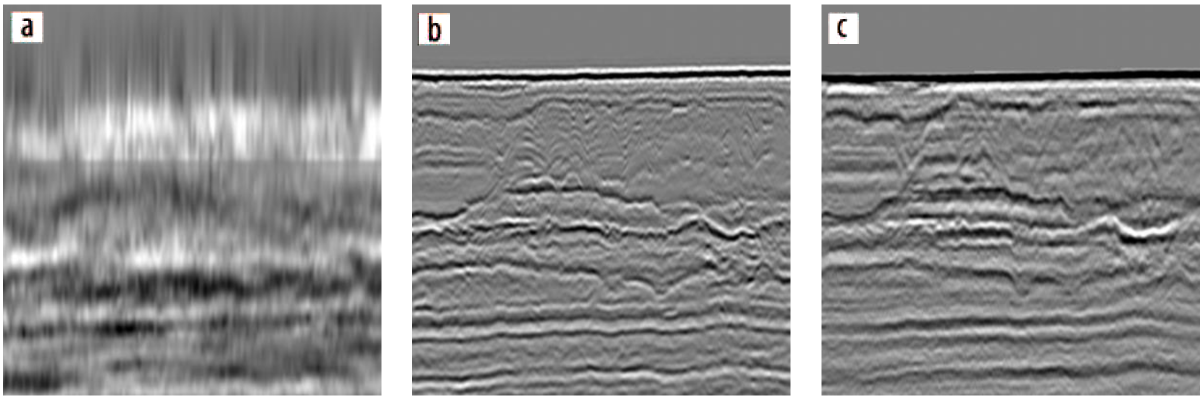

***Figure 3**. a) Conventional imaging on OBC data. b) Conventional imaging on site survey data. c) Separated wavefield imaging on OBC data.*

In Figure 3a it can be seen that the conventional imaging of the ocean bottom cable data has poor image clarity. Most primary imaging data is post-critical and the data quality means that it is uninterpretable for geohazard analysis. By contrast the site survey data (Figure 3b) shows resolution fit for geohazard assessment. However, to achieve this an additional and significant outlay is required. To mitigate this using separated wavefield imaging on the ocean bottom acquired data gives an image with similar clarity and resolution at the site survey (Figure 3c).

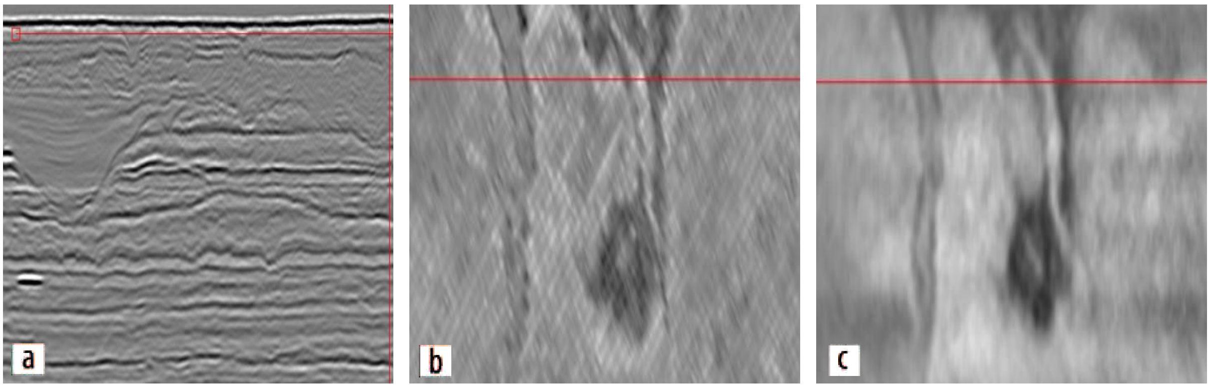

***Figure 4**. a) Conventional imaging on site survey data. b) Shallow time slice on site survey data. c) Shallow time slice of separated wavefield imaging on OBC data.*

In Figure 4 we see that data resolution in a common time slice obtained from using separated wavefield imaging on the OBC data (4c) is equivalent to the site survey slice (4b). The product has the same survey-wide suitability for geohazard assessment.

Conclusions

We have introduced separated wavefield imaging. The results of this have been demonstrated to produce data suitable for geohazard assessment on conventionally acquired ocean bottom data. By using separated wavefield imaging for geohazard assessment, we have presented an approach to mitigate the additional expenditure associated with performing this kind of analysis using site survey acquisition and processing.

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