The effects of gas clouds on converted-wave imaging: A case study from Valhall

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Summary

We investigate the effects of gas clouds on P-S converted waves (C-waves) and evaluate practical schemes which compensate for these effects to improve C-wave imaging using the 2D4C dataset from Valhall. The Valhall C-wave data suffer from severe *diodic* effects (variations with the source-receiver direction) due to gas clouds. These include *diodic illumination effect*, *diodic velocity (V_c) effect*, and *diodic velocity ratio (γ_{eff}) effect*. Careful processing is required to compensate for these effects. Firstly, the dataset is separated into positive (+) and negative (-) offset data volumes to perform separate velocity analyses. Secondly, since the P-wave velocity is not reliable due to the gas clouds, a data-driven approach, based on optimizing the focus of the C-wave imaging, is required to quantify γ_{eff} . This approach works well in areas free of the diodic illumination effect, and leads to the identification of not only a vertically varying but also a laterally varying γ_{eff} between 2.2 and 2.8. A simple partition of the dataset is adopted to account for the vertical and lateral variation of γ_{eff} before a full prestack depth migration, and yields an improved C-wave image at Valhall.

Introduction

The Valhall reservoir cannot be well imaged by conventional P-wave techniques due to the effect of a gas cloud (Thomsen *et al.* 1997). Although P-S converted-waves (C-waves) have been successfully used to image beneath gas clouds in Valhall as well as in other areas (Berg, 1994; Granli *et al.*, 1999), C-waves may still suffer from undesirable effects due to the gas clouds. These side effects, compounded with the asymmetric raypath of the C-wave, will further increase the difficulties and costs in processing. Here, using the Valhall 2D4C dataset as an example, we examine these effects and discuss ways to compensate for these effects during processing.

The effects of gas clouds

At the edge of a large gas cloud, depending on the source/receiver direction, the (downgoing) P-wave leg of a C-wave arrival may or may not go through the gas cloud (Figure 1). On one hand, if the P-wave leg **is** going through a gas cloud (-offset, Figure 1), the resultant C-wave will be very weak if not absent; on the other hand, if the P-wave leg **is not** going through the gas cloud, the resultant C-wave can be very strong. We refer to this as the diodic illumination effect as shown in Granli *et al.* (1999). Figure 2 shows an example of this effect from Valhall. The event (white arrow) in positive offset has strong energy, but it fades in negative offset. If the gas cloud is small and represents a mild velocity variation, the target will still be illuminated from shooting in both positive and negative offsets, but it will result in different stacking velocities (V_c) with source/receiver direction, and this is referred to as the *diodic V_c* , as shown in Thomsen (1999). During processing of the Valhall dataset, we also find that γ_{eff} is laterally changing (due to inhomogeneity) and *diodic*. (More details are discussed in the section on focusing analysis). As a result, it is difficult to select a correct velocity and γ_{eff} suitable for both positive and negative offsets for subsequent processing.

Data processing

Offset separation. The dataset is separated into positive (+) and negative (-) offset volumes in order to compensate for diodic effects. Figure 3 shows the C-wave images for positive and negative source/receiver direction. Due to the effect of *diodic illumination*, the target event (between 5s – 6s) is not clear between CCP 1150 and 1230 on the negative offset section and between CCP 950 – 1100 on the positive offset section. Although the events between

CCP 850 – 950 appear in both offsets, their shapes are different. We believe this difference is caused by possible diodic variation in γ_{eff} . To account for this, a separate focus analysis is required for the two data volumes.

Focusing analysis: γ_{eff} is an important parameter in C-wave processing. It affects the conversion point position, and hence the C-wave stacked image. The lateral variation of γ_{eff} may cause an event to differ on two separate offset images. In order to examine the effect of γ_{eff} variation, we CCP bin the C-wave dataset allowing different γ_{eff} and process each dataset accordingly (CCP scanning). Figure 4 shows the CCP scanning results for shallow events (0.5s – 2.0s) for both offsets. If γ_{eff} is either too big or too small, the events on the two images with +/- offsets have a different appearance. With a proper γ_{eff} (e.g. 2.5), the events on the two images are nearly identical and focused.

We also perform focusing analysis at the target zone (4.5s – 6.0s). We subdivide the selected data into two blocks: block 1 - CCPs 900-1000, and block 2 - CCPs 1000-1100. For block 1, a common γ_{eff} equaling 2.2 can be identified for both the positive and negative offset dataset (bottom left, Figure 5). However, for block 2, it is difficult to select a common γ_{eff} . For positive offset $\gamma_{eff} = 2.5$ is the best pick (middle right), whilst for negative offset, there is no obvious choice of γ_{eff} .

To sum up, our analysis shows that the events are better focused on the C-wave image with γ_{eff} between 2.2 and 2.5. The image is smeared with γ either too large or too small, and a laterally varying and diodic γ_{eff} is evident from focusing analysis.

Depth- and offset-dependent CCP binning: Full compensation for gas cloud effects requires prestack depth migration which is expensive and needs a precise macro-velocity model. This approach may not be practical in certain circumstances. A simple alternative is to perform a depth- and offset-dependent CCP binning procedure in order to account for lateral and vertical velocity variation followed by DMO and post-stack migration (Zhu, et al, 1999). Here we subdivide the data into five blocks. Separate depth-dependent CCP binning with three vertical zones is performed for these five blocks for both positive and negative offsets. Different V_c 's and γ_{eff} 's are used to process the data. The final image is combined from these blocks and is shown in Figure 6. Apart from the blank zone (near the center of the gas clouds), an improved C-wave image of the target is achieved before pre-stack depth migration, which was not obtained on the P-wave image (Figure 7).

Conclusions

This work examines the *diodic* effects of gas clouds on C-waves using the Valhall 3D4C dataset. The Valhall data show strong *diodic illumination*, *diodic V_c* and *diodic γ_{eff}* and lateral variation in γ_{eff} . Carefully choosing the correct γ_{eff} can improve the C-wave image. A depth- and offset-dependent CCP binning procedure is proposed to compensate for these *diodic* effects before pre-stack depth migration, and an improved image of the target is achieved.

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Figure 1. The diodic effects of a hypothetical gas cloud. For C-waves with -offset, the downgoing P-wave passes through the gas cloud. For C-waves with +offset, the downgoing P-wave does not. The two C-waves have different V_c and amplitude.

Figure 2. An example showing diodic illumination from the Valhall 2D4C dataset. The right panel is the CCP (1250) gather and the left panel is the velocity spectrum. The event in +offset (right side) is clear, but it fades in -offset (left side).

Figure 3. An example of diodic C-wave imaging. The upper panel is obtained from -offset data with $\gamma_{eff} = 2.2$ in which the event on the left is clear. The lower panel is obtained from +offset data with $\gamma_{eff} = 2.2$ in which the event on the right is clear.

Figure 4. A shallow event obtained from +/- offset with different γ_{eff} . The image with $\gamma_{eff} = 2.5$ has the best quality and the events in both offsets are similar and well focused.

Figure 5. The target (deep) event obtained from (+/-) offset with different γ_{eff} . The events between CCPs 900 - 1000 have the better image and is well focused for both offsets with $\gamma_{\text{eff}} = 2.2$. However the events between CCPs 1000 - 1100 have a better image and are well focused with $\gamma_{\text{eff}} = 2.5$. This shows the lateral changes in γ_{eff} .

Figure 6. A C-wave image of the target event. The processing considers the effects of diodic V_c and the lateral variation in γ_{eff} . The time is converted into P-P time.

Figure 7. The P-P image corresponding to the C-wave image of Figure 6. There is no clear event to indicate the target.