Compensating for the Effects of Gas Clouds by Prestack Migration: A Case Study from Valhall

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Summary

In this paper, we develope a practical scheme for compensating for the effects of gas clouds using the 4C 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. To compensate for these effects, the dataset is separated into positive and negative offset data volumes and a Kirchhoff prestack migration method that can handle both vertical and lateral velocity variations is applied to the positive and negative datasets separately. This allows the determination of the migration velocity and velocity ratio by imaging optimization and focusing analysis. This approach yields an improved C-wave imaging in Valhall.

Introduction

The Valhall reservoir of North Sea is a classical example that cannot be well imaged by conventional P-wave techniques due to the effect of the 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 (Granli *et al*, 1999), C-wave may still suffer from severe 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 C-waves. Due to the effect of gas clouds, both depth and lateral variations of P- and S-velocities and γ should be taken into account during C-wave processing.

Conventional methods have difficulties to deal with the velocity variations for C-wave processing, especially in the common conversion point (CCP) binning procedure. *P-S asymptotic conversion point (ACP) binning* uses only one γ value for the whole dataset. *Depth varying CCP binning* can only deal with depth variation of γ. Hence, the common conversion point in a CCP gather is not the true conversion point. As a consequence, the final stacked image is often smeared. To overcome this problem, one possible solution is to use Kirchhoff prestack migration, which avoids the CCP bining and may provide a natural method to deal with this problem.

The effects of gas clouds

The presence of gas clouds has some major effects on C-waves, some of which are described in the literature (Granli et al. 1999; Thomsen, 1999). At the edge of a large gas cloud, depending on the direction of shooting, e.g. positive or negative offsets, the P-wave may or may not go through the gas cloud. On one hand, if the P-wave leg is going through the gas cloud, 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 will be very strong. We refer to this as the diodic illumination effect as shown in Granli et al (1999). 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 velocity (Vc), and this is referred to as the *diodic V_c* as shown in Thomsen (1999). During processing of the Valhall data, we also found that γ_{eff} changes laterally (inhomogeneity). As a result, it is difficult to select a correct velocity and γ_{eff} to suit both positive and negative offsets for subsequent imaging processing. In order to handle this velocity variation, we use Kirchhoff prestack migration to process C-wave data.

Prestack migration

Kirchhoff (time and depth) prestack migration is a very efficient method for imaging processing of 2D and 3D seismic data (Bevc, 1997). According to the way traveltime is calculated, Kirchhoff prestack migrations are divided into two groups: depth migration and time migration. Kirchhoff depth migration assumes a known velocity structure and estimates the correct diffraction shape. It uses a ray tracing method to calculate the travel time, and can handle the depth and lateral velocity variations. However, it is time consuming and requires the exact velocity structure which may be difficult to obtain. The time migration uses the prestack migration ellipse or ellipsoid to calculate the travel time. It is fast and only requires the RMS velocity, which are easy to obtain by conventional velocity analysis. However, it is restricted to constant or depth varying velocities.

In order to handle the lateral variation of velocities for C-wave, we combine the concepts of depth and time migration, to perform prestack time migration. In this method, we calculate the traveltime using the RMS velocity along a straight raypath instead of using a ray-tracing method. The RMS velocity may laterally change corresponding to the data.

The input velocity profiles are the C-wave velocity (Vc), the velocity ratio (γ), and vertical velocity ratio (γ_0). Vp and Vs can be calculated using following equations (Thomsen, 1999).

$$V_c^2 = \frac{V_p^2}{1+\gamma_0}(1+\frac{1}{\gamma_{eff}}) \qquad (1)$$

where

$$\gamma_0 = \frac{t_{s0}}{t_{p0}}, \ \gamma_{eff} = \frac{\gamma^2}{\gamma_0} \text{ and } \gamma = \frac{V_p}{V_s}.$$

The advantage of using Vc and γ as inputs is that they can be obtained from C-wave alone by a data driven approach. Vc, γ and γ_0 can be specified for different CDPs to handle lateral variation. The input velocity data are then linearly interpolated to all time and all CDPs.

Prestack migration velocity analysis

As a time migration, the migrated image is a time section. The event location is independent of the velocity ratio. However, the event focusing depends on the velocity ratio. This provides a method to perform focusing analysis for C-wave. The procedures to perform the velocity analysis are:

(1) Obtain initial Vc from semblance velocity analysis and initial γ from joint P- and C-wave analysis;
(2) Apply Kirchhoff time migration to the C-wave data, separated into positive and negative offsets.
(3) Adjust Vc for best imaging quality;
(4) Adjust γ for best focus between the postive-and negative offset images.
(5) Repeat (2),(3) and (4) till the images are well optimized and focused.

Results

We applied this approach to the Valhall C-wave data. Figures 1 and 2 show parts of the migrated image of C-wave after several iterations to analysis the velocity and improve the imaging focus. Figure 1 is the result from positive offset data and Figure 2 from negative offset data. Different velocities are used for the two (+/-) offset data volumes. There is a sharp difference in the two images (Figures 1 and 2), and this differences is caused by the gas clouds due to the *diodic* illumination effects. For example, the events in the left part of Figure 1 (+offset data) and the events in the right part of Figure 2 (-offset data) are very weak. The final migrated image can be obtained by adding the two images together (Figure 3).

For comparison, Figures 4, 5 and 6 show, respectively the ACP stacked section, the DMO stacked section and the corresponding P-wave stacked section. Comparing Figure 3 with Figures 4 and 5 shows that the migrated imaging is much sharper and the fault blocks underneath the gas clouds are well imaged. In the other hand, smearing in both the ACP and DMO stacked section is evident (Figures 4 and 5) and the P-wave imaging is completely degraded by gas clouds (Figure 6).

Conclusions

A practical scheme is developed to perform the C-wave Kirchhoff prestack migration with vertical and lateral velocity variations. It avoids the problem of CCP binning for processing C-wave. Applying this scheme to Valhall C-wave data demonstrates its ability to compensate for the effects of gas clouds. The migrated result shows a better imaging under the gas cloud than other conventional methods.

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Compensating gas cloud effects using prestack migration

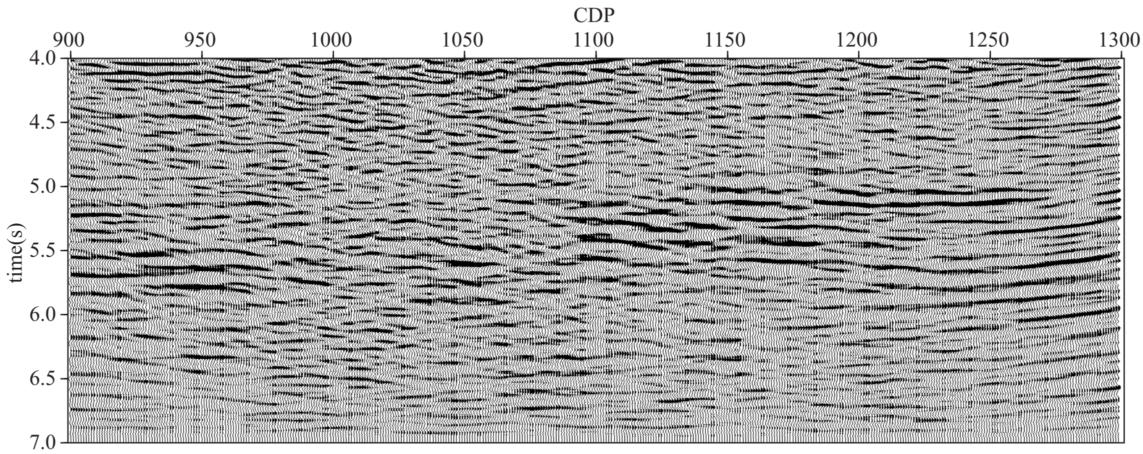

Figure 1. The migrated image of positive (+) offset data. The velocities used vary vertically and laterally. Due to the effect of gas clouds, it only undershoots at the right side of the gas clouds.

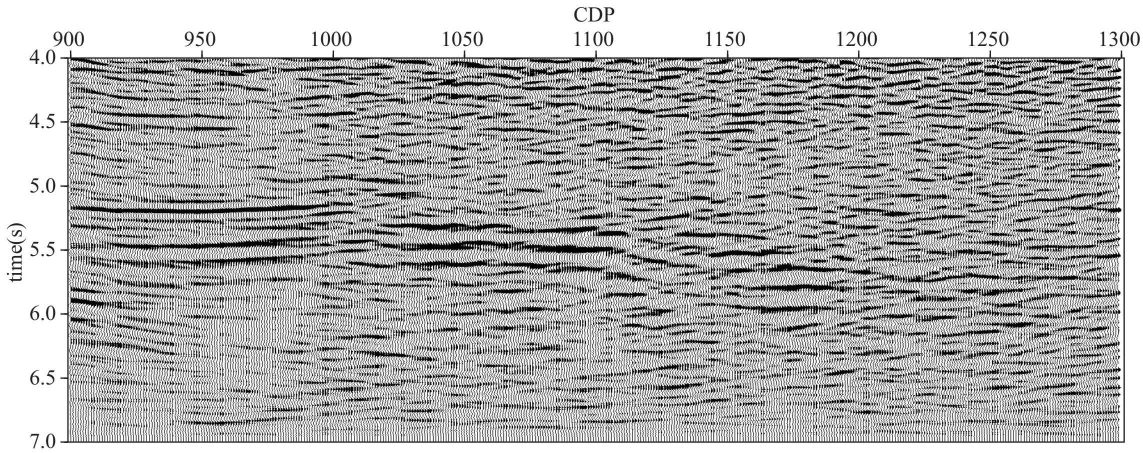

Figure 2. The migrated image of negative (-) offset data. The velocities used vary vertically and laterally and are different from Figure 1. Due to effect of gas clouds, it only undershoots the left side of the gas clouds.

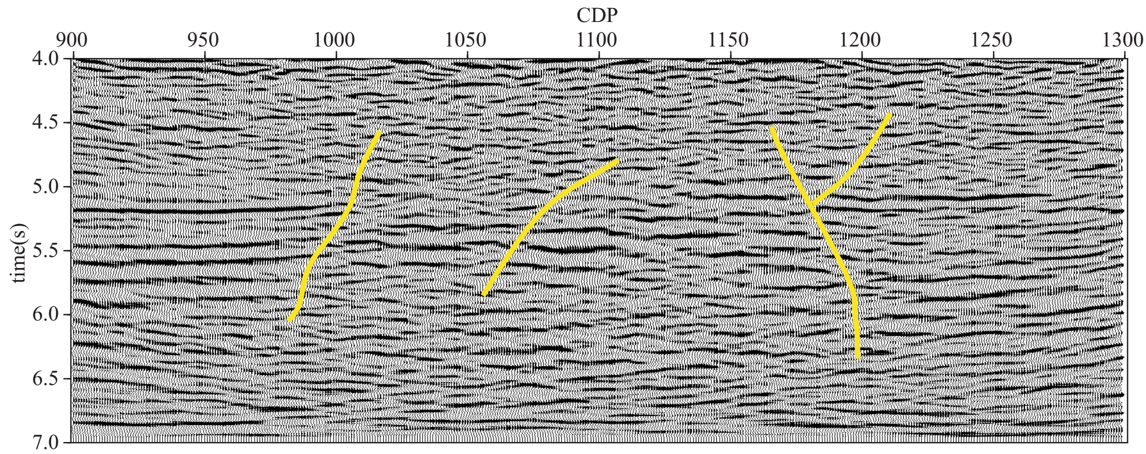

Figure 3. Combination of Figures 1and 2. The imaging is very sharp with a clear display of the fault blocks underneath the gas clouds.

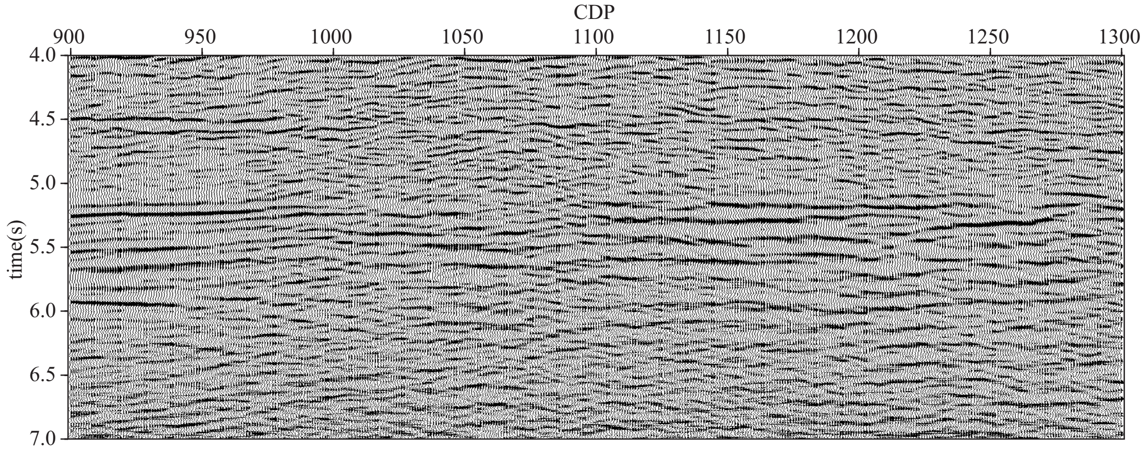

Figure 4. The stacked image using C-wave CP binning

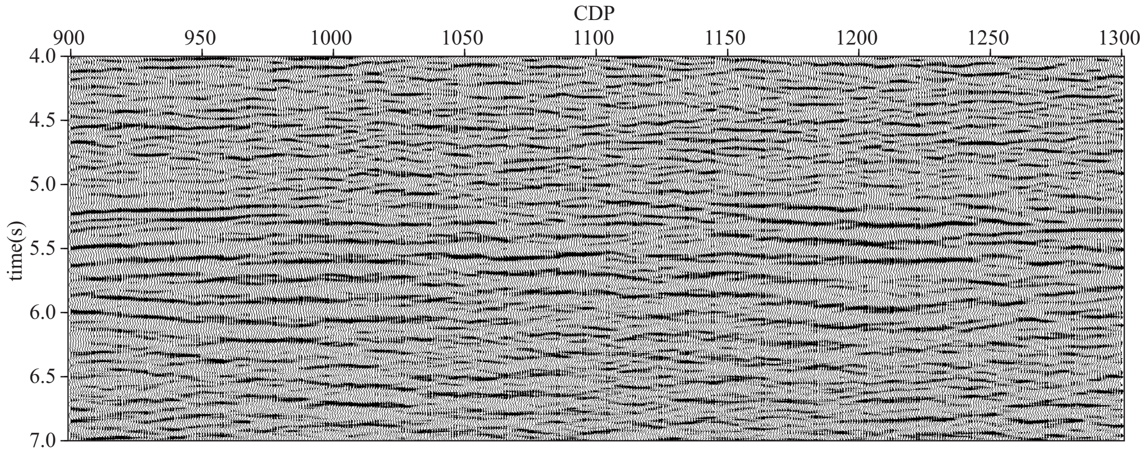

Figure 5**.** The stacked image after CP binning and D

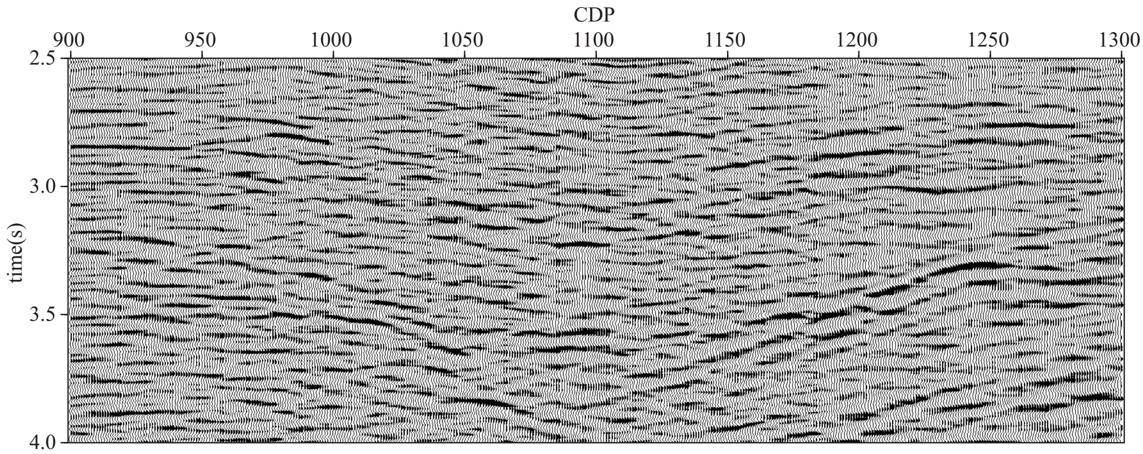

Figure 6. The P-wave stacked image under the gas cloud corresponding to the C-wave image.