Separation of focusing and positioning effects using wave equation based focusing analysis and post-stack modeling

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Summary

We have developed a new methodology to produce a best-focused zero-offset image, even though the migration velocity model has errors. In this methodology, first we generate Common Focusing Error (CFE) images using wave equation based prestack migration and applying zero-time as well as non-zero-time imaging conditions. Then a semi-automatic procedure is applied to pick the focusing error ($\Delta T$) field, and the picked $\Delta T$ field is used to select the best-focused image from the CFE images. To produce an accurately positioned and well-focused zero-offset image, we separate the prestack focusing effect from the post-stack focusing effect, by performing post-stack demigration followed by $\Delta T$ compensated post-stack remigration.

Introduction

Recently the migration perturbation scan technique (Yilmaz and Chambers, 1984; Wang et al., 2006) has become common for use in updating subsalt velocity models. Though the subsalt scan technique is promising, the cost of generating a seismic migration scan is still very high, and it requires multiple prestack migration runs. To address the cost issue, last year we presented two low-cost alternatives for subsalt scan (Wang et al., 2005). The first alternative is to separate prestack focusing effect from post-stack modeling effect. In that approach, we perform one prestack migration to produce a reasonably good subsalt image, then we take that image as a zero-offset image, upon which we perform post-stack demigration, followed by post-stack subsalt perturbation scans. The second alternative is subsalt scans using wave equation based focusing analysis (Faye and Jeannot, 1986; McKay and Abma, 1992; Audebert and Diet, 1993; Wang et al., 1995, 2005). In that approach, we use only one migration velocity model, and perform only one prestack migration, but applying zero-time as well as non-zero-time imaging conditions to produce multiple images.

In this paper, we present a consolidated approach that combines advantages of both alternatives. One of the assumptions of the first approach mentioned above is that prestack migration has already taken care of prestack focusing effects. This means that if we were to produce Common Image Point (CIP) gathers, the observed residual moveout would be insignificant. In this paper we present how to use focusing analysis to further reduce prestack effects, in an equivalent way to residual moveout analysis. By combining the two above-mentioned approaches, we can produce a better-focused zero-offset (stack) image. This image is similar to the improved Kirchhoff image obtained by residual moveout correction prior to stacking (Lemaistre et al., 2005), but in our case with the benefits of wave equation migration, and without the need to produce expensive image gathers in angle.

Common Focusing Error (CFE) images in focusing depth domain

As described by Faye and Jeannot (1986) and McKay and Abma (1992), when the migration velocities are in error, reflected energy collapses to zero offset, at some extrapolation depth, but at a time that is inconsistent with the zero-time imaging condition at this depth. This results in a deteriorated seismic image. In the classic depth-domain focusing analysis, sparse 1D focusing panels are formed and a focusing error is defined as the depth difference between the focusing depth and the migration depth, with the true reflector depth positioned in between.

As described in our previous work (Wang et al., 1995; 1998; 2005), we form full volume CFE images where the focusing error is defined as the required deviation from the zero-time imaging condition in order to form a well focused image (DeVries and Berkhout, 1984; Willis, 1990, 1991). The CFE images are produced through downward continuation of wavefields and application of zero-time as well as non-zero-time imaging conditions at each depth level. Each CFE image is formed through the application of
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a discrete ∆T imaging condition, whereas the regular migration image corresponds to ∆T equals to zero.

Picking focusing error (∆T) field in pseudo depth domain

For a 3D case, the full volume CFE images represent a 4D seismic cube, the 4th dimension being the focusing error (∆T). To facilitate the picking, the CFE images are first converted to pseudo depth: in their original focusing depth scale, even a flat event would move up and down according to the different focusing error (∆T) values. To convert from focusing depth to pseudo depth the CFE image corresponding to a given ∆T, we first vertically stretch each trace of the CFE to time domain using the migration velocity model, then we statically shift the time trace by the amount –∆T, then we vertically stretch it back to depth domain. To pick the best-focused CFE images we use the same tools and techniques as described in Dirks et al. (2005).

Figure 1 is an example of a migration image using a wrong 1D subsalt velocity. Figure 2 is the composite focused image, in pseudo depth, extracted from the volume of CFE images, according to the picked ∆T field. For comparison, Figure 4 is the migration image using the true velocity model. Clearly, the composite focusing analysis image, in pseudo depth, is much better focused than the migration image (Figure 1), but the reflectors are wrongly positioned, checked against Figure 4.

There are many advantages to picking the focusing error (∆T) in the pseudo depth domain. First, the conversion to pseudo depth scale is simple and reversible: the pseudo depth can be accurately converted back to the focusing depth, which is needed along with ∆T if we want to perform a tomographic velocity update (Wang et al., 2005). Secondly the vertical conversion does not move around laterally the energy of the picked foci and thus preserves the focusing already obtained in both prestack domain (across offsets or reflection angles) and post-stack spatial domain (across diffractions in CDP and Line directions).

Producing a best focused zero-offset image in migration depth domain

The composite image (Figure 2) in pseudo depth, though better focused, is not a good starting point for our post-stack demigration and subsalt scans for two reasons. First, in the case of dipping reflectors, there are positioning errors due to lateral movement, which is not correctly handled during the vertical conversion of focusing depth to pseudo depth. Second, a true zero-offset image obtained by genuine migration in a wrong migration velocity model should contain some residual diffraction energy that will be useful for subsequent post-stack subsalt scan. In other word, the composite image, though better image, is not kinematically consistent with any zero-offset migration process.

In order to produce a well focused zero-offset image, we need to separate the prestack focusing from the post-stack focusing: prestack focusing handles the residual moveout effect in an actual or virtual CIP gather, post-stack focusing handles the collapsing of diffraction energy across CDPs and Lines back to the diffractors.

To achieve this, previously Audebert and Diet (1993) described an approach in the framework of shot-receiver migration. They migrated (upward and downward) the zero-offset wavefield reconstituted at each focusing depth (equivalent to a datuming depth). In their process, it was in fact the time (∆T) dimension that was migrated; hence losing the (∆T) information while the focusing depth was preserved. In the process we apply here, it is the focusing depth that is lost in the conversion to migration depth, while the information (∆T) is preserved.

We choose here to convert CFE images from focusing depth to migration depth using post-stack modeling. For each CFE image (a migrated image whose vertical scale is in focusing depth), we first perform a post-stack wave equation demigration. To avoid artifacts caused by shadowing effect due to high velocity contrast across steep dip Base Of Salt (BOS), we need to stop the demigration at the BOS horizon (Wang et al., 2005). The demigrated seismic data are statically shifted with –∆T, and then a post-stack wave equation migration is performed with the
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statically shifted data. Same as in the case of the CFE volume converted in pseudo-depth, we can extract a composite image from the demigrated-remigrated CFE volume. Figure 6 shows such a composite image extracted from the demigrated-remigrated CFE volume, according to the $\Delta T$ field shown in Figure 4. For better comparison, the migration image also went through the similar demigration and remigration procedure: the result (Figure 5) is equivalent to an image extracted from the CFE volumes following a $\Delta T$ field correction equals to zero at every location.

By careful comparison between Figure 6 and Figure 2, we can observe that in Figure 2 (the composite image obtained after vertical conversion to pseudo-depth) the point diffractors are well collapsed, which indicates both that prestack focusing and post-stack focusing are achieved. We can conclude therefore that the pseudo depth CFEs obtained by pure vertical stretching constitute a better domain for the picking of focusing error, but for this picking only. Then, with the demigration and the $\Delta T$-compensated remigration, we undo the residual post-stack focusing effect, and now the composite image after demigration-remigration (Figure 6) displays the same residual diffraction pattern as the migration image (Figure 5): the composite demigrated-remigrated image is kinematically consistent with the original migration velocity model, but with improved reflector amplitudes.

Correction of positioning errors for final image

Regardless of the effort dedicated to velocity analysis, errors in the final velocity model are a certainty. Therefore, there are residual positioning errors present in the final migration image. We may consider performing the focusing analysis to create the focusing error ($\Delta T$) field for the final image. Not only can we use the $\Delta T$ field to produce a better-focused migrated image, but we can also use the $\Delta T$ field to correct for residual positioning errors. Conceptually, $\Delta T$ gives the traveltime error from migration depth to focusing depth along the normal incidence ray direction (Wang and Pann, 1998), with the true depth positioning lying approximately in between. Therefore we could perform a poststack demigration starting from the best-focused image in migration depth, then remigrate poststack with half the $\Delta T$ compensation for traveltime. Figure 7 is the positioning corrected image using the best-focused image (Figure 6) and $\Delta T$ field (Figure 3) as input. In comparing (Figure 7) to the image using the true velocity model (Figure 4), the positioning errors are greatly reduced.

Conclusions

We have developed a new methodology to produce a best-focused zero-offset image in the framework of wave equation migration. CFE images in pseudo depth domain are ideally suited for focusing analysis, and to obtain the focusing error ($\Delta T$) field, because they retain both prestack focusing and post-stack focusing. To provide a good starting point for our post-stack subsalt scan, we produce a well-focused zero-offset image in migration depth. To achieve that, we decouple prestack focusing from post-stack focusing, by performing wave equation based post-stack demigration and $\Delta T$ compensated remigration.

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References


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Figure 1. Migration image with a wrong 1D subsalt velocity model.

Figure 2. Composite image in pseudo depth based on focusing analysis.

Figure 3. Picked focusing error (ΔT) field.

Figure 4. Migration image with true model.

Figure 5. Migration image after demigration and remigration in the 1D subsalt model.

Figure 6. Composite image in migration depth formed after demigration and remigration of the CFE panels, in the 1D model.

Figure 7. Composite image with positioning correction using focusing error field.