Quantitative common angle depth migration: A tool for AVA analysis in complex media.

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Summary

Amplitude versus offset/angle analysis of seismic reflection data has been of increasing interest for exploration studies over the past decade. Today, the ambition is to apply such analysis to more subtle and complicated subsurface structures. In this kind of area, multipathing has to be taken into account. Here, we present a 3D, amplitude preserving, prestack Kirchhoff depth migration/inversion scheme (PA-PSDM) and its results on both synthetic and real data. This algorithm is designed to deal with multipathing and thus provides common image gathers in the angle domain. Specific weights have been implemented to preserve amplitudes in angle-sorted Common Image Gathers (CIGs). In this paper we propose to validate preserved amplitude migration in the angle-domain, by comparing it to a calibrated algorithm in the offset domain. We first use this migration/inversion tool on true amplitude synthetic data, to underline the accuracy of angle dependent reflection coefficients estimation. We then apply the technique to process real 3D data. Furthermore, results for both synthetic data and real data from angle migration are compared with today's practice in amplitude preserving imaging. With this calibrated angle PA-PSDM scheme, more complicated geological media, where triplications occur, may be studied.

Introduction

There is increasing evidence that more reliable and better resolved AVO/AVA attributes can be obtained by inversion after 3D amplitude preserving imaging. Prestack time imaging can improve the quality of an AVO analysis (Mosher et al, 1996). However, the underlying assumptions will fail in complicated geological settings. Prestack depth imaging is recommended when we are facing complex overburdens with dipping and curved target structures (Beydoun et al., 1993, Thierry et al., 2000, Baina et al., 2002). In the traditional case of common offset sorting, double diffraction stack migration provides the necessary information for offset to angle mapping of the CIG, as firstly proposed by Bleistein (1987). However, this technique requires the averaging or application of thresholds at the post-processing stage (Lumley and Beydoun, 1991). Furthermore, this technique does not account for multipathing, and so can not be applied to targets of structural complexity such as sub-salt imaging. To overcome these difficulties, new ray-based algorithms for 3D PSDM have been proposed (De Hoop et al., 1994, Xu et al. 1999, Brandberg-Dahl et al, 2003). Those techniques work in the angle domain. Therefore, to deal with multipathing and to avoid offset to angle conversion as post-processing before an AVA study, we developed a 3D PA-PSDM algorithm taking multipathing in the angle domain into account.

In this paper, we first present an overview of the amplitude preserved theory that we developed for common angle PA-PSDM. We propose to calibrate the common diffraction angle, amplitude preserved migration/inversion algorithm on synthetic data. The 3-D preserved amplitude processing is then applied on a real 3D marine dataset. We will focus on the validity and benefit of using common angle migration/inversion compared to common offset migration/inversion, in the framework of preserved amplitude migration following by AVA analysis. With this angle PA-PSDM we will be able to study complicated media where multipathing occurs.

Theory

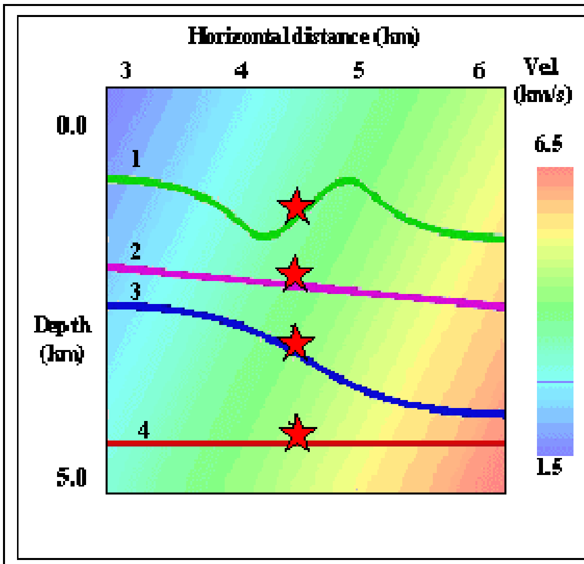

Figure 1: Cross-line slice of the canonical synthetic model used for calibration tests. Stars denote the positions where amplitudes are picked versus offset or angle for the calibration shown on Figure 2.

Our 3D ray-based Kirchhoff imaging algorithm follows the method proposed by Bleistein (1987). It uses for imaging all the multipathing information computed by wavefront construction methods (Lucio et al., 1996). CIGs are then sorted in the angle domain. Stolk (2002), however reported that imaging artifacts will remain even in the angle domain, due to the ray-based scheme. We believe that a different implementation in the angle domain can suppress such imaging artifacts.

The migration weights used here are designed for common angle sorting and are derived using the inverse generalised radon transform technique. Essentially, they correct for geometrical spreading, stretching effects and irregular illumination of the subsurface due to the inhomogeneous velocity model ant to the acquisition geometry.

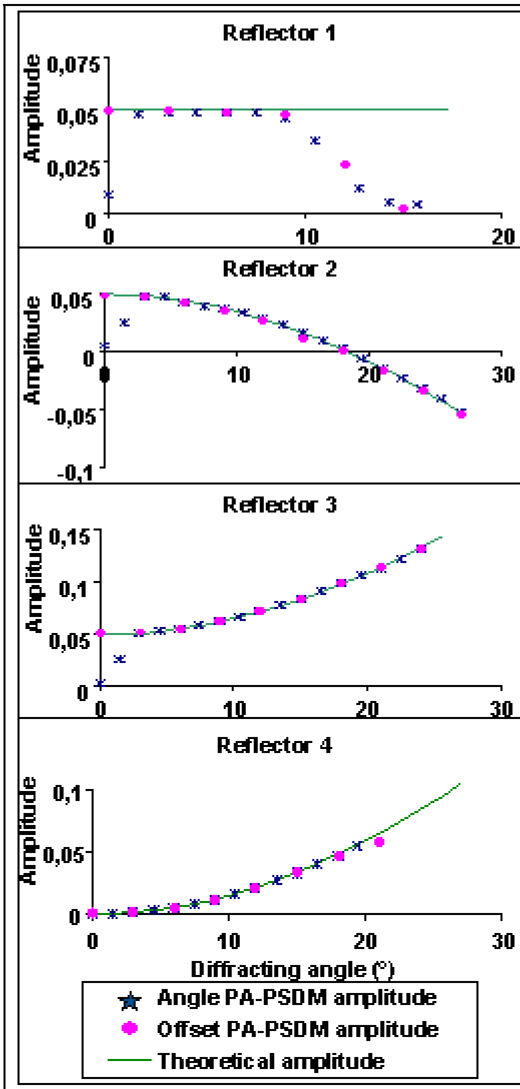

Figure 2 : Picked amplitudes on migrated reflectors compared to the theoretical curves, as a function of angle for a CMP in the middle of the model. All reflectors tie except the first one because of lack of illumination for high angles.

Validation on a synthetic example

To calibrate the amplitude preserving algorithm, we constructed a canonical synthetic model (Figure 1). This model consists in 4 reflectors with different shapes (horizontal, dipping and different curvatures) embedded in a velocity field presenting vertical and lateral velocity variations. AVA attributes are defined by constant values of intercept and slope for each reflector. The canonical synthetic model has no geological meaning, but it combines complex geological characteristics. On the basis of this model, a 3D true amplitude synthetic dataset was modelled. The acquisition design consists in 101 survey lines with 241 shots per line, one streamer per shot, and 120 receivers separated by 25m on each streamer. The mean distance between navigation lines is 50m. These unmigrated data have been tested using traditional AVO analysis (Baina et al., 2002) and results show the failure of classical AVO methods.

We applied algorithms described in the previous section to this synthetic dataset and we picked on the migrated CIG's the recovered amplitudes along the offset and angle directions. Figure 2 shows the comparison of theoretical amplitudes versus recovered amplitudes using (1) direct common angle sorting, and (2) double diffraction stack methods followed by offset to angle conversion of CIG's.
We observe a good fit to the theoretical curve for both approaches and for all reflectors, even for strongly dipping or curved reflectors. The lack of accuracy at small angles is due to singular weights when approaching zero incidence. For the first reflector, the poor amplitude recovery at large incidence angles is due to missing illumination.

Following these observations, we conclude that, on a complex structural and heterogeneous synthetic model, the previously described angle PA-PSDM scheme produces results fitting theoretical curves.

Application to a 3D real dataset.

We now apply our algorithm on a real 3D marine dataset. Shot and receiver spacing are 25m and the distance between navigation lines is 50m. We define a small 3D target around the reservoir zone. The target size is 2 km in depth, 6.5km in-line and 1km cross-line, with associated sampling of 2.5m in depth and 25m in-line and cross-line. The data were processed with designature, antialias filters, resampling, noise attenuation, predictive deconvolution, gun and cable statics. It was then fed into our 3D amplitude preserving depth imaging algorithms, using weights and sorting in the offset and angle domains respectively
Figure 3 shows common image gathers computed with the offset and angle migration/inversion. On the left is the offset gather, the middle gather is the offset gather

converted to angle using migrated angle attributes. The angle gather on the third panel is directly obtained from the angle PA-PSDM. All these gathers have only a mute as post-processing. The last gather shows already flat and noiseless events compared to the offset gathers. We observe that, in this case of smooth geology without triplications, angle gathers computed from offset and angle migration/inversion are equivalent, as expected.

The image gathers were then post-processed with an AVA inversion procedure to derive attribute images. Common angle gathers were used directly as input for AVA analysis with no extra manipulation on data, whereas the offset gathers required offset to angle conversion, which may affect amplitudes. Figure 4 shows the fluid line section in both cases (offset and angle PA-PSDM), indicating the hydrocarbon anomalies with respect to the background trend. Offset migration/inversion fluid-line results were already calibrated on real data (Baina, 2000). Angle migration/inversion results have similar amplitude behaviour. Comparison of a well synthetic seismic to the migrated seismic will be shown in the oral presentation.

In the case of a smooth medium without multipathing, offset and angle migration/inversion produce equivalent amplitude results on real data. These observations on real data confirm the calibration of our algorithm. With this angle migration/inversion scheme, more complicated geological media may now be studied with amplitude preserved prestack depth migration.

Conclusions

We have demonstrated the quantitative capabilities of 3D amplitude preserving depth imaging algorithms in the angle domain to directly produce gathers well fit for AVA inversion. Tests on a structurally complex synthetic model with strong lateral velocity variations show a good fit between theoretical curves and migrated results. The application on real data show that equivalent results are obtained using angle and classical common offset migration. Furthermore, preserved amplitude angle migration does not need offset to angle post-processing which may affect amplitude, before an AVA study. Therefore those migration/inversion algorithms are more reliable in the case of complex geological areas. This calibration is a necessary step before dealing with more complex areas where we face multivalued ray fields.

Acknowledgement

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References

Baina, R., Thierry, P., Calandra, H., december 2002, 3D preserved-amplitude prestack depth migration and amplitude versus angle relavance, The Leading Edge, 1237-1241.

Beydoun, W. B., Hanitzsch, C., and Jin, S., 1993, Why migrated before AVO? A simple example: 55th Annual EAEG Meeting, Eur. Ass. Expl. Geophys., Extended Abstracts.

Bleistein, N, 1987 , On the imaging of reflectors in the Earth, Geophysics, 52, 931-942.

Brandsberg-Dhal, S., de Hoop, M. V. and Ursin, B., 2003, Focusing in dip and AVA compensation on scattering-angle/azimuth common image gathers: Geophysics, Soc. of Expl. Geophys., 68, 232-254.

De Hoop, M. V, Burridge, R., Spencer, C. And Miller, D., 1994, Generalized radon transform amplitude versus angle (GRT/AVA) migration/inversion in anisotropic media : Proc. SPIE 2301, 15-27.

Lucio, P.S., Lambaré, G., and Hanyga, A., 1996, 3D multivalued traveltime and amplitude maps, PAGEOPH, 148, 449-479.

Lumley , E. D. and Beydoun, W. B., 1991, Elastic parameter estimation by Kirchhoff prestack depth migration/inversion, 70th Standford Exploration Project Report.

Mosher, C. C, Keho, T. H., Weglien, A. B. and Foster, D, J., 1996, The impact of migration on AVO, Geophysics., 61, 1603-1615.

Stolk, C. and Symes. W. W., 2002, Artifacts in Kirchhoff common image gathers, 72th Ann. Internat. Mtg Soc. of Expl. Geophys., 1129-1132.

Thierry, P., Jousset, P., Baina, R., Ribodetti, A., Billette, F., 2000, 3-D preserved amplitude processing sequence in a real case, 70th Ann. Internat. Mtg. Soc. of Expl. Geophys., 239-242.

Xu, S., Thierry, P., Lambaré, G., 1999, 3D Migration/ inversion in complex media, 69th Ann. Internat. Mtg. Soc. of Expl. Geophys., 1390-1393.

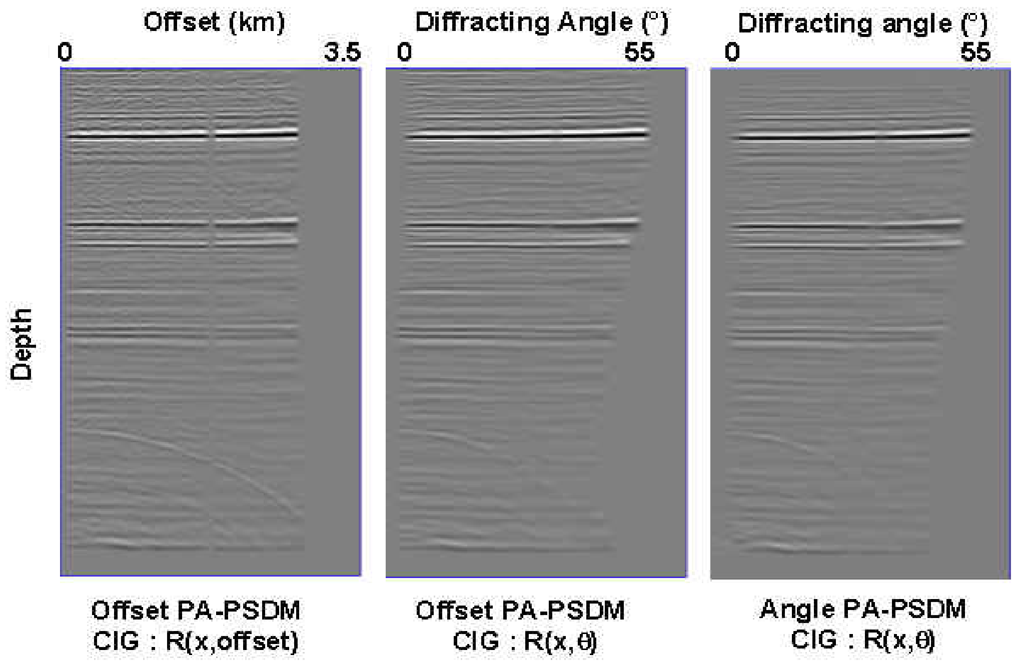

Figure 3 : Offset, offset converted to angle and angle gathers on real data. Angle gathers have similar amplitude behaviour in the case of smooth geological media without multipathing.

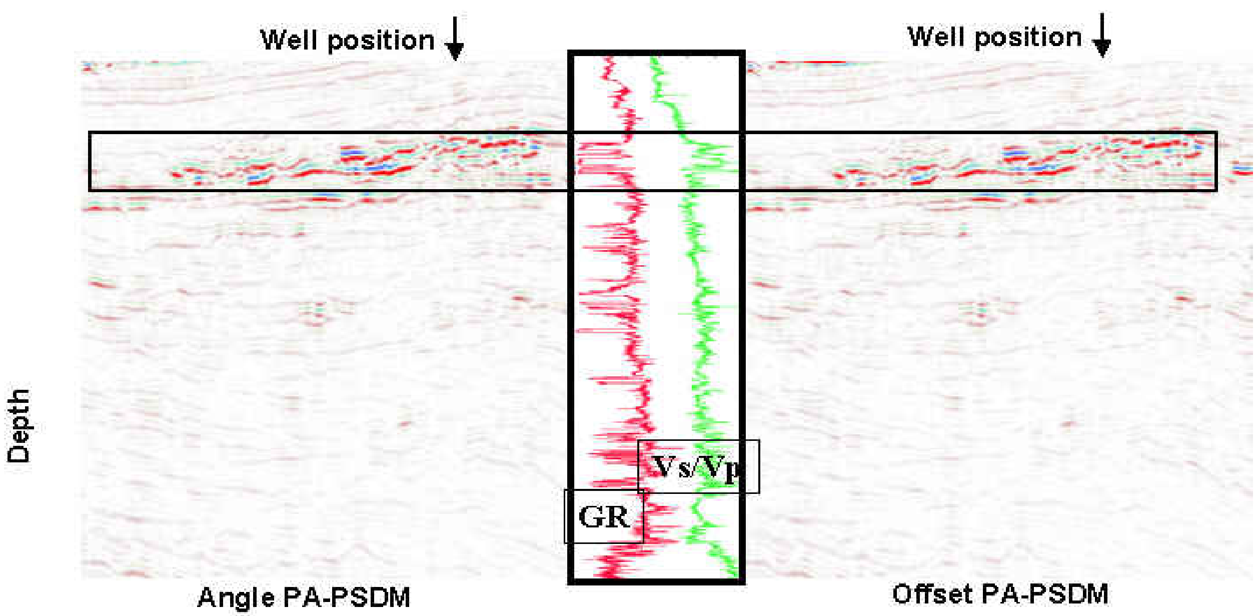

Figure 4 : Fluid line sections computed from the common offset and common angle migration/inversion. The main anomaly due to the reservoir is clearly visible and it is well tied to well log data.