Velocity Model Building and Pre Stack Depth Imaging Using Common Reflection Angle Migration: A Case Study from WOF Basin

R.Pathak*, Mamta Jain, Arjeesh Gupta, Surendra Kumar, T.R.Murali Mohan, GEOPIC, ONGC, Dehradun

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Summary

Depth imaging is the preferred seismic imaging tool for most challenging exploration and reservoir-delineation projects. The estimation of velocity models is still crucial in seismic reflection imaging as it controls the quality of the depth-migrated image. In this present study common reflection angle migration has been used as imaging technology which is recently developed ray based seismic subsurface imaging technique.

For velocity model building and refinement tomography based structural attributes driven approach has been adopted. Calibration velocity has been derived through well-tie tomography and well log data for time to depth conversion. A comprehensive case study has been demonstrated using data of Western offshore basin unveiling high quality depth imaging and very good matching of seismic events with well markers.

Introduction

There is an ever increasing demand for advanced velocity modeling and imaging techniques to provide an improved knowledge of subsurface structures in geologically complex areas as well as more accurate and quantifiable description of reservoir properties. Common Reflection Angle Migration is a new ray based seismic subsurface imaging technology that is recently presented for generating high-resolution, amplitude preserved, and angle dependent reflectivity gathers in the local angle domain. Such local angle domain common image gathers (CIG) can be obtained from a multi arrival, ray based Common Reflection Angle Migration (CRAM) creating a uniform illumination at the subsurface image points from all directions. The Common Reflection Angle gathers are ideal input for Amplitude versus Angle (AVA) and pre-stack inversion studies since they are amplitude and phase preserved. Unlike conventional ray-based imaging methods working in depth-offset domain, the ray tracing is performed from image points up to the surface, forming a system for mapping the recorded surface seismic data into the Local Angle Domain at the image points. (Figure 2) CRAM's imaging process combines a number of ray pairs representing the incident and reflected/diffracted rays from the subsurface. The procedure is based on a uniform illumination at the image points from all directions, ensuring that all arrivals are taken into account while amplitudes and phases are preserved.

CRAM is specifically designed for detailed velocity model determination, target-oriented, high-resolution reservoir Imaging, accurate AVA and reservoir property extraction, and imaging data recorded in areas of complex structure and velocity. The migration supports isotropic and anisotropic models, and can be performed using all types of marine and land datasets, including OBC/OBS. The CRAM algorithm is extremely versatile; thus it can be adapted to any exploration objective. It can be used for full volume imaging with full-apertures. It can also be run over small target areas of interest with background dip azimuth information, leading to a model-driven aperture for achieving fast turnaround, high-quality and high-resolution.

The accurate estimate of velocities is the key factor for successful depth domain imaging. Tomography based velocity model building and refinement tools supplemented by structural component extracted from data plays very important role in this arena. 3D Grid/Model-Based tomography aims to flatten the common image gathers and minimize their residual moveouts (RMOs) to update the velocity model. The model update is driven by a measure
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of the non-flatness of pre-stack migrated gathers which are obtained by migration with the background subsurface velocity parameters. The output of the 3D Grid Tomography is an updated subsurface model. The derived parameters should yield flatter output gathers after an additional migration of the input data. The tomography equations relate travel time errors measured on the migrated gathers to the subsurface model change through rays which are traced from subsurface reflectors to the surface.

A good seismic image is not enough for an exploration or field development interpretation. Good well tie and reliable time to depth conversion is also required.

The RMS velocity volume used for earlier pre stack time migration was used for deriving initial interval velocity model in depth. CRAM is a resource intensive process, hence Kirchhoff’s algorithm has been used for velocity model building and refinement and CRAM has been used for imaging. The salient features of velocity model building are as mentioned below.

**Initial Depth-Interval Velocity Model Building**

Initial Depth-Interval velocity model was created using Constrained Velocity Inversion (CVI). This application enables to create a smoothed and physically credible velocity volume. In order to generate interval velocity in depth, RMS velocity volume obtained from earlier processed data was taken as input.

**Target Line Kirchhoff Depth Migration for Velocity Modeling**

Kirchhoff Depth migration with Initial Depth-Interval velocity model was run on target lines for estimating residual move out and updation of velocity field. Suitable Migration full aperture of 5000 m was used and output was generated for every 20\textsuperscript{th} inline for velocity refinement.

**Updation of Initial Interval Velocity using grid tomography**

3D Grid Tomography is divided into two parts which need to be run separately. The first part constructs the tomography equations from the input data, and in the second part the equations are solved. This division enables testing different input parameters by performing a number of tomography runs without having to repeat the most time consuming part of the tomographic equation building.

In first part, Dip, Azimuth and continuity (DAC) volumes were created and automatic picking of interlayer horizons was done (Figure 3, 4, 5 & 6). For DAC volume generation and auto picking of interlayer horizons plane wave Destructor (PWD) method was used. These structural attributes facilitate grid tomography as a ray shooting source and for smoothing along the geological structure model

Pencil file is created using Kirchhoff migrated PSDM stack volume, interval velocity volume, DAC volumes and interlayer horizons. The pencil database is the main data repository used for structure and attribute data. In a Tomography workflow, all RMO-related information is saved to a pencil data base. That is, a single pencil file is used within one global tomography iteration between the different applications, and accumulates all the RMO-related information.
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After creating pencil file, automatic RMO picking, QC and masking (filtering) was done. Automatic picking of the RMOs is a key step in workflows and the quality of the picked RMOs is crucial to the success of the tomographic updating process. 3D Grid Tomography supports automatic RMO picking on several types of common image gathers, among them are Kirchhoff offset gathers and common reflection angle (CRAM) gathers. In addition, there are various ways to view and QC the results of the auto-picker and filter out problematic RMOs curves/surfaces in a flexible and interactive manner from the tomographic calculation. Minimum and maximum values for each QC moveout attribute can be fixed by defining a filter for masking pencil points whose attribute values are out of the defined range. This information can be saved to a pencil file in the form of a mask group. 3D (Grid/Model-Based) Tomography can later read this mask group and omit masked pencil points from the tomographic calculation in the build stage.

Build matrix involves building the grid tomography matrix. It is the most resource consuming mode in terms of computation time, memory, and disk space. Prior to running the Build Matrix mode, QC of ray tracing process was run. This application displays the upward ray path from a single image point in the subsurface to the surface. The parameters for tomography may be decided using interactive ray tracing application. Second part involves solving the matrix created in Build Matrix mode described above. This mode is parallelized on distributed memory. Distributing the matrix between nodes reduces memory requirements and compute time. The outputs of this mode are the updated and residual model parameters.

For the data under study, two iterations of grid based tomography were run to update interval velocity model. Depth migration using CRAM (common reflection angle migration) technique

CRAM (Common Reflection Angle Migration) was run with the conditioned CMP gathers and the final interval velocity model which is obtained from the final iteration of tomography. The parameters like opening and directional angle are tested using the ray tracing that gives the number of failed and successful ray counts. Final values are decided by
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taking into account the more successful rays and by testing those parameters on some inline having the complex structure.

The opening and directional angle along with aperture can be tested interactively and for other parameters we have to run the jobs. Frequency is a very crucial parameter which needs to be optimized with utmost care as increase in frequency increases the run time exponentially. The final parameters used in CRAM imager are given in Table 1.

<table>
<thead>
<tr>
<th>The final parameters used in CRAM</th>
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<tbody>
<tr>
<td>Opening angle</td>
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<tr>
<td>Directional angle</td>
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<td>Pencil distance</td>
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<td>Aperture</td>
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<td>Reference depth</td>
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<td>Frequency</td>
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<tr>
<td>Offset</td>
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<td>Fold Angle</td>
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Table 1: Final parameters used in CRAM

Welltie Tomography

No depth imaging is complete unless it is validated with well data. Calibration velocity was derived using well tie tomography. Seismic image volume obtained from CRAM imager was scaled to time using migration velocity and subsequently scaled back to depth. Applying this calibration velocity, Welltie Tomography is a full tomographic inversion procedure used to correct depth of seismic reflectors using depth misties generally obtained from well markers data. Welltie Tomography updates the model while honouring the travel times along the traced rays. This means that the updated model preserves travel times and is consistent with the seismic data.

Area of study

The area under study lies in Heera-Panna-Bassein tectonic block. This block is situated south of Tapti-Daman block and east of Bombay High, west of the Deccan trap out crops and north of Vijaydurg Graben. The study pertains to the Pre Stack Depth Migration of 338 sq. km 3D seismic data, using Common Reflection Angle Migration (CRAM) technology. The 80 fold 3D data was acquired using four steamers with group interval 12.5 m and shot interval 12.5 m flip flop during 1999 using 160 channels per streamer. The minimum offset is 150 m and the maximum far offset is 2150 m. Record length of data is 4.0 sec. sampling interval 2.0 ms. The dimension of bin size is 12.5 x 37.5 m. The main objective of processing was to get realistic depth model for reservoir characterization using CRAM technology in a zone of 500-3500 m depth.

Discussion

Velocity model building is very critical for depth imaging. Manual picking and updation of velocity volume is time consuming. Here state of the art velocity model building and updation technique has been demonstrated which is very efficient accurate and time saving Grid based tomography has been used with a new work flow. Structural attributes derived from the data and automatic picking of interlayer horizons improved accuracy of ray tracing resulting into more reliable and geologically consistent velocity model. Final migration and calibration velocity section is shown in Figure 8.

Figure 8: Migration (a) and calibration (b) velocity section along in line L1.

Figure 9: Mistie maps for horizon H1A before (a) and after calibration (b)

Figure 9, 10 &11 show comparison between mistie maps generated along horizons H1A, H3B & H4 respectively. It is clearly envisaged that over all misties are within the admissible limit of 2% indicating very good match of seismic with well markers.
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Figure 10: Mistie maps for horizon H3B before (a) and after calibration (b)

Figure 12 illustrate comparison between earlier KPSDM and CRAM images along in line direction. Looking around the deeper part of the images it is found that CRAM images are highly focused and sharp demonstrating better continuity and amplitude preservation as well. This would certainly be helpful to interpreter for understanding the subsurface geology in complex areas.

Figure 11: Mistie maps for horizon H4 before (a) and after calibration (b)

In figure 13 depth slices generated through legend KPSDM (a) and CRAM (b) images have been compared at the same level. It is observed that structural features are more clear and sharp in the case of CRAM. This can give a lead to interpreters in delineation of sub surface structures.

Figure 13: Depth slices from the volume generated through legend KPSDM (a) and CRAM (b) at 1450 meter depth.

In figures 14&15 arbitrary lines before and after calibration passing through 8 wells used for well tie have been shown. It can be concluded that seismic horizons are fairly matching with well markers at well location.

Figure 12: Comparison of a legend Kirchhoff (a) and CRAM (b) PSDM stack along in line L1.

Figure 14: An arbitrary line passing through wells W-1, W-2, W-3 W-4, W-5, W-6, W-7 and W-8 before calibration.

Figure 15: An arbitrary line passing through wells W-1, W-2, W-3, W-4, W-5, W-6, W-7 and W-8 after calibration.
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Figure 16: CRAM stack section and gather in complex geological situation. Gather is shown at a well position w-4 marked by black vertical line.

Figure 16 demonstrate a CRAM gather at well location W-4 structurally complex location of a section. It is seen that gather is flat and noise free at locations where higher dip and undulation is observed.

Conclusions

In this present study both the issues of depth migration commonly known as imaging and depthing have been addressed simultaneously with an adaptation of high end technology. The final processed CRAM depth stack volume has shown very good reflection character and better resolution in the zone of interest. CRAM generates angle gathers which can directly be used for AVA study. Better preservation of relative amplitudes has been claimed in CRAM outputs. After Calibration very good matching of seismic horizons with well markers have been observed. Velocity models thus obtained are accurate and suitable for depth imaging as well as highly reliable for time to depth conversion. It may also be pointed out that this process of velocity model building and refinement is very less time consuming as compared to conventional methodology being used for this purpose.

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Statement from authors:

Views expressed in this study are those of the authors only and do not reflect the official views of the company i.e. the Oil and Natural Gas Corporation Ltd.