Interval Velocity Modeling and 2D Pre-Stack Depth Migration of Synthetic Seismic Data

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Summary

The requirements and benefits of PSDM are better realized in case of complex geological setups involving strong lateral variations. As comparison of first velocity section obtained by velocity analysis in time domain on velocity gather and the same obtained by horizon velocity analysis shows later to be more coherent and geologically meaningful. This shows the benefits of interpretive processing where interpreted horizons add value to velocity modeling. The corresponding improvements in time section (stack) are commensurate to velocity improvements.

Further comparison of RMS velocity section obtained in the first step and the one after residual updation shows improvement in the quality of section which will have corresponding effect on PSTM output.

The initial interval velocity model obtained by Coherency inversion is better than simple Dix conversion of stacking velocity. By tomographic refinement, velocity depth model is further refined. Interval velocity section after tomographic refinement better represents the actual geological model. This good initial estimate also ensures faster convergence of final model in fewer refinement iterations.

The final interval velocity section obtained after three iterations of tomographic updates is very close to the model velocities showing the strength of whole process of velocity model building. The corresponding seismic depth section is also well positioned for the most parts. This section is also much better than the first PSDM section obtained.

Introduction

For finding the hydrocarbons by seismic method, we try to have the best possible “picture” of the subsurface for which meaningful application of exploration and exploitation programs is required. A possible scenario of these programs may be thought of as having some Initial idea, Geological field work, planning and acquiring seismic data, seismic data processing, and seismic data interpretation, drilling program, well completion and production.

Seismic data is generated by the interaction between the waves propagating through a subsurface and the properties of the subsurface. The image that is obtained through the normal process of stacking, in common geological settings is a distorted image that does not correctly reflect the true geometry of the subsurface structure. In the case of uniform overburden, a horizontal reflector in depth will appear as a horizontal reflector on the time section. However, a dipping reflector or even a horizontal reflector in laterally varying velocity scenario will incorrectly positioned on the seismic section. It is the task of migration to correct this mis-positioning. (Mehta et. al, 2002-03).

There are many different types of migration. They can be classified in three ways:

1. Based on the domain in which the migration operates viz. Pre-stack / Post-stack.
2. Based on the migration algorithm viz. F-K, Kirchhoff etc.
3. Based on imaging domain viz. Time or Depth.

Depth Migration is a step in seismic processing in which reflections in seismic data are moved to their correct locations in space, in areas where there are significant and rapid lateral or vertical changes in velocity that distort the time image. Strong lateral velocity variations give rise to non-hyperbolic moveout of the reflection time in the CMP gathers. Hence when we do conventional time migration (based on hyperbolic moveout assumption) amplitudes and travel-time associated with the reflection events (which have non-hyperbolic move out) get distorted. (Yilmaz, 2001)

The first step in depth migration is to choose an interval velocity depth model. Using all available information and the seismic section a best guess model about subsurface is evolved. Then a synthetic time plot can be generated to check the match between the recorded data and iterative changes are made until a good match is obtained. This approach gives a consistent velocity depth model.

Residual moveout analysis is a velocity analysis
performed after applying an imperfect initial velocity function to the data. Residual moveout analysis is used to find the remaining error in the velocity field. It is an iterative procedure. We first define our initial velocity model and then perform the analysis. If it is a stacking velocity model, we apply NMO; if it is an RMS or interval velocity model we apply pre-stack migration (time or depth respectively). The second step is residual moveout analysis updating our initial velocity model and applying the new model (NMO or pre-stack migration). This process can be repeated as long as the gathers are not flat.

Theory & Method
Interval Velocity and Depth Model Building

I. Model based Interval Velocity Analysis: The simplest method for estimating layer velocity is the DIX conversion of RMS velocities. This method requires the RMS velocities associated with the layer boundaries. The RMS velocities are ideally estimated from pre-stack time migration. Alternatively a smoothly varying form of stacking velocities estimated from the dip-moveout corrected data can also be taken as reasonably substitute for the RMS velocities. Also with less desirably, stacking velocities with a fair degree of smoothing may be applied in lieu of RMS velocities. The DIX conversion is valid for horizontally layered earth models with constant layer velocities and small offsets. For an earth model with the dipping layer boundaries and layer velocities with vertical and lateral variations, more accurate methods are required as coherency inversion and stacking velocity inversion. (Yilmaz, 2001; Mehta et. al, 2002-03)

II. Coherency Inversion: This is one of the horizon based interval velocity estimation methods, in which, the laterally varying interval velocities can be obtained in a data driven manner. This method does not make any hyperbolic assumption as is the case with DIX’s conversion and any time-offset curve (non-hyperbolic) can be modeled while estimating the interval velocities. The coherency inversion compares predicted time curves with actual seismic data (CMP gathers) and computes semblance. (Yilmaz, 2001)

This essentially a layer stripping approach, where the interval velocity is estimated layer-by-layer starting from the shallowest to deepest. This means that we must start at layer no. 1. We define the velocity for layer no. 1, and then define depth structure for layer no. 1 (by ray migrating the time model to depth) and only then go to layer no. 2. We can not perform interval velocity analysis for all layers at once because the velocity and depth of an upper layer affects the velocity and depth of the lower layer. (Online help: Geodepth 2002)

As comparison to DIX conversion, which assumes a hyperbolic moveout for the reflection event that corresponds to the base of the nth layer under consideration, interval velocity estimation from coherency inversion is based on the non-hyperbolic CMP travel time modeling.

III. Interval velocity and Depth model refinement: Tomography

Tomography is an imaging technique which generates a cross sectional picture (tomogram) of an object by utilizing the object’s response to the non-destructive, probing energy of an external source. Seismic tomography is based on the wave propagation model in the subsurface. If the target size is much larger than the seismic wavelength, the wave propagation can be modeled as rays using ray theory. If the target size is comparable to the seismic wavelength, then the seismic wave propagation has to be modeled as scattered energy using diffraction theory. Tomography techniques are based on these two models are known as Ray Tomography and Diffraction Tomography respectively. In the present context, the ray tomography is used to update the velocity depth model.

Tomography is based on the principle that if the migration was carried out with correct velocity-depth model, the image gathers should be flat i.e. event depth is same at all source receiver. (Tian-wen Lo et. al, 1994) Tomography of depth migrated gathers is a method for refining the velocity - depth model. When pre-stack depth migration is performed with an initial, incorrect, velocity model derived from inversion methods based on non-global approaches, the depth gathers will exhibit non-flatness. The degree of non-flatness is a measurement of the error in the model. Tomography uses this measurement of non-flatness (residual moveout) as input and attempts to find an alternative model, which will minimize the errors. The tomographic principle attributes an error in time to an error both in velocity and depth. Horizon velocities and depth models can usually be updated using:

1) Horizon based global depth tomography
2) Grid based tomography (update velocity section only)
IV. Residual Moveout analysis

Residual moveout analysis is a velocity analysis performed after applying an imperfect initial velocity function to the data. Residual moveout analysis is used to find the remaining error in the velocity field. It can be performed for stacking velocity after NMO correction. Residual velocity analysis identifies the residual moveout required to flatten reflection events. It can also be performed on CRP depth gathers after PSDM. If, after migration, the gathers are not flat, we can analyse the remaining error in interval velocities. It can also be performed on migrated time gathers after PSTM. Here the residual analysis identifies the remaining error in RMS velocities. The method of performing residual moveout analysis utilizes semblance sections and is similar to that of standard stacking velocity analysis. The theoretical curves describe error in velocity. The error in velocity is defined by time residual.

Residual moveout analysis is an iterative procedure. We first define our initial velocity model and then perform the analysis. If it is a stacking velocity model, we apply NMO; if it is an RMS or Interval velocity model we apply pre-stack migration (time or depth respectively). The second step in the residual moveout analysis, updating our initial velocity model and applying the new model (NMO or pre-stack migration). This process can be repeated as long as the gathers are not flat.

Pre-stack depth migration of Synthetic data

Current work is an exercise in gaining a first hand knowledge (theoretical and practical) of pre-stack depth migration. As real data over a sufficiently complex geological setup was not available, synthetic data over a complex geological model involving strong lateral velocity variations, low angle thrusts and velocity inversion was generated. This model is shown in figure-1. While generating the synthetic data following options were exercised:

1. No diffractions, multiples and ghosts
2. Attenuation spreading transmission effects
3. Non reflecting fault planes

A sample shot record is shown in figure-2. The time domain processing of data was done using Focus 5.1, software of M/S Paradigm Geophysical. The depth domain processing including interval velocity modeling was done using Geodepth also from same vendor.

Time domain processing on FOCUS:

After doing time domain processing, a stacked section is obtained as shown in figure-3. Also figure-4 shows the result of post stack time domain processing.
Depth domain processing on GEODEPTH:

Interval velocity analysis and pre stack depth migration process can be described by the following general workflow:

- Stacking velocity analysis along time horizons
- RMS velocity analysis along time migrated horizons
- Stacking velocity refinement along time horizons
- RMS velocity refinement along time migrated horizons
- Interval velocity and depth model creation (coherency inversion)
- Interval velocity and depth model refinement and modeling (tomography)

For pre stack depth migration, an interval velocity section is required. The initial interval velocity model has been created using coherency inversion. To obtain an initial interval velocity model, CMP gathers and a depth model by migration (using refined RMS velocities) of horizons from time migrated domain have been used as input. Pre-stack depth migrated section is shown in figure-5. Thus it can be seen that depth gathers are not completely flat, which means that the initial velocity model was not perfect. For interval velocity refinement, the degree of non-flatness in CRP depth gathers was analyzed. The velocity model was updated by using tomography, which is a ray based global approach. Its output is a new depth and interval velocity interpretation, which can be used to build a new depth-velocity. The final interval velocity section is shown in figure-6 and the PSDM section after tomography refinement is shown in figure-7.

Conclusion:

In conclusion it can be stated that:
- PSDM is the most sophisticated and effective method of migrating seismic data to depth domain in complex geological areas with strong lateral velocity variations and steep dips etc.
- PSDM does not involve making any unrealistic assumption like hyperbolic NMO etc. and also accounts for ray bending at interfaces.
• The basic strength of PSDM is derived from Interval Velocity Modeling in Depth unlike the RMS velocities in case of PSTM etc.
• Depth model building is a layer-based approach where top layer model is firmed up before going down to next deeper layer.
• A good starting Interval Velocity Model prepared by using Coherency Inversion helps reach conversion much faster than using a simplistic Dix based conversion from stacking / RMS velocity.

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