Depth Imaging – More than PSDM

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Abstract

In principal, depth imaging refers to application of pre stack depth migration (i.e. PSDM). In practice, Depth Imaging grew to occupy a central role in almost all segments of seismic data processing and interpretation, both structural and quantitative.

This presentation describes the various aspects of depth imaging technology. Today depth imaging covers the tasks of construction of anisotropic geological models, interpretation, final imaging, time to depth conversion, preparation of data for AVO analysis and impedance inversion, and simulation to assist geologists in the understanding of seismic data and in the design of seismic data acquisition.

The evolution of depth imaging has erased the traditional distinction between data processing and interpretation. Today, the construction of a subsurface depth model involves the interpretation and success depends on constant and consistent geological input. Thus upon completion of a model building project, a large portion of the interpretation has been completed.

Introduction

Historically, seismic processing, imaging and interpretation were applied in a linear manner, where one process followed the previous one. Time domain pre-processing was the starting point, followed by velocity analysis and pre stack time migration (PSTM). The PSTM gathers were used for AVO analysis and impedance inversion and the PSTM stack, or a map interpreted from it, was used for time-to-depth conversion. Interpretation of the time PSTM or the time to depth converted PSTM volume was the last step.

Today, Depth Imaging plays a central role in the integration of these processes. Following time domain pre-processing, depth model building and interpretation work proceed simultaneously. The model building workflow needs to be adjusted to the geology of the area investigated, and therefore geological guidance is key to a successful construction of the velocity model. As the anisotropic model is developed during iterations of model update and PSDM, multiple 'trial PSDM volumes' are generated. The interpretation work progresses using multiple PSDM volumes. Arriving at the final anisotropic model and final PSDM is done aiming to (1) produce the best seismic image, and (2) accurately convert the seismic data from time to depth. The final products of depth imaging are a depth domain PSDM stack volume and PSDM gathers. These gathers can be input to material parameter inversion, resulting with depth domain rock properties volumes and attributes.

With this industry standard workflow, interpretation and imaging work are done concurrently. This enables Geophysicists to produce a more accurate interpretation of the subsurface. Moreover, with this current workflow, the focus of the work has shifted to the construction of a reliable anisotropic earth model.

Velocity Model Building

Pre stack depth migration can only be as good as the input velocity model used. This is the reason why most of the efforts done in a 'pre stack depth migration project' are in the construction of the velocity model.

Pre stack depth migration is used in two different manners for construction of the velocity model. Full stacks are used for layer interpretation, and gathers are used for measurement of residual moveout which is the common input to reflection tomography inversion. A newer Velocity Model Building procedure is 'full waveform inversion (FWI). FWI is an automatic procedure that involves generation of synthetic data using a trial model, subtraction of the synthetic data from the field data and application of a wave equation PSDM like procedure using the difference dataset. Using either of these two methods for the estimation of velocity field, pre stack depth migration is simply the 'engine' that is used for generation of multiple 'trial' gathers and stacks.

Anisotropy

Anisotropic models are used today for any type of geological setting, from offshore deep water pre salt to on-shore horizontal beddings. The use of Anisotropy in pre stack depth migration enables us to migrate the data to the correct depth as well as true spatial location. For all types of anisotropy, from the simpler vertical transverse anisotropy (VTI) to the more complex Tilted Orthorhombic anisotropy (TOR), multiple volumes are needed to describe the material response. Tomographic inversion tools are used to update the anisotropic field. This is done by measure of residual moveout on pre stack depth migration gathers. For generation of dip and azimuth volumes, pre stack depth migration stacks are used for interpretation of key markers. The type of anisotropy is selected to match the geological settings. The choice of the type of anisotropy will dictate the number of volumes that need to be defined during the construction of the anisotropic model. The order in which these volumes are constructed is also very important. In general anisotropy can be determined at well locations using well logs. However, away from well location PSDM gathers and stacks are using to define the complete anisotropic model.

Interpretation

Interpretation work used to be carried out after processing. This included creation of horizons and faults, mapping, and time to depth conversion of the final maps. With depth imaging, Interpretation is done as part of the 'processing' work. Model building consists of two parts: (1) Estimation of layer velocity and anisotropy and (2) Construction of the layered model. Construction of the layered model involves interpretation. Moreover, since multiple iterations are used, the interpretation needs to be adjusted each iteration. This is done for any type of Geology. For deep water pre-salt cases we normally include a water layer, post salt layer, salt layer and pre-salt layer. Each needs to be interpreted. For on-shore faulted geology we need to build each of the fault blocks, interpreting both horizons and faults. For construction of TTI models we interpret horizons that will be used for construction of dip and azimuth volumes.

As a result, at the end of Depth Imaging work, a large portion of the interpretation work has been completed. In practice, geophysicists that are involved in Depth Imaging need to gain knowledge of the geology of the project area, as well as the knowhow in using interpretation software packages. In general, depth Imaging is a discipline that involves both 'processing' work as well as 'interpretation' work.

Pre stack Depth Migration

Pre stack Depth Migration (PSDM) is applied in two different manners: (1) During iterations of model building PSDM is used as the tool for velocity estimation by producing gathers from which residual moveout is measured, and for generation of trial depth migrated volumes which are used for construction of the model key layers. (2) Having the final anisotropic earth model, PSDM is used for generation of the final depth migrated image.

Over the years, three different PSDM methods have been developed and used by the industry. These include (1) Ray based Kirchhoff (or beam) summation algorithms, (2) Downward continuation wave equation methods, and (3) Reverse Time Migration (RTM) PSDM. RTM is the most accurate and the most computationally expensive algorithm. With current computer hardware RTM is routinely used as the algorithm of choice for generation of the final PSDM image.

RTM PSDM is based on solution of the 'full' wave equation (i.e. where waves are propagated in all directions), and includes a forward modeling step. With small modifications the RTM engine can be used as the kernel for inversion procedures. Two inversion procedures are commonly used in the industry: FWI for automatic construction of the velocity model and Least Square RTM (LSRTM) which is used for producing an 'amplitude preserved' depth migrated volume. This means that PSDM is extended to be more than an imaging tool, it is actually the kernel of inversion procedures. Today, this is the area that most effort in development of new technologies is taking place, both in theory and practice.

Time to Depth Conversion

When applied using an accurate velocity model, PSDM correctly converts the recorded time domain data to depth. In the past, time to depth conversion was carried out by (1) Interpretation of key markers using PSTM data, (2) Producing maps from the interpreted horizons, and (2) Time to depth vertical stretch of these maps. The velocity which was used for the vertical stretch was most commonly derived from well check shots. Three deficiencies existed in this workflow: (1) If the PSTM image was not optimal, the mapping using this volume would not be satisfactory. (2) Time to depth conversion using vertical stretch does not take into account any lateral displacements of seismic events, and (3) Check shot data is limited, and is not always reliable.

Today, with the accuracy of depth interval velocity models, PSDM can successfully be used as the tool for accurate time to depth conversion. Furthermore, the models that are constructed are fully anisotropic, producing the correct vertical and lateral position of seismic events. With this advancement, final PSDM volumes can be directly used for interpretation and the maps resulting from the interpretation of PSDM volumes do not need to require any additional adjustments.

Impedance Inversion

Impedance inversion followed by evaluation of Rock properties is an integral part of prospect generation. Although seismic imaging is done in depth, in many cases impedance inversion is still performed using PSTM data. There are a number of disadvantages of inverting PSTM results: Firstly, if the data used as input to the inversion is not migrated to the correct spatial location, the inversion result will not be positioned in the correct spatial location. Secondly, incorrect imaging will lead to erroneous estimation of material properties. This is particularly true for pre stack inversion where positioning errors induce erroneous AVO effects. Moreover, when impedance inversion results are delivered in the time domain they need to be converted to depth for comparison with well data. The reason for the use of PSTM gathers in inversion is historical. In the past, PSDM used to be of lower frequency and due to algorithm deficiencies amplitudes were not preserved. Over the years PSDM technology has greatly improved and today's PSDM data is as high frequency as any PSTM data. In areas of uniform illumination PSDM can preserve seismic amplitudes as well as any PSTM algorithm. As a result, we see a growing use of PSDM data as input to seismic impedance inversion. With this advancement seismic inversion products can be delivered directly in the depth domain and exactly match the PSDM images. Furthermore, we expect that the accuracy of rock property evaluation will increase with the use of PSDM gathers as input to impedance inversion work. With this integration of imaging and quantative interpretation (QI) work, depth imaging technology occupies a central role in improving both QI work as well the accuracy of evaluation of rock properties.

Seismic Simulation

In principal depth migrated volumes consist of reflections from geological units. In practice depth migrated volumes include coherent noise such as inner bed multiples, converted waves, prism waves etc. If not identified as coherent seismic artifacts, these events can be very confusing during the interpretation process. A way to assist the interpretation in these cases is the use of seismic simulation. Seismic simulation includes generation of synthetic data using a trial model and imaging of this data. The PSDM of the simulated data is then compared to the PSDM of the real data and with that artifacts can be identified. The key to this procedure is having a reliable anisotropic earth model, which is the model developed during application of Depth Imaging.

This concept has been extended to the analysis of seismic data generated using various acquisition designs. This include analysis of wide azimuth (WAZ) streamer data setups, comparisons between marine streamer surveys to ocean bottom node (OBN) surveys, as well as various on-shore acquisition setups. This use of numerical simulation for testing acquisition parameters plays a key role in linking the final PSDM image to the acquisition setup used to collect the data and actually plays an important role in optimization of acquisition design parameters.

Conclusions

Seismic data processing technology has evolved from time domain data preparation and time migration to depth Imaging. Today the time domain processing part consists mainly of data conditioning (i.e. gaining, filtering, multiple suppression and statics in the case of land data), while depth Imaging consists of much more than depth migration. In this presentation we detailed the wide scope of depth Imaging including construction of a detailed earth model, determination of the appropriate anisotropic parameters, structural interpretation during model building, selection of the optimal pre stack depth migration algorithm and parameters, time to depth conversion (replacing any vertical stretch of seismic volumes or maps), preparation of gathers for material parameter inversion and simulation for assisting both interpretation as well as acquisition design work. This ‘full scope’ depth imaging is what today’s seismic data processing is.