3D PRE STACK DEPTH MIGRATION (PSDM) USING TRAVEL TIME INVERSION (TTI) METHOD

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A thesis submitted in partial fulfilment of the requirements for the award of Degree in

Master of Technology
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This is to certify that **Mr. Shijhu Josi**, Student of M.Tech (Petroleum Exploration), University of Petroleum and Energy Studies (UPES), Dehradun, has successfully carried out his dissertation work entitled **"3D Pre Stack Depth Migration (PSDM) using Travel Time Inversion (TTI) method"** in the satisfactory manner as a partial fulfillment of curriculum for **M.Tech (Petroleum Exploration)** degree from 3rd Jan to 29th April, 2011 at Geodata Processing and Interpretation Center (GEOPIC), Oil and Natural Gas Corporation (ONGC), Dehradun.

Mr. Shijhu Josi is a sincere and hard working student who is innovative in approach, open to discussion & suggestions, and quick in learning. He has shown keen interest in seismic data processing.

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(SHIJHU JOSI)

ABSTRACT

The escalating oil and gas prices and increased need for energy security has led to a lot of technological advancements in hydrocarbon exploration field. The need to accurately locate the hydrocarbon reserves in the subsurface is increasing day by day. The main phases of seismic exploration - Acquisition, processing and interpretation which were initially viewed as independent steps has undergone radical change and there are integrated work flows evolved to improve the efficiency of the entire exploration phase. The Depth Imaging technique is an example where the processing and interpretation domains are intergrated. In this work a 3D real seismic marine dataset is taken for Pre-Stack Depth Migration (PreSDM) processing. The Interpretive Processing work flows are followed to image the subsurface in depth. It involves the building of velocity models using I2I plug-in suite of PETREL and depth migration using OMEGA 2010 seismic data processing software.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF PLATES

Seismic representation of an earth model in depth usually is described by layer velocities and reflector geometries [Yilmaz, 2001]. Depth migration is a very effective tool for better imaging of subsurface reflectors. If individual layer velocities are estimated accurately, subsurface reflector geometries can be imaged by iterative depth migration. Ambiguity in finding layer velocities with a good accuracy level make the earth model estimation a very challenging and daunting task for the geophysicist. The important requirement for depth imaging is that the data should be pre-conditioned for removal of multiples and noise factors.

The seismic dataset should have good signal to noise (S/N) ratio and therefore requires the selection of optimum acquisition parameters. Data acquisition is all about gathering or collection of information for analysis and understanding an object. The understanding of the object is then used to derive benefits in some form or other. The collected data, on most of the occasions, is not immediately suitable for meaningful analysis as it may contain some unwanted component(s). This mixing of unwanted information (in the context of the objective) might have given rise due to improper or inadequate collection of the data and warrants some pre conditioning before being subjected to analysis. Improper conditioning of data often leads to incorrect analysis and understanding of the objectives. Thus the data conditioning or Data Processing becomes an important bridge between the data collection and data analysis. Data Processing essentially involves implementation of certain logical set of operations on the input data without tampering the embedded all-important information, and simultaneously aimed at minimization of the unwanted contents. The useful part of the data, termed as Signal and the unwanted part of the data, termed as Noise are the two important issues of any data processing or Signal conditioning or Noise reduction strategy.

The resolution of the method is now approaching fineness adequate for finding stratigraphic traps such as pinch outs and facies changes. However, the successful exploration for stratigraphic targets by reflection techniques requires skilful coordination of geological and seismic information. Seismic data processing is becoming more and more compute-intensive as the exploration objectives are becoming complex and two-dimensional (2D) cross sections are not reliable as the subsurface features to be imaged are essentially three dimensional (3D) in nature. Imaging of salt diapiric structures, sub salt, sub basalt and sub thrust regions are the present day challenges involving the oil exploration. All this hi-tech demand has pushed the seismic API (Acquisition, Processing and Interpretation) to incorporate newer and sophisticated state of art technology to meet the objectives in more deterministic, time bound and revenue-oriented manner.

In seismic data processing, our aim is to improve signal to noise ratio by using various technique i.e. Convolution, Stacking, Filtering, Migration etc. The Geophysicist must know and understand the functionality of each processing step. In addition, a high level of experience is required for quality control at each step to ensure its validity before proceeding to the next step.

In addition, various Deconvolution and filter test are done, then parameters are designed to enhance signal to noise ratio and increase vertical resolution. Finally, we want to convert our seismic reflections into a picture representing a true subsurface geology. Extensive testing must be done to study the problems involved and to design the optimum parameters for each step of the data processing flow. It is important to have a good idea about regional geology of the basin and specific problems in the area where the seismic data was acquired.

Once the conditioning of seismic data have been done, the data is suitable to image in depth. The interval velocity model building and the depth migration is to be done iteratively. The depth imaging process is very time consuming and expensive, therefore it must be used in a justified manner. There are a number of commercial algorithms available for depth imaging like: Kirchhoff depth migration, Wave extrapolation migration, Beam migration etc. Each algorithm has its own advantages and disadvantages. The selection of algorithm needs to be done according to the requirement. The advancements in computational power both in hardware as well as software capabilities have made it economically feasible to execute depth imaging projects in a large scale. The time frame for the completion of depth imaging projects has come down drastically due to these technological advancements like cluster and parallel computing. In this project work the pre stack depth migration of a 3D marine dataset is attempted to image the area of interest in depth.

1.1) Necessity for processing

Necessity for routine processing arises because of:

- Simultaneous recording of noise along with reflected signals
- Modification of the reflection signal due to propagation effects (spherical spreading, anisotropic wave propagation)
- Interference (or tuning effect) between reflected signals or between the primary reflections and multiples.
- Necessity to bring in focusing of the weak reflection events (stacking)
- Necessity to search for clues or patterns in the record (like diffractions, correlations or phase relationship)
- Necessity to assign real locations of the origin of reflected signals (migration)
- Necessity to appropriately account for geometry of reflectors, or reflector curvature
- Need for preparing depth sections (velocity analysis)

1.2) Objectives of seismic data processing

- To improve the signal to noise (S/N) ratio
- To generate image of the subsurface which can be visualized for structural and stratigraphic interpretation
- To extract velocities that can be used for building velocity-depth model, and possibly for inferring lithological and fluid properties.
- To condition seismic amplitudes suitable for inversion in terms of elastic parameters this, in turn can be used for inferring lithological and fluid properties.
- To get a higher resolution seismic section.

2.1. Introduction

'Seismic Data Processing' is a series of mathematical operations, which are performed to extract the useful information from the set of raw data recorded in field. It provides the interpreter with a seismic section, which are then translated into geological information. There is a well-established sequence for standard seismic data processing. However the seismic data processing strategies and outputs are highly affected by field acquisition parameters and input data quality. Seismic data processing begins with the field tapes along with the observer reports mentioning the details about shots, receiver stations, shot and receiver elevations, number of channels, locations of shots and receivers, etc. Data processing can be divided into two main stages:

1) Pre-processing
2) Processing

In the pre-processing stage, the inputs given in the observer reports are to be carefully studied, before preparing a job sequence. The field data is recorded in time sequential form, which cannot be directly processed. So in pre-processing stage the data is demultiplexed (i.e.) the time sequential data is converted into trace sequential data. A spread sheet is generally prepared which include information about the shot, receiver and shooting pattern. This seismic acquisition geometry is merged with the seismic raw data.

Preprocessing also involves trace editing. Noisy traces, traces with transient glitches or mono frequency signals are deleted or made zero amplitude. Polarity reversals are also corrected. After editing, traces are sorted in CDP mode and verified whether we get full foldage in expected region or not (Figure1). It's a Quality Control (QC) step. QC checks are applied after each step to see the quality of data. Following trace editing, removal of noises (Coherent, Incoherent, Random noises) is done by applying different types of filters.

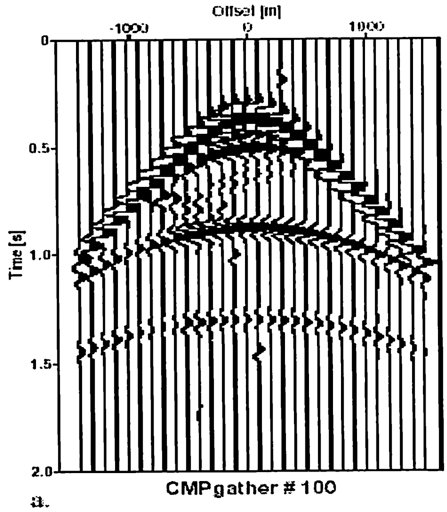


Figure 1: CMP gather

A gain recovery function is applied on the data to account for the amplitude effect due to the propagation wave front (Spherical divergence). This geometric spreading function depends upon travel time and an average primary velocity function. Additionally, an exponential gain may be used to compensate for attenuation cases. Field static is applied to bring the shot and receiver at the same datum plane (generally below weathering layer).

Now, data is sorted in CDP gather and 1st pass velocity analysis is performed. It is a very important part of processing that's why we perform velocity analysis several times in processing sequence to get more and more refined velocity. The most popular method of velocity analysis is velocity spectrum method. In velocity analysis we pick stacking velocity by plotting semblance value and generally pick highest value. Now using velocity function we apply NMO correction to align the reflection, but stretching effect appears at large offset and to overcome this problem we mute the stretched part and stack. This step is like a quality check, next, major step is to apply Deconvolution.

This process improves the temporal resolution in seismic data by compressing the basic wavelet and normally Deconvolution is applied before stack (DBS), but is sometimes applied after stack (DAS). The main processing stage involves three principal processes – deconvolution, stacking and migration. Also, there are some auxiliary processes that help improve the effectiveness of the principal processes. Deconvolution improves the vertical resolution by compressing the seismic wavelet to nearly a spike and minimizes reverberations. Common Mid-Point stacking is the most robust of the three principal processes. Stacking can reduce uncorrelated noise to a great extent, thus improving the signal-to-noise ratio. The normal move out correction is applied before stacking, using a preliminary velocity function. As multiples have larger move-out than the primaries due to low velocity, they are under corrected and hence, attenuated during stacking. The data is also corrected for elevation differences at shot and receiver locations and travel time deviations caused by near-surface weathering layer. Finally, migration step converts the diffractions to a point and relocates the dipping reflectors to their original subsurface positions. The processing work flow has been depicted in the next section (Figure 2).

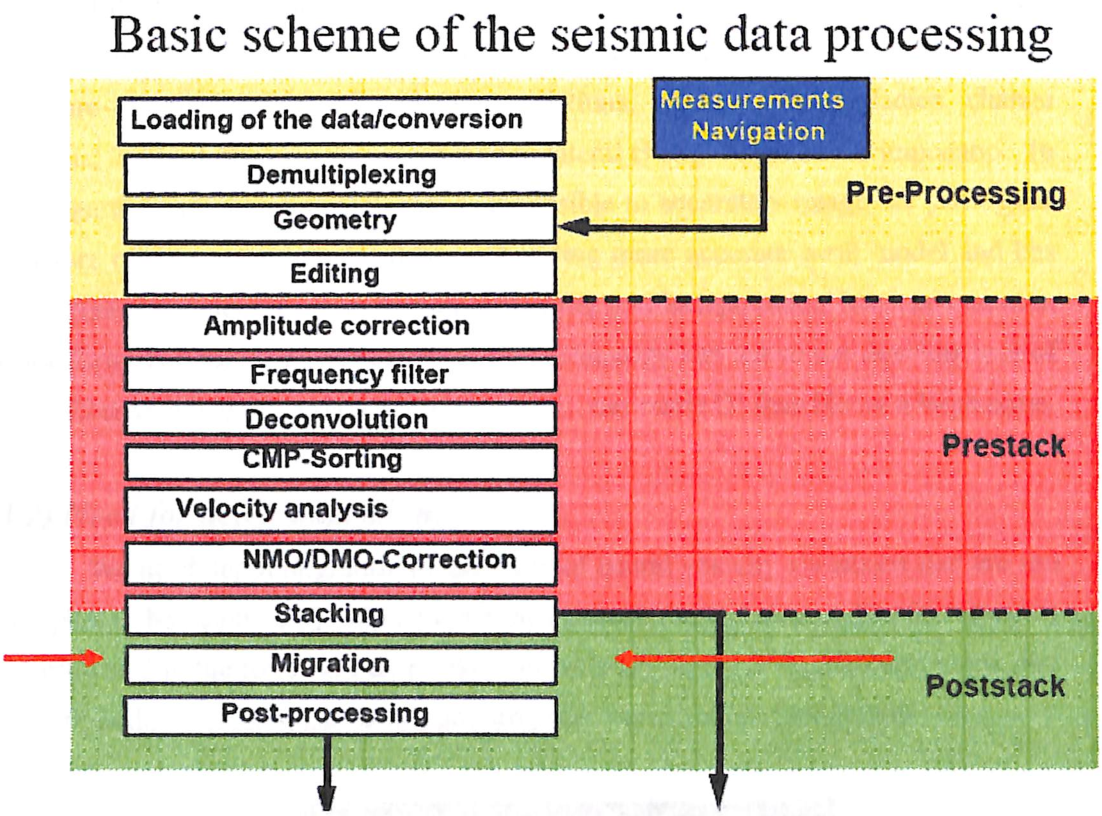


Figure 2 : Basic seismic data processing flow

2.2) Significant tasks in processing

- Selecting a proper sequence of processing steps that are required for the field data under study.
- Selecting an optimum set of parameters for each processing step, and
- Checking the quality of output from each processing step, and then trouble shooting any problems caused by wrong parameter selection.

3.1) Introduction:

The interest in depth imaging has increased very much in recent times because although during the seismic experiment, data is acquired as a function of time the main objective of the experiment is to obtain a correct image of the subsurface geology in depth domain. Strong lateral velocity variations due to complex structures require depth imaging of earth. Structure-dependent lateral velocity variations are involved diapiric structures formed by salt tectonics, complicated structures formed by over thrust tectonics and uneven water-bottom topography. Another type is structure-independent lateral velocity variations, involved with facies change [Yilmaz, 2001]. Lithology variations lead to lateral changes in acoustic impedance. In this regard, Depth Imaging (DI) makes it possible to accurately image the geological structure of the subsurface. DI helps in building more accurate earth model and has the potential to integrate seismic data processing and interpretation into one common work flow. The recent advancement in the technology has led to the development of cost effective powerful computers which in turn has made DI feasible on a large scale.

3.2) Need for depth migration:

We need depth migration to take care of lateral velocity variations that are too complex to be resolved by conventional time processing techniques. Depth migration is performed in the following cases like high velocity layers (e.g. salt, carbonates, and basalt), faults, channels, gas clouds and irregular water bottom topography.

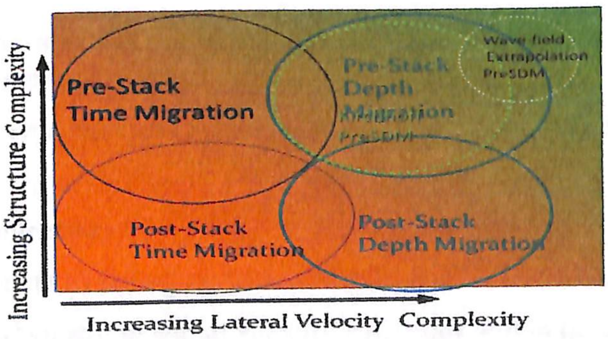


Figure 3: Selection for type of migration

3.3) Requirement for time migration and depth migration

Migration can be done in two ways depending on the requirement:

Post-stack migration:

The CMP stack data volume is migrated. DMO is applied before stacking so that all dipping events are preserved in the stack data.

***Post-stack time migration*:**

- Assumes wave field propagation through a horizontally layered medium.
- Cannot handle strong lateral velocity variations associated with steep dips.
- Assumes zero-offset (coincident source & receiver) section as input – stack sections not always a good representation.

***Post-stack depth migration*:**

- If the velocity field is accurate
- Post stack depth migration will provide accurate imaging of complex structures in many processing cases.
- Depth migration equations are modified to take account of ray bending caused by dip and velocity variations.
- Depth migration is very sensitive to velocity errors.

Pre-stack migration:

Pre-stack migration is performed on unstacked data. Pre stack migration transforms the CMP gathers into CIP gathers. These are stacked; amplitudes are summed from a single subsurface reflection point. It is performed in both Time and Depth domains.

***Pre-stack Time migration*:**

- Correct treatment of constant velocity and velocity field.
- No complex structures and no strong lateral velocity variations.

***Pre-stack Depth migration*:**

- Correct treatment of strong variations in velocity.
- Works well when strong lateral velocity variations within the overburden.
- Ability to focus and position reflections in the context of strong lateral velocity variations.

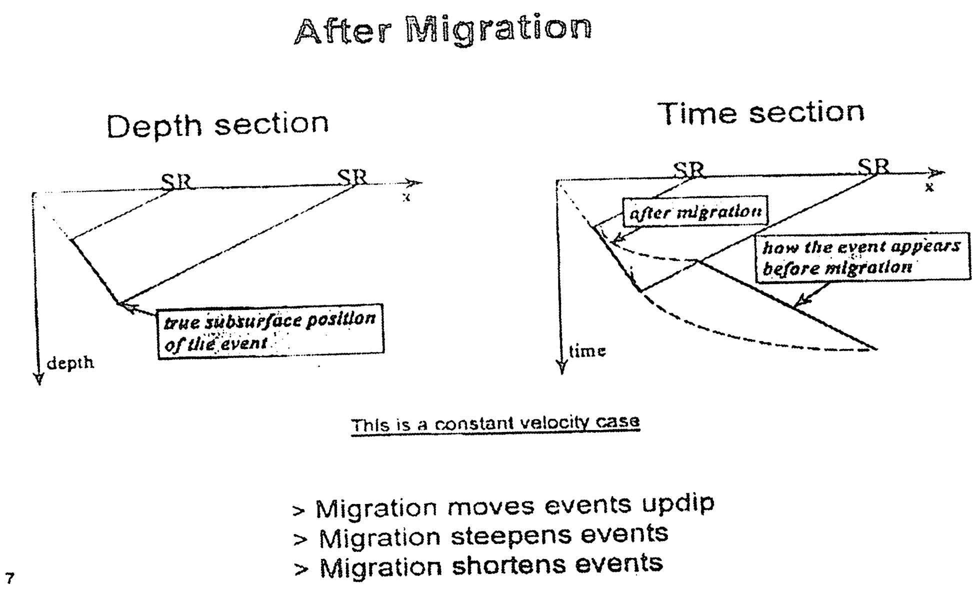


Figure 4: Differences between depth migration and time migration

<u>Post or Pre-Stack Migration?</u>

Geological conditions	**Type of migration**
Simple velocities, simple structure	Post stack time migration
Complex velocities, simple structure	Post stack depth migration
Simple velocities, complex structure	Pre stack time migration
Complex velocities, complex structure	Pre stack depth migration

3.4) Iterative depth migration:

Depth migration is usually performed in an iterative manner to obtain an earth image in depth from CMP-stacked data. Depth migration is done using an initial velocity-depth model and the result is interpreted for the layer boundaries included in the model. The velocity-depth model then is updated accordingly and next iterations are continued until convergence is achieved. Convergence is achieved when the input to depth migration as the velocity-depth model matches with the velocity-depth model obtained from the output of depth migration. By way of convergence, the final velocity-depth model from iterative depth migration can be made consistent with the input data. Consistency means that the modeled zero-offset travel times match with the observed reflection travel times on the stacked data associated with the layer boundaries included in the velocity-depth model. Convergence and consistency are the two important conditions for an earth model to be certified as a valid, geologically plausible solution from seismic inversion. Another requirement for the validity of velocity-depth model is that it also needs to be consistent with prestack data and hence prestack depth migration is carried out for accurate earth imaging in depth.

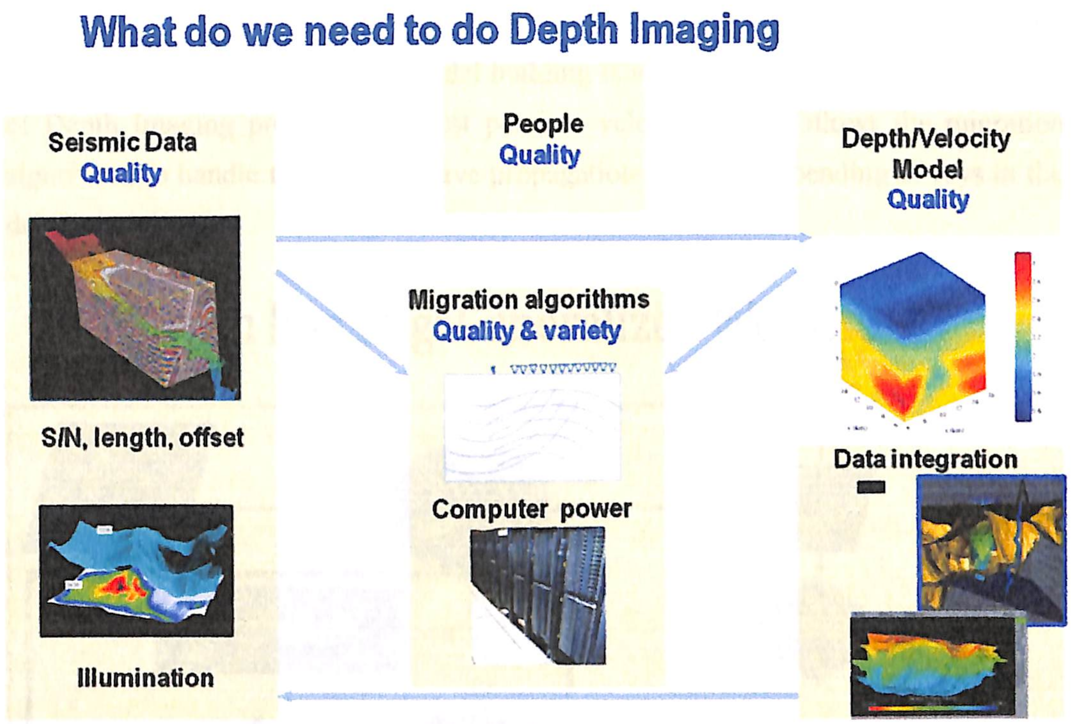


Figure 5: Inputs required for depth imaging

3.5) Data requirements for depth imaging:

- Seismic data of sufficient quality. It must be well conditioned and should not contain any type of noise or multiples.
- A depth/interval velocity model adequately representing the true earth model.
    - Geological constraints
    - Well log data
    - Vertical Seismic profiling (VSP) data, etc.
- Migration algorithm suitable for achieving the objective of the given depth imaging project.
- Experienced personnel to execute the depth imaging project as it involves both the domains of processing and interpretation in an integrated way.
- Sufficient time to complete the depth imaging project as it is a time consuming

and expensive process.

- High computational power is required to execute the depth migration process.

3.6) Steps in depth migration:

The most accurate seismic imaging solution for representing the subsurface geological structures is Pre-Stack Depth Migration (PreSDM) because of its inbuilt capability to focus and position reflection points in the presence of considerable lateral velocity variations. An accurate velocity model building is very much required for the success of Depth Imaging process. The best possible velocity model allows the migration algorithms to handle the seismic wave propagation effects and bending of rays in the depth domain.

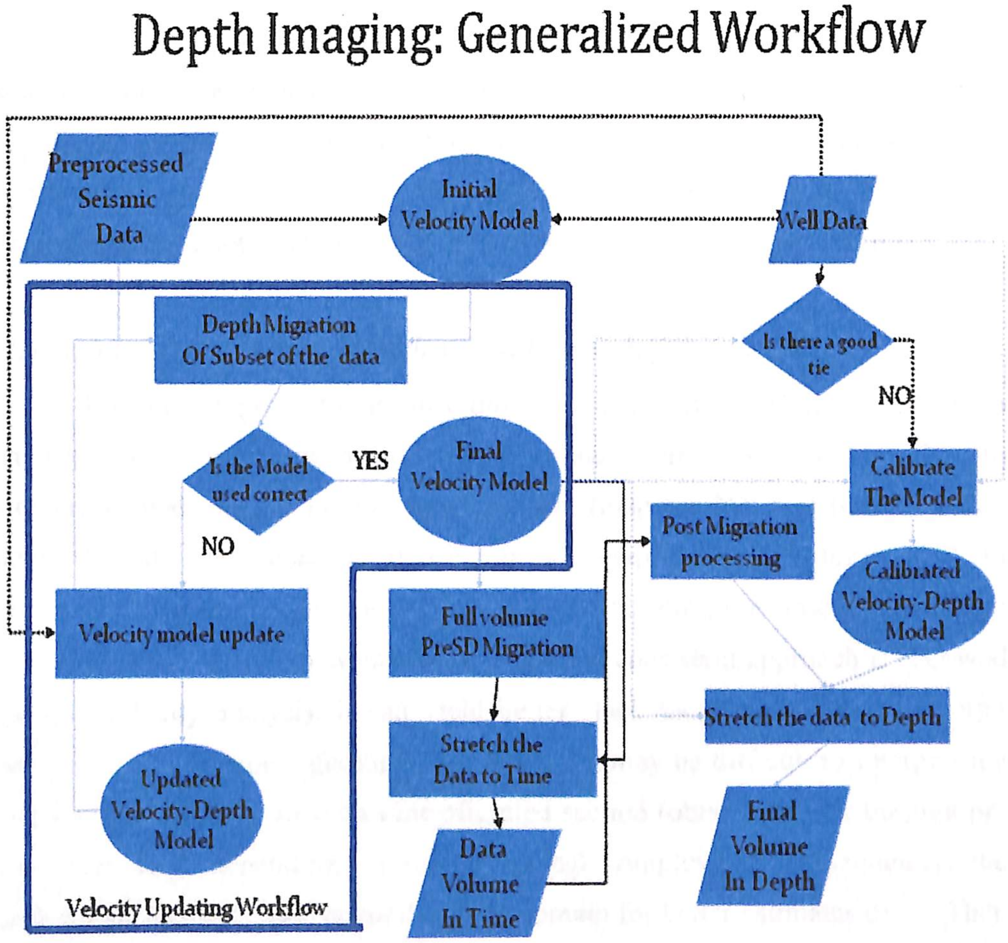


Figure 6: Generalized PSDM work flow

The primary step in depth imaging is to find the interval velocity depth model using all available information and the seismic data .Then a synthetic time plot is used to check the coherency between the acquired data and changes are made in a iterative manner till a perfect match is obtained . This approach gives a consistent velocity depth model.

These inversion processes suffer from the fundamental problem of velocity-depth ambiguity, which requires independent estimation of layer velocities (for best focussing) and reflector geometries (for accurate positioning). Due to the velocity-depth ambiguity, output from inversion is an estimated velocity-depth model with a measure of uncertainty in layer velocities and reflector geometries. This requires a sound interpretation and analysis of data to bring out a geologically plausible velocity-depth model. This brings a paradigm shift between time domain processing and depth domain processing approaches. Depth domain processing is built around workstations having a lot of interpretational and graphical visualisation facilities.

4.1) Horizon consistent approach for velocity-depth modelling:

It is advantageous to visualise three domains while working for inversion projects i.e. *Time domain, Time Migrated domain* and *Depth domain.* Time and depth domains are related through normal incidence ray (map for 3D) and time migrated and depth domains are related through image ray (map for 3D) (Hubral, 1977). In general, inversion methods for velocity-depth model building use time interpretation for zero offset travel time (T_0). Sometimes, if horizon consistent approach is followed for stacking velocity analysis, it can yield better stack section and hence, a better estimation of T_0. In complex geological situations, it may be difficult to interpret the time section and it can be done on time migrated section (obtained either through pre stack or post stack depending on the geological complexity). Subsequently, the interpreted picks are to be ***demigrated*** to time domain for better estimates of T_0. Then fault interpretation are generally, defined in the time migrated domain and can be migrated to depth domain for inclusion in the velocity-depth model building.

The different schemes of velocity analysis and their refinement can be summarised as follows:

- Stacking velocity analysis along time horizons

- Stacking velocity refinement along time horizons
- RMS velocity analysis along time migrated horizons
- RMS velocity refinement along time migrated horizons
- Interval velocity and depth model creation
- Interval velocity and depth model refinement
- Fourth order term (Eta) correction along time, time migrated and depth migrated horizons

4.2) Different approaches for velocity-depth model building:

USING HORIZON CONSISTENT STACKING VELOCITY	DIX CONVERSION
USING STACKING VELOCITY AND TIME INTERPRETATION PICKS	STACKING VELOCITY INVERSION
USING CMP GATHER AND TIME INTERPRETATION PICKS	COHERENCY INVERSION
USING CMP GATHER AND TIME INTERPRETATION PICKS IN THE COMMON OFFSET DOMAIN	TRAVEL TIME INVERSION

4.2.1) 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. Vertical velocity gradients can be incorporated if known from well data. There is no hyperbolic assumption in this method

This is a layer stripping technique, where the interval velocity is determined layer-by-layer beginning from the shallow to deep regions (Figure-7a). The inputs required to are time interpretation (which defines the zero offset times for different layers) and CMP gathers in time. At a given CMP location, the interpretation around the analysis point is ray migrated (normal incidence) to depth locally for the layer under consideration. This is done for a range of trial interval velocities to predict a number of move out curves through ray tracing. The ray tracing takes into account the established depth-interval velocity model for the upper layers and the local depth model for the current layer. These curves are correlated with the data and semblance values are calculated. Peak semblance defines the interval velocity for the CMP under analysis. This is repeated for each (or at certain interval) CMP(s) along the layer. Having picked the interval velocities, the active layer is converted from time to depth through ray migration (normal incidence).

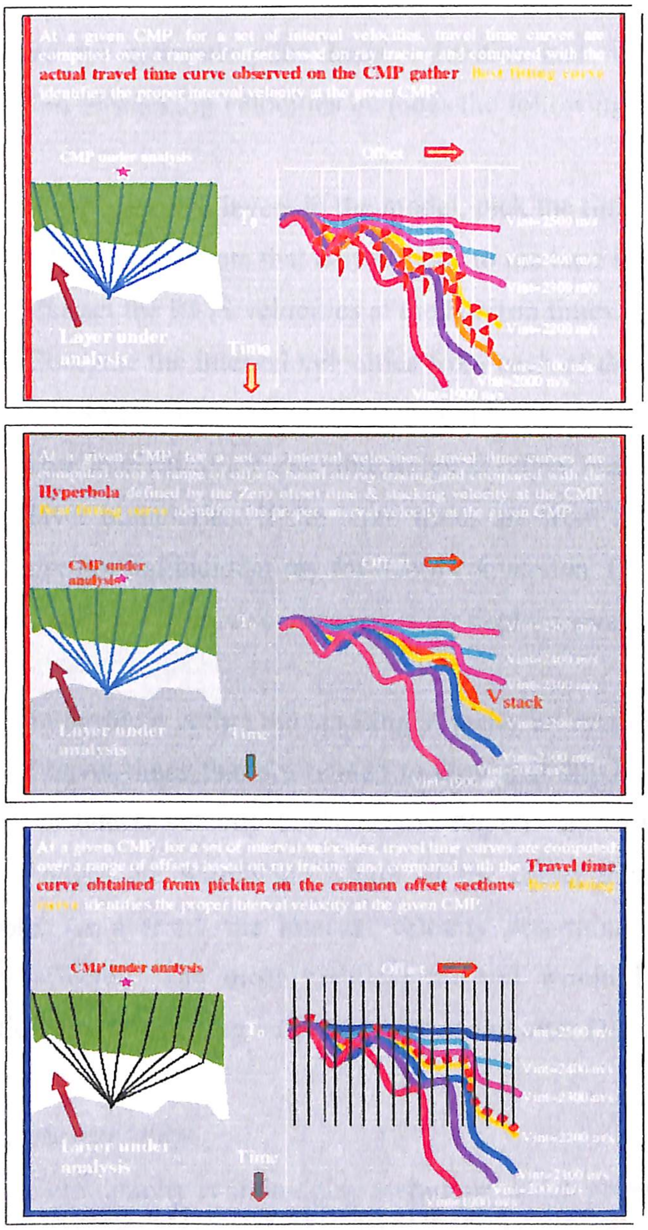
4.2.2) Stacking Velocity Inversion

This is similar to the Coherency Inversion with the exception that the inputs are time interpretation and the Stacking velocities and not CMP gathers. The main idea behind the method is that the stacking velocities represent the pre-stack data in a best-fit (hyperbolic) sense (Figure 7b). This method is best used for environments where there is direct relation between the velocities and the geological structures. The advantage with this method is large volume 3D data can be analyzed in a quick way, compared to the costly and large disk space requiring Coherency or other methods involving pre-stack data.

For a given layer at a given CMP, a range of trial interval velocities are used to predict time-offset curves through ray tracing (full for 3D) procedure which includes ray bending due to velocity variations. Before computing the travel time-offset relation, a depth model (around the analysis point) is obtained locally by normal incidence ray migration of the interpreted time picks for each of the trial velocities. Ray tracing takes into account the depth-velocity model for the upper layers and the local depth model for the current layer. The stacking velocity at that point corresponding to the interpreted horizon defines the hyperbolic time-offset curve. The interval velocity yielding the best match is assigned to the layer at the point of analysis (Figure-7b). This is repeated for each (or at certain interval) CMP(s) along the layer. Having picked the interval velocities, the active layer is converted from time to depth through ray migration (normal incidence). For 3D data, the azimuthally effect can also be accounted for the azimuth range present in the data. Similarly, the Dip Move Out correction (if implemented to derive the stacking velocities during the processing) can be accounted during this analysis. The accuracy of stacking velocity inversion is highly dependent on the quality of the picked horizon and the stacking velocities used.

4.2.3) Travel Time Inversion

This is also similar to Coherency and Stacking velocity inversion with the exception that the time interpretation picks are not based on the zero offset data, but based on common offset picks. This is cumbersome but very accurate in the sense that the errors in T_0 (which is sensitive to the velocities used for stacking) can also be properly taken care of. Partial stacking can reduce the number of common offset sections to overcome the limitation. This method can handle moderate quality input data. Coherency inversion analyses one CMP gather at a time and hence, is dependent on the data quality at that location. The inaccuracies to honor the far offset travel times in the presence of noise can severely limit the confidence of velocity estimation in the coherency inversion. Often, the weak energies at the far offset regions are overlooked while trying to fit the best travel time curve to the observed data. Travel time inversion is a better approach as the interpretations are done in common offset sections.



a. Coherency Inversion

b. Stacking Velocity Inversion

c. Travel Time Inversion

Figure 7 a, b, c: Different process for Velocity modeling

4.3) Dix conversion technique

This is the most simple technique for determining interval velocities from the RMS velocities. The RMS velocities are extracted from pre-stack time migration dataset. A smoothened stacking velocity that are estimated from the DMO corrected data can used in place of RMS velocities. This method works well for horizontal reflector earth models having constant layer velocities and less offset distance. For dipping reflector models and varying vertical and lateral velocities methods like coherency and stacking velocity inversion are used for getting accurate results. The procedure for estimating the layer velocities and reflector depths using the Dix conversion of stacking velocities includes the following steps:

- For each of the layers in the model, pick the time of horizon on the unmigrated CMP stacked data that corresponds to the base layer boundary.
- Extract the RMS velocities at the horizon times.
- Compute the interval velocities from each of the layer from known quantities-RMS velocities and times at top and base layer boundaries.
- Use interval velocities and times at layer boundaries to compute depths at layer boundaries. If the input times are from an un-migrated stacked section use normal incident ray for depth conversion. If input times are from migrated stacked section, use image rays for depth conversion.

The main problem is that the stacking velocity estimation done by fitting a hyperbola to CMP travel-times that are related to with spatially homogenous subsurface model. In case of lateral velocity deviations in regions above the layer under study, and if these changes are within the length of the cable, then stacking velocities will be unstable. As a result the interval velocity determination using Dix conversion is highly affected. The most practical method would be to smooth out the rapid variations in the stacking velocities before and after Dix conversion [Yilmaz, 2001].

4.4) 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. The technique was a phenomenal success in medical applications as early as 1980. Seismic tomography came to existence in the late 1980s and uses the seismic waves, which probe the geological target of interest.

The object is probed in many directions by sending the source energy from one end and recording the response from the other end. The measured response of the object (projection data) is used by image reconstruction to create a tomogram. In seismics, seismic ray tomography uses the direct-arrival travel times and can be suitably modified to accommodate refraction and reflection data as well to construct the P-wave velocity tomogram. Quantitative interpretation of the tomogram leads to identification of lithology.

Seismic tomography is conceptualized on the basis of wave propagation model in the subsurface. For target size larger than the seismic wavelength, ray theory is used and if it is comparable to the seismic wavelength, then diffraction theory is used. Tomographic techniques based on these two models are known as Ray Tomography and Diffraction Tomography respectively. Currently Seismic Ray tomography is popular because it is simple to implement under variety of situations. In the present context, the ray tomography is used to update the velocity depth model.

A standard geophysical problem is that of finding the velocity of the subsurface by observing the different kind of travel times (direct arrival in cross well, refraction, reflection, etc). For example, the travel time of a seismic pulse through a region can be imagined to be divided into small segments of travel times through small rectangular cells.

This can be formulated as

$$T = \sum_{i=1}^{N} P_i * d_i$$

Where, T is the travel time from source to receiver,

P_i is the slowness in the i –th cell

d_i is the ray path segment in the i –th cell and

N is the total number of cells from source to receiver

Travel time tomography problem is to find the slowness values P_i from a number of ray travel times.

4.5) Methods for Updating 3D Depth Models and Interval Velocities

The interval velocities and depth models can be updated using a) Horizon based global depth tomography; b) Grid based tomography (update velocity model only) and c) Hyperbolic update (using Dix's method). The principle of Tomography is that if the depth imaging was carried out with accurate interval velocity-depth model, the common image point gathers should be flat; i.e., event depth is same at all source-receiver offset locations (Stork, 1992; Whitmore & Garing, 1993). Tomography of depth migrated gathers is used to build the correct the velocity - depth model. The depth gathers after PreSDM will not be flat if the initial, incorrect, velocity model derived from inversion methods based on non-global (local) approaches is used. The extent of non-flatness is an indication of the amount of error in the model. Tomography uses this measurement of non - flatness (RMO- residual move out) as input and attempts to find an alternative model, which will minimize the errors.

The first step in tomography is to scale the CIP gathers to time. When the gather is not flat, the time at zero offset, t_o, varies from the time t at the offset. The difference, Δt, is the input data for tomography. The tomographic principle relates an error in time to an error both in velocity and depth. The error in time, measured at a specific CMP location, can be the result of an error in the model through which the ray propagation takes place.

An important feature of tomography, as compared to layer stripping, is that it is a global approach. Tomography can attribute an error in time at one location to an error in velocity and depth at another location. It takes into consideration the entire model. Layer stripping may result in accumulation of error at the deep parts of the section when there are errors at the shallow parts. Tomography updates the shallow and deep sections simultaneously. After pre-stack depth migration, we measure on CIP gathers. For a given offset, Δt is the error in travel time with respect to Zero Offset travel time. It is the results of cumulative error, Δt_i, along the ray.

4.5.1) Horizon-Based Tomography

Horizon-based tomography uses a very simple method for model parameterization: it samples horizons at a typical interval of 30 CIPs. At each sampled point, the depth of the reflector and velocity at that point is registered. Tomography updates the values of the velocity and horizon depth at those "sampling" points.

Therefore, tomography updates are long wavelength. Tomography can use three types of input data:

1. Tomography using CIP Panels: When CIP panels are used as input to tomography there is no need to pick events (along with errors) on CIP gathers because the tomography application performs this operation. The automatic picking algorithm operates on migrated CIP panels, rather than on migrated CIP gathers. CIP panels contain reflections at all offsets from a CIP, as do CIP gathers. However, CIP panels are reflections, which fall in a fixed window around a depth interface, whereas CIP gathers, are full length. Thus, for every CIP, there are several panels in a window around each interface, but only one depth gather. The vertical scale in panels is in time.

2. Tomography using Residual Move out: Tomography uses as input data a measurement of non-flatness Δt. Δt is the difference in travel time between near and far offset.

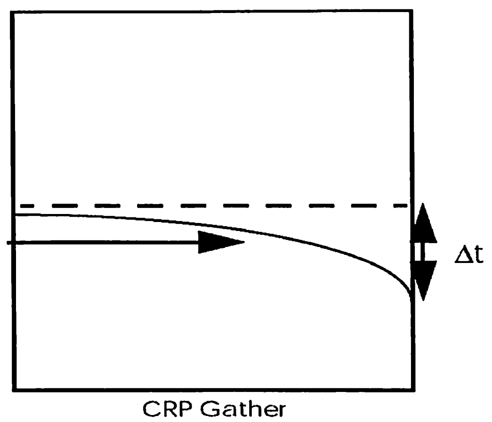


Figure 8: Residual Moveout

It is derived using semblance analysis. Semblance is calculated along the picked horizons using a residual moveout analysis technique. You pick the "residual move outs" (Δt) where semblance value is maximal.

3. Tomography Using Stacking Velocity: You can approximate the true travel time along a ray by using the travel time corresponding to the stacking velocity. The travel time error can be the difference between the time corresponding to the stacking velocity and the time predicted by CIP ray tracing. This method should only be used if good stacking velocities are available.

Tomography yields consistent results for initial models, which are different from the corrected model by up to 15%. When you are unsure of actual lateral velocity variation, we recommend that you begin tomography from an initial model with laterally uniform velocities and let the tomography detect the actual velocity variation. The Tomography application can be used to solve residual static problems. These may occur if your survey includes weathering horizons for which residual static analysis was not performed correctly at the pre-processing stage. Tomography results can be verified by displaying CIP panels.

4.5.2) Horizon- based Tomography versus Grid Tomography

Horizon- based tomography and grid tomography are global approaches, which involve solution of a simultaneous set of equations for calculating the updating parameters (depth and velocity) of the model. However, the two approaches are quite different. The main difference is in the spatial discretization. Horizon- based tomography requires a subsurface depth- velocity model, and updates both the interface depths and layer velocities. The updates are calculated at equally spaced spline nodes and then interpolated. Conversely, grid- based tomography does not require a model dataset, but instead uses picks on a migrated section. It calculates the update parameters for velocity only at equally spaced points on a grid. The input model for grid tomography is an updated velocity section. In addition, grid tomography uses as input a depth model and/ or picks of segments on the depth section. These picks do not have to define a complete depth model, but rather define some segments of a reflector that can be identified on the migrated image.

4.5.3) Why use Grid Tomography?

Grid tomography is useful in a number of situations where a horizon- based velocity determination method may not be applicable. For example, in very complex structures it may be difficult to initially define the subsurface model. The features of the model become clear only after a number of iterations of depth migration followed by grid tomography. Another situation is when the shallow layers can be easily defined whereas the deeper layers cannot (e. g. sub-salt imaging). Poor quality data is another case where it may be difficult to build a consistent depth model. Furthermore, there are times that one may wish to improve a velocity section without having to build a model.

4.5.4) Does Grid Tomography Replace Horizon- based Approaches?

When the topology of the subsurface can be, and is, defined, a first and very important step of the velocity and structure determination has been performed. In such a situation the subsurface velocities will be geologically plausible, and hence, horizon based tomography precedes any other approach. Conversely, when not used properly, grid tomography can produce a velocity section which yields flat pre- stack migrated gathers, yet makes no geological sense. Therefore, whenever possible, the horizon-based approach is recommended, whereas the grid- based approach should only be used when the horizon- based approach is not applicable.

4.5.5) Grid-Based Tomography

Grid- based tomography is a velocity updating procedure for refining and improving the initial velocity section. Grid- based tomography uses the velocity section as input. The output is an updated velocity section, i. e. the tomography updated velocity section, which is a grid- type representation of the model. Grid based tomography can be used in situations where it is difficult to pick horizons and build a model as is the case with complex structures or poor- quality data. Grid based tomography can also be used to further refine velocity sections, after several iterations of horizon- based tomography. The input used for grid- based tomography is either velocity - residual move out sections or depth gathers after migration. Grid- based tomography does not require a model as input. This is an advantage over horizon-based tomography in cases where it is difficult to build a consistent model. Alternately, segments of events can be picked on the depth section. However, if a horizon-based model can be built, it should be used, since horizon- based tomography is faster and provides better results by updating horizons and velocities simultaneously. The required input for grid- based tomography is an initial velocity section, gathers or a residual move-out section, and tomography picks. The output of grid- based tomography is a new, updated velocity section. The velocity section can be converted to a horizon model, which can then be updated using horizon–based tomography. Tomography yields consistent results for initial models, which are different from the corrected model by up to 15%. When the actual lateral velocity variation is not known, tomography can be attempted with an initial model with laterally uniform velocities and let the tomography detect the actual velocity variation. The Tomography application can be used to solve residual static problems, which may arise if the survey includes weathering horizons for which residual static analysis was not performed correctly at the preprocessing stage.

4.5.6) Combined Approaches

There are situations where a combination of the grid- based approach and the horizon- based approach is recommended. For example, in salt structures it may be desirable to define a model for the salt body and maintain a constant velocity for it. This option is available in the grid tomography application.

4.6) Tomography applications in Exploration seismic:

The tomography process is carried out in two steps. First step involves forward modeling of the predicted result and determining the differences with the observed data thus formulating the equations. The second step is the inversion process where the solving of equations is done so as to minimize the differences. The important thing to be considered is that no unique solutions are obtained. The data has to be constrained using hard data like well logs, VSP etc., to achieve a reasonable velocity model representing the geological conditions of the area under study.

4.6.1) Reflection Tomography

Reflection Tomography is an inversion method that updates the velocity and reflector depth model to be consistent with the data collected in migrated/ pre migrated time domain. It reduces the deviations of the measured and the modeled data in the migrated/pre migrated domain. There are different methods that are used to determine the appropriate model. The input data is represented by Travel Times (TT) of the reflection events. The events are difficult to pick in the pre-migrated domain which is data driven. Another alternative is to perform reflection tomography in the post migrated domain. Main advantage of this method is the continuity and even strength of subsurface reflections. This method is model driven and hence the success and failure depends on the initial assumptions about subsurface.

4.6.2) Advantages of Tomography

- It is computationally fast.
- Accuracy is good
- It has the ability to include even small velocity variations and can handle very complicated structures as well.
- It provides the opportunity to find out the different possible solutions.
- The entire process can be automated.

4.6.3) Disadvantages of Tomography

- Tomography finds a velocity field that satisfies the selected criteria like removing Residual Move Out (RMO) on Common Image Point (CIP) gather without considering the geological plausibility.
- Poor quality or incomplete seismic data will cause errors in the tomography solution.
- Geology based constraints using well logs, synthetic seismograms are required for stabilization.
- The software implementation is complex and still in development stage.
- There is limitation in resolution of the output obtained.

4.6.4) Common Image Point (CIP) Tomography Workflow Overview

The following are the steps involved in the CIP Tomography workflow:

- Structural Interpretation:
- Load and Edit horizons and faults if required
- Interpret horizons and faults
- Create an Interpretation Model
- Create a Structural Model
- Create a Velocity Model
- (Optional) Velocity Model Building (VMB)
- Automatic CIP Pick interpretation (CIP PICK)
- Interactive CIP Pick Editing
- Automatic DIP Estimation (DIP EST)

- Compute Tomographic Differential Equations, based on raytracing (CIP DIFF)
- Compute Tomographic Inversion (Ztomo)
- QC and Update Velocity Model
- Run Pre-stack depth migration with the updated velocity model and start again.

4.7) Interpretation to Imaging

Introduction

Interpretation to Imaging (I2I) is a suite of Ocean components integrating interpretation, modelling, and seismic processing tools to execute imaging workflows through seamless access to the Omega2 seismic processing system and the Petrel seismic interpretation and modelling software package. I2I bridges the gap between two previously separate worlds: the highly visual and interactive world of interpretation and velocity model building, and the computationally intensive world of migration and tomographic inversion.

New features in I2I v2.0 include access to the Petrel Interpretation toolkit, which eliminates the current disconnect between interpretation and model building, and also the ability to execute complex salt modelling. I2I v2.0 has enhanced visualization, data management and well information capabilities, as well as an increase in available model size and resolution.

From velocity-depth model building and tomographic update through to final imaging, I2I delivers the most accurate depth imaging solutions in a shorter timeframe. I2I v2.0 boasts improved turnaround time, estimating to reduce it by half. Typical workflows include isotropic and anisotropic depth imaging, migration velocity model building and updating, 4D imaging and anisotropic illumination studies, and borehole to surface calibration.

I2i v2 has the capability to support several defined workflows across the Omega2 and Petrel software systems. These workflows include the CIP (Common Image Point) Tomography workflow the Residual Moveout (RMO) Quality Assurance workflow, and the Velocity Scanning workflow.

The I2I components are listed below.

4.7.1) Visualization

- The Petrel 3D window is where all geological and geophysical objects are displayed together, navigated synchronously, and is viewed in their geographical position. This includes views of higher dimensional datasets such as pre-stack gathers.
- The scalable visualization engine, Seismic Server, allows very large data sets to be used.

4.7.2) Interpretation

- Pre-stack interpretation: This feature allows access to the global Residual Moveout (RMO) batch picking and its output data, and provides local interactive editing of those data.
- Velocity scans picking: This feature provides interactive manual line by line velocity picking.

4.7.3) Modelling

- Structural Modelling: This feature allows surface and fault modelling, and intersection and trimming into a structural framework.
- Velocity Modelling: This feature provides interactive layer definition and property population in formats of acoustic, elastic, or anisotropic (VTI and TTI) in multi-property multi-resolution Cartesian grids. The velocity model format is optimized for the ray tracer.
- Access to batch automatic velocity model builder is provided.

4.7.4) Inversion (Omega 2)

- CIP tomography: This feature provides access to high resolution ray-trace based grid tomography using complex RMO picked in (multi-azimuthal) offset gathers or common angle gathers.
- Sub salt tomography: This feature provides access to the same inversion engine, when using velocity scan picks.

4.7.5) Time to depth conversion (Omega 2)

- Map Migration: This feature provides access to batch functionalities for vertical, zero-offset, and multi-offset time to depth conversion.
- Velocity conversion: This feature provides access to batch functionalities for general conversions, including time to depth.
- Post stack seismic attribute computation: This feature is interactive and provides access to batch (e.g., automatic Dip Estimation) functionalities.

4.7.6) QC tools

- Petrel 3D window
- QC data: 4D residuals, illumination cubes and points, % velocity change (linearization assessment), illumination points and histograms
- QC of 3D RMO volume output by CIP_RMO_FIT

4.7.8) Data access and communication

- Omega2 files, required for Velocity model building and updating, can be accessed through local networks to the Linux based Omega2 system.
- Supports required Omega2 file formats such as velocity fields in IVEF text file format, binary velocity grids, interpretation in text file format and binaries for tomographic velocity update

CHAPTER- 5 CASE STUDY

5.1) Introduction

The following case study deals with the results of pre stack depth migrations of a model dataset. A 3D Marine seismic dataset is taken for the depth domain processing. The various steps are followed to obtain the seismic volume in depth. The critical aspect of depth imaging is the interval velocity model building. In this case, grid tomography is used for the velocity updates. The final interval velocity model is obtained once the Common Image Point (CIP) gathers are flat and consistent with the geological constraints (well logs, VSP data, etc.). The full volume migration is run using the final velocity model to get the seismic volume in depth.

5.2) Data Prerequisites

The input dataset required are as follows

- Pre-conditioned CMP gathers after attenuating noises and multiples.
- RMS velocity volume in time.

5.3) PSDM work flow

STEP01	Preparing initial data for Depth migration Sorting of Data in to Offset sections, regularization etc.
STEP02	Preparing RMS velocity in omega in velman format
STEP03	Converting RMS velocity into Interval Velocity, smoothening of interval velocity using VMB Module in Omega
STEP04	Exporting text format velocity function to I2I for making Initial Velocity model Building (100 * 100 Grid)
STEP05	QC of initial velocity model in I2I and exporting Initial Velocity Model to Omega in Volcan Model
STEP06	Converting Volcan Model to DIO format Using TR3Convert Module in omega

STEP07 — Running of TT Calculation Job as First step of Kirchhoff depth Migration

STEP08 — Ruining Kirchoff depth Migration as second step For creating initial Depth Migrated Offsets

STEP09 — Sorting of data to create Initial CIP gathers

STEP10 — Picking of multiple offset Residual move out In CIP_PICK Module of Omega

STEP11 — Running CIP_DIFF job to create differential Equations corresponding to picked event in CIP_PICK

STEP12 — Running tomography inversion in ZTOMO Module to Solve differential equations created with CIP_DIFF

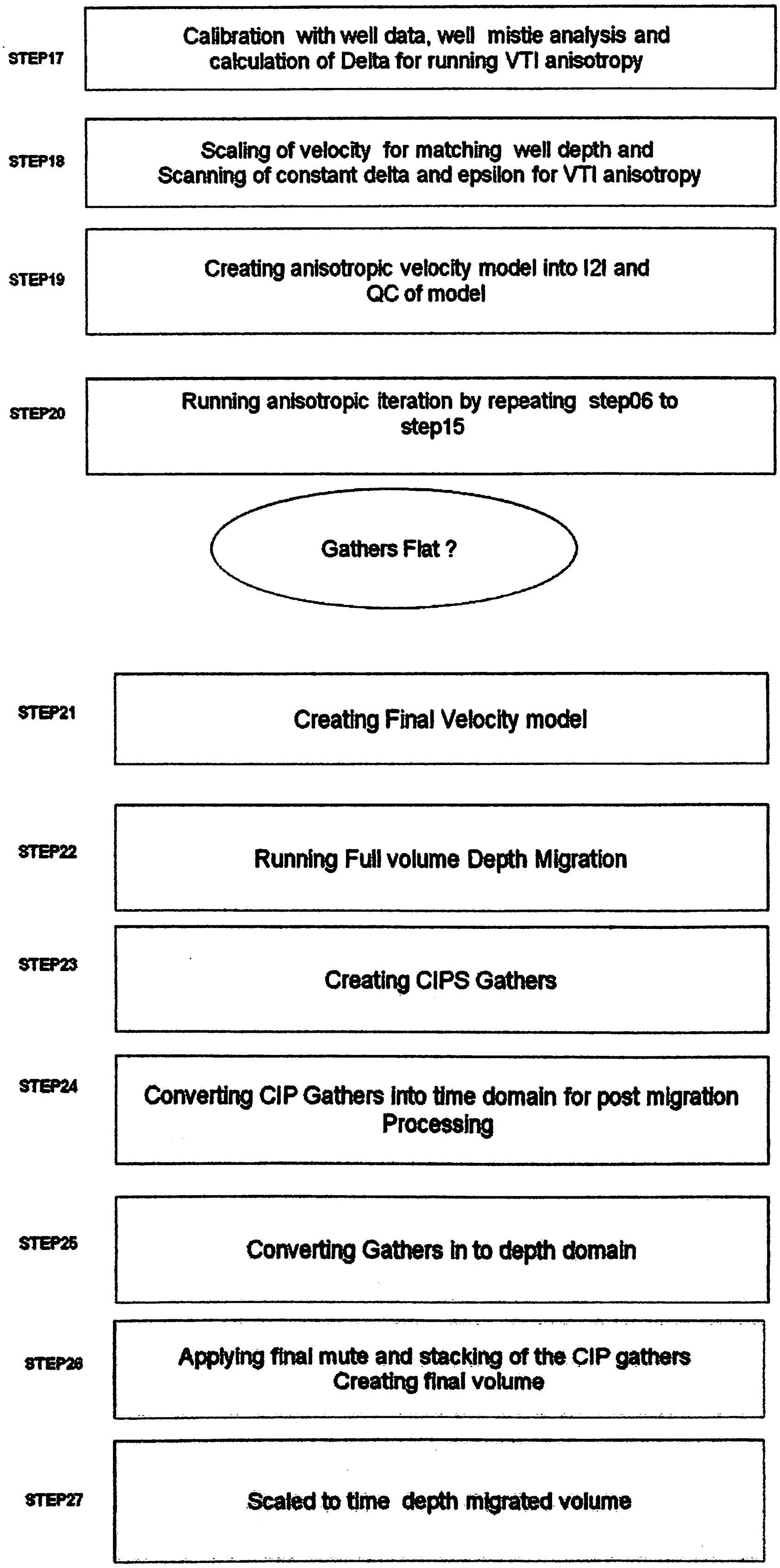
STEP13 — ZTOMO provides solution for velocity update, exporting ZTOMO solution to I2I Software for Initial Update

STEP14 — QC of Updated Velocity Model in Omega as well In I2I for Quality output

STEP15 — Exporting updated velocity model to Omega for running Kirchoff depth migration

STEP16 — Repeating step06 to step15 until and unless CIP gathers are flat

Gathers Flat ?


STEP17
Calibration with well data, well mistie analysis and calculation of Delta for running VTI anisotropy
STEP18
Scaling of velocity for matching well depth and Scanning of constant delta and epsilon for VTI anisotropy
STEP19
Creating anisotropic velocity model into I2I and QC of model
STEP20
Running anisotropic iteration by repeating step06 to step15
Gathers Flat ?
STEP21
Creating Final Velocity model
STEP22
Running Full volume Depth Migration
STEP23
Creating CIPS Gathers
STEP24
Converting CIP Gathers into time domain for post migration Processing
STEP25
Converting Gathers in to depth domain
STEP26
Applying final mute and stacking of the CIP gathers Creating final volume
STEP27
Scaled to time depth migrated volume

5.4) Offset Regularization

There are some areas in the data set where nominal fold is absent. To remove this effect and to get good stack, offset regularization has been done which generally is used to equalize the fold and regularize the traces within the gathers. Even zero amplitude traces is dropped and an interpolated trace is replaced in the input trace wherever possible.

5.5) Depth Imaging Sequence

Accurate velocity model building for prestack depth migration is critical aspects for the success of any depth imaging projects. The depth velocity model building technique involves iterative applications of cell-based common-image-point tomography. I2I modeling system is used to construct 3D models from surfaces and velocities. A key part of this system is the capability for 3D visualization. Seismic volumes, gathers, velocities, and other attributes can be viewed simultaneously, allowing efficient QC of the velocity model. Common image point tomography is applied to iteratively update the velocity model. The prestack migration algorithm used for the project is based on the Kirchhoff summation integral.

5.6) Depth Velocity Model Building Overview:

The first steps in the velocity modeling workflow are the creation of the initial velocity model followed by Pre-Stack Depth Migration of the seismic data using this model. The initial model can be created from a number of sources of velocity information. In many cases the initial model is created from smoothed stacking velocities produced during time processing.

The initial velocity model used for the first iteration of tomography was derived from edited time RMS stacking velocities that were smoothed. The smoothed velocity field was converted to depth to create the sediment velocity field. The initial model consists of a water layer with a velocity of 1500 m/s, with the smoothed sediment velocity field below to the bottom of the model. By starting with this simple model the tomography updates can be made at longer scale lengths (low resolution, long spatial wavelengths) initially, allowing the data to guide the modeling. This is usually preferable to starting with a more detailed model, where certain features may be in error, because the tomography will have to be pushed to shorter scale length updates before these errors can be corrected. Kirchhoff Pre-SDM was run using this model, and a grid of output gathers was produced. These output gathers form the input for CIP tomography and are analyzed for residual move out.

Full 3D common-image-point (CIP) tomography was applied to refine the initial velocity field. CIP tomography is a robust, 3D ray-based inversion method used for updating velocity-depth models suitable for use in prestack depth imaging algorithms. It uses residual travel time errors picked from CIPS (prestack depth migrated gathers) and 3D ray tracing to derive an updated velocity model aimed at improving the depth migration result. CIP tomography accuracy improves significantly with the inclusion of a 3D dip field in the inversion process. This provides the necessary inputs required to compute the incident and reflection angles from the depth image point, thereby improving the fidelity of the 3D ray tracing.

Successive tomography iterations produce a solution at a shorter spatial scale length, i.e., higher resolution. The end result is a highly detailed velocity model that is used to create the final pre-stack depth image volume.

Beginning with the CIP gathers created by prestack depth migration using the initial velocity model, the tomography update procedure is as follows:

1. Automatic residual move out picking of CIP gathers to generate a database table of the actual depths of seismic events across all offsets.

2. Creation of dip estimates from volume modified with most recent velocity.

3. Calculation of the tomography equations, which are essentially residual migration equations aimed at aligning all picks of an event to the same depth level.

4. Application of CIP tomography inversion to solve these equations in a global, least squares sense and update the velocity model.

5. Ray tracing the updated velocity model to obtain travel times.

6. Prestack depth migration with these travel times as input to generate the next set of common image gathers.

7. Visual inspection of CIP gathers to assess their flatness vs. original CIP's.

The process is repeated until the seismic events on the CIP gathers are deemed to be satisfactorily flat, i.e., event wavelets are aligned across all offsets, at all depths. These steps are summarized below.

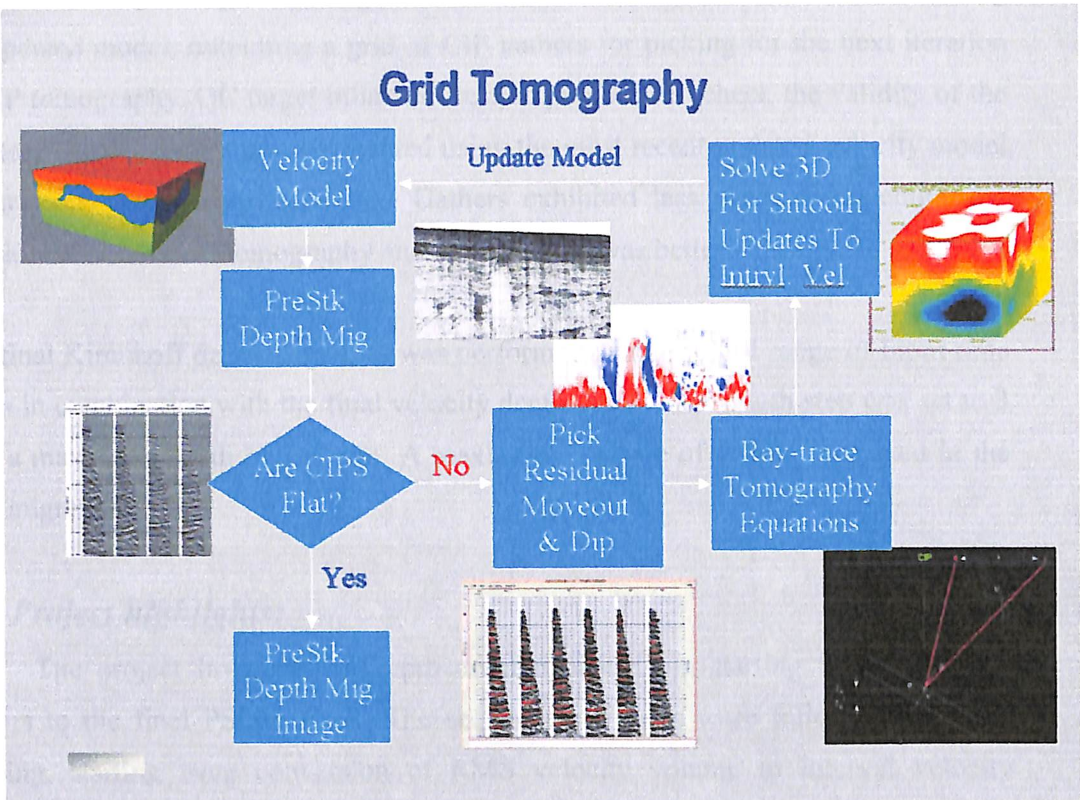


Figure 9: Overview of tomography model building

5.7) Depth Velocity Model Building Using Common CIP Tomography

Kirchhoff prestack depth migration was run using the initial velocity model, outputting a 100m by 100m grid for input to CIP tomography. Sixty offsets were migrated to a maximum depth of 16000m. The automatic picking of reflections was performed on CIP gathers. The dip field was created from a time migrated volume that was converted to depth using the initial velocity model and was input to the 3D dip estimation program. CIP picks, dip volumes and the initial velocity model were then used as input for CIP TOMO, a global gridded tomography that solves for the tomographic equations to produce a global velocity update to minimize the depth errors that were observed from the picks. The velocity model was updated with the optimum tomographic solution.

Kirchhoff PreSDM was run using the updated velocity model, producing target lines for QC. Gathers generally exhibited less residual moveout after tomography, and stack quality was better. Three more iterations of CIP tomography were run exactly as the 1st iteration, on a grid spacing of 100x100 m. Kirchhoff PreSDM was run using the updated model, outputting a grid of CIP gathers for picking for the next iteration of CIP tomography. QC target inlines were also produced to check the validity of the updates. The 3D dip field was recreated using the most recent updated velocity model to get more accurate dip estimates. Gathers exhibited less residual moveout from iteration to iteration of tomography and stack quality was better.

The final Kirchhoff depth migration was performed using the full range of input time traces in combination with the final velocity depth model. The depth step was set to 3 with a maximum depth of 16000m. A maximum aperture of 4000m was used in the final migration.

5.8) Project highlights:

The project involved the depth domain processing starting from the CMP gathers to the final PSDM stack. The sequences of steps were followed for depth imaging, starting from conversion of RMS velocity volume to Interval velocity volume. To create the initial velocity model, two minimum inputs were required-interval velocity in binary format created with VMB module in omega and water bottom picked in omegavu programme. Initial velocity model was used to create the initial CIP gathers using the same velocity grid.

The initial interval velocity model was built in PETREL and first run of Kirchhoff Depth migration in OMEGA was done. CIP gathers were muted for RMO analysis and picking. Picked RMO were used for tomography inversion in omega. The RMO picks were used for QC in omega as well as in I2I for qualitative output. Predicted picks based on picked events were created and visualized in I2I to have preliminary idea about the next update results. Synthetic picks generated through picked RMO were applied different tomography solution as QC.

Grid Tomography was carried out to find the velocity corrections, updating the interval velocity model for the next iteration of depth migration and continuing the loop sequence till the flat gather condition is achieved.

Well Mistie calculation was carried out manually and on the basis of average mis-tie, velocity model was scaled to 96%. Anisotropic velocity model building in I2I was introduced considering the well mistie. Constant value of delta and epsilon was chosen for anisotropic update. The migration result was by varying epsilon and delta values. Depth to time using the previous velocity model and Time to depth conversion using updated anisotropic velocity model was analyzed.

Updates were repeated with different tomographic solution (small scale solution) and well mistie was calculated with depth to time conversion and time to depth with updated velocity models. After third update, CIP gathers were flat at shallow level but at deeper level complex move out was seen. On the basis of accepted well mistie, final velocity model was prepared in I2I which was used for running full volume migration.

The final interval velocity model was checked for consistency with the synthetic seismograms obtained from the well logs available well log data available. With this final interval velocity model, the full depth migration was performed and the final PSDM stack obtained.

CONCLUSIONS

- The prestack depth migration was significantly improved over the time migration in several respects: resolution of the geological structure and continuity has improved after depth imaging.
- The structures have become simpler and hence easy to interpret.
- Also, the success of the depth imaging owes much to the excellent quality of the field data, and a good job of time preprocessing.
- The data responded very well to the iterations of CIP tomography, resulting in a detailed velocity model that is consistent with geological trends.

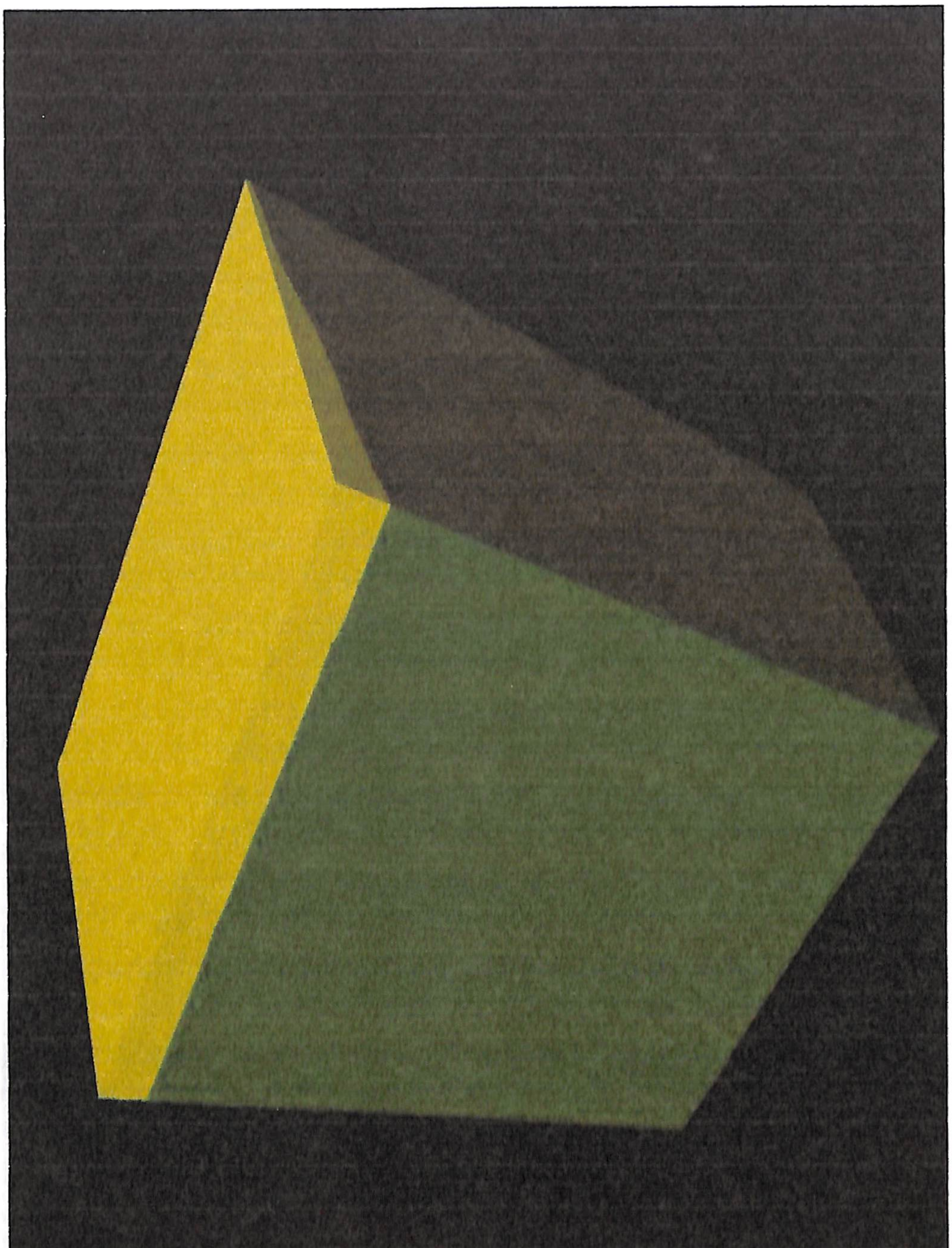


Plate 1: Velocity structural model

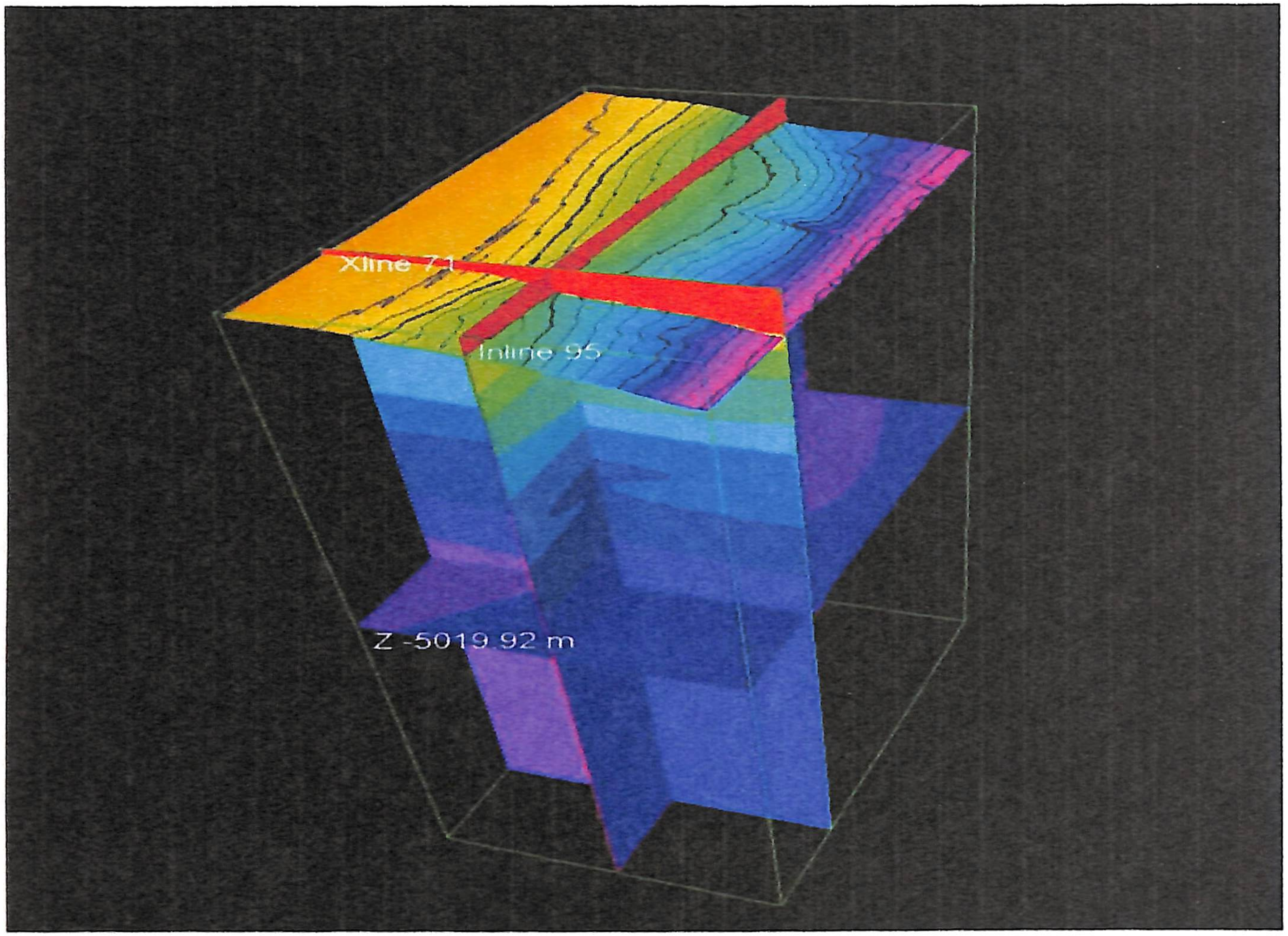


Plate 2: Initial velocity model with water bottom surface

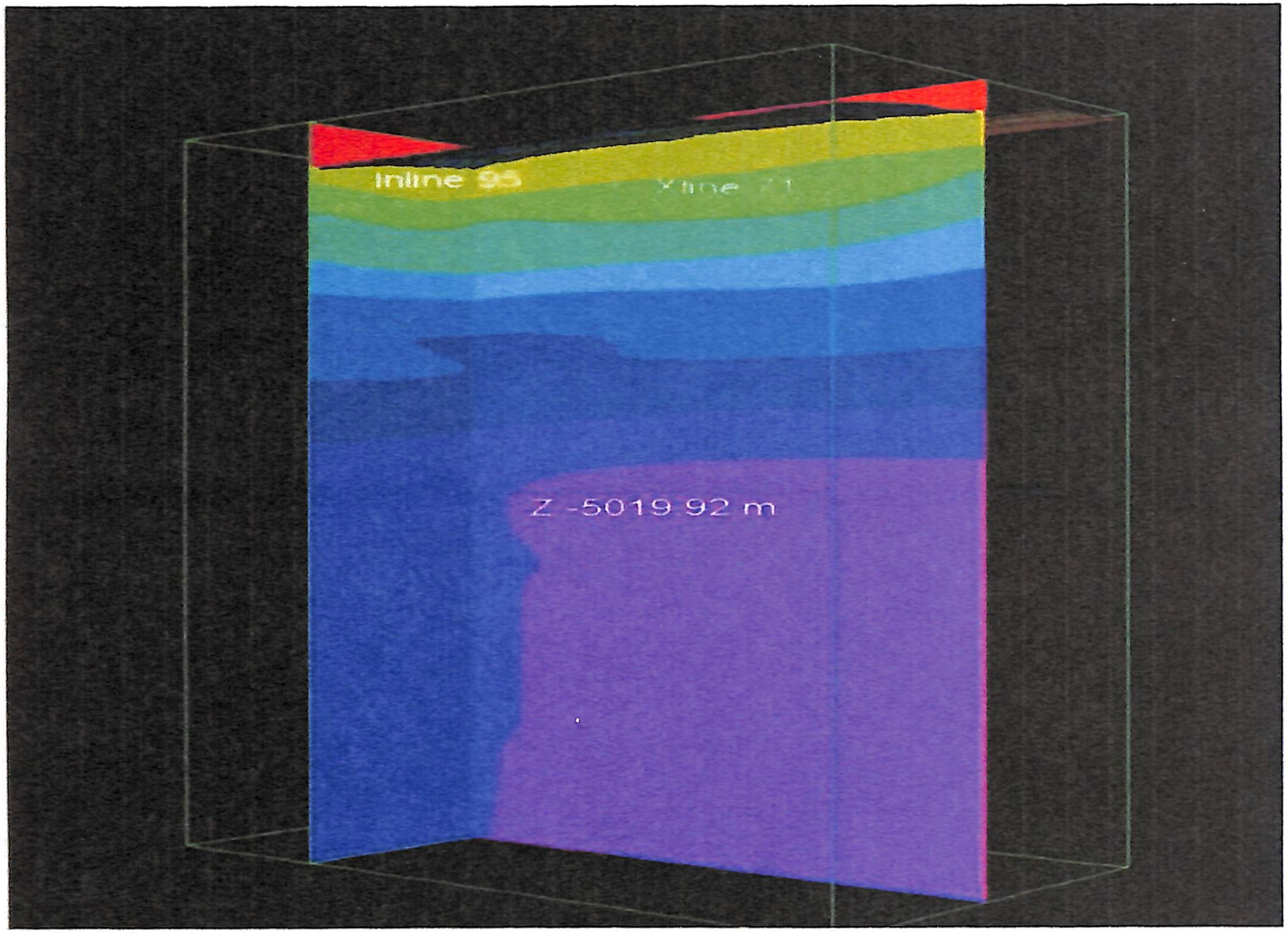


Plate 3: Initial interval velocity model

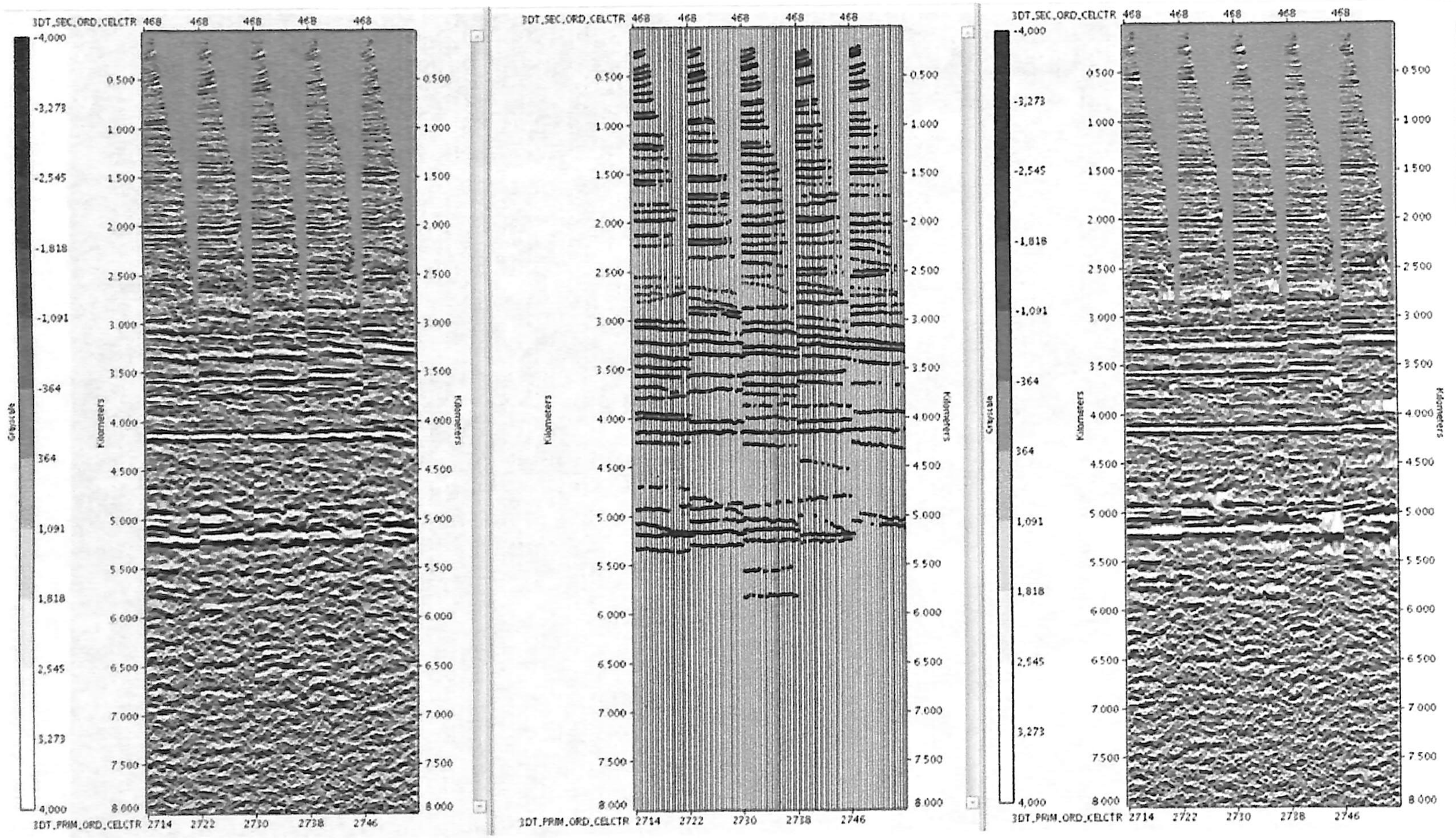


Plate 4: RMO picking of Initial Common Image Point (CIP) gathers

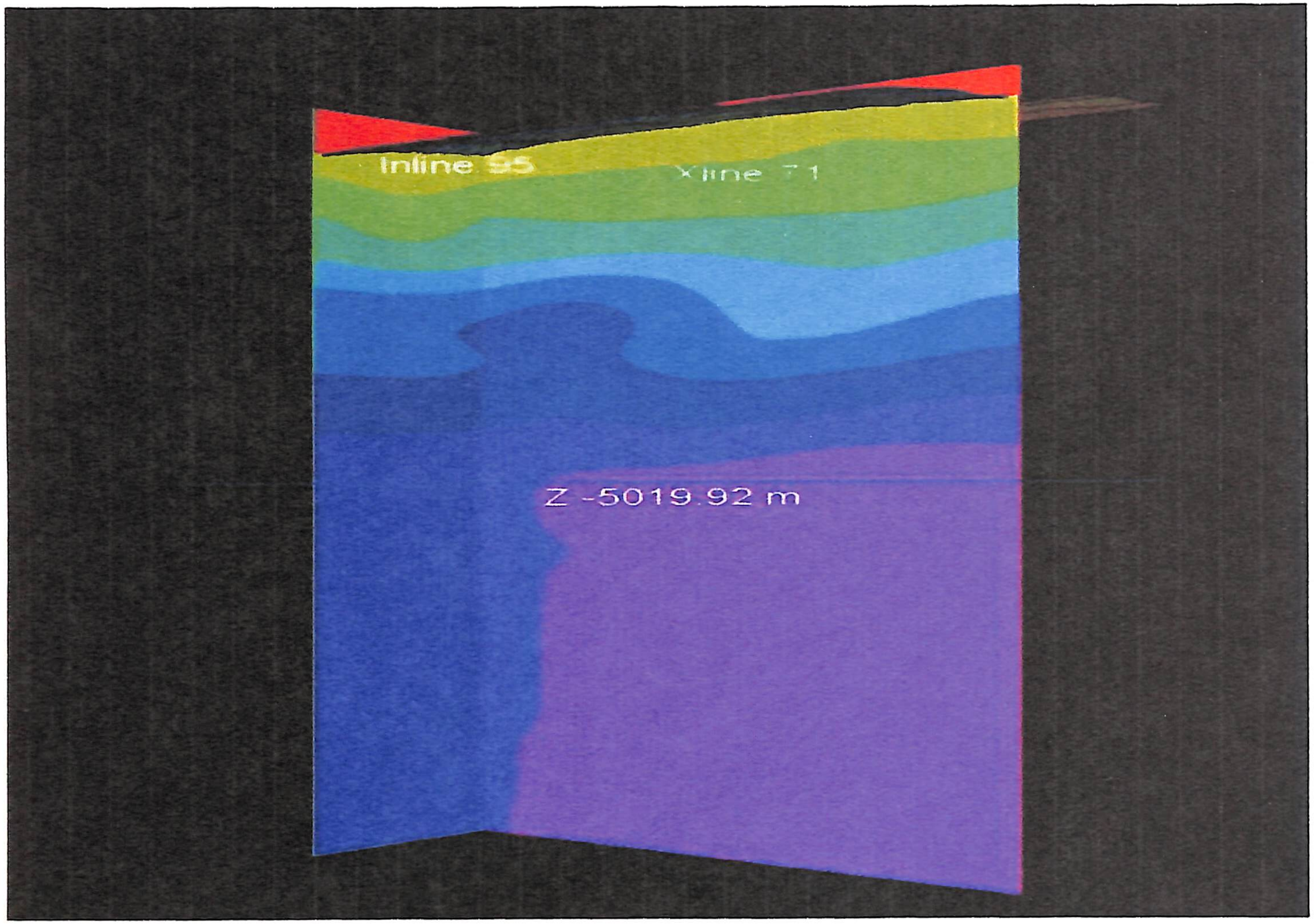


Plate 5: Interval velocity model after first update

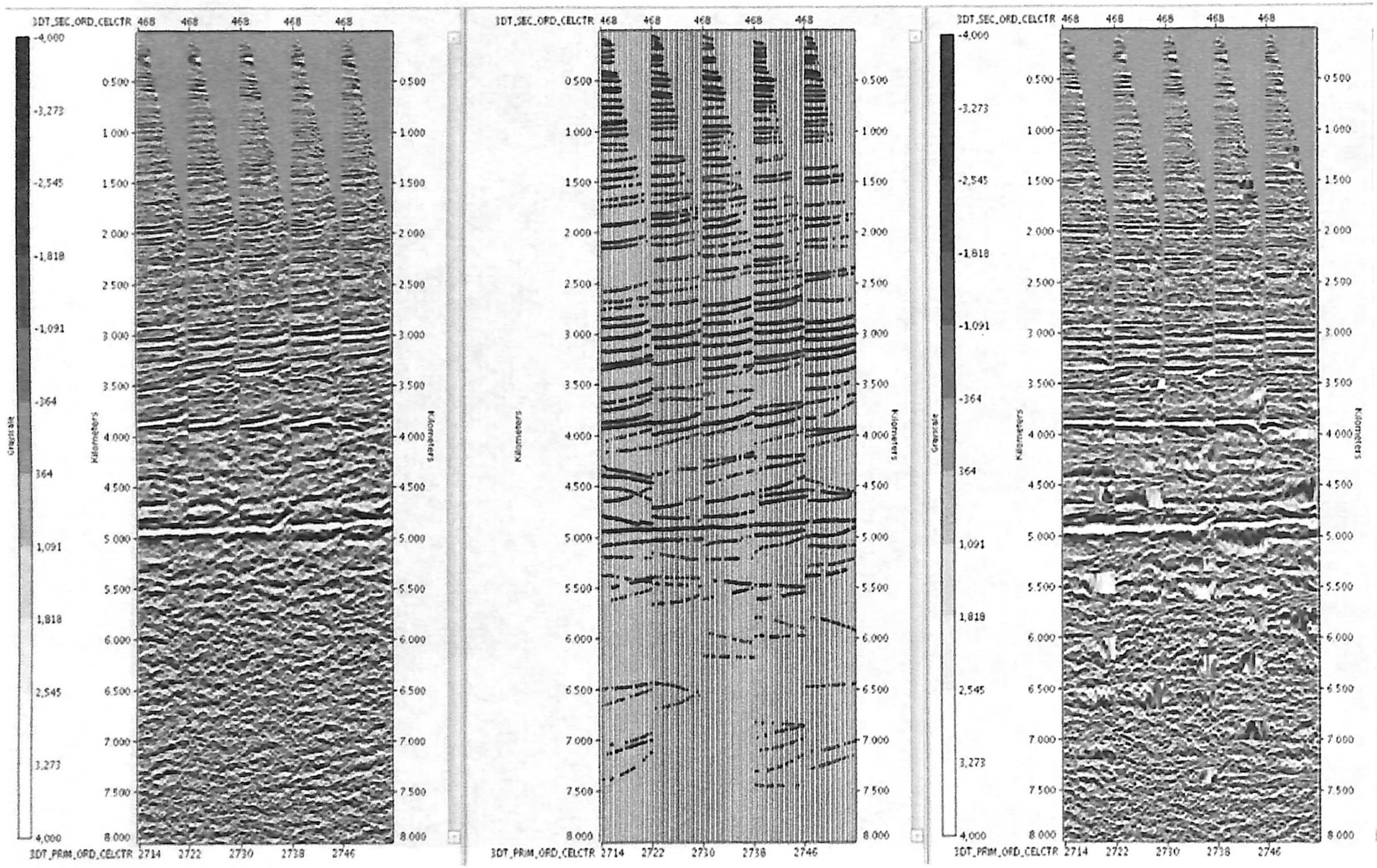


Plate 6: Common Image Point (CIP) gathers and RMO picking after update 01

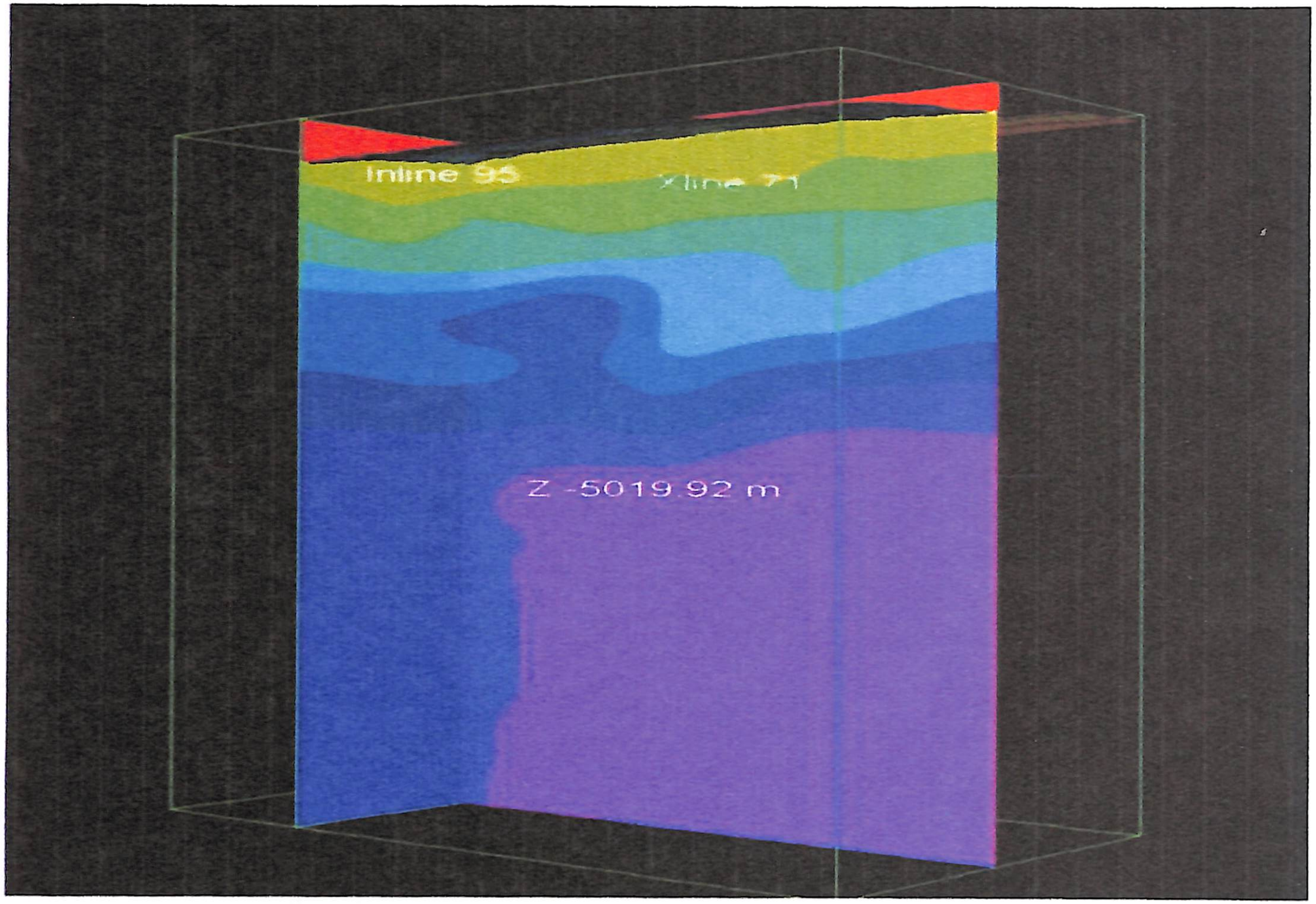


Plate 7: Interval velocity model after second update

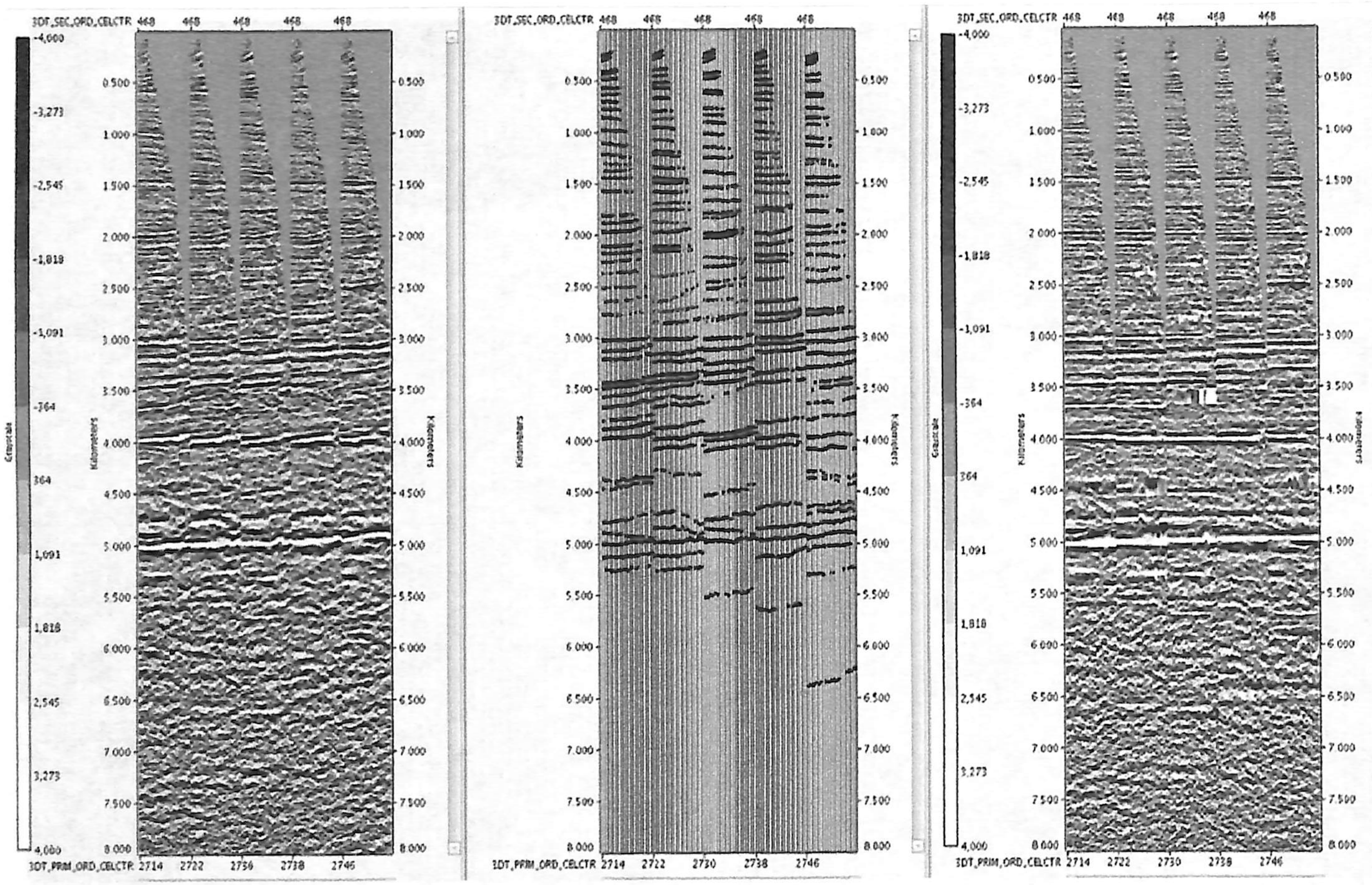


Plate 8: RMO picking of CIP gathers after second update

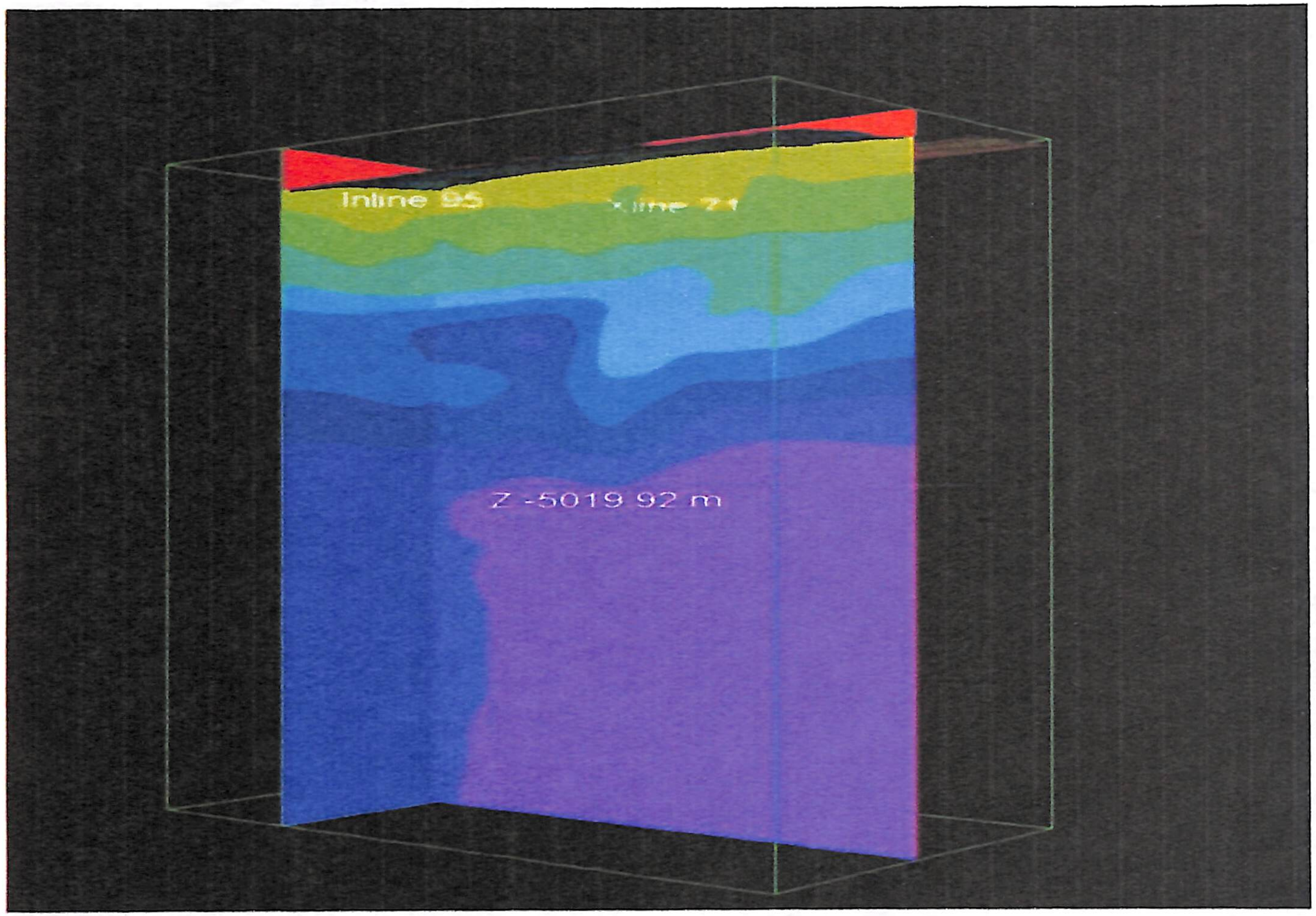


Plate 9: Interval velocity model after third update

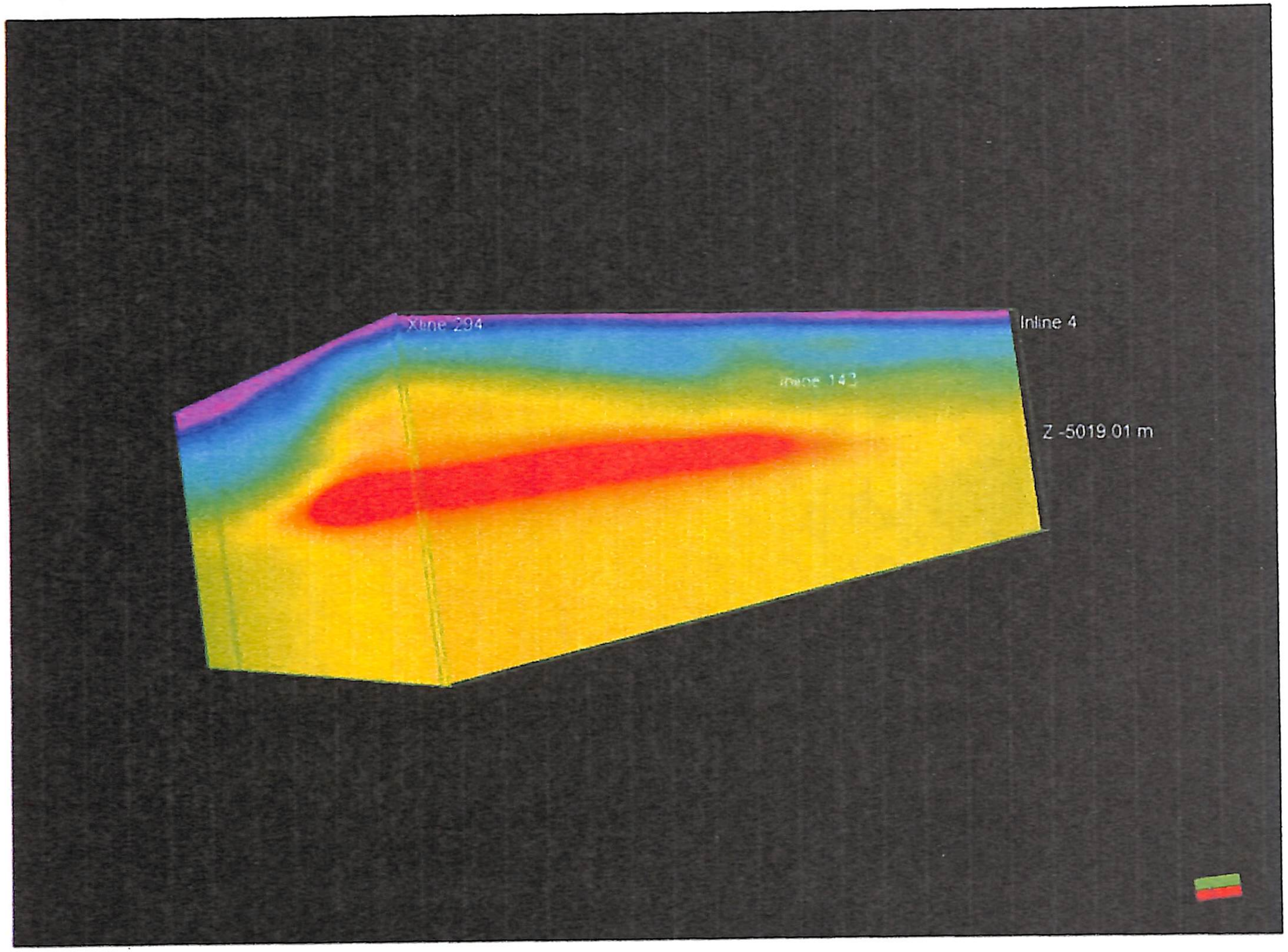


Plate 10: Final interval velocity model for depth migration

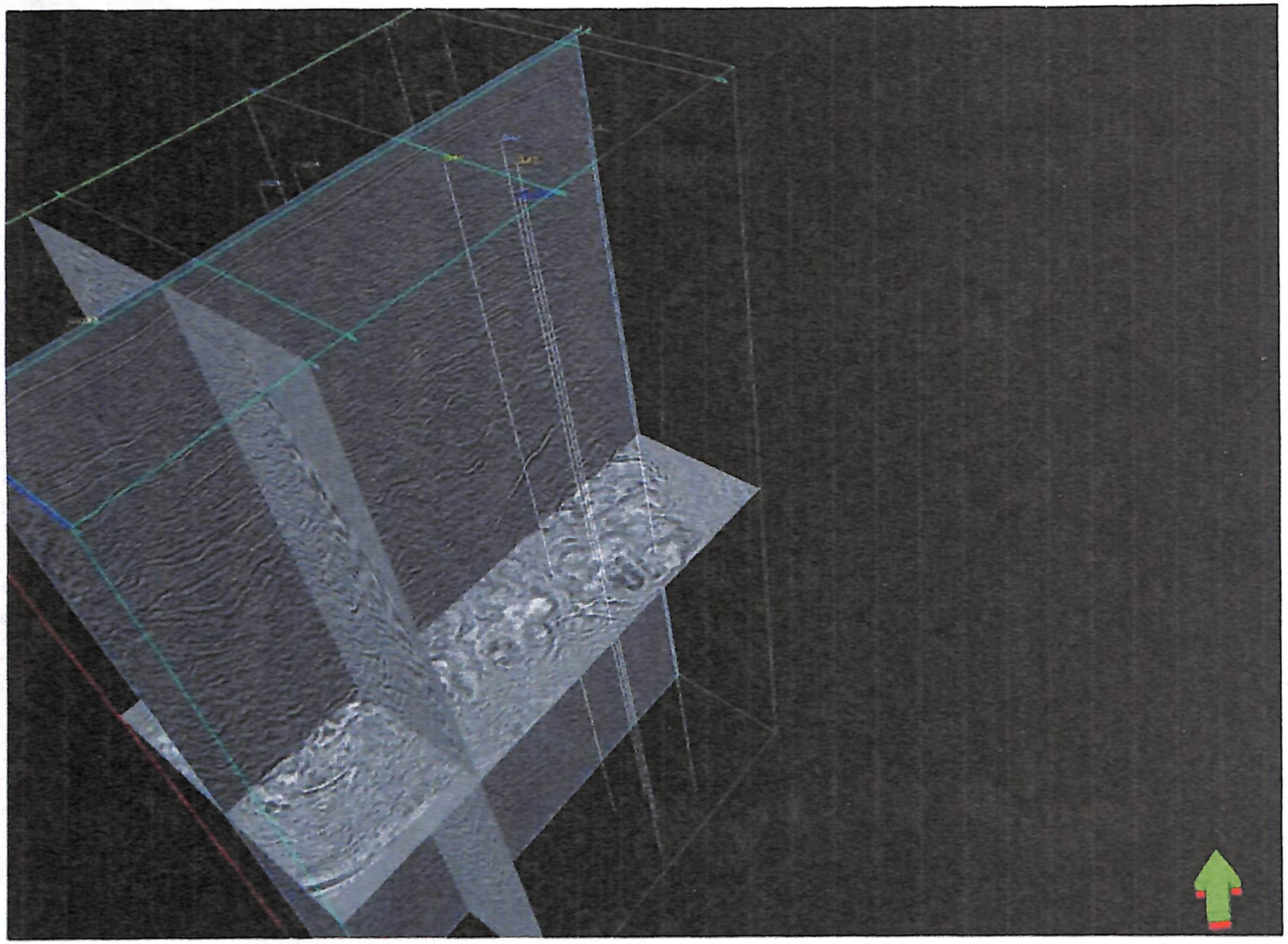


Plate 11: Well mistie analysis

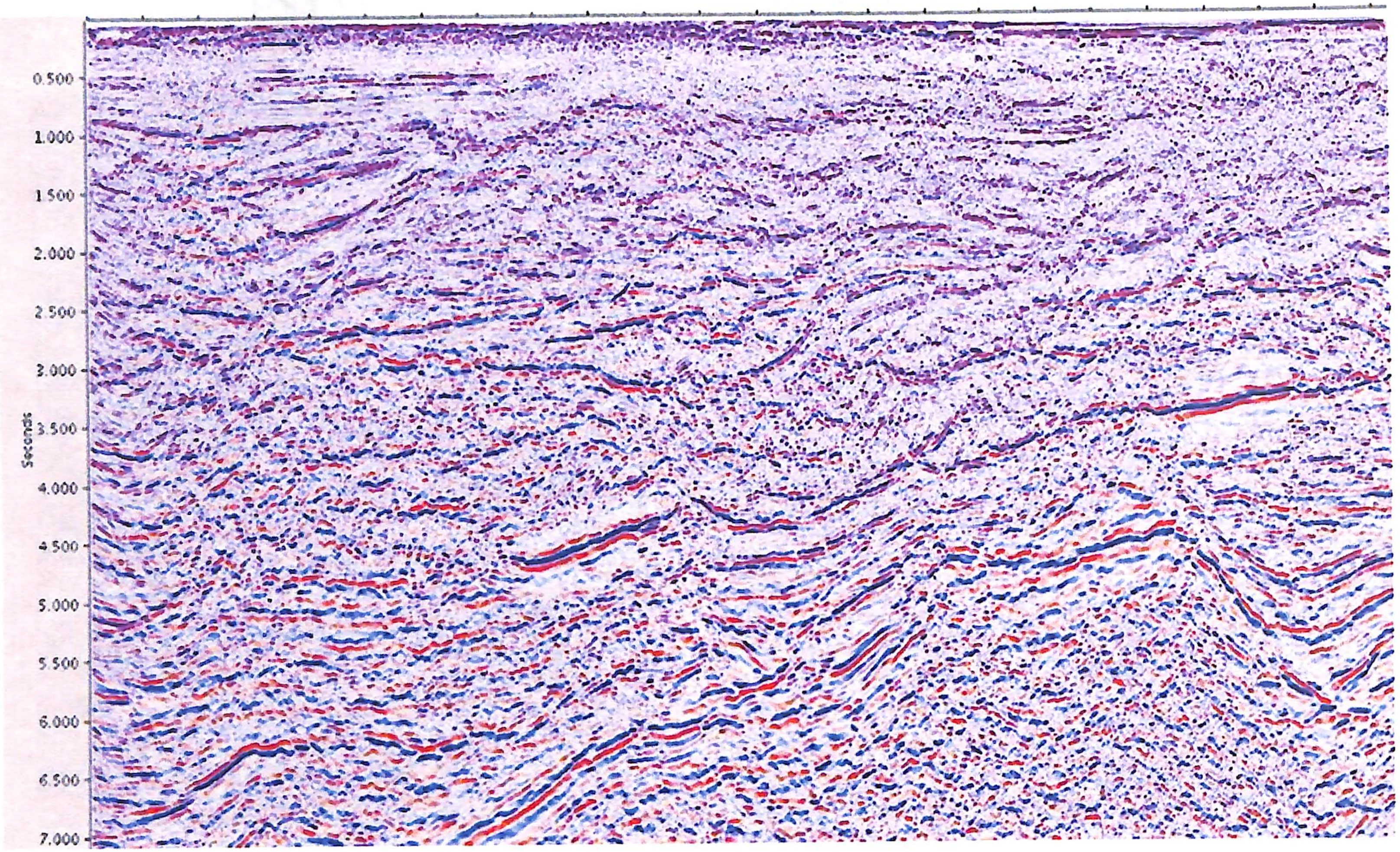


Plate 12: Pre Stack Depth Migration (PSDM) Stack

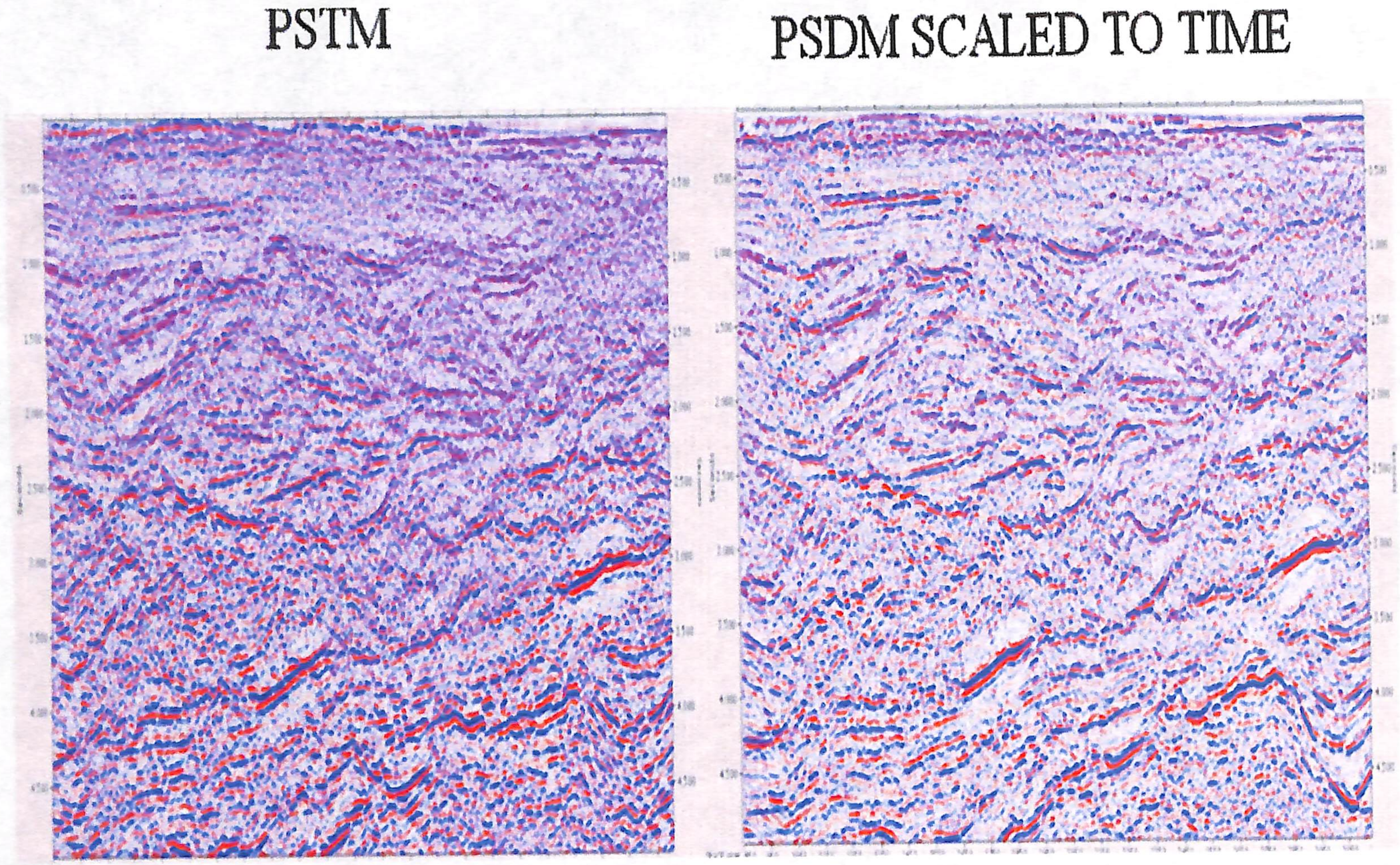


Plate 13: Comparison of PSTM and PSDM scaled to time stack

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