

# Anisotropic Velocity Model Building and Pre Stack Depth Imaging Using Earth Study 360: A Case Study from Cauvery Basin

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**Keywords:** Local angle domain, Angle Gathers, Azimuth, Tomography

## Summary

Accurate depth imaging of subsurface is very important for reservoir characterisation and delineation of geological features. The quality of a migration image depends strongly upon the accuracy of the velocity model. This article focuses on both the aspects. An innovative work flow has been adopted using well tie tomography during the process of anisotropic velocity model building, which serves the purpose of imaging and depthing all together. In this present study Earth Study 360 has been used as imaging tool which is recently developed full-azimuth angle domain imaging and analysis system designed to image, characterize, visualize and interpret the total seismic wave field in all directions.

A comprehensive case study has been demonstrated using data of Cauvery basin unveiling high quality depth imaging and very good matching of seismic events with well markers. Application of the AFE technique to diffraction imaged data yielded sharp and crisp definition of fault and fractures.

## Introduction

There is an ever increasing demand for advanced velocity modeling and imaging techniques to provide an improved knowledge of subsurface structures in geologically complex areas as well as more accurate and quantifiable description of reservoir properties. The EarthStudy360 Imager (ES360 Imager) is a versatile cluster-based depth migration tool that simultaneously uses the full recorded wave field within a controlled aperture to generate amplitude preserved, multi-dimensional, subsurface angle gathers. ES360 is Bottom up ray tracing which easily handles the multi-pathing. Unlike conventional ray-based imaging methods (e.g. Kirchhoff migration), EarthStudy360 uses a point-diffractor operator to shoot rays from subsurface grid points to the surface, forming an accurate system for mapping the recorded surface seismic data into the subsurface Local Angle Domain (LAD) for each image point. This procedure ensures maximum illumination of the image points from all subsurface directions and surface source-receiver locations; all arrivals are taken into account and amplitudes and phases are preserved.

EarthStudy360 directional angle azimuth gathers enable specular and diffraction imaging, resulting in simultaneous emphasis on continuous structural surfaces and discontinuous objects such as faults or small-scale fractures. Structural attributes at each subsurface image point (e.g. dip, azimuth and specularity) can be derived directly from the directional angle azimuth gathers.

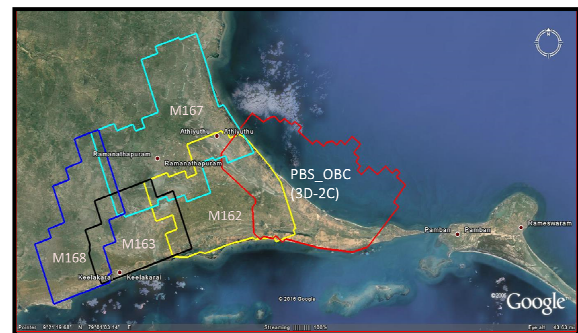


Figure 1: Location map of the area

ES360 reflection angle-azimuth gathers display reflectivity as a function of opening angle and opening azimuth and are most meaningful in the vicinity of actual local reflecting surfaces, where the reflection angles are measured with respect to the derived background specular direction. They are used for automatic picking of full-azimuth, angle domain residual move outs (RMO), which together with the derived background orientations of the subsurface reflection horizons, provide a complete set of data for anisotropic velocity model determination, fracture detection and reservoir characterization. Reflection angle gather are generated from the reflection angle azimuth gather by stacking over the azimuth.

The accurate estimate of velocities is the key factor for successful depth domain imaging. Tomography based velocity model building and refinement tools supplemented by structural component extracted from data plays very important role in this arena. 3D Grid/Model-Based tomography aims to flatten the common image gathers and minimize their residual moveouts (RMOs) to update the

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velocity model. The model update is driven by a measure of the non-flatness of pre-stack migrated gathers which are obtained by migration with the background subsurface velocity parameters. The output of the 3D Grid Tomography is an updated subsurface model. The derived parameters should yield flatter output gathers after an additional migration of the input data. The tomography equations relate travel time errors measured on the migrated gathers to the subsurface model change through rays which are traced from subsurface reflectors to the surface.

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

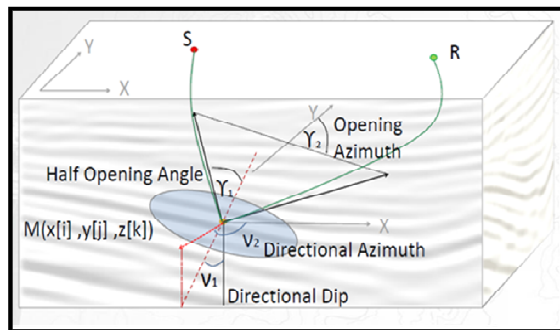


Figure 2: The Imaging in local angle domain. Picture demonstrate the subsurface angle configuration, Here  $M(x, y, z)$  is the subsurface image point, the ray-pair emerging from  $M$  propagate through the depth-interval velocity model and maps the energy, recorded by the shown surface shot-receiver pair, into the subsurface local angle domain. The subsurface local angle domain (LAD) is consisting of half-opening angle, opening azimuth, dip-angle and dip azimuth. (Koren, Z.)

### Methodology

Velocity model building is a key critical element in depth domain imaging. Keeping this fact into mind special attention has been given for deriving precise interval velocity model.

The salient features of velocity model building are as mentioned below.

### Horizon picking/editing

The interpreted horizons were edited as and where it were required. Another horizon is picked in the shallower level in order to pick velocity. The basement was shifted downward by a constant amount (1000 ms) and a flat bottom boundary is added below that in order to pick velocity.

Horizon grids are generated from the picks. Time migrated model map are generated in order to give the horizon grids

a geological dominancy. QC of the model maps were performed.

### Horizon based RMS velocity picking

After creating the time migrated model maps RMS velocity was picked along all the horizon at an inline interval of 20 (400 m). Velocity grids are generated from the velocity picks. RMS velocity volume was then generated using these velocity maps, QC was performed and test line PSTM was done in order to check the migrated gather flatness. A formation volume was also generated using the time migrated (TM) horizons. The horizon based velocity analysis is shown in figure 4.

### Depth interval velocity modelling

The initial depth-interval velocity modelling is performed through constraint velocity inversion (CVI). Since horizon velocity analysis (HVA) preserves the lateral consistency, in CVI more weightage was given to the RMS data misfit. QC of the interval velocity volume is done and test line ES360 is performed in order to check the flatness of reflection angle-azimuth gather. TM horizons are then image ray map migrated to depth using the initial depth-interval velocity volume and depth model maps are generated.

Target line full azimuth angle domain migration was then performed for interval velocity refinement. 3D residual moveouts were picked on the reflection angle-azimuth gather using 3D prestack autopicker. The moveouts are picked along the depth maps. These full azimuth moveouts, initial interval velocity and the depth maps are the inputs for structural model based tomography. Tomographic matrix is then built that contain a sets of coupled equations relating the travel time delay. Finally this tomography matrix is solved in isotropic mode with optimized parameters. The outputs are updated isotropic depth-interval velocity and updated depth model maps. Structural model based tomography not only compensates the travel time delay it also update the depth of ray shooting point, causing a proper positioning of reflectors in depth. Two iteration of structural model based full azimuth tomography was performed and the gathers were found to be flat upto 30 degree.

### ISO to VTI Conversion

Isotropic interval velocity thus obtained was converted into anisotropic (VTI) mode using well tie tomography. Anisotropic parameters epsilon and delta volume were updated. Further refinement of anisotropic interval velocity was done using RMO picking and grid base tomography in VTI mode. Three more iterations were done. Now gathers were found reasonably flat in far offset. The work flow for the velocity model building is illustrated in figure 3

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### Depth Migration using Earth Study 360

The input used for the ES360 is conditioned residual statics applied gathers (CMP) and the final interval velocity volume. The parameters like half opening angle and aperture are finalized interactively using the ray tracing that gives the number of failed and successful ray counts. Target line experiments are also carried out to finalized opening and dip angles. Imaging was done in anisotropic mode, therefore, epsilon and delta volumes were also taken as input along with interval velocity. The final parameters used in ES360 imager are given in Table 1

### ES360 gather processing

The output of ES360 is Directional Angle-Azimuth gather and reflection Angle-Azimuth gather. Parameters for both specular & diffraction filters are optimized before taking the final stack. QC is performed on generated stack volumes and reflection angle gather. Specular stack contains the reflection energy coming from true subsurface reflection direction

So specular stack has greater continuity, higher signal to noise ratio and sharp edges. On the other hand the diffraction stack contains the diffracted energy coming from subsurface discontinuities. Since the recorded energy is decomposed in local angle domain (LAD) information regarding the subsurface dip & dip-azimuth can be extracted from the ES360 directional angle azimuth gather. This subsurface dip & dip-azimuth volumes extracted from prestack gather shows significant improvement over the conventional way of calculating dip & dip-azimuth from post stack volume generated by summing over all directional angles and azimuth with proper weighting factor from the 5D LAD gather.

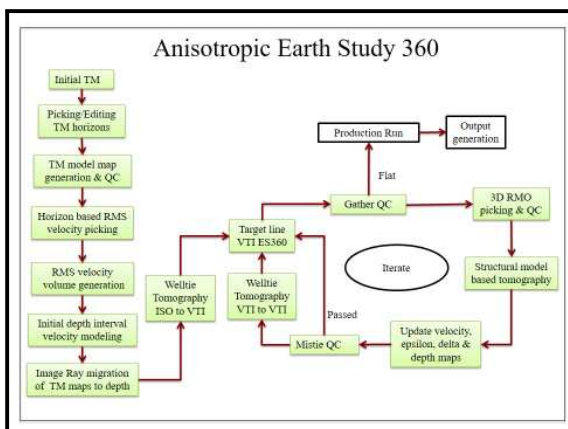


Figure 3: Work flow for anisotropic velocity model building for ES360 imager.

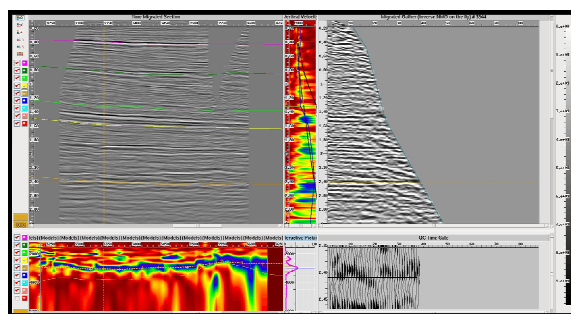


Figure 4: Horizon based velocity analysis along in line

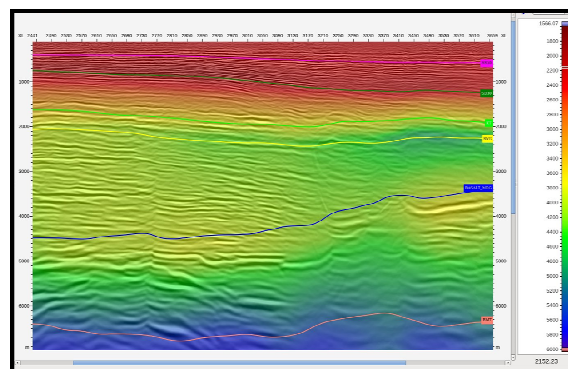


Figure 5: A section along in line L1 from the interval velocity volume generated by constrained velocity inversion (CVI) along with seismic section overlay.

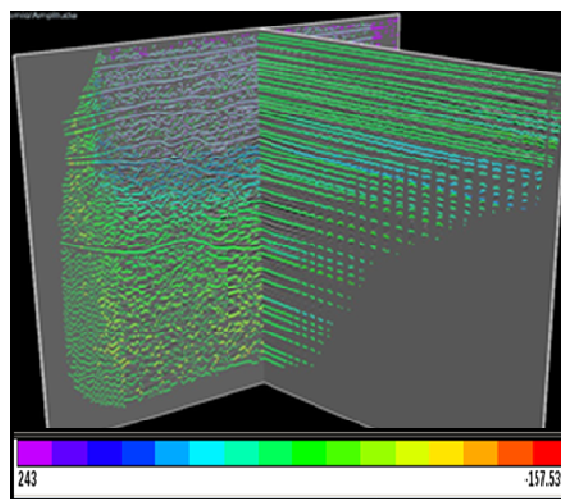


Figure 6: Residual move out on angle azimuth gather and stack section along in line L1

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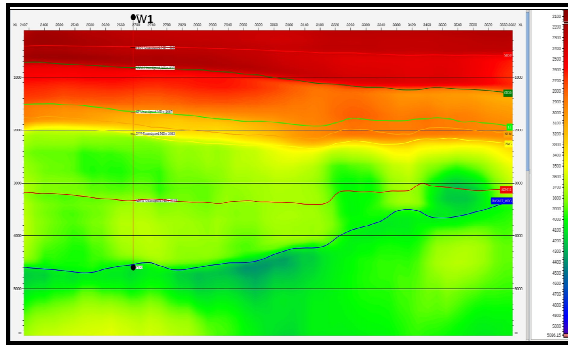


Figure 7: Interval velocity section after VTI update along with well markers and depth horizons over layed.

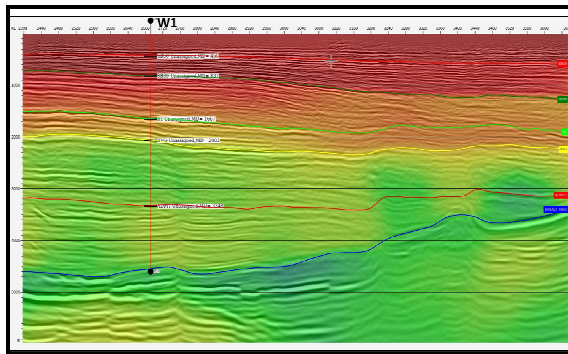


Figure 8: After VTI Update ES360 Stack, Well Markers, Depth Horizons along with interval Velocity overlay

The final parameters used in ES360	
Opening angle	65 (top) /50 (bottom)
Directional angle	80 (top) /60 (bottom)
Pencil distance	50 m
Aperture	10000 m x 10000 m;
Frequency	80 Hz
Frequency taper	0.16
Lateral distance (pencil)	80 m (Min)/320 m (Max)
Lateral resolution factor	3
Vertical resolution factor	2
Vertical Increment	4 (Min)/8 (Max)
Reflection/Diffraction fold	500

Table 1: Final parameters used in ES360

### Area of study

The area under study falls in Ramnathpuram Palk Bay tectonic block of Cauvery Basin. Ramnathpuram sub-basin and its continuation in Palk Bay-Gulf of Mannar area are bounded in the northwest by Pattukottai - Mannargudi ridge and in the southeast by Mandapam-Delft ridge. The sub basin holds over 6000 m thick sediments, ranging in age from Lower Cretaceous to Recent. The synrift sedimentary column comprises mainly shale and sandstone in the Andimadam formation and Sattapadi Shale formation.

Data in the area was acquired under five different seismic investigations. Residual statics applied deconvolved CMP gathers of merged data volume was taken as input for depth imaging deploying ES360. The nominal fold of the data is 80 and bin size is 20x20m. Location map is shown in figure 1. The study pertains to the Pre Stack Depth Migration of 400 sq. km 3D seismic data, using Earth Study 360 (ES360) Migration technology. The main objective of processing was to get realistic depth model for reservoir characterization using ES360 technology in a zone of 1000-5000 m depth.

### Discussion

Velocity model building is very critical for depth imaging. Manual picking and updation of velocity volume is time consuming. Here state of the art velocity model building and updation technique has been demonstrated which is very efficient accurate and time saving Grid based tomography has been used with a new work flow. Structural attributes derived from the data and automatic picking of interlayer horizons improved accuracy of ray tracing resulting into more reliable and geologically consistent velocity model. Final migration velocity section after VTI update is shown in Figure 7 & 8.

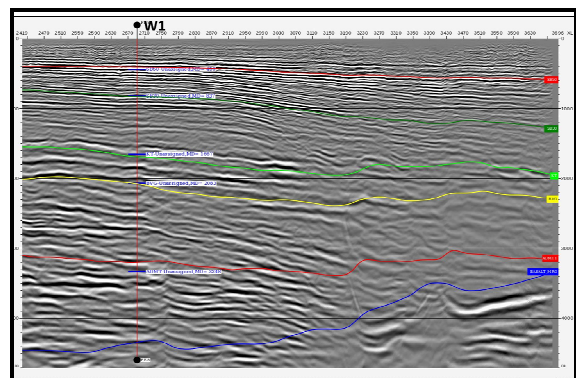


Figure 9: ES360 specular stack before VTI updation

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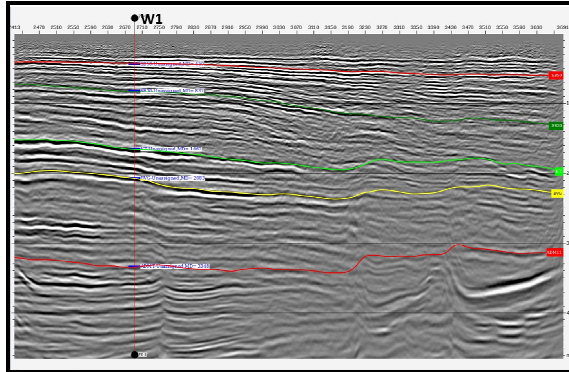


Figure 10: ES360 specular stack after VTI updation showing perfect match of horizon with markers

Figure 9 &10 illustrate comparison between ES360 specular stacks before and after anisotropic velocity modelling. It can be concluded that seismic horizons are fairly matching with well markers at well location in case of anisotropic imaging.

In figures 11&12 results of Automatic Fault Extraction (AFE) technique have been demonstrated using specular and diffraction stack. Application of this technique have yielded sharp and crisp definition of faults and fractures.

Figure 13 shows comparison of legend KPSDM and ES360 both scale to time. It is observed that ES360 images are more crisp, having higher resolution, better continuity along with fault definition.

In figure 13 depth slices generated through legend KPSDM and ES images have been compared at the same level. It is observed that structural features are more clear and sharp in the case of ES360. This can give a lead to interpreters in delineation of sub surface structures.

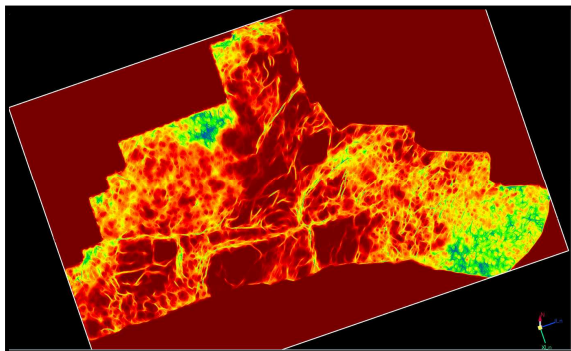


Figure 11: AFE using ES360 specular stack (Time slice at 3000 ms.)

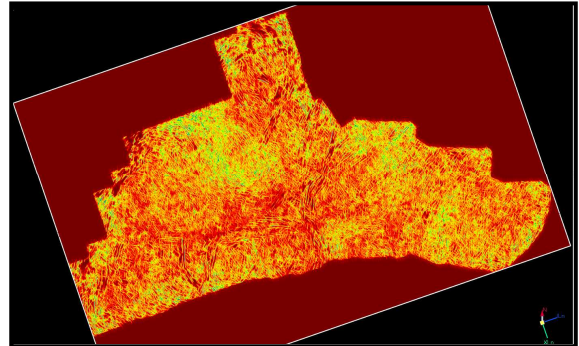


Figure 12: ES360 AFE\_Dip\_Enhancement on ES360 Diffraction Stack (Time slice at 3000 ms)

Figure 16 demonstrate a comparison between legend KPSDM and ES360 specular stack. It is seen that the specular images depicts more enhanced, detailed and cleared geologic features. This will give a value addition to the process of refinement of subsurface geological model and structural interpretation.

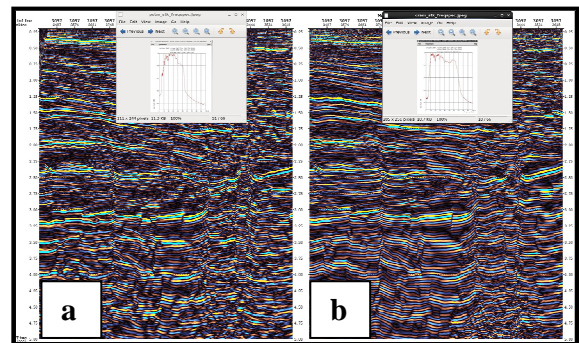


Figure 13: Comparison of a legend Kirchhoff PSDM scale to time (a) and ES360 specular stack scale to time (b)

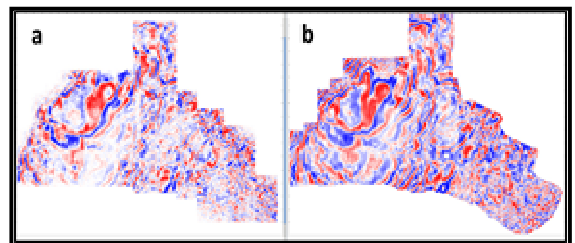


Figure 14: Depth slices from the volume generated through legend KPSDM (a) and ES360 (b) at 3000 meter depth.

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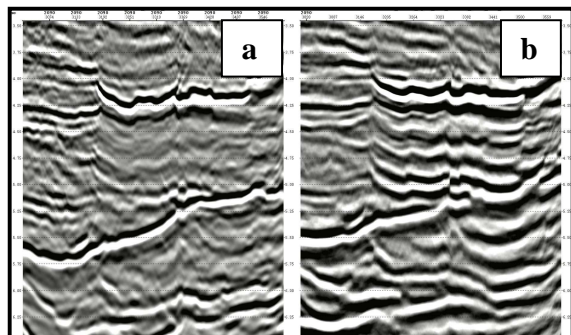


Figure 15: Comparison of a legend Kirchhoff (a) and ES360 PSDM stack (b) along in line direction.

S.No.	Horizons	Misties before VTI (mts.)	Misties after VTI (mts.)
1	SB50	31	6
2	SB30	-8	0
3	KT	-36	-2
4	BVG	-10	-2
5	ADMT	137	4

Table 2: Comparison of misties before and after VTI along well W1

### Conclusions

In this present study both the issues of depth migration commonly known as imaging and depthing have been addressed simultaneously with an adaptation of high end technology. Specular & diffraction imaging is performed on ES360 migrated gathers. Final processed specular stack has better structural continuity, high S/N ratio and sharp edges. The diffraction stack delineates highly dipping events and subsurface fault networks. The combine output set will give better subsurface insight.

After anisotropic velocity modelling and ES360 imaging a very good matching of seismic horizons with well markers have been observed as shown in table 2.

Velocity models thus obtained are accurate and suitable for depth imaging as well as highly reliable for time to depth conversion. It may also be pointed out that this process of velocity model building and refinement is very less time consuming as compared to conventional methodology being used for this purpose. The processed output has brought out improved sub-surface imaging and better fault delineation. The output shows a remarkable improvement at all levels in the volume as compared to the earlier processed outputs and clearly depicts the reduced noise level and better continuity of seismic events on the stack section.

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### Statement from authors:

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