Anisotropic Kirchhoff's Pre-Stack Depth Migration - A case study from Western Offshore Basin

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Abstract

The anisotropic Pre stack depth Migration was taken up to resolve the issue of pseudo structures, especially highs, in Mukta and Bassein sequences in an area in Western offshore Basin of India. These structures, seen on Pre Stack Time Migrated stack data, were found to be non-existent on drilling. The seismic data was reprocessed for Pre Stack Time Migration, to get a realistic sub surface picture of the area but the pseudo structures, caused by velocity anomalies, could not be resolved.

To address this issue, Anisotropic Pre Stack Depth Migration using Kirchhoff method, (AKPSDM), was taken up to get a realistic depth model of the area for reservoir characterization. The anisotropic pre-stack depth migration gives better imaging and show depth of the sequences more accurately compared to, generally used, isotropic pre stack depth migration. In the current case study, TTI (Tilted transverse isotropic) approach instead of VTI has been used.

The gridded tomography methodology is used for isotropic as well as anisotropic interval velocity model updates. Grid based approach is much better than the layer based tomography to get converging solutions. AKPSDM results shows more accurate imaging and very good match at the existing wells, the well misties being under 1% for most of the wells falling in the area.

Introduction

The area of study is a marginal field located in the south west of Mumbai in the Heera-Panna-Bassein (HPB) block of Western Offshore Basin (Fig-1).The block is to the east of Mumbai High and south of Surat Depression. It has three distinct N-S to NW-SE trending tectonic units which lose their identity in Miocene (Fig-2). It is a composite high block dissected by a number of small grabens. The area under study lies within the Central graben which is a syn sedimentary sink formed during Paleogene and Early Neogene, between Eocene and Early Oligocene times (Fig-3).

In the area, Miocene Carbonates at shallower levels, occurring in patches, affect the structural disposition and reflection responses at deeper levels. These sporadic depositions lead to the incorrect depth values. These carbonates are having higher velocities than enclosing shale. Because of lateral and temporal variation in velocities at shallower levels, pseudo structures are created at deeper levels. As a result the success ratio of the production wells, within the reservoir, decreased. The area under study is characterized by shale deposition of around 900 m, underlain by thick limestone - shale alternations. The shale sequences exhibit strong anisotropic behavior. Keeping this geological setting in mind, anisotropic approach is utilized to evolve a more realistic depth velocity model to get better imaging and accurate depth of sub surface features. The PSTM stack along a representative cross-line, showing pseudo structure is shown in fig-4.

Fig-1. Location map of the area under study.

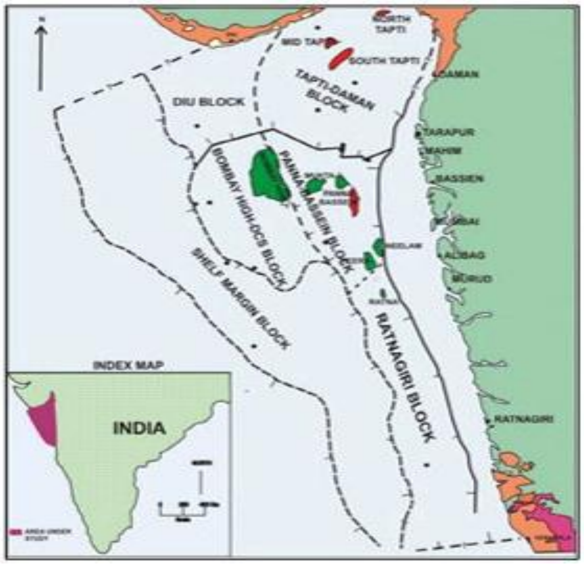


Fig-2. Tectonic map of Western Offshore Basin.

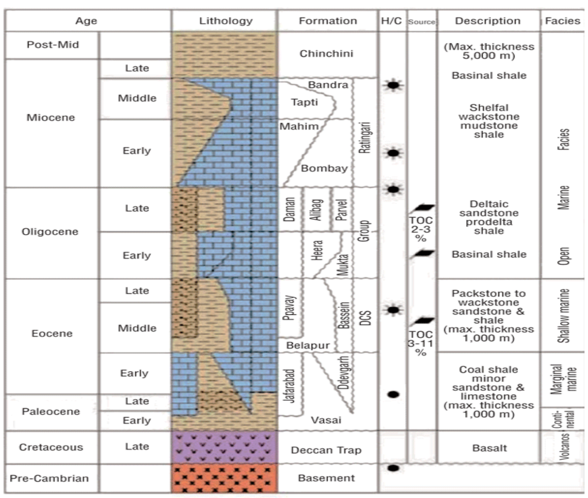


Fig-3. General stratigraphy of Western Offshore Basin.

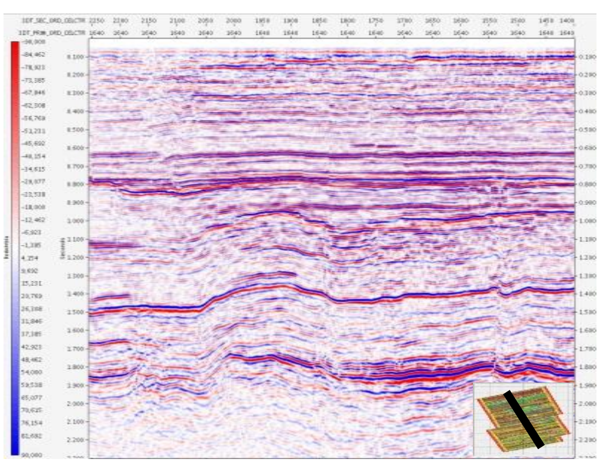


Fig-4. PSTM stack section at a representative line.

Objective of study

The objective of the study is to get realistic depth model of the area for reservoir characterization. The zone of interest is 600 m – 2800 m. Miocene Carbonates at shallower levels, occurring in patches, affect the structural disposition and reflection responses at deeper levels. These sporadic depositions lead to the incorrect depth values, which needs to be resolved.

Methodology

In general, rocks are anisotropic in nature. This could be due to fracturing, layering and complex crystal structure of rocks. The isotropic Pre Stack Depth Migration addresses the proper focusing and lateral positioning of reflectors upto great extent, but does not give accurate depth of sub surface features (Al- Chalabi,1994; Schultz,1999). Anisotropic depth migration reduces inherent shortcomings of isotropic depth migration, particularly in areas of complex stratigraphic and structural features, resulting in improved imaging and better tie of seismic data with the well data, leading to more confidence in planning new wells in the area.

The input to KPSDM is time pre-processed seismic data and smoothed final RMS velocity volume, used for time migration. This initial velocity is converted to interval velocity in depth through Dix method and subsequently smoothed to get first depth interval velocity model. The depth imaging workflow consists of multiple iterations of KPSDM, picking residual move out on common image point gathers (CIP gathers) and reflection tomography based velocity model updation.

The tomography workflow begins with a velocity model derived from the stacking velocities obtained from the KPSTM processing (fig-5). First of all, an accurate water depth is picked on the KPSTM stack converted to depth. The final RMS velocity is converted to interval velocity in depth and is smoothed to build the initial velocity model. Using this model, PSDM is run to get output on velocity lines, generally at an interval of 100 m. If the migrated gathers are flat, the velocity model is correct and is used for running PSDM on the required output grid. However, gathers usually are not flat so further iterations are necessary to correct the residual move out. The solution represents the velocity model update for the iteration under consideration. This is followed by another KPSDM step using the new, updated velocity model. The initial iterations of CIP-tomography are parameterized such that velocity updates are done using large-scale lengths. Choice of scale length depends on lateral and vertical (anisotropic) velocity variations. As the velocity model improves through successive iterations, progressively smaller scale lengths resolve the finer details in the velocity field.

After final isotropic KPSDM update, anisotropic parameters are estimated (discussed in the following section) for inclusion of anisotropy in the velocity model. Again the tomographic workflow as described earlier begins for anisotropic velocity model update to arrive at the final anisotropic velocity model. The final migration is run using this improved depth interval velocity model. The depth volume show very good match with the wells in the area as misties are less than 1%.

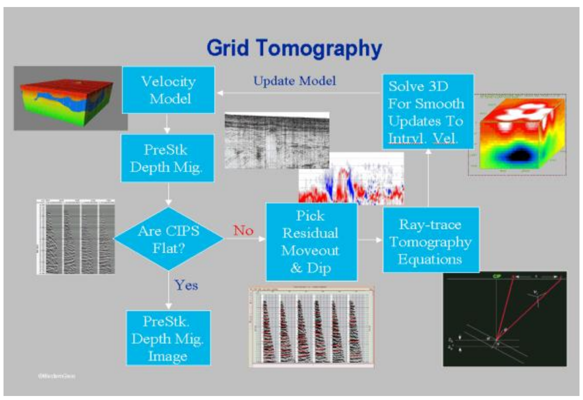


Fig-5. General methodology of grid tomography.

Quality control

The gamma value is the measure of flatness (Fig-6). For an event at a particular depth, gamma is the average of values at all offsets in the gather, calculated using below given formulae. It is a single trace output at each CIP gather location, based on gamma values for events picked at different depths.

$$\gamma^2 = 1 + (z^2 - zo^2)/h^2$$

where, zo is the depth of a picked event at zero offset

z is the depth for the same event at offset h

A gamma value of 1.0 represents perfect flatness across all offsets; greater than 1.0 means the move out is fast (under corrected), less than 1.0 means it is slow (over corrected). RMO statistics show distribution of picks in terms of gamma values over different windows in depth, for histogram displays (Fig-7).

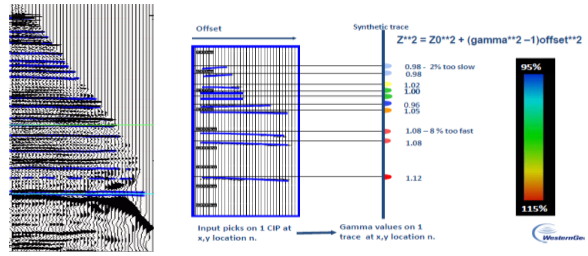


Fig-6. CIP picking on one CIP location and calculation of gamma values.

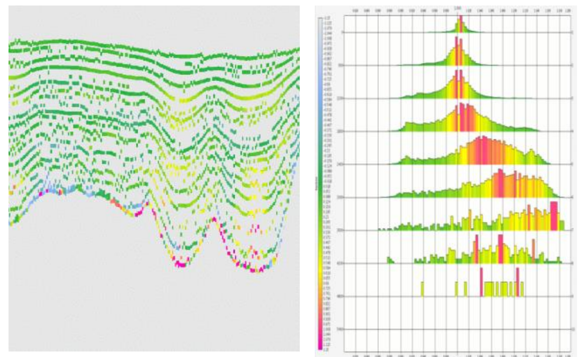


Fig-7. Gamma values and rmo histogram.

Estimation of anisotropic parameters

Seismic velocities are anisotropic, i.e. waves propagate with different velocities in different directions. Isotropic migrations can produce flat gathers up to 30 deg angular offsets and a reasonable image, but in general the events will be deeper and dipping events will be displaced laterally. Modern imaging has to target the reservoir in production environments and it is a requirement that events tie with well markers and have accurate positioning of faults. Therefore it is essential to include anisotropy in the velocity model. The isotropic wavefront spreads with the same velocity in all directions but the anisotropic wavefront spread faster in the horizontal direction compared to vertical direction.

"Tilted transverse isotropy (TTI)" form of anisotropy was used as it represents the real earth better. Thomson defined several parameters to describe anisotropy; these are ratios of different velocities. They are represented by the Greek characters, delta (δ) and epsilon (ε). The parameter delta depends on vertical interval velocity derived from well (Vpz) and vertical interval velocity derived from seismic data (Vpn), while epsilon depends on vertical interval velocity (Vpz) and horizontal interval velocity (Vpx).

Typical ranges of values for these parameters are,
Epsilon : 0 to 0.25
Delta : 0.05 to 0.1

Both epsilon and delta are usually positive and epsilon is greater than delta. These parameters are either spatially invariant or vary quite slowly during estimation of interval velocity model. The layers or regions with high shale content for example, will have larger delta and epsilon values.

For TTI velocity model two additional parameters are required in order to define the tilt of the axis of symmetry. The tilt is normally the same as the dip of the local bedding. The parameters are the tilt angle (or dip) α and the dip azimuth β. The dip angle α varies between 0 and 90 deg, and the azimuth β varies between 0 and 360 deg.

To estimate delta, depth for a particular horizon in seismic data and corresponding marker in well are used. The ratio of difference in depths and depth of the horizon in seismic gives the initial delta value. These delta values were calculated for all the markers for all the wells in the area. Initial delta volume was generated using all these values. Compressional velocity (Vp), values of final isotropic model are scaled down by using the equation given below to get an intermediate anisotropic model,

$$Vz = Vp/\sqrt{2 * (delta) + 1}$$

The vertical velocities (Vz) were applied on the gathers at well locations (Fig10). Depth gather and vertical velocity function at a well location were loaded in the utility tool. In the model spreadsheet editor in the utility, delta values at different depth locations were varied and the corresponding changes in the gather at well location were observed. Delta values which flattened gather at different depth locations, in the near offset zone, were finalized. After fixing the delta values, the epsilon values were varied at different depth locations in the same manner to see the changes in the gather at well location. The epsilon values for which the gather became flat at far offsets, removing the hockey-stick effect, were finalized.

Finalized model spreadsheet is exported to local disk. The same exercise was then repeated for all the well locations present in the area. Thomson delta and epsilon volumes were generated using all Thomson delta and epsilon profiles exported.

For dip and azimuth calculation, PSTM stack was scaled to depth using this velocity model. Inline & xline dip fields were estimated from the depth stack. Dip files were smoothed and saved. Inline dip field is taken as dip field and xline dip filed is taken as azimuth field.

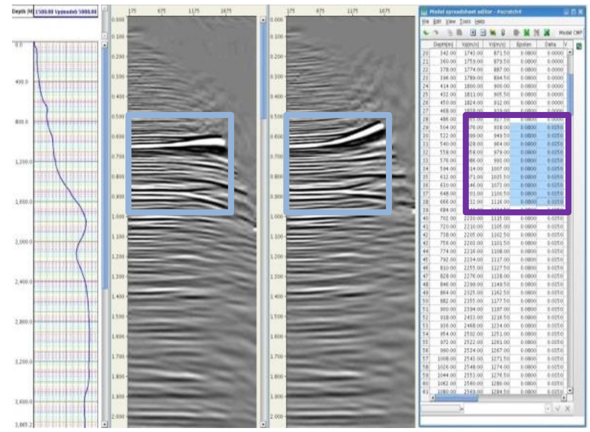
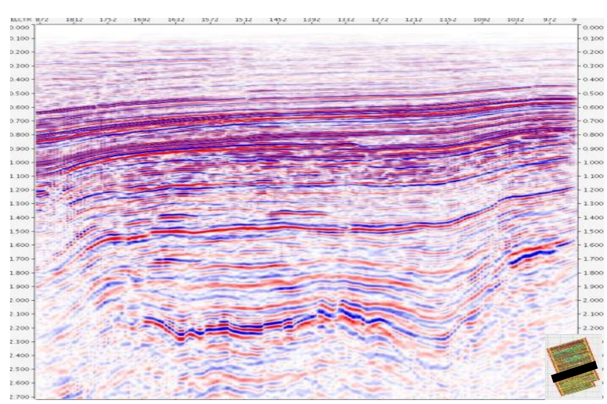


Fig-10. Estimation of delta and epsilon using Seiscal. Panel1 – Vertical velocity at well location, panel2 – validation of δ & ε values on gather at well, panel3 – gather at well location for δ & ε estimation, panel4 – model spreadsheet tool for δ & ε estimation.

Anisotropy inclusion & AKPSDM

Thomson delta, Thomson epsilon, dip and azimuth files were populated in the intermediate anisotropic model to make the initial anisotropic TTI model. Using this model as the starting model, KPSDM was run to update the interval velocity model. Anisotropic KPSDM update take cares of the flatness of gathers upto about 46 deg angular offset ranges. Usually three to five iterations are enough to get the convergence in the updated velocity values. In this case five iterations were run to flatten gathers upto 46 deg angular offset ranges.

Results:



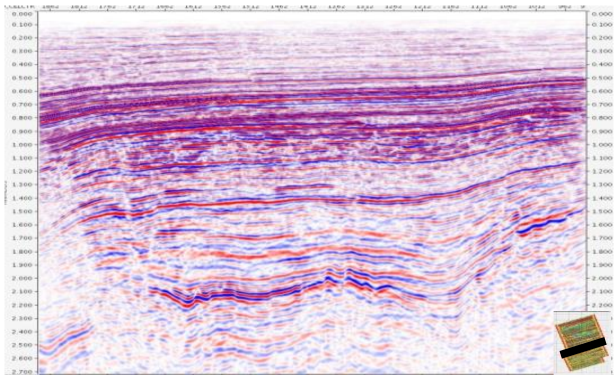


Fig-10. Comparison – stack section for a representative inline before and after AKPSDM.

Comparison shown above (Fig-10) shows better resolution and hence imaging after AKPSDM.

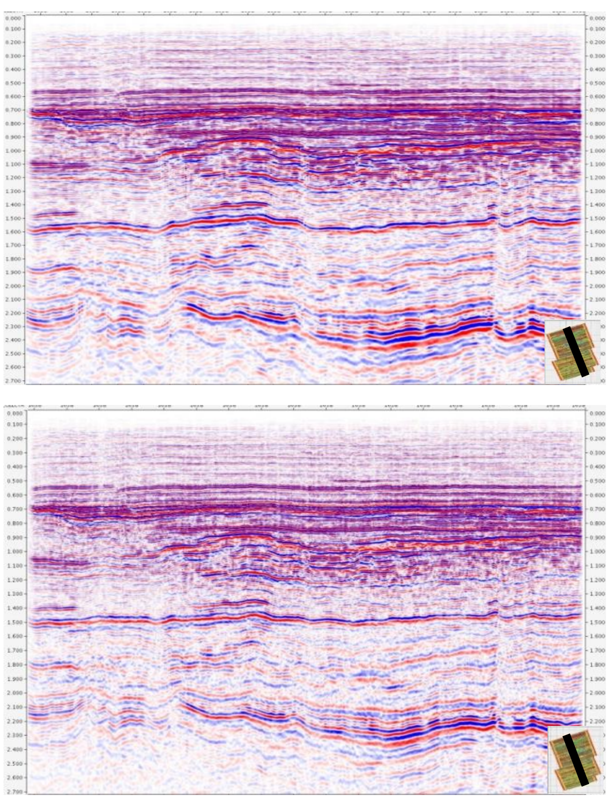


Fig-11. Comparison – stack section for a representative xline before and after AKPSDM.

Comparison shown above (Fig-11.) shows better resolution and hence imaging after AKPSDM in the xline direction. The pseudo structure visible before AKPSDM is resolved after AKPSDM.

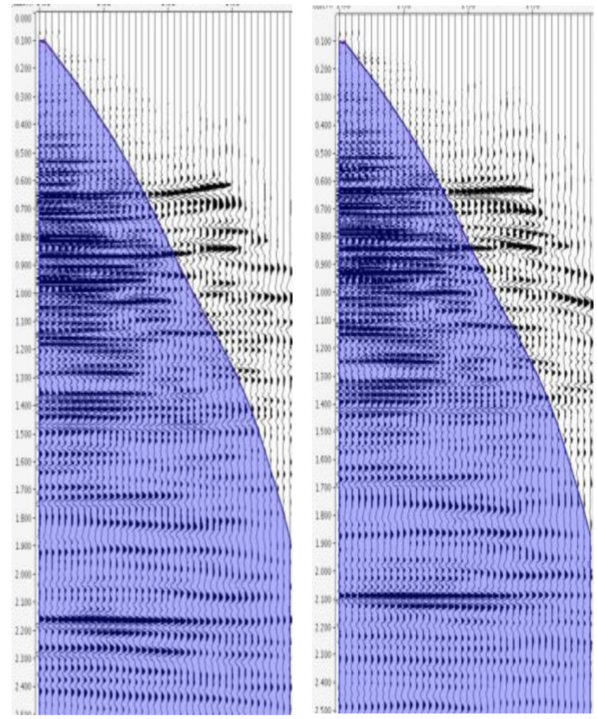


Fig-12. Comparison – gather for a representative location (angle overlaid is 0–46 deg) before and AKPSDM.

Comparison shown above (Fig12.) shows improvement in the flatness of the gathers upto 46 deg angular offset range.

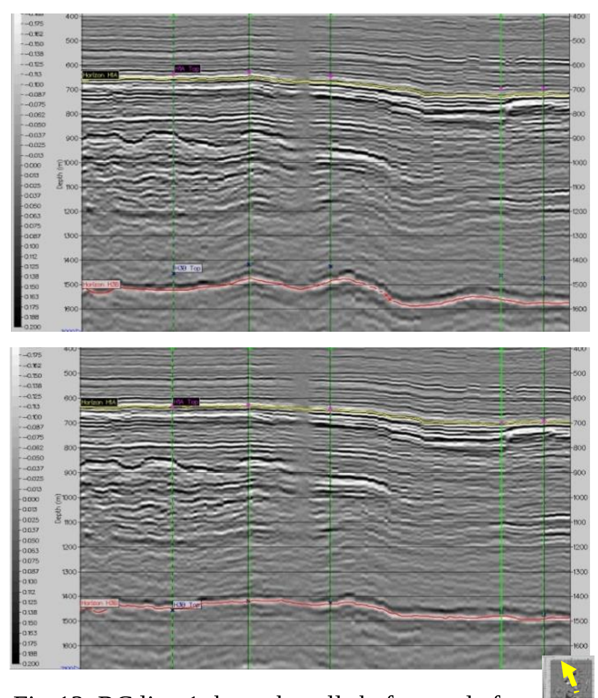


Fig-13. RC line 1 through wells before and after AKPSDM.

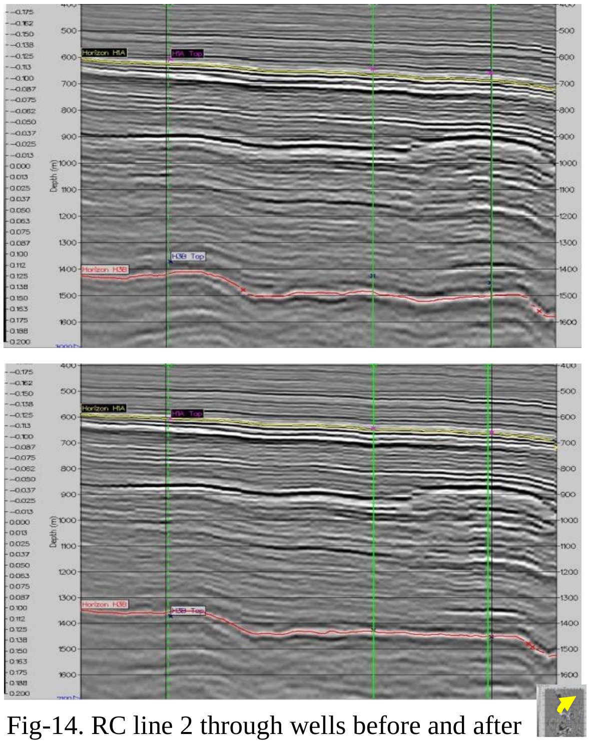


Fig-14. RC line 2 through wells before and after AKPSDM.

Comparisons shown above (Fig-13&14.) and in table below (Fig-15.) shows that well misties are reduced to under 1% after AKPSDM for the representative wells falling in the area.

Well	Horizon	Well marker depth [m]	Horizon depth [m] After Isotropic	Horizon depth [m] After Anisotropic	Percent Mistie After Isotropic	Percent Mistie After Anisotropic
A1	H1A	-599.00	-624.00	-603.00	4.17	0.67
	H3B	-1382.00	-1419.00	-1380.00	2.68	0.14
A2	H1A	-607.00	-624.00	-609.00	2.80	0.33
	H3B	-1372.00	-1401.00	-1362.00	2.11	0.73
A3	H1A	-635.00	-657.00	-639.00	3.46	0.63
	H3B	-1455.00	-1500.00	-1443.00	3.09	0.82
A4	H1A	-628.00	-648.00	-630.00	3.18	0.32
	H3B	-1418.00	-1458.00	-1428.00	2.82	0.71
A5	H1A	-643.00	-666.00	-648.00	3.58	0.78
	H3B	-1426.00	-1464.00	-1434.00	2.66	0.56
A6	H1A	-660.00	-687.00	-663.00	4.09	0.45
	H3B	-1452.00	-1494.00	-1452.00	2.89	0.00
A7	H1A	-697.00	-687.00	-705.00	1.43	1.15
	H3B	-1463.00	-1533.00	-1497.00	4.78	2.32
A8	H1A	-693.00	-720.00	-699.00	3.90	0.87
	H3B	-1474.00	-1539.00	-1509.00	4.41	2.37

Fig-15. Mistie comparison between Isotropic KPSDM and Anisotropic KPSDM.

Conclusions

Anisotropic KPSDM approach for depth imaging has been demonstrated in the present study. It has been found that the well misties after anisotropic KPSDM is less than 1% for most of the wells falling in the area. The depth gathers showed flatness for more than 46 degrees angular offset, thus making them highly amenable for structural modeling, inversion and attribute analysis.

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