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Analysis of Balkassar Area Using Velocity Modeling and Interpolation to Affirm Seismic Interpretation, Upper Indus Basin

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Abstract Balkassar area envelops itself in the Potwar sub basin in Himlayan collisional regime tacitly known for its hydrocarbon structural traps. Proposed research was conducted via SEG Y and well data issued by DGPC using licensed K-tron software. The aftermaths of the research delineate the compressional regime due to thrust faulting. Heretofore, five reflectors were marked based on stratigraphic studies and after correlating with well tops were named as Chorgali, Sakesar, Lockhart, Khewra and Basement. Initially time sections were prepared and were converted to depth section via velocity analysis system to delineate subsurface structure. Fundamental outcome of this research was helpful to velocity factor in affirming the interpretation. It shows the significance of lateral velocity variations in time to depth conversions which is unnoticed by some interpreters by simply averaging the velocity functions into a single function. Confronting this, velocity model was generated using duo interpolation algorithms. The velocity model indicates the importance of lateral velocity variations. Henceforth, the processed velocity models showcase better results for further analysis on structure evaluation and decision making. Effects of velocity in time to depth conversion using layered cake time model was interpreted. Seismic velocities were interpolated and 2D seismic models had been generated through convolution with a klauder wavelet using velocity models. Duo Spatio-temporal and horizon interpolation are best description of velocity modeling and interpolation. Corollary results indicate that horizon based interpolation expatiates best velocity model and thus used in time to depth conversion.

Keywords Seismic, Velocity, Stratigraphy, Interpretation, Modeling, Interpolation

1. Introduction

Hydrocarbons are one of the most mandatory constituents while describing the economics of any country. The necessity of delineating those buried hydrocarbons and structures is of extreme importance of geophysical studies. Proposed research of Balkassar area using K-tron software was conducted to reveal the structural information. The Balkassar area is located about 100km southwest of capital Islamabad (Figure 3), in the Chakwal district, Punjab Province. The estimate terrain elevation above sea is 506 meters having Latitude: **32°55'59.99"** Longitude: **72°39'0.01**. Geographically Balkassar abuts borders with Kalar Khar in South, Chakwal city in East and Talagang city lies towards West. Directorate General Petroleum Concession (DGPC), Government of Pakistan granted the navigation and the velocity data of eleven lines. Base map of the Balkassar area (Figure 1) was generated via K-tron Precision Matrix an Integrated Geo Systems application [1] which lies in Universal Transverse Mercator (UTM, Zone 43) projection system. Proposed study area lies in south eastern part of the Salt Range Potwar foreland basin (SRPFB) bounded by Salt Range thrust in south, Main Boundary thurst (MBT), Kala-Chita and Margalla hills in the north and left lateral Jehlum fault, Jhelum River, Hazara Kashmir Syntaxes in the east and right lateral Kalabagh fault, Indus River, Kohat Plateau is located in the west [2] Potwar sub-basin was originated because of the intense Himalayan collisional orogeny and represents thrust sheets of Precambrian to recent rocks comprised of Northern Potwar Deformed Zone (NPDZ) and Southern Potwar Platform Zone (SPPZ) separated by asymmetrical Soan Syncline. General Stratigraphy of Potwar Basin is given in Table 1.

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2. Work Flow and Methodology

Narrating the workflow and software used (Figure 2), a series of genre modules of Ktron software were accomplished to perform various processes to explain outcomes. The complete work flow showcases the software tools being used along with the processes is given in Figure. Initially reflectors were marked on the basis of prominent reflection on the lines from subsurface interfaces with different colors so that to display the disparity amongst them. Velocities were calibrated using Velocity Analysis System (VAS) [1] and was used in time to depth conversion. Latterly work flow for velocity modeling techniques was accomplished using two interpolation algorithms. Moreover, 2D modeling was performed to confirm structural interpretation. Rock Physics and Engineering Properties for the confirmation of seismic interpretation were also calibrated.

Table 1. Stratigraphic Chart of Area

Period	Epoch	Formation	Lithology	Hydrocarbon System
Tertiary	Pliocene	Nagri	Greenish grey Sand stone and Clay, Conglumerate	
		Chinji	Bright red clays with Sandstone	R/C
	Miocene	Kamlial	Massive red and brown sandstone, dark red clays	
		Murree	Interbedded light grey Sandstone	R/C
	Oligocene	Unconformity		
	Eocene	Chorgali	Dark-medium grey argillaceous Limestone	S/R
		Sakesar	Massive and nodular Limestone with Marl	S/R
		Nammal	Dark grey Calcarious shale, Light -dark grey Limestone	S/C
	Paleocene	Patala	Grey greenish Shale and Limestone	R/S
		Lockhart	Massive light -dark grey Limestone with minor Shale	R/S
		Hangu	Light grey Sandstone and Dark grey Shale	
Cretaceous	Composite Unconformity			
Jurassic				
Triassic				
Late Permian				
Early Permian		Sardhai	Dark purple Clays with streaks of Sandstone	S
		Warcha	Red and Light colored Sandstone and Grit	
		Dandot	Olive -Green and grey Sandstone and Shale	
		Tobra	Conglomerate Sandstone ,Boulder, Shale	
Late Cambrian	Unconformity			
Cambrian		Khewra	Maroon fine textured Sandstone	
Pre Cambrian		Salt Range	Red Gypsum, Marl, Rock salt	ND
		Basement		ND

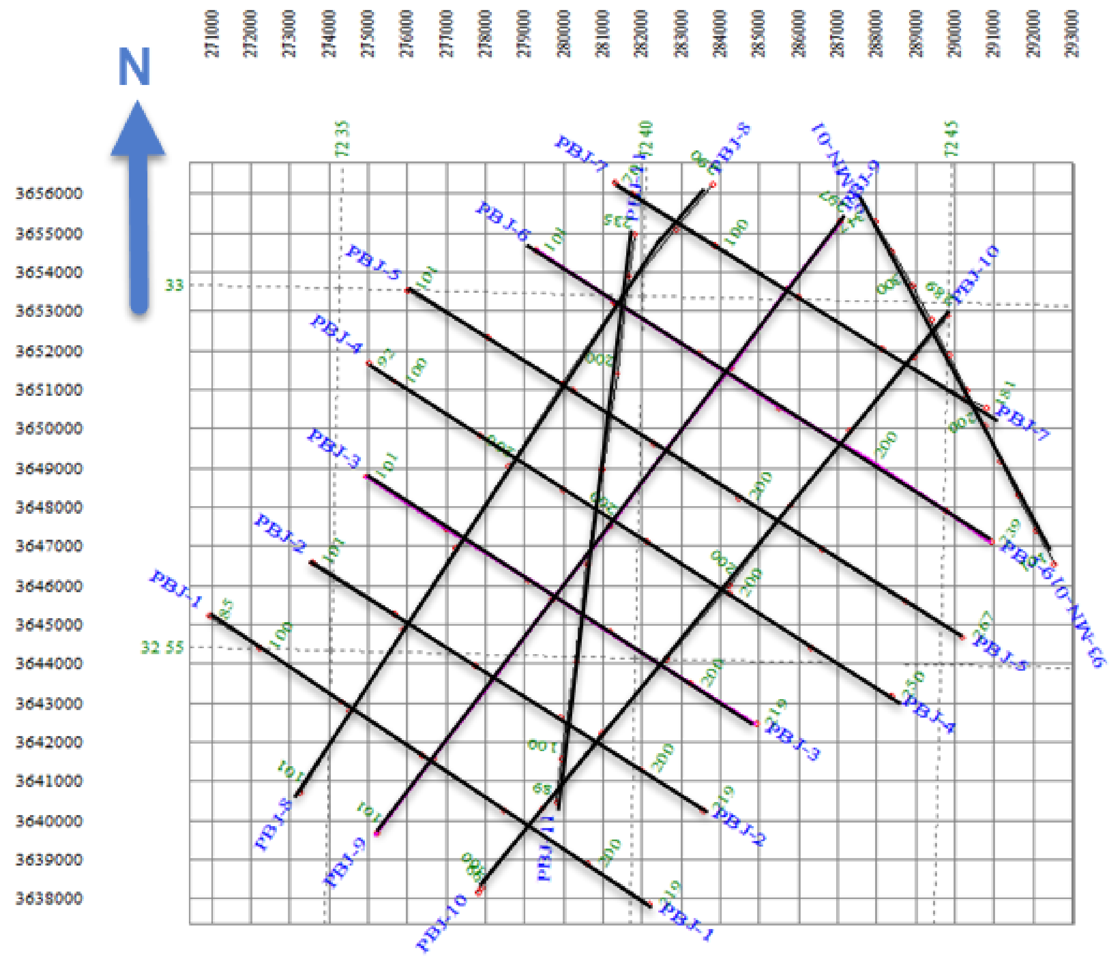

Figure 1. Base map of the Balkasaar Area displaying seismic lines (Khan, 2000)

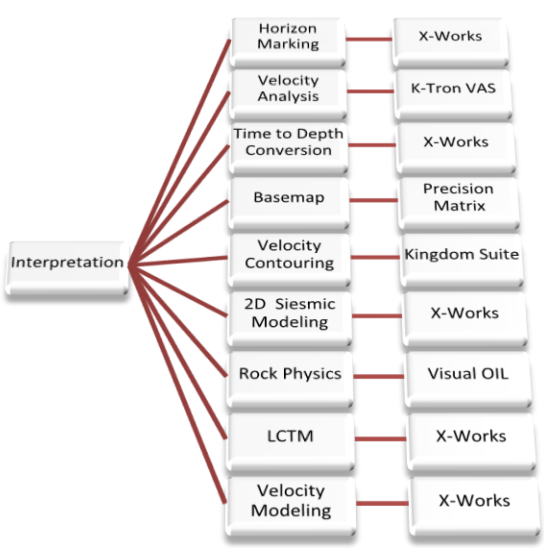

Figure 2. Interpretation Work and the software modules used for Research

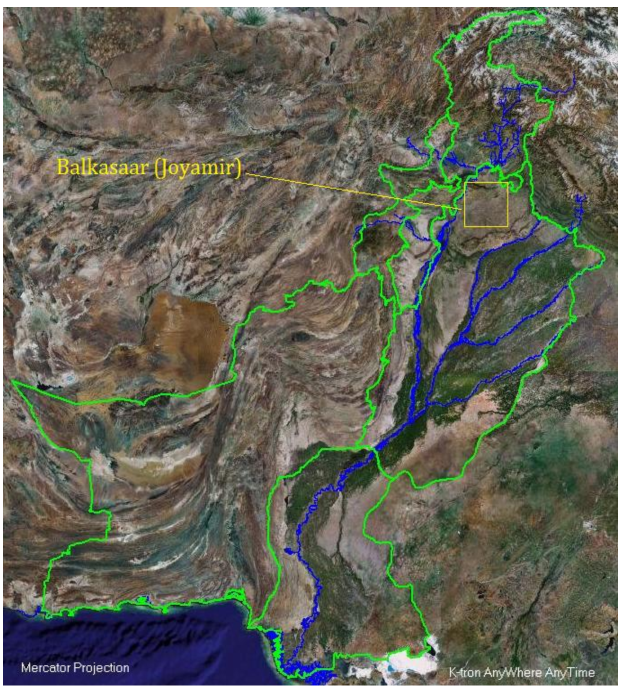

Figure 3. Satellite image of Pakistan showing Balkassar area [5]

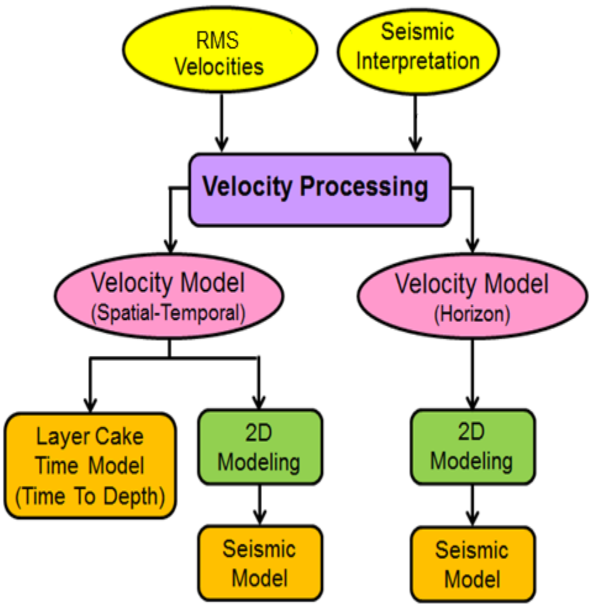

Figure 4. Velocity modeling techniques and their applications

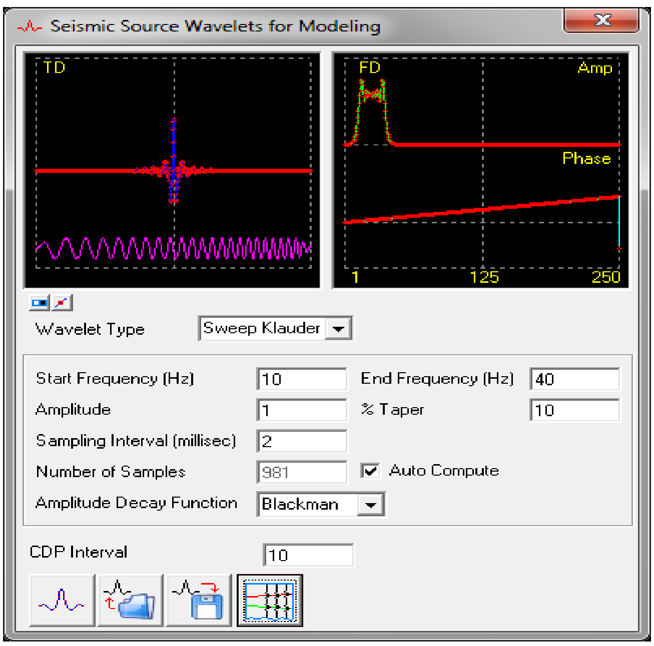

Figure 5. A Sweep Klauder wavelet Generated with frequency 10-40 Hz with 10 % tapering and Blackman Amplitude Decay Function as a source for 2D Seismic Modeling

3. Results and Discussions

Seismic Interpretation

On seismic lines, reflectors were identified on the basis of prominent adjacency of reflectors from the subsurface interfaces. Each reflector was marked with different color as to disseminate the disparity amongst them. Moreover, secondary information of subsurface depths was utilized from well data to pick five prominent reflectors. The Chorgali formation which is limestone reservoir displays prominent reflections on seismic section. The radical reflectors marked on the seismic sections that are of interest are Chorgali, Sakesar, lockhart and khewra formations. Categorically the time section annotates the position and configuration of reflectors in time domain. Reflectors were marked on seismic line PBJ-05 and named explicitly on the basis of stratigraphic column encountered in well Balkassar Oxy -01. However, the attempt is to investigate the source, reservoir and seal rock formations. Ingenuously seismic image is inadequate for an exploration or field development interpretation. Appropriate well ties and reliable depth conversion are also important. The seismic sections are in time domain (Figure 6) and are insufficient to delineate the results, as the subsurface structures are in depth domain so time sections were modified to depth sections using velocities data. X-Works reads velocity data in IGS Velocity format for time to depth conversion. The seismic section velocities are Root Mean Square (RMS) velocities. These must be converted into interval and finally average velocities for time to depth conversion. The seismic velocities are processed (Converted, Interpolated and Smoothed) by using Velocity Analysis System (VAS) [3] (Figure 7) used for Time-to-Depth conversion and Modeling. The velocity data is converted into the X-Works format using data formatting scripts available in Visual OIL. The input seismic velocities (Root Mean Square) in IGS velocity format are uploaded in X-Works and a spatio-temporal or horizon Interpolated velocity model is generated. Lateral and vertical velocity variations provide true depth imaging using velocity model. The horizon velocity map of Chorgali is shown. (Figure 8). These velocities were multiplied with time of each reflector and divided by two to acquire the depth section (Figure 9).

Volume of shale

Oxy-01 depicts reservoir and source zones. The shale signature is prominent in the areas closely matching the location of Patala and Dhandot at depth 2600 and 2850 as given by the information from the well tops, while the zones located above the shale signature indicates the reservoir zone at the depth of 2400-2600 meters which is approx. depth of Chorgali and Sakesar formation. The Gamma Ray log along with sand and shale lines are linearly computed. (Figure 10)

Rock Physics

To compute the rock physical and engineering properties, velocity functions were used. Interval velocities are used, which represent the true lithological properties of the sub-surface layers. The velocity functions are processed to compute rock physics sections using a scripted program written in Visual OIL [4]. Cross-sections of rock properties such as density (Figure 12) and porosity (Figure 11) have been generated to understand the variation of these parameters across the sections.

Spatio-Temporal Velocity Interpolation

The X-Works provide us with the Spatio-Temporal Velocity Interpolation Feature. The RMS velocity functions are basically velocity-time pairs (VT-Pairs) without fixed time intervals. In this technique, first temporal (vertical) interpolation of 100 milliseconds is applied to get velocity functions with VT-Pairs after regular time intervals. If required, then 3 to 5 point moving average operator is applied along each function to get vertical smoothing of velocities. Next spatial interpolation at 5th CDP is applied to generate velocity functions at the specified CDP interval. This is followed by a 3 to 5 point moving average operator across the velocity functions or along the time slice to get lateral smoothing of velocities. This generates the spatio-temporal interpolated RMS velocity model. (Figure 13)

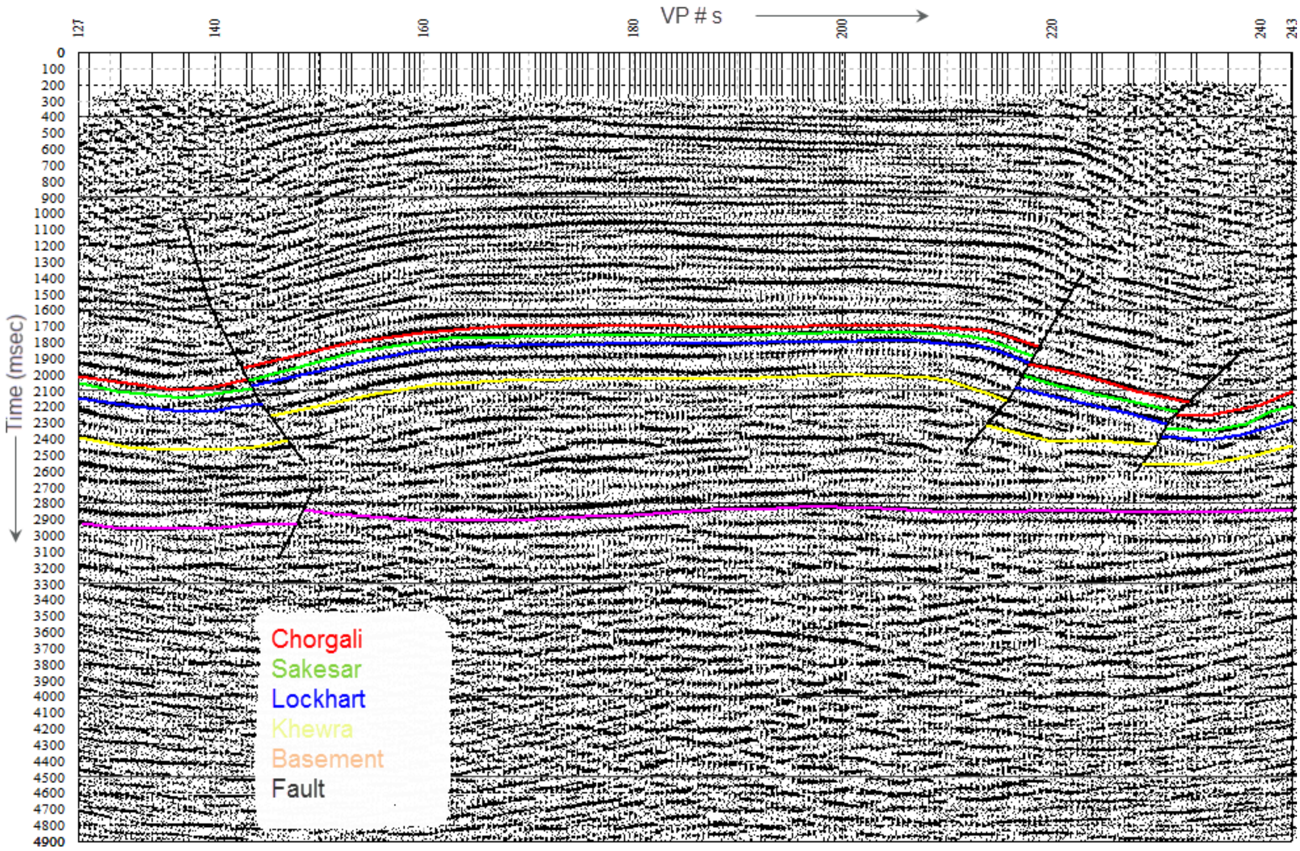

Figure 6. Interpreted Time Section of Seismic Line PBJ-05 (Chorgali: Red, Sakesar: Green, Lockhart: Blue, Khewra: Yellow Basement: Pink)

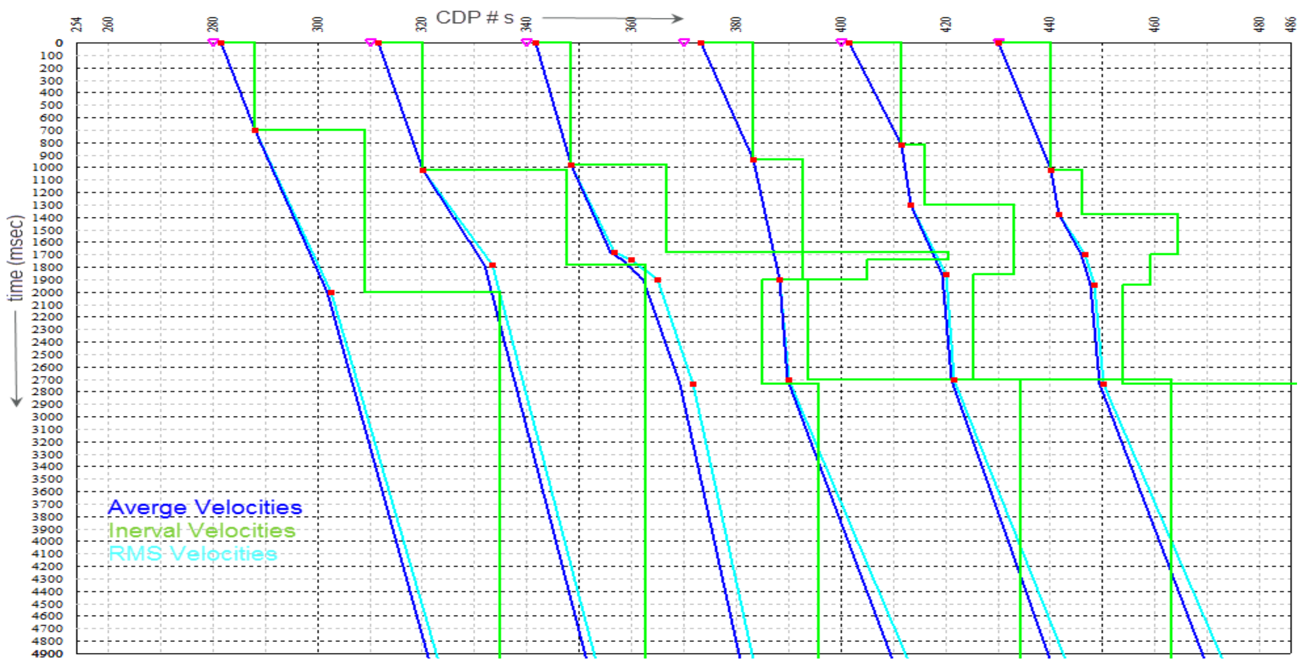

Figure 7. Seismic velocities of line PBJ-05 combine displayed at different CDPs

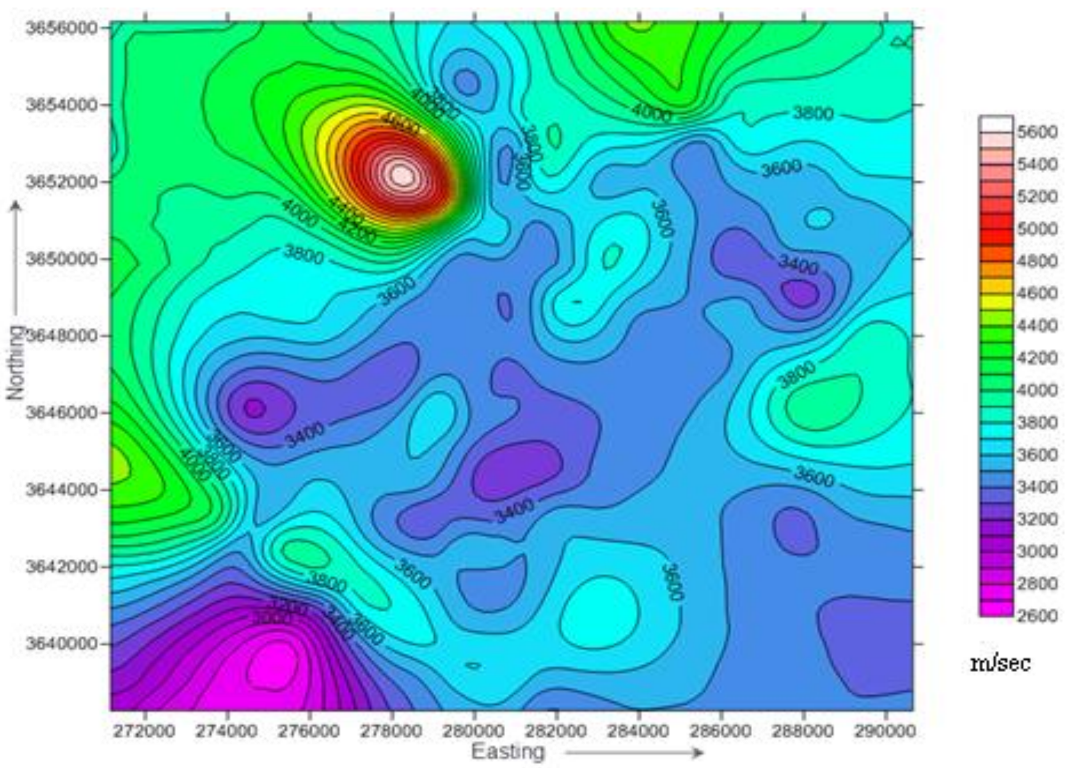

Figure 8. Horizon Velocity Contour Map of Chorgali Formation

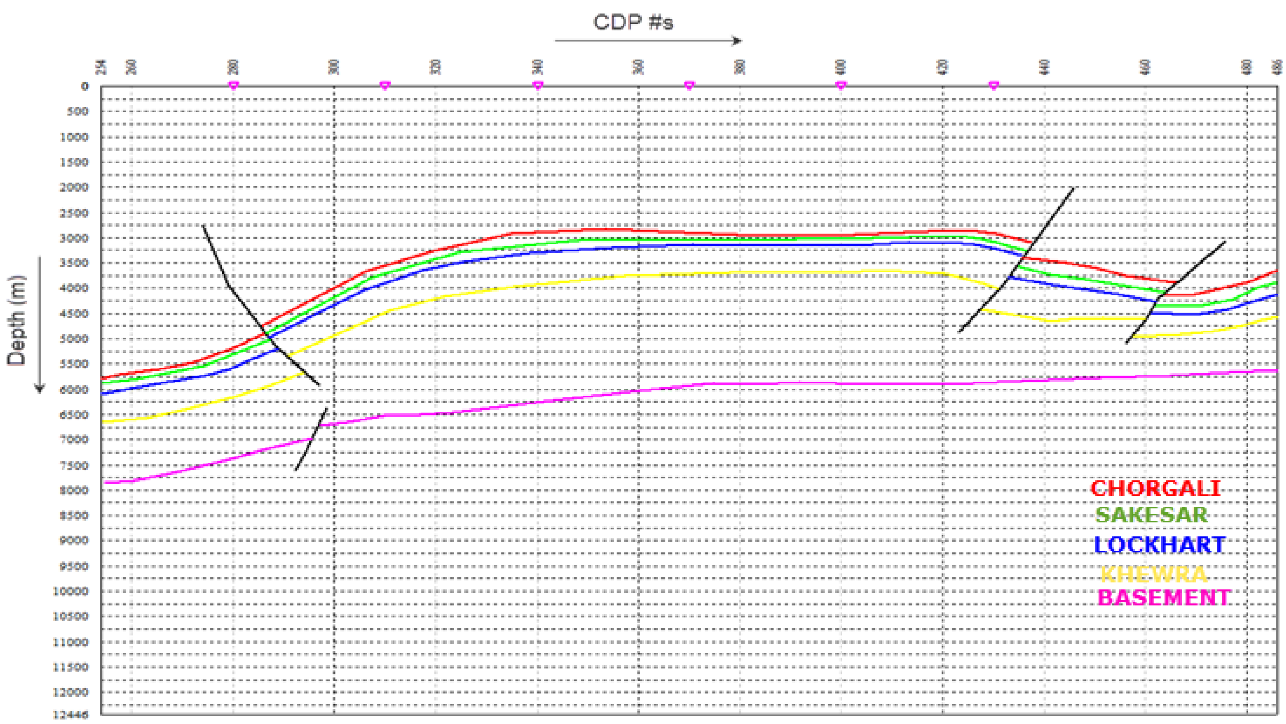

Figure 9. Depth Section of seismic line PBJ-05

Horizon Velocity Interpolation

Horizon interpolation is composite interpolation method which requires input of interpreted horizons, in addition to the velocity data. The velocity was interpolated along these horizons, instead of interpolation along the time slice (Figure 14). It requires computation of nodes for each horizon at the specified CDP interval. VT-Pairs are then interpolated at these nodes to generate velocity functions. The velocity model generated by this technique closely matches the subsurface as structures as shown in Figure. Compendiously these sorts of velocity models are commonly used for velocity imaging using modeling and Pre-Stack Depth Migration (PSDM).

LCTM

A Layered Cake Time Model (LCTM) consisting of flat horizons or time slices after every 100 milliseconds with nodes at every 5th CDP was generated for PBJ-05 seismic line (Figure 15). The calibrated velocity functions are loaded and processed to generate an unsmoothed spatio-temporal velocity model with a temporal interval of 50 milliseconds and spatial interval of 5 CDP as narrated earlier. Velocity model was then used in time to depth conversion of the LCTM to generate a depth section (Figure 16) which depicts the deformation of the LCTM in the form of pull ups & downs in the depth section due to lateral velocity variations. Tacitly the attained depth section is not smooth due to fluctuations in the velocity model. Thus a spatio-temporal smoothing with a 3x3 kernel operator is applied to generate a smoothed velocity model, which is again used in time to depth conversion of LCTM. The resulting depth section was much smoother as compared to that (Figure 17). Corollary, it concludes that velocity models must be smoothed to get realistic time to depth conversions. It also shows the significance of lateral velocity variations in time to depth conversions which is unnoticed by some interpreters by simply averaging the velocity functions into a single function.

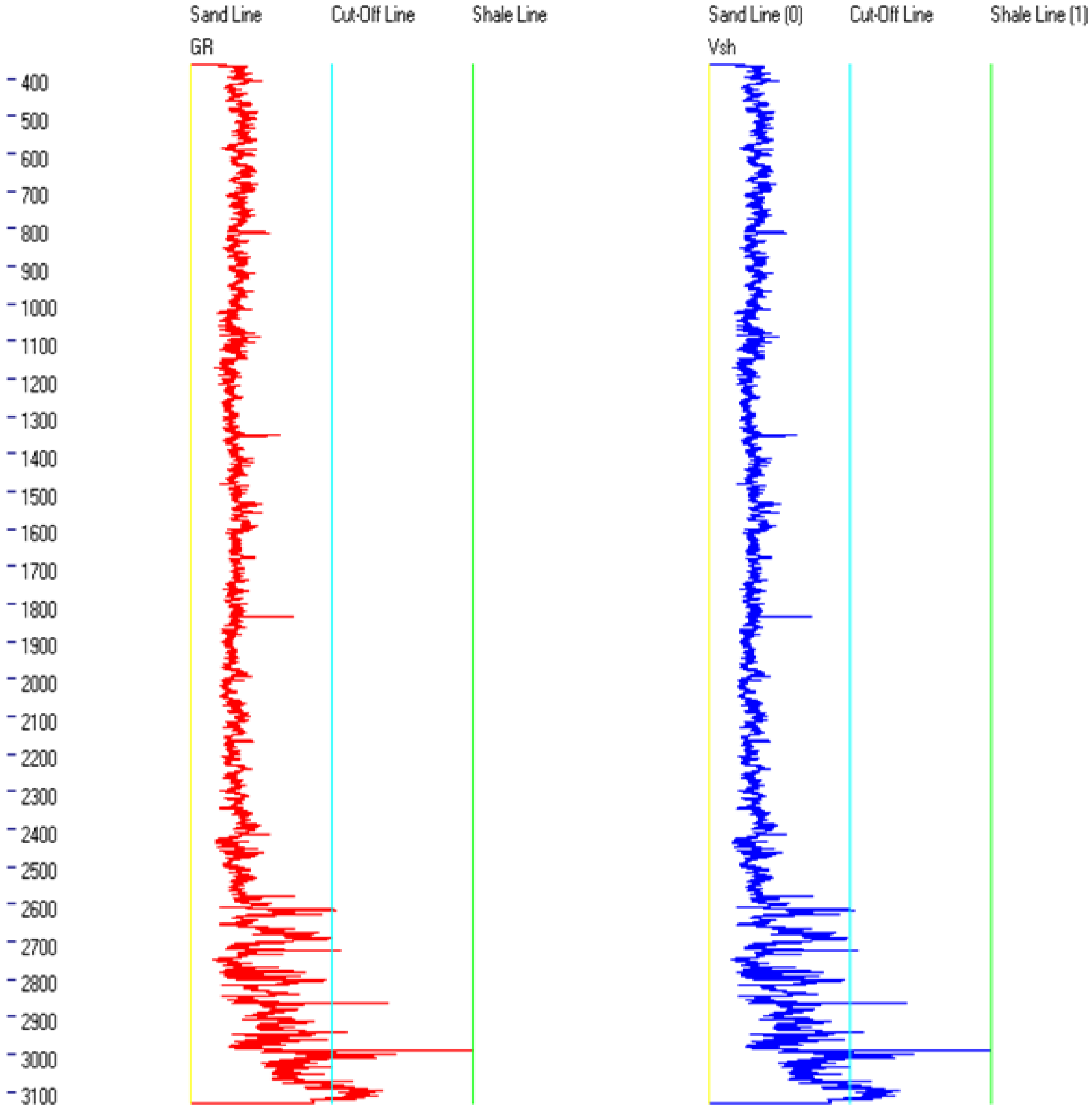

Figure 10. Gamma Ray log (Red) along with calculated Volume of Shale curve (Blue). [Sky-Blue=cutoff line, Green=shale line and Yellow=sand line]

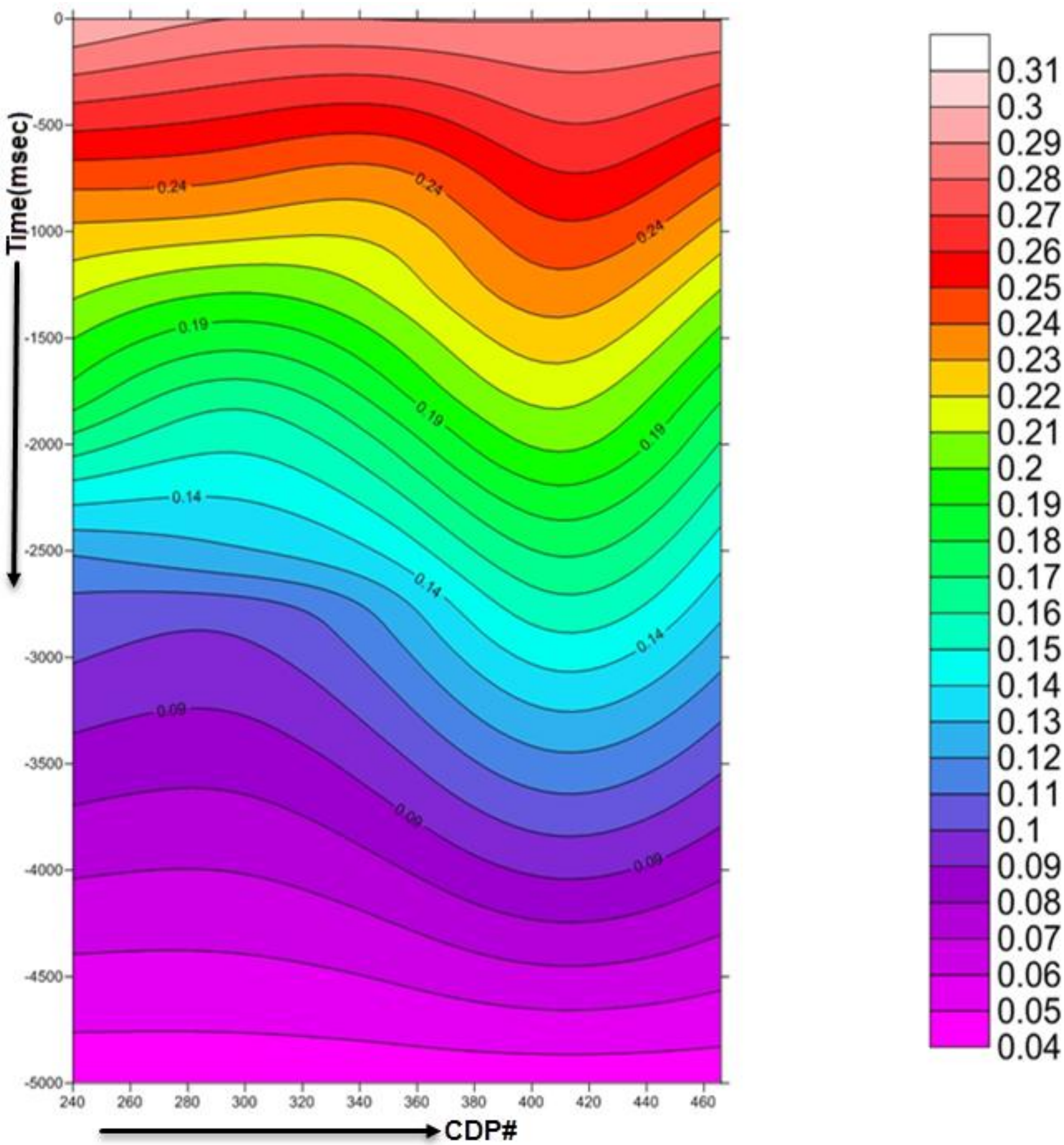

Figure 11. Porosity Cross-Section of line PBJ -06

2D Seismic Modeling based on velocity functions

2D seismic models were generated for line PBJ-05 using three methods. First two were generated from the velocity models explained earlier, while the third is generated from the interpreted seismic depth sections. In all these methods a klauder wavelet of 10-80 Hz sweep frequencies with 20% linear tapering with a blackman amplitude decaying function was used as a source (Figure 5). The wavelet was convolved with velocity models or interpreted depth section at every 10 CDP to generate a seismic section. As the modeling is applied at zero offset, the resulting synthetic seismic model is a migrated section. The three seismic modeling techniques are discussed below.

2D Seismic Modeling based on Spatio-Temporal Velocity interpolation

The spatio-temporal interpolated velocity model was used as input. The RMS velocity functions are converted into interval velocity functions. The VT-pairs in these functions were at regular intervals and therefore they do not portray the sub-surface structural information. The interval velocity functions were used to generate reflectivity series which in turn are convolved with the source wavelet to generate seismic traces forming a 2D seismic model (Figure 18). It can be considered that the seismic section generated from this method does not show any structural features. Corollary it concludes that structural information contained in original velocity functions is lost due to spatio-temporal interpolation. Thus spatio-temporal interpolated velocity models can be used in time to depth conversion, but they cannot be used in modeling and rock physics applications.

2D Seismic Modeling based on Horizon Velocity interpolation

The basic modeling procedure is the same as elaborated earlier, except horizon interpolated velocity model is used as input. The model seismic section generated by this technique is shown in Figure 4. It can be observed that this seismic model displays a reasonable sub-surface image clearly depicting structures whilst zoomed image of 2D seismic model generated by using horizon velocity interpolated model along with seismic is also enclosed (Figure 19).

Seismic Model based on 2D Interpreted Depth Sections

This is the conventional modeling in which the interpreted time section is converted into a depth section. Reflection coefficients are assigned to each reflector as an attribute. The section is convolved with the source wavelet to generate a 2D synthetic seismic section (Figure 20). As this modeling is completely based on the structural data so the derived synthetic section completely matches the structures. This type of modeling is commonly used to adjust acquisition parameters for neo surveys based on geological cross-sections with velocities assigned to each formation and get seismic response of stratigraphic models as well as confirmation of seismic interpretation.

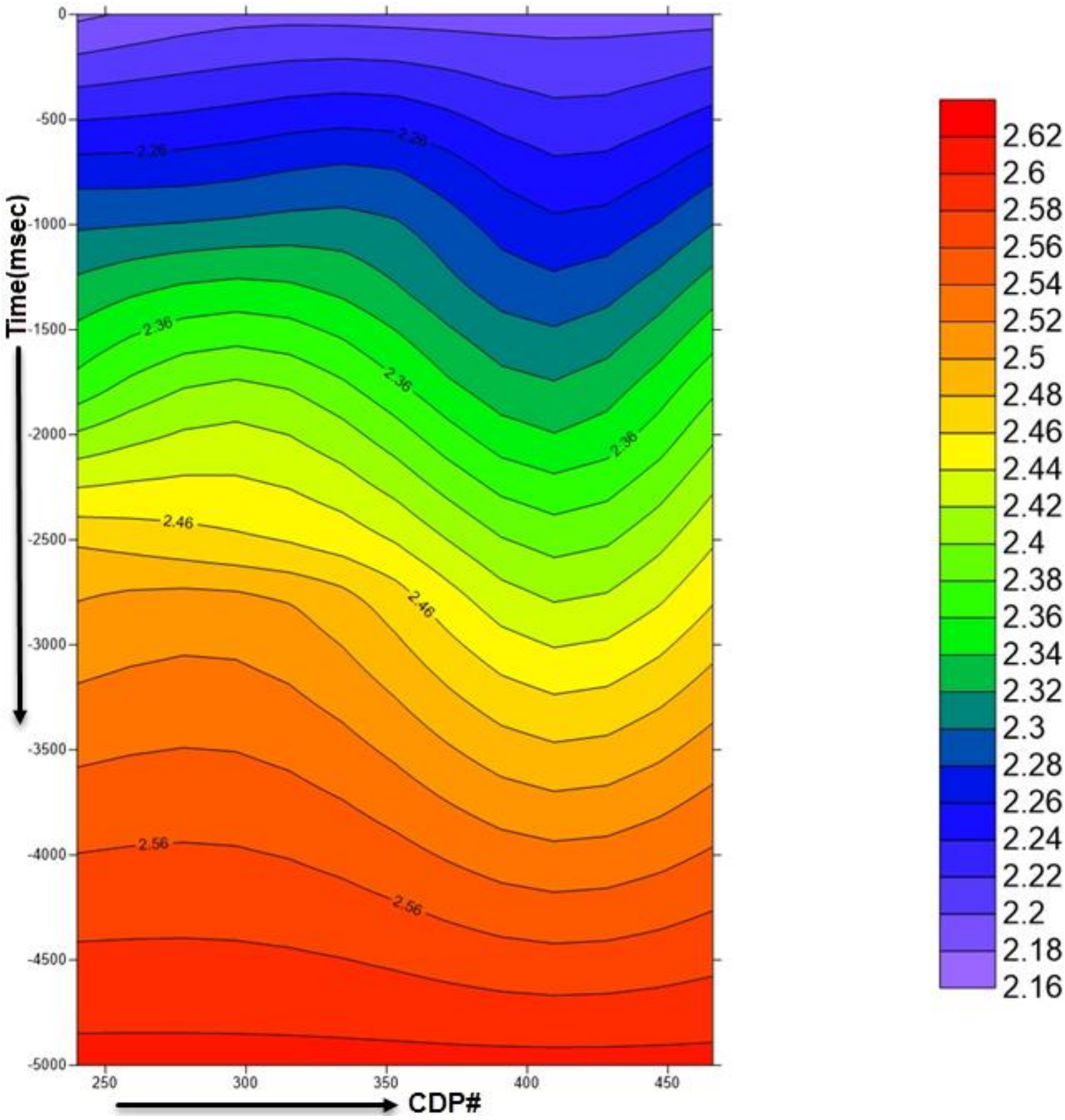

Figure 12. Density section showing the variation of Density along the seismic line PBJ-06

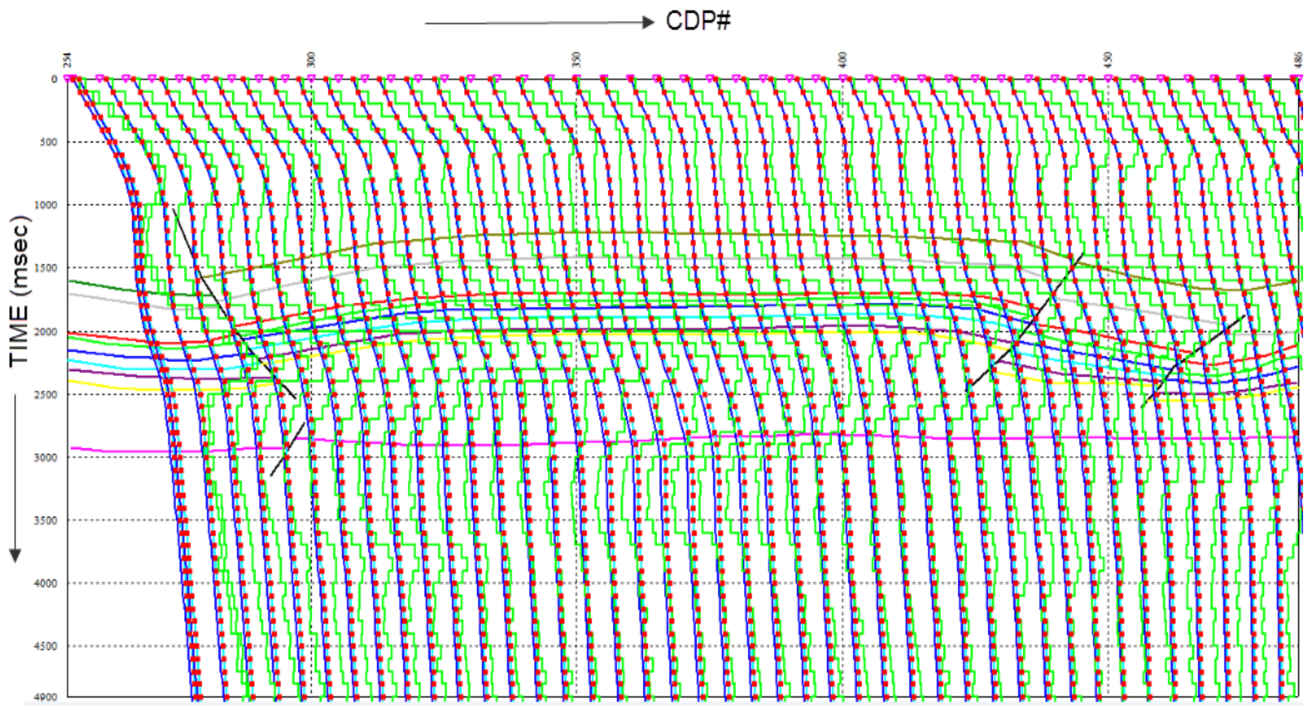

Figure 13. Spatio-temporal Velocity model using spatial interpolation at 5 CDP intervals RMS velocities (Light-Blue) Interval (Dark Green) Average (Dark Blue) velocities

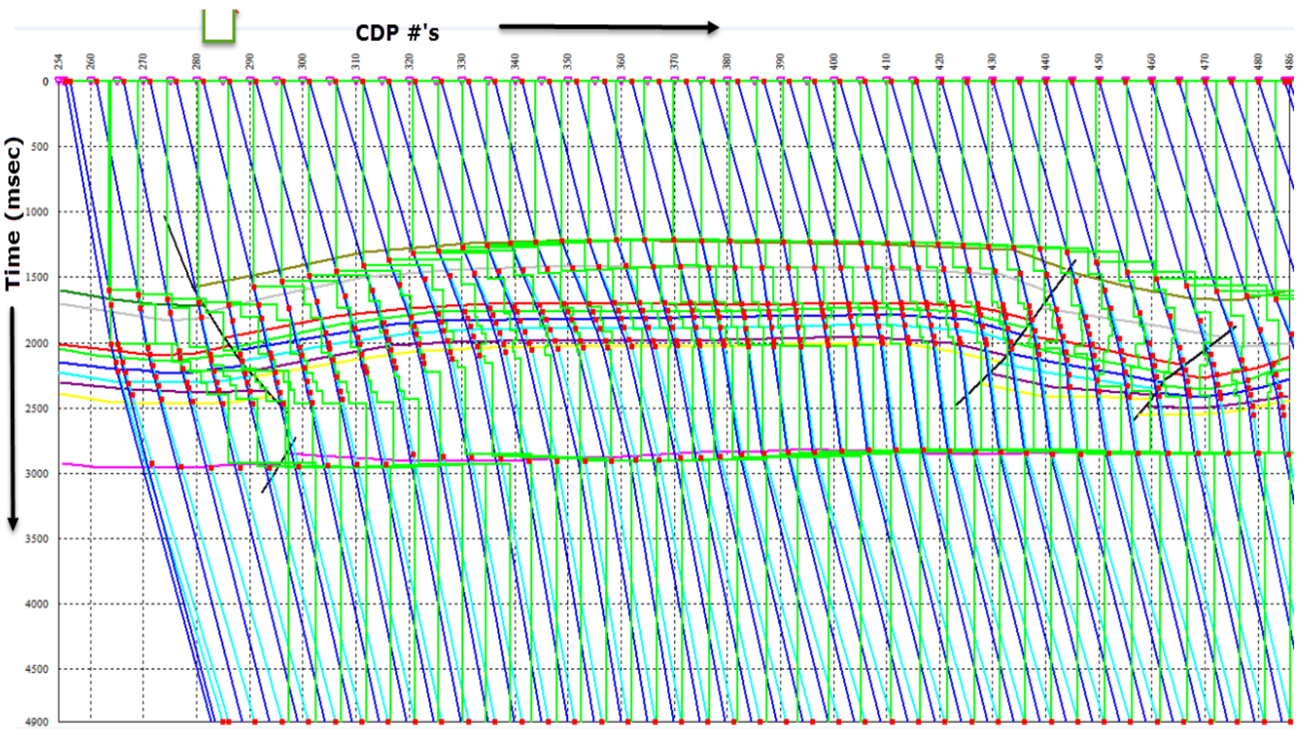

Figure 14. Velocity model generated by interpolation of velocity functions at every 5th CDP along the interpreted horizons RMS velocities (Light-Blue) Interval (Dark Green) Average (Dark Blue) velocities

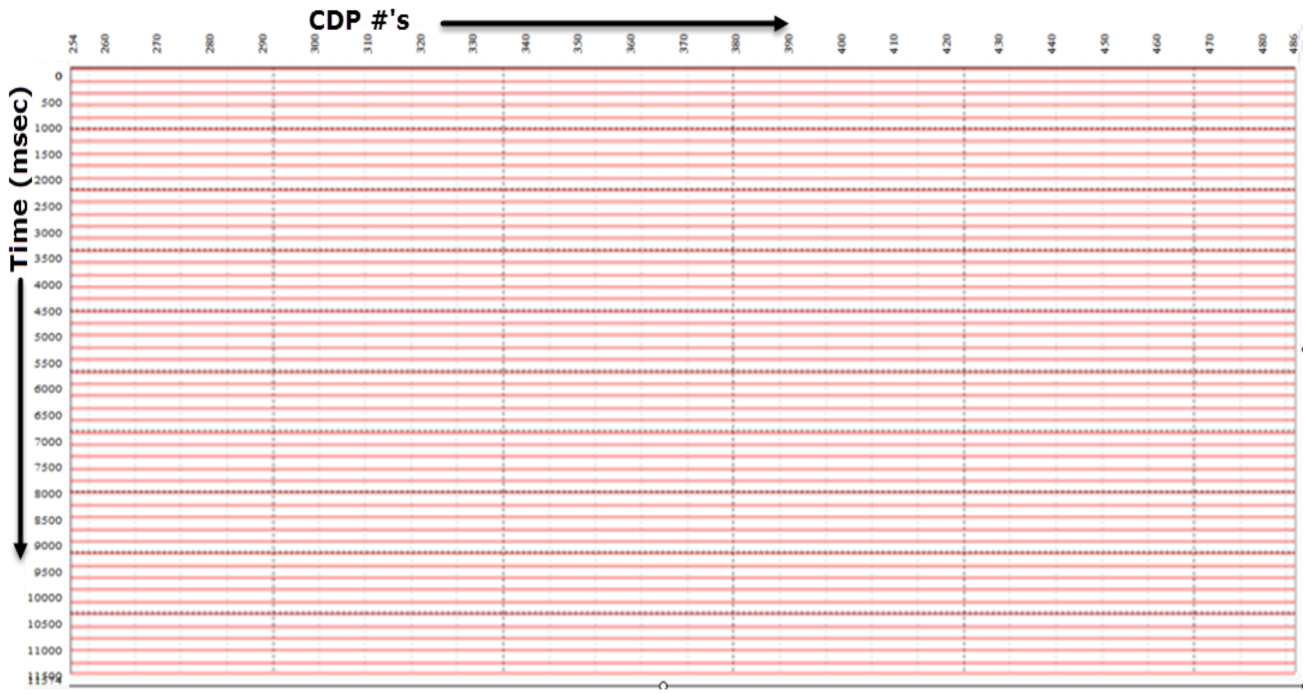

Figure 15. Layered Cake Time Model (LCTM) of seismic line PBJ-05

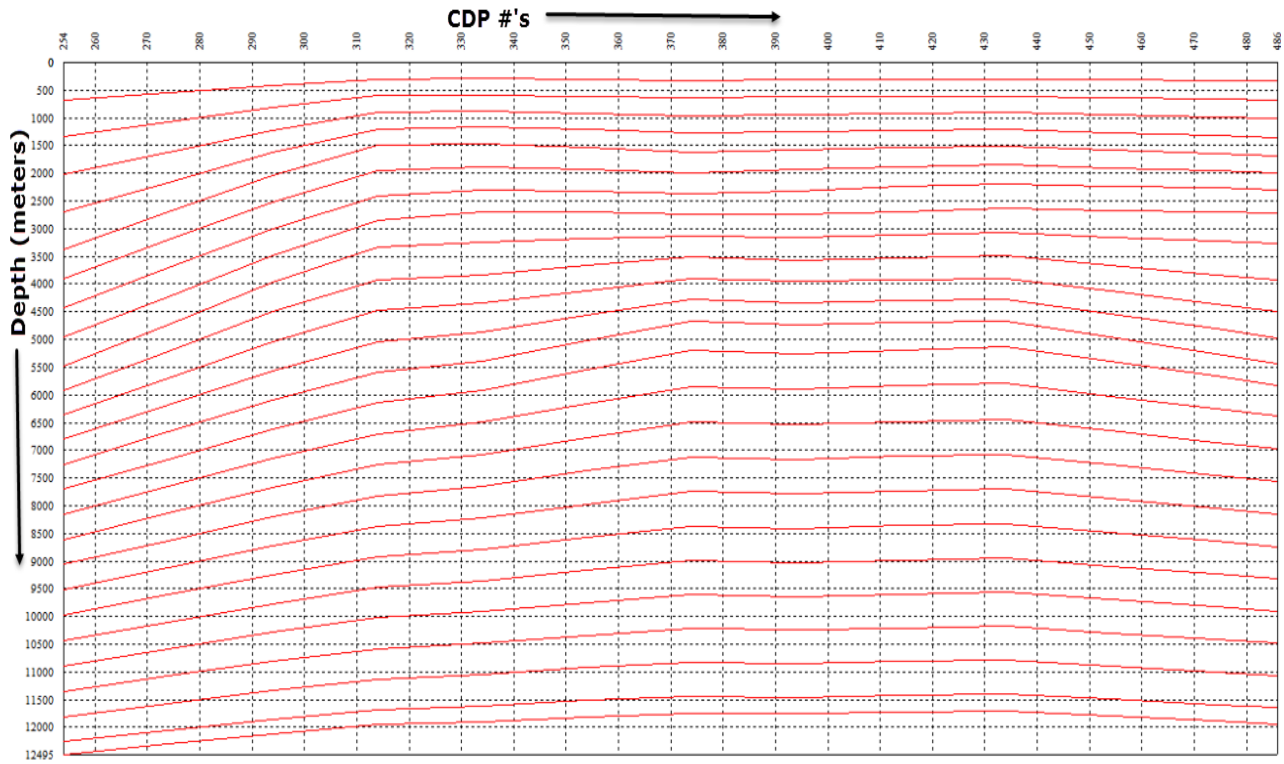

Figure 16. Depth converted LCTM with sharp pull ups and pull downs due to lateral velocity variations

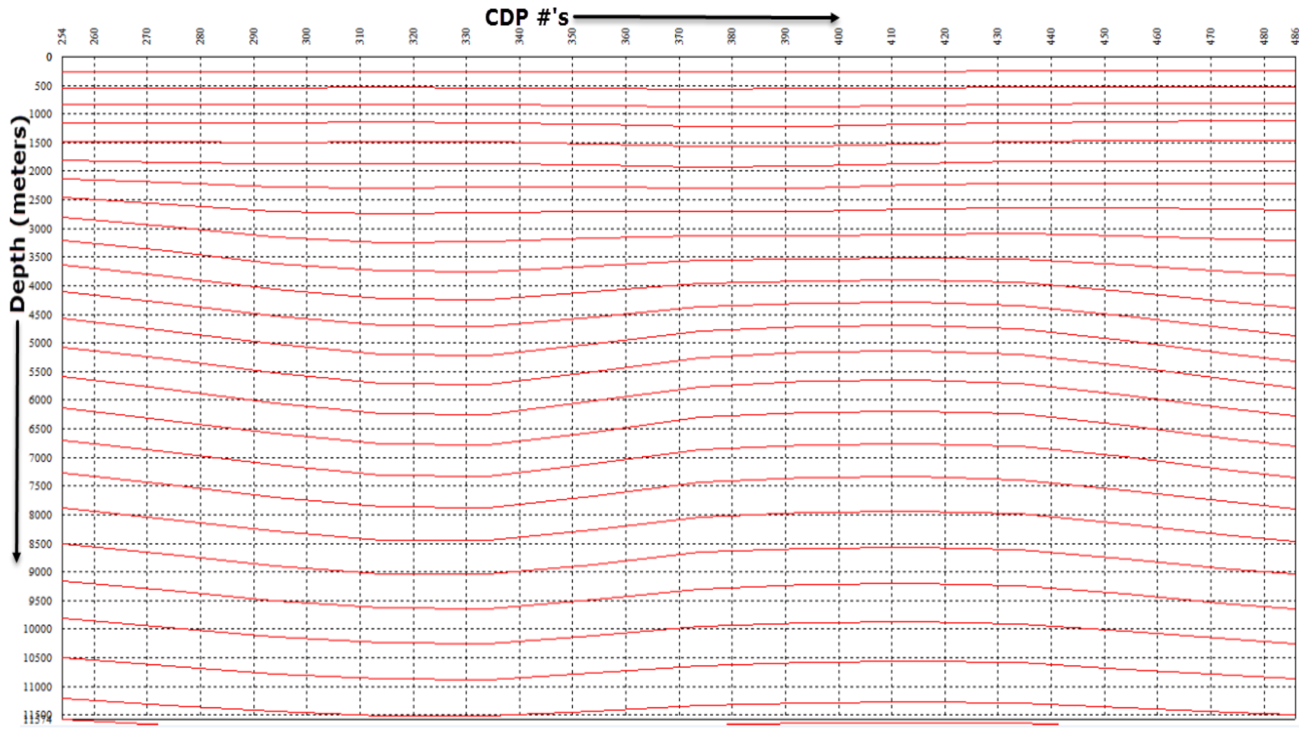

Figure 17. Effect of smoothed velocities on a depth converted section

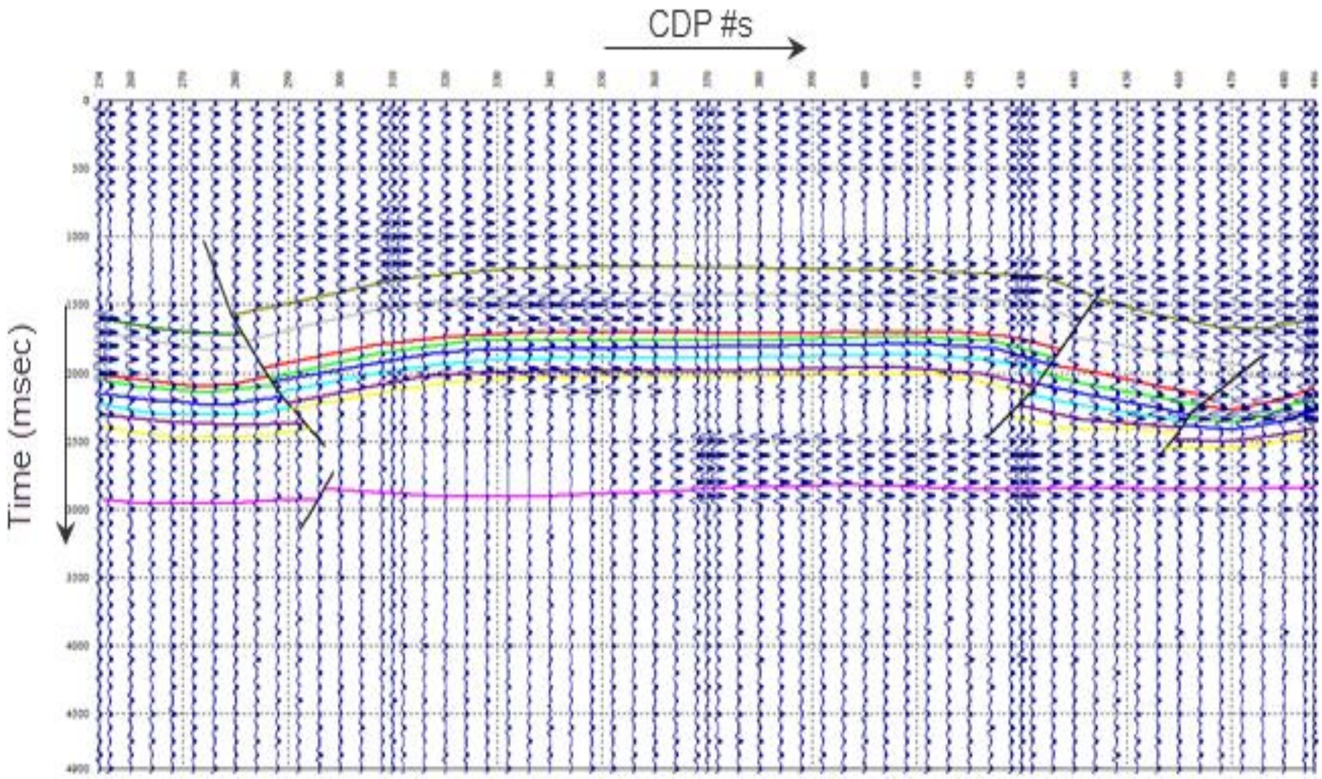

Figure 18. 2D seismic model generated by using spatio-temporal velocity interpolated model without seismic

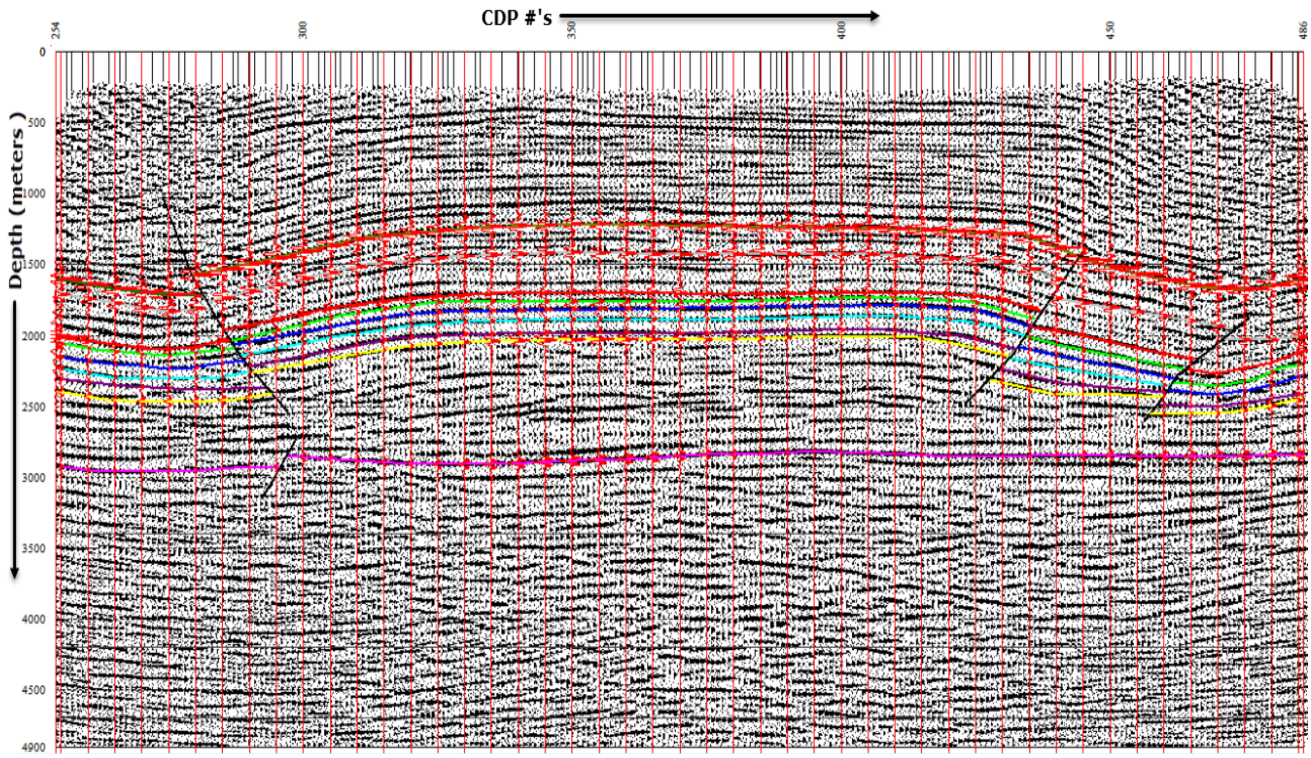

Figure 19. 2D seismic model generated by using horizon velocity interpolated model with seismic

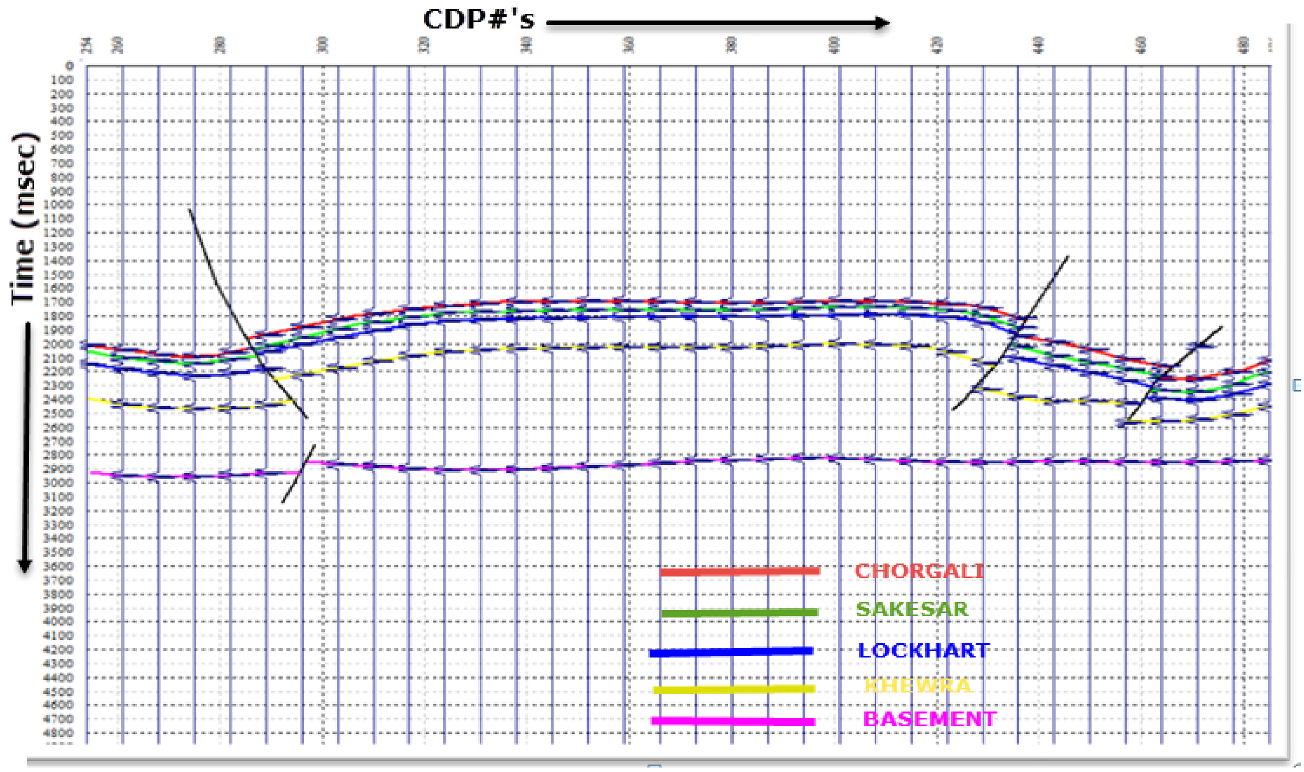

Figure 20. Synthetic Seismic Section using K-Tron X-Works

4. Conclusions

- Interpretation of seismic structural model shows severe thrust faults which confirm the compressional tectonic regime with anticlinal structure in the proposed area.
- Rock properties are calculated, these are helpful to confirm the nature and type of sub-surface material. Porosity and density are used to confirm the reservoir.
- The Iso-velocity contour map shows the vertical and lateral variation in velocity due to compaction of material with the depth of burial as well as lithological changes (both vertically and laterally).

- o Velocities vary latterly as well as vertically. Due to various types of velocities and diverse parameters and usages, this fact must be taken into consideration during processing and interpolation of velocity data. While appropriate smoothening must be applied to acquire true depth sections.
- o Spatio-temporal velocity model with smoothening operators are satisfied and are recommended for time to depth conversion. Unfortunately, this model cannot be used for modeling applications as the structural information is obscure during time-slice interpolation.
- o Horizon interpolated velocity model is vigilant and reliable but its algorithm is very complex. Availability of productive computing power with appropriate software tools, this model can now be studied adeptly and is recommended for time to depth conversions, seismic modeling and Pre-Stack Depth Migration (PSDM).

5. Recommendations

- o Seismic data affirms interpretation as the usage seismic data is of ultimate necessity.
- o Velocity modeling based upon interpolation shouldn't be neglected because it illustrates the lateral and vertical variations.
- o Horizon based velocity interpolation is most productive and must be used as it displays correct results for the time to depth conversion.

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