

VELOCITY ANALYSIS: A PRECURSOR FOR PROSPECT APPRAISAL IN AN ONSHORE NIGER DELTA BASIN, NIGERIA

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ABSTRACT

Velocity model analysis and its implication for prospect appraisal in an Onshore Niger Delta basin has been attempted. The objectives of the study are to resolve issues related to velocity slowness or reversibility that contributes to obscured and dim events challenges. Also, to create an improved subsurface seismic resolution signal for prospect velocity model building and amplitude variation with offset analysis. 3D raw pre-stack seismic gathers were used for the analysis. Coherent noise and other associated noise was attenuated using filtering technique. Normal move out procedure was obtained with the accurate picked primary velocities, after picking the velocity values on the semblance panel. Also, Dix velocity relation was implemented by transforming the root mean square to interval velocity models. The principle adopted for velocity analysis is to find the velocity that flattens primary reflections for a favourable imaging executed on common-mid-point gather. The study result shows localized anomalies and abnormal trends of interval velocity regression due to probable coherent noise (inter-bed multiples) and other associated noise presence. Comparison of velocity model after subjecting the seismic gather to filtering procedures revealed a robust model that supports velocity increase with depth. Hence, the effect of coherent noise (inter-bed multiples) must be accounted for in the seismic processing sequence for a quantitative interpretation, in order to optimize hydrocarbon enhanced recovery in Onshore Niger Delta.

Keywords: Onshore, Velocity model, Prospect, Appraisal.

INTRODUCTION

Velocity approximation of the subsurface models is imperative in determining the existing horizontal reflections and refractors location, depth and its dip. Also the consideration of the velocity models can highlight if the velocity anomalies existed, thereby contributing in delineation of lithology, fluids and rock types (Ivan, 1988; Sheriff and Geldart, 1995; Emujakporue and Nwosu, 2017). Velocity models from the subsurface can be achieved through the use of sonic logs, well velocity surveys, as well as subsurface reflections from normal moveout (NMO) correction procedure (Ivan, 1988). This seismic velocity model appraisal or evaluation is important in seismology studies because of its contribution in the interpretation and processing of seismic signal data (Ivan, 1988; Emujakporue and Nwosu, 2017). There is possibility of seismic velocity signal changing laterally or vertically, the compaction or overburden of rock types within the layers gave rise to lateral velocity variation (Ivan, 1988). This compaction or overburden with depth contributes to the velocity increase with depth. For the case of horizontal variation, the velocity change can be due to effect of dip, faulting systems and changes or variations within the subsurface sequence (Telford et al., 1976;

Ivan, 1988; Coffen, 1984; Emujakporue and Nwosu, 2017). Stacking, migration and depth conversion procedures in hydrocarbon exploration can only be achieved through subsurface velocity modeling analysis (Ivan, 1988; Al-Chalabi, 1997b; Al-Chalabi, 2001; Ravve and Omatsola, 1990).

According to Azuoko (2016), processing of 3D seismic data from an Onshore Niger Delta basin has lead an emphasis on velocity values that flattens or straightens the full gathers during normal moveout correction processes (Ivan, 1988). While the events that were not flatten from low velocity values during the normal moveout (NMO) correction were regarded as noise and was subsequently cut off from the seismic gather. Seismic imaging from 3D seismic data in an Onshore Niger Delta has been obscured beyond travel time of value of three (3) seconds.

The velocity values of the obscured events are lower in values compared to the events above three (3) seconds travel time from the velocity analysis (Ivan, 1988; Azuoko, 2016b). Anisotropy, overpressure or inter-bed multiples are considered to be the likely cause of the obscured events (Ivan, 1988; Aikulola *et al.*, 2010; Oni

et al., 2011). For hydrocarbon enhancement in an Onshore Niger Delta basin of deeper prospects, Azuoko (2016b) studied how velocities and its impact play a vital role for prospect assessment (Ibe and Oyewole, 2018). The worker used 6 km cable length, single deep hole; in order to image deeper reflection signal. By adopting standard data preparation and enhancement procedures from static or time lag corrections to coherent noise attenuation, this will ensure an improved signal to noise ratio (Azuoko, 2016b). Velocity values from semblance was picked manually using a tool that supports the estimation from velocity analysis of common image gathers and subsequently present or demonstrate the graph as the two way time of root mean square changes (Yilmaz and Chambers, 1984). The peak power spectrum was identified on the semblance plot as the primary reflection and hyperbolic moveout events (Zeng, 2006). Interval velocity model can be obtained through the transformation of root mean square (RMS) velocity values, which is the input parameter for prestack depth migration (Dutta, 2002; Azuoko, 2016b). Sonic log can deduce direct measurement of the velocity values as a function of depth while seismic data, provides an indirect measurement or wide coverage of the field velocity with respect to time (Yilmaz, 2001). Based on this information, the processor derives a large number of different types of velocities which include interval, apparent, average, root mean square (RMS), phase, group, normal moveout (NMO), stacking and migration velocities (Yilmaz, 2001). The rock velocity values of lithology and porosity can be affected by geopressure, and this category of pressure arises from the overburden of the surface and also increases with depth.

It is generally true that velocity probably increases with depth (Miller *et al.*, 2002). But due to the factors such as pore pressure, multiples etc, there might be velocity inversion or reversal within the layer (Yilmaz, 2001; Ibe, 2017). Velocity estimation requires the data recorded at non-zero offsets to be provided by common-mid-point (CMP) recording (Al-Chalabi, 1973; Ivan, 1988). Travel time as a function of offset for a series of a horizontal layer is approximated by a hyperbola. For small offsets, the normal moveout velocity for a horizontally layered model is equal to the root mean square (RMS) velocity through the layer boundary under consideration (Bevc, 1997; Yilmaz, 2001). In practice, as long as dips are gentle and the spread is less than the reflector depth; the hyperbolic assumption can still hold. Zero offset time and stacking velocity for a given reflector can be estimated from the line that best fits the travel time picks since it can be plotted on the time offset (t-x) plane (Thore and Kelly, 1992; Yilmaz, 2001). Another form of the normal moveout (NMO) velocity estimation is to

apply different NMO corrections to a common-mid-point (CMP) gather, using a range of constant velocity values, and then displays them side by side (Yilmaz, 2001). The velocity that best flattens each event as a function of offset is picked as its normal moveout (NMO) velocity (Yilmaz, 2001).

Alternatively, a small portion of a line can be stacked with a range of constant velocity values, these constant velocity stacks can be plotted on panel form (Claerbout, 1978, Yilmaz, 2001). Stacking velocities that yield the desired stack can then be picked from the constant velocity stack (CVS) panel (Yilmaz, 2001). The regularization of velocity analysis procedure can also be based on computation of velocity spectrum (Taner *et al.*, 1998; Yilmaz, 2001). The aim is to display some measures of signal coherency on a graph of velocity against two-way zero offset time. The fundamental value is to compute the coherency of signals on the common-mid-point (CMP) gather within small time gates that follows a trajectory offset (Yilmaz, 2001; Castelino, 2012).

Claerbout (1978), proposed another method of determining interval velocities manually from a common-mid-point (CMP) gathers. The basic idea is to measure the slope along a slanted path that is tangential to both the top and bottom reflections on the interval of interest. The method of constant velocity scans of common-mid-point (CMP) gather is an alternative technique for velocity analysis. Accuracy in velocity picking depends on cable length, the two-way zero offset time associated with the reflection event and the velocity itself. Migration, stacking and multiples suppression are seismic processing stages that require subsurface velocity model. The signal travel path depends on the subsurface reflection arrival time from a single event (Ivan, 1998; Castelino, 2012). Subsurface velocity estimation is an important tool used in velocity analysis that is based on the reflection moveout. The interval parameter of the individual reflectors can be estimated in order to ascertain its properties, since the travel time and normal moveout (NMO) velocity were affected as it moves along the reflected wave ray path (Ivan, 1988; Pawan, 2006). Parameters such as interval velocity and thickness of the subsurface layers can be obtained either by layer stripping or through tomographic methods that were needed for both pre-stack and post-stack migrations (Dix, 1955; Zeng, 2006).

GEOLOGY OF THE STUDY LOCATION

The study area is within the latitudes $4^{\circ}7'0''N$ and longitudes $3^{\circ}9'0''E$ located on the Eastern part of the Onshore Niger delta (Fig.1). This forms a three -way

arrangement within the Cretaceous duration of the continental disintegration (Short and Stauble, 1967;

Ajewole and Enikanselu, 2014; Ibe and Oyewole, 2018).



Figure 1: Base map of the study location (source: Google map, 2016)

Niger Delta is the largest Delta in Africa with a sub-aerial exposure of about 75,000 km² and a clastic fill of about 9,000 m to 12,000 m and terminates at different intervals by transgressive sequence. Southern Nigeria and Southwestern Cameroon geology represents the onshore Niger Delta basin (Short and Stauble, 1967; Opara, 2010). The basement of West African massif along the south trending line of the northern boundary is the Benin flank. This boundary is the Benin flank and its boundary can be identified through the Cretaceous outcrop of the Abakaliki high and Calabar flank adjacent to the Precambrian hingeline (Michele *et al.*, 1999). Ridges and trenches of deep Atlantic are controlled by fractures of Cretaceous zones along the equatorial Africa of the West coast. This is known as the continental margin tectonic frame work. The margins are divided by the fracture zones into basins (Tuttle *et al.*, Lehnert and De Ruiter, 1977).

The main deformational process came through gravity tectonism after the stoppage of rifling mechanism (Kulke, 1995; Michele *et al.*, 1999). According to Kulke, 1995; two process was triggered through an induced interval deformation of shale mobility. They are: firstly, the diapirs of shale that was established through the compaction of poorly loading clays, overpressured, delta slope and prodelta. This is known as Akata Formation. Secondly, shale diapirs that were established by delta front sands of higher density. This Formation is known as Agbada. The deposition of Benin

Formation was after the completion of the gravity tectonics, this can be defined as complex structures such as rollover anticlines, and collapsed growth fault crests steeply dipping back to back features (Evamy *et al.*, 1978; Xiao and Suppe, 1992). Petroleum source rock in Niger Delta basin has been discussed by numerous workers (Evamy *et al.*, 1978; Ekweozor *et al.*, 1979; Ekweozor and Okoye, 1980; Lambert-Aikhionbare and Ibe, 1990; Michele *et al.*, 1999; Opara, 2010). The presumed better source rock in Agbada Formation has estimated intervals that contain organic carbon rich content (Ekweozor and Okoye, 1980; Nwachukwu and Chukwura, 1986; Opara, 2010). Evamy *et al.*, 1978 and Stacher, 1995 stated that the interval and thickness of Agbada Formation is insufficient and immature to contain world class producing province system. The Akata shale that is under the Agbada is large enough to generate high yield class oil (Michele *et al.*, 1999). The source rock for Niger Delta basin are the marine shale of Akata Formation and the interbedded shale with paralic sandstone of Agbada Formation, based on the type of organic matter content (Evamy *et al.*, 1978; Edwin *et al.*, 2018).

MATERIALS AND METHOD

The data used for this study is a raw seismic data acquired from Niger Delta basin. The recorded data were stored in a raw format and have to be processed before interpretation. However, some parts were previously processed through de-multiplexing and

sorted according to common-depth-point gathers (CDP). Different kinds of mute functions were realistic during top or bottom and surgical mutes procedure. To scale with the time variant scaling command, a mute function that was defined in mute flow can be use to minimize the direct wave arrivals (www.software.slb.com/products/vista). The essence was to define a set of time windows, since the size of the window normally increased with time due to the data frequency losses from absorption (www.software.slb.com/products/vista).

The raw dataset were used as an input gather with the common-mid-point bin selection spread sheet that was set up for a 3D common-mid-points centered bins. This procedure does not require all the dataset and the three generated datasets was highlighted before been exposed to the velocity picking window. The proper icon in the tool was used in picking the velocity points as it moves over the semblance velocity. Constant velocity stack was performed by taking the entire input dataset in the specified sort order, thereby applying normal moveout and common-mid-point stack procedure (www.software.slb.com/products/vista).

Normal moveout was performed with the first velocity picked from the function list and it is consistent throughout the entire trace length. The generated semblance of the entire input traces at each sample position across the defined hyperbola was estimated through the semblance function calculation algorithm (www.software.slb.com/products/vista).

Each output samples are traces with semblance function values at a given period and it is normally set at a common offset stacked traces. The velocities picked in the semblance panel will indicate the points on the constant velocity stack display. Normal moveout procedure was obtained with the accurate primary velocities picked (www.software.slb.com/products/vista). Also Dix velocity relation was implemented by transforming the root mean square to interval velocity models. The principle adopted for velocity analysis is to find the velocity that flattens primary reflections for a favourable imaging executed on common-mid-point gather. To reposition the events to its accurate or actual subsurface positions, migration analysis was adopted (www.software.slb.com/products/vista). A full volume kirchhoff migration algorithm was implemented in this study. The input gather contains root mean square and interval velocity values at various common-mid-point along the possible line. Rephrase filter process was applied in order to correct for the phase change that will be caused due to migration procedure (www.software.slb.com/products/vista).

RESULTS AND DISCUSSION

The data is from a raw seismic data land survey area that was sampled at 2000 μ s, the raw field shot gather of the field data reviews both coherent and other associated noise events (Figure 2 and Figure 3). Brute stack and linear moveout correction was initially generated to evaluate and also quality control the overall data features, in order to validate the acquisition geometry coordinates. This reveals the continuity of the subsurface reflection returns with linear moveout showing good flat horizontal line of better recording geometry position (Figure 4). Before the application of the refraction statics, the regression on the first break picks indicates abnormal trends, which proves the existence of seismic time lag or variations. The direct and refraction events observed from the records were removed, since they are linear in nature using muting procedure. It is mostly experienced from above 2000 ms time on the raw seismic gathers (Figure 5). From the velocity model; by principle, velocity supposed to increase with depth due to subsurface compaction or overburden, but this is not the case in our study location. It was also necessary to obtain the most accurate velocity model from seismic data that is needed for a better stacked model interpretation, migration model and predrill geopressure predictions. Figure 6, shows several velocity analysis calculated from a common-mid-point gather before coherent noise and other associated noise attenuation attempt, the velocity semblance trajectory trend pattern was difficult to follow due to the presence of probable coherent events. The possible presence of coherent events tends to reduce the magnitude of the picked velocities during velocity analysis procedure. The generated root mean square velocity model exposes localized velocity anomalies with high subsurface reflector. To prove and validate the presence of coherent noise as a possible cause of abnormal velocity model within the study location, an interval velocity approximation was obtained and demonstrated using Dix relation. This interval velocity regression shows an abnormal increase in trend pattern or velocity reversal at 3.5 s to 4 s, which is attributed to be as a result of localized velocity anomaly arises from a poorly picked velocity trajectory that is unclear in semblance flow pattern, due to possible coherent noise occurrence that aid in increasing the events amplitude with depth (Figure 7). After subjecting the raw seismic gathers to various filtering processes, it was revealed that the abnormal trend in interval velocity pattern was as a result of probable coherent noise presence. From Figure 8, we noticed a better defined velocity trajectory on semblance that will enhance the primary velocity picks after the attenuation of coherent and other associated noise from the velocity analysis plot of common-mid-point gathers. The interval velocity and root mean

square velocity model shows a smooth regression with a probable geopressure regime prediction. The velocity spectra comparison after the coherent noise attenuation shows a better and distinct pattern for primary velocity picking contrary to the spectrum before attenuation (Figure 9).

In order to generate the subsurface image structures within the earth, migration was carried out to reposition the reflection events to its appropriate locations. These has been a recognized seismic imaging device, since its generated images are always reliable with defined geological configuration results and as well as estimating the depths with acceptable precision. Figure 10, shows Kirchhoff prestack depth migration before and after the coherent noise attenuation with chaotic gather quality or responses. Also after the attenuation of coherent noise and other associated noise, the migration model shows better subsurface image quality and geological structures (Figure 11). After the application of the filter, events increase with offset was identified; this could be migration smiles or frowns. This lead to several velocity analysis procedures, in order to ascertain the true cause of the anomaly. It was concluded that coherent noise and other associated noise was the probable cause of this anomaly, since it contributed to erroneous velocity model needed as input

for the migration procedure.

CONCLUSION

This study validates the successes of the processing approach through the use of actual raw dataset and also described how to effectively obtain a robust velocity model. The analysis of the velocity models has enabled us to evaluate migration models obtained. It was revealed that the input seismic gather produces an improved migration model after several velocity analysis procedures. The enhanced migration model obtained can be interpreted with respect to probable hydrocarbon accumulation and also used for a robust subsurface image for amplitude variation with offset analysis.

ACKNOWLEDGEMENT

We sincerely thank SPDC Port Harcourt Division for the provision of datasets. VISTA and PROMAX for the provision of Geophysical seismic processing software academic license. The authors are also grateful to Mr. Olaleye Oluwaseun of CNPC Port Harcourt, for his technical contributions and promax results generation.

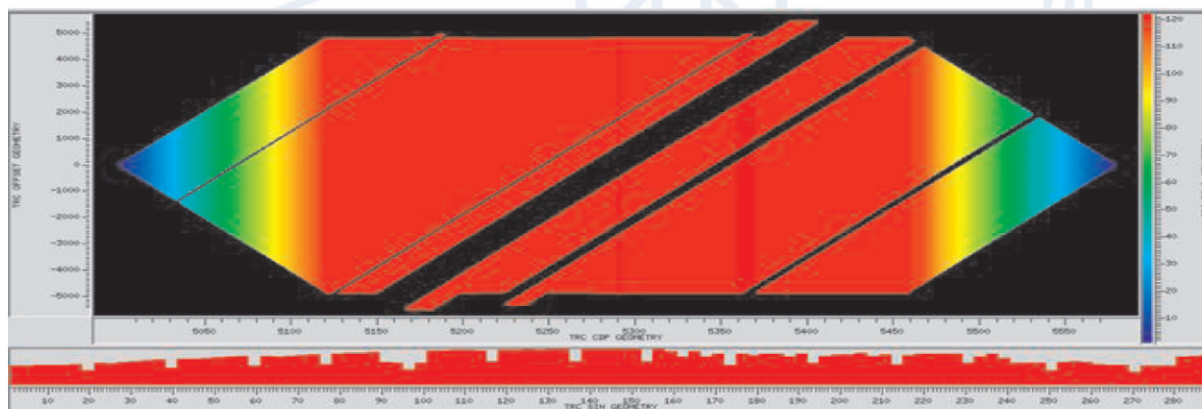


Figure 2: Acquisition map

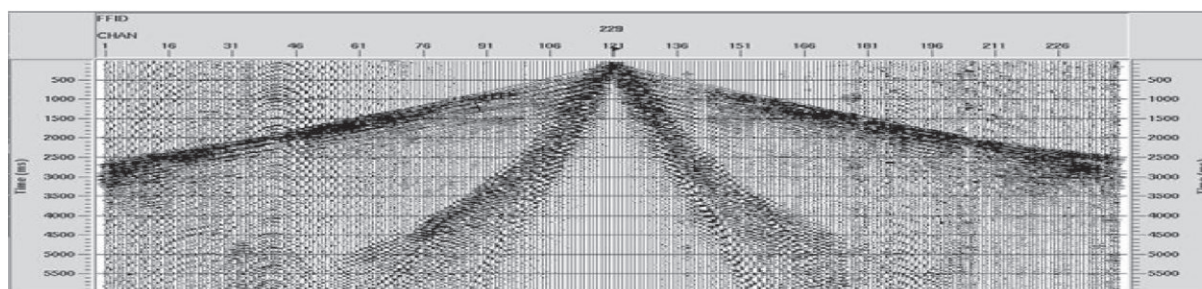


Figure 3: Raw seismic data showing coherent noise

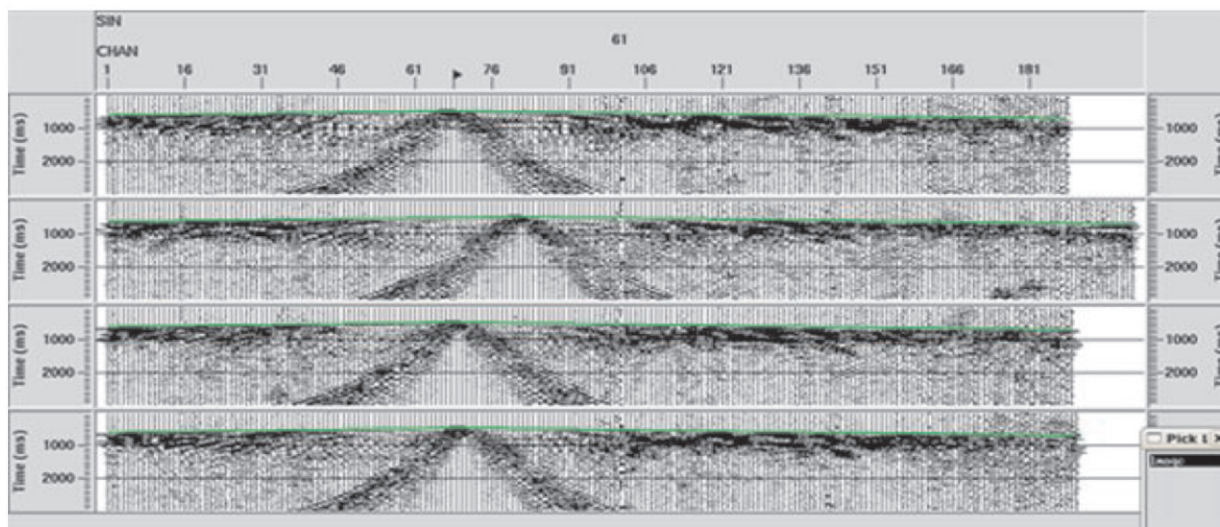


Figure 4: After linear moveout correction

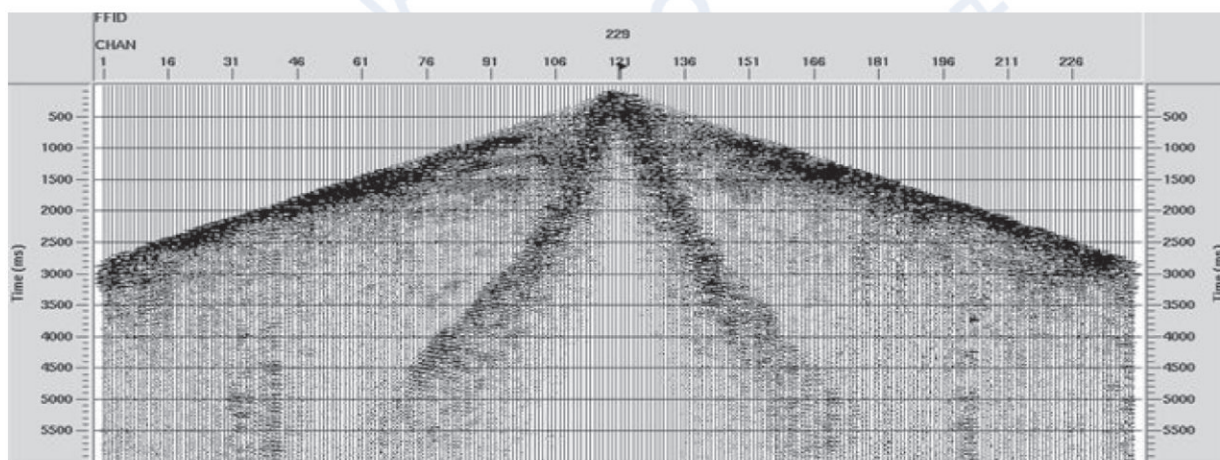


Figure 5: Raw seismic gathers free from coherent noise

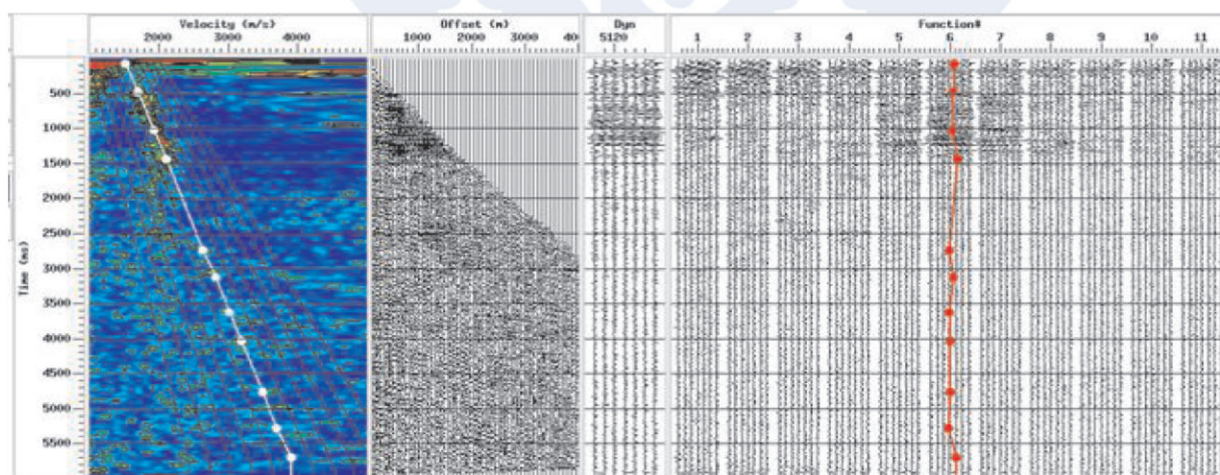


Figure 6: Velocity semblance before coherent noise attenuation

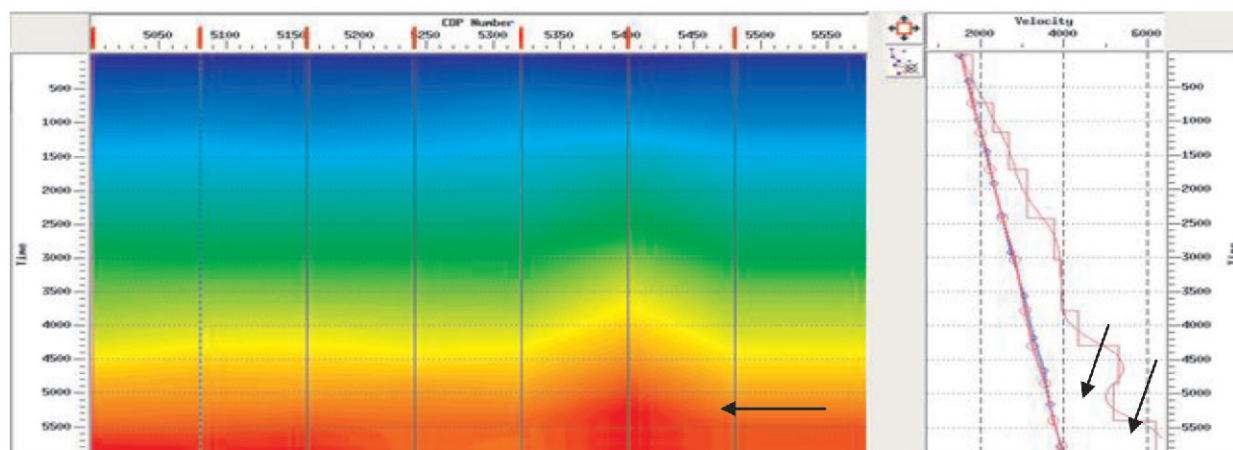


Figure 7: Interval velocity model before coherent noise attenuation

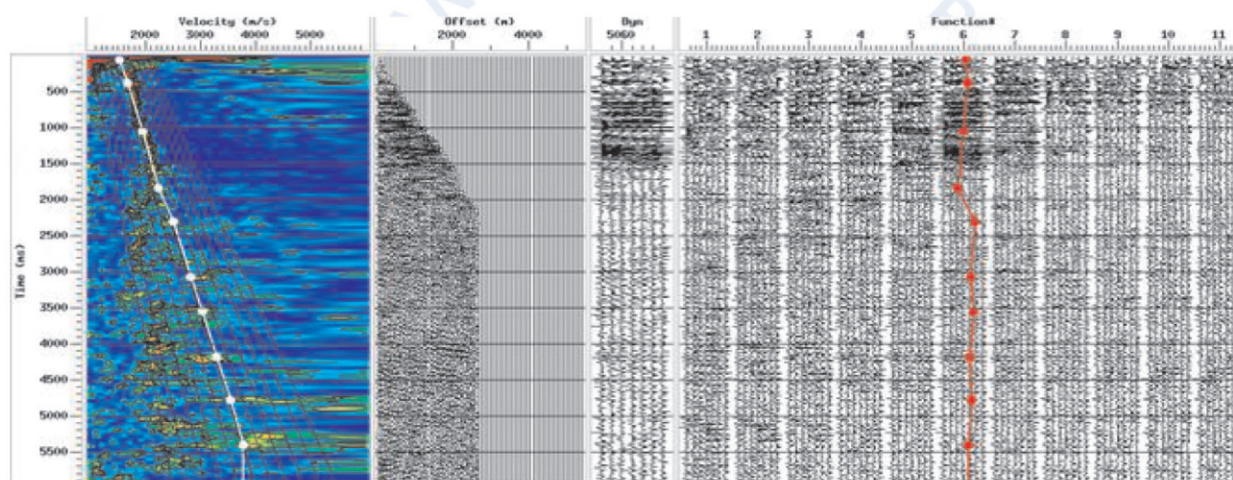


Figure 8: Velocity semblance after coherent noise attenuation

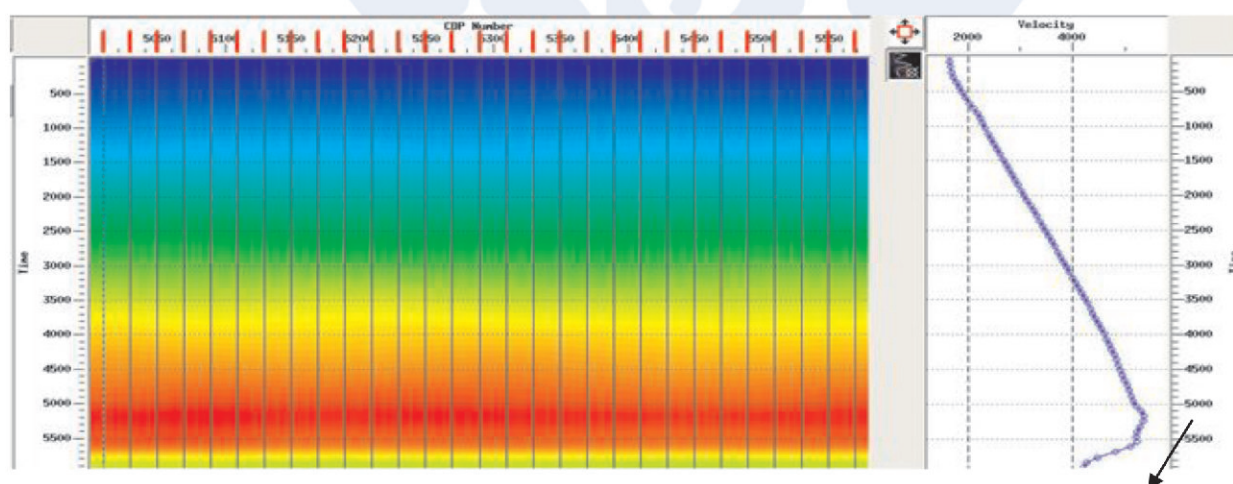


Figure 9: Interval velocity model after coherent noise attenuation

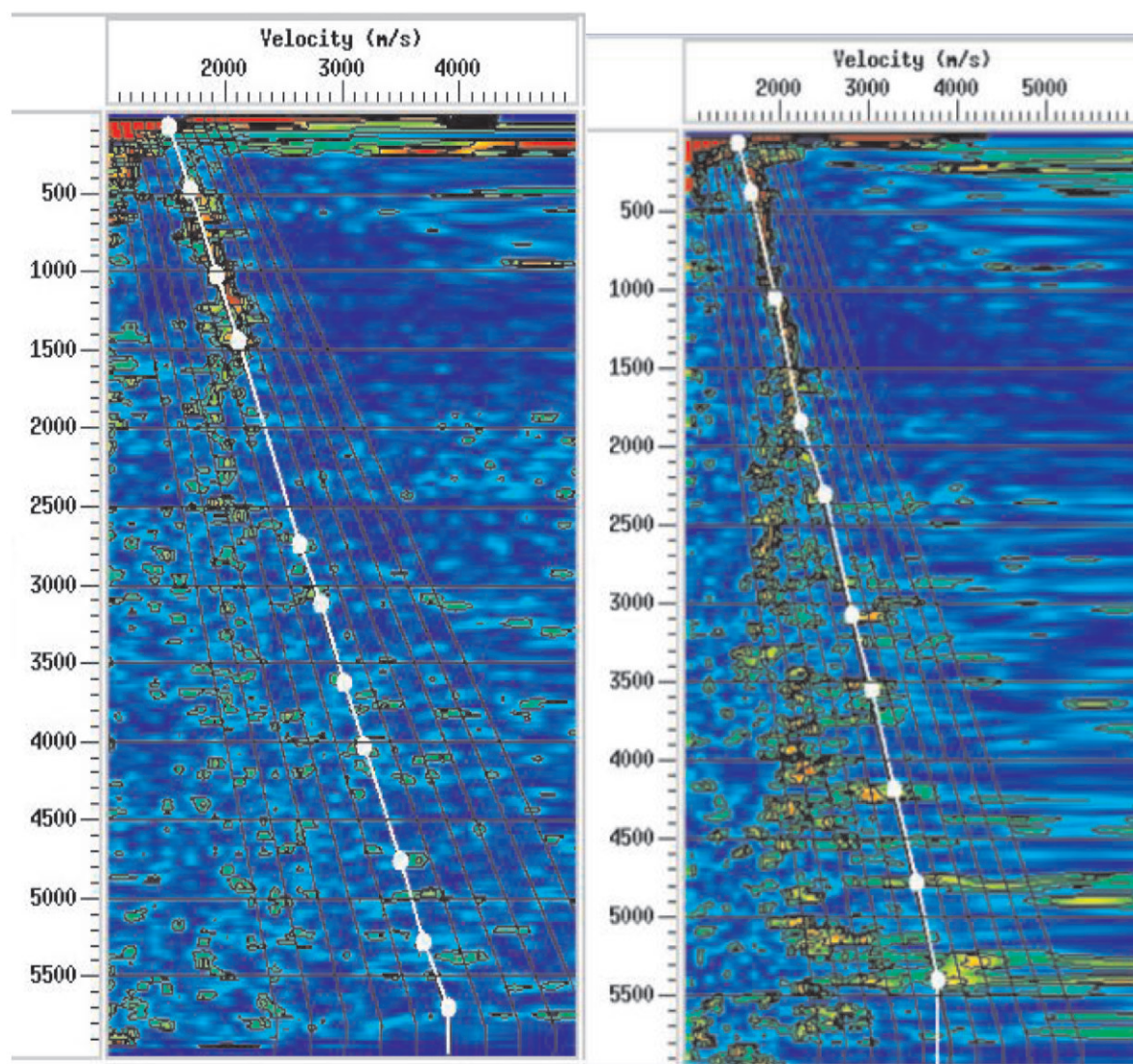


Figure 9: Velocity spectra before and after coherent noise attenuation

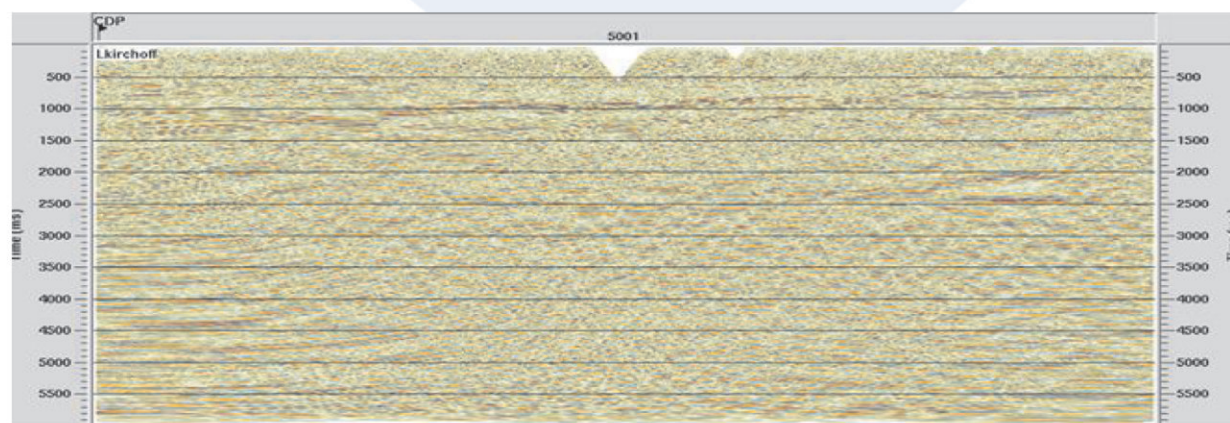


Figure 10a: Kirchhoff migration model after first velocity analysis

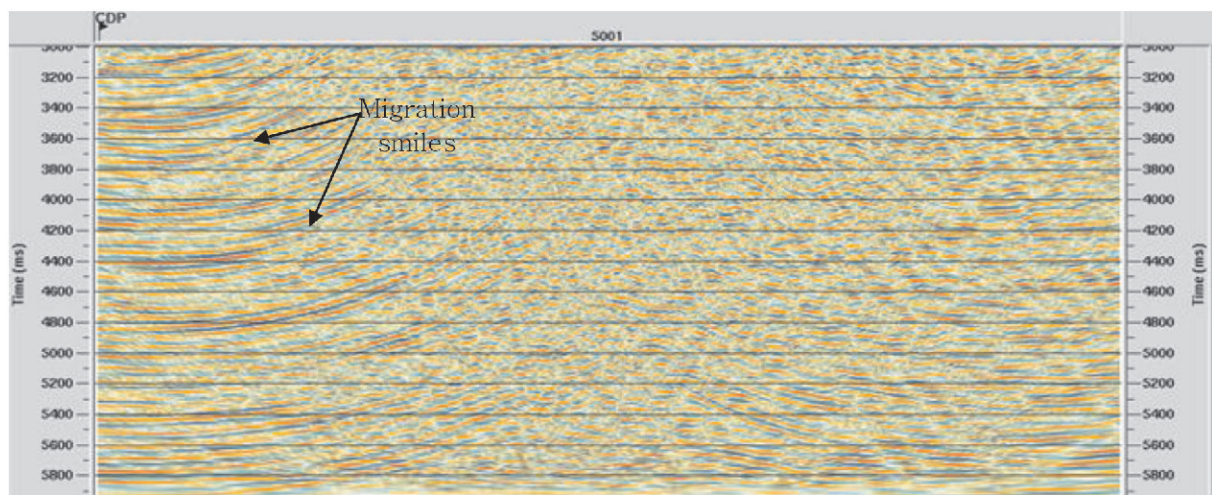


Figure 10b: Kirchhoff migration model after first velocity analysis

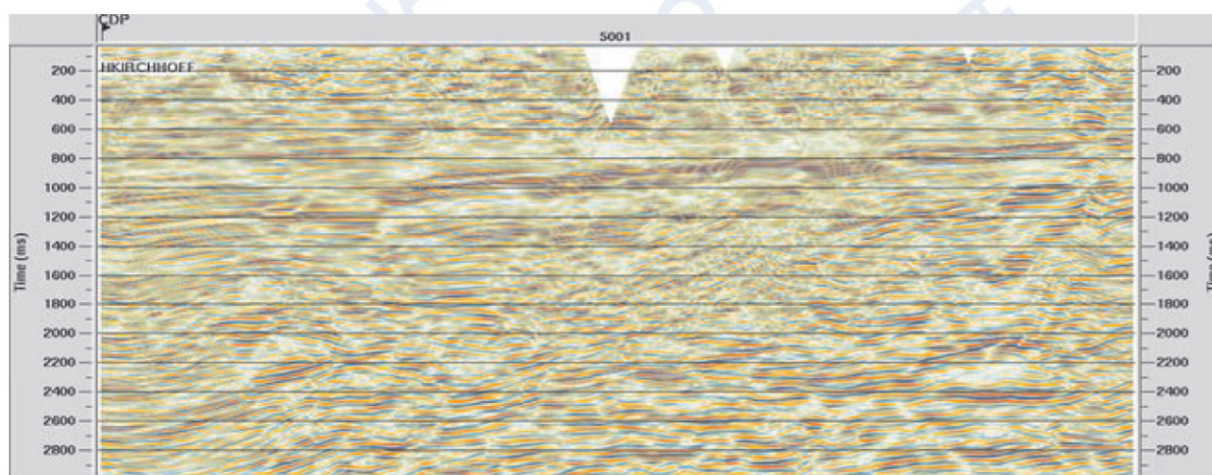


Figure 11: Kirchhoff migration model after second velocity analysis

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