



# Study of inter-bed multiples in an onshore Niger Delta field

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## Abstract

This study presents the existence of inter-bed multiples in an Onshore Niger Delta field. Multiples interfere with primary reflections in a manner that results in, among other factors, poor velocity model building, unclear seismic images of the subsurface, and definition of geological features that finally lead to pitfalls in interpretation. Analysis of the velocity model revealed localized anomalies and abnormal trends in the interval velocity regression due to possible multiples effects. Confirmation of existence of inter-bed multiples was established and the parabolic Radon transform algorithm attenuation technique was implemented on a seismic dataset acquired from onshore Niger Delta field in a bid to suppress multiples' presence. The events experience slower velocity and low amplitudes due to energy dissipation along the propagation paths and the separated artifact. The effectiveness of parabolic Radon transform algorithm in suppressing multiples was verified by comparing the migration models obtained before and after the application of the algorithm; which shows improved image values and clarity of plays that can be characterized in terms of amplitude variation with offset studies for optimal prospect identification and appraisal, enhanced oil recovery, and reservoir management.

**Keywords** Multiples · Suppression · Onshore · Parabolic Radon transform · Prospect appraisal · Niger Delta

## Introduction

The Niger Delta basin is located geologically on the extensional rift that is characterized by rollover anticlines, shale diapirs, growth faults; which can be known as structural and stratigraphic complexities (Azuoko 2016; Haack et al. 2000). This forms a three-way arrangement within the Cretaceous duration of the continental disintegration (Ajewole and Enikanselu 2014).

Recently, there is distortion and non-continuity of stratigraphic events experienced at a two-way travel time of 3 s from seismic data acquired from the onshore Niger Delta field. Well placement has become difficult due to the existence of

multiples effects that gave rise to fault shadow phenomenon (Azuoko et al. 2017; Kanu et al. 2014). The existence of inter-bed multiple reflections in raw seismic gather has been one of the main issues in the seismic processing sequence; they repeatedly obscure and interfere with the signal of importance. Elimination of these multiple events remains the key challenge that must be resolved, before the accomplishment of a reliable or true subsurface interpretation from seismic data (Alvarez and Lerner 2004). Seismic data lines acquired from either onshore or offshore settings contain multiples reflection events. However, land multiples reflections lack the periodicity characteristics associated with the marine environment. Hence, these contribute to the difficulty that is experienced with the identification and possible attenuation of onshore multiple reflections (Hampson 1986).

Multiple reflections are thought to be either surface (mostly long period) or internal (mostly short period) generated. Long-period multiples are produced at or near the surface of the earth; these include those generated at the top of the water column for marine data and the weathered layer generation for land data. The short-period multiples are generated within the layers bounded by high acoustic importance contrasts (Alvarez 1995; Ebeniro 1993).

Regular processing procedures like convolution and predictive deconvolution are always used to eliminate some

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unwanted signals. Other events like multiple reflection events require specified techniques and practices that are explicit to the geological environment (Castelino 2012). Inter-bed multiples are the seismic waves that propagate at least more than one bounce on subsurface before being detected by the receiver. They mostly obscure the signals of interest; these complications not only occur in marine settings, but also in onshore locations (Weglein 1999). The amplitude spectrum is very significant for seismic data processing and interpretations (Naseer and Asim 2017b; Naseer and Asim 2018a; Naseer and Asim, 2018b; Naseer and Asim 2018c; Naseer and Asim 2017a; Tayyab et al. 2017; Tayyab and Asim 2017).

Moore (2001) suggested modeling and subtraction using the primary reflections in the data themselves, a technique similar to surface multiple attenuation as a robust approach to inter-bed multiples attenuation. They predicted a future reliance on this method, when alternative algorithms fail. Ogagarue and Nwankwo (2019) examined the possibility of removing free surface multiples reflections in the Niger Delta basin, by adopting 3D surface related multiple elimination technique. They established that 3D SRME method can only attenuate surface related multiple reflection events that can be consistent with seismic amplitude gather, and suggested the use of stratigraphic analysis algorithm in subsurface geological interpretation.

Azuoko et al. (2017) in a velocity-analysis based study of the cause of the distortions in the fault shadow zone, beyond 3 s in 3D seismic data from onshore Niger Delta, established the existence of inter-bed multiples reflection events in the study area, identifying the Agbada Formation as the possible multiple generator in the area. They observed that reflection distortions and misalignment of events were actually due to the presence of multiples reflections, especially beyond 3 s. Due to the periodicity characteristic observed in inter-bed multiple events in 3D seismic data from onshore environment, velocity analysis procedure was suggested as a robust separation technique for the events (both primary and multiples reflection), though this does not attenuate the unwanted reflection events.

Pre-stack multiple suppression method improves the primary to multiple amplitude ratio, preserves signal quality on stacked common-mid-point gathers and also improves the seismic data that will be used during amplitude variation with offset (AVO) analysis (Gabriel and Ken 2004). Proper prediction of multiples in an onshore seismic data can also be affected by statics and several noise issues. Coherency, periodicity, and velocity discrimination are different multiples properties that can be used during attenuation (Li and Lu 2014). Tau-p Radon transform introduction improves the quality of event separations in the common-mid-point gather (Hampson 1986). This study re-affirms the observation by Azuoko et al. (2017) that inter-bed multiples reflection events exist in 3D seismic data sets from onshore Niger Delta, Nigeria, and presents the Parabolic Radon transform algorithm as a robust tool for the attenuation of multiples reflection events in 3D

seismic data from an onshore environment in the Niger Delta basin.

## Materials and methods

The data used for this study is raw 3D seismic data that was acquired from an onshore location in the Niger Delta basin, Nigeria. All acquisition holes were drilled up to 30 m in order to account for weathered layers and reduce surface waves within the study location, each of them was loaded with seismic energy source, with geophone units used as receivers. The necessary coding for explosives (the safety guidelines for charge detonation), pattern types, geophone and bunched stations were duly specified during the data acquisition, according to the report of the seismic data acquisition team.

From raw field data, linear moveout plots were generated for geometry or position confirmation to correct the shots with the wrong header shots position. Brute stack was generated to appraise general data quality for the verification of correct recording geometry and subsurface reflection returns. Random noise on the acquisition line was due to human activities, mostly resulting in power generating sets, market activities, bicycle and vehicular movements. However, coupling and non-responsive geophones could have resulted in random noise generation (Ahmed et al. 2018) during the data acquisition, and this type of noise (noise train or noise burst) can be eliminated through muting technique. More so, coherent noise such as surface waves or ground rolls could also have generated noise during seismic data acquisition.

They exhibit low frequency, low velocity, high amplitude and dispersive properties and can be removed with f-k or radial trace transform filtering technique (Halliday et al. 2010; Oppert and Brown 2002; Yilmaz 2001). For field processing, the data that was recorded in the SEG-D format was changed to SEG-Y. All survey coordinates of the source and receivers positions on the acquired line were merged with the bin out files to produce a set of geometry for the corresponding set of data. The geometry was merged with the new seismic data traces, the sampling rate of 2 ms was inputted on the seismic data processing tool (Table 1). The data is on the frequency domain, where the frequency increment is derived from the number of times in which the event has been sampled round to power two of the sampling rate ([www.software.slb.com/product/vista](http://www.software.slb.com/product/vista)). The frequency spectrum range of the acquired 3D raw seismic data from the study location was obtained using spectrum analysis. The spectrum established the existence of frequency energy curve with a minimal noise level.

The elevation was calculated and applied to the elevation statics, thereby moving shots and receivers in the time domain to the already defined fixed datum. The essence is to carryout static correction to compensate for topographic differences, in

**Table 1** Acquisition parameter

|                  |            |
|------------------|------------|
| Far offset       | 5421 m     |
| Sample rate      | 2 ms       |
| Recording format | SEGD       |
| Polarity         | SEGY       |
| Recording length | 5.5 s      |
| Group interval   | 50 m       |
| Coverage         | 120-fold   |
| Low cut filter   | 0          |
| High cut filter  | Anti-alias |

**Table 2** Parabolic Radon transform

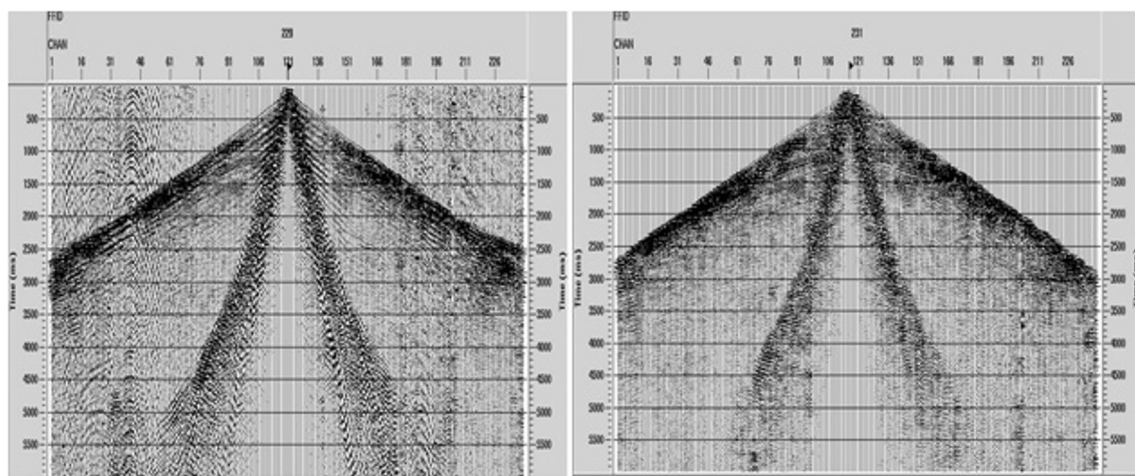
|                   |       |
|-------------------|-------|
| No. of p-values   | 120   |
| Minimum p-values  | -100  |
| Maximum p-values  | 400   |
| P-increment       | 4.20  |
| Minimum time      | 0     |
| Maximum time      | 6000  |
| Minimum frequency | 10    |
| Maximum frequency | 90    |
| Damping           | 0.030 |
| Reference offset  | 5421  |

order to reposition the events to its appropriate datum. This step is very vital in hydrocarbon exploration and production, as it facilitates robust interpretation and ultimate placement of wells. After inputting the appropriate fixed datum that depends on the dataset and replacement velocity (1750 m/s), shot up-hole information, weathering velocity estimate or surface source was picked to estimate the low velocity layer (LVL). This was achieved with refraction seismic data. The first break pick was introduced by studying the trace offset, thereby calculating the theoretical first break time that is equal to offset or linear moveout velocity. Manual and automatic single component picking was performed on several different gathers where refracted and direct time arrival changes significantly. Areas that experienced gaps in offsets and receivers were also sorted out. Due to irregularity in sampling the raw dataset, we selected the ensemble with a significant change in first break times while moving from one ensemble to another. After picking the first break times at the selected ensembles usually on z-component, the recognized picked ensembles were repeated using automatic parameter adjustment at each of the ensembles ([www.software.slb.com/product/vista](http://www.software.slb.com/product/vista)). Coherent and other associated noise events were eliminated

with a radial trace transform model, these operate by mapping the events from offset time to velocity time domain.

According to Henley (1999), the two way travel time TWT and offset coordinates of seismic trace amplitude, can be mapped using radial trace transform algorithm. We dramatically lowered the velocities of linear events by remapping seismic data into the radial trace domain, while a reflection event that does not share similar velocity and origin within the radial trace domain will be unaffected (Fig. 1). Velocity analysis was introduced by picking the accurate primary velocities it was prepared for normal moveout analysis. The output data for normal moveout (NMO) velocities are characterized by x-y coordinates of the common-mid-point, where the velocity analysis was performed and subsequently picked. Once the computed velocity was achieved, root means square velocities were derived at each sample trace.

The procedure then uses the standard NMO equation to calculate for each output sample ([www.software.slb.com/products/vista](http://www.software.slb.com/products/vista)). For the case of the interval velocity model, Dix relation was adopted by transforming the root mean square to interval velocity models. The parabolic Radon

**Fig. 1** Raw seismic gather before and after the application of radial trace transform

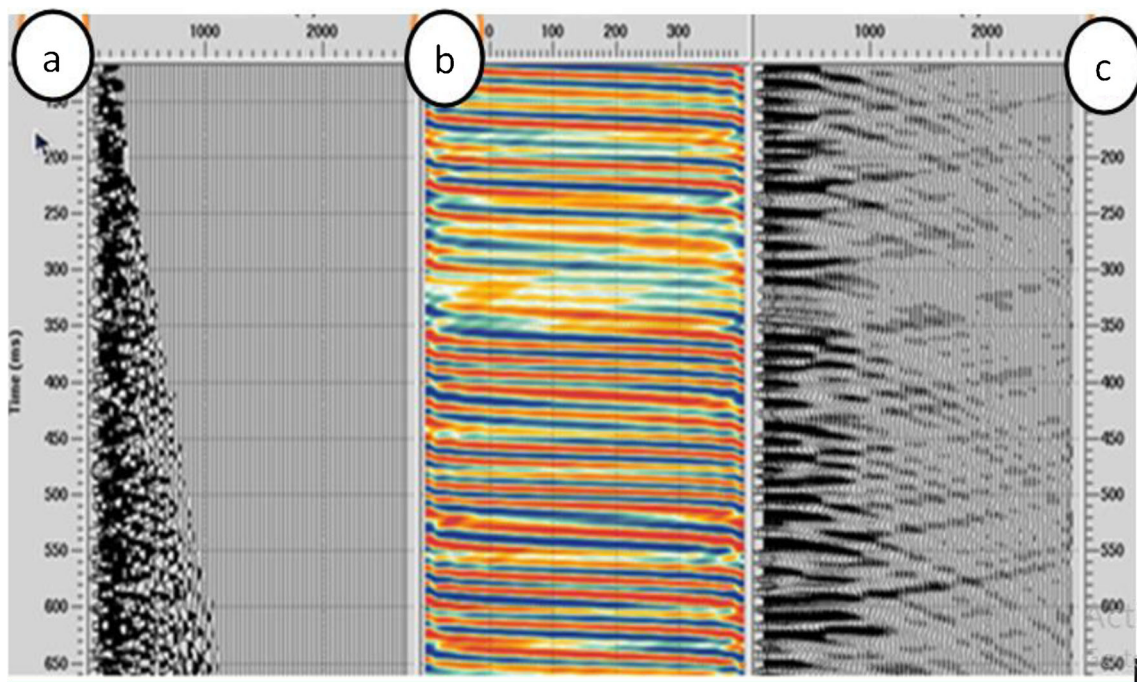


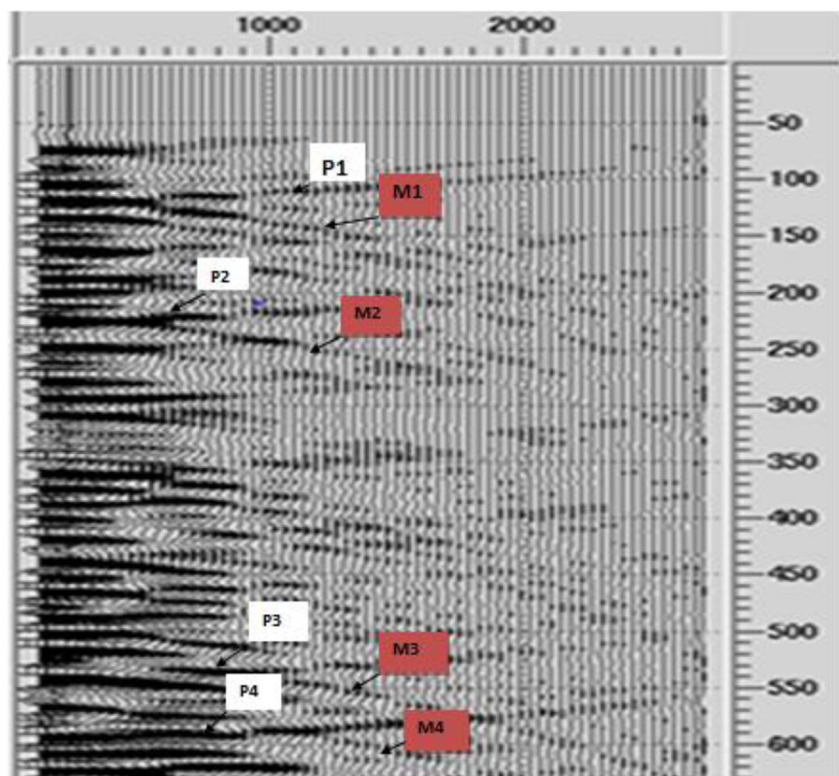
**Fig. 2** Moveout of input gathers

transform algorithm was chosen by specifying the modeling input parameters. These are the mathematical formulation upon which the algorithm was built (Sacchi 1999, 2002). Using the velocity of the primary events to compute the normal moveout correction yields

$$t_p = t_0 \quad (1)$$

The implication of Eq (1) is that the primary events will experience the same time at every offset and the normal moveout velocity is the velocity of the primary reflection.

**Fig. 3** Forward parabolic radon domain



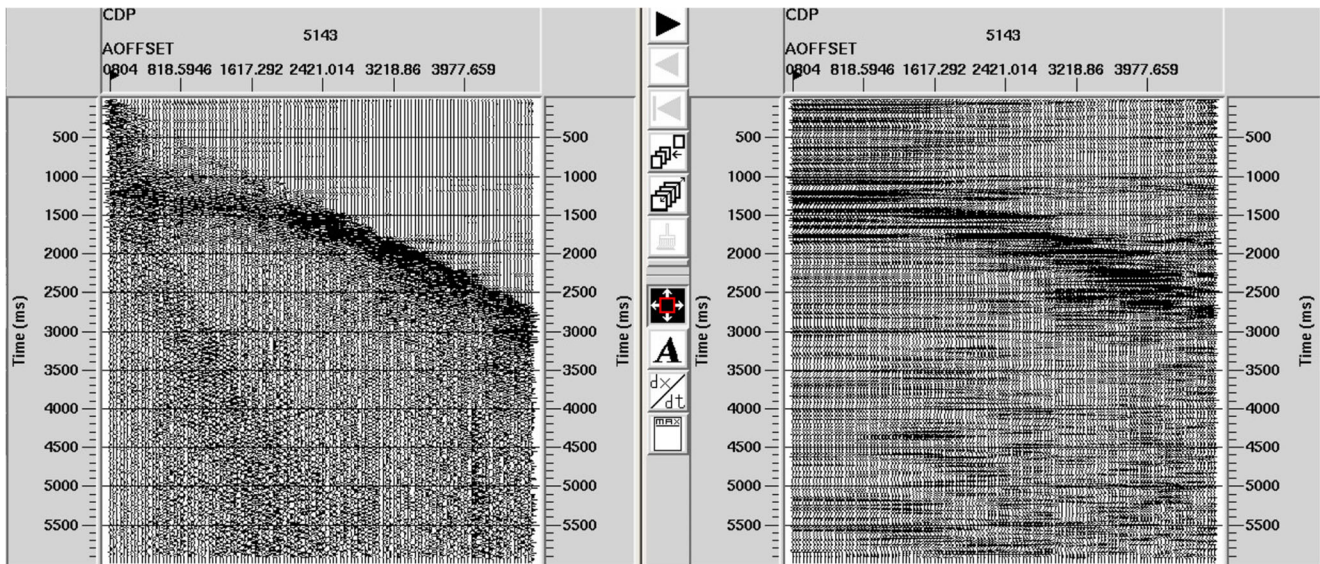


Fig. 4 Comparison of primary signal and filtered events

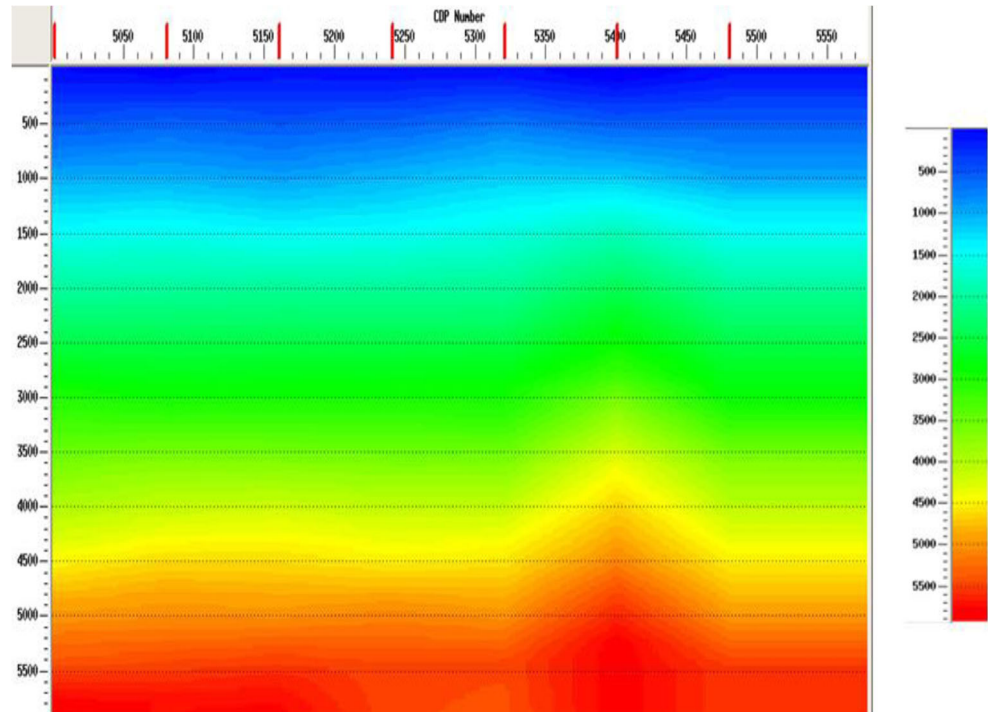
Hence, it will be flattened when subjected to parabolic Radon transform algorithm (Sacchi 2002). For the case of multiples reflection NMO correction yields Eq. (2):

$$t_m = t_0 + \sqrt{t_0^2 + \frac{x^2}{V_m^2}} - \sqrt{t_0^2 + \frac{x^2}{V_n^2}} \quad (2)$$

The residual moveout is given as:

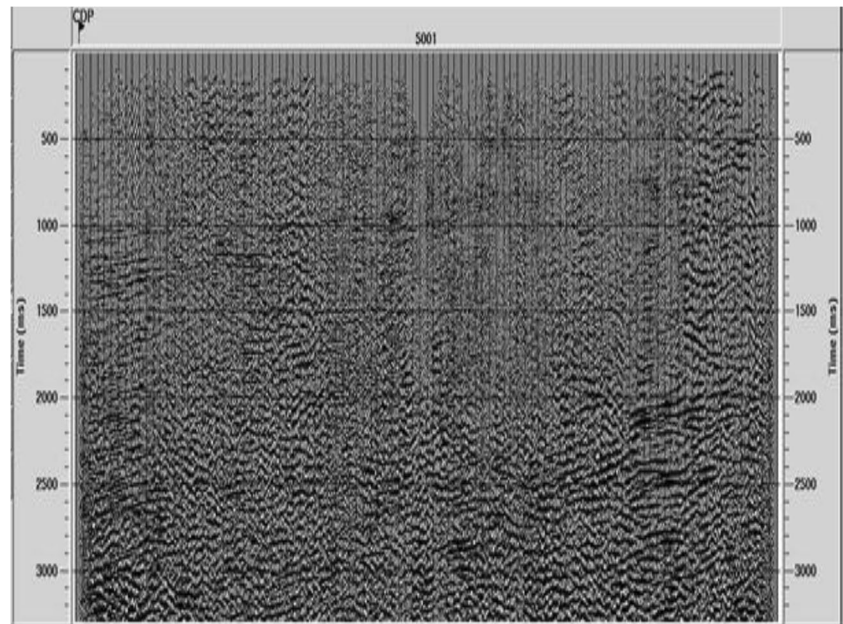
$$q = \frac{1}{2t_0} \left( \frac{1}{V^2} - \frac{1}{V_n^2} \right) \quad (3)$$

Fig. 5 Root mean square velocity model



The input common-mid-point (CMP) gather is a NMO corrected event with primary reflection velocity that is derived from the velocity analysis. The frequency range of possible multiples was determined from the spectrum analysis of the input gathered in the offset time domain. To separate the primary from multiples in the forward parabolic transform domain, the moveout range needs to be determined to choose the maximum and minimum offset reference values.

Fundamental algorithm for Radon de-multiples was established on the postulation that the model is characterized by parabolas of several curvatures which can be focused at

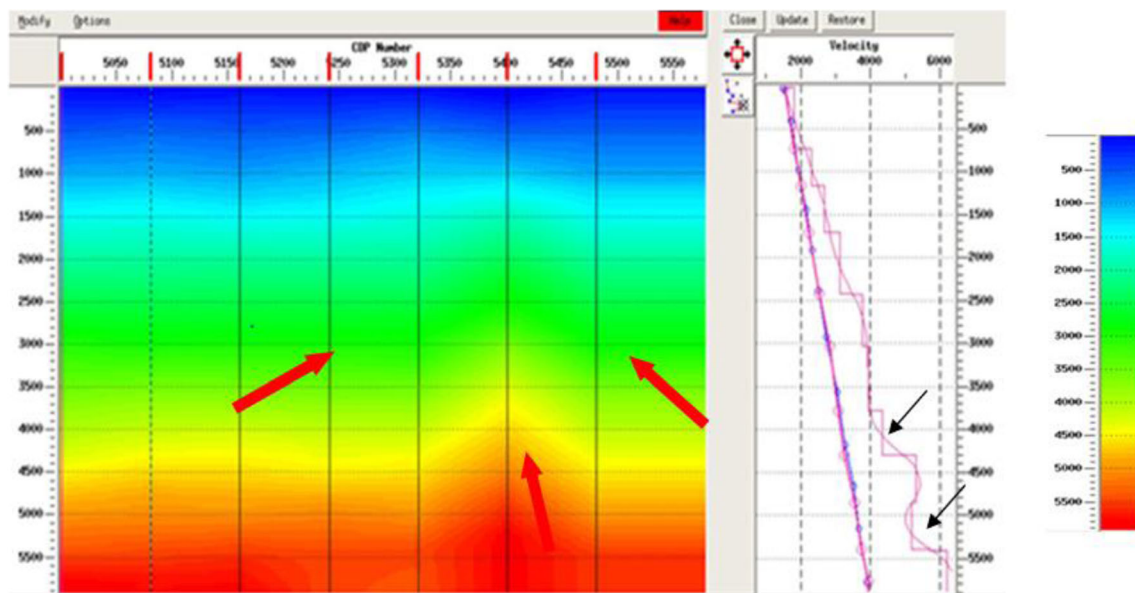
**Fig. 6** Stacked model

zero offsets. The forward parabolic Radon transform outputs an amplitude plot of the model curves (parabolas) against time at zero offset intercepts for sample times (Foster and Mosher 1992). To evaluate the minimum and the maximum value of residual moveout, the near and far values were defined. The maximum moveout time was obtained to be 400 ms and minimum at -100 ms, the negative minimum value of residual moveout was adopted to accommodate the primary reflections that must have been overcorrected during normal velocity analysis. The reference increment was kept at 4.20 to obtain better separation of the two events (Table 2) when the input data decays into the parabolic domain. The modeled forward Radon output ensembles were transformed back to the offset-

time domain by subtracting probable multiple events from the primaries after the application of Radon filter. The gather was high cut filtered to remove the artifacts that might be introduced during the reverse or inverse parabolic transform. The algorithm was verified by comparing the migration models before and after the application of the algorithm.

## Results and discussion

The raw shot gathers of the field data reveal ground roll with other associated coherent noise, primary and multiples that cannot be distinguished due to comparable offset interval

**Fig. 7** Interval velocity model before the algorithm application

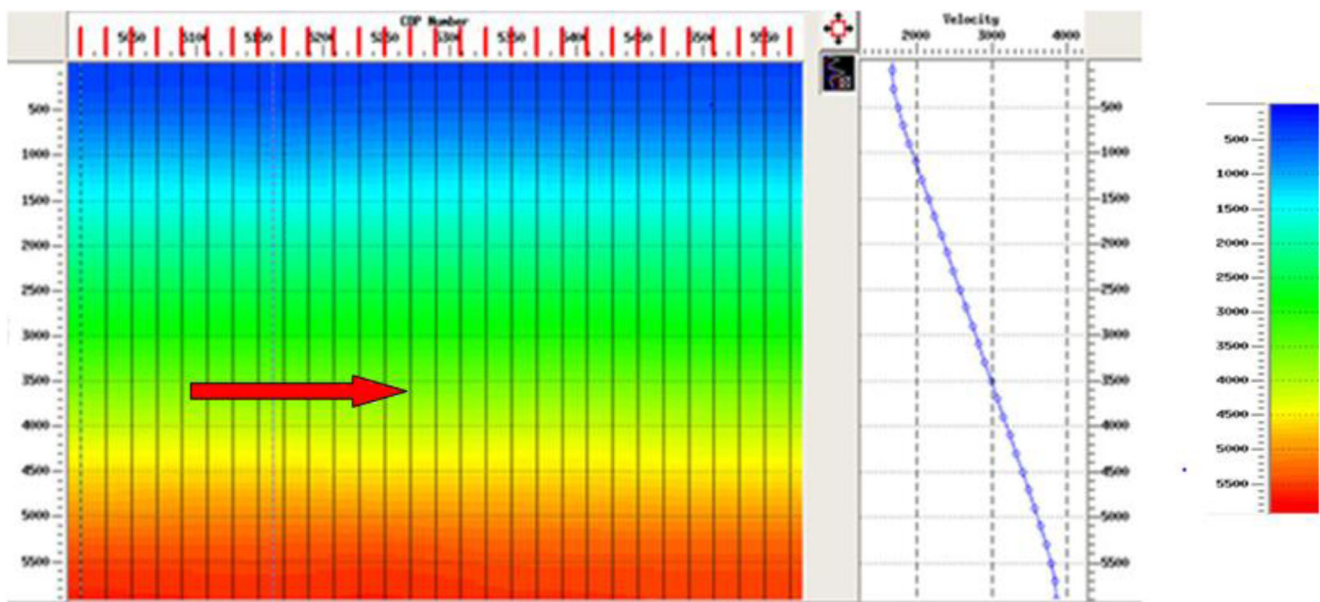


Fig. 8 Interval velocity model after the algorithm application

(Fig. 1). After normal moveout correction procedures with the velocity derived from the primary reflections during velocity analysis, the transform distinguishes the reflection events based on velocity moveout differences (Fig. 2). Figure 3 shows likely multiples that are visibly noticeable with different moveouts stretching from M1 to M4, then the primaries with the symbol P1 to P4 and other multiples at near and far offsets. This moveout common-mid-point gather before suppression shows the interference between multiples and primaries. Primary events were flattened, but inter-bed multiples have outstanding moveout that increases with offset. Regions occupied by the primary reflections in the forward parabolic

domain is removed with Radon filter, which leaves only the non-primary events that were modeled back to the offset time using inverse transform, thus attenuating inter-bed multiples events.

Figure 4 shows improvement in amplitude of a particular common-mid-point gathers after the suppression of inter-bed multiples. The implemented parabolic Radon transform provides a robust validity of event localization and also the possibility to exploit the separation to suppress or attenuate inter-bed multiples events. This model shows the reduced computational cost that is advantageous over the traditional approach. The velocity trajectory was difficult to follow from

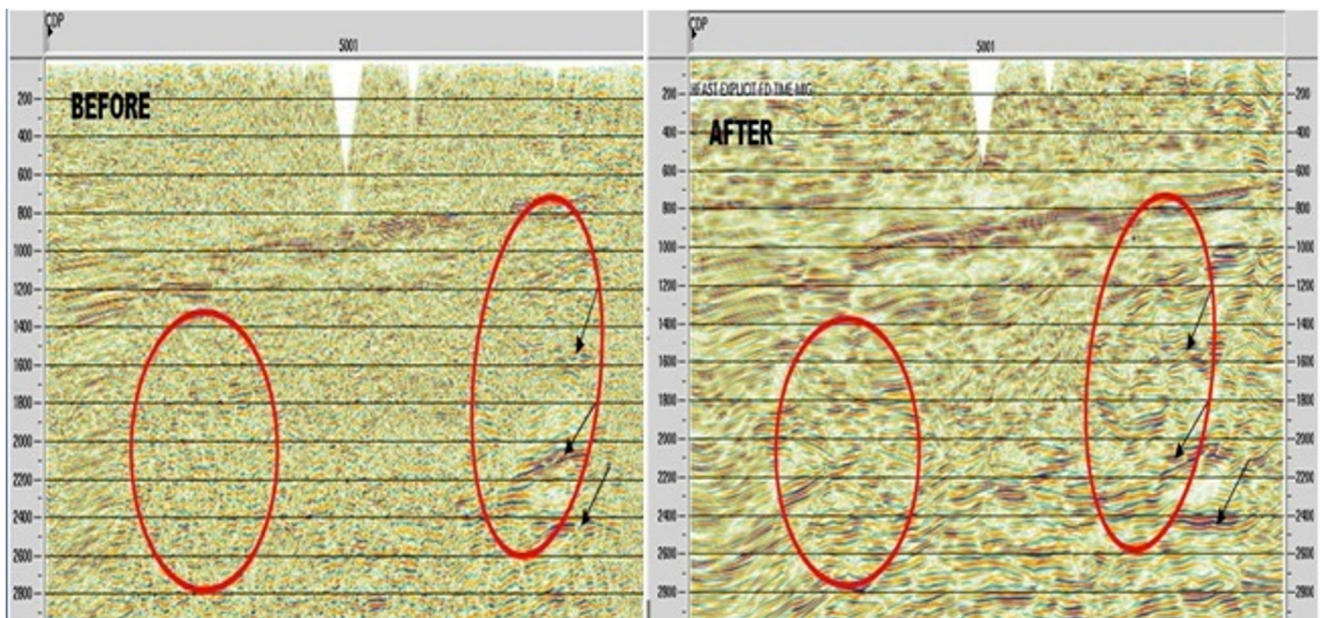


Fig. 9 Migration model after the algorithm application

the velocity analysis calculated before the application of the parabolic Radon transform algorithm. The possible inter-bed multiples presence tends to reduce the magnitude of the picked velocities during velocity analysis. Generated root mean square model exposes localized velocity anomalies with sharp or high subsurface reflectors (Fig. 5). Initially, it was thought that the stacking of seismic data suppresses multiples enough to allow for the good quality interpretation. This assumption is not generally true since probable multiples interference makes it difficult to establish accurate stacking velocities needed to obtain improved stacks for interpretation (Gabriel and Ken 2004; Kanu et al. 2014). The stacked model obtained exposes smeared or distorted amplitudes, which was as a result of possible multiples reflection presence (Fig. 6). The interval velocity regression from Dix approximations shows an abnormal increase in trend pattern of velocity reversal, which we attributed to a relatively high subsurface reflector effect. These localized velocity anomalies arise possibly from poorly picked velocity trajectory that is unclear in semblance flow pattern due to possible inter-bed multiples occurrence that increased the event amplitude with depth (Fig. 7).

The interval velocity and root mean square velocities then show smooth regression that supports the Physics of velocity increase with respect to depth and disappearance of the localized velocity anomalies identified by Azuoko et al. (2017) after multiples suppression (Fig. 8). Confirmation of the modified parabolic Radon transform algorithm was done by comparing the migration models obtained before and after the application of the algorithm. This shows improved image values and clarity of structures that can be characterized in terms of amplitude variation with offset studies for optimal prospect identification and reservoir management (Gabriel and Ken 2004), as observed in Fig. 9.

## Conclusion

This study has validated the successes of the processing approach through the use of raw 3D seismic dataset and also proves the existence of inter-bed multiples in an onshore Niger Delta field. Parabolic Radon transform algorithm suppresses multiples, which not only reduces the computational cost but also conserves the amplitude scales of primary reflection. The application of this algorithm shows a remarkable enhancement of the subsurface image. Furthermore, the evaluation of inter-bed multiples in onshore Niger Delta should be included in the seismic data processing sequence. The result obtained from the implementation of the parabolic Radon transform algorithm will provide a better semblance or robust velocity analysis for pre-drill geo-pressure predictions, yield thin bed resolution, and ultimately reveal more structures for subsurface image interpretation.

The results obtained in this study demonstrate the robustness of Radon transform algorithm in suppressing multiples in onshore 3D seismic data. This further validates the studies of Azuoko et al. 2017 which posited that inter-bed multiples are the possible cause of subsurface distortions like the fault shadow phenomenon in 3D seismic data from onshore Niger Delta.

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