

2D Acoustic Modelling Studies in Strong Velocity Contrast Area of Mumbai Offshore Basin

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Abstract

Areas having high velocity gradient and strong velocity contrast exist in Mumbai offshore Basin of India due to presence of carbonates layers. Refracted, critically refracted, diving rays and converted mode seismic events are present in such areas in addition to surface related multiples & other form of multiples. Artifacts are also generated in high velocity contrast area on application of NMO or Kirchhoff depth migration. Identification of type of noises, their behavior on migration and proper techniques for their attenuation is very important. Modeling studies were carried out for identifying these non-reflecting events and their behavior on application of NMO and migration. The acoustic modelling was performed taking the interval velocity model in depth representing an area of Mumbai Offshore Basin India. The studies were, first, carried out on a grossly simplified model but representative of the area. Modelling studies were also carried with more complex 2D velocity model extracted from the final interval velocity volume obtained during PSDM project carried out recently in this area. Only acoustic (P-wave) modelling was undertaken. Elastic modelling could not be carried out but mode converted energy is expected in the area. The bifurcation of events was observed on modeled data with the application of NMO or migration and compared with real CRP gathers. The spurious events observed in migrated gathers during the processing of PSDM project were well understood with the modeling studies.

Key Words: Carbonates, Forward Modelling, PSDM, Mumbai Offshore Basin

Introduction

Mumbai offshore area (Fig. 1) is prolific producers of hydrocarbon mainly from carbonates reservoir. Deccan trap of Upper Cretaceous age unconformably rests on granitic basement of Achaean age in the area. The Panna formation of Paleocene to Lower Eocene age overlies unconformably on Deccan trap. It consists of mainly basal clastics and becomes the limestone towards the top part. The Bassien formation, which is limestone, overlies unconformably and overlaid by Mukta, Heera & Bombay Formations. The Bassien lime stone deposited during middle to late Eocene times is porous and forms the reservoir in the area. Overlying

formations of late Tertiary age dominantly consists of Shale interspersed with limestone bands and exhibits strong velocity gradient. Fig.2 shows the P-wave sonic log from a well in the area. The velocity gradient of roughly 1 s^{-1} (1 m/s increase of velocity per meter) is present above a high velocity layer at a depth range of 2200 mts to 2500 mts. Anisotropic depth migration had been carried out recently in this area. The interval velocity volume from this project was used for modeling studies. The data pre-conditioning, initial velocity model building and tomographic iterations issues encountered during the progress of the project had prompted to carry out modeling studies in this area. However, these modeling studies are valid for any area having high velocity contrast.

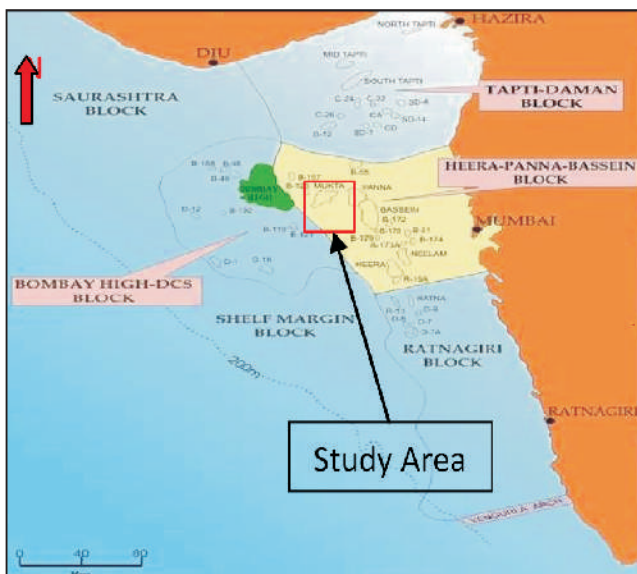


Fig. 1: Study area

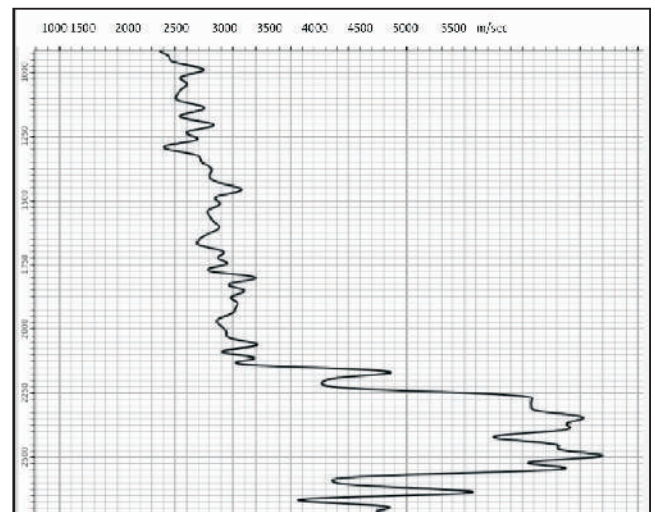


Fig. 2: High Velocity gradient and strong velocity contrast observed from P-wave Sonic log.

NMO and Travel Time Bifurcation

The bifurcation of events on application of NMO and depth migration had been studied earlier and provided the explanation of these artifacts (Sheng Xu 2007 and Jones I. F. 2013). NMO correction is: (i) proportional to square of offset; (ii) inversely to the zero-offset time of the events, and; (iii) inversely to the square of stacking velocity. In the environment of increasing velocity with depth, which is the usual case, makes it decreasing with time for any particular offset. Finite width of wavelet forces it to experience higher velocity for calculation of NMO at end part of the wavelet than starting part of the wavelet. This differential NMO application at extreme ends of the wavelet causes the serious stretching of the wavelet at higher offsets of shallower events. For large velocity contrast reflectors, it can create artifacts and looks like as bifurcated events both with application of NMO correction and Kirchhoff migration. (Stolk C.C. and Symes W.W., 2002, 2004 and Jones IF, 2013).

Fig. 3 shows a wavelet on the real hyperbolic trajectory with zero-offset time as t_1 is corrected with NMO from t_1 at offset x to t_1 . However, higher velocity may assume it as curve emanating from t_2 and passes through t_1 at offset x will be positioned to t_2 after NMO correction with higher velocity. Hence, NMO repositions a version of the input wavelet to time t_2 as well as time t_1 . For low or mild vertical velocity gradients, the wavelet only appears to be stretched with increasing offset. But for a rapid velocity increase, the wavelet separates out into a distinct event with almost linear trajectory. Similarly, Fig. 4 explains the generation of artifacts during depth migration in the presence of strong contrast. The source S and receiver R at offset x , the reflection travel path SzR has the same travel time as the path SabcR, which involves the deeper higher velocity medium. Hence, the input wavelet can be migrated to an output location 'b' during migration as well as to the real reflection location 'z'. As with the NMO artifact, this spurious event tends to be almost linear in migrated gathers. Fig. 5 shows the bifurcated event on synthetic migrated gather for two horizontal layers

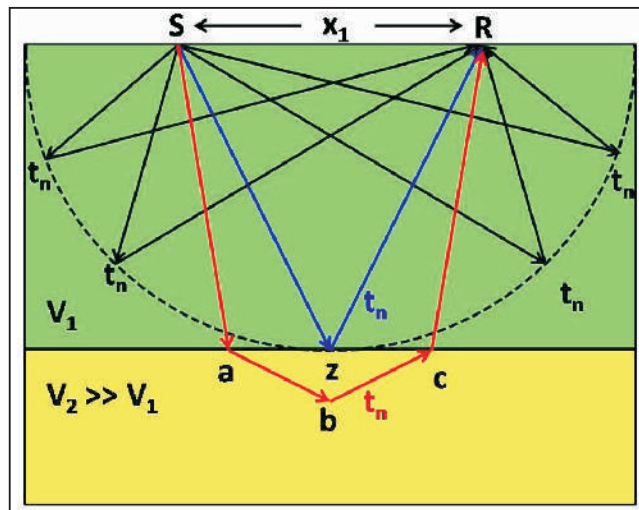


Fig. 4: Travel Time Bifurcation

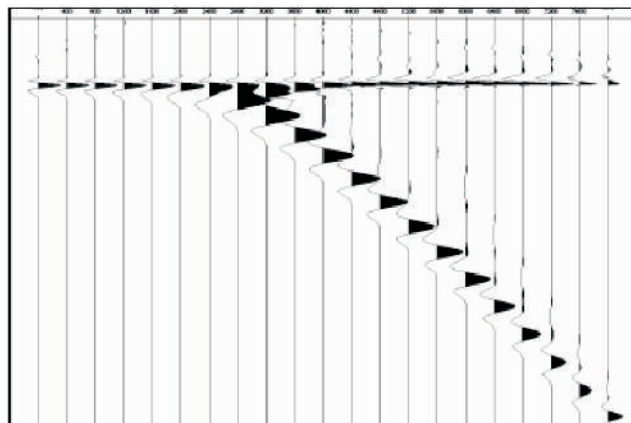


Fig. 5: Bifurcation of event on migration (Sheng Xu, 2007). Velocity model as in fig 3 or 4.

having strong velocity contrast as shown in fig 3 or 4 (Sheng Xu 2007).

Modelling Study

Forward acoustic modelling was performed using 2D finite difference on Promax software. Isotropic acoustic finite difference modeling was carried out using gridded models with a grid size small enough to avoid numerical dispersion in the Finite Difference propagation. The modelling was carried out first on a simplest interval velocity model representing velocities near a well in the area (Fig. 6). Forward modeling was repeated with complex model (Fig. 7) extracted from the interval velocity volume of the area along an inline passing through the well. The velocity model was calibrated using available sonic logs. Density was estimated using a modified Gardner relationship. The maximum source receiver offset was 5km, the depth of the model was 5 km, and record lengths of 5 sec. A zero-phase Ricker wavelet with a peak frequency of 20 Hz was used in the Finite Difference modelling. The objective of creating synthetic data using this model was to reproduce the overall gross features observed in the real data. For assessment of surface-related multiples, the surface boundary condition was set to be reflecting.

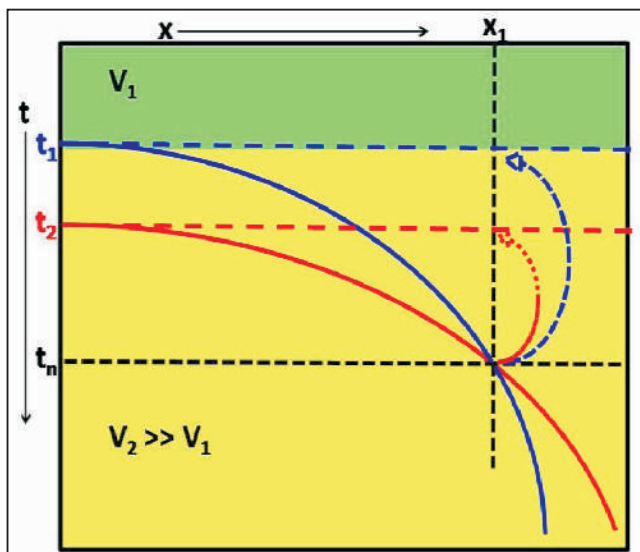


Fig. 3: Event bifurcation on NMO application

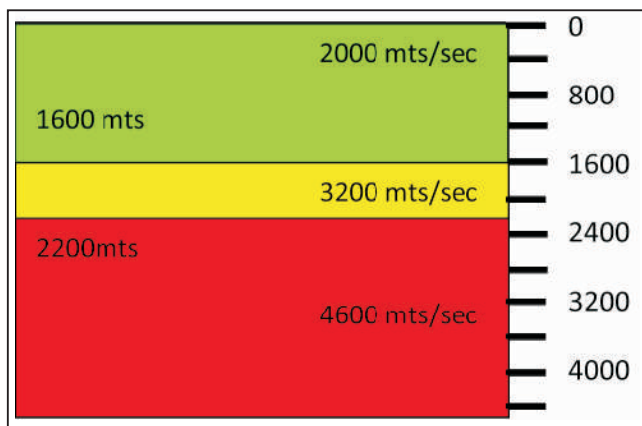


Fig. 6: Simplest interval velocity model

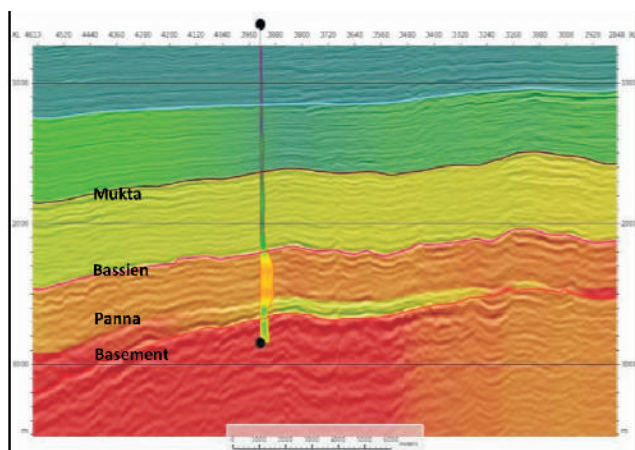


Fig. 7: Model with section and well log

Observations from Simplified Model

The simplified 1D layered model used for the analysis is shown in Fig. 6, but it is only the Eocene and Oligocene events of interest us in target zones which shows the strong velocity contrast. Before carrying out Finite Difference modeling with the complex velocity model and comparing the result with the observed data, a simplified model was used to better understand the observed events and bifurcation of events on NMO application. Fig. 8, 9 & 10 shows a shot gather for model of three layers having P-wave velocity of 2000, 3200 and 4600 m/s. These values are representative of the observed interval velocities at the well location in study area. The Fig. 8 shows the linear direct wave in the upper medium and hyperbolic reflection from the boundary with its associated refraction beyond critical angle. The surface multiples of first and second interface as well as a peg leg multiple were also generated because of reflecting boundary condition. The critical angles are 38 and 44 degree for first interface at a depth of 1600 mts and bottom interface (depth 2200 mts) respectively. Hence, event become critical at offset 2300mts and 2700mts for first and second interface. Applying NMO with the velocity function including the sharp boundary between 3200 and 4600 flattened the hyperbolic event, but also introduced the spurious travel time bifurcation effect (Fig. 9) for both the layers. The multiples are not flattened because of high velocity. However, if we apply NMO with a constant velocity of 2000, the travel time bifurcation disappears and event corresponding to first interface is flat. Lower reflections and its multiple are overcorrected while multiple of first interface is also flat (Fig. 10). In both these cases (Fig. 9&10), the refraction after critical angle curls upwards.

Observations from Acoustic Modelling

Acoustic Modelling was repeated with complex model as shown in Fig. 7. A PSDM section with well superimposed on it shows high-velocity layer in log. The background interval velocity model is also superimposed. Synthetic gathers were created with acoustic modeling. Many of the non-flat events seen in CRP gathers at the well location and Bassien formation levels are associated with post-critical energy which is prevalent here due to the strong velocity contrasts.

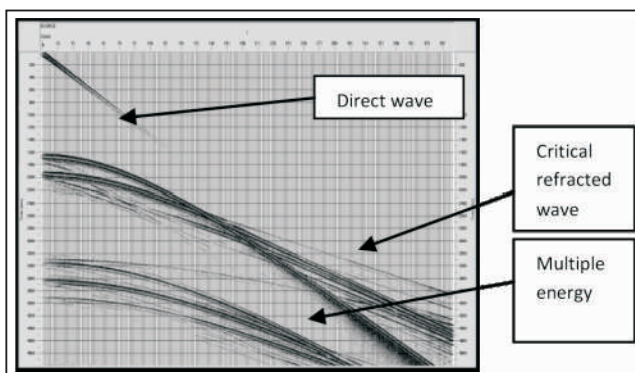


Fig. 8: Shot gather at well location with velocity model shown in Figure 5

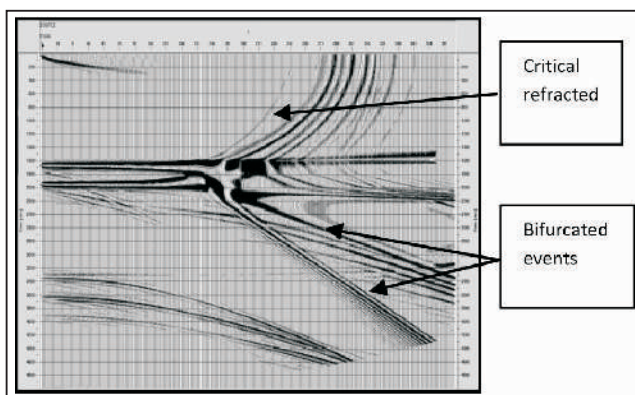


Fig. 9: Application of NMO with correct velocity

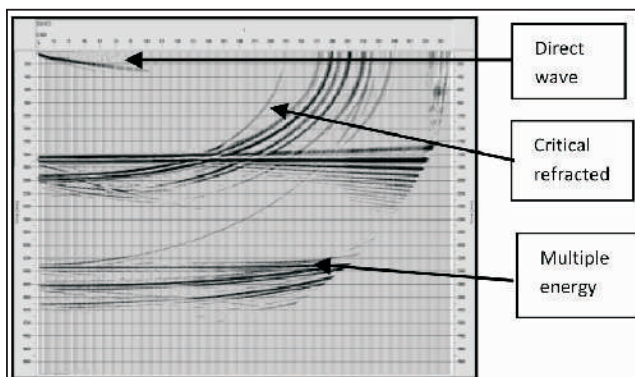


Fig. 10: NMO with constant velocity of 2000 m/s (top layer velocity)

- The critical angle at Mukta is about 38 which correspond to an offset less than 2200 mts. Hence, most of the higher offset events are post critical.
- The critical angle at top of Bassien is about 45 which correspond to an offset less than 2700 mts Hence, most of the far-offset events at Bassien levels are post critical.

A CMP gather near the well is shown in Fig. 11. The events corresponding to geologic interface are depicted. The CMP gather with NMO applied with correct RMS velocity (obtained from the interval velocity model) are shown in the Fig. 12. Various anomalous events and critically refracted events are depicted. The synthetic data is also subjected to PSDM using correct velocity model (i.e. the model which have been used for creating gather) and a CRP gather is shown in the Fig. 13. As the case with NMO corrected gather, the distorted refracted and travel time duplication events are visible in the CRP gather.

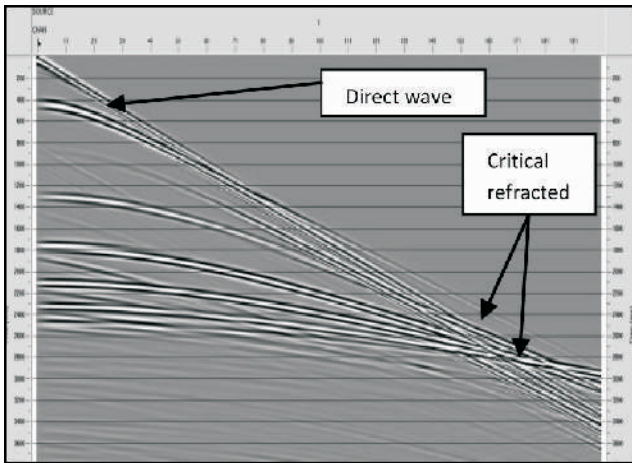


Fig.11: Modelled CMP gather

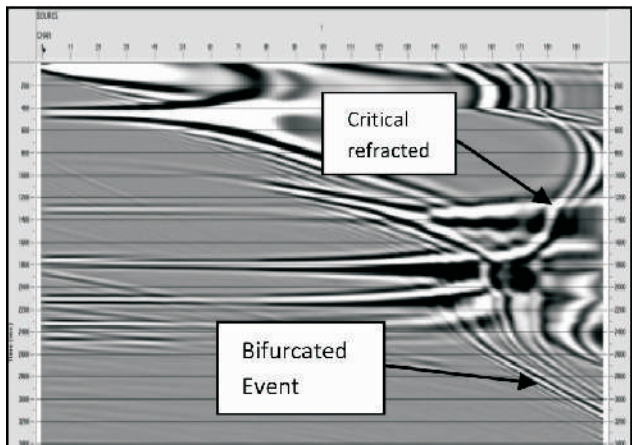


Fig.12: Synthetic gathers after NMO correction

Comparison with real Data Set

The raw CRP gathers (anisotropic depth migrated) from the area are shown in the Fig. 14 and exhibits many features seen in the modeled data. The travel time duplications and refracted events are present in the real data. These events may be remnant multiples or converted waves. The elastic

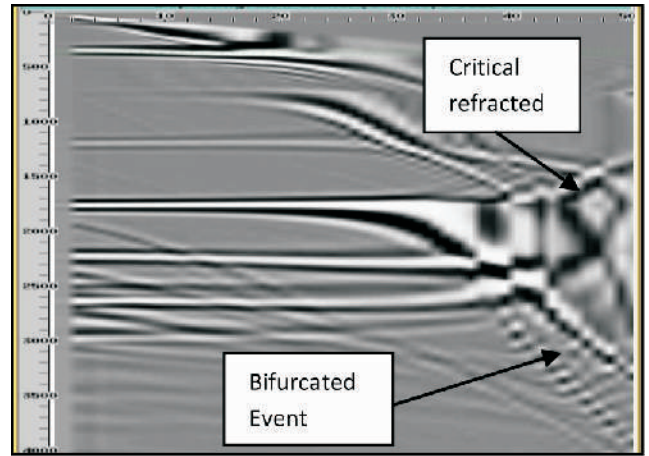


Fig. 13: Synthetic CRP Gathers(PSDM)

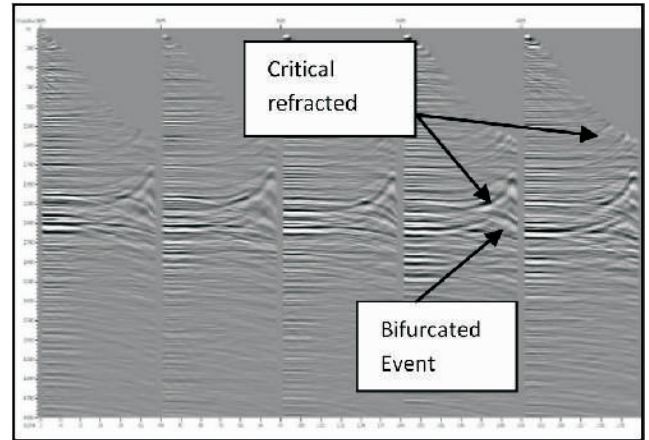


Fig. 14: Real CRP gathers (PSDM)

modeling could not be carried out to analyse the mode converted events. However, reflected mode converted events are expected from high velocity contrast interface. These energies could not be handled by conventional processing in which it is assumed that each event is a compressional wave that has gone a single reflection. They need to be removed in pre-processing however, remnant energy from such events invariably remains in the data.

Conclusions

- The acoustic modelling studies had successfully been carried out with actual interval velocity model of the area.
- The bifurcation of events is observed on application of NMO and migration due to presence of high velocity gradient and contrast in the area.
- Good comparison of modeled data with real data set is observed. This explained the spurious event which was observed in depth migrated gathers of PSDM project.
- Some of the non-flat events present in the real data could not be explained since comparison was made with acoustically modeled data. The study may be extended for elastic modeling to study the converted wave.
- This study was carried out from the velocity model from Mumbai Offshore Basin but it may be valid to any area having high velocity contrast.

- The study will give some insight into what details we should be focusing on and what we should be ignoring in resultant gathers and images.

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