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Lessons Learnt From Pilot Study for Reservoir Characterisation – The Case of Mumbai High

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Summary

Mumbai High is a mature field producing hydrocarbons for over thirty years. The production peaked during late 1980's to early 1990's and then started declining. Massive redevelopment programme was launched during 2000-2001 with the objective to improve oil production and maximise recovery from the field, to quantify additional producible reserves. In a bid to sustain and improve recovery from the ageing field, it is necessary to identify areas of by-passed oil through various state of the art and emerging technologies. Maximising knowledge extraction from the available 3D seismic data is one such important effort in achieving these goals.

Quantitative estimation of reservoir properties and identification of locales of the by-passed oil can be done through suitable inversion techniques on 3D seismic data calibrated with direct measurements in bore holes, which leads to a reliable geological model building for bringing out sub-layers' geometry, lithology, porosity and fluid saturation. Keeping this objective in view, the relative amplitudes preserved anisotropic Pre-Stack Time Migrated (PSTM) seismic data of Mumbai High calibrated with well data was planned to generate a high resolution geological model of L-III reservoir in depth domain in a pilot area in Mumbai High North (MHN).

Prior to taking up pilot study the reprocessed seismic data was considered to be good even by the internationally renowned experts who examined the available 3D angle stacks and full stack PSTM and PSDM volumes. The data showed good match with drilling results as far as the structural aspects are concerned. However, during the course of the pilot study, rigorous quality checks and well to seismic ties revealed interesting insights in the 3D seismic data and it became evident that the available 3D seismic data in the pilot area in MHN is inadequate to accurate prediction of reservoir properties between wells. Thus, the pilot study was not successful due to inherent problems in seismic data which ultimately proved detrimental in accurate prediction of reservoir properties between wells. This paper deals with the methodology adopted for the study, quality issues in seismic data which caused such failures and the lessons learnt for future data acquisition campaigns / processing for a more meaningful and successful reservoir characterisation.

Introduction

Mumbai High is a mature field and has been producing hydrocarbons since 1976. The production from this field peaked during late 1980's to early 1990's and then started declining. Massive redevelopment programme was launched during 2000-2001 with the objective to improve oil production and recovery from the field. This involved re- interpretation and integration of all available data and preparation of an upgraded reservoir model followed by in-fill drilling. These efforts resulted in not only arresting the decline but envisaging a higher recovery also. This turn around could be achieved through concerted efforts involving huge capital and technological inputs.

A lot of initiatives have been taken to make use of the latest technologies in Mumbai High. The main objectives in Mumbai High, like in any other field, are to maximise recovery and quantify additional producible reserves. As a first step in this direction it is imperative to sustain and improve production from the ageing field through various state of the art and emerging technologies. In this endeavor, seismic data plays an important role for additional in-fill drilling in planning the locations and deciding the trajectories of horizontal wells. Seismic data can also significantly contribute by quantitative analysis of various reservoir properties This paper deals with the methodology adopted for the study, quality issues in seismic data which caused such failures and the lessons learnt for future data acquisition campaigns / processing for a more meaningful and successful reservoir characterisation.

Input Data

An area of about 100 sq. Km was selected in Mumbai High North such that it covers zones of water injection, oil production, gas cap area and the north-south permeability barrier in the Mumbai High Field. This was done to test the capability of the technology in different situations. In addition to such diversified situations, the selected area has certain wells logged with sonic, DSI, VSP which are required during the course of inversion study to derive the impedance characters. Three angle stacks of PSTM (0 - 12.5, 12.5 – 25 and 25 – open) were used for the study whereas PSTM gathers and full stack PSTM volume were also analysed for QC purpose. Well data of over fifty wells was scanned and the best ten wells were used for calibration, integration and wavelet extraction for inversion.

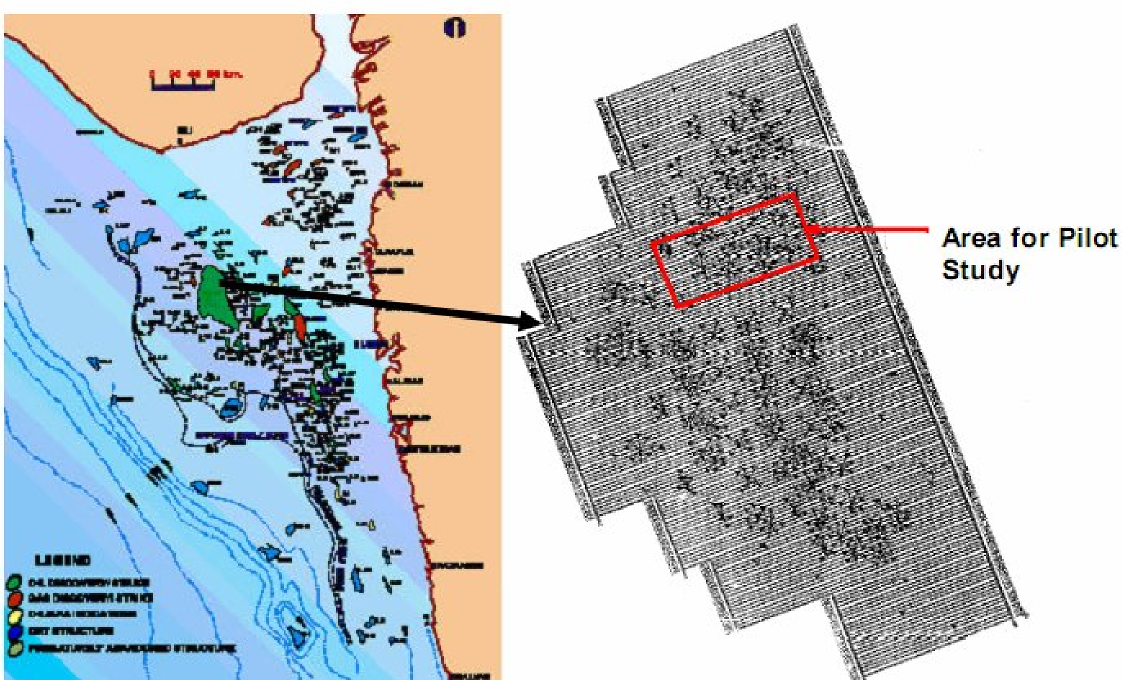

Figure-1 : Schematic depiction of the area of pilot study in Mumbai High North.

The target was L-III reservoir which is the main producer in Mumbai High Field. It is a carbonate reservoir having thin layers of limestone with intercalated shale. The total L-III package consists of nine units A to J, of which, unit A is further classified as A1 and A2 (A2 is sub-divided into seven distinct layers). The total thickness of L-III is of the order of 250m and thickness of individual layers varies between 2 to 11m.

2. Petrophysics and Rock physics - well log data was conditioned to remove artifacts created by bore hole or acquisition problems. Rock physics modeling was done to establish relationship between measured elastic logs such as density, sonic & DSI etc. and formation evaluation (mineral and fluid contents etc.)

3. Well to seismic tie and wavelet estimation – it is a complex iterative process. The well is placed in time domain and wavelet is estimated. Then time-

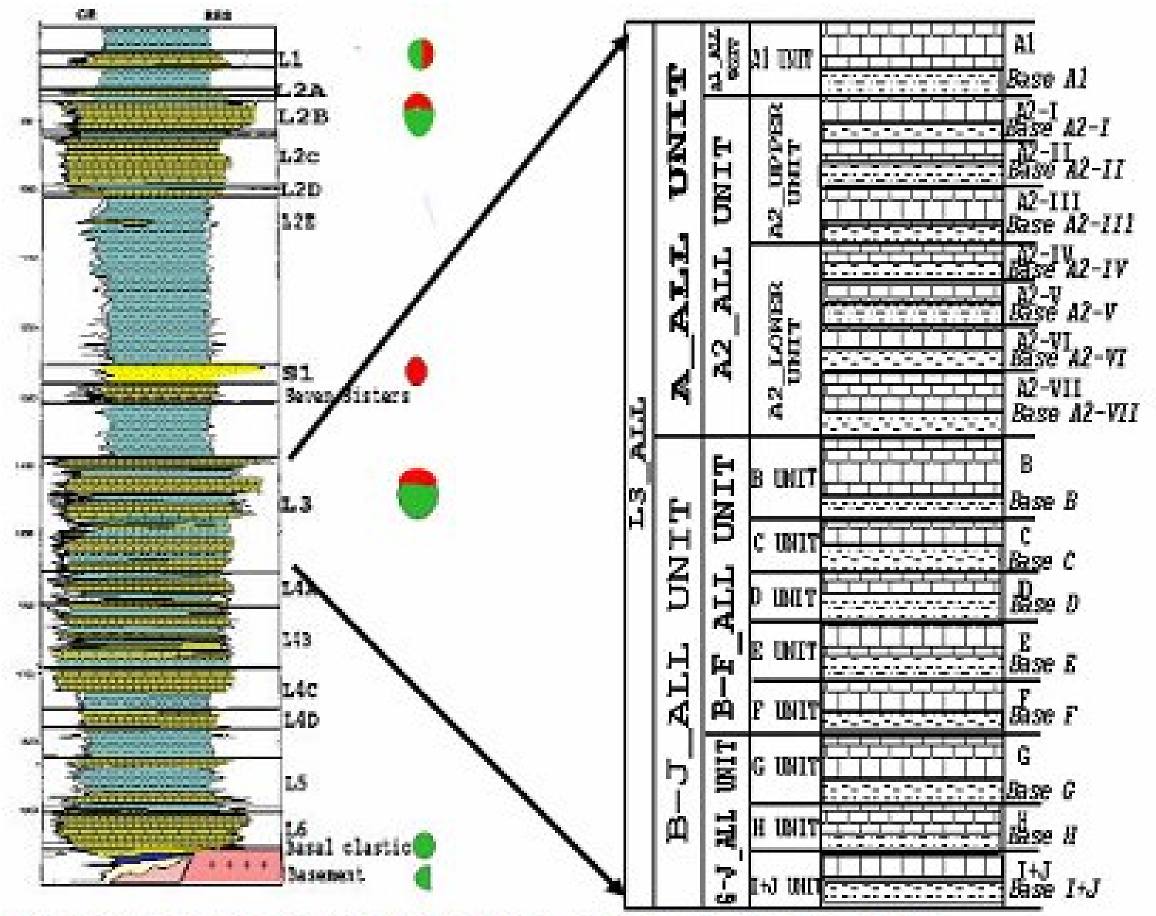

Figure-2 :Generalised stratigraphy of Mumbai High showing detailed L-II layering

Methodology

Simultaneous Angle Dependant Inversion (SADI) of partially stacked 3D OBC seismic data volumes followed by AVA Geostatistical Inversion was the chosen project work flow. Broadly, the methodology consisted of the following steps:

1. Data preparation - all available seismic and well data were loaded and checked for quality and consistency. Missing data were identified and synthesized if required.

depth relationship of the well was subjected to a series of iterations until a reasonable time-depth relationship and a stable wavelet is obtained.

4. Low frequency model building – low frequencies are vital for generating absolute values of impedance but, in general the seismic data lacks the low frequencies particularly in the range 2-10 Hz. The low frequency content between 2 Hz upwards up to the lowest available seismic frequency can be estimated from stacking velocity and well log data. Interval velocities obtained from stacking velocity are calibrated with well data and used to generate impedance. A final calibration with well

data was performed. A layered geological model was constructed from seismic horizons in which the well track is also placed and log data values were interpolated along the defined stratigraphy forming a model of log properties. This model was then merged with stacking velocity data to generate the low frequency trend model.

5. Seismic Inversion - Amplitude Vs Angle (AVA) deterministic inversion was applied simultaneously on the three angle stacks to generate P-impedance and S-impedance which were then used to generate Vp/Vs volume. This can be used to determine lithology, porosity and fluid saturations using different cross-plots.

QC and Data Analysis

Seismic data should ideally be free from noise and multiples, be processed with relative amplitudes preserved and should have a wide bandwidth. However, in reality no seismic data fully satisfies these criteria. Therefore, data QC was carried out regularly during the course of the project which included QC of well and seismic data. This included conditioning of well log data, rock physics modeling and assessment of lithology & fluid separation at log and seismic scales. The inversion results were interpreted and compared with the available drilled data for validation. It was found that at many places, the predictions were not matching with the actual drilling data. The reasons were analysed for this mis-match which revealed inherent quality issues in the 3D seismic data set.

Efforts were made to reprocess the data one more time with objective to remove the impediments in data quality and make necessary corrections wherever possible. However, such attempts could not succeed in the zones where the interpreted multiples superposed the primary events. L-II is a strong reflector in the study area and water column reverberations from top of L-II were interpreted to be present in the zone of interest within the L-III reservoir which could not be suppressed while preserving the primary events, the project had to be aborted after SADI when it was realised that the out puts of SADI were not satisfactory to carry forward the project into next stage i.e. AVA Geostatistical Inversion. The quality issues which were notable in the seismic data and had a direct bearing on the reservoir property predictions are described below.

(a) Lack of AVA response in seismic data

Success of simultaneous AVA deterministic inversion depends on the presence of AVA response in seismic data. The available PSTM gathers contained noise and therefore, it was difficult to assess whether the seismic data is responding to expected fluid and lithology changes or not. A synthetic gather was generated from conditioned well logs at well location SN-511 as representative which shows AVA effects associated with fluid in L-III carbonate (figure-3).

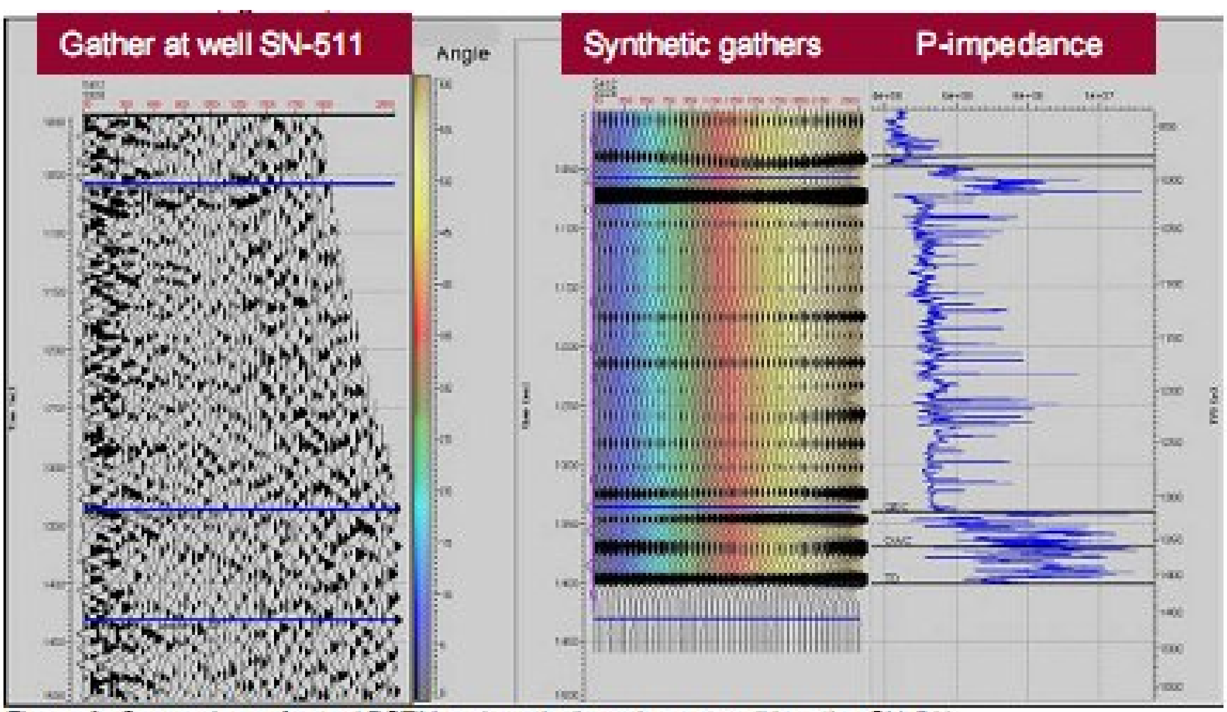

Figure-3: Comparison of actual PSTM and synthetic gathers at well location SN-511

This comparison may not be very correct as the synthetic data is free from noise whereas actual seismic data contains some noise most of the time. Also, the actual seismic response of the subsurface need not necessarily match the synthetic calculations. However, care needs to be taken while designing the future 4C-4D seismic data acquisition to see how AVA response can be preserved in the seismic data.

(b) Acquisition footprints

The data acquisition was done using two receiver lines 400m apart. The data was recorded with 12.5 x 25m bin size. This affected the signal distribution in the 3D volume which was high at the receiver cable locations and less at in-between cable locations. This uneven distribution resulted in acquisition foot prints (stripes) in the 3D volume.

Further, The Mumbai High Field has a high density of offshore installations (over 125) and the receiver cables have to be laid avoiding these offshore installations. Thus, the receiver cables were away from the well locations and hence, the wells were located in poorer (less foldage) signal zone (figure – 4b). Because of this, the calibration of seismic data with well data may not have been very accurate. This problem is more pronounced in the near angle stack and may be addressed to some extent by reducing the receiver line separation during next data acquisition campaign. But, it probably cannot be fully taken care due to obvious logistic constraints.

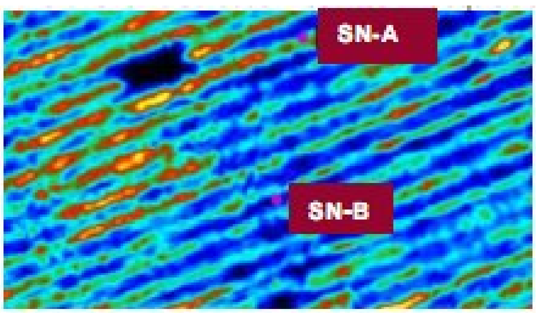

Figure – 4 (a): A representative time slice showing striping in seismic data (an acquisition artifact). The uneven signal strength affected the calibration of well to seismic data.

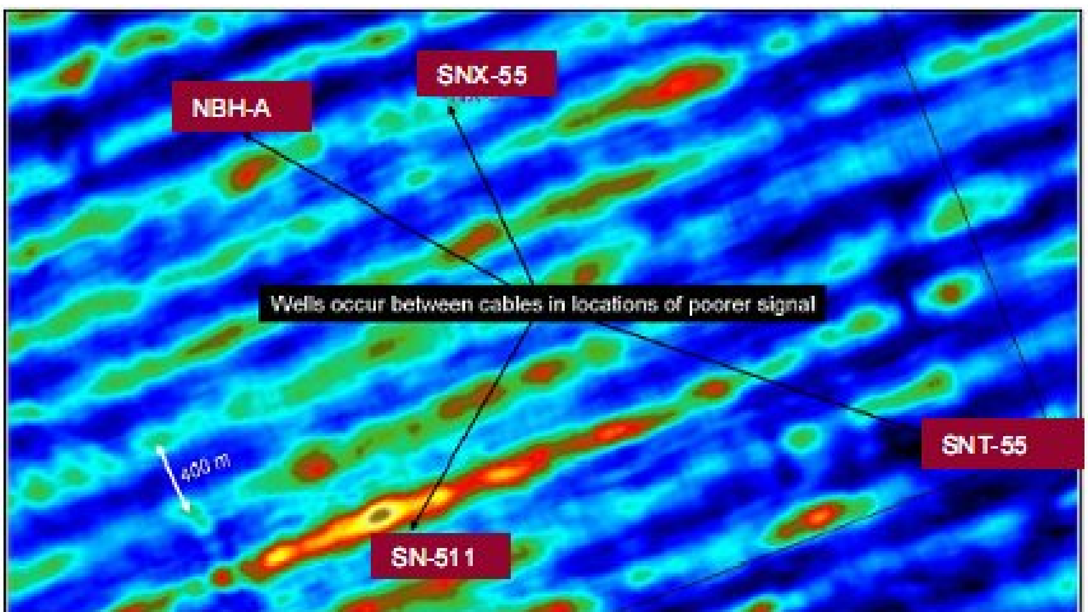

Figure – 4 (b) : Seismic RMS amplitude map - wells occur in-between the locations of receiver cables, i.e. the areas of poorer signal *(c) PSTM in-fill artifacts*

Due to large separation between receiver cables, the zones in-between cable locations had poorer signal and variations in foldage affected the migration process. PSTM artifacts were noticed in the form of migration smiles filling the areas of less foldage (figure – 5).

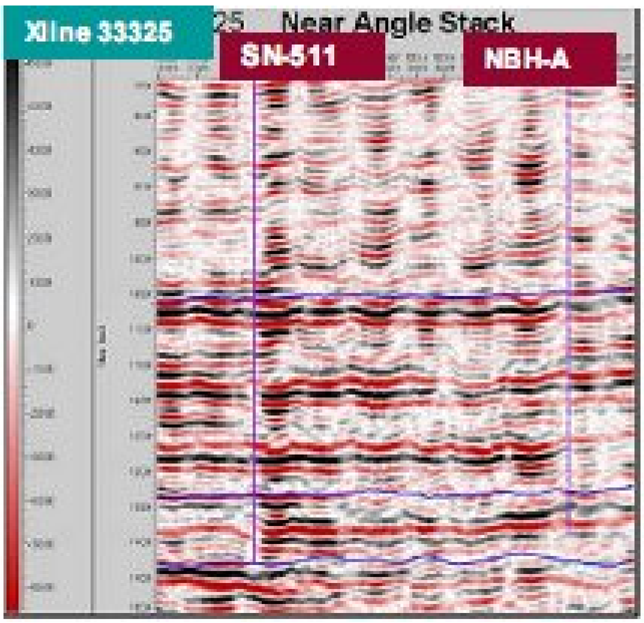

Figure – 5 : Showing PSTM in-fill artifacts. PSTM filled the low fold areas leaving migration smiles which extend in the zone of interest. The well locations occur in the zone of data loss.

This problem was prominent in the near angle stack in particular and the process of time alignment was applied to minimise this artifact. A time shift volume was generated using full stack volume as reference and near angle stack as the target volume. Maximum allowable time shift was fixed at 20ms. Other parameters for this correction were time gate : 500-2000ms, correlation window size : 200ms and vertical smoothing : 9ms. A vertical median filter of 200ms was applied to the time shift volume. The conditioned time shift volume was applied to the target volume to bring it in time alignment. QC of the time shift volume is done carefully and the minimum values of the time shift generated after alignment are to be applied. The result of this effort is shown in figures – 6a and 6b.

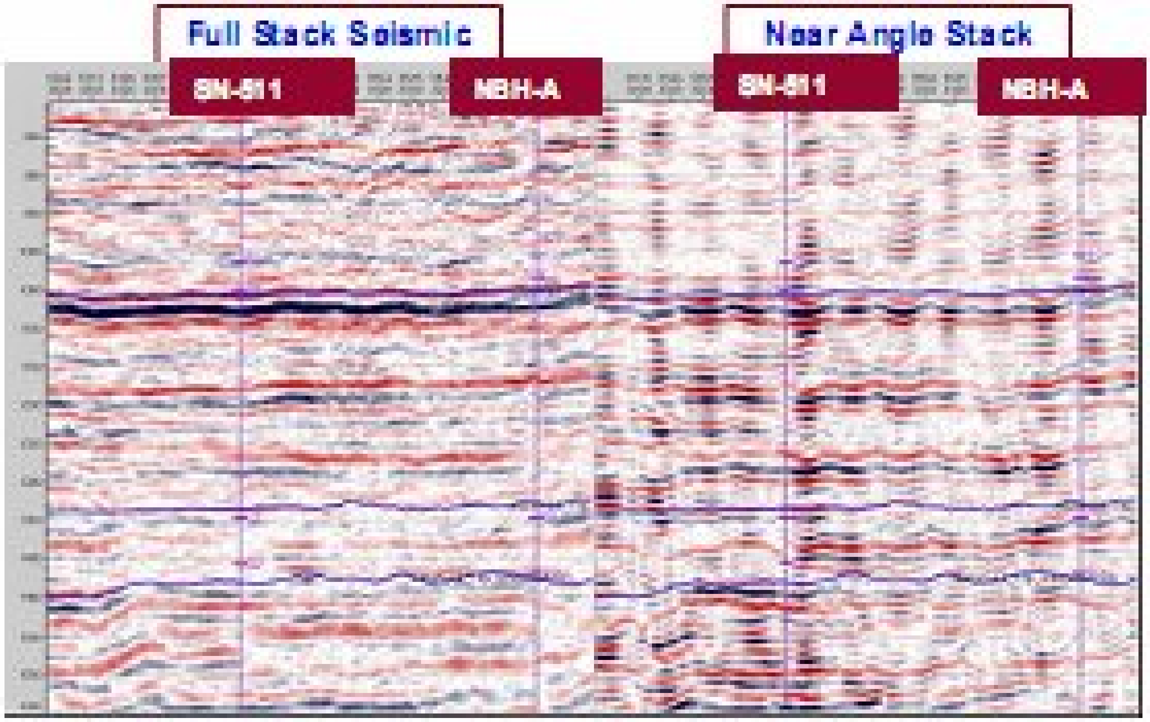

Figure – 6a: Before time alignment

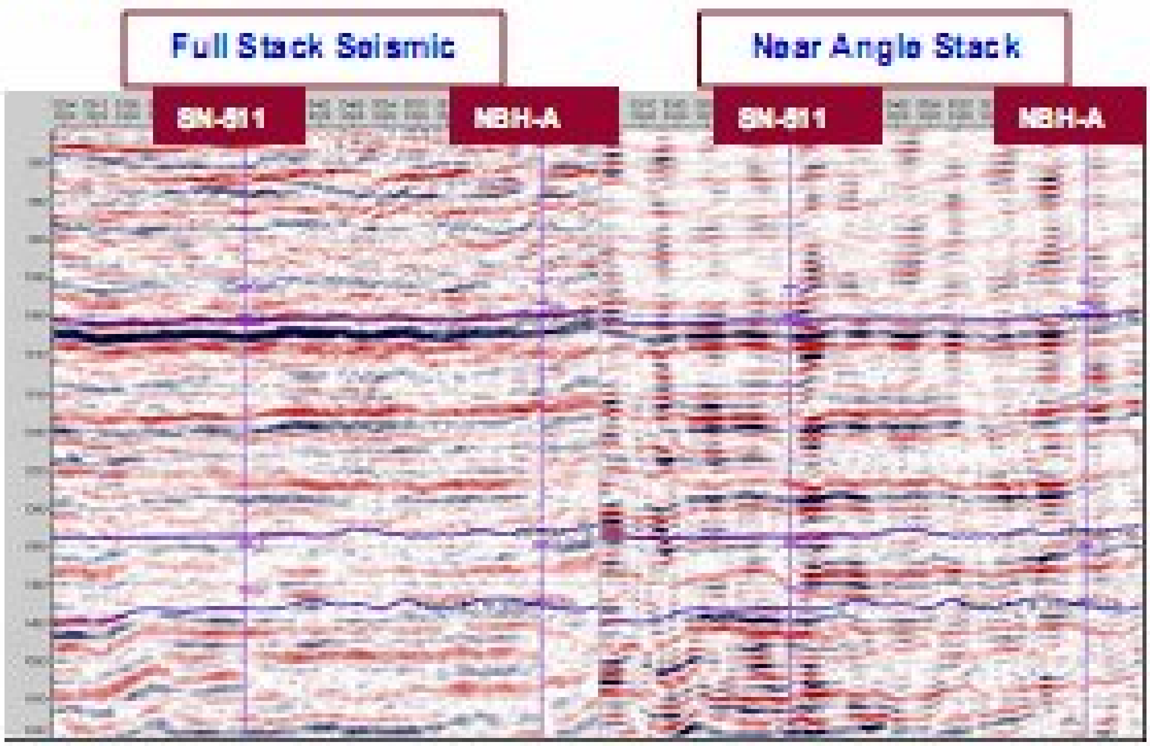

Figure – 6b :After time alignment

(d) Presence of water column reverberated multiples

Occurrence of multiples in seismic data was observed. While analysing well to seismic tie, it was observed that the actual seismic data contained some extra events than the synthetic seismic data (figure-7).

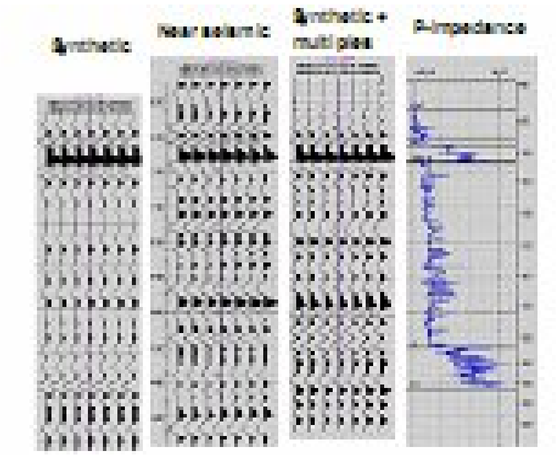

Figure-7 : Comparison of synthetic, actual near angle seismic, synthetic with multiples and P-Impedance data of well SN-511within the area of study. The extra events seen in near angle seismic data are interpreted to be the multiples.

This was further analysed and it was noticed that some events were getting repeated at about 100ms interval above the L-III as well as within L-III. This is same as the water column two-way time interval. These events were interpreted to be the water column reverberated multiples of L-II top (figure-8).

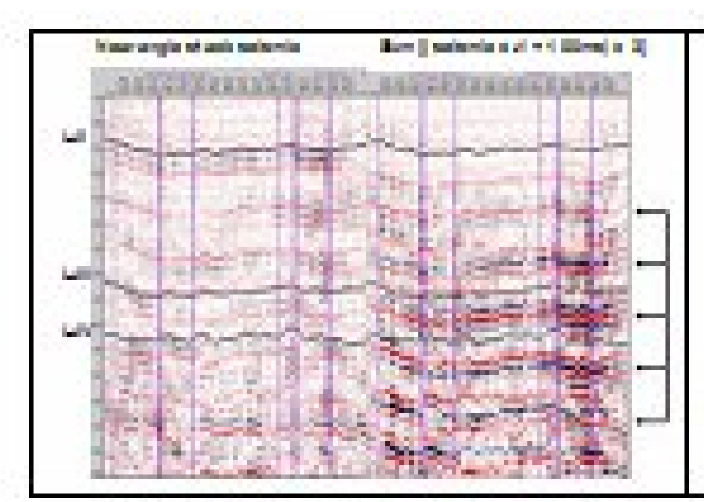

Figure-8 : Indicates occurrence of multiples in seismic data. First panel is near angle stack seismic data. The second panel shows the reversed seismic shifted by 100ms and then added to the original seismic data. This reverse-s hift- summation process was repeated three times. In this process the multiples have got boosted whereas the primary signal is summed destructively (e.g. the L -II). Thisis indicative of the presence of multiples.

Results:

The end product expected from this study was a high resolution geological model of the reservoir having details of layer geometry, lithology, porosity and fluid content which can serve as input for reservoir simulation. However, due to various quality issues in the available seismic data as stated above, the study could not achieve the desired objectives. The predicted impedance and porosity values obtained from this study did not match those available at the drilled well locations. These variations created a lot of uncertainty in the results.

Conclusions

The seismic interpretation is moving from qualitative to more advanced quantitative stage where we begin to look beyond the conventional interpretation to the point of reservoir property estimation. Extraction of maximum information and details like identification and mapping of fractures, type of fluid present in the reservoir, prediction of porosity pods and areas of by-passed oil are increasingly being expected from seismic data. The seismic data therefore should have the necessary details recorded and preserved to cater to the ever rising needs of the industry. Although the reservoir characterisation study discussed above could not bring out the desired results, it gave an insight into the quality issues in seismic data which are quite often over looked. The quality aspects need to be taken care at every step right from the planning stage while designing the data acquisition parameters up to the various processing stages. It is to be kept in mind that processing technology and interpretation skills are evolving at a fast rate and therefore the seismic data that we acquire today has to be future ready. The important lessons learnt from the above study may be summarized as follows:

1. The 3D data should have field geometry preferably with no acquisition foot prints. However, if due to logistic or other constraints, acquisition foot prints cannot be avoided then these should be minimised which can be controlled in processing and must not propagate further into inversion results.

2. The 3D data should preferably be multi component and should have wide azimuth to take care of any blind zones due to gas cap, prediction of hydrocarbons and mapping of fractures etc.

3. Adequate removal of water column multiples of strong reflectors while preserving the relative amplitudes both at the summation stage (in case of OBC data) and subsequent pre-stack processing is to be ensured. A delicate balance needs to be maintained between multiple noise removal and relative amplitude preservation as the left over multiples will always be present in the impedance inverted volume and add to the uncertainty in reservoir characterisation.

4. Well to seismic tie should be good and therefore, there should be no multiples in the processed seismic data (Particularly in the zone of interest) so as to minimize uncertainties in the predicted results.

5. Lower frequency band (all recordable frequencies less than 10 Hz) of the seismic signal should also be preserved for improved resolution and building trend model which is vital for inversion.

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