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Exploration in Frontier Areas - Imminent Challenges & Endeavor: A case study from Upper Assam Basin, India

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Summary

Seismic exploration in rough topography & geologically complex areas such as the thrust belts are challenged by several factors which if remain unaddressed may lead to poor subsurface images. The thrust-belt areas lying in East and South-east part of the Upper Assam Basin, India are a geologically prospective province in terms of hydrocarbon resources. Oil India Limted's (OIL's) continual endeavor to unravel the complex subsurface geology in and around these thrust belts areas has led to a series of seismic survey campaigns. There are a few success stories, however, the same are limited due to poor mapping & imaging of the subsurface. The initiatives have been primarily challenged by several factors, notable among them are the presence of rough topography, complex subsurface geology, presence of high-velocity rocks at the surface, ground roll, back scattered energy among others. Lack of adequate well control and velocity information in the area also reduces reliability of migrated images and depth estimations and is a compounded challenge. Seismic data acquisition and processing have been constrained by such challenges leading to lower image quality and thereby reduced interpretability.

A case study over a part of these thrust belt areas is being presented in this paper wherein a fresh seismic campaign had been carried out recently based on the geological leads of previous survey campaigns to infer meaningful information on the subsurface features. Ingenuity in planning, effective implementation of the survey design, stringent quality control measures, fit-forpurpose operational methodology & seismic data processing approach & workflow has enabled in achieving the primary objectives of imaging the Girujan and Tipam formation of Oligocene age in the area with a higher degree of confidence.

Introduction

Upper Assam Basin is one of the most petroliferous basins in India. The South-East part of the basin is associated with Thrust-belts normally called as 'Belt of Schuppen'. The 'Naga' thrust is the younger most and is in the periphery of this thrust belts towards the Assam plain. Commercial Oil was first discovered in Digboi area, a part of 'Naga' thrust and adjoining areas. Though oil fields have been discovered in and around these areas, the number of prospective leads identified & discoveries made is not commensurate with the hydrocarbon potential of these areas.

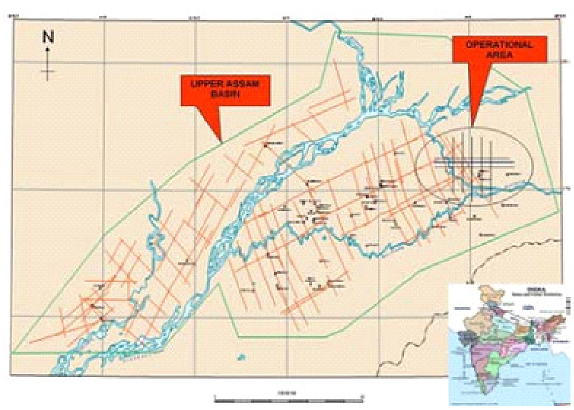

Fig. 1: Showing the Study area

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Identifying and zeroing down on prospective leads for exploratory & development drilling locations in such high risk high gain areas or vice-versa is still limited and is attributed primarily to the poor imaging of the subsurface geology. The hydrocarbon prospects are in supra thrust as well as sub-thrust and encompass multiple formations viz. Girujan, Tipam and Barail of Oligocene to late Miocene age. Dips of target formations in the thrust belt area are of the order of 30- 40 degrees. Though, the difficulties in taking up exploration initiatives in such frontier areas have been daunting, OIL has taken up the challenge in its endeavor to unravel the subsurface geology with higher degree of confidence using latest and fit-for-purpose technology.

The study area lying in Kumchai and part of Manbhum area of Arunachal Pradesh near the Eastern Himalayan foot hills is shown in Fig.1. In the study area, a 2D seismic survey campaign was carried out way back in the year 1990 after compilation of Gravity-Magnetic and other geological information. The seismic survey campaign had limited success, however it provided valuable insight on the near surface and subsurface challenges. The complexity of the area in terms of structural elements is clearly evident from the geological cross- section displaying structures formed due to thrusting in the area as shown in Fig.2

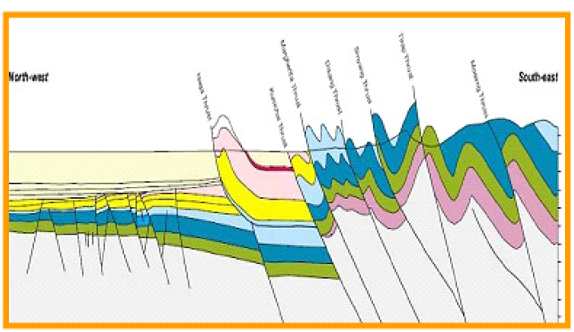

Fig. 2: Cross section displaying structures formed due to thrusting in the area.

The case study presented here relates to 2D seismic survey campaign carried out recently in Kumchai & part of Manabhum areas of Arunachal Pradesh. The study delves on how the use of existing geoscientific information, innovative techniques in seismic data acquisition and processing have helped in addressing the exploration challenges and enabled OIL to realize the broad objectives of the survey.

Seismic Data Acquisition Strategy

Logistics & Environmental Challenges:

Detailed reconnaissance survey was carried out in the area. The area is associated with difficult logistics viz. rapid variation in topography with hard rock at surface, poor accessibility and thick columns of surface/nearsurface boulder beds at the flanks etc. The challenges are further compounded by the presence of numerous brooks, forests, teagardens, cash crops and dwellings of many protected tribal inhabitants. The forests are rich in flora and fauna and the home of many endangered animals. Previous experience, reports and other ancillary information were also reviewed to identify critical areas of concern that could affect the exploration campaign. It was inferred that if all these factors are not addressed properly the objective of good quality seismic data acquisition could be constrained in terms of the following:

- Effective Shot-hole drilling in the surface/near surface boulder areas.
- Poor energy penetration attributed to poor shot-hole depth and loose near surface formation in boulder beds as well as hill tops.
- Poor coupling of shots and receivers due to hard rocks exposed at the surface, surface boulder beds etc.. These may produce misalignments due to improperly determined statics at processing stage.
- Severe access constraints may permit only manual carrying of geophones and ground electronics. This could limit the deployment of high channel count in light of overall operational efficacy despite increased involvement of manpower and material.
- Skipping of large nos. of shot points due to Tea-gardens, forest , cash crops & dwellings, steep terrain and even lack of access etc. may leave significant holes in the data.
- Strong ground roll associated with the near surface

To overcome the challenges highlighted above, a well thought of acquisition methodology/strategy was adopted and implemented during the course of field operation. The key elements of the same among others are as following:

Operation plan

The area has numerous brooks, uneven topography and lack of roads. Considering the poor accessibility for ease of operation an appropriate geometry ('END-ON') was choosen which involves minimum manpower & materials. A number of fly camps were also set up at various points along the lines and were used as operation hubs.

Survey technology

There are very few permanent topographic features and benchmarks available in the study area, which could help in surveying the shots and receivers points. A grid of DGPS positioned points was established in the area of operation based on the grid of pre-plan lines using stateof the art DGPS based positioning system. It was ensured that the DGPS positioned points are available at every crossing between the seismic lines to QC the final surveying precision. The DGPS based benchmarks thereafter were used as control / reference point to stake out the receiver and shot points using Electronic Total Stations. The surveyed data was processed on a regular basis at the base camp using standard software.

QC in implantation of sensors

The fidelity of the seismic signatures recorded in areas comprising of loose surface boulder beds, sands of the brooks site and hard rock surface were constrained by poor coupling of the receivers with the surface. Test shots were taken on a regular basis at the start of recording operation and rigorous QC was carried out for proper implantation of receivers. Based on the inferences drawn in areas compounded by such problems an innovative approach was adapted to record seismic signatures of high fidelity. Lumps of clay were used as pads for implantation of receivers to ensure good coupling required for picking up seismic signal properly.

Shot-hole drilling

Considering the presence of thick columns of surface/near surface boulder beds and hard rocks at surface in several places in the operational area, portable mechanized shot hole drilling rigs were deployed. Shot holes were cased immediately on completion of drilling to prevent hole-collapse. Multiple holes in a pattern had been used for the shots in places where the optimal shothole depth could not be reached. The shot-holes were loaded with optimal charge size considering generation of quality signal with minimal surface damage.

Data Quality Control (QC)

Despite taking all possible measures during the course of acquisition, there were numerous patches in the operational area where the mappability of the subsurface was poor primarily attributed to loose formation surrounding the shot-hole. Such poor records (bad shots) were identified and rejected daily after the shooting. An on-site field data processing system & design software suite was used for QC of the recorded shots on a daily basis. Representative raw monitor records indicating poor and good energy penetration are shown in Fig.3 & Fig.4 respectively.

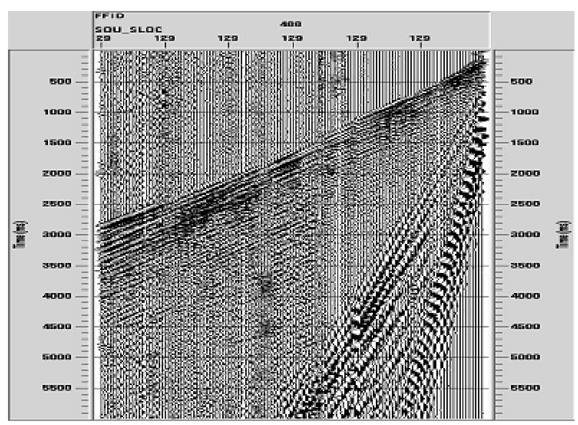

Fig.3: Rawdata with poor energy penetration.

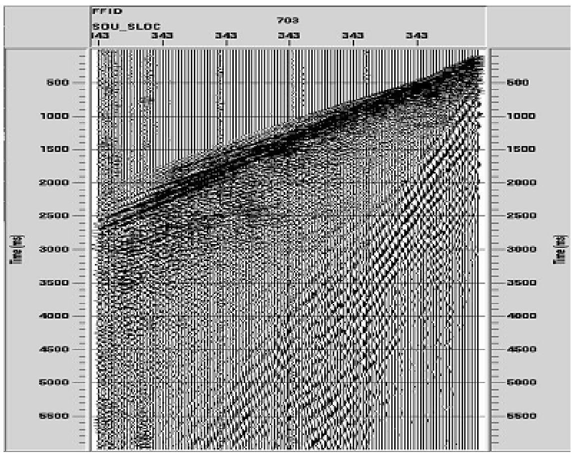

Fig.4: Rawdata with good energy penetration

Compensation of low fold and missing offsets

The area of operation comprises of several patches of loose near surface formation near the thrust plane and brook sites. Shots were rejected due to poor data in these patches. Moreover, in order to ensure environment friendly operation it was decided to skip shots to avoid surface damage in tea-garden, cash crops and dwelling areas. So, a large nos. of shots were rejected /skipped continuously in these areas. It is well understood that skipping of shots in such large numbers would lead to poor imaging of target horizons during the course of subsequent processing (Vermeer, 1990). In order to compensate for the loss of information attributed to skipped shots, simulation studies were carried out on a regular basis for planning and taking appropriate recovery shots. In order to compensate for skipped shots besides offset and fold distribution surface and near surface location capable of generating good quality signal were explored by a team on a regular basis to place the shots appropriately.

A reversed 'end-on' spread, having unique shotreceiver combination, without duplication of the fold was planned and implanted in the field. It was observed that in most of the CMPs, the low fold and missing offsets could be recovered. Across the wider patch of loose near- surface formation around the thrust plane, the shallow and intermediate offsets (below 800-1000m) were missing for several CMPs. Since the target horizons for the survey were 3000m to 4000m depth, it was still considered adequate for imaging the zone of interest. It was decided that the impact of missing shallow offsets while carrying out velocity analysis would be negotiated during the processing effort.

Seismic Data Processing Strategy

Despite several measures taken during field operation there still exsits noise on raw shot records and the mappability in certain areas is fair only due to several factord discussed as part of Seismic Data Acquistion strategy. The Processing approach to be implemented was dictated by the overall objectives of the survey and the mappability achieved on raw shot records. We scanned all the shots records on navigation stamped data and QC'ed them in terms of their spatial location. The good and bad record areas on the shot gathers were grouped in terms of their overall characteristics. Analysis was carried out to extract information viz. frequency, amplitude and manifestation of different kind of noise on the shot record.

An optimal processing approach was selected that could best represent the area under study for noise suppression and signal enhancement schemes. Rather than having a generic workflow each line was later on treated separately on individual merit with the ultimate objective of getting the best images of the subsurface. Moreover, while addressing the S/N ratio of the dataset a minimal process application approach was adopted to reduce any processing artificats that may hurt the dataset. Extensive quality control for each parameter and workflow was carried out so that the desired results are conformable with the objectives of the processing.

The key steps involved in seismic data processing sequence are discussed as follows:

Surface and Random Noise attenuation

Noise manifests itself in various forms on land seismic surveys. Suppression of coherent and incoherent noise on shot gathers is a pre-requisite for enhancing the S/N ratio on the raw shot gathers for efficacy in subsequent processing steps to start with. Moreover, irregularities in near surface topography, inadequate penetration of energy from seismic sources, poor geophone coupling surface scattering of energy from the sources among others combine to reduce the signals on seismic records.

Therefore the effort was focused on preserving all the signals on the seismic records while minimizing the noise.

Several noise attenuation schemes are in practice, however for the dataset under study it was observed that surface wave noise attenuation (SWNA) followed by surface consistent decinvolution (SC decon) with mild pre-whitening and spectral balancing is found to be effective in suppressing the noise. The same is illustrated in Fig**.** 5 & Fig.6 wherein the increased bandwidth, prominence and continuity of primary events after application of the process stand out clearly in Fig.6.

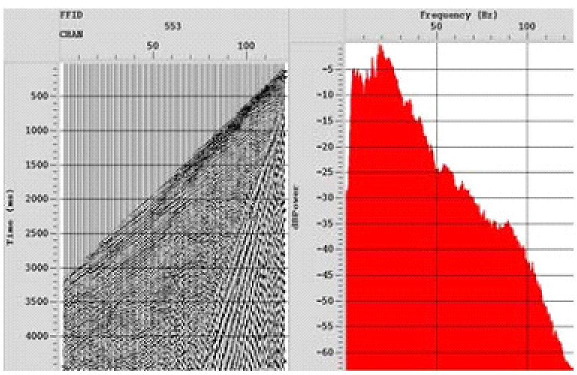

Fig.5: Spectral analysis of raw data indicates contamination at lower frequencies

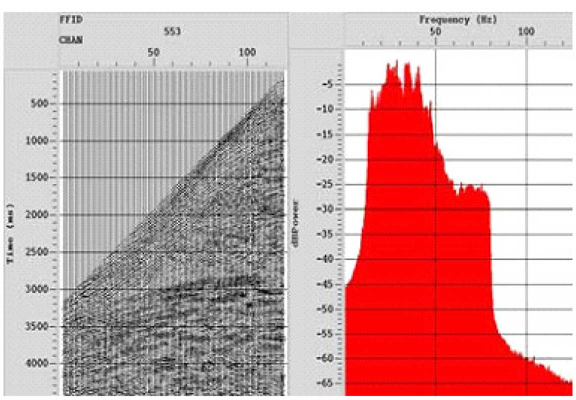

Fig.6: Spectral analysis of noise attenuated data indicates the improvement of S/N ratio.

Primary Statics Computation

Since the area of operation has varying topography & lateral velocity variation, it was well appreciated that precise static solution will have an implication on the deciphering the correct structural geometry of the subsurface. Analysis revealed that the application of elevation statics did not offer a very good solution in general. Moreover, due to difficult logistics and shot hole drilling problem in the area, Up-Hole / LVL surveys could not been carried out at regular grid intervals and could only be scarcely recorded.

Efforts were made to construct a near surface velocity model from available Uphole & LVL data, however the same was not found to be satisfactory due to very scarce grid of observation and non-conforming relationship between LVL & Uphole data at places. Finally refraction statics solutions were viewed as the next alternative.

However, near surface velocity model & refractions static's solutions based on first break picks require the first break to be distinctly and accurately picked on the common shot gather records for robust solution. Therefore, the first break picks were made with a great degree of caution and wherever the confidence in picking the first break was low traces were excluded from the analysis. Despite above, the refraction Statics solution yielded better results and were finally applied on the gathers based on floating datum for velocity analysis. The gathers before and after application of statics also showed marked improvement in continuity.

Velocity Estimation/Analysis

Estimating velocity in Thrust belt areas generally characterized by variation in near surface topography and complex subsurface geology has always been a challenging task. In fair to poor record area the question of where to pick the velocity function /field haunts the processors many a times and the processor is fraught with enormous difficulty and constraint to pick the right velocities for having a geologically conformable stack section. Representative velocity semblance panel on a selected gather in poor to fair record area after application of elevation statics and keeping the other optimized workflow same viz. SWNA, SC decon & spectral balancing is illustrated in Fig. 7

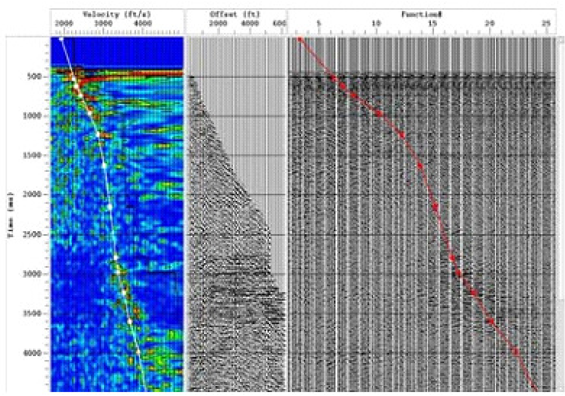

Fig. 7: Velocity semblance in poor to fair record area using elevation statics

In the study area velocity analysis was carried out iteratively based on the coherence, analytical thinking and interpretive insight. It was observed that in poor record areas characterized by low signal to noise ratio constant velocity stacks (CVS) panels were effective in determining the optimum velocities, whereas on semblance plots they were difficult to pick. A mixed approach to velocity analysis was therefore carried out over the entire area of study based on the fidelity of mapping & imaging. The choice of velocity was based on the flatness of NMO gathers and quality of the final migrated seismic section. The velocity analysis was constantly carried out with the geological understanding of the area in mind. After each intermediary output and final migration the interpretation was reviewed in light of the geological insight of the area. In sum total an iterative approach was taken up to strengthen the estimation of velocity and residual statics.

Interpolation of velocity Field

In spite of best efforts to compensate for the low fold and missing offsets across the wider patches, where large nos. of shots was rejected, several CMP were deficient in offsets below 800-1000m on few seismic lines. It was anticipated that in absence of shallow and intermediate offsets for CMPs lying beneath these patches, the velocity estimation using conventional techniques might not be reliable. In order to circumvent this problem, the missing velocities were interpolated from adjacent CMPs where entire velocity profiles were available. In order to account for lateral velocity variations, a correlation between the structural trend and velocity profile in the area was established. Stacks were produced to see the effectiveness of the interpolated velocity function, to ascertain, whether the image produced was geologically conformable or not. Such iterative studies were carried out over select areas where such data gaps existed. Finally most conformable velocity function was selected and it was observed that the lateral velocity variation more or less follows the structural trend.

Residual Statics Computation

It is well known that unndetermined residual statics can be an impediment in successful imaging of the subsurface in poor S/N ratios area such as the thrust belt. Since velocity estimation is a critical element of residual statics computation multiple passes of static's and velocity analysis were carried out on the stacked image until no further improvement resulted. After the application of refraction statics, residual statics algorithms were tested on the dataset, Maximum power auto Statics algorithm giving good result was used for all computation.

DMO Stack & Pre-Stack Time Migration (PSTM)

Considering the complexity of subsurface geology, dipping beds and variation in lateral velocity dip move out correction (DMO) followed by Prestack time migration was carried out to obtain more reliable images of the subsurface. Dip move out correction invariably helped to resolve the subsurface structures in the areas comprising of conflicting dips, reduction of noise and consequently resulted in improved imaging of the subsurface.

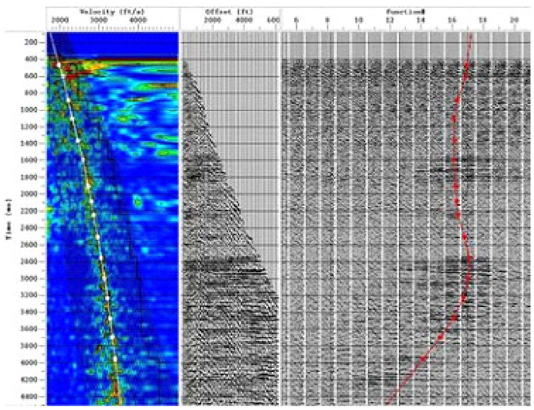

Fig. 8: Velocity semblance in poor to fair record area after Refraction & two passes of residual statics

Further Migration velocity analysis was carried out iteratively in two passes, as shown in Fig.8 ,with DMO Velocity as the initial velocity model in order to obtain the best possible velocity field of the subsurface that is conformable with the geology under investigation. The PSTM process further increased the spatial resolution and provided a more reliable image of the subsurface.

Results

Despite severe constraints in terms of difficult logistics in undertaking the seismic survey campaign in the study area, innovative ideas in acquisition and processing have helped in realizing objectives of the survey. The well thought of acquisition strategy helped in averting several challenges posed by the area in terms of acquiring good quality seismic data. On the processing front methodical approach and good geological insight of the area helped in selection of the right set of tools and techniques for processing the dataset. The overall efficacy of the processing in imaging the subsurface is clearly evident from Fig. 8, 9, 10,11 & 12. It is clearly evident that Stack & Migrated sections based on refraction statics solution employing SWNA, SC deconvolution & Spectral balancing have resulted in far superior images of the subsurface. The structural geometry of the subsurface features of interest in hydrocarbon exploration could be delineated and understood in better details , during the course of interpretation and therefore yielded in validation of earlier leads and release of location for exploratory and development with an increased degree of confidence.

Conclusions

The study demonstrates how a well thought of acquisition strategy with innovative approach was successfully implemented for the 2D seismic survey campaign in the logistically difficult and environmentally sensitive thrust belt area. Despite severe constraints in terms of difficult logistics in undertaking 2D survey in the study area, the combination of fit-forpurpose innovative schemes in data acquisition methodology and methodical approach in processing processing have helped in realizing the objectives of imaging the subsurface with confidence. Moreover, the present survey has also facilitated further understanding of the basin and may help in minimization of exploration risk in the area.

Acknowledgement

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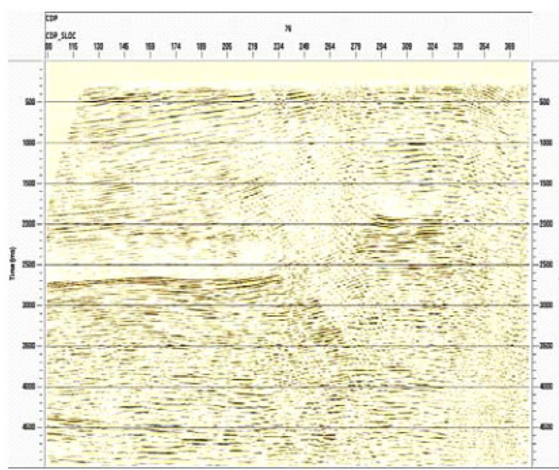

Fig.9.Stack with Elevation statics, spiking decon & without First Break Noise suppression scheme

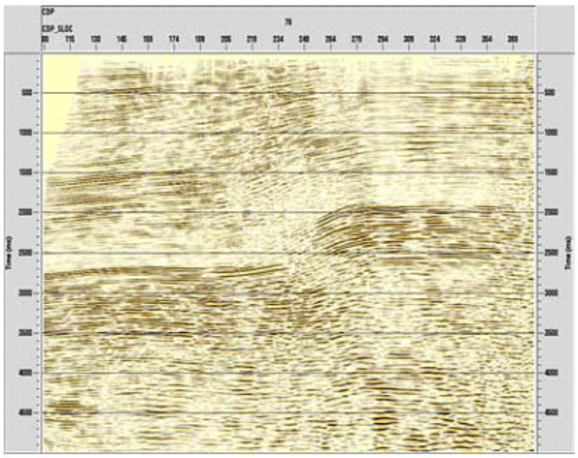

Fig.10. DMO stack employing SWNA, SC decon , Spectral Balancing & Refraction Statics solution

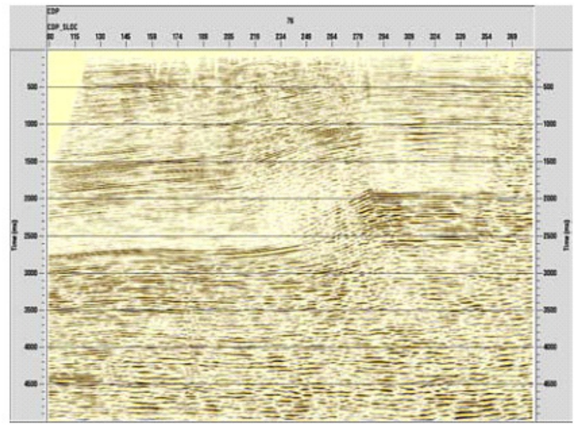

Fig.11. Post Stack Time Migration employing SWNA, SC decon , Spectral Balancing & Refraction Statics solution

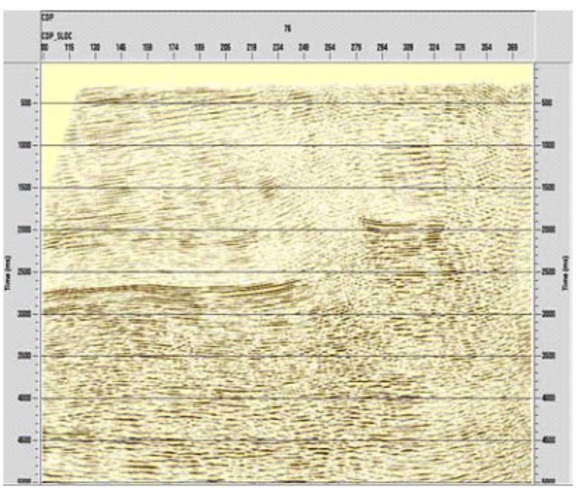

Fig.11. Post Stack Time Migration with Elevation static's, spiking decon & without First Break Noise suppression scheme.

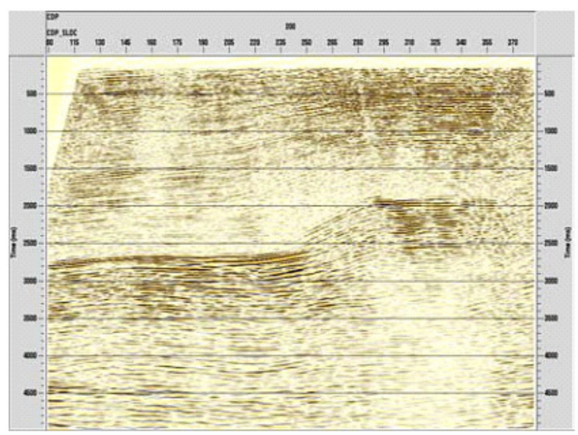

Fig.12. Pre-Stack Time Migration employing SWNA, SC decon, Spectral Balancing & Refraction Statics solution showing improved and reliable image of the subsurface.