An Integrated Pre-Stack Time & Depth Migration of 2D High Resolution Seismic Data using Model based Velocity Estimation & Refinement - A Case Study in CBM

*Subhendu Dutta *, Apurba Kumar Basak, RCC, ONGC Ltd., Kolkata*

Summary

The problem of imaging the sub-surface accurately is always a challenge to the Geoscientists. This requires a proper understanding of the geology of the area/basin, objective of survey, adequate acquisition geometry to delineate the prospect and overall a smart processing of the data. In this paper, we will discuss the efficacy of time & depth migration in a 2D high resolution dataset of CBM block. The Time Migration algorithm result in events being spatially mispositioned and the results have the obvious drawback being represented by a two way travel time. The depth migration, not only provide an image in depth, but also avoid many assumptions and simplifications that causes mispositioning of events in the time domain. The reflections are positioned correctly and provide precise subsurface images with minute structural discontinuities, i.e. imaging of faults. The depth imaging techniques such as Pre stack depth migration is very much dependent on the interval velocity, which requires more accuracy in velocity model building. In this paper, a 2D high resolution data pertaining to CBM block has been taken as a case study. An integrated Pre-Stack Time & Depth Migration using model based velocity estimation and iterative refinement, reveals better sub-surface configuration and resolution of coal seams in the area.

Introduction

The acquisition of high resolution 2D survey was executed by departmental Geophysical Party of ONGC with acquisition geometry of symmetrical split spread, placing 300 active receivers on each side of the shot position, thus, incorporating a total no. of 600 active receivers for each shot. The receiver interval and the shot interval were chosen as 5m and 10m, respectively. The nominal fold is 150 and sampling interval is 1 ms. The field data recording was accomplished by deploying I/O-4 Scorpion Digital system along with MEMS technology based sensors known as SVSM, which is capable of recording three components i.e. Vertical P-Component, Shear components S_H and S_V. The use of SVSM provides recording of data with broad frequency band. Only P-component processing was taken up in this case study.

The objective of the survey is to map the *areal extent of the coal seams* in the subsurface lying at shallow depths, and to identify/map the sub-surface geological features e.g., small scale folds, faults, basement topography as well as to detect presence of other geological bodies like the dykes or sills, which were present either as exposures or concealed in the subsurface. The imaging of these geological bodies is very much critical in developing CBM (Coal Bed Methane) prospects.

The Raniganj Coalfield, which covers an area of 1550 sq.km, is the easternmost member of the chain of Gondwana Basins (**Fig. 1**). The Basin has a semi-elliptical elongated shape and is bounded on the north, west and south by the Archaean metamorphics except in the east, where it is covered by alluvium.
The CBM exploration venture was initiated by ONGC in 1995-96 through drilling of Exploratory / R & D Wells in Durgapur area of Raniganj Coal Field. The results obtained from the Exploratory Wells, D#1 and D#2, were not much encouraging forcing ONGC shift its focus of attention to the northern part of Raniganj Coal Field covering an area of 240 sq. km (Sector-X) leaving the area around D#1&2 wells. In 2002, an additional area of 110 sq. km. (Sector-Y) in the south/south central part of Raniganj Coal Field for both Sector-X & Y was identified for further CBM exploration work. The area under study is depicted in Fig.1 below.

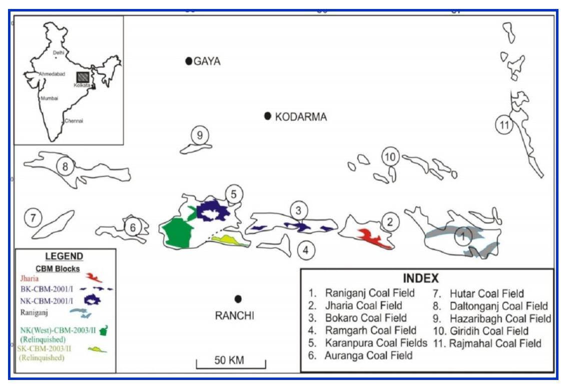

Fig. 1 : Location Map of Raniganj coalfields in the Damodar Valley Coalfields

In the Sector-X seven Coreholes were drilled by ONGC targeting the coal seams of Barakar Formation. Five to six major, regionally correlatable coal seams were encountered in most of these Coreholes. The erratic behavior/variation of the CBM specific data due to intrusive effects on coal seams made it difficult to delineate any prospective area in this sector.
2D High resolution seismic data was acquired within Sector-X of CBM Block and processed at RCC, MBA Basin, Kolkata for proper understanding of the subsurface disposition of coal seams, tectonically disturbed areas and to know areas of extent of igneous bodies vis-a-vis it's effects on coal seams.

* Email: dutta_subhendu@ongc.co.in

Geology of the Area:

Raniganj Basin is one of the few coalfields of peninsular India where both the Lower Gondwana and Upper Gondwana sediments are present. Raniganj coalfield in addition to being the oldest coal mining area of the country is also the only coalfield (except Singrauli) to house commercial 2 coal deposits in both Barakar and Raniganj formations.

Basement of Raniganj coalfield is represented by Archean metamorphic rocks consisting of Granite gneiss, migmatite gneiss, hornblende schist, hornblende gneiss, metabasic rocks, pegmatite and quartz veins etc.

Basement rocks are unconformably overlain by Talchir Formation of Upper Carboniferous age. Talchir sediments are exposed along narrow irregular strip along the northern edge of the western half of the basin. Talchir sediments are represented by medium to coarse-grained khaki feldspathic sandstones with silty shale and needle shales.

Talchir Formation is conformably overlain by Barakar Formation, which is exposed as an irregular belt roughly parallel to the northern boundary of the coalfield. The Formation covers an area of about 155 sq. km. and a maximum thickness of about 650 m. is reported. Barakar Formation shows maximum development in the western and northern parts and gradually thins towards east and south. Barakar sediments are represented by coarse to gritty arkosic sandstones, grey and carbonaceous shale. Eight regional coal seams have been identified within the Barakar Formation.

The Barren Measures conformably overlies the Barakar Formation, is exposed as an irregular belt in the northern, northeastern and western part covering an area of 113 sq. km. in between Barakar and Ajay River and a thickness of around 365m is reported. Barren Measure sediments are characterized by dark-grey to black carbonaceous, fissile shales with ferruginous laminae and thin bands or nodules of hard clay ironstone.

Structural Setup of Raniganj Coalfield :

Structurally, the basin shows a typical half graben configuration, elongated along a broad east-west trending and westerly plunging synform. The half-graben configuration is controlled by the prominent boundary fault to the south and homoclinal tilt of the basin floor towards it. Southern boundary fault dips steeply towards north with a throw of around 1000-1500m. Apart from the southern boundary fault (trending E-W to NW-SE), intrabasinal faults also locally modifies the basin configuration, resulting in variation of bed dips. Intrabasinal normal faults trend NNW-SSE and NNW-SSE in the western part and ENE-WSW and WNW-ESE in the eastern part. Beds generally dip gently (~10°), however, considerable steepening is observed near the boundary fault and adjacent to prominent intrabasinal faults.

The Post-Gondwana intrusives generally show a NNW-SSE to NW-SE trend. The most prominent intrusive in the Raniganj Coalfield is the Salma Dyke which traverses across the coalfield from north to south dividing it into two halves.

Coal Seams :

The Raniganj Coalfield is distinguished for having commercial coal deposits in both the Raniganj as well as Barakar Formations. In the Sector- X, Barakar coals are the main targets for CBM exploration. Seven regionally correlatable coal seams are present within the Barakar which have been designated as seams BI to BVII in an ascending order with thickness ranging from 1 to 40m having a cumulative thickness of 30 to 120m. The lower seams are relatively thicker. The coals are mostly High Volatile - A Bituminous with VRo ranging between 0.95 to 1.20 and ash content range from 15 to 25%. Coals of Barakar Formation are widely affected by igneous intrusive.

Objective of Study

Geological Objectives:

A. To map vertical and lateral extension of coal seams of Barakar Formation.

B. To Map intrusive bodies and Basement configuration.

Zones of Interest:

Depth: 300m to 1300m

Time : 200ms to 1500ms

Structural Dip: Variable (10 - 12°)

Data Acquisition Parameters	
Parameters	**Survey Geometry**
Type of Spread Geometry	**2D Split Spread**
No of active receivers per line	**600 (300+300)**
Group Interval	**5 m.**
Shot Interval	**10 m.**
Fold	**150**
Spread Length/Max. Offset	**2995.0m/1497.5m**
Min offset	**2.5 m**
Recording Instrument	**I/O Scorpion 4 (Digital)**
Sampling Interval	**1.0 ms.**
Sensor	**SVSM (3 component-MEMS)**
Source	**Explosive (Single Hole)**
Charge Size	**1 kg.**
Record Length	**6 seconds**
Record Format	**I/O SEGY**

The Data acquisition parameters are depicted above.

The study area along-with the 2D lines of the area is shown in Fig. 2. The two test lines (one dip & one strike) have been taken for study.

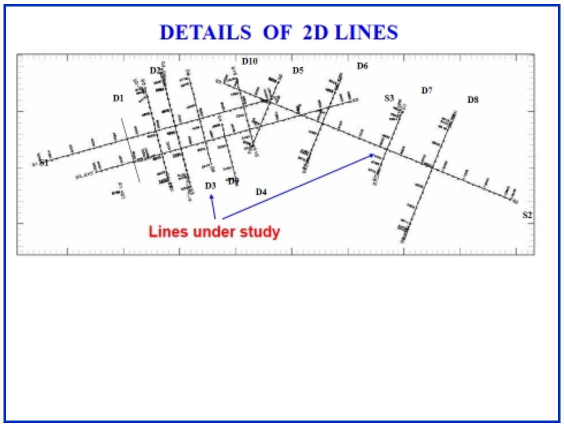

Fig.2: Study area of CBM block showing 2D lines

Methodology & Procedure

Input Data & Conditioning

Being a densely populated area, having several active coal mines and other industrial activities, the acquired seismic data was contaminated with noises. Large amplitude bursts, spiky traces, repetitive noises of stone crushers, seismic interferences due to coal mining activity were common occurrences in raw shot gathers. The recorded data were broadband and recorded with both high cut and low cut "out" setting. Contribution of both high and low frequency noises were observed in the data. Since, noise bursts (ref Fig. 3) were of comparable amplitude or stronger than the signal automated suppression of noises were not that effective & adequate. However, after appropriate filtering and manual editing at different stages of processing resulted in a good quality imaging. Thus, manual editing of noises were extensively used for conditioning of data. This processes consumed long time and more man power but end product were good quality image. The raw gathers vis-à-vis frequency spectrum is shown in Fig. 4 and data conditioning before & after manual editing is shown in Fig. 5.

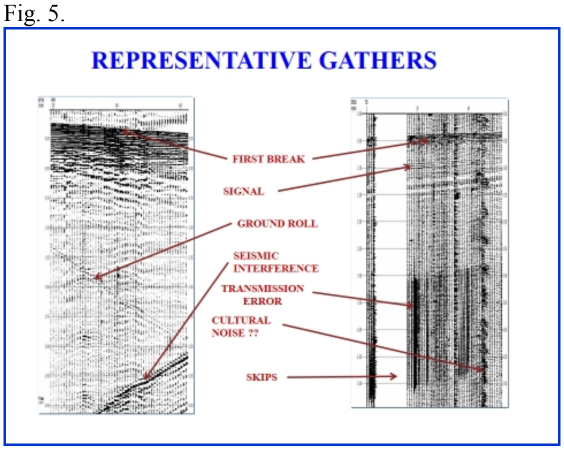

Fig-3: Raw Gather

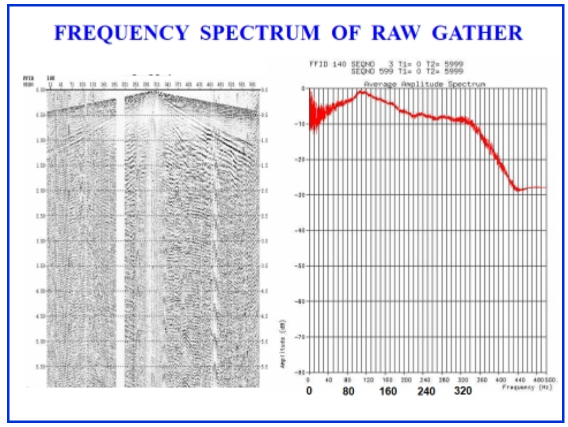

Fig-4: Frequency Spectrum

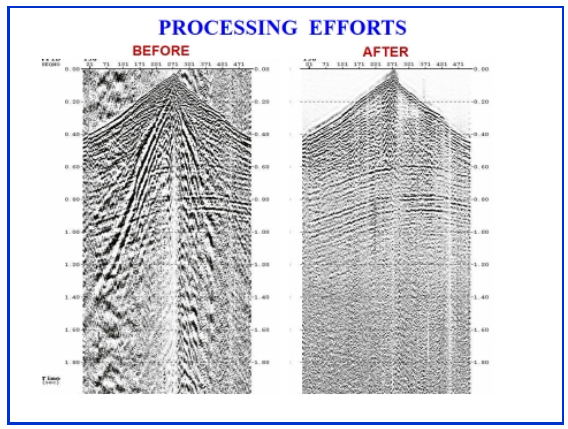

Fig-5: Data Conditioning

Processing Sequences:

The input data has been taken as SEGD from field and after internal format conversion, the following processing steps have been followed for PSTM processing.

1. SEGD to internal format
2. Segregation of P-component
3. Reformatting and Geometry Merging
4. Noise Burst Removal (Median Based)
5. Manual editing of noises
6. Band Pass Filter
7. Trace Editing
8. Static Corrections
9. De-convolution
10. First Pass Velocity Analysis
11. Two pass Auto-statics computation and application
12. Velocity analysis after each pass of auto-static application
13. Initial Migration
14. Velocity refinement and preparation of final velocity section
15. Kirchhoff's Eikonal Pre Stack Time Migration
16. Stack
17. Post Stack Processing
18. SEGY Conversion

The PSTM stack section of one dip line and strike line is shown at Fig. 6 & Fig. 7 respectively.

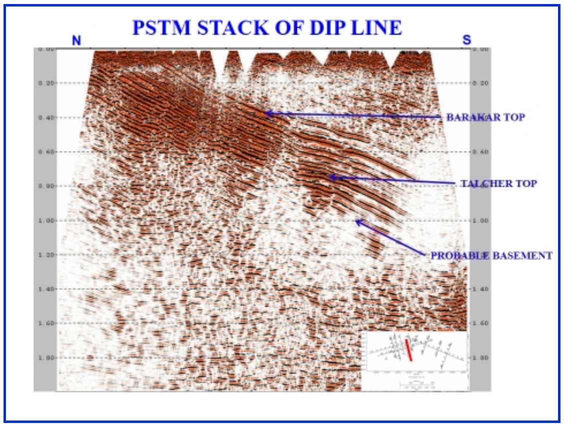

Fig-6: PSTM Section

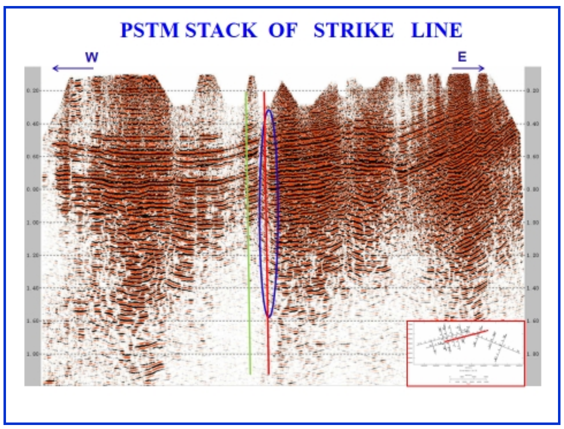

Fig-7: PSTM Section

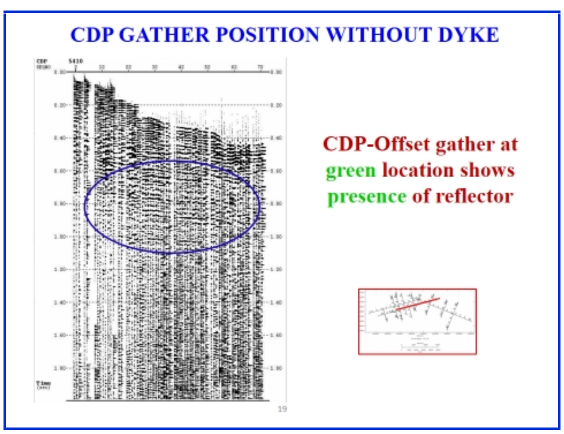

Fig-8: CDP Gather without presence of Dyke

The CDP gathers without presence of Dyke and in presence of Dyke is shown in Fig. 8 & 9 respectively.

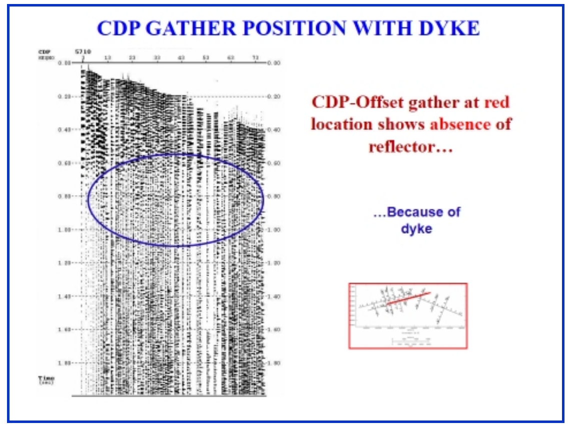

Fig-9: CDP Gather with presence of Dyke

Depth Interval Velocity Model Building

Recent advances in computer-based interpretation systems have significantly reduced the cycle time for exploration projects while improving the accuracy of interpretations in the time migrated domain. However, as every interpreter knows, the final test for any interpretation lies in the ability to produce an accurate prognosis in the depth domain. It is inadequacies in this step of converting an interpretation from the time to the depth domain that are commonly the cause of poor predictions, leading to increased drilling costs or at worst, creating prospects that simply do not exist.

There are several approaches that can be taken to improve our predictions in the depth domain, from simply improving our initial velocity models using model-based techniques through to the ultimate in depth imaging, pre-stack depth migration (PSDM). Whether we interpret on time migrated data and scale our maps to depth or choose to interpret on depth migrated data, there are many tools available that can assist in building more accurate depth models. Whatever approach we take, our accuracy in depth is wholly dependent on our ability to produce an accurate interval velocity model i.e. the earth model and this can only be achieved by taking a model-based approach using the interpreter's knowledge of the region to constrain that model.

Model refinement techniques that rely on tomographic approaches i.e. horizon based semblance creation and manual picking of depth residuals in a very close CRP interval as the sole method of model re-building or refinement.

As first step, interpreted time horizons on the PSTM data from the interpreter was obtained. The time horizons were plotted on the PSTM stack section and any kink on the horizons , if any were removed by smoothing the horizons at all level.

After smoothing of the horizons, a model has been prepared in the time-migrated domain. Then RMS velocity extraction was done along the interpreted horizons to build up a horizon based RMS velocity map/section.

Velocities derived during the processing of seismic data provide substantial additional control away from wells but are seldom accurate representations of the earth velocity. The most common approach to convert this RMS velocity obtained from the data, i.e. inversing NMO from the time migrated gather (PSTM) and actually pick the RMS velocity from the velocity semblance, to interval velocity using the Dix formula.
Several model-based techniques exists that can estimate the interval velocity of a layer from the travel time through it, but these techniques requires more time to complete a project as the travel time computation for layer stripping methods require more time. Therefore, when a data already undergone through PSTM, a fairly accurate RMS velocity information for each interpreted layers are available. Thus, interval velocity obtained from this transformation gives an initial interval velocity model to run initial PSDM.

Pre Stack Depth Migration

Kirchhoff's Pre Stack Depth Migration was done using the conditioned decon gather and initial interval velocity model as the input. The interval velocity model of test dip line is shown in Fig. 10.

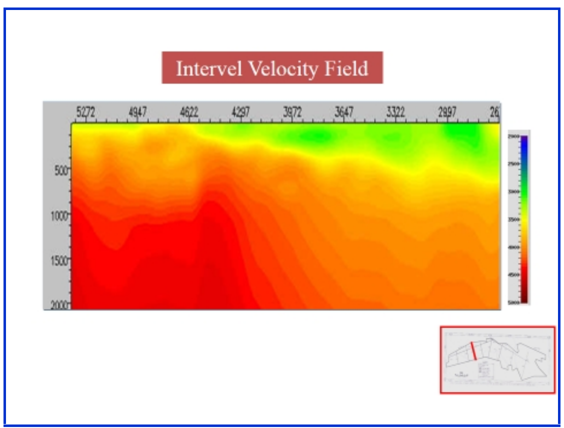

Fig-10: Interval Velocity Field

Velocity Model Refinement Using Tomography

Tomography is a technique used to refine the velocity/depth model when PSDM has been performed with an incorrect velocity model. The depth migrated gathers from PSDM, get stacked applying a mute. The time migrated horizon interpretation are then converted to depth domain i.e. depth horizons using the initial interval velocity model. These depth horizons are then plotted on the initial depth section and the depth interpretations are redefined according to the depth section obtained from PSDM. The model was prepared for the re-defined depth interpretation and the tomographic semblance creation was performed for all the horizons one by one followed by actual picking of depth residuals from the depth migrated gather. Tomography flow is shown in Fig.11 .

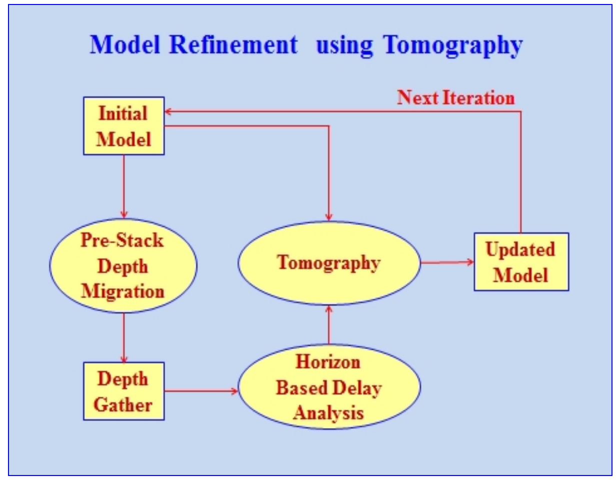

Fig-11: Tomographic Workflow

The schematic processing flow for 2D PSDM for CBM data is shown below:

Process Step	Processing Stage	QC Measures	Observations/measures taken
1	Initial Int. Vel Model Building	DIX Conversion, QC of horzs.	Velocity field for structure Consistency
2	PSDM-Pass-I	Signal Conditioned Gather	Flatness of Depth Gathers
3	RDMO Estimation & Tomographic update of initial velocity	Checking of interpreted horizons	Removal of outliers (Two Pass Tomography)
4	Migration Aperture Test	Comparison of stack section with different apertures	Checking with well information
5	Final PSDM	Flatness of Depth Gathers & Stack response	Checking of depth of coal seams with available well information
6	Scaled to Time	Using the same interval velocity convert the depth Gathers to time	Scaled Gather flatness checking. Stack of scaled gather with mute.
7	Post stack Processing	Cond. of gathers & stack	To minimise spatially smeared random noise

The PSDM section is shown in Fig. 12 .

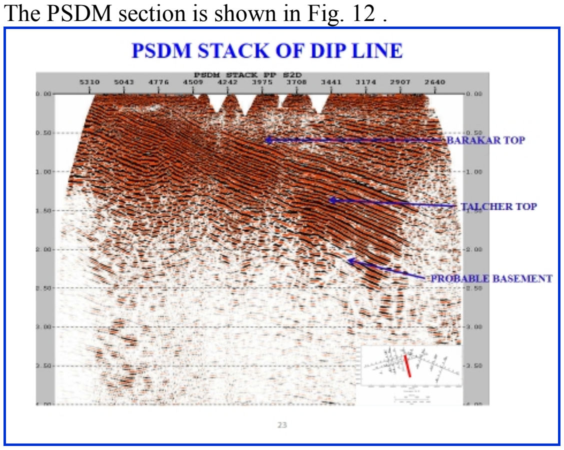

Fig-12: PSDM Section

Quality Assessment

The quality essentially lies on the flatness of the migrated gathers in depth & time domain. Depth gathers already checked while performing tomographic iterations. The residual velocity analysis is performed on PSDM gather S2T to check for any velocity residuals & flatness of gathers in time domain as well. Fig-13 shows Seismic sections showing data match in inline & cross-line crossings.

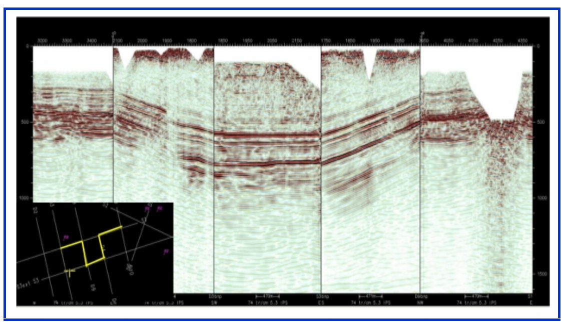

Fig.13 : Seismic sections showing data match in inline and cross-line crossings.

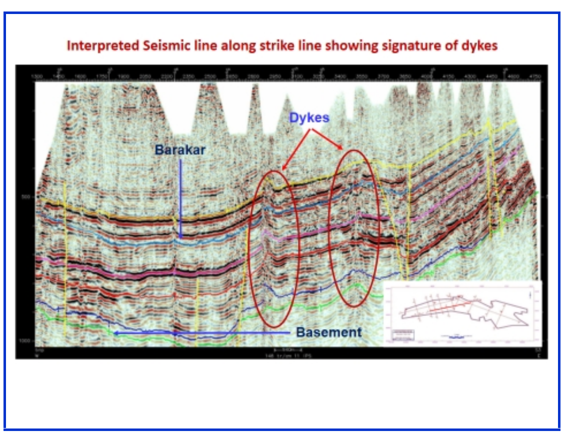

Fig-14: Interpreted Section

Conclusion

The study has brought out the basinal configuration of the CBM block indicating the depositional pattern of the sediments, various subtle highs & lows, and depocentres within the block.

The time structure maps prepared from seismic data for various stratigraphic horizons are in consonance with the depth maps prepared from geological data.

The sub surface fault pattern in the block will help in placing the future core holes/wells in favourable locations.

The presence of dykes was observed in many of the seismic lines which are also exposed on the surface. The reflection characteristic of dykes on the seismic data is chaotic, cut across the sequences and observed in vertical column. Though a number of sills are present in the study area, but it is difficult to identify the same in the seismic due to its conformable relationship with the coal seams and other clastics.

Thus, the processed 2D high resolution seismic data (Fig.14) has resulted in a noticeable improvement in output data quality enabling better interpretation. The processed PSTM & PSDM section reveals an improvement in terms of seismic resolution, noise attenuation and fault definitions.

References

Brian Russell et. al., Noise elimination & Radon transform, The Leading Edge, SEG , Oct. & Nov. 1990

David C Henley,Coherent noise attenuation in the radial trace domain, Geophysics,68,1408 (2003)

Interpretation of High resolution 2D seismic data, Sector-A, Raniganj CBM Block by SK Das etal, Jan., 2015

John C.Bancroft- A Practical Understanding of Pre and Post Stack Migration- Vol:2.

Operational Report of 2D high resolution seismic survey, July, 2014

Acknowledgements

The authors sincerely thank Shri A.K.Dwivedi, Director (Exploration) ,Shri BSN Murthy, ED-Basin Manager-MBA Basin, Shri S.Chakraborty, GM(GP)-HGS to carry out this work and permitting to publish the paper. The authors also thank Shri S K Das, GM-Block Manager-Mahanadi Block, Shri N.K.Punjrath, GM-Block Manager-CBMDP for their help and constant encouragement to carry out this work. The authors also would like to thank to Geophysical Party No-17 and their members for sharing their technical views on the subject and for their constant support through effective interactions in various stages of processing of the data.

Views expressed in this paper are that of the author(s) only and may not necessarily be of ONGC.

****