9th Biennial International Conference
& Exposition on Petroleum Geophysics

"HYDERABAD 2012"

P-281

Gravity-Magnetic & Magneto-Telluric surveys in Purnea Onland Basin, India - A case history.

A.K. Roy, D.P. Paine*, S. Sett, and H.N. Bhattacharya, *ONGC*

Summary

This paper describes a case history of Gravity-Magnetic (GM) and Magneto-Telluric (MT) surveys in parts of Purnea Basin, more precisely, in the NELP Blocks: PA-ONN-2004/1, PA-ONN-2005/1 and PA-ONN-2005/2 carried out during the year 2010-11.

The data acquisition, processing and interpretation were done through a geophysical contractor M/s MSU- Geophysics LLC, MOSCOW, Russia. The main objectives of the Gravity-Magnetic survey were to bring out major tectonic features and estimation of sedimentary thickness in each block. The objectives of Magneto-Telluric survey were to bring out Basement / Trap Top configuration and delineation of major resistivity boundaries to be interpreted in terms of geological boundaries.

The Gravity–Magnetic station interval was kept at 1.0 Km. in the blocks PA-ONN-2004/1 and PA-ONN-2005/2; and 0.6 Km. in the block PA-ONN-2005/1. For MT survey the station interval was kept at 2.0 Km. in the block PA-ONN-2005/1 and PA-ONN-2005/2. A total of 2500 GM stations were observed in each of the above mentioned three blocks. However, volume of MT work was confined to 250 MT stations in each of the blocks, PA-ONN-2005/1 and PA-ONN-2005/2.

The instruments deployed were Scintrex CG5 gravity meter for gravity data acquisition with an accuracy of 5 micro gal; MMPOS-1 for magnetic data recording (Total Magnetic Field) with resolution of 0.001 nT and MTU-A for MT recording.

An absolute gravity base station was established by ONGC at Kolkata by tying the absolute gravity base station situated in New Delhi. All secondary bases which were established within the operational area were also tied with the primary gravity base station established at Kolkata.

The raw gravity data were processed for deriving and subsequent mapping of absolute gravity, absolute gravity anomaly, Free Air anomaly, Bouguer Anomaly; and the magnetic data were processed to compute and mapping of total magnetic field and total magnetic field anomaly. Simultaneous modeling for Gravity-Magnetic anomaly along selective seismic lines / profiles was carried out for integrated interpretation. The major fault trends and different structural highs and lows are well depicted in the Bouguer anomaly / Total Magnetic field anomaly maps.

Each MT sounding data consisting of time series Ex, Ey, Hx, Hy and Hz were processed to compute impedances Zxy and Zyx Vs. period and finally resistivity values ρxy and ρyx Vs. period. 1-D Inversion for all MT stations was carried out to get resistivity Vs. Depth plot. Selective 2-D Inversion along existing seismic profile was also carried out for obtaining resistivity section that could be correlated with selective interpreted seismic sections.

The main elements which are delineated through 2-D Inversion of MT data are: thickness of sedimentary cover, existence of heterogenetic basement and presence of vertical deep rooted conductive layers. These vertical deep rooted conductivity areas are thought to have an origin from Mantle.

Keywords*: Gravity-Magnetic Surveys, Purnea Basin, Bouguer anomaly, Total field magnetic anomaly, Resistivity, 1-D & 2-D GM-MT Models, etc.*

ONGC, 50, Chowringhee Road, 4th floor, Kolkata-700 071;
e-mail address: dppaine@gmail.com

Introduction

Purnea Basin, like other Gondwana basins, exhibits typical rift geometry and it is characterized by normal faults and block tilting that are common features of extensional regimes. All the longitudinal normal faults in this basin have created a series of horsts and half-graben like features by successive spasmodic subsidence along syn-depositional faults. Basement in Purnea basin corresponds to Precambrian age having maximum depth of about 4.5 Km. The oldest sediments encountered in the Purnea basin belong to the Gondwana group.

Hydrocarbon exploration activities in Purnea Basin were initiated since 1956. Ground Gravity-Magnetic survey was carried out by ONGC during 1960-63 followed by preliminary CDP Seismic work. Only recently detailed Gravity-Magnetic (GM) and Magneto Telluric (MT) surveys were planned in the three NELP blocks i.e. PA-ONN-2004/1, PA-ONN-2005/1 and PA-ONN-2005/2 during the year 2010-11. The surveys were carried out by ONGC through contractual services provided by M/s MSU-Geophysics-LLC, MOSCOW. The services included acquisition, processing and interpretation of GM-MT data. The main objectives of the Gravity-Magnetic survey were to bring out major tectonic features and estimation of sedimentary thickness in each block. The objectives of the Magneto-Telluric survey were to bring out basement configuration / trap top configuration and delineation of major resistivity boundaries to be interpreted in terms of geological boundary.

Method

Gravity-Magnetic:

The Gravity-Magnetic survey was carried out by establishing 2500 GM stations in each block (total 7500 stations) with station spacing of 1.0 Km. in the blocks PA-ONN-2004/1 and PA-ONN-2005/2, and 0.6 Km. in the block PA-ONN-2005/1. The entire topographical survey was carried out by deploying DGPS units. The positional accuracy was maintained at ± 2m and elevation accuracy was maintained at ±10cm (above MSL).

An Absolute Gravity Base station was established at Kolkata dedicated for this particular GM survey campaign, by tying the Absolute Gravity Base station situated at New Delhi. All secondary gravity bases established within the survey area were also connected to have origin with respect to the Kolkata gravity base.

The instruments deployed were Scintrex CG5 Autograv gravity meter for gravity data acquisition with accuracy of 5 micro gal; MMPOS-1 for magnetic data recording (Total Magnetic Field) with resolution of 0.001 nT.

Four nos. of CG5 gravity meters were deployed for completing the survey before onset of monsoon. The drift of each gravitymeter was observed before deploying the same in the field for data recording and also at frequent interval for monitoring the drift and also the consistency of the readings. A sample drift curve for a particular gravity meter used in the survey is shown in fig.1

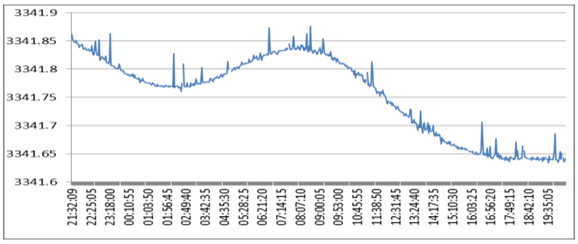

Fig.1: Sample drift curve for a CG-5 Gravitymeter.

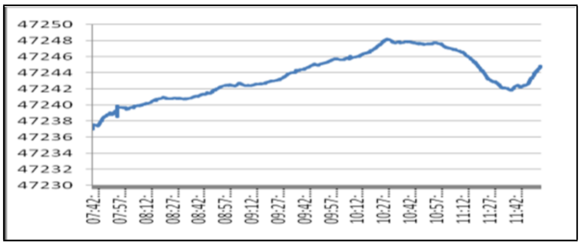

Fig.2: Sample diurnal curve

For magnetic recording four nos. of MMPOS-1 instruments with resolution of 0.001 nT were deployed. Out of the four magnetometers, three nos. were deployed for station readings, whereas, one instrument was dedicated only for

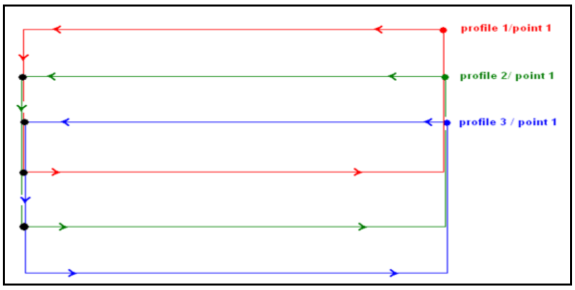

Fig.3: GM station observation loops.

continuously recording of diurnal variations of earth's total magnetic field at an interval of 1 minute (fig.2). This diurnal variations data were used during reduction of magnetic field data for precise estimation of diurnal variation of earth's total magnetic field. The field observation followed pre-determined loops. One operator used to start taking reading from point1 on, say, profile1 and continued taking reading and would complete the arm in the way shown (red arrow) in fig.3. Subsequently, the same operator would start taking GM reading from the end of the profile 4 and after completing the arm would close the loop by taking reading again at Profile 1 / point 1. The second operator started the loop from profile 2 / point 1 and so on. The first point1 on each profile also acted as secondary bases during the survey. The survey also accompanied with repeat observations (more than 2%) of some GM stations for quality control. On an average, the crews were almost observing 50 to 60 GM stations on daily basis. The base camp was initially established at Islampur township for covering the blocks PA-ONN-2005/1 and PA-ONN-2004/1 and later the camp was shifted to Gajole township for covering the block PA-ONN-2005/2.

For magnetic observations stations were sifted within a radius of 100m if magnetic noise was prevailing in the station. Repeatability of readings was maintained to be within 5nT.

Magneto-Telluric:

Magneto-Telluric survey was conducted at an average rate of about three per day. Four sets of MT instrument, namely, MTU-A were deployed for data acquisition after calibrating the receivers and sensors. The layout of the sensors is shown below in Fig.4.

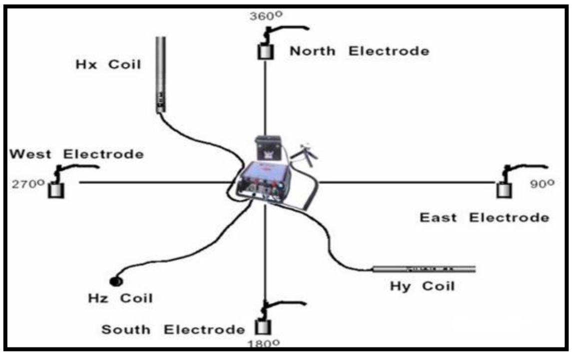

Fig.4: Typical MT observation layout.

The station interval was 2.0 Km.. However, in case high tension line was passing within 200m. of the MT stations, the observation was shifted to such position so that the electrical interference was minimum. The electrodes were planted (telluric lines) on flat ground because electric fields of filtration origin occur on slopes. Magnetic sensors were put far away from sources of vibration.

The duration of the recording was fixed at about 8 hours based on experimental work. The five time series which were recorded were, Ex, Ey, Hx, Hy and Hz. (fig.4). This enabled recording of the impedances in the range 0.0025-100 sec. to have optimal skin depth / depth of penetration of MT signal. The direction of Ex was maintained along the regional dip i.e. 155 degree north.

Processing of GM data:

Processing of GM data allowed obtaining gravity and magnetic maps, after including required corrections. For field processing following corrections were estimated utilizing following relationships:

- Bouguer correction:
  $\Delta g_{Bouguer} = (0.3086 - 0.0419 * \sigma * h)$ m.gal
- Free Air correction:
  $\Delta g_{free\ air} = 0.3086 * h$ (m.gal)
- Relief correction:
  $\Delta g_{relief} = 0.0419 * \sigma * h$ (m.gal)
  where, h = elevation in meter,
  σ = interlayer density in gms/cc
- Bouguer anomaly = $g_{observed} - g_{theoretical} + \Delta g_{Bouguer\ cor.}$
- Free Air anomaly = $g_{observed} - g_{theoretical} + \Delta g_{free\ air\ cor.}$

For estimation of $g_{theoretical,}$ international gravity formula of 1930 as given by the following relationship was used:

$$g_{theoretical} = 9.78049(1+0.0052884\sin^2\lambda - 0.0000059\sin^2 2\lambda)$$

Where, λ = Latitude at the point of calculation i.e. gravity station

For magnetic data, the first processing job was to correct each station value for diurnal variation by using daily recorded diurnal variation readings in the field. Once the diurnal correction was applied, the Total magnetic field anomaly was simply the difference between the observed value – normal total magnetic value i.e.

$\Delta Ta = (T_{observed} - T_{normal})$ in nT.

Following outputs were generated for GM data interpretation for all the three blocks:

- Contour map of absolute gravity values of the established gravity stations.
- Free Air Anomaly contour maps.
- Bouguer anomaly contour maps
- Total intensity magnetic field contour maps.
- Total intensity magnetic anomaly maps.
- Total integrated list of the reduced values of the GM data in MS Excel Format.

Processing of MT data:

Processing of MT data, i.e. of time series allowed obtaining Six complex-valued functions of frequency, four components of impedance tensor [Z] and two components of tipper matrix [W]. During data processing noises, mainly caused by sources of industrial EM fields, are depressed. On the first stage of data processing standard software SSMT2000 developed by Phoenix Geophysics was utilized. It implements approach, based on spectral analysis of stochastic processes (Zhdanov and Keller). It includes:

1) Computation of auto- and cross-correlation functions for all pairs of channels and Fourier transform of these functions to determine auto- and cross-power spectra.
2) Rejection and averaging of power spectra, corresponding to different intervals of time, using robust statistics methods, and their recalculation to components of impedance tensor and tipper matrix.

Attenuation of EM field, caused by local sources, was performed using records obtained at another (remote) site, at which this noise is absent (it is called "uncorrelated noise"). Software known as 'MT Editor' was also used to visualize frequency dependences of impedance tensor and tipper matrix components, allows removing outliers and plot smooth curves (fig.5).

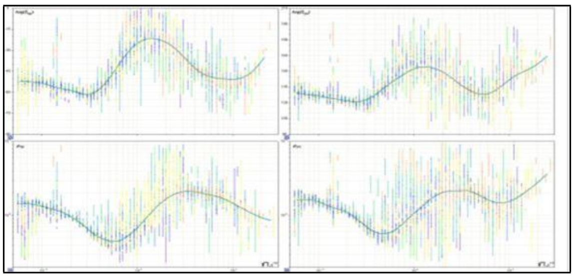

Fig.5: Sample MT curves showing Zxy, Zyx, ρ_{xy} and ρ_{yx} Vs. period.

In addition to above, polar diagrams and skewness parameters were generated. The polar diagrams and skewness parameters characterize horizontal in homogeneity of the ground, and display how modulus or phase of impedance tensor component varies when coordinate system is rotating. Example of skewness is shown in fig.6.

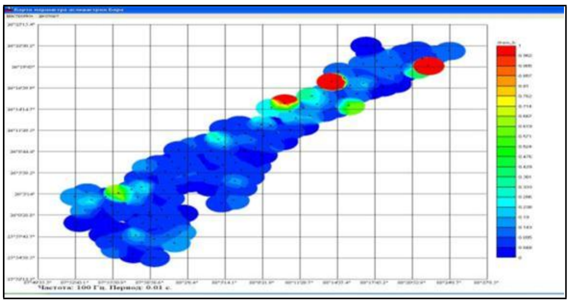

Fig.6: Skew Parameter with period 0.01s (Block : PA- ONN-2005/1)

We should note the shift between ρ_{xy}, and ρ_{yx} curves along vertical axis due to near-surface in homogeneities, distorting information about deep structures. To minimize such distortions, static shift correction of ρ_{xy} and ρ_{yx} curves was performed. Curve at each site was shifted to a new level so that this level smoothly varied along the profile.

Interpretation of GM-MT data:

The maps and models were interpreted qualitatively as well as quantitatively for all the three blocks covered in the survey.

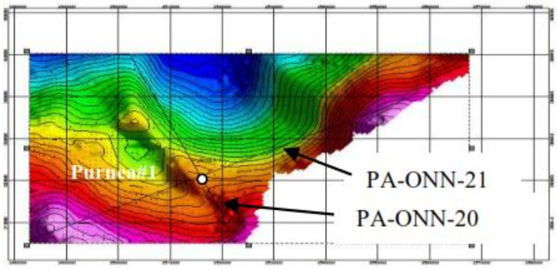

Fig.7: Bouguer Anomaly map in the block:PA-ONN-2004/1.

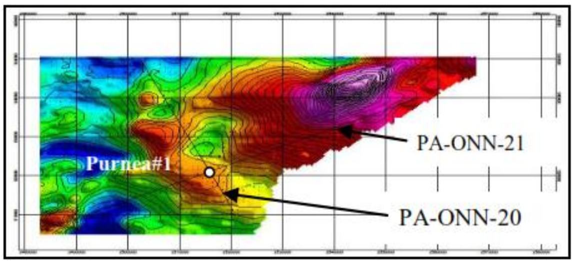

Fig.8: Total Magnetic Field Intensity Anomaly map in the block: PA-ONN-2004/1.

The gravity-magnetic anomaly maps as shown above in fig.7 and fig.8 for the block PA-ONN-2004/1 bringing out the shallowest and deepest parts of the basin coinciding with lower to higher (negative) anomaly, respectively. The depth models shown in fig.9 and fig.10 for the same block depict basement depths to be lying within the range of 2.5 to 3.5 Km. along NE-SW direction and 2.0 to 3.2 Km. along the direction NW-SW.

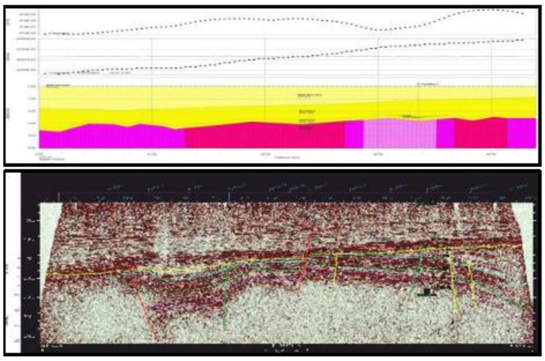

Fig.9: Modeled output along seismic line PA-ONN-20 in the block: PA-ONN-2004/1 based on GM data

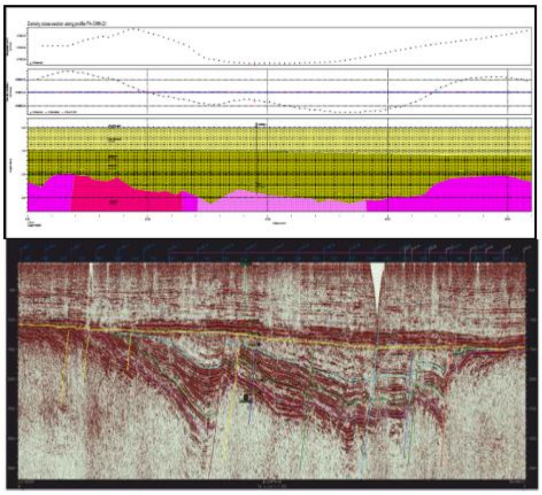

Fig.10: Modeled output along seismic line PA-ONN-21 in the block: PA-ONN-2004/1 based on GM data

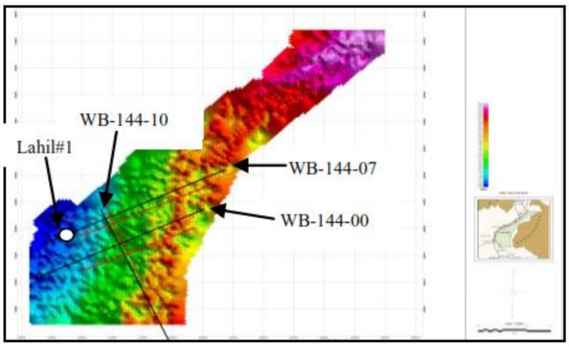

Fig.11: Bouguer Anomaly map in the block: PA-ONN-2005/1.

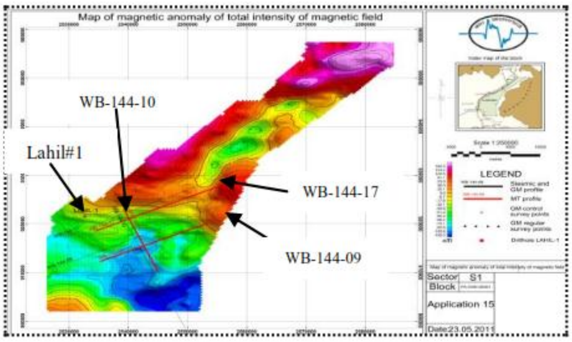

Fig.12: Total Magnetic Field Intensity Anomaly map in the block: PA-ONN-2005/1.

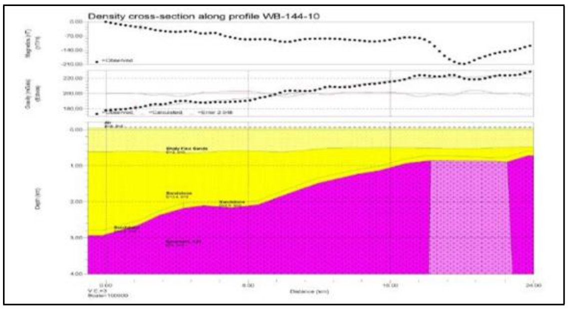

Fig.13: The depth model based on Gravity data along profile WB-144-10 in the block: PA-ONN-2005/1

In case of the block PA-ONN-2005/1 the Bouguer anomaly map (fig.11) and total field anomaly map (figs.12) also corroborate with each other as per as depth to basement is concerned. The depth model (fig.13) along the profile WB-144-10 depicts monotonous dip of the basement with depths ranging from 1Km to 3 Km. An additional feature is observed characterized by low magnetic anomaly located almost over Purnea#1 well (fig.9) and also over the extreme south end of the profile WB-144-10 (fig.13). This kind of anomaly is interpreted to be originating from low magnetic intrusion within the basement rock. Probably, it can be a kind of mantle plume but additional detailed surveys and further studies are required to establish the postulation. Depth model in the block PA-ONN-2005/2 along the lines PA-2005-2-2 (fig.16) and PA-2005-17 (fig.18) based on only gravity data (fig.14) also reveal the basement topography which is in line with the observations available from seismic data.

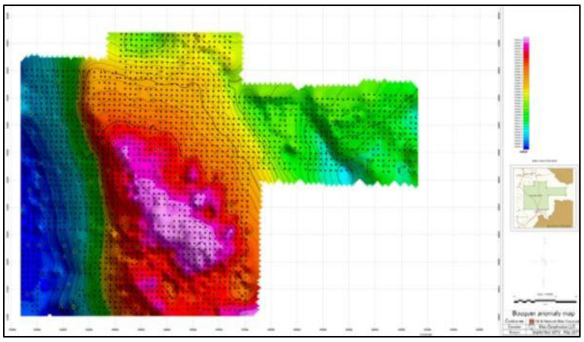

Fig.14: Bouguer Anomaly map in the block: PA-ONN-2005/2

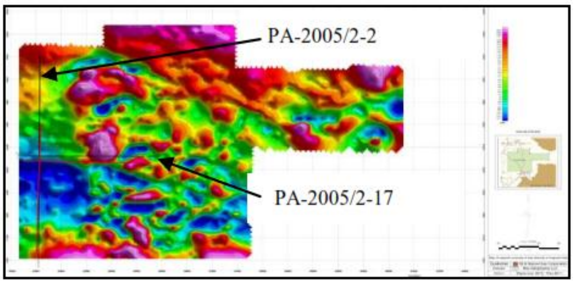

Fig.15: Total Magnetic Field Intensity Anomaly map in the block: PA-ONN-2005/2

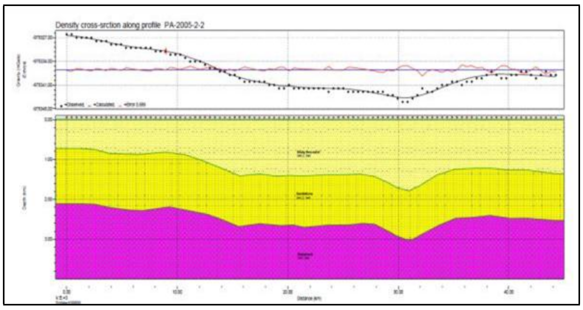

Fig.16: The depth model based on Gravity data along line PA-2005-2-2 in the block: PA-ONN-2005/2-2

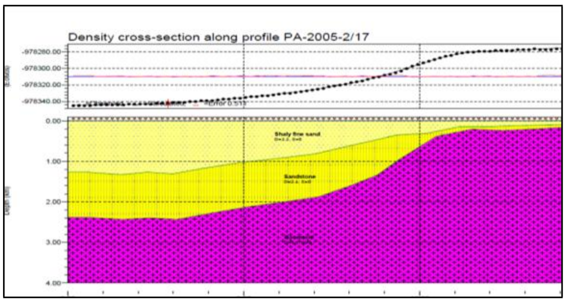

Fig.17: The depth model based on Gravity data along line PA-2005/2-17 in block PA-ONN-2005/2

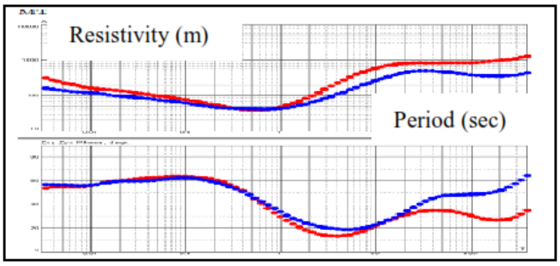

Fig.18: Apparent resistivity (Ohm m) Vs. Period (T)

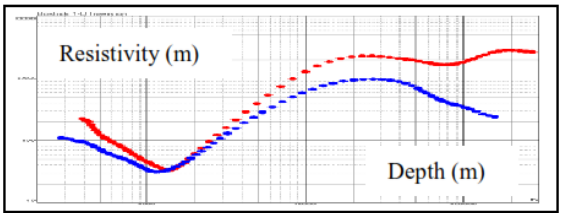

Fig.19:1-Dimensional inversion result of MT station no.3

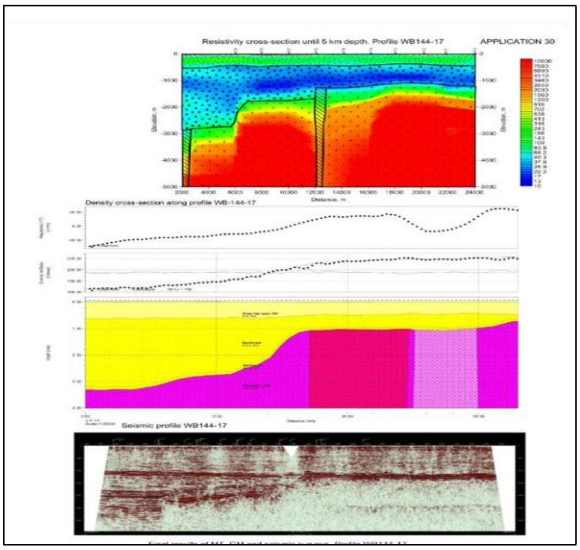

Fig.20: Final combined modeled output of GM-MT data along one dip Seismic line WB-144-17 in the Block PA-ONN- 2005/1.

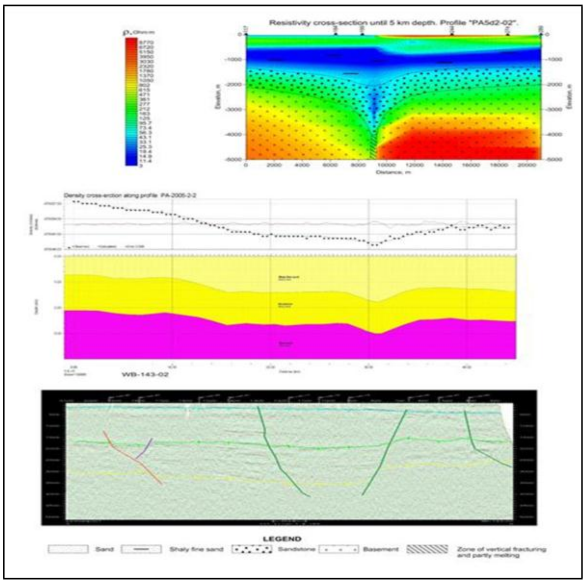

Fig .21: Final combined modeled output of GM-MT data along one dip Seismic line WB-143-02 in the Block PA-ONN- 2005/2.

According to the MT data three layers have been found in both the blocks i.e. PA-ONN-2005/1 and PA-ONN-2005/2, shown in fig.20 & fig.21, respectively, which are basically 2-D MT depth models. However, 1-D depth models for each MT station have been done for further use (fig.18 & 19). The origin of the different resistance may be connected with the difference of the lithology of the rocks down to the cross-section from sands to sandstones. The negative anomalies of the magnetic field are considered to be an interesting feature and interpreted to be associated with the negatively magnetized intrusive vertical rock bodies within the basement. Heterogeneity of the basement can be noticed in the interpreted model. The presence of the narrow deep rooted conductive zones is also supposed to be an important feature of the models. The origin of these anomalous zones can be linked with the deep subsurface faults extending down to the mantle with the overlying sedimentary cover. This feature of the models may be indicative of mantle origin of hydrocarbons.

Conclusions

- The depth models derived from observed Gravity-Magnetic and Magneto-Telluric data in parts of Purnea Basin closely match with the known Basement topography of the Basin.
- An important feature in the GM-MT models represented by narrow shaped zone that extends very deep and characterized by lower magnetic but higher conductivity. These features are interpreted to be associated with deep faults connecting the mantle and subsequent occurrence of intrusive activities replacing the higher resistivity basement rocks with lower resistivity intrusive. This feature of the models may be indicative of mantle origin of hydrocarbons.

References

Gravity-Magnetic & Magneto-Telluric Survey in Purnea Onshore Basin for field season 2010-11, Purnea Basin, Blocks: PA-ONN-2004/1, PA-ONN-2005/1 and PA-ONN-2005/2, Internal Reports, 2010, ONGC, India.

Acknowledgement

Authors extend their sincere thanks and gratitude to Shri D.P. Sahasrabudhe, ED-Basin Manager, MBA Basin, ONGC, Kolkata and Shri B.K. Das, GGM-Head, Geophysical Services, MBA Basin, ONGC, Kolkata for their encouragement and permission to publish this paper.