



Imaging of Sub-Basalt Geology in the Deccan Volcanic Province of Central India from Gravity Studies

*D.T. Diljith, Niraj Kumar and B. Singh**

*National Geophysical Research Institute, Uppal Road, Hyderabad – 500 007 (A.P), India. *bsingh_ngri@yahoo.co.in*

Summary

Presence of thick sequence of Mesozoic sediments underneath the Deccan volcanic cover in the north west India has opened a new frontier for hydrocarbon exploration. Recently, detailed gravity measurements were carried out over the Deccan Syncline of central India as a part of integrated geophysical studies for the delineation of subtrapped Mesozoic sediments.

Bouguer anomaly map of the region depicts number of significant short wavelength anomalies due to shallow sources superposed on long wavelength regional anomalies due to deep-seated sources. Important among them are (i) an ENE-WSW trending broad relative gravity high associated with the Satpura mountains belt suggests presence of high density magmatic material at the deeper level (ii) a large wavelength regional gravity low in the southern part bears an inverse correlation with topography of Ajanta hills indicating mass deficiency beneath the excess topography load due to isostatic compensation (iii) short wavelength gravity lows suggest the presence of sediments below the volcanic cover.

Power spectrum of the Bouguer gravity anomalies have been effectively used to decompose the gravity field into its component parts arising from sources lay at different depths. Since our interest in hydrocarbon exploration lies in shallow targets, contributions from deep seated sources are removed employing a high pass Butterworth filter with a cutoff length of 125 km. The resultant residual map shows anomalies that are attributed to the basement and sub-basalt sedimentary depocentres. Inversion of residual field in terms of a single-density interface reveals presence of thick Subtrappean sediments in the region bounded by Tapti and Burhanpur lineament.

Key words: Mesozoic sediments, basalt, gravity modeling, frequency filtering

Introduction

Presence of hydrocarbon in the Mesozoic sediments currently holds nearly half of the world's reserves. In India, significant hydrocarbon finding in this stratigraphic sequence has not been established largely because major part of the Mesozoic sediments is underlying the Deccan traps. Detection and mapping of the Mesozoic sediments below the Deccan trap has been a long-standing complex geophysical problem facing the oil industry. The vast sheet of volcanic cover, which overlies the Mesozoic sediments acts as a geophysical shield and inhibit the effective use of conventional seismic techniques. To explore the Mesozoic formations beneath the volcanic cover, an integrated geophysical approach involving the application of four different geophysical methods viz: seismic refraction, gravity, magnetotelluric (MT) and deep resistivity sounding were tried in region of Saurashtra and Kuchchh and substantial

thickness of Mesozoic sediments have been delineated (NGRI, 1998). In this paper, results of gravity surveys carried out as a part of integrated geophysical studies in the Narmad-Tapti region of the Deccan volcanic province are presented.

General Geology and Tectonics

The surface geology of the study area is largely covered by the Deccan Traps with a central belt of Quaternary sediments (Figure 1). The western part of the east west trending Narmada-Tapti region constitutes the Deccan syncline of central India. Mesozoic sediments occur throughout the western part of the Narmada valley as both inliers and outliers which appear to have been deposited during Cretaceous times in a depression between the Satpura and the Vindhyan range (Murthy and Sharad, 1981). These sediments were uplifted, faulted, intruded, and finally covered by the Deccan



"HYDERABAD 2008"

basalts (Bhattacharji et al., 1996). The most significant tectonic element of the study area is Narmada-Son Lineament (NSL). It is believed that the NSL represent an intra-plate rift system with a central horst (Satpura Mountains) bounded on each side by grabens: the Narmada graben on the north and the Tapi graben on the south (Nayak, 1990; Verma and Banerjee, 1992).

The topography (Figure 2) of the Deccan Syneclise is characterized by E-W to NNE-SSW trending Satpura Mountains in the centre having altitude ranging from 150 to 400 m with sporadic value reaching as high as 1000 m. The E-W trending hill ranges to the south of the Tapi River represent Ajanta Plateau. Towards the north of NSL, Vindhyan Mountain ranges represents the up land in central India.

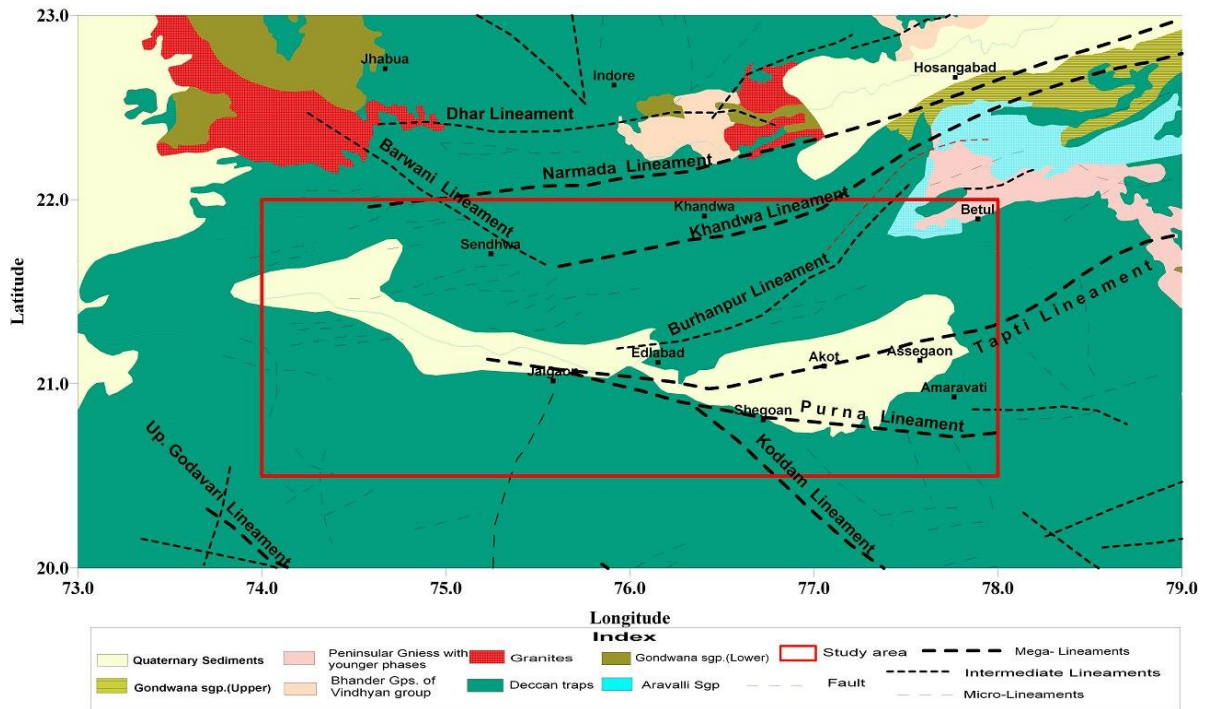


Figure 1: Geology and Tectonics of the Deccan Syneclise, Central India

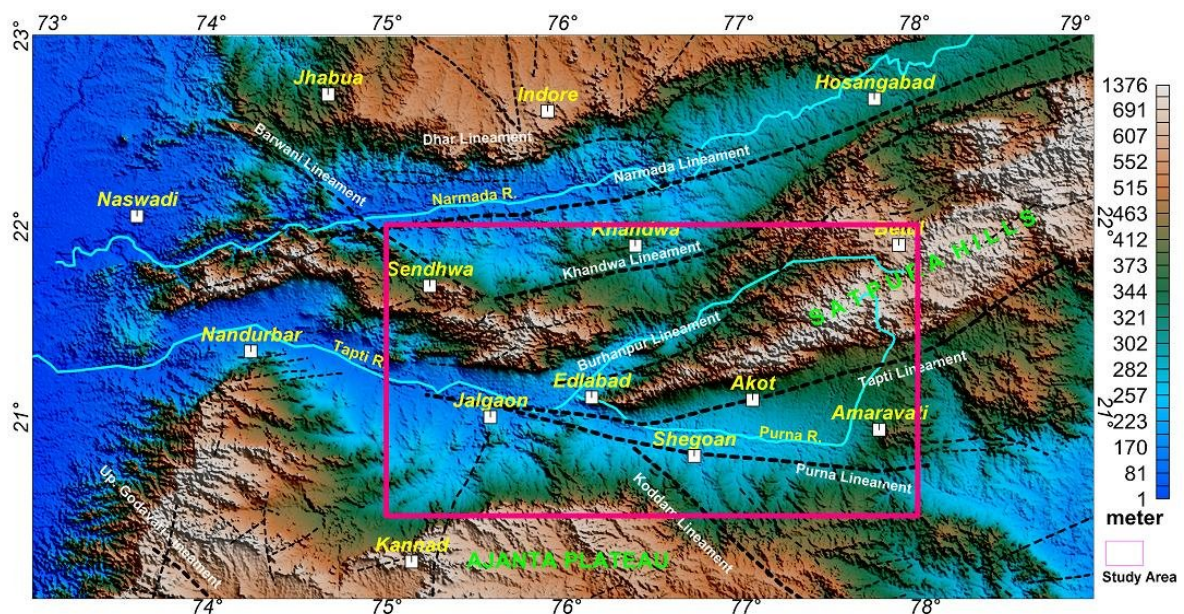


Figure 2: Topographic Map of the Deccan Syneclise



"HYDERABAD 2008"

The Gravity Data

As a part of integrated geophysical studies in the Narmada-Tapti region, 8000 gravity measurements were made with reference to IGSN 71 datum and gravity anomalies were calculated using GRS80 international gravity formula. After applying the necessary corrections, Bouguer anomalies were calculated using standard crustal density of 2.67gm/cm^3 . Figure 3 depicts the Bouguer anomaly map of the Narmad-Tapti region of Deccan Syncline.

small wavelength relatively gravity lows (L2, L3 & L4) may be due to subtrappean sediments. A circular gravity high (H2) may be attributed due to high density intrusive

The most conspicuous feature of the map is the relative gravity high (H1), aligned in the E-W direction, between the rivers Narmada and Tapti. This relative gravity high associated with the Satpura Mountains was interpreted due to thick 10-15 km mafic body at the base of the crust that finds support from deep seismic sounding studies along Ujjain-Mahan profile (Singh and Meissner, 1995; Reddy et al., 1997). The other prominent features on the map are the relative gravity lows towards south of the Tapti (L1) which show inverse correlation with topography of Ajanta mountains. Nearly ENE-WSW trending

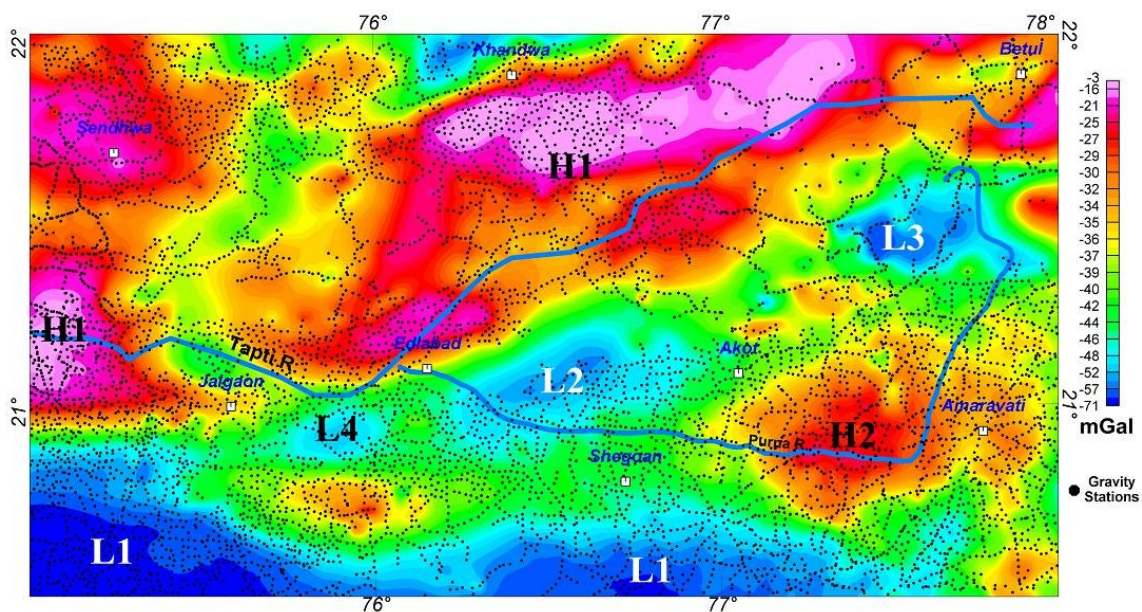


Figure 3: Bouguer Anomaly Map of the study area

Wavelength filtering

Since the Bouguer anomaly represents the total sum of gravitational attraction of all subsurface causative sources, decomposition of gravity anomaly in to its component part is an integral part of gravity interpretation. Although, there is no unique method for separation of anomaly components, wavelength-filtering technique is an efficient and easy method for decomposition of anomalies. In the spectral analysis approach, depth to various sources can be estimated based on their frequency content. In general, high frequency anomalies are due to shallow sources, while low frequency anomalies are due to sources at greater depth. The radial averaged power spectrum of the data shows a curve decaying with increasing frequency and depth to the statistical ensemble of sources is determined from the slope of the log (power) spectrum. The slope of each segment provides the average depth estimate of the ensemble of sources lying at different depths. The cut-off wave number corresponding to different linear segments

on the frequency spectrum plot can be judiciously used in the filter operator to filter the different frequency contents present in the observed data leading to regional and residual maps. Figure 4 shows the power spectrum of the Bouguer anomalies, which indicates distinct segments corresponding to sources at a depth of 38.0, 11.6, 3.4, 1.85 and 1.2 Km.

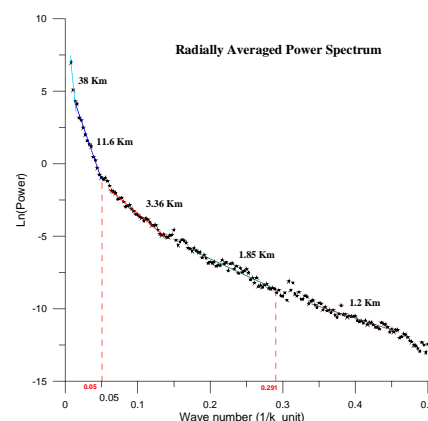


Figure 4: Power Spectrum of the Bouguer Anomalies



Analysis and Interpretation

In order to decompose the observed gravity fields into different component, low pass and high pass frequency filters were applied corresponding to cutoff wave numbers as shown in Figure 4. Since our interest in hydrocarbon exploration lies in shallow targets, contributions from deep seated sources are removed employing a high pass Butterworth filter with a cutoff wave number of 0.05 (wavelength= $2\pi/\text{wave number}$ =125 km). The resultant residual map (Figure 5) shows

anomalies that are attributed to the basement and sub-basalt sedimentary depocentres.

The most significant among them are ENE-WSW trending moderate amplitude negative anomalies (L1) in the central part of the region bounded by positive gravity anomalies (H1& H2) on either side. These negative anomalies are interpreted due to sub-trappen Mesozoic sedimentary basins. Gravity low (L2) in the western part represent yet another Subtrappen sedimentary depocentre.

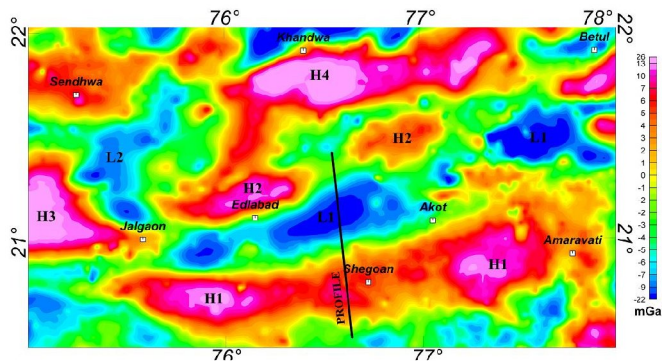


Figure 5: Residual Gravity Map derived from a High-Pass Butterworth Filter applied to Bouguer anomalies with Cutoff Wavelength of 125 Km

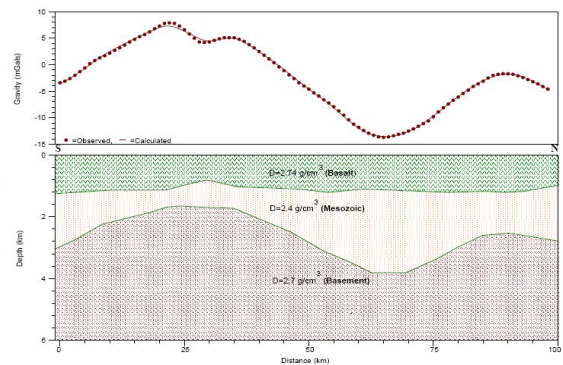


Figure 6: Basement structure derived from modeling along S-N profile marked in (Fig 5.)

In order to know the basement geometry, residual anomalies along the profile marked in Figure 5 has been modeled using 2D GMSYS software. The gravity low in the center of the profile has been accounted due to low-density Mesozoic sediments (density 2.4 g/cm³) sandwiched between the high-density basalt (2.74 g/cm³) of about 1.0 Km thickness on the top and basement (2.70 g/cm³) below (Figure 6). The model shows thick subtrappean Mesozoic sediment attaining a thickness of more than 2.5 Km.

5) using high pass Butterworth filter with a cut off wave length of 22 km. representing the last segment on the power spectrum plot. The resultant residual map (Figure 7) shows small amplitude anomalies which may be caused due to variations in the thickness of the basalt. These anomalies were subjected to a gravimetric single density-interface inversion procedure based on Parker's (1973) algorithms (Ortiz, 2005) to provide the geometry of basalt-sediment interface for a density contrast of 0.34 g/cm³. Figure 8 shows the thickness of basalt which varies from 800m to about 1.1Km.

Contribution of basaltic layer lying on the top of the sediments were removed from the residual map (Figure

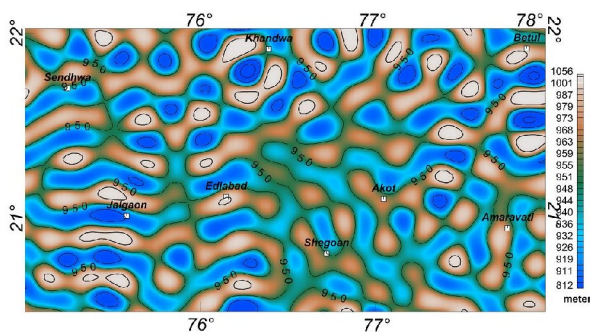


Figure 7: Residual Gravity Anomaly Map Derived from High-Pass Butterworth Filter with Cutoff Wavelength of 22 Km representing shallow source

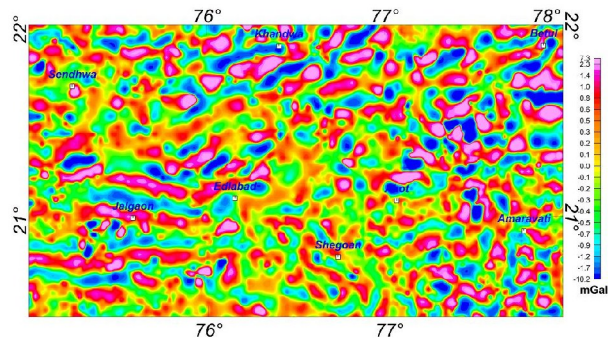


Figure 8: Variations in Thickness of Basalts Derived from Inversion of Residual Gravity Anomalies (Fig 7.) Using Parker' Algorithm



"HYDERABAD 2008"

To map the basement configuration, effect of basaltic layer (Figure 7) was removed from the residual anomaly map (Figure 5). The resultant map is shown in Figure 9 which is equivalent to band pass filter with lower and higher cut off wavelength of 22 km and 125 Km. The map shows medium amplitude and medium wavelength gravity anomalies associated with basement structures and probably represent pre-basalt extensional tectonics. Gravity lows may be attributed due to sediment fill and highs may be caused due to basement up warp. Based on the single density-interface inversion procedure as outlined earlier, inversion of residual gravity anomalies

in figure 9 for a density contrast of 0.3 g/cm^3 provides the basement geometry which is shown in figure 10. It is observed that the depth to the basement varies from about 1.1 Km to about 4.0 Km. The most significant feature of the map is the ENE-WSW trending basement depression bounded by Tapti and Burhanpur lineament. After removing the thickness of basaltic layer from the basement depth the resultant map shows the thickness of the sediment in the study area (Figure 11). It varies from as low as 100 m to about 3.0 Km. and therefore has a good potential for detailed hydrocarbon exploration.

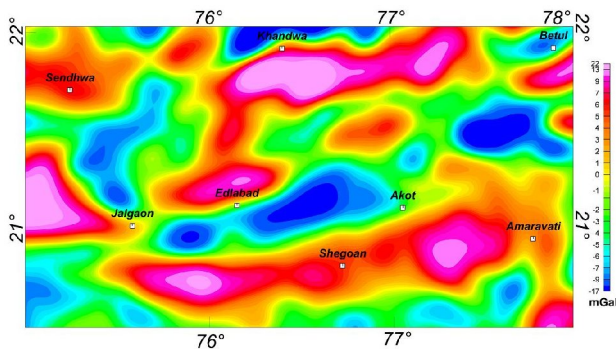


Figure 9: Residual Gravity Anomaly Map Derived from Bandpass Filter Corresponding to Lower and Higher Cutoff Wavelength of 125 Km and 22 Km Respectively. Residual Anomaly Probably Represents Variations in Basement Depth

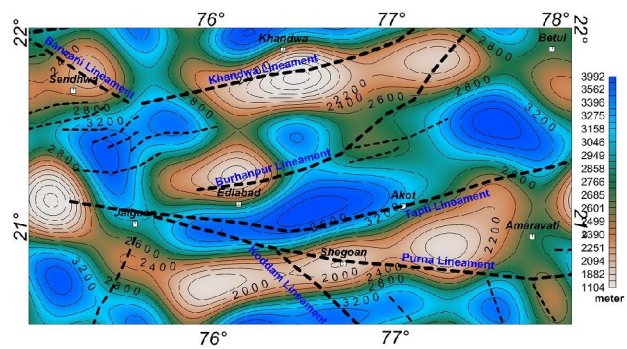


Figure 10: Depth to the Basement Derived from Inversion of Residual Anomalies (Fig 8.) Using Parker' Algorithm

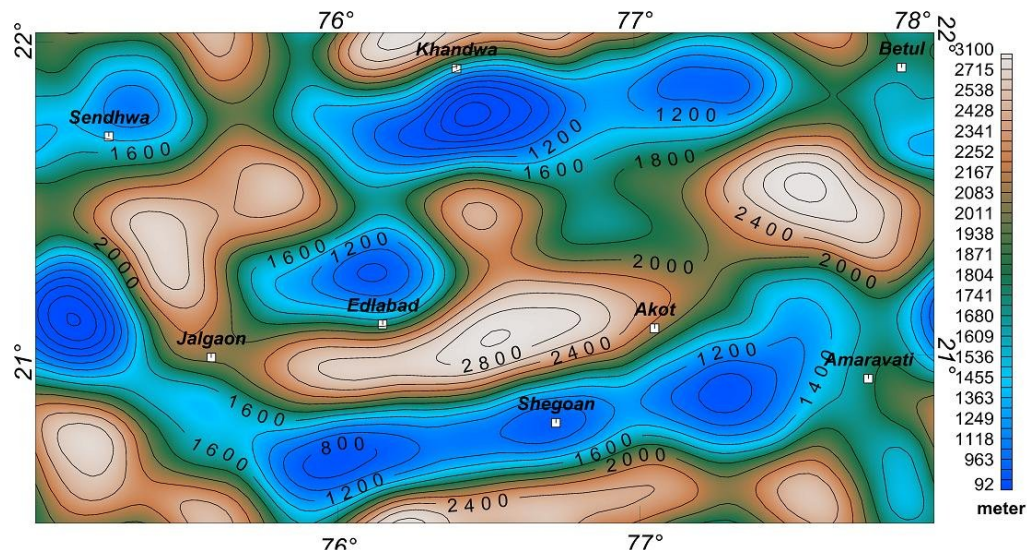


Figure 11: Thickness of Subtrappean Sediments Derived by Removing the Thickness of Basalts from the Basement Depth



"HYDERABAD 2008"

Conclusions

Gravity investigations in the Narmada-Tapti region of Deccan Syncline have brought out the following:

1. ENE-WSW trending dominant relative gravity high in the Bouguer anomalies represent regional field and has been effectively filtered using High pass filter with a cut off wavelength of 125 km.
2. High pass filtered residual gravity field reveals ENE-WSW trending prominent negative anomalies along the Narmada-Tapti zone bounded by positive anomalies on either side reflecting basement depression and up warp which probably represent pre-basalt extensional tectonics.
3. Quantitative modelling of residual gravity field has brought out prominent subtrappean Mesozoic basins along the Tapti zone where the subtrappean sediments attain the maximum thickness of more than 2.5 km.
4. Inversion of residual anomalies in terms of single-density interface has finally brought out sediment thickness map which clearly reveals thick Mesozoic sedimentary basin in the region bounded by Tapti and Burhanpur lineament.
5. Presence of widespread subtrappean Mesozoic basins in the Tapti region leads us to believe that during the early Cretaceous Era there was a wide shelf which received thick deltaic sediments. It is therefore inferred that the Deccan Syncline region of central India has large potential for hydrocarbon exploration.

Acknowledgements

We are thankful to the Director, Dr. V.P. Dimri, for granting permission to present and publish this paper. We are also thankful to CSIR for providing financial support to carry out detailed gravity studies in the Deccan Syncline region of Narmada-Tapti region.

References

- Bhattacharji, S., Chatterjee, N., Wampler, J.M., Nayak, P.N. & Deshmukh, S.S., 1996, Indian intraplate and continental margin rifting, lithospheric extension, and mantle upwelling in Deccan flood basalt volcanism near the K/T boundary: evidence from mafic dike swarms: *Journal of Geology*, 104, 379-398.
- Biswas, S.K., 1987, Regional tectonic framework, structure and evolution of western marginal basin of India: *Tectonophysics*, 135, 305-327.
- Murthy, P.V.V.G.R.K. & Sharad, M.K., 1981, The Narmada-Son lineament and the structure of Narmada rift system: *Journal of Geological Society of India*, 22, 112-120.
- NGRI, 1998, Integrated geophysical studies for Hydrocarbon exploration in Saurashtra, India. NGRI Technical Report No: NGRI-98-EXP-237 (Restricted).
- Nayak, P.N., 1990. Deep crustal configuration of Central India: Geological Survey of India Special Publication, 28, 67-98.
- Ortiz, D.G., and Agarwal B.N.P., 2005, 3DINVER.M: A MATLAB program to invert the gravity anomaly over a 3-D horizontal density interface by Parker-Oldenburg's algorithm, *Computers & Geosciences*, 31, 513-520.
- Parker R.L., 1972, The rapid calculation of potential anomalies. *Geophysical Journal International*, 31, 447-455.
- Reddy, P.R., Mall, D.M. & Prasad, A.S.S.R.S., 1997, Subhorizontal layering in the lower crust and its tectonic significance in the Narmada-Son region, India: *Pure and Applied Geophysics*, 149, 525-540.
- Singh A.P. & Meissner R., 1995, Crustal configuration of the Narmada-Tapti region (India) from gravity studies: *Journal of Geodynamics*, 20, 111-127.
- Verma, R.K. & Banerjee, P., 1992, Nature of continental crust along the Narmada-Son lineament inferred from gravity and deep seismic sounding: *Tectonophysics*, 202, 375-397.