

Gravity Anomalies and Basement Structure below Deccan Traps in Gondwana Basins of Eastern Maharashtra, India

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ABSTRACT

The Gondwana basins with their complex tectonics and high hydrocarbon potential have become targets of serious geophysical investigations in the last decade. It is increasingly concluded that the Deccan Syncline (DS) in the west and central regions of India is underlain by highly prospective hydrocarbon bearing Gondwana basins. However, the nature and thickness of sedimentary basins and the associated basement structure are yet to be geophysically ascertained. In this paper, the Bouguer gravity anomalies of Gondwana basins of Eastern Maharashtra are modelled to infer the thickness and structure of the basins beneath the Deccan trap cover. The modelling studies along six profiles indicate the depth to the basement and thickness of sediments is gradually decreasing from N to S. The study also indicates that the basement undulates with alternative highs and lows with concealed sub-trappean rift basins at the eastern extremity of Deccan Syncline (DS).

Key words: Deccan Traps, Gondwana basins, Gravity anomalies, Modelling and Basement structure.

INTRODUCTION

With the discovery of commercial grade oil and gas fields and Coal Bed Methane in the Gondwana sediments of the Krishna–Godavari sub basins and in the northern part of the Godavari basin in 1978, Gondwana basins of India are being increasingly subjected to intensive geophysical exploration (Subramanian, 2003). The prime objective of geophysical investigations by different investigative agencies is to estimate the thickness of the Gondwana sediments underneath the Deccan trap cover. The initial geophysical investigation by ONGC in Nagpur-Pusad-Betul area brought out the thickness of sediments as about 2.1 Km in the West of Wardha town and 4.17 to 5.74 Km near Katol (Ghildyal, 1985). Ramakrishna et al., (1999) brought out a comprehensive Bouguer gravity anomaly map (on 1:250,000 scale) based on the regional gravity surveys conducted by GSI in different blocks of DS for Gondwana basins of eastern Maharashtra region covering parts of Nagpur, Wardha, Yeotmal and Chandrapur districts. They also attempted for a qualitative and quantitative interpretation of residual gravity anomalies along two profiles constructed from this map. They estimated the thickness of sediments (the Gondwana and Vindhyan put together) as varying between 3 and 4 km for a constant density contrast of -0.3gm/cc between the sediments and the Archean basement. However, their profiles did not cover all the possible depositional areas. Serious efforts were made by several other investigators (Sarma et al., 2004; Jitendra Kumar et al., 2004; Yash Rastogi et al., 2014) to press into service deep electromagnetic and

magnetotelluric (MT) techniques to understand the nature of the hidden sediments beneath the Deccan traps. Of the two, MT has proven to be the effective technique in identifying the sediments below volcanic rocks like basalts as demonstrated by the results obtained from Saurashtra Peninsula, India (Sarma et al., 1992; Srinivasan and Khar, 1995), Columbia River Basaltic areas in USA (Corine Prieto et al., 1985) and Parana basin in Brazil (Stanley et al., 1985; Padilha et al., 1992). The success has been attributed to the higher conductivity of the sediments in relation to the overlying volcanic rocks and the underlying Archean basement. Chakravarti et al., (2007) attempted 3D modelling of Katol gravity low in the Gondwana basins of eastern Maharashtra region after calculating and removing the effect of the basalts from the gravity anomalies and deep resistivity values. According to them the thickness of basalts around Katol varies between 100 and 400 m with an average of 300 m and the maximum depth to the basement is in excess of 3.2 km. Considering the MT and Gravity data modelling, Jitendra Kumar et al., (2004) and Sarma et al., (2004) have indicated that the basement depth is of the order of 5 km in Katol low. However, most of these studies are either limited to only Katol gravity low or qualitatively interpreted.

In this paper an attempt is made to model the gravity anomalies along six profiles covering all possible depositional areas constructed from the gravity anomaly map of Ramakrishna et al., (1999) to identify nature and structure of the basement and thickness of sediments below trap cover. The objective is to understand the broad architecture of Nagpur-Wardha sub basin which is believed

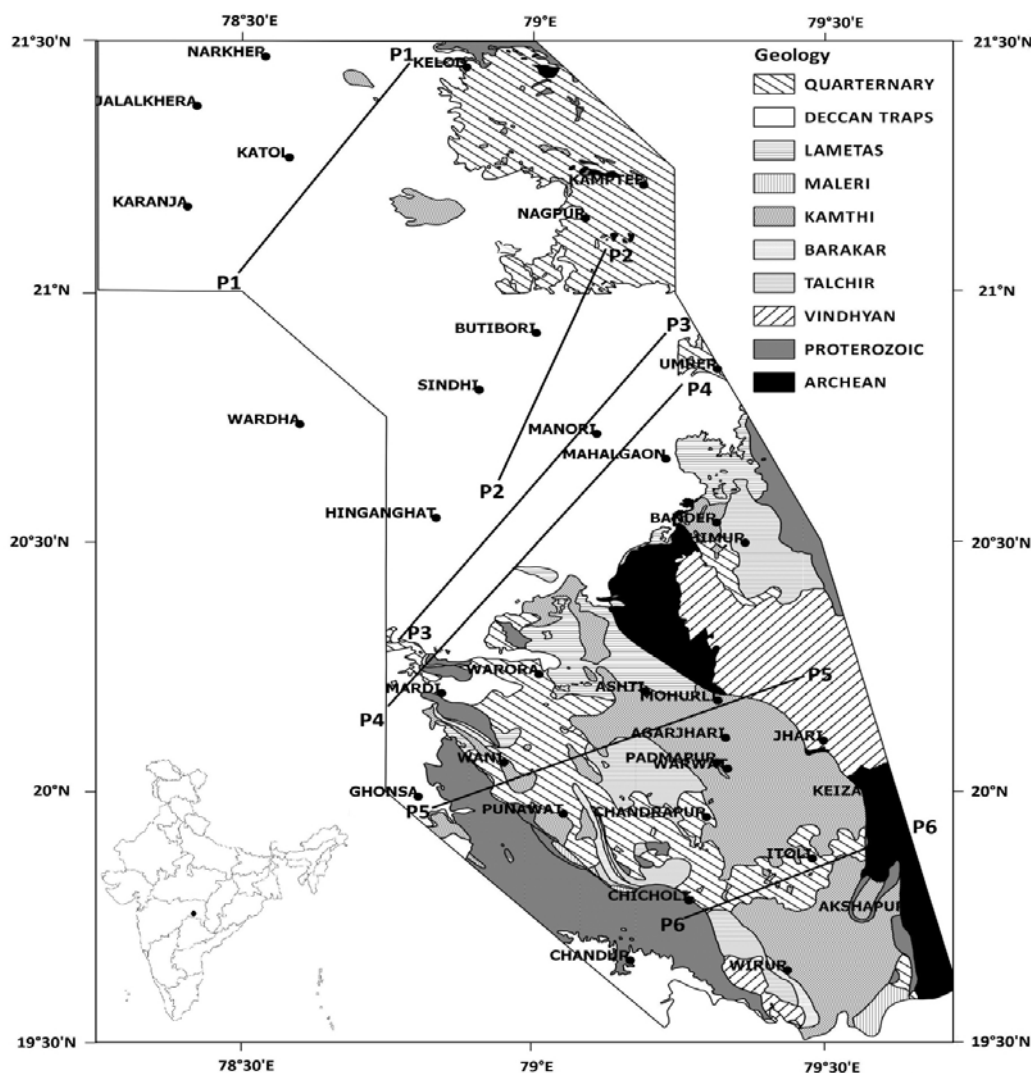


Figure1. Study area with geology.

to be a concealed subtrapean rift basin at the eastern extremity of DS.

Study area, its geology and tectonics

The study area forms a part of the DS measuring about 13,000 km² and it is bounded by 19°30'N to 21°30'N latitudes and 78°15'E to 79°45'E longitudes. Its outcrops range from Archean gneisses to Quarternary sediments (Figure 1). Its northern part is dominantly covered by the Deccan traps of Cretaceous-Paleocene age, whereas its southern part has exposures of Archean gneisses and sediments including post- syn- and pre-Gondwanas.

Tectonically, the Gondwana basins of peninsular India correspond to linear zones of structural weakness in the craton (Chatterjee and Ghosh, 1991) and are believed to have been formed under accumulated stress conditions

due to tensional and gravitational forces without the involvement of orogenic tectonics. They are considered to be irregular, elongated intracratonic depressions, trough-like rags and rift basins having graben/half graben structures marked by a major normal fault on one side making them highly asymmetric. Mukhopadhyaya (1994) opined that these basins underwent multiple phases of faulting, mostly aligned in E-W, ENE-WSW, N-S and ESE-WNW directions. Padhi and Ramakrishna (1999) based on Landsat (MSS) imagery of the Gondwana basins, geology, geomorphology and Bouguer gravity map of the area concluded that the tectonics of Katol region is controlled by two major NW-SE trending crustal faults, a two stage crustal subsidence and few other sub-basinal faults. Such faults identified geologically, are marked as solid circles in Figure 2 and most of these faults are correlated with gravity anomaly flexures.

Gravity anomaly map and its qualitative analysis

The Bouguer gravity anomaly map (Figure 2) interpreted in the present study was compiled by the Geological Survey of India on 1:250,000 scale (Ramakrishna et al., 1999). The Bouguer gravity map exhibits distinct anomaly variations from -20 mGal to about -85 mGal with contours following a general NW to SE trend. E-W trending contours can also be observed at places locally. From the gravity map, several anomaly closures having distinct anomaly variations could be identified. These are marked as A1, A2, A3, A4, A5, A6, A7, A8, A9 and A10 respectively in Figure 2. Several NE-SW trending faults can be identified in the area based on the termination of these anomaly closures as marked. All these observed closures are anomaly lows - each having a limited areal extent- and hence may be attributed to individual basin-like structures bounded by faults.

The observed gravity lows distinctly occur along three axes named as northern gravity low axis (NGL), central gravity low axis (CGL) and the southern gravity low axis (SGL). The NGL with a clear SE-NW trend, extends to about 150 km length between Chimur and Jalalkhera. This axis is composed of few gravity lows viz., A10 around Katol (-85 mGal) in the NW, A8 around Butibori (-70 mGal), A7 around Mahalgaon (-65 mGal), A6 around Bander (-60 mGal) and A5 around Chimur (-55 mGal) in the SE. Each of these gravity low features can be explained by an individual basinal structure filled with sediments. Butibori, Mahalgaon, Bander and Chimur anomalies are bounded on their western side by a steep linear gradient anomaly indicating the presence of faulted contact.

The CGL axis initially runs roughly about 55 km in NNW-SSE direction between Wirur and Warwat and can be considered to be the northward extension of Godavari graben. Beyond Warwat this axis swings towards the west and runs in a SE-NW direction for about 80 km upto Hinganghat from where it appears to swing further towards the west making gravity contours align almost E-W. This central axis of depositional basin appears to be consisting of three sub areas/ basins of deposition characterized by three gravity lows, one lying between Wirur and Warwat towards the south i.e., A1, another lying around Ashti in its central portion i.e., A2 and the third towards north lying south of Hinganghat i.e., A4. Relatively high gravity anomalies observed between Padmapur and Jhari appear to indicate the presence of a ridge- like feature separating the sub-basins characterized by anomalies A1 and A2.

The SGL is comparatively a smaller one and extends for about 40 km from Warora in the North to Punawat in the south. This axis is characterized by a single gravity low of -55 mGal. The trend of this anomaly axis is almost N-S and swings towards NW to the west of Warora. Interestingly these three linear axes of gravity lows viz., NGL, SGL and CGL are separated by intervening gravity

highs of the order -35 to -20 mGal, indicating the presence of horst and graben structures in the area. This horst and graben structural setup can also be explained by the rift related tectonic activity as inferred in the following lines. One such important relative gravity high characterized by broad anomalies lies between Chimur in the East and Hinganghat in the West following the trend of the CGL of deposition. It runs initially in a NW-SE direction for about 80 km between Jhari and Manori and then takes an E-W trend to join Wardha. Either side of this relative gravity high is bounded by steep gradients indicating the presence of faulted contacts. This is to imply that the deposition of Gondwana sediments had taken place along the three sub-parallel axes along which characteristic low gravity anomalies are observed. Several researchers earlier have also indicated the presence of Gondwana sediments and pre-trappean tectonic settings concealed below the Deccan traps (Jitendra Kumar et al., (2004), Sarma et al., (2004), Ramakrishna et al., (1999), Yash Rastogi et al., 2014).

Quantitative interpretation of anomalies

To understand the nature and configuration of basement underlying the Gondwanas buried below the trap rocks, six representative profiles namely P1-P1, P2-P2, P3-P3, P4-P4, P5-P5 and P6-P6 are constructed by digitizing the anomalies at an interval of 4 km across various gravity lows and modelled employing the program GR2DMODE (Radhakrishna Murthy, 1998) which is equally applicable for a submerged basin and an undulating topography over an assumed mean depth. This program works out to get the thickness of the basin at each point of observation along the profile. The program starts with determining the initial depths to the interface at various points and modifies them iteratively. These determined depths are constrained to be not less than ZTLT and not greater than ZBLT. These limiting depths- ZTLT may be the thickness of the Deccan trap and ZBLT the depth to the basement. At the end of the each iteration, an error function called the objective function, being the sum of squares of differences between the observed and calculated anomaly values, is calculated. The program is terminated either when the objective function tends to exceed or fall below a tolerance level, or when the specified number of iterations, 50 in this case, are completed.

Gravity modelling in the present case was carried out for different values of density contrast between sediments and basement rocks. The interpreted model that does not contradict the known geology is taken as the final solution to the modelling. In the present case the modelling of gravity anomalies is carried out for different values of density contrasts varying from -0.3 gm/cc to -0.5 gm/cc. Taking an average density of 2.30 gm/cc for the sediments (post-Gondwanas, Gondwanas and pre-Gondwanas put together) and 2.75 gm/cc for the

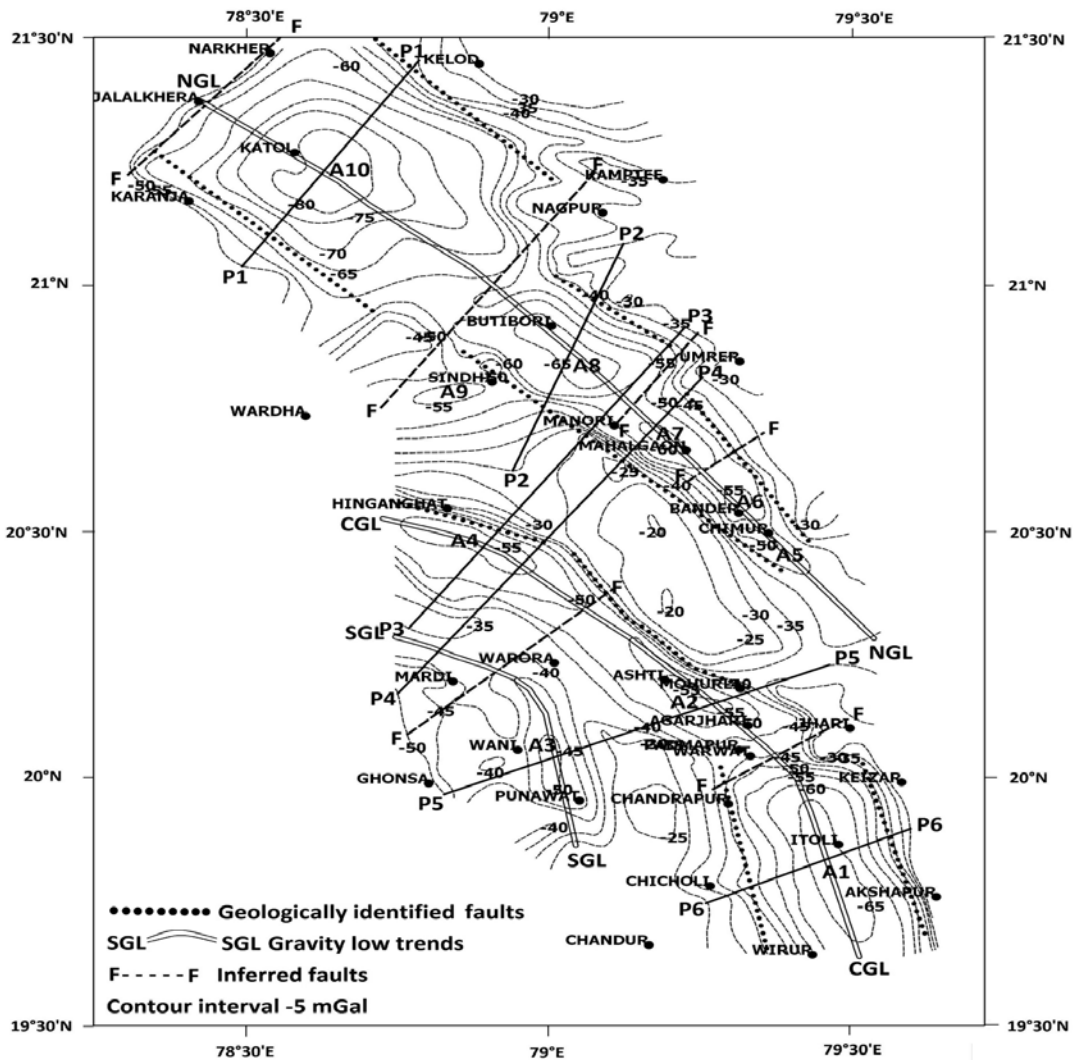


Figure 2. Bouguer anomaly map of the study area.

Archeans a value of -0.45 gm/cc for the density contrast between the sediments and the basement rocks was found appropriate in the present study. The intrinsic assumption in the present interpretation is that the effect of trap rocks that is present in the observed anomalies is removed by the regional-residual separation.

Profile P1-P1: Observed gravity anomalies along P1-P1 are shown in the Figure 3. This profile runs through the major Katol gravity low (A10) which is nearly a circular feature. The profile starts from the SE of Karanja, passes through Katol towards west of Kelod with its entire length occupied by the trap rocks on the surface and showing a broad low of -85 mGals . The modelling of residual anomalies along this profile shows a maximum of 5.63 km as depth to the basement at the center of the profile which is decreasing towards the periphery. Interestingly the structure on the basement shows that the basin had formed due to a series of step faults and existence of several

sub basins separated by horst like structures as seen that below 56 km point on the profile. A maximum of 3.2 km was estimated for the basement depth by Chakravarti et al., (2007) through 3D modelling for a density contrast of -0.5 gm/cc . A basement depth of the order of 5 km and a thick sequence of Gondwana sediments are predicted by Jitendra Kumar et al., (2004) and Ghildyal, 1985 using MT surveys and gravity studies.

Profile P2-P2: The profile P2-P2 (Figure 4) covers the Butibori low (A8) and runs from the NE of Hinganghat, through Butibori towards south of Nagpur. The modelling of residual anomalies along this profile gives the maximum depth to the basement as about 3.93 km and shows presence of two grabens separated by a horst in the centre of the profile. Earlier Murty et al., (1985) had estimated $4 \text{ to } 5 \text{ km}$ thick sediments around Butibori. However, Ramakrishna et al., (1999) estimated a basement depth of 2.8 km below Butibori low and opined that the sediment

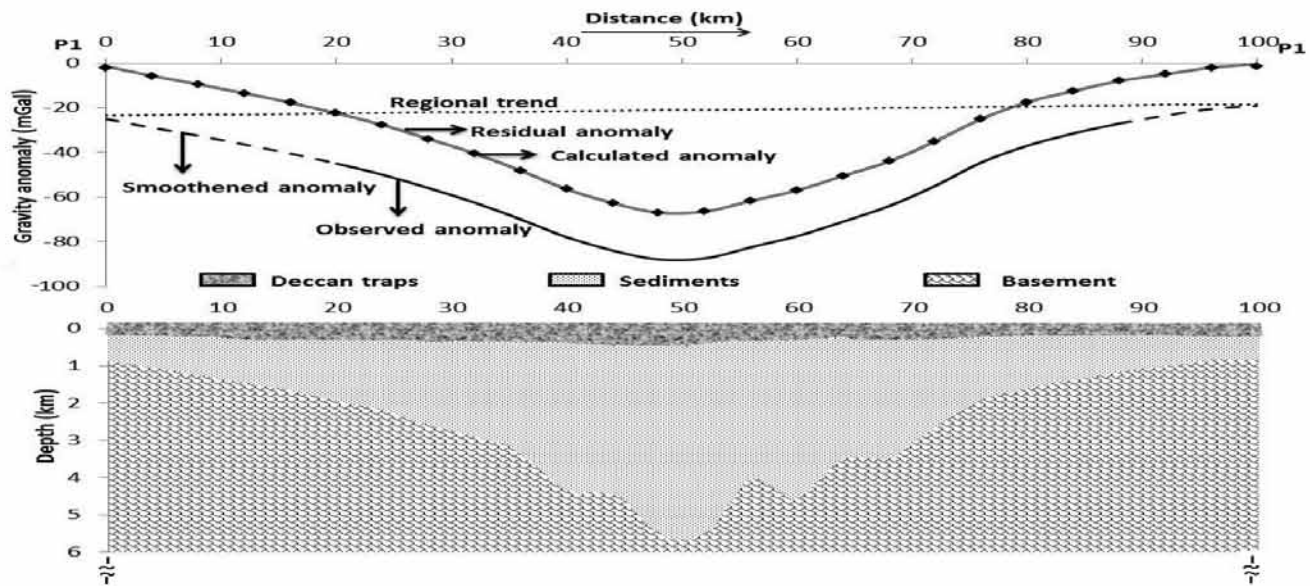


Figure 3. Gravity anomalies along profile P1-P1 and its interpretation.

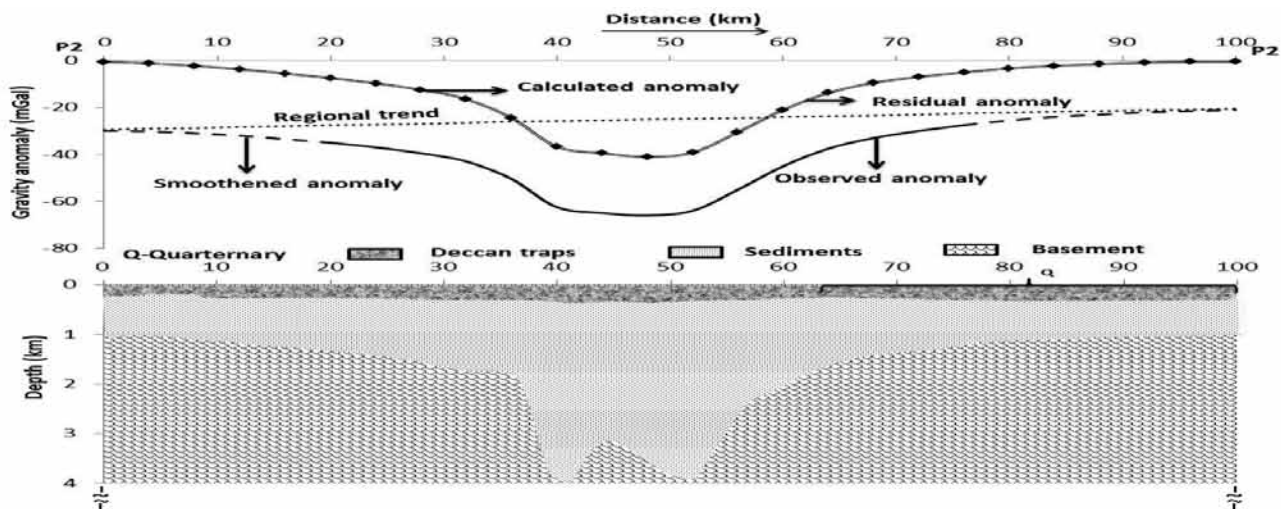


Figure 4. Gravity anomalies along profile P2-P2 and its interpretation.

thicknesses estimated by Murthy et al., (1985) are on the higher side as the low gravity anomaly may not be entirely due to only Gondwanas.

Profile P3-P3: This profile (Figure 5) is drawn to cover the main Hinganghat low (A4). The profile starts from the SW of Hinganghat passing through the major Hinganghat low up to the west of Butibori. The modelling of residual gravity anomalies shows that this profile covers two basins, one in the SW corner and the other in the NE corner characterized respectively by gravity lows A4 and A8 of magnitudes -60 and -65 mGal and a central broad basinal structure with a depth about 1.3 to 1.4 km. The modelling puts a maximum depth to the basement at 3.58 km below the SW low showing the role of step faulting in its formation and 3.6 km below the NE low. Ramakrishna

et al., (1999) have estimated a maximum depth of 2.7 km to the basement below Hinganghat low.

Profile P4-P4: Profile P4-P4 (Figure 6) runs almost parallel to the profile P3-P3. It starts from the west of Mardi, runs through NE of Hinganghat and ends SW of Umrer. Major length of the profile is occupied by trap rocks on the surface except between 15 km and 20 km distances where small patches of Quaternaries and Proterozoics are exposed. Modelling of the residual anomalies along this profile suggests three basins corresponding to the three gravity lows which the profile crosses. The maximum depth to the basement obtained with the present modelling below the SW low anomaly is 1.74 km, that below the central gravity low is 2.89 km and below the NE end gravity low the maximum depth of basement is 4.67 km. Interestingly,

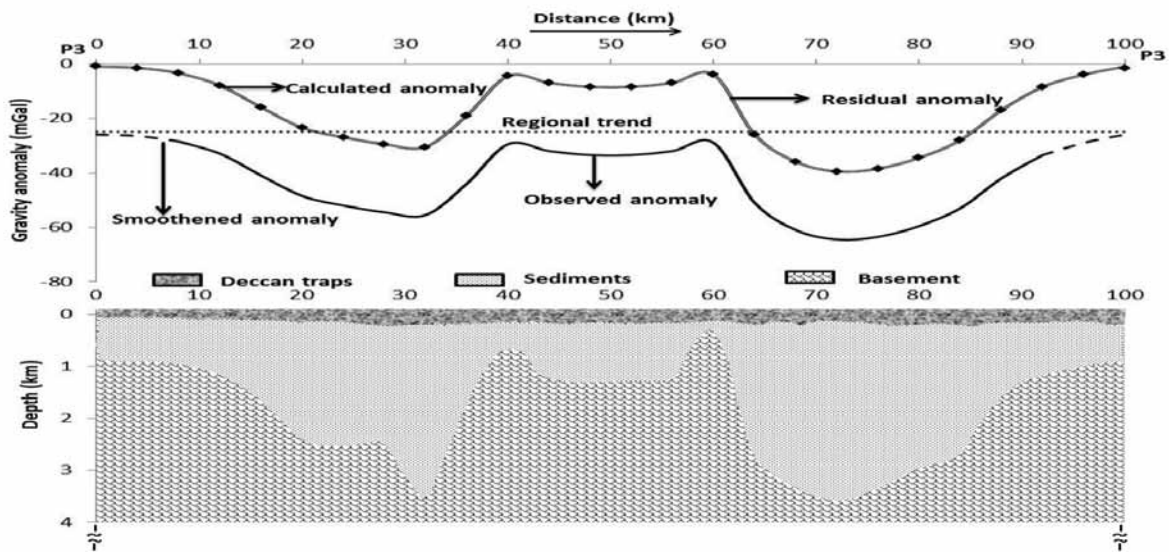


Figure 5. Gravity anomalies along profile P3-P3 and its interpretation.

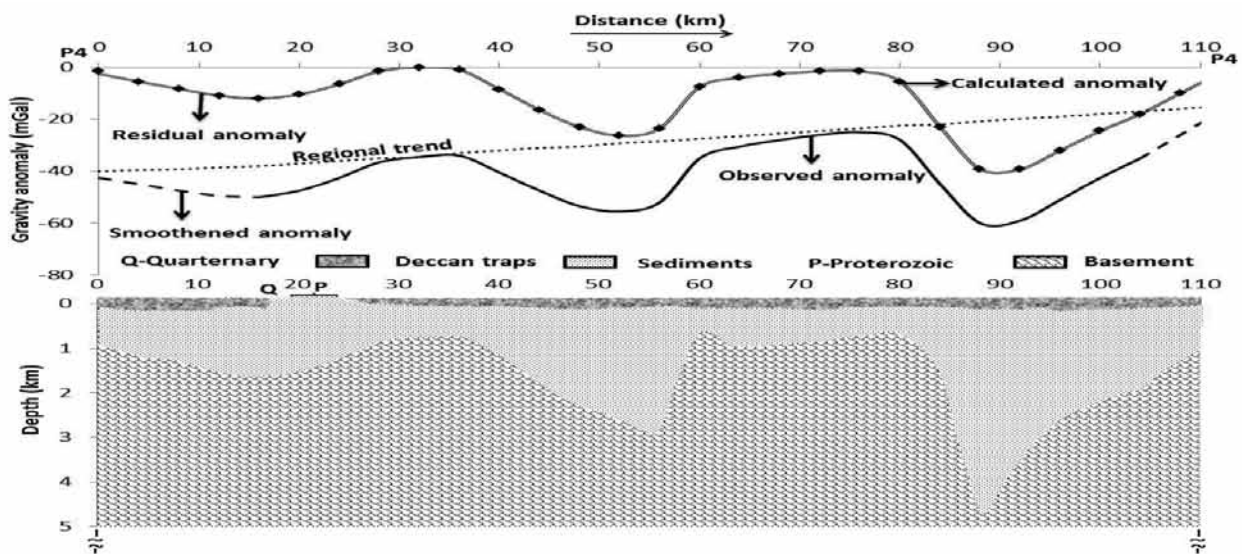


Figure 6. Gravity anomalies along profile P4-P4 and its interpretation.

modelling scheme brings the basement to a level of around 1.2 km where Proterozoic sediments are exposed at the surface. Jitendra Kumar et al., (2004) had estimated a maximum thickness of 1000 m to Proterozoic rocks in DS area. The profile passes through the conspicuous gravity high of -25 mGal where the basement comes to a level of 0.86 km showing that the two major basement lows are separated by a ridge-like feature.

Profile P5-P5: This profile (Figure 7) runs from the south of Ghonsa through the south of Wani and north of Agarjhari to the west of Mohurli. This profile covers the Wani (A3) and Agarjhari (A2) lows characterized by anomalies -50 and -55 mGal respectively. The modelling of the residual anomalies along this profile places the maximum depth to the basement at 2.74 km below the

Wani low and at 3.45 km below the Agarjhari low bringing it to a minimum depth of 0.6 km at the ends of the profile. The reduced depths to the basement along this profile may be explained by the occurrence of pre-Gondwana sediments (Vindhyan & Proterozoic) on the surface and the absence of Gondwanas and younger sediments along the profile.

Profile P6-P6: Profile P6-P6 (Figure 8), starting from the south of Chicholi and extending to the south of Keizar runs across Itoli anomaly low (A1). Modelling of residual anomalies along this profile with the assumed density contrast brings the basement close to the surface towards the periphery of the profile from its maximum depth of 3.07 km at the center, which can be explained by the exposure of Proterozoic and Archean formations at either end of the profile.

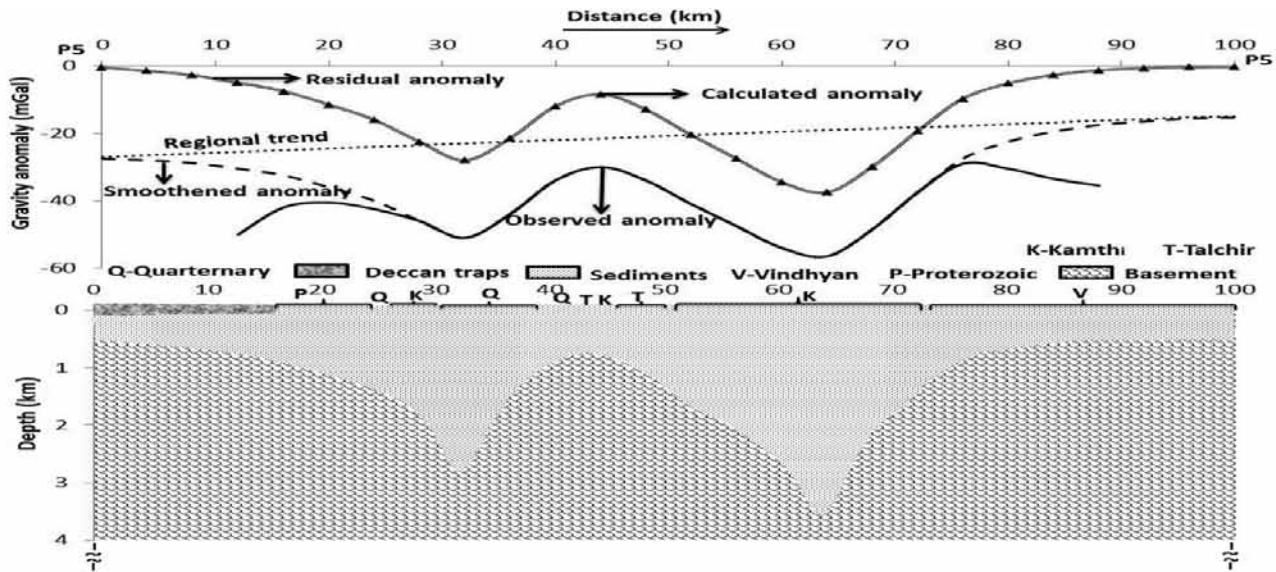


Figure 7. Gravity anomalies along profile P5-P5 and its interpretation.

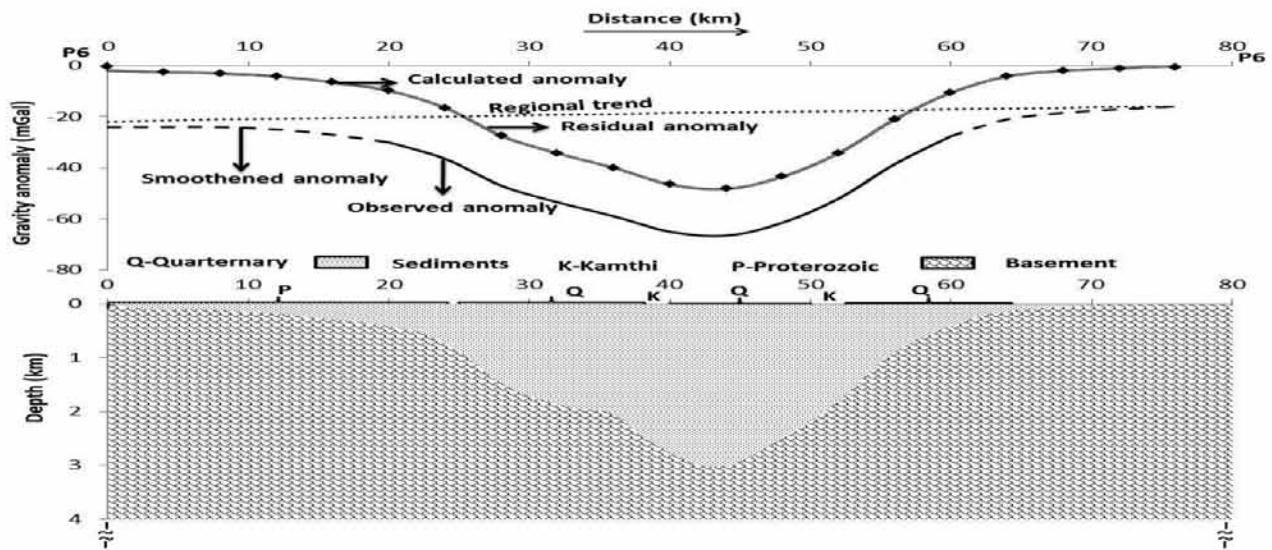


Figure 8. Gravity anomalies along profile P6-P6 and its interpretation.

CONCLUSIONS

Modelling of Bouguer gravity anomalies indicates the presence of two sub-parallel NW-SE trending basinal features below the Deccan traps in parts of Eastern Maharashtra. The gravity anomaly map also indicates presence of few more smaller basinal features- one between Punawat and Warora almost trending in the N-S direction parallel to 79° E longitude and the other almost trending E-W around Sindhi.

Gravity modelling along the six profiles indicates the presence of a ridge-like feature between the two NW-SE trending long basins viz., NGL and CGL. It also indicates

that these basins are filled with a thick pile of sediments varying between 5.33 km near Katol in the NW corner to 1.44 km near Mardi in the SW corner. All the faults identified above indicate that the basement is highly faulted and show alternate horst and graben structures or relay ramps. There is a gradual decrease in the basement depth from NE to SW and also from NW to SE which indicates an en-echelon pattern of faults. The NW-SE faults appear to be more prominent and associated with horst and graben-like structures as evidenced by the interpreted basement depths and inferred faults (Figure 2). Padhi and Ramakrishna (1999) also came out with almost similar results in the Gondwana basins of Maharashtra. Relay

ramps, normal fault planes and transfer fault zones are typical in an extensional environment and play a major role in the development of rift basins (Morley et al., 1990; Nelson et al., 1992 and Peacock and Sanderson, 1994).

Therefore the present interpretation supports that this part of the study area in DS is a concealed sub-trappean rift basin at the eastern extremity of DS. The Katol basin was identified as one of the 26 potential hydrocarbon Gondwana basins of India by Singh (2013) along with others. As such the present results are of value in the context of searching for hydrocarbon reserves in India.

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Compliance with Ethical Standards

The authors declare that they have no conflict of interest and adhere to copyright norms.

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