Crustal Structure from Gravity and Magnetic Anomalies in the Nizampatanam Sub-Basin of K-G Basin, Andhra Pradesh, India

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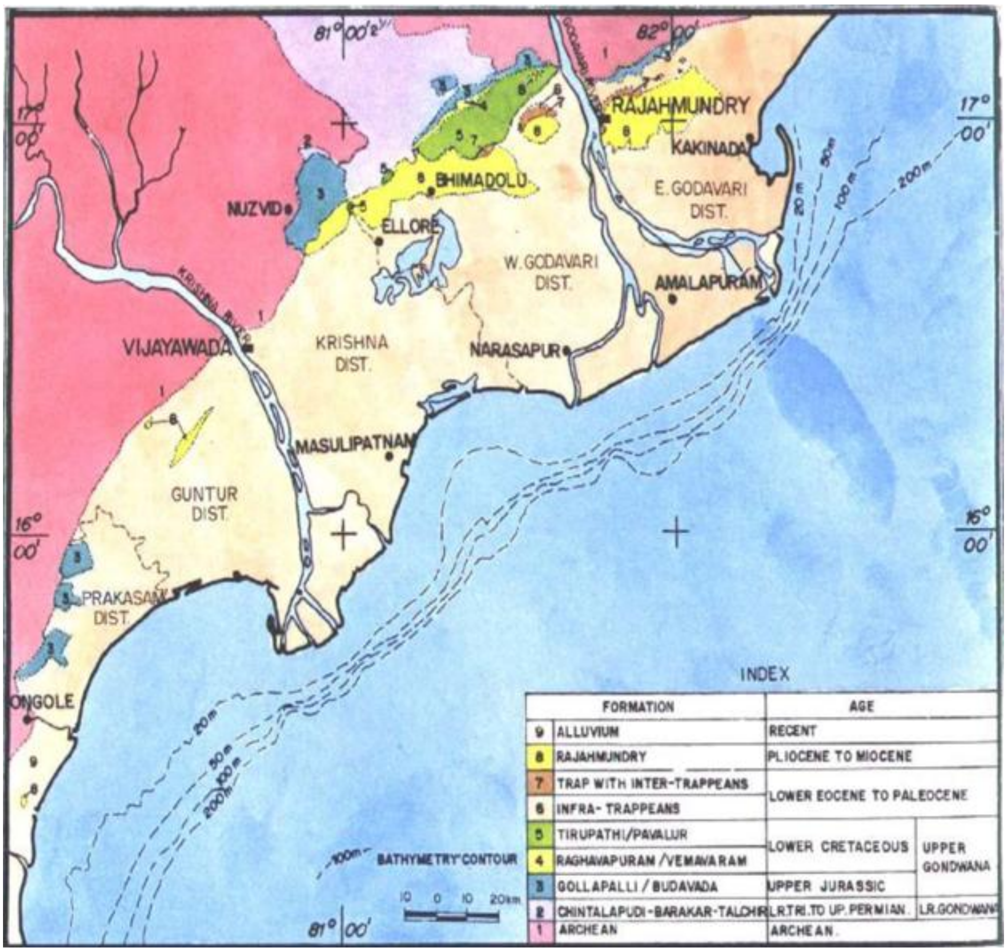
Abstract: ***The gravity and magnetic data along the profile across the southern part of the K-G basin of India have been collected and the data is interpreted for crustal structure depths. The first profile is taken from Nadimpalem to Gokarnamaham covering a distance of 90 km and the gravity lows and highs have clearly indicated various sub-basins and ridges. The density logs from ONGC, Chennai, show that the density contrast decreases with depth in the sedimentary basin, and hence, the gravity profile is interpreted using variable density contrast with depth. From the Bouguer gravity anomaly, the residual anomaly is constructed by graphical method correlating with well data, subsurface geology and seismic information. The residual anomaly profile is interpreted using polygon model. The maximum depths to the Khondalitic basement are obtained as 4.50 km, The regional anomaly is interpreted as Moho rise towards coast. The aeromagnetic anomaly profiles are also interpreted for charnockite basement below the Khondalitic group of rocks using prismatic models.***

Keywords: Bouguer anomaly, Total Magnetic Intensity, Krishna Godavari basin, 2D Joint Modeling

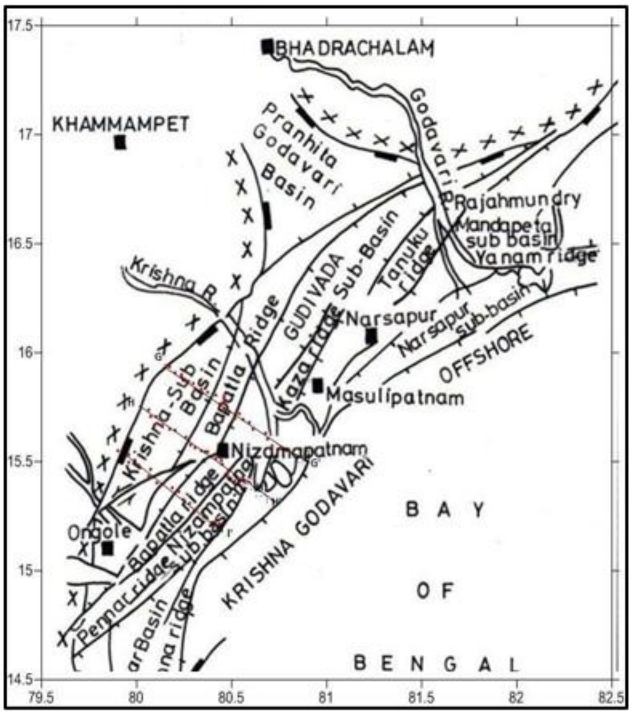
1. Introduction

The Krishna-Godavari basin is located between 15°30'N - 17°N latitudes and 80°00'E - 82°30'E longitudes and covers 15,000 sq.km on land and about 25,000 sq. km on adjoining offshore regions on the east coast of India. It is an important and promising petroliferous basin of India. Tectonically, it is a pericratonic basin and it occurs on the margin of the Indian plate which is of highly metamorphosed Precambrian rocks consisting of mainly Khondalites. The sedimentary strata consists of clay, sandstone, limestone, and shale etc., deposited in marine as well as continental environment ranging in age from the Permian to Pliocene (Rao, 2001 and Sastri et al, 1981). RamamohanRao et al (1994) have studied the tectonic features of the basin and presented a basement configuration map of Chintalpudi and K-G basins.

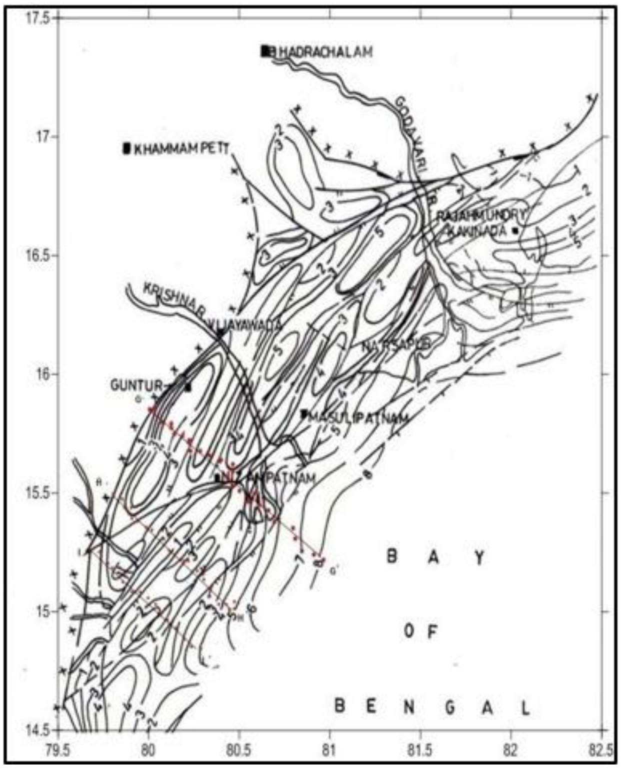
O.N.G.C has carried out gravity and magnetic surveys in the K-G basin in 1960s (Kumar, 1993) and presented the Bouguer gravity anomaly map Venkateswarulu (1971) has carried out gravity surveys over a part of the K-G basin and presented the Bouguer anomaly map and features. Radhakrishna Murthy and BangaruBabu(2006) have carried out regional magnetic surveys over a part of the K.G basin. Verma (1991) has analyzed few gravity profiles in the K-G basin. The geological and geophysical work clearly delineated the presence of a number of ridges and sub-basins trending in NE-SWdirections (Prabhakar and Zutshi, 1993 and Hardas, 1991), viz; Gudivada sub-basin, Mandapeta sub-basin, Narasapur sub-basin, Krishna sub- basin, Nizampatanam sub-basin and Bapatla ridge, Yanam ridge, Tanuku ridge and Kaza ridge. The gravity and magnetic surveys are carried out on the entire K-G basin along nine profiles, at closely spaced interval, and placing the profiles at approximately 30 km interval and perpendicular to various tectonic features. In this paper one gravity and magnetic anomaly profile is presented along the lines shown in the tectonic map of Prabhakar and Zutshi (1993) (Figure1). The gravity anomalies are interpreted with variable density contrast for Khondalitic basement depths and the aeromagnetic profile is interpreted for the chornockite basement below the Khondalite group of rocks.



Figurer 1: Geology map of the Krishna-Godavari basin



Figurer 2: Tectonic elements of Krishna-Godavari basin (after Prabhakar and Zutshi,1993).



Figurer 3: Basement configuration map of Krishna-Godavari basin (after Prabhakar and Zutshi,1993).

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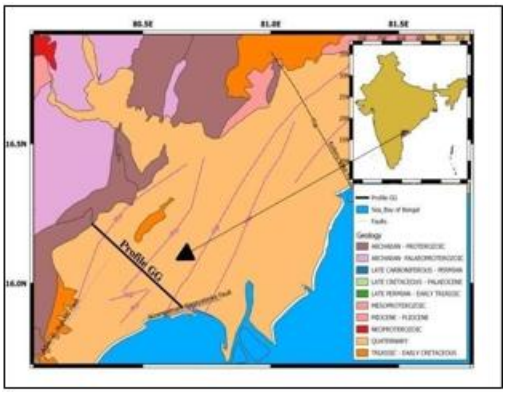


Figurer 4: Study area of Krishna-Godavari basin

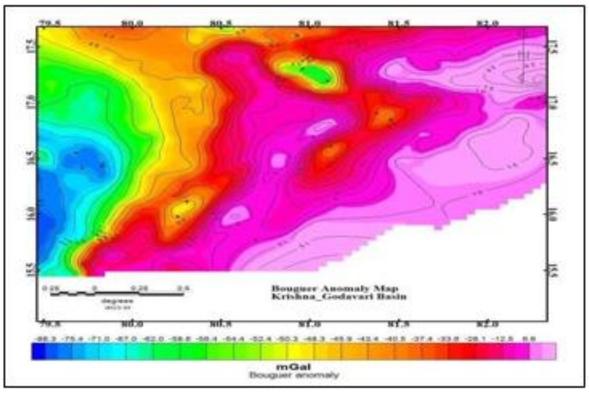


Figure 5: Bouguer Anomaly Map of K_G basin

2. Gravity and magnetic surveys

The gravity, magnetic and DGPS(Differential Global Position System) observations are made along profile GG[1] across the various tectonic features (Prabhakar and Zutshi, 1993) in the Southern part of the K- G basin as shown in Fig.2.Gravity measurements have been made at approximately 1.5 to 2km station interval. Gravity readings are taken with Lacoste-Romberg gravimeter and Position locations and elevations are determined by DGPS(Trimble).The HIG (Haiwaii Institute of Geophysics) gravity base station located in the Ist class waiting hall of Rajahmundry railway station is taken as the base station. The latitude and longitude of this base are 16°59'08.11818"N and 81°46'59.3941"E respectively. The gravity value at this base station is 978475.90 mgals. With reference to the above station, auxiliary bases are established for the day to day surveys. The Bouguer anomaly for this profile is obtained after proper corrections viz (i) drift (ii) free air (iii) Bouguer and (iv) normal. The Bouguer density is taken a value of 2.0gm/cc after carrying out density measurements of the surface rocks. The gravity observations are made along available roads falling nearly on straight lines as shown in Fig.2.The maximum deviations from the straight lines at some places are around 5 km.

Total field magnetic anomalies are also observed at the same stations using Proton Precession Magnetometer (Geometrics) but the data is later found to be erroneous. This might be due to faulty instrument and hence discarded. In order to get magnetic picture, aeromagnetic anomaly maps in toposheets 65G, 65H, 65L, 56P, 65D, 66A, 66 and 66B covering the entire K-G basin on land from GSI are procured and anomaly data is taken along GG[1]profile. The total field magnetic anomalies are observed at an elevation of 1.5 km above msl. IGRF corrections are made for this data using standard computer programs and the reduced data is used for interpreting magnetic basement.

3. Variation of Density Contrast with Depth

The density data with depth from 16 wells in the K-G basin drilled by ONGC have been collected. The kondalite basement is assumed to be having an average density of 2.7gm/cc. This value is subtracted from the well densities to obtain the density contrast with depth in the basin. The curve representing the variation of density contrast with depth has been plotted and shown in Fig.4.The well log density is available up to a depth of 4.5km. However, the curve is extended up to a depth of 6.5km as the maximum depths deduced from the gravity anomalies are around this value. The density contrast is about –0.67gm/cc at the surface and falls to –0.21gm/cc at 4.5 km depth. The decrease of density contrast is due to compaction, age etc. of the sedimentary strata. Hence, the interpretation of the gravity anomalies cannot be carried out with the assumption of a constant density contrast. The variation of density contrast with depth is approximated to a quadratic function (Bhaskara Rao, 1986) such as $\Delta\rho(z) = a_0+a_1z+a_2z^2$, where a_0, a_1, a_2 are the constants to be found. Accordingly, the variation of density contrast is fitted to a quadratic function and the coefficients are solved by the least squares method. The values of the coefficients so obtained for a_0, a_1, a_2 are -0.67374, 0.18321 and -0.0166 respectively.

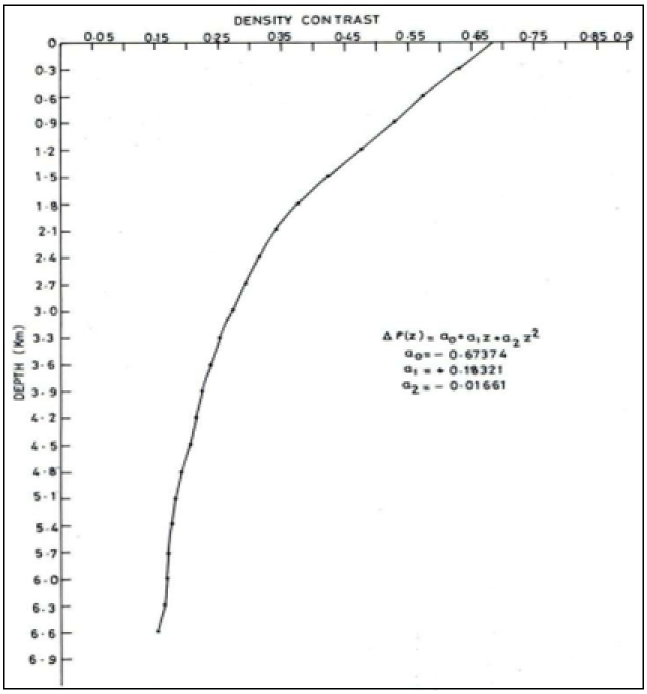


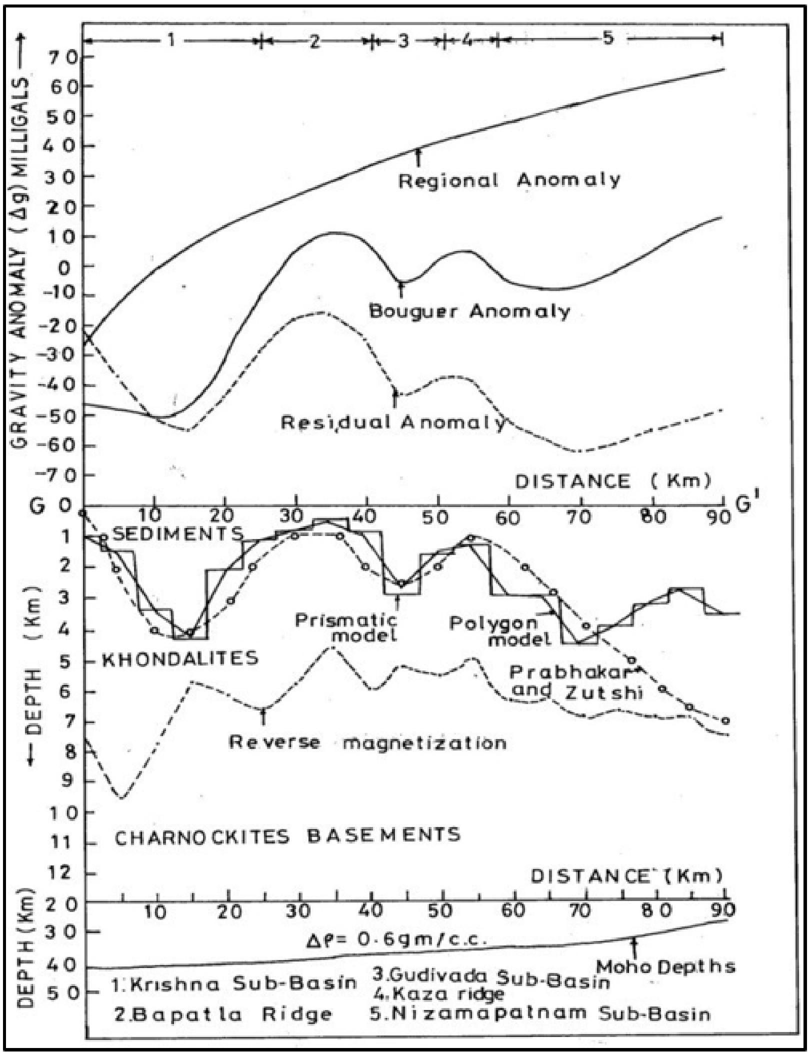
Figure 6: Variation of density contrast with depth

4. Interpretation

The gravity profile is interpreted with quadratic density function by methods described by BhaskaraRao and Radhakrishna Murthy (1986) using polygon model and BhaskaraRao (1986) using prism model. The results obtained by both the methods are nearly the same and hence the depths with prism model are not plotted. The aeromagnetic anomalies are interpreted for charnockite basement below the Khondalite group of rocks assuming prism models. The computer program TMAG2DIN is taken from Radhakrishna Murthy (1998) for interpretation of magnetic anomalies.

5. Gravity profile along GG'

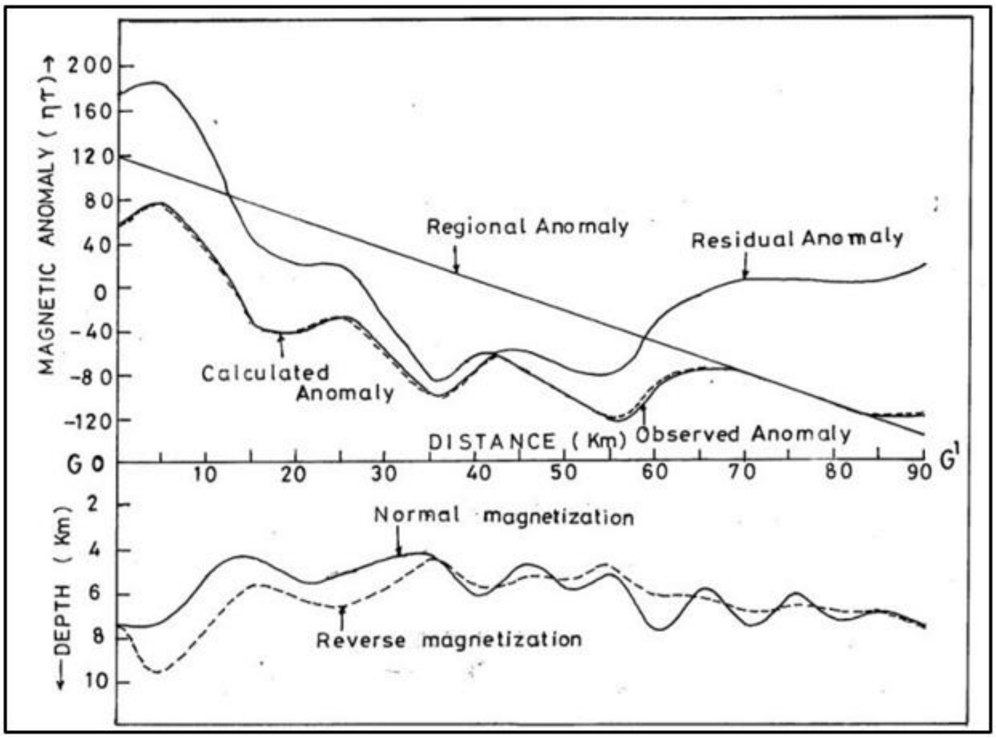
The profile GG' is taken from Nadimpalem (Latitude 16°13'01.89008"N and Longitude 80°18'14.090855"E) to Gokarnamaham (Latitude 16°01'01.15784"N and Longitude 80°50'21.93814"E) covering a distance of 90 km and 43 stations are established along this profile (Fig.3.). This profile passes across the Krishna sub- basin, Bapatla ridge, Gudivada sub-basin, Kaza ridge and Nizamapatnam sub–basin (Fig. 3.). These tectonic features are clearly visible on the Bouguer and residual gravity anomaly profile. An auxiliary base station is established at Nidubrolu (land mark is Railway station) for this profile and the gravity value at this place is 978477.2396 mGals. The profile is sampled at 5 km station interval. The minimum and maximum Bouguer gravity anomalies over the basins and ridges are given in Table 1. The basement depths based on sub- surface geology (Prabhakar and Zutshi, 1993), shown in Fig.7, are plotted as dotted curve. Based on this data, and by trial and error method of modeling, a smooth regional curve is drawn such that the interpretation of the resulting residual anomalies with quadratic density function gives rise to the depths conforming to the depths given by subsurface geology. The regional is -25 mGals at the origin and continuously increases reaching a maximum of 65 mGals at 90 km distance from the land border of the basin and is shown in Fig.7. The regional is subtracted from the Bouguer anomaly and the residual is plotted as shown in Fig.7. The minimum and maximum residual anomalies on the basins and ridges are given in Table 1. The residual anomaly is interpreted with quadratic density function using polygon and prism models. The depths are obtained by iterative method using Bott's method and the results at 10^{th} iteration are plotted as polygon and prisms respectively in Fig.7. The errors between the residual and calculated anomalies are below $\pm$0.5 mGals. The maximum and minimum depths obtained over the basins and ridges are shown in Table1.The interpreted depths are nearly coinciding with sub-surface geological depths. The regional anomaly is interpreted for Moho depths. For this, the normal Moho value outside the basin is taken as 42 km from Kaila et al (1990) and the regional anomaly is obtained by removing a constant value of -25 mGals from the regional and a density contrast of +0.6 gm/cc is assumed between the upper mantle and crust. The depths to Moho are deduced from the regional anomaly by Bott's method and the disposition of Moho is plotted at the bottom of Fig.7. and the Moho is identified at 27.4 km depth near the coast to 42 km on land border of the basin in NW.



Figurer 7: Interpretation of gravity anomaly profile along GG'

6. Magnetic profile along GG'

The magnetic data for the profile GG' is taken from two topo sheets (56P&65D and 66A). The survey was conducted in the year 1985-1987. To construct the profile, the observed stations are placed on the topo sheets of the magnetic anomaly map and a mean straight line is drawn. The points of intersection of the magnetic contours with the straight line are noted and these values are plotted against the distance. IGRF corrections are made to this data using 1990 coefficients and the magnetic anomaly profile is constructed. The length of the magnetic anomaly profile is 90 km and is sampled at 5 km interval. The magnetic anomalies vary from -120 ɳT to184 ɳT (Fig 8.). The anomalies are interpreted for the magnetic basement structure below the Khondalites using prism models. The profile is interpreted by taking the mean depth of the basement at 7.5 km and constraining the depths to upper and lower limits of the basement as 2.0 km and 10.5 km respectively. The FORTRAN computer program TMAG2DIN to interpret the magnetic anomaly profile for basement interfaces is taken from Radhakrishna Murthy (1998).The program is based on the Marquadt's algorithm and this seeks the minimum of the objective function defined by the sum of the squares of the differences between the observed and calculated anomalies. A linear order regional, viz; Ax+B, is assumed along this profile and the coefficients A and B are estimated by the computer. The profile is interpreted for different magnetization angles (Φ) and intensity of magnetizations (J). The average values for the total field (F), inclination (i) and declination (d) along this profile and the measured angle between the strike and magnetic north (α) are given in Table 2. Based on this data, the magnetizations angle Φ is calculated to be 25.49°. But by trial and error, the values for the best fit of the anomalies for Φ and J are given in Table 2. The values of the objective function, lamda (ג), regional at the origin (A), regional gradient (B) and the no. of iterations executed for normal as well as reverse magnetization are also tabulated in Table 2. Here the objective function for normal magnetization is 0.03 and that for reverse magnetization is 0.01. The interpretations with normal and reverse dips are not much different (Fig. 8). The magnetic basement for reverse magnetization is presented in Fig. 8. There is no correlation between the Khondalitic and charnockite basements. For the reverse magnetization, the linear order regional is as shown in Fig.8. The residual anomaly after removing the regional from the observed anomaly is plotted in the figure. The differences between the residual and the calculated anomalies are negligible as shown in the figure. The existence of charnockite basement below the Khondalitic group of rocks was also noted by Narayanaswamy (1975) and Radhakrishna Murthy and BangaruBab(2006). As the average susceptibility of the Khondalites is of the order of $10*10^{-6}$cgs units and that of charnockite is $2000*10^{-6}$cgs units, the Khondalitic basement cannot explain the observed magnetic anomalies. The modeling results place the charnockite basement at depths 2.4 to 9.5 km below the Khondalitic basement along this profile.



Figurer 8: Interpretation of total field magnetic anomaly profile along GG'

7. Results

The profile GG' is taken from Nadimpalem to Gokarnamaham covering a distance of 90 km. This profile passes across the Krishna sub-basin, Bapatla ridge, Gudivada sub-basin, Kaza ridge and Nizamapatnam sub –basin. The residual anomaly is interpreted with quadratic density function using polygon and prismatic models. The depths obtained by gravity methods on the Krishna sub-basin, Bapatla ridge, Gudivada sub-basin, Kaza ridge and Narasapur sub-basin are 4.30 km, 0.6 km, 2.80 km, 1.40 km and 4.50 km respectively and these are nearly the same as sub-surface geological studies. The regional gravity anomalies are interpreted for Moho depths. It is observed that the Moho depths are decreasing towards the coast.

The magnetic anomaly profile is interpreted with different intensity of magnetizations (J) and dips (Φ) for charnockite basement. There is no correlation between the gravity and magnetic basements. The observed magnetic anomalies can be best explained with the intensity of magnetization of 320 gammas and dips of ± 28.0 degrees. The objective functions for normal and reverse magnetizations are 0.03 and
0.01 respectively.

8. Discussions

The gravity and magnetic surveys have been carried out along the profile laid perpendicular to various tectonic features, approximately at 30 km interval, in the central part of the K-G basin. The subsurface geology, depths obtained from seismic reflection surveys and information available from the boreholes along these profiles are used to estimate the regional in the case of gravity anomalies. The residual gravity anomalies are interpreted for the thickness of the sediments in the basins and on ridges using variable density contrast. The density data obtained from various boreholes drilled in connection with oil and natural gas exploration is used to estimate variable density contrast, which is approximated by a quadratic function. The gravity anomalies are interpreted with polygon model (BhaskaraRao and Radhakrishna Murthy 1986) and depths are plotted. The anomalies are also interpreted with prism model (BhaskaraRao, 1986), and as the depths are nearly the same for both the methods, these are not shown in the figure. The basement for the sedimentary fill is the Khondalitic group of rocks. The depth obtained by gravity methods on the Krishna sub-basinBapatla ridge, Gudivada sub- basin,Kaza ridge and Nizamaptanam sub-basin are 4.3 km, 0.6 km ,2.80 km,1.40km and 4.50 km respectively along the profile GG'. These depths are nearly the same as those given by seismic and sub-surface geological studies except in the Gudivada sub-basin as the depths are much greater than the depths obtained by seismic The aeromagnetic anomalies 0 to 10 km below the khondalite basement. The regional anomaly is interpreted for Moho depths and it is rising towards the depths.

Acknowledgements
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Table 1: Anomalies in mGals/Depths in km on various tectonic features

Profile	Type of anomaly /Depths	Krishna sub- basin	Bapatla ridge	Gudivada sub- basin	Kaza ridge	Nizamapatnam sub-basin
GG'	Bouguer(mGl)	-47	+11	-5.0	+5.0	-7.0
GG'	Residual(mGl)	-54	-16.0	-43.0	-39.0	-62.0
GG'	Depths(km)	4.3	0.6	2.80	1.40	4.50

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Table 2: Results of magnetic interpretation

Pro file	Magne tization	Average Value of total field(F)	Average value of i nclination (i)	Angle between strike and magnetic north(α)	Calculated magnetization angle (Φ)	Assumed magnetization angle for best fit (Φ)	Assumed value of intensity of magnetization for best fit (J) in gammas	Regional at the origin (A)	Regional gradient (B)	Damping factor (λ)	Iterations carried out	Objective function
GG′	Normal	41880	17.04	40	25.49	+28.0	320	83.6	-2.1	0.00	3rd	0.03
GG′	Reverse	41880	17.04	40	25.49	-28.0	320	119.6	-2.9	0.00	3rd	0.01