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Gravity and magnetic studies in parts of Odisha and Chhattisgarh (India): implications in regional geology

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ABSTRACT Geophysical mapping using gravity and magnetic (Total Field) surveys were carried out in 3600 km^2 with the aim of identifying the regional geological units and shedding light on the associated structures that may have a bearing on possible mineralisation. The Bouguer gravity anomaly deciphered the anomalous bodies trending in a NE-SW direction, characterised by high gravity signature in the order of -45 to -6 mGal and interpreted in terms of Eastern Ghats Supergroup rocks including charnockite, khondalite, and pyroxene granulites. The conspicuous low gravity zone in the order of -84 to -69 mGal represents the cumulative effect of granites and sediments of the Indravathi Supergroup. The NW-SE trending Sileru shear zone reflects the moderate gravity in the order of -69 to -45 mGal, separating the Archaean Bastar Craton in the west and the Eastern Ghats Mobile Belt in the east, is attributed to a major shear/thrust fault and may be a significant feature in view of mineralisation. Northern and central parts are dominated by medium to small amplitude bipolar nature of anomalies ranging between -247 to 352 nT, where the concentration of magnetite is a natural phenomenon along the fault plane. The Sileru shear zone NW-SE trending alignment is mainly dominated by small amplitude anomalies of bipolar nature. The radially averaged power spectrum of gravity data has highlighted three interfaces at depths of around 6.6, 3.5, and 2.0 km, and for magnetic data two interfaces at the depths of 2.2 and 1.5 km respectively. The studies observed a linear clustering of Euler depth solutions, trending in a NE-SW direction towards the eastern part, whereas curvilinear and NW-SE trending linear cluster towards western and north-western part may be inferred as geologic/faulted contacts. The geophysical mapping in the area was thus useful in characterising not only the surface geology but also the nature of the crust, which primarily influenced the gravity and magnetic anomalies.

Key words: gravity and magnetic methods, EGMB and Bastar Craton, Sileru shear zone, Euler 3D solutions, structures, mineralisation.

1. Introduction

The study area comprises parts of the Archaean Bastar Craton, the Precambrian Eastern Ghats Mobile Belt (EGMB) and their contact zone. The Archaean Bastar Craton (also known as Central Indian Craton or Bhandara Craton) and Proterozoic EGMB are prominent geological domains in peninsular India (Fig. 1).

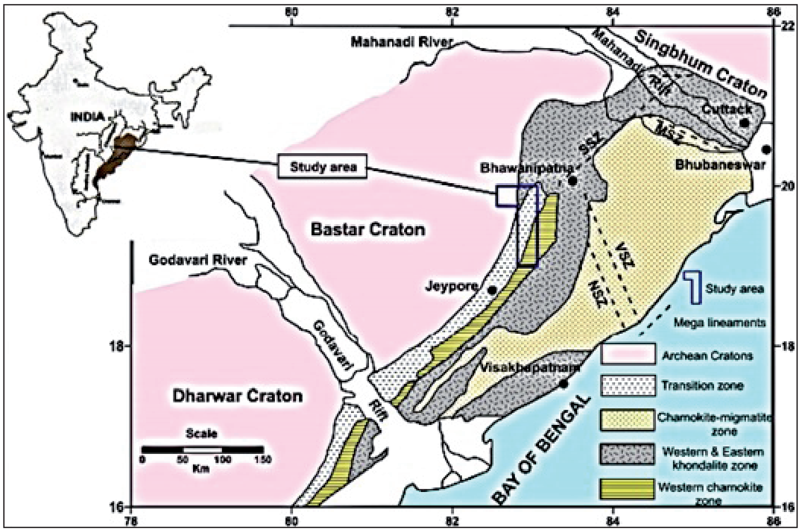

Fig. 1 - Location map of the study area along with regional geology.

Several researchers studied the area to ascertain its geochemical characteristics in the frame of the National Geochemical Mapping (NGCM) program of the Geological Survey of India (GSI) (Behera *et al*., 2015; Bhattacharya *et al*., 2015; Kumar and Dule, 2015; Ray and Mishra, 2015). High values of U and Th were reported from granite and khondalite of EGMB. An aeromagnetic map prepared by GSI (1995) under the National Remote Sensing Agency (NRSA) project during 1990-1992 at a terrain clearance of 5000 ft, with N-S oriented flight lines and 4 km line spacing, shows low to a moderate magnetic anomaly over EGMB due to associated less magnetic granulitic and gneissic masses. Kannadasan and Natarajan (2010) inferred some prominent lineaments close to the Bastar-EGMB contact through an integrated study of remote sensing satellite and aeromagnetic data. Prominent magnetic breaks in aeromagnetic maps were identified to be associated with fault/shear zones, stretches of basic intrusive bodies, quartz/pegmatite veins, etc. Kaila and Bhatia (1981) and Subramaniyan (1983), on the basis of gravity data across the western margin of the EGMB, pointed to the thrusted nature of the contact. However, Chetty and Murthy (1994) indicated the Bastar-EGMB contact as a regionally extended ductile shear zone known as the Sileru shear zone. Anand and Rajaram (2003) identified the shear zone on the basis of its magnetic nature. Chakraborty *et al*. (1986) identified graphite-bearing zones in khondalite, which is supported by exploratory drilling. Subrahmanyam and Verma (1986) observed a general gravity high over the belt and a steep gravity gradient across its boundary with the adjoining Bastar and Dharwar cratons, attributing them to a possible high-density material lying below EGMB. Rajaram and Anand (2003), using the analytic signal (AS) and Euler deconvolution of the aeromagnetic data, revealed the subsurface structure of the region in relation to broad tectonic elements. Niraj Kumar *et al*. (2004) inferred a paired gravity anomaly structure with a relative gravity high over the belt and low over the adjoining cratons. Nayak *et al*. (1998) advocate a multi-layered crust below EGMB invoked a low angle thrust in the crust and hypothesised the emplacement of basic (?) magmatic units into the lower crust and presence of granites and syenites along the vertically faulted margins. Radhakrishna Murthy *et al*. (2005), based on Bouguer anomaly profiling, demarcated two gravity highs and two gravity lows along the trend of the EGMB and linked them to the faulted nature of the Moho developing graben/graben-horst like structures below Bastar Craton and EGMB. Kumar *et al*. (2007) suggested that thermal models of the EGMB crust are indicative of Moho temperature of 550 °C, and the estimated radioelement concentrations and heat production in the northern segment of the Eastern Ghats Belt are the highest amongst the granulite belts of India. So far, no comprehensive study of all available information has been undertaken that would enable a regional analysis for the structures, which controls the mineralisation of the area. In the present study area (latitudes: 19°00’ to 20°00’ N and longitudes: 82°30’ to 83°00’ E; toposheet 65I/9, 13, 14, 15, and 16), the variations in lithology and structure would give rise to density and susceptibility contrasts invoking gravity and magnetic studies to shed light on the subsurface geological architecture (Fig. 2) (GSI, 2016). Structurally weak zones in the belt are a common exploration target, which act as locations for possible mineral-charged hydrothermal deposits.

2. Geology of the study area and economic geology

Several works have extensively studied a range of geological aspects of the Bastar Craton and EGMB from over time (Crookshank, 1938; GSI, 1983, 2007; Radhakrishna and Naqvi, 1986; Nanda and Pati, 1989; Chetty and Murthy, 1994; Ray and Devdas, 1994; Nanda and Panda, 1998; Ramakrishnan *et al*., 1998; Bhattacharya *et al*., 2011). The cratonic part is comprised of a sedimentary sequence of two units, namely the Indravathi Supergroup and the batholithic mass of granite/granite gneiss known as Bengpal granitoid in the east. The oldest unit is the Bengpal Group followed by khondalite, charnockite, and granite gneiss (migmatites), collectively known as the Eastern Ghat Supergroup of rocks (Archaean to Proterozoic age), occurring east of Bastar Craton. Rocks of the EGMB bear evidence of polyphase deformation that has resulted in the development of folds and faults. They show mostly N-S and NE-SW to NNE-SSW trends with moderate dip (45°-60°) towards SE. Geochronological data of the EGMB reveals that khondalite sediments were deposited on older mafic crust now represented by the hornblendemafic granulitic mass (Bhattacharya *et al*., 2011). The Tel Granite (Paleoproterozoic), intrusive (Proterozoic), Indravathi Supergroup (Meso to Neoproterozoic) and Laterites of Cainozoic age (Fig. 3) are the lithounits present in the area. The generalised stratigraphic succession of the area is shown in Table 1 (GSI, 1983). The study area is endowed with a large and rich deposit of bauxite and a minor occurrence of asbestos, graphite, iron ore and mica, etc. Occurrences of bauxite and aluminous laterite are found in association with ferruginous laterite in a number of flat-topped hills in the south-eastern part of the area (GSI, 1983, 2007). Graphite veins, lenses and flakes/lumps are sometimes found in khondalite, granite gneiss, and calc-granulite rocks. Khondalite, charnockite, granite, and granite gneiss are extensively quarried for local use as dimension stones/road building materials.

Table 1 - Generalised stratigraphic sequence of the study area.

Lithology	Group	Supergroup	Age
Laterite			Cainozoic
Sandstone with Conglomerate	Jagadalpur Formation Tirthagarh Formation	Indravathi Supergroup	Meso to Neoproterozoic
Dolerite/gabbro	Intrusives		Proterozoic
Tel granite (unclassified granite)			Palaeoproterozoic
Granite gneiss Acid to intermediate charnockite, pyroxene granulite/basic charnockite Quart-garnet-sillimanite gneiss, ferruginous magnetite quartzite, calcareous quartzite	Migmatite Charnockite Group Khondalite Group	EGMB Supergroup	Archaean to Proterozoic
Amphibolite/Hornblende schist, pillowed meta basalt	Bengpal Group		Archaean
Basement			

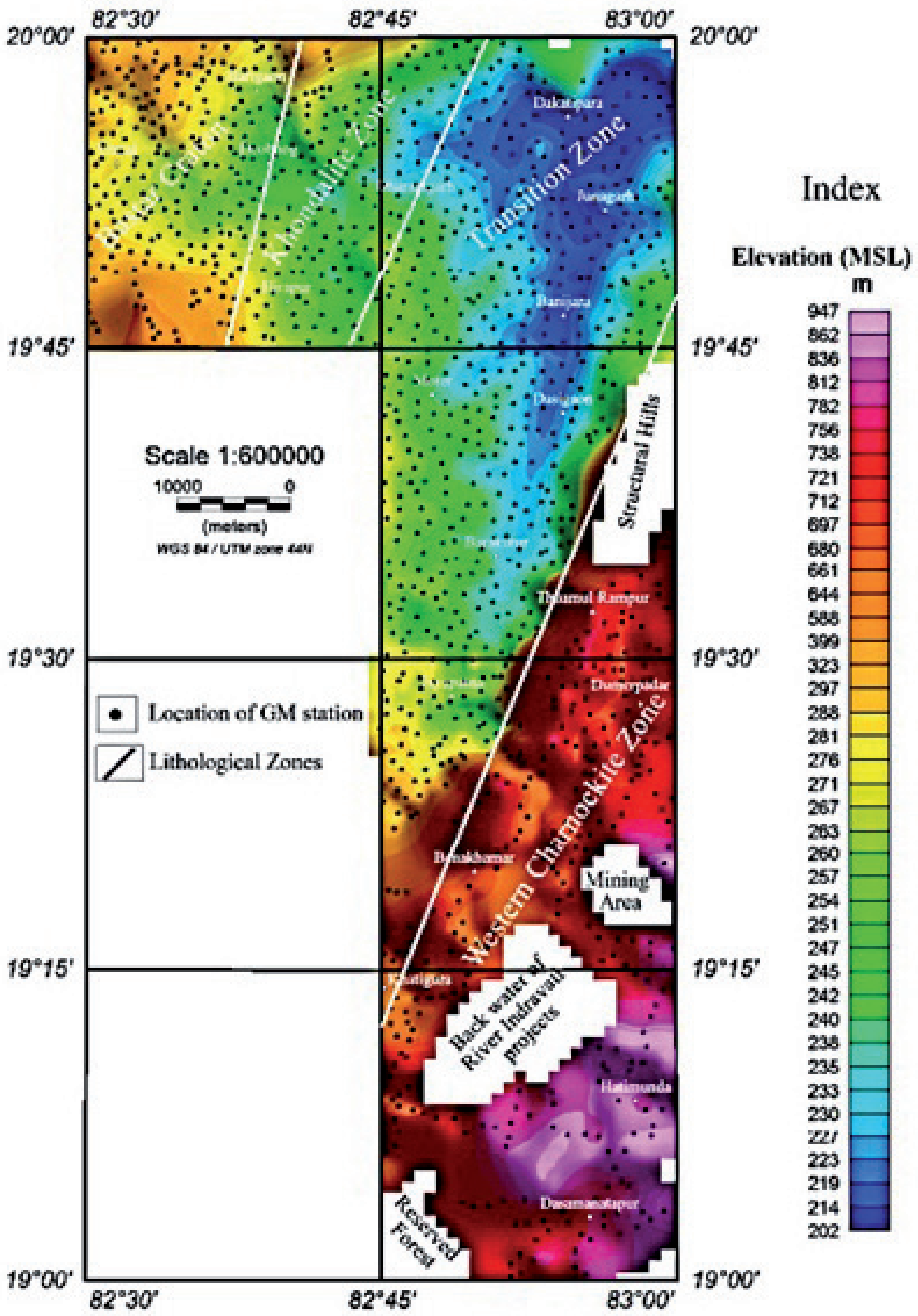

Fig. 2 - Gravity and magnetic observation points along with elevation map.

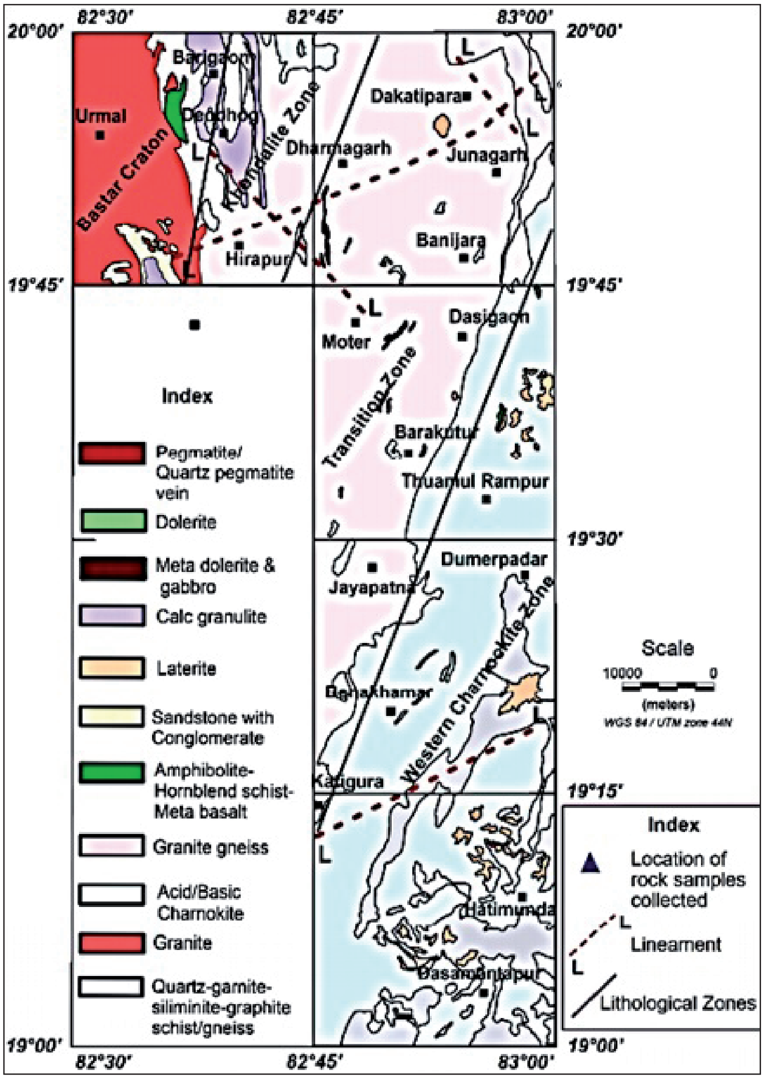

Fig. 3 - Geology map of the study area.

3. Geophysical surveys

3.1. Data acquisition, processing, and instruments

In the geophysical surveys undertaken in this work, gravity and magnetic data were recorded at 1200 locations along available roads and tracks with average station interval of 1-1.5 km. A CG-5 Autograv gravimeter, with resolution of 0.001 mGal and equipped with real time clock, and a GPS receiver (Scintrex make, Canada) have been used for the gravity survey. A Total Field (TF) magnetometer with resolution (0.1 nT) (GSM-19T, GEM, Canada) devised with proton-precession technique, has been used to acquire magnetic data. Measurement of elevation of gravity stations was done by Differential Global Positioning System (DGPS) (Model: Viva, Leica, Switzerland), which is equipped with GPS antenna (AS10), receiver (GS10), and control unit (CS10). Data were processed with Leica Geo Office 10.3 software to determine station coordinates and elevation through post-processing technique, with positional and elevation accuracies in the order of

0.0005 and 0.001 m, respectively. The drift corrected gravity data are reduced to the mean sea level using International Gravity Formula-1980 (IAG, 1980) with reference to IGSN-71 base and was established for present survey (Table 2). Average crustal density of 2.67 g/cm^3 is assumed for making Bouguer corrections. The IGRF corrections are applied to the magnetic data, using IGRF-10 coefficients for the 2015-2020 epoch to evaluate the magnetic anomaly at each station. The Oasis Montaj (ver. 8.5) package of Geosoft (2015) is used for the preparation of various gravity and magnetic anomaly maps, considering World Geodetic System (WGS-84) datum and the Universal Transverse Mercator (UTM) projection system. Bouguer gravity and magnetic anomaly maps are gridded at 1000 m intervals and contours are drawn on 1 mGal and 50 nT intervals, respectively.

Table 2 - Location of IGSN gravity base established in the present study area.

Serial no.	Location	Longitude	Latitude	IGSN value (mGal)
1	Dharamgarh: in front of Inspection Bungalow, ground level (entry gate), Junagarh-Ranchi road, Dharamgarh, Kalahandi district, Odisha	82° 46’ 45.1”	19° 52’ 11.2”	978526.488
2	Bhavanipatna: in front of main building, Circuit House, Bhavanipatna, Hq. Kalahandi district, Odisha	83° 09’ 00.5”	19° 54’ 17.9”	978534.869

3.2. Physical properties of rock samples

A total number of 100 rock samples were collected from different locations for the measurement of density and magnetic susceptibility values. The objective is to analyse gravity and magnetic responses of the lithounits with reference to their physical properties determined from the representative rock samples. The samples are megascopically identified, and grouped as per their mineralogical make-up (Table 3) (GSI, 2016).

Table 3 - Measured physical properties of rock samples in the study area.

Lithounit	Density (g/cm^3)	Susceptibility in cgs unit
Charnockite	3.01 to 3.06	10 to 205
Cal-quartzite	2.57 to 2.76	0.9 to 20
Cal-granulites	2.69 to 2.88	161 to 1426
Hornblende schist	2.72 to 2.76	6 to 1236
Quartz-garnet-sillimanite-gneiss	2.62 to 2.81	23 to 159
Dolerite	2.97 to 3.13	22 to 1048
Gabbro	2.89 to 2.91	13 to 347
Garnetiferous granite gneiss	2.65 to 2.77	1.2 to 2.62
Granite	2.58 to 2.67	4 to 469
Quartz vein	2.58 to 2.60	-0.9 to 1.10
Sandstone	2.51 to 2.57	-0.1 to 1.82
Bauxite	1.94 to 2.07	10 to 18

4. Results and discussion

Potential fields, involving gravity and magnetic methods, have wide applications in geophysical mapping and mineral exploration as they pick up responses from concealed geological structures, which sometimes promote the formation of mineral deposits (Grant and West, 1965; Paterson and Reeves, 1985; Sharma, 1986; Blakeley, 1995; Nabighian *et al.*, 2005).

4.1. Bouguer gravity anomaly

The gravity anomalies show a wide variation in value ranging from -84 to -6 mGal, with a relief of -78 mGal. There is a decrease in value from SE to NW, forming some gradient zones (Fig. 4). Such variation in Bouguer gravity anomaly is due to the diverse lithology of the area. The short wavelength of anomalies in the mapped area is mainly caused by shallow sources. On the basis

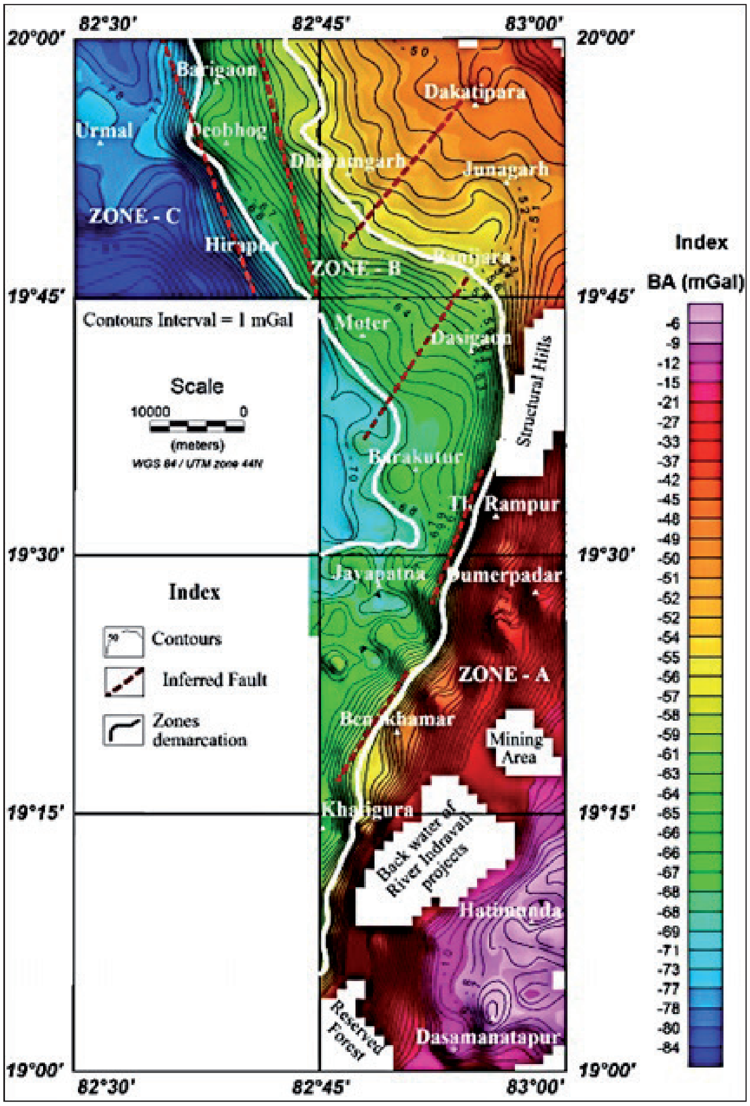

Fig. 4 - Bouguer gravity anomaly map.

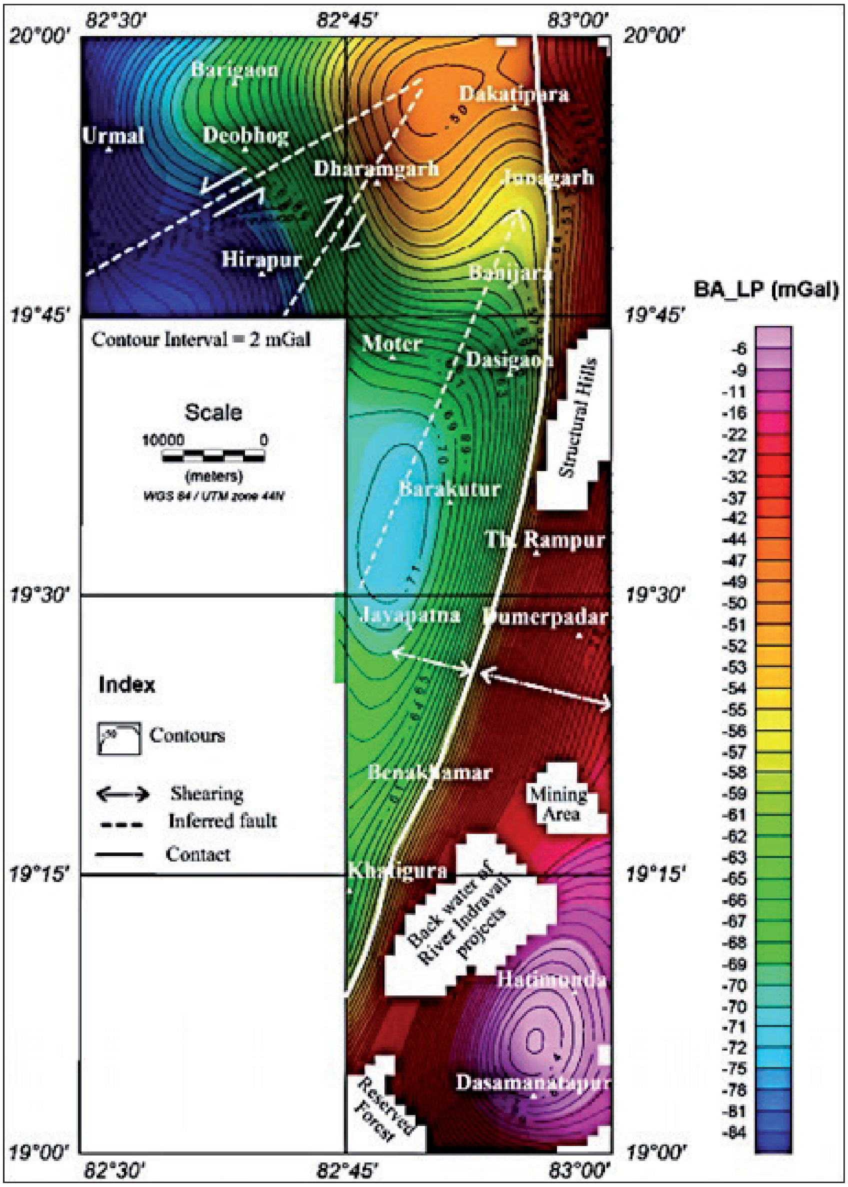

Fig. 5 - Regional Bouguer gravity anomaly map (low pass filtered).

of gravity responses, the entire area can be broadly divided into three distinct zones: A, B, and C. The predominantly high gravity (Zone A) anomaly zone (yellow, orange, red, and pink shades) in the Dasamantapur - Hatimunda - Dumerpadar - Thuamul Rampur - Junagarh - Dakatipara section, trending NE-SW and truncated again NW-SE direction from Banijara to Dharmagarh area, represents the contact of the EGMB (viz.: khondalites, charnockites, migmatites, and pyroxene granulites) and the transition zone / Sileru shear zone. It is attributed to a gradational contact/structural fault between the EGMB in the east along the Terrane Boundary shear zone and the Archaean Craton in the west. High gravity anomaly closures (elliptical/circular nature) in the Dasamantapur and Hatimunda area in the southern part reflects high-density basic bodies intruded within country rock where mining activities are undertaken and exploit the bauxite

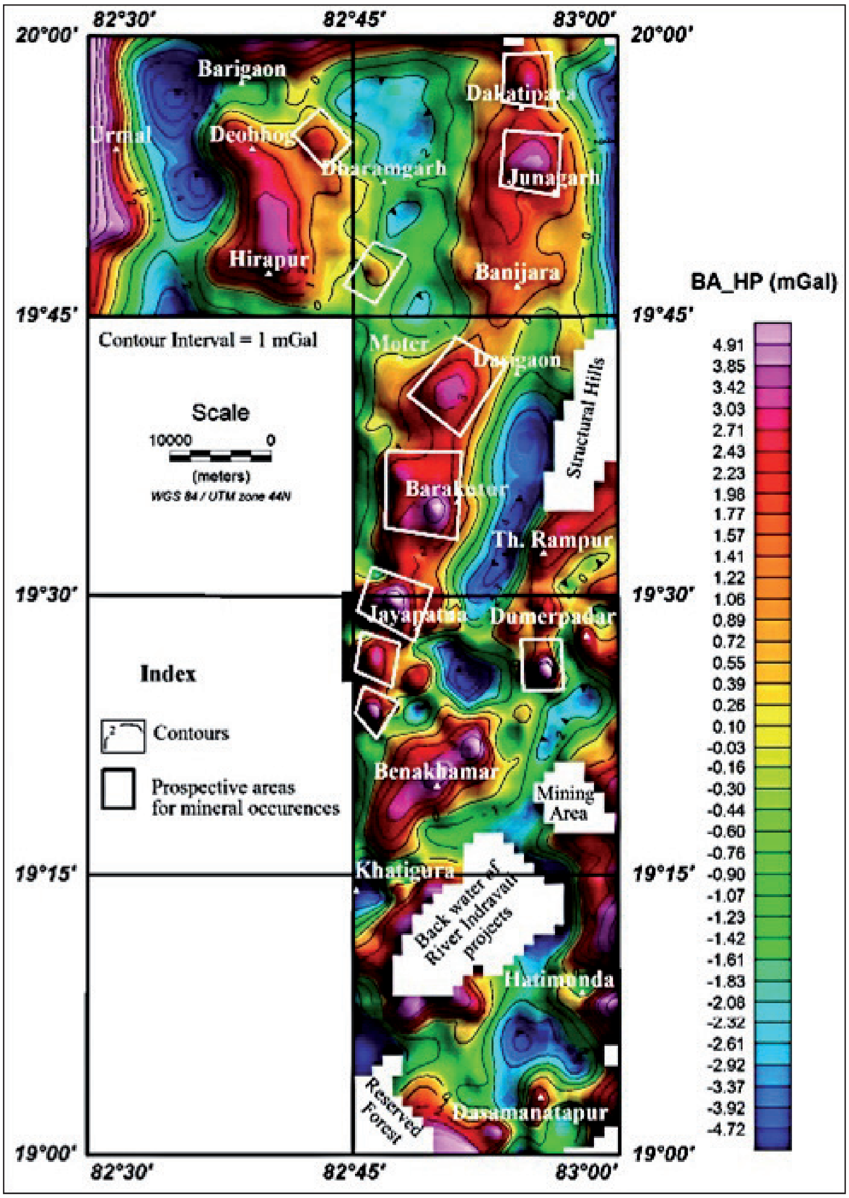

Fig. 6 - Residual Bouguer gravity anomaly map (high pass filtered).

ores. A prominent low gravity zone (Zone C), with contours in NW-SE direction having values varying from-84 to -69 mGal in the Jayapatna - Hirapur - Urmal section, represents the cumulative effect of granites (density 2.58-2.67 g/cm^3) and the sediments of Indravathi Supergroup of rocks (density 2.51-2.57 g/cm^3). A moderate gravity zone (Zone B), with values varying from -69 to -59 mGal trending NW-SE direction separating zones A and C and reflecting the transition zone / Sileru shear zone, has clearly revealed the contact of the EGMB and the adjoining low grade supracrustals (granite gneiss; density 2.65-2.77 g/cm^3).

The NW-SE and N-S aligned loci of high gradient points towards the north-western part, may represent a major contact/fault in the area separating crustal blocks into two major fragments at its west and east, having different geological packages. The NW-SE trending Sileru shear zone

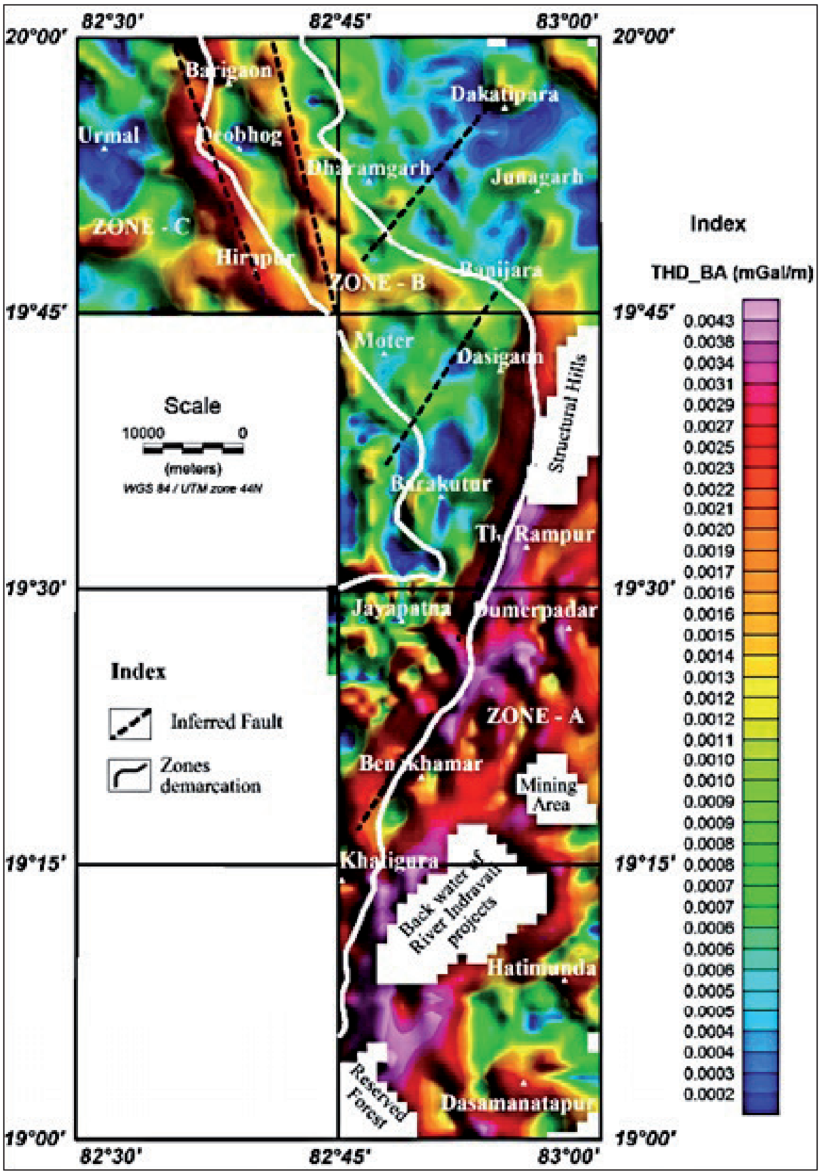

Fig. 7 - Total horizontal derivative of Bouguer gravity anomaly map.

is reflected by a moderate gravity anomaly as a major shear/thrust zone that separated the Archaean granite greenstone terrain in the west and the EGMB in the east and its extension towards the south is clearly demarcated. The high gravity over the EGMB flanked to the west by gravity lows over the Archaean Craton with a steep gradient characterised by crowding of contours and parallelism (NW-SE) relationship suggestive of a faulted contact, may assume importance for a potential zone of mineralisation. The regional Bouguer anomaly map (Fig. 5) has highlighted this general characteristic very well and also indicates the basement upliftment in the eastern side over the EGMB with high gravity signature.

A moderate gravity anomaly nosing and breaking the contour pattern is prominent in the transition zone in between the Jayapatna - Dakatipara section trending NE-SW direction and is well-reflected as a high residual gravity anomaly on the residual gravity map (Fig. 6) and may

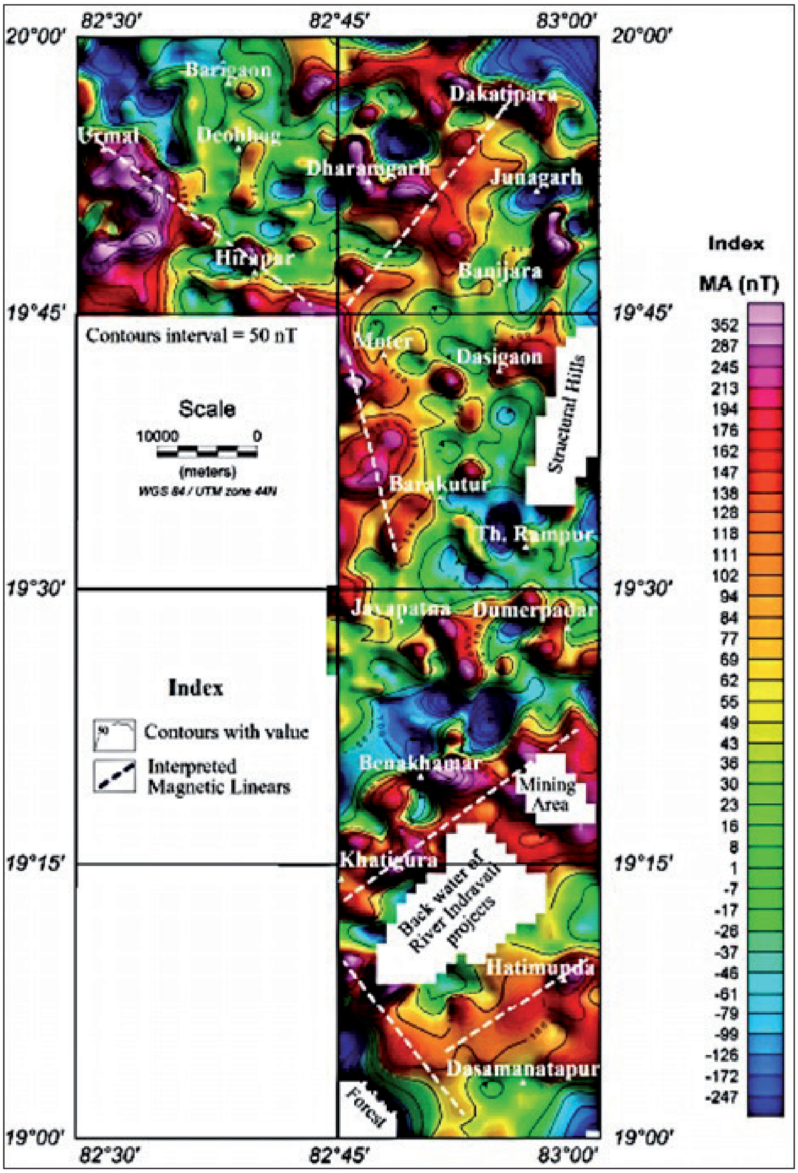

Fig. 8 - Magnetic anomaly map.

be significant for mineralisation. Apart from this, residual highs are observed in between the Benakhamar - Thuamul Rampur section, trending NE-SW in the eastern part, and the Hirapur - Deobhog section, trending N-S in the NW portion, and flanked on both sides by residual gravity lows. These highs are related to the basement below the sediments of the Indravati Supergroup and may assume importance for mineralisation.

The Total Horizontal derivative contour map of the Bouguer gravity anomaly (Fig. 7) reveals that the NE-SW trending gravity gradient coincides with the EGMB trend as it detects the edge of a body as well as the sharpness of anomalies and its depth estimate. The NW-SE trending Sileru shear zone and its extensions are clearly demarcated through a small shift. Significantly, all the structural faults/contacts demarcated in the Bouguer gravity map (Fig. 4) are also picked up in this map with a small shift for locating the horizontal position of the entire boundary.

4.2. Magnetic (TF) anomaly

Of the many geophysical methods, magnetic mapping is one of the cheapest, oldest, simplest and widely used techniques for locating hidden mineral deposits associated with structures. The magnetic anomaly map exhibits variations of magnetic susceptibility with lithology (McIntyre, 1980). However, low magnetic latitudes and remanent magnetisation make the interpretation complicated, particularly for data collected from equatorial regions where weak field intensity and low inclination produce smaller anomalies. Magnetically susceptible bodies show negative instead of positive anomalies at low latitudes, and the anomaly pattern varies considerably with structural azimuth (Beard *et al.*, 2000). The magnetic anomaly (TF) map (Fig. 8) shows bipolar magnetic anomalies ranging between -247 to 352 nT.

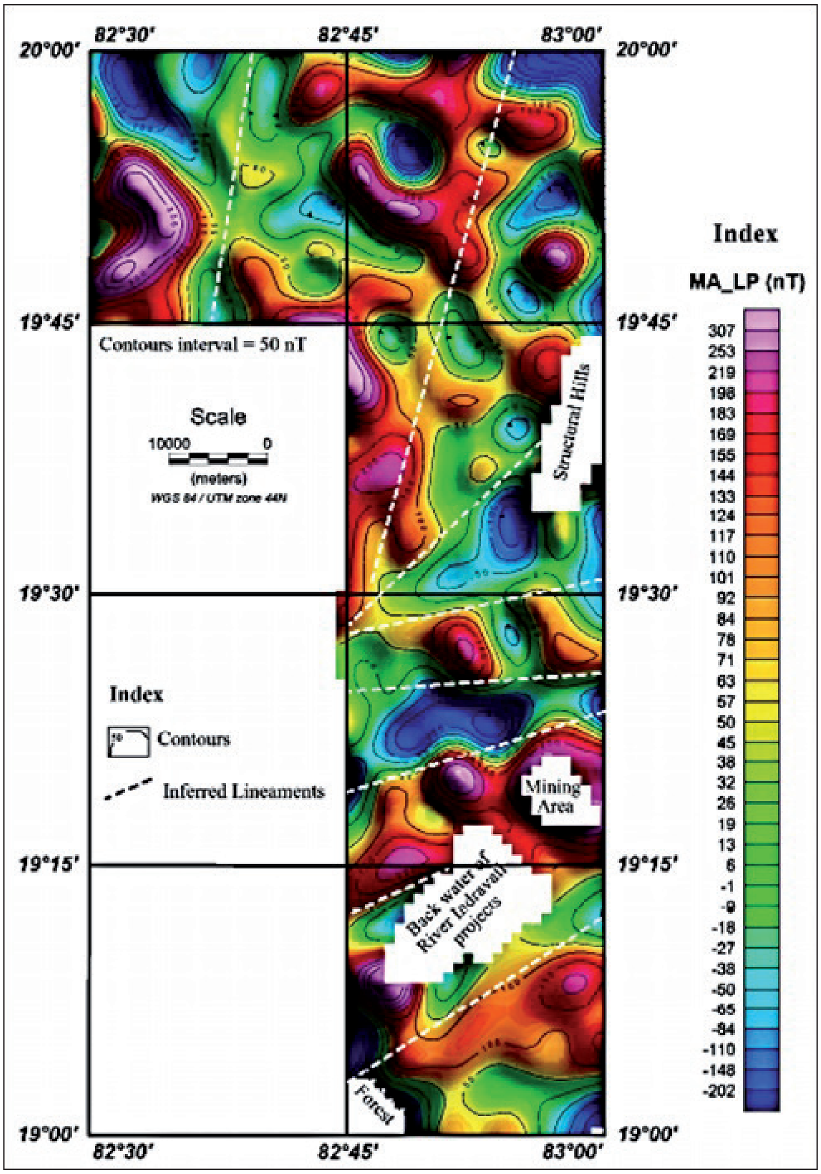

Fig. 9 - Regional magnetic anomaly map.

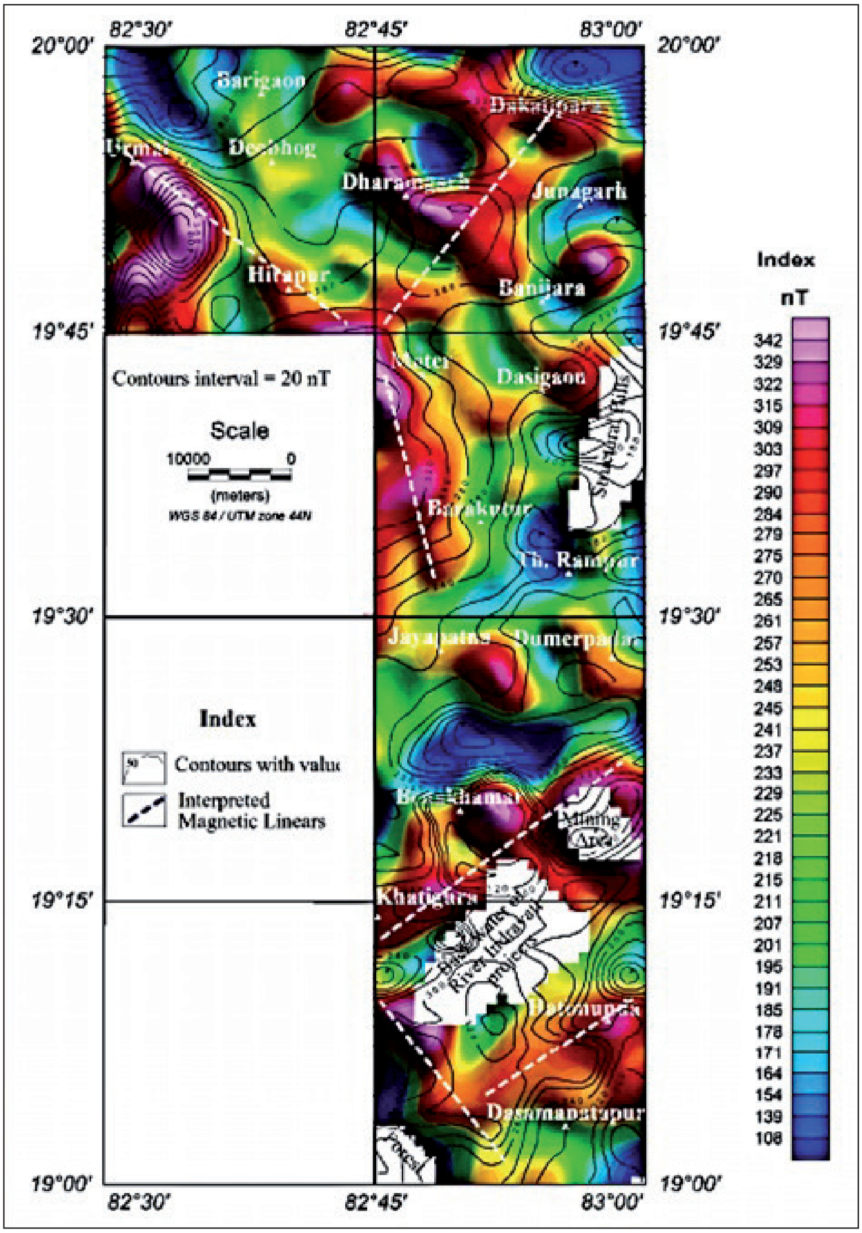

Fig. 10 - Aeromagnetic anomaly map.

Several magnetic linears of high amplitude characterised by magnetic high axes are observed trending NE-SW and NW-SE, in conformity with the trend of the Sileru shear zone and the EGMB of the study area. One tri-junction type anomaly has been observed around Muter and considered a promising potential zone of mineralisation. The regional magnetic anomaly map (Fig. 9) and aeromagnetic anomaly map (Fig. 10) show the general characteristics of the magnetic anomaly map. A very good correlation has been obtained in both aeromagnetic and ground magnetic data.

The aeromagnetic map prepared by the GSI (1995) under the NRSA Project during 1990-1992 at a terrain clearance of 5000 ft (1524 m), with N-S oriented flight lines and 4 km line spacing, shows a low to moderate magnetic anomaly over the EGMB due to associated less magnetic

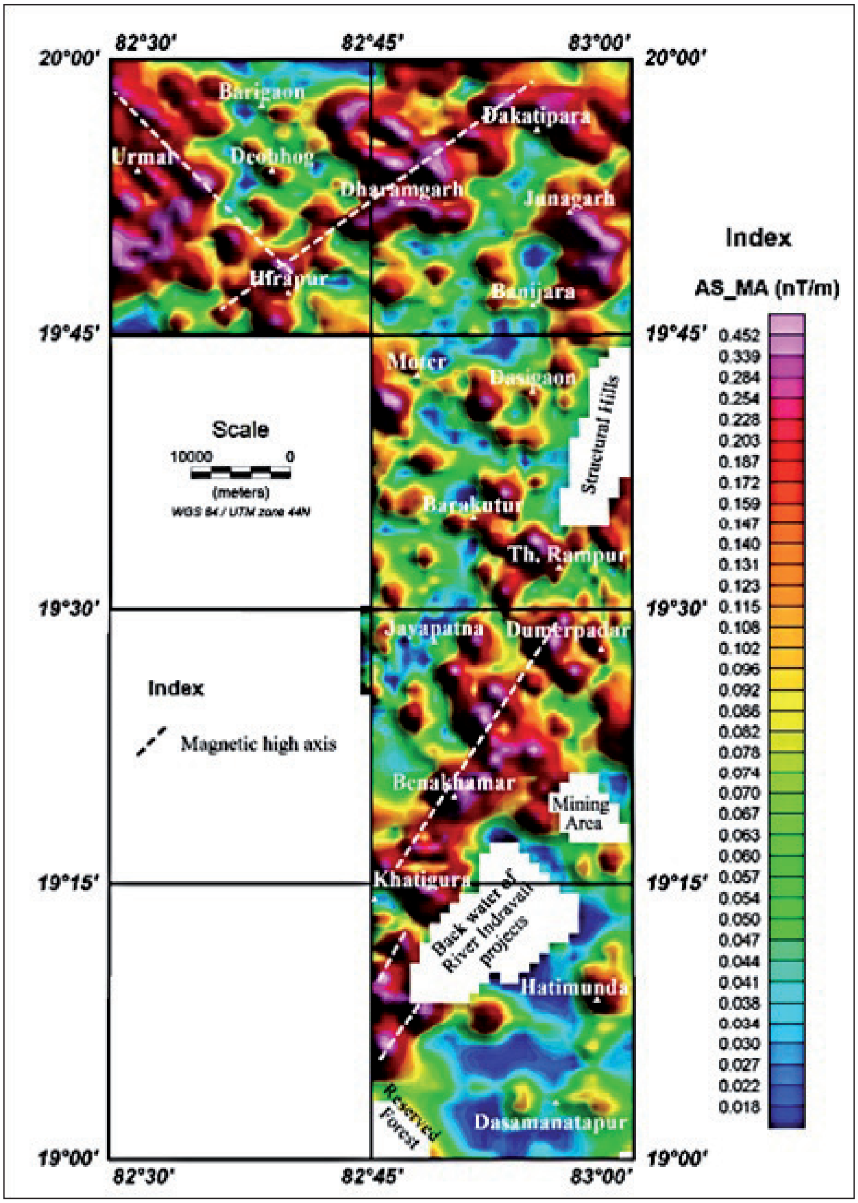

Fig. 11 - AS magnetic anomaly map.

granulitic and gneissic masses. The northern and central parts are dominated by medium to small bipolar nature of anomalies, where the concentration of magnetite is a natural phenomenon along the fault plane (Fig. 8). The Sileru shear zone is mainly dominated by a small amplitude bipolar nature of anomalies.

The AS map of magnetic data (Fig. 11) has also revealed predominantly high magnetic anomaly peaks in these parts. The map accentuates the formational contacts trending NE-SW and NW-SE in the form of peak anomaly values or in the form of ASs. The NW-SE trending Sileru shear zone is clearly delineated as a low amplitude AS that separated the Archaean Craton in the west and the EGMB in the east. The matching relationship of magnetic contours and formation boundaries in the Khatigura - Benakhamar - Dumerpadar section, trending NE-SW in the south-central part, possibly accounts for the measurable susceptibility contrast in between the adjacent lithounits (Sileru shear zone assemblages and western charnockite zone of EGMB). This feature is well corroborated with the residual gravity high anomaly (Fig. 6).

The high AS anomaly in between the Hirapur - Deobhog section in the NW portion trending N-S is substantiated with the high residual gravity anomaly (Fig. 6). The low-intensity magnetic anomaly observed in the AS map in the south, trending N-S in Dasamantapur - Hatimunda and further north over the EGMB Supergroup of rocks, may be indicative of a susceptible causative magnetic source in the basement. The AS map has picked up several highs and lows, which account for causative sources occurring at shallow depths. AS maps highlight short-wavelength anomalies and, hence, are useful for locating shallow bodies, delineating formational contacts and edges of the magnetic source bodies, particularly where low magnetic latitudes and/or remanent magnetisation complicates the interpretation. The width of AS maxima is proportional to the source depth (Nabighian, 1972, 1984; Roest *et al*., 1992; MacLeod *et al*., 1993). The area under investigation lies in the low magnetic latitudes, which may cause complexities in magnetic signatures due to low inclination of the induced magnetic field.

5. Quantitative analysis of gravity and magnetic data

Quantitative interpretation aims to determine the depth, dimensions, and other information of the causative sources. Any given gravity and magnetic anomaly can be explained by a variety of mass and susceptibility distribution at different depths. In this section, an attempt is made to determine the source depths of causative anomalies by calculating the power spectrum and the Euler 3D depth solutions using Geosoft (2015) software.

5.1. Radially averaged power spectrum of gravity and magnetic data

Spectral analysis of gravity and magnetic data are conventional techniques, which have wide applications in determining the depths of geological features, such as the basement (Maus and Dimri, 1996). Since the depth of an anomalous body controls the shape of the power spectrum, the depth can be determined directly from the power spectrum of the gravity/magnetic field by Fast Fourier Transform (FFT) operations. In a frequency domain spectrum the segment with a smaller wave number corresponds to deeper features, whereas higher wave numbers represent shallow features. In the present study, the gravity and magnetic data have been transformed into the frequency domain to calculate the average depths to different interfaces using radially averaged power spectrum (Spector and Grant, 1970; Naidu and Mathew, 1988) represented by notable density or susceptibility contrasts. The radially averaged power spectrum of gravity data has highlighted interfaces mainly at depths around 6.6, 3.5, and 2.0 km (Fig. 12) and magnetic data at depths around 2.2 and 1.5 km (Fig. 13), respectively. Detailed analyses of the spectrum pertaining to individual major lithounits such as khondalite, charnockite and granite gneiss, reveal that the depth value of 1.5-2.2 km corresponds to the average thickness of granite gneiss, 3.5 km for charnockite, and 6.6 km for khondalite in the EGMB. The depth of interfaces may be valuable inputs in selecting the body parameters for the model study.

Gravity and magnetic methods are potential field methods and, while gravity varies as the inverse of the square of distance, the magnetic field varies as the inverse of the cube of distance. Magnetic properties diminish quickly unlike gravity. At a deeper interface there is insufficient susceptibility contrast and accordingly it is not highlighted. For this reason, the deeper interface could not be ascertained as a gravity evidence by spectral analysis of magnetic data, where there is sufficient density contrast because, generally, all high-density materials do not show high susceptibility.

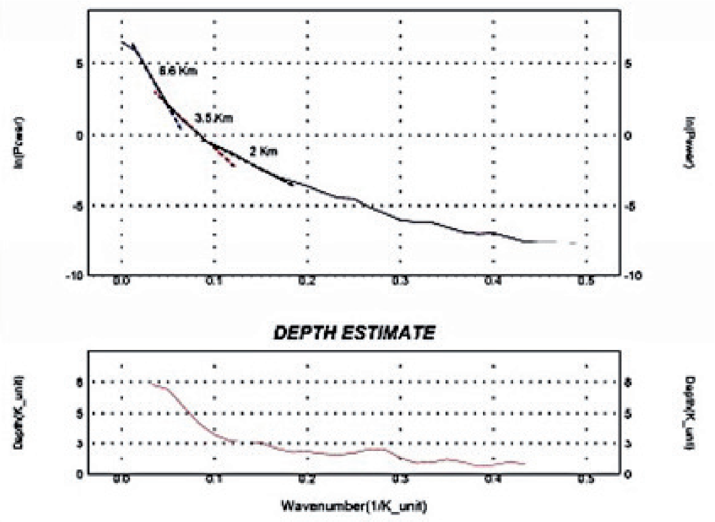

Fig. 12 - Radially averaged power spectrum of gravity data.

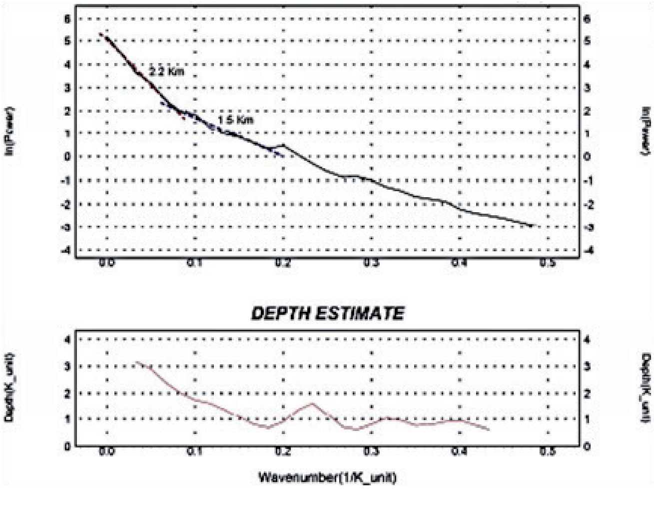

Fig. 13 - Radially averaged power spectrum of magnetic data.

5.2. 3D Euler deconvolution for depth estimation

The 3D Euler deconvolution of Reid *et al*. (1990) is a technique applied to the gridded potential field data to determine the position, depth, and nature of sources on the basis of the gradient of the potential field. The Structural Index (SI) is based on the nature of geological features and the geometry of the body and is a measure of rate of change of the potential field with distance from the source.

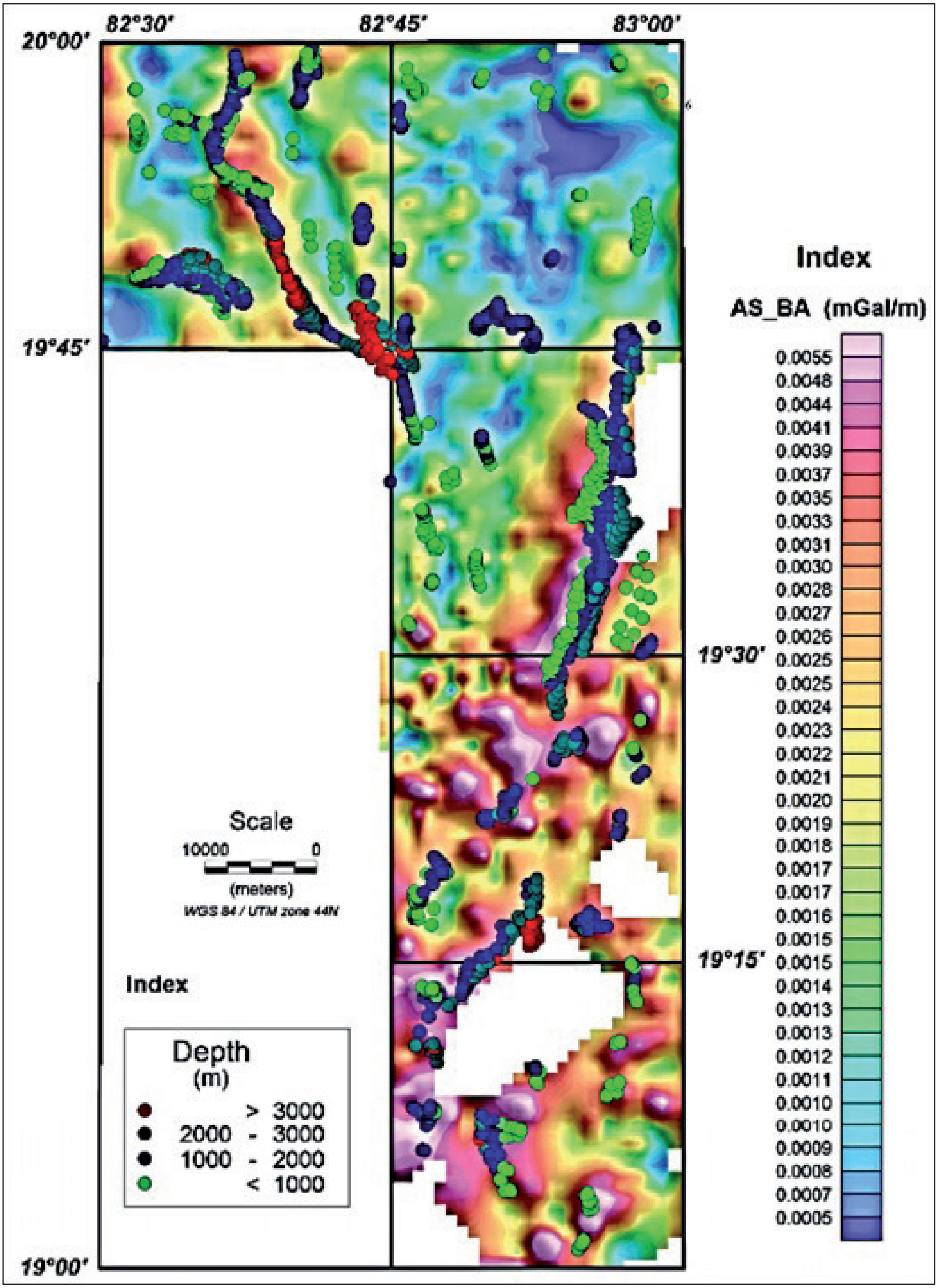

Fig. 14 - 3D Euler depth solution of gravity data.

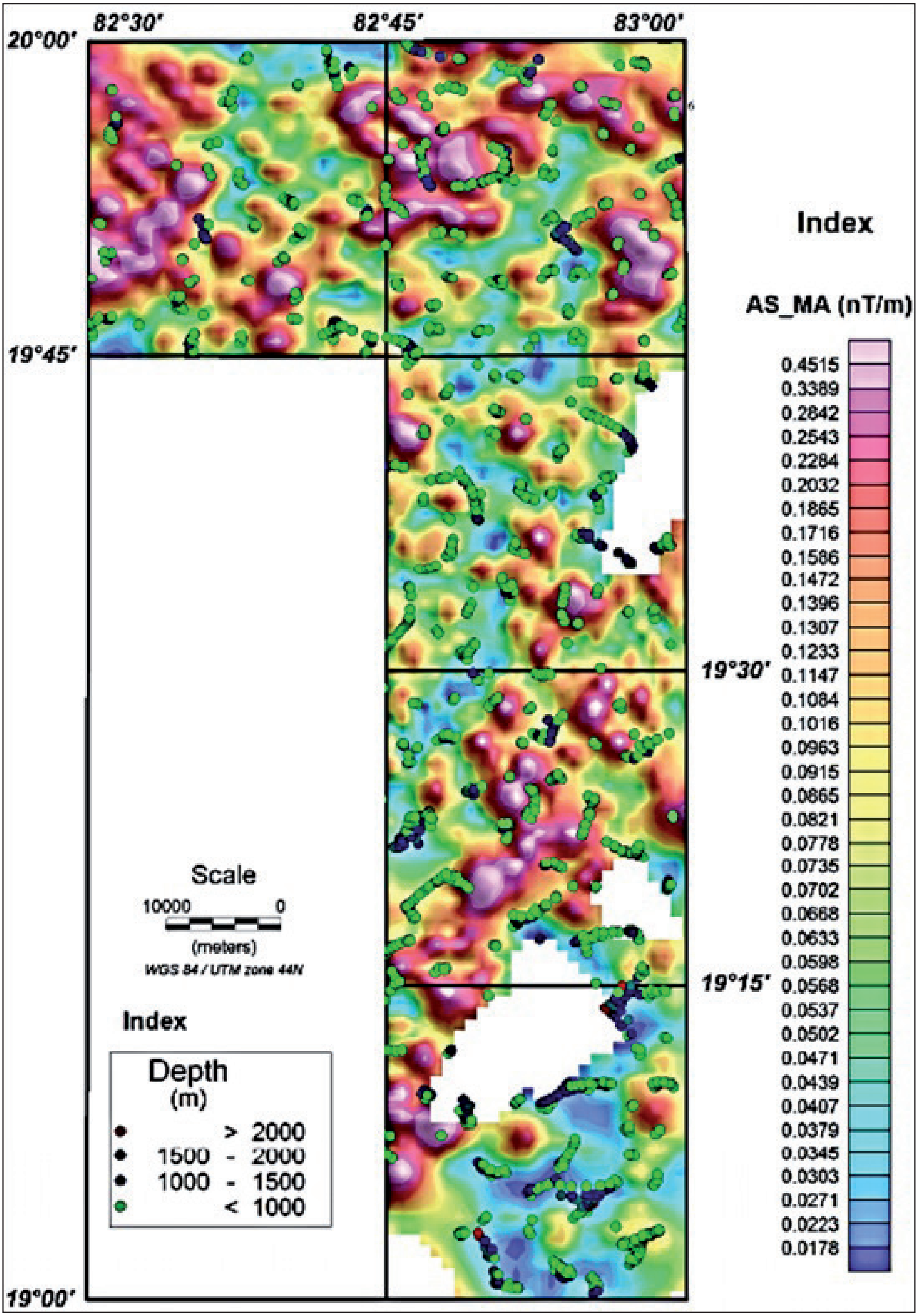

Fig. 15 - 3D Euler depth solution of magnetic data.

Solutions of Bouguer gravity anomaly for grid cell size 1000 m, SI 0.5, and window size 10 have been superimposed on the AS of the Bouguer anomaly map (Fig. 14). The depth range <1000, 1000-2000, and 2000-3000 m identified by blue and green solid circles dominates the southern and central part over the EGMB Group of rocks trending NE-SW, in conformity with the regional trend, and demarcate the boundary between the Sileru shear zone and the EGMB. The remaining north-western part is dominated by a deeper depth range of 1000-3000 m identified by blue and green solid circles, and red solid circles, with depth >3000 m trending NW-SE, demarcate the boundary between the Sileru shear zone and the Bastar Craton. One curvilinear contact is also seen in the NW in a deeper depth range. This linear and curvilinear clustering of depth solutions may be inferred as due to geologic/faulted contacts.

Depth solutions derived from the magnetic anomaly, for grid cell size 1000 m, SI 0.5, window size 5×5 km^2, and depth tolerance 20%, have been plotted in a magnetic AS map (Fig. 15). Major scattered responses are from source bodies occurring at depths of less than 1000 m marked with blue solid circles and lie over peaks of Ass, implying the depth of a magnetic interface in this area. Unlike the clear distribution pattern of gravity solutions, the plots of the magnetic solutions do not show any definite trend. Nor are they aligned along the trends of lineaments because of a lack of significant susceptibility contrast of adjacent lithounits. Some curvilinear plots are seen in the northern and southern part with depth range <1000 m.

6. Conclusions

The results of gravity and magnetic (TF) surveys conducted on regional basis have provided information and useful inferences on the subsurface crustal structure of the study area, which are summarised below. Gravity and magnetic surveys demarcate the area under further detailed investigation for ore body occurrences/minerals. The magnetic survey only supports the gravity method.

The main pieces of evidence identified are:

i) a moderate gravity anomaly nosing and breaking the contour pattern is prominent in the transition zone in between the Jayapatna - Dakatipara section trending NE-SW and is well-reflected as a high residual gravity anomaly on the residual gravity map and may assume importance for mineralisation;

ii) the NW-SE trending Sileru shear zone is reflected by a moderate gravity anomaly as a major shear/thrust zone that separated the Archaean granite greenstone terrain in the west and the EGMB in the east and its extensions towards south is clearly demarcated;

iii) the NW-SE trending Sileru shear zone is clearly delineated as a low amplitude AS of magnetic anomaly that separated the Archaean Craton in the west and the EGMB in the east;

iv) one tri-junction type magnetic anomaly has been observed around Muter and inferred for promising potential zone of mineralisation;

v) detailed analyses of spectrum pertaining to individual major lithounits, such as khondalite, charnockite and granite gneiss, reveal that the depth value of 1.5-2.2 km corresponds to the average thickness of granite gneiss, 3.5 km for charnockite, and 6.6 km for khondalite in EGMB;

vi) the linear and curvilinear clustering of depth solutions may be inferred as due to geologic/faulted contacts.

Gravity methods, supported by magnetic ones, could not directly indicate orebody occurrences. It cannot be concluded that the magnetic method distinguishes the ore occurrences, but only that certain structures may or may not be associated with ore bodies/minerals. Gravity and magnetic methods only provide the areas for detailed surveys and further integration with other geophysical methods are warranted. For this, Controlled-Source Audio-frequency Magnetotelluric (CSAMT) is derived from magnetotelluric and uses an artificial electro-magnetic source with frequency >1 Hz and is suitable for the delineation of minerals or ore bodies up to a depth of 1 km. Moreover, depth of investigation depends not only on the transmitted frequency but resistivity of the subsurface as well. In general, the lower the frequency and the higher the ground resistivity, the greater the depth of the data.

With this investigation, we only specify the areas for detailed mineral investigation through structures delineated by these methods.

REFERENCES

Anand S.P. and Rajaram M.; 2003: *Study of aeromagnetic data over part of Eastern Ghat Mobile Belt and Bastar Craton*. Gondwana Res., 6, 859-865.

Beard L.P., Goitom B. and Skilberi J.R.; 2000: *Interpretation of low latitude magnetic anomalies*. Geological Survey of Norway, Trondheim, Norway, NGU-report 2000.012, 31 pp.

Behera S., Moharana P. and Behera B.; 2015: *Regional geochemical mapping around Belpara-Turekela area in Balangir and Nawapara districts of Odisha, covering Toposheet 64L/14 and L/15 (part) (FS 2014-15)*. Geological Survey of India, Kolkata, India, unpublished report.

Bhattacharya A., Swain S.P. and Behera B.; 2015: *Regional geochemical mapping around Golamunda-Sindhekela area in Nawapara, Kalahandi and Balangir districts of Odisha, covering Toposheet 64L/16 and L/15 (part) (FS 2014-15)*. Geological Survey of India, Kolkata, India, unpublished report.

Bhattacharya S., Kar R., Saw A.K. and Das P.; 2011: *Relative chronology in high-grade crystalline terrain of the Eastern Ghats, India: new insights*. Int. J. Geosci., 2, 398-405.

Blakeley R.J.; 1995: *Potential theory in gravity and magnetic applications*. Cambridge University Press, New York, NY, USA, 461 pp., doi: 10.1017/CBO9780511549816.

Chakrabarti A.K., Madhusudanan I.C. and Murthy N.V.S.; 1986: *Report on the geophysical investigation for regional of graphite resources of Bolangir district, Orissa*. Geological Survey of India, Kolkata, India, unpublished report.

Chetty T.R.K. and Murthy D.S.N.; 1994: *Collision tectonics in the late Precambrian Eastern Ghat Mobile Belt: mesoscopic to satellite scale structural observations*. Terra Nova, 6, 72-81.

Crookshank H.; 1938: *The western margin of the Eastern Ghats in southern Jeypore*. Rec. Geol. Surv. Ind., 73, 398-434.

Geosoft; 2015: *Oasis Montaj data processing and analytical system for earth science applications, vers. 8.5*. Geosoft Inc., Toronto, ON, Canada.

Grant F.S. and West G.F.; 1965: *Interpretation theory in applied geophysics*. McGraw-Hill, New York, NY, USA, 583 pp.

GSI (Geological Survey of India); 1983: *Geology Quadrangle map*. Geological Survey of India, Kolkata, India.

GSI (Geological Survey of India); 1995: *Catalogue of aerogeophysical maps, airborne mineral survey and exploration wing*. Geological Survey of India, Kolkata, India, RSAS, Report.

GSI (Geological Survey of India); 2007: *Geology Quadrangle map: Nuapada Quadrangle.* Geological Survey of India, Kolkata, India, Map Series, Degree sheet 64L.

GSI (Geological Survey of India); 2016: *Report on the geophysical mapping in parts of Kalahandi, Rayagada, Nabarangpurb & Koraput districts of Odisha and Gariyabandh district of Chattisgarh (toposheet 65I/9, 13, 14, 15 & 16), FSP 2015-2016, ER, GSI, Kolkata, item GPM/ER/HQ/2015/002/035*. Geological Survey of India, Kolkata, India, unpublished report.

IAG (International Association of Geodesy); 1980: *The Geodesist's Hand Book [Müller (ed.)].* Bull, Geod., 54(3), 246-468.

Kaila K.L. and Bhatia S.C.; 1981: *Gravity study along Kavili-Udipi deep seismic sounding profile in the Indian peninsular shield: some inferences about the origin of anorthosites and Eastern Ghat orogeny*. Tectonophys., 79, 129-143.

Kannadasan T. and Natarajan A.; 2010: *Interpretation and integration of aerogeophysical data and remote sensing data with modelled aerogeophysical anomaly data pertaining to Chattisgarhand Orissa: part-B-Khariar Road (FS 2004-2005)*. Geological Survey of India, PGRS Division, Bangalore, India, unpublished report, 40 pp.

Kumar M. and Dule P.G.; 2015: *Regional geochemical mapping around Sinapali-Nilji area in Kalahandi and Nuapara districts of Odisha, covering Toposheet 64L/12 and L/15 (part) (FS 2014-15)*. Geological Survey of India, Kolkata, India, unpublished report.

Kumar P.S., Menon R. and Reddy G.K.; 2007: *The role of radiogenic heat production in the thermal evolution of a Proterozoic granulite-facies orogenic belt: Eastern Ghats (Indian Shield)*. Earth Planet. Sci. Lett., 254, 39-54.

MacLeod I.N., Jones K. and Dai T.E.; 1993: *3D analytic signal in the interpretation of total magnetic field data at low magnetic latitudes*. Explor. Geophys., 24, 679-687.

Maus S. and Dimri V.; 1996: *Depth estimation from scaling power spectrum of potential fields*. Geophys. J. Int., 124, 113-120.

McIntyre J.I.; 1980: *Geological significance of magnetic patterns related to magnetite in sediments and metasediments - A review*. Explor. Geophys., 11, 19-33.

Nabighian M.N.; 1972: *The analytic signal of two-dimensional magnetic bodies with polygonal cross-section: its properties and use of automated anomaly interpretation*. Geophys., 37, 507-517.

Nabighian M.N.; 1984: *Toward a three-dimensional automatic interpretation of potential field data via generalized Hilbert transforms; fundamental relations*. Geophys., 49, 780-786.

Nabighian M.N., Grauch V.J.S., Hansen R.O., LaFehr T.R., Li Y., Peirce J.W., Phillips J.D. and Ruder M.E.; 2005: *The historical development of the magnetic method in exploration*. Geophys., 70, 33-61.

Naidu P.S. and Mathew M.P.; 1988: *Computer program for radial and angular spectrum estimation*. Geological Survey of India, AMSE, Bangalore, India, unpublished report, 11 pp.

Nanda J.K. and Pati U.C.; 1989: *Field relations and petrochemistry of the granulites and associated rocks in the Ganjam-Koraput sector of the Eastern Ghat Mobile Belt*. Indian Miner., 43, 247-264.

Nanda J.K. and Panda P.K.; 1998: *Progress report on the study of alkaline and ultramafic rocks in the northern and western margin of Eastern Ghats and possible associated mineralization*. Geological Survey of India, Kolkata, India, unpublished report.

Nayak P.N., Choudhury K. and Sarkar B.; 1998: *A review of geophysical studies of the Eastern Ghats Mobile Belt*. Geol. Surv. India, Kolkata, India, Special Publication, 44, 87-94.

Niraj Kumar, Singh A.P., Gupta S.B. and Mishra D.C.; 2004: *Gravity signature, crustal architecture and collision tectonics of the Eastern Ghats Mobile Belt*. J. Indian Geophys. Union, 8, 97-106.

Paterson N.R. and Reeves C.V.; 1985: *Applications of gravity and magnetic surveys: the state-of-the-art in 1985.* Geophys., 50, 2558-2594.

Radhakrishna B.P. and Naqvi S.M.; 1986: *Precambrian continental crust of India and its evolution*. J. Geol., 94, 145-166.

Radhakrishna Murthy I.V., Rama Rao P., Sudhakar K.S. and Bangaru Babu S.; 2005: *Moho structure beneath the Eastern Ghats Mobile Belt and adjacent Bastar Craton as deduced from gravity anomalies*. J. Indian Geophys. Union, 9, 167-171.

Rajaram M. and Anand S.P.; 2003: *Central Indian tectonics revisited using aeromagnetic data*. Earth Planets Space, 55, e1-e4.

Ramakrishnan M., Nanda J.K. and Augustine P.F.; 1998: *Geological evolution of the Proterozoic Eastern Ghat Mobile Belt*. Geol. Surv. India, Kolkata, India, Special Publication, 44, 1-21.

Ray S.B. and Devdas V.; 1994: *Report on the integrated study of Archean-Proterozoic activated contact zone between Eastern Ghat and Chhattisgarh Supergroup of rocks with emphasis on petrology and mineral association in Barabanki-Komna-Clierichuan area, Bolangir and Kalahandi districts, Orissa*. Geological Survey of India, Kolkata, India, unpublished report.

Ray B. and Mishra N.; 2015: *Regional geochemical mapping around Rajna-Karalkot area in Nawapara and Balangir districts of Odisha, covering Toposheet 64L/11 and L/15 (part) (FS 2014-15)*. Geological Survey of India, Kolkata, India, unpublished report.

Reid A.B., Allsop J.M., Granser H., Millet A.J. and Somerton I.W.; 1990: *Magnetic interpretation in three dimensions using Euler deconvolution*. Geophysics, 55, 80-91.

Roest W.F., Verhoef J. and Pilkington M.; 1992: *Magnetic interpretation using 3D analytic signal*. Geophys., 57, 116-125.

Sharma P.V.; 1986: *Geophysical methods in Geology.* Elsevier Science Publishing Co., New York, NY, USA, 460 pp.

Spector A. and Grant F.S.; 1970: *Statistical model for interpretating aeromagnetic data*. Geophys., 35, 293-302.

Subramaniyan C.; 1983: *An overview of gravity anomalies, Precambrian terrains and their boundary relationships in the southern Indian shield*. Mem. Geol. Soc. India, 4, 553-566.

Subrahmanyam C. and Verma R.K.; 1986: *Gravity field, structure and tectonics of the Eastern Ghats*. Tectonophys., 126, 195-212.

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