Gondwana Research, V. 6, No. 4, pp. 859-865.

ISSN: 1342-937X

GR Gondwana Research

Study of Aeromagnetic Data Over Part of Eastern Ghat Mobile Belt and Bastar Craton

S.P. Anand and Mita Rajaram*

Indian Institute of Geomagnetism, Mumbai - 400 005, India, E-mail: mita@iig.iigm.res.in

* *Corresponding Author*

(Manuscript received February 22, 2003; accepted June 18, 2003)

Abstract

A portion of the aeromagnetic anomaly map of India, from 17° to 20° N and 78° to 84° E has been analysed to understand the tectonics of the region. The distribution of magnetic sources in the study region are clearly brought out in the analytic signal map and found to be associated with charnockitic rocks, iron formation and trap flows. The Godavari Graben is devoid of any magnetic sources. High-grade charnockitic rocks on surface and sub-surface, flank the shoulders of the Godavari Graben on either side. From the analysis of magnetic data, Sileru Shear Zone (SSZ) is identified as the contact of the Bastar craton and the Eastern Ghat Mobile Belt (EGMB). The Eastern Ghat is divided into two blocks: Block-N north of Srikakulam is devoid of magnetic sources while the charnockitic rocks are the main magnetic carriers in Block-S. The difference in magnetic characteristics of the two blocks has been attributed to the difference in metamorphic history. Block-N has an over print of amphibolite facies metamorphism while Block-S to the south depicts granulite facies metamorphism. The Euler solutions within the EGMB shows that the magnetic sources along SSZ is shallower than the south east implying that the exhumation process in the EGMB has a differential rate.

Key words: Aeromagnetic anomaly, Dharwar, Bastar, Eastern Ghats, metamorphism.

Introduction

Peninsular India is a multi-cratonic assembly of Precambrain crustal blocks, surrounded by mobile belts, with varied lithologies, tectonic style and evolutionary history, that have been brought into juxtaposition and sutured together during different epochs. However the surface cover often complicates the picture and it is in this context that the aeromagnetic data can play a very crucial role in delineating the sub-surface structures. All the tectonic models available so far are based largely on inadequate data sets e.g., gravity and geology maps have huge data gaps as data collection is heavily dependent on road access. On the contrary, aeromagnetic data has excellent data coverage with the data points being very closely spaced along flight line with a flight line spacing of 4km. The inherent nature of this data set leads to very reliable information content almost independent of any extrapolation in the maps generated and their subsequent interpretation/analysis.

Harikumar et al. (2000), through long wavelength magnetic anomaly studies up to 17° N, identified charnockitic rocks as the main source of magnetic anomalies in the Southern Granulite Terrane and Banded Iron Formation (BIF) in the Dharwar craton. Reddy et al. (1989) analysed the aeromagnetic data up to 12°N and showed the usefulness of aeromagnetic data in deciphering the crustal structure. From the study of aeromagnetic data from 12° to 17°N, Anand and Rajaram (2002) showed that the difference in magnetic signatures of the Eastern and Western Dharwar craton was related to the difference in metamorphic grades. The region from 17° to 20°N, comprising the Eastern Dharwar and Bastar cratons separated by the Godavari Graben and surrounded by the Eastern Ghat Mobile Belt (EGMB) towards the east, is important as this region witnessed tectonic activity right from Archean times to Recent and so far no analysis of aeromagnetic data of this region has been published. The present paper aims at looking into the aeromagnetic data from this area to understand the exposed and sub-surface structural and tectonic features and to throw light on their evolutionary history.

Geology

Figure 1, compiled from Tectonic map of India (GSI, 2001) and Geological map of EGMB (Ramakrishnan

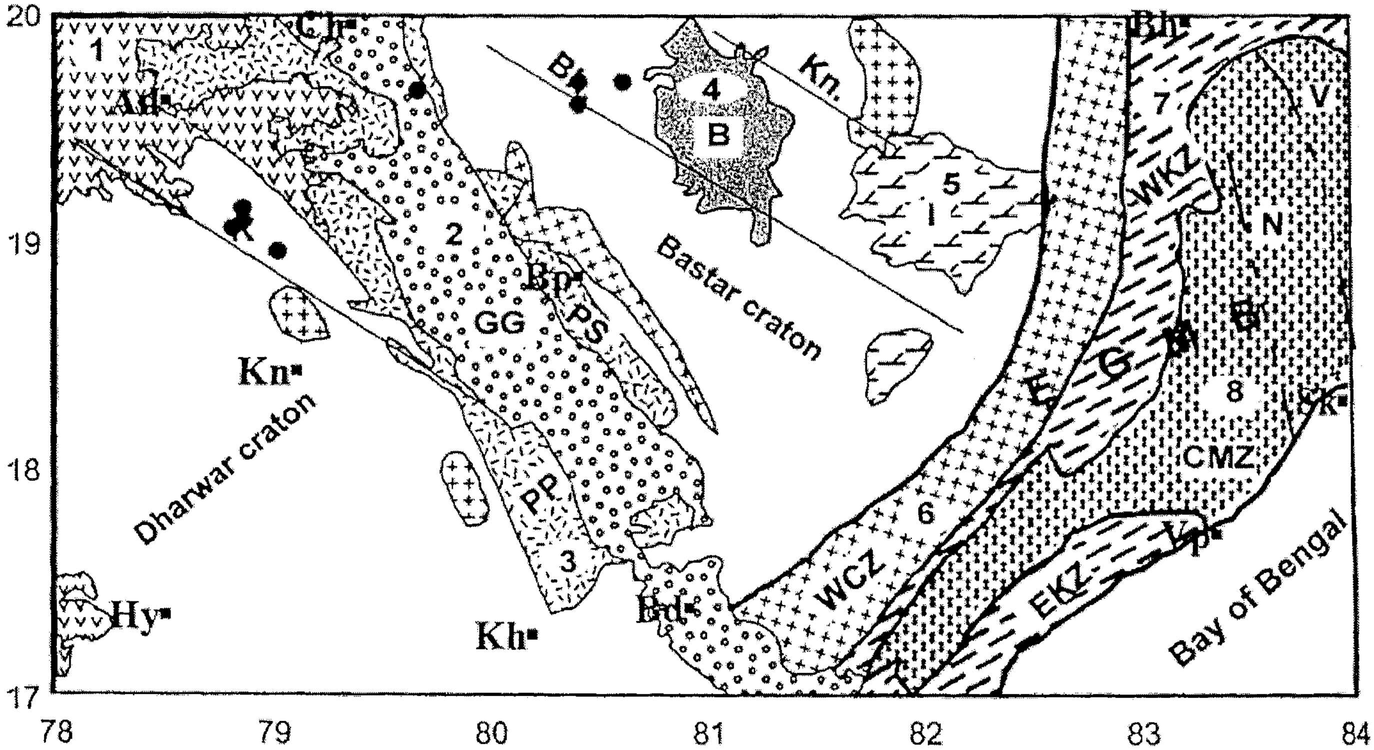

Fig. 1. Geology and Tectonic Map. B–Bailadilla Iron ore, GG–Godavari Graben, PP / PS–Proterozoic Pakhals / Sullavais, I–Indravati Basin, K–Kadam fault, lineaments: Bh– Bhamragarh, Kn–Khondagaon, N–Nagavalli, V–Vamasadhara, U–unclassified granites/gneiss, 1–Deccan Trap, 2–Gondwana Sediments, 3–Proterozoic Pakhals/Sullavis, 4–Banded Iron formation, 5–Proterozoic Basin, 6–Charnockite, 7–Khondalites, 8–Migmatites/charnockites. WCZ–Western Charnockite Zone, WKZ–Western Khondalite Zone, CMZ–Charnockite Migmatite Zone, EKZ–Eastern Khondalite Zone. Black dots represents mapped iron ore, Ad–Adilabad, Bd–Bhadrachalam, Bh–Bhavanipatana, Ch–Chandrapur, Hy–Hyderabad, Kn–Karimnagar, Kh–Khammam, Sk–Srikakulam, Vp–Visakhapatanam.

et al., 1998) presents the main geological and tectonic information of the region under study. The Eastern Dharwar craton is represented by basement elements comprising gneisses, migmatites and granulites with associated BIF. The basement gneisses are overlain by the meso-proterozoic shelf facies rocks of the Pakhal and Sullavai group which are exposed respectively (GSI, 2000) along the western and eastern shoulders of the NW-SE trending Godavari Graben (GG). The GG is a polycyclic rift bounded by parallel en-echelon gravity faults (Mishra et al.,1989). The Dharwar craton and cover rocks of the GG in some areas have been overlain by continental flood basalts. NW-SE (eg., Kadam river fault) to E-W trending fault/lineaments traverse the terrain (GSI, 2000). The Bastar craton exposes the earliest basement as well as recent alluvial cover with the principal structural trend being NNW-SSE, NS and WNW-ESE including the Bhamragarh and Kondagaon lineaments and volcano-sedimentary sequence of Bailadilla with BIF. Some Proterozoic sedimentary basins (Indravati basin) are also identified in this craton. The principal structural trend in the EGMB is NE-SW in the southern part that swerves to NS in the northern part. EGMB consists of granulite facies metamorphosed charnockites, khondalites, migmatitic gneisses and granitoids. Younger intrusions of anorthosites, alkaline rocks and granites are also present in the belt. The EGMB is divided into four zones (Ramakrishnan et al., 1998): Western Charnockite Zone (WCZ), Western Khondalite Zone (WKZ), Charnockite Migmatite Zone (CMZ) and Eastern Khondalite Zone (EKZ). In the context of the EGMB, the crustal scale Sileru Shear Zone (SSZ) is much debated. Chetty and Murthy (1994) suggested that SSZ is the contact of EGMB and Bastar craton while Ramakrishnan et al. (1998) placed it between WCZ and WKZ.

Aeromagnetic Map Preparation and Analysis

Aeromagnetic data over the study area collected by the National Remote Sensing Agency (NRSA) for the Geological Survey of India (GSI) during 1990–1992 at a terrain clearance of 5000 ft, with NS oriented flight lines and 4 km line spacing are available as analog degree sheets with the GSI. These analog degree sheets have been digitized along each contour. The digital data were corrected for the Earth's field and gridded at 2 km interval, as a grid interval of less than 2 km (related to Nyquist frequency) is likely to give some spurious results. The anomaly map thus obtained (Geosoft, 1999) is represented as grayscale image map in figure 2. The anomaly map depicts NW-SE trends in the Dharwar and Bastar cratons consistent with the typical Dharwarian trend with a few EW and NS trends. The 3D and sub-circular anomalies represent the iron ore bodies in the cratons. The NW-SE anomalies are terminated at the contact of the Bastar craton and the EGMB; the EGMB are dominated by NE-SW trends.

The magnetic inclination in the study region varies from 20° to 26° and this changing inclination of the magnetic field makes it difficult to identify the sources directly from the anomalies. Due to the large variation in the inclination parameter conventional methods like reduction to pole may not be reliable. The analytic signal of the total field marks the edges of the magnetized bodies regardless of the direction of magnetization (Roest et al., 1992). The width of the Analytic Signal Maxima (ASM) is proportional to the source depths (MacLeod et al., 1993). The analytic signal is useful in locating the edges of magnetic source bodies, particularly where low magnetic latitudes and/or remanent magnetization complicates the interpretation. The analytic signal (A) of the magnetic total field (T) is the square root of the sum of the squares of its derivatives in the x, y, and z directions:

$$A = \mathrm{sqrt}\,[\,(dT/dx)^2 + (dT/dy)^2 + (dT/dz)^2\,]$$

The derived analytic signal map of the area is reproduced in figure. 3. The contours representing the highs are superposed on the grayscale map. Rajaram and Anand (2003) have published the coloured figures of the anomaly map and its analytic signal for the region 17° to 24°N, although no interpretation of the present study region is included in that paper. On comparison with Geology and Tectonic map (Fig. 1), it can be seen that the BIF (A1, D1, D2), trap flows (A1) and high-grade charnockitic rocks (B2, E3) are the main lithological units associated with analytic signal maxima. This is true even in Dhrawar craton (Anand and Rajaram, 2002) and Southern Granulite Terrain (Harikumar et al., 2000). Even in the regions overlain by thick sedimentary cover, the analytic signal maxima would identify the extent of sources within the subsurface.

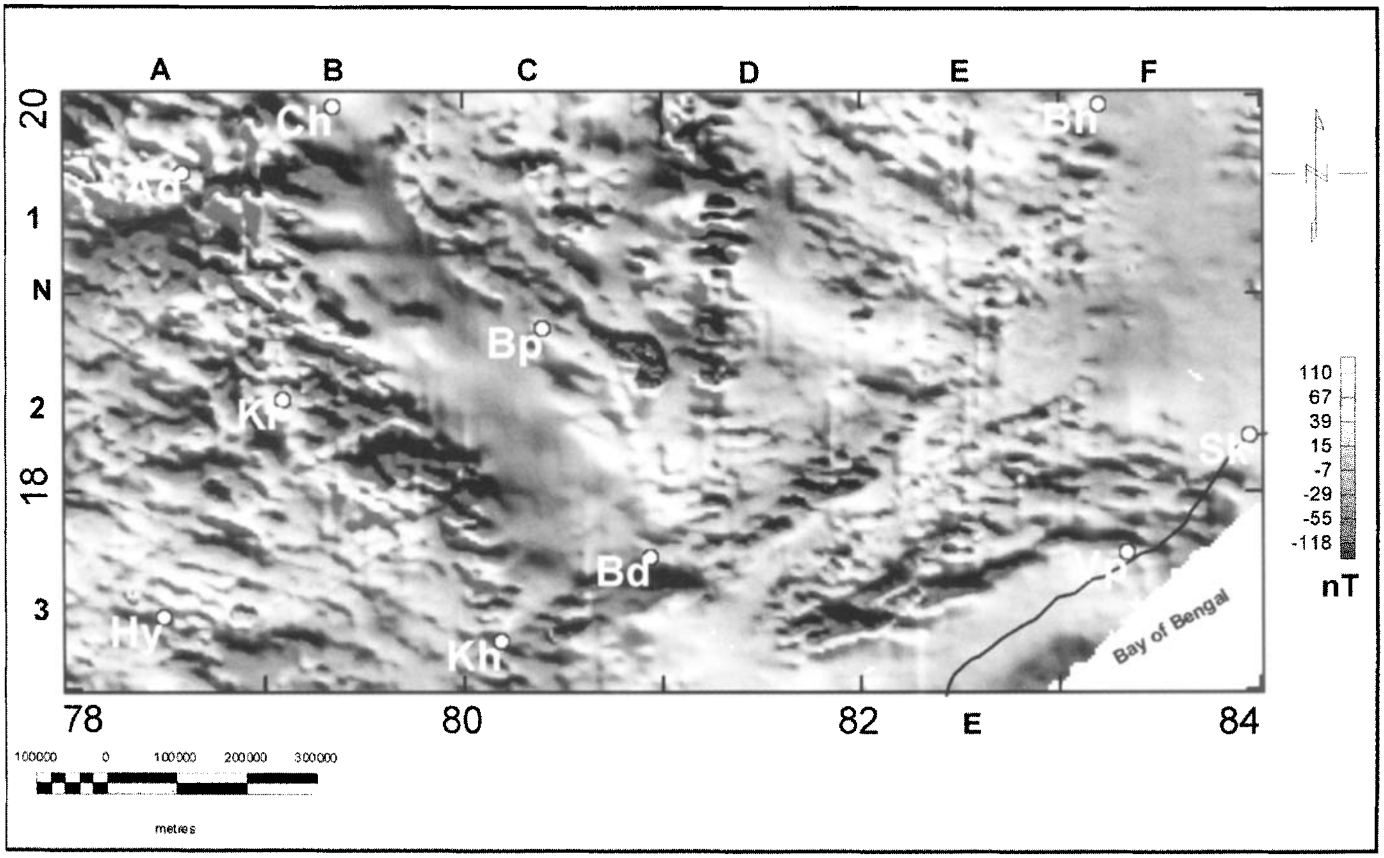

Fig. 2. Image map of aeromagnetic anomalies in grayscale. Place name abbreviations as in figure 1.

To be able to locate the sources in terms of depth we make use of the 3D Euler deconvolution method which is a technique applied to gridded potential field data to help determine the position, depth and nature of any sources present (Reid et al., 1990). If (x_0,y_0,z_0) is the position of a magnetic source whose total field T is measured at (x,y,z) and the total field has a regional value of B then

$$(x-x_0)dT/dx + (y-y_0)dT/dy + (z-z_0)dT/dz = N\ (B-T)$$

The degree of homogeneity N can be considered as a structural index (SI) that is a measure of rate of change with distance of the potential field. For example the magnetic field of a point dipole falls off as the inverse cube giving an index of three while a narrow vertical pipe gives rise to an inverse square field fall-off and an index of two. Extended bodies formed from assemblages of dipoles have indices ranging from zero to three. The optimum source location is found by least squares inversion of the data. Euler solutions in the region of study were calculated for different structural indices (SI = 0, 0.75, 1, 1.25, 1.5, 2, 3) with depth uncertainty set to a maximum of 15%. To pick the deeper solutions without being affected by the shallow solutions, the data was also gridded at 5 km and 10 km interval and Euler solutions calculated. The number of solutions with SI = 0, 0.75,1 and 1.5 were few for both: data gridded at 2 km and 5 km interval. We also calculated Euler solutions using the above SI and grid spacing of 1 km; this resulted in too many noisy solutions. But it is very heartening to see that the locations of the solutions were very consistent throughout although the scatter of the solutions varied. Although the actual depth estimates may be deep with data gridded at 5 km interval the relative depths will still be very meaningful. The best solutions where obtained for SI = 2, window length 10, position uncertainty (dXY) of 25% and grid interval 5km (Fig. 4). It may be noted that all the solutions are plotted.

Results and Discussion

The combination of the total field aeromagnetic anomaly map, its analytic signal and Euler solutions help in bringing out the main structural features and magnetic sources in the study region. On the basis of anomaly patterns, trends and magnetic sources the study region can be divided into four main blocks: the Dharwar block having a combination of NW–SE and NE–SW structural

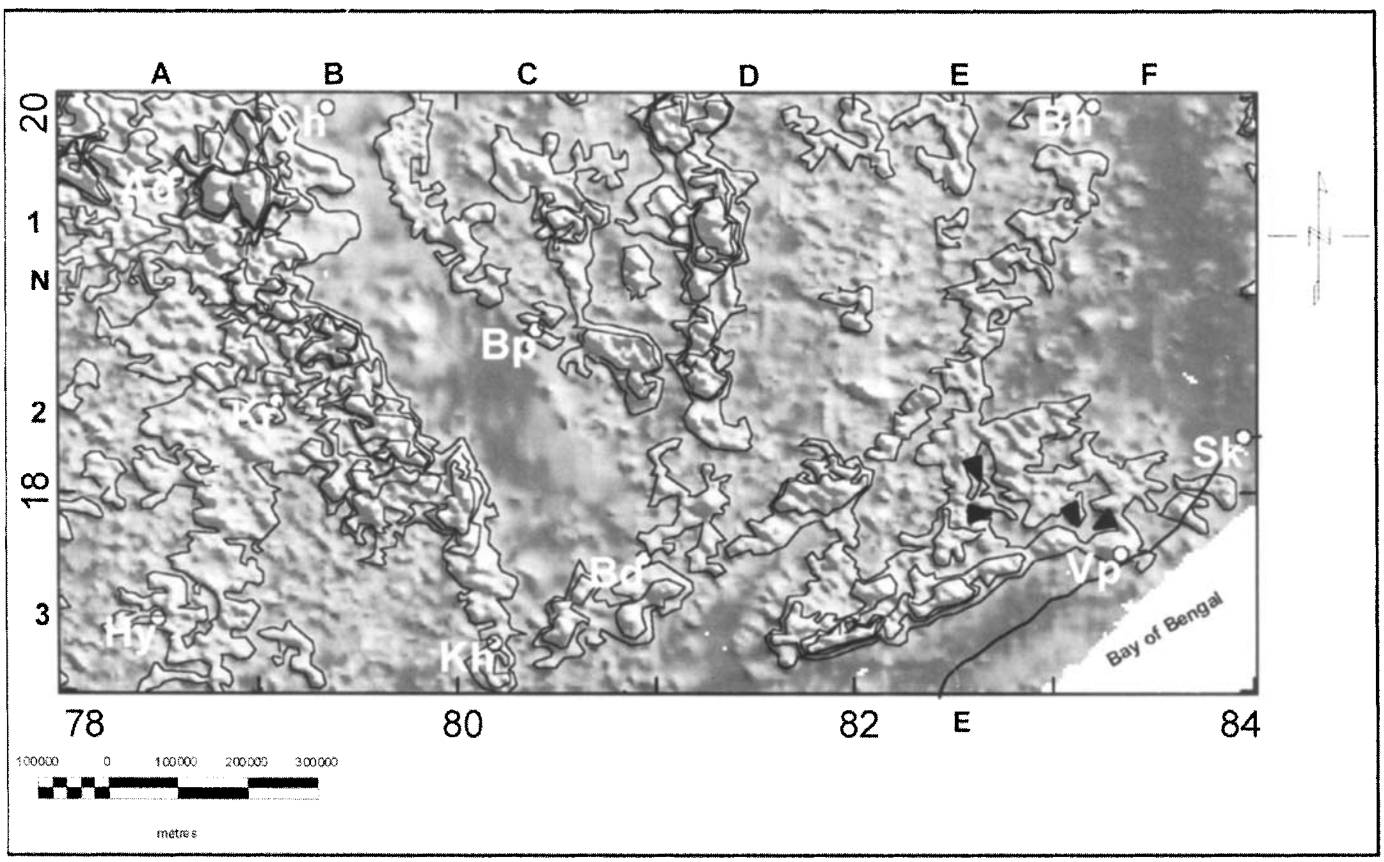

Fig. 3. Analytic signal map. Contours representing analytic signal highs (sources) are superposed on the grayscale map. Place name abbreviations as in figure 1.

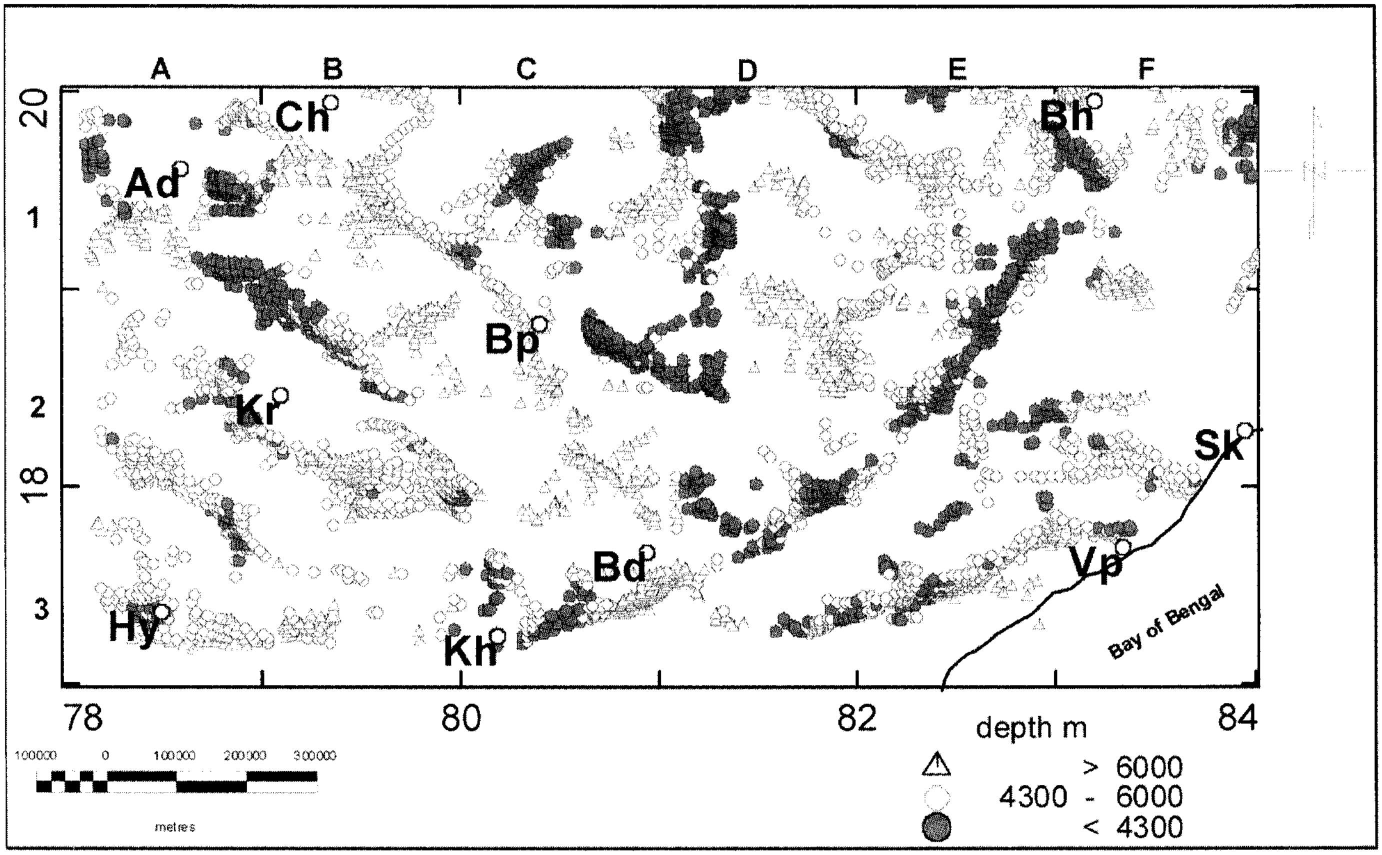

Fig. 4. Magnetic source depth and location using Euler deconvolution. (window length=10, position uncertainty=25%, grid interval=5km and structural index=2). Place name abbreviations as in figure 1.

features at deep and shallow levels respectively, the Godavari Graben which is devoid of magnetic sources, the Bastar block dominated by NS and some NW–SE structural features and the Eastern Ghat block with NE–SW trends. All the NW–SE/NS structures are terminated at the EGMB which in turn is divided into two blocks: Block-N north of Srikakulam devoid of any magnetic sources and Block-S to the south with NE–SW trending magnetic sources. The magnetic sources interpreted from the present study are schematically represented in figure 5.

The major magnetic sources in the Dharwar block are trap flows, BIF and exposed and subsurface granulitic rocks while the Bailadilla iron ore series and some charnockitic rocks comprises the magnetic sources in the Bastar craton. The BIF of the Bailadilla series, which appear as 3D anomalies (D1, D2) in figure 2, are found to extend further south upto Bhadrachalam (Fig. 5). On comparison with figure 1, it can be seen that the circular and sub-circular 3D features (A1, B1) appearing as maxima in figure 3 in the cratonic block, represent mapped iron ore and its continuation under cover. The NW–SE trending GG is conspicuous by a broad subdued field suggesting thick non-magnetic sediments. A striking feature is the termination of all the NW-SE trends at the base (southeast) of the Godavari Graben by NE-SW trends of Eastern Ghat. From the total field anomaly map it appears that the GG is terminated by the EGMB, but through the analysis of ground magnetic data, Rajaram et al. (2000) have shown that the NW-SE trends associated with the GG extend offshore underneath the coastal basin till the ocean continent boundary. Guided by the geology map (Fig. 1), the magnetic sources along the shoulders of the GG, from south of Adilabad to Khammam in the west and from Bhopalpatana to south of Chandrapur in the east, are inferred as exposed and buried charnockites (Fig. 5) probably forming the basement for the deposition of Proterozoic sediments. The latter are also associated with prominent NNW-SSE trending gravity highs suggesting the presence of high-density rocks in the basement. From the Euler solutions (Fig. 4) it can be seen that the magnetic sources (charnockites), forming the platform for the deposition of Proterozoic sediments, are shallower on the western side and deeper on the eastern shoulder. Basic intrusives into the Karimnagar granulite belt has been dated at 2600 Ma (Acharya, 1997). This suggests that high-grade metamorphic conditions existed in the Archean period. High-grade metamorphism is often related to crustal thickening during a compressive regime (England and Thompson, 1984). A concentration of earthquake epicenters noted along the GG in the Karimnagar and Bhopalpatana areas implies that these regions are tectonically active. Integrated results throw light on the fact that NW-SE trending weak zones existed in this region since Precambrian times. Several NW-SE/NNW-SSE and NE-SW lineaments are identified in the Dharwar and Bastar craton (some are marked in Fig. 5) from the data set gridded at different intervals. The NW-SE features are consistent with typical Dharwarian trend. We believe that the NE-SW lineaments are younger (as they appear only on the data set gridded at 2 km) compared to the NW-SE trends. These NE-SW trends may be associated with the Eastern Ghat orogeny. It is worth mentioning that these transverse faults are absent in the Godavai Gondwana Graben implying that the Gondwana Graben may have formed after the cessation of Eastern Ghat orogeny.

The NE-SW trending anomalies, extending from Bhadrachalam to Bhavanipatana mark the contact of the Bastar craton and EGMB; all the NW-SE trends associated with the craton are found terminated at this contact, which represents the Sileru Shear Zone (SSZ). Within Block-S, the WCZ and CMZ are associated with ASM, implying magnetic sources while WKZ and EKZ depict lows suggesting absence of sources or relatively deeper sources. This confirms the division of EGMB by Ramakrishna et al. (1998). Figure 1 gives the impression that the Eastern Khondalite Zone (EKZ) is associated with a magnetic high. But the analytic signal (Fig. 3) clearly shows there are no sources associated with the EKZ and WKZ. This is supported by susceptibility measurements by Murthy and Rao (2001) who showed that Khondalites have an average susceptibility of 10 μcgs, leptenites 300 μcgs compared to charnockites at 2000 μcgs. This shows the importance of analytic signal as a tool for identifying magnetic sources when there is large variation in inclination. A close look at the Euler solutions (Fig. 4) in the EGMB shows that by and large the magnetic sources (charnockites) along the SSZ is shallower than those to the south-east implying that the western side has been uplifted to a greater extent. If the magnetic sources, to begin with, were at the same depth, then it appears that the exhumation process within the EGMB has a differential rate.

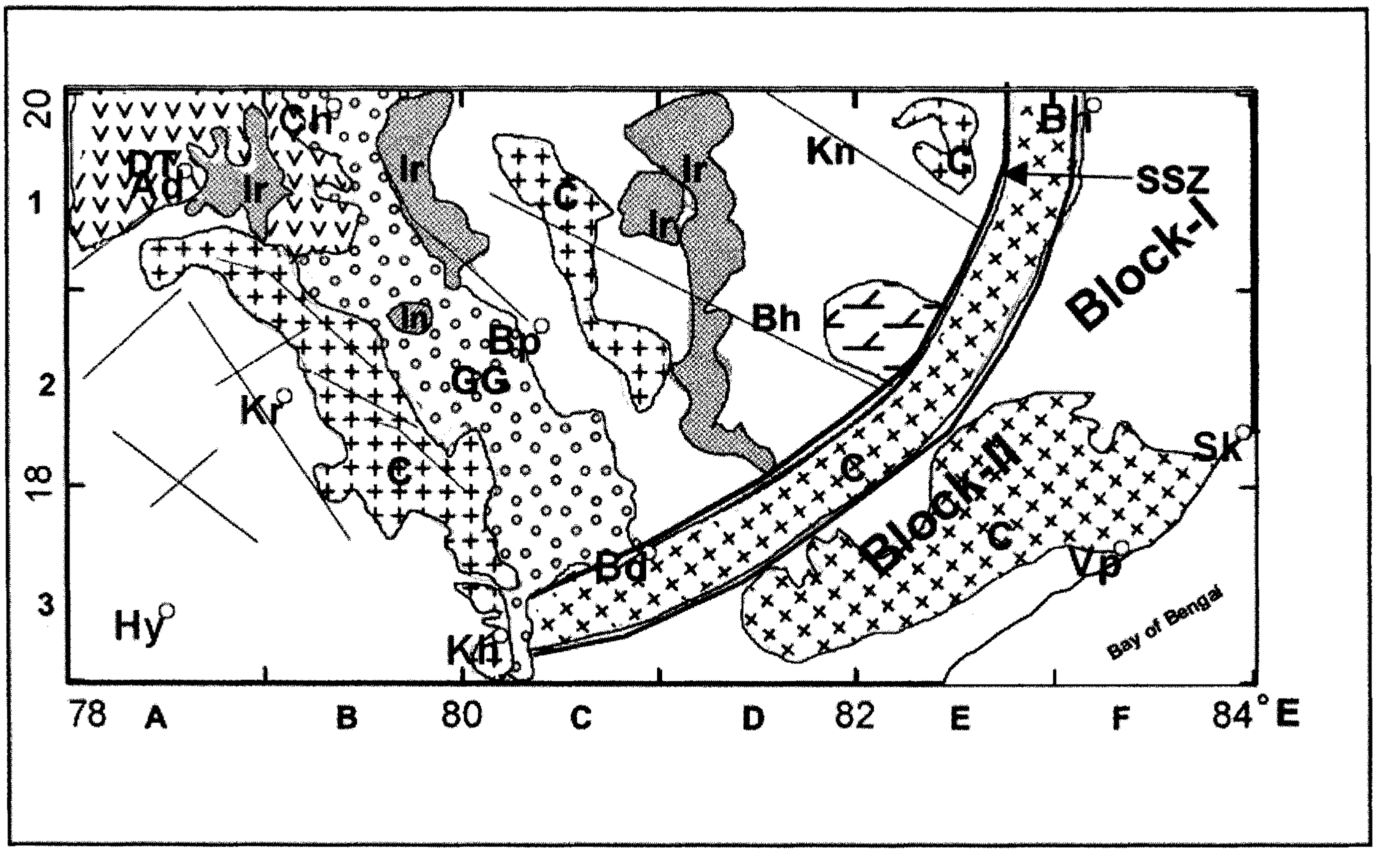

Fig. 5. Map of magnetic sources interpreted from the present study. DT–Deccan Traps, Ir–Iron Ore, C– Charnockites, GG–Godavari Graben and SSZ–Sileru Shear Zone, lines represent lineaments identified from present study, Bh–Bhamragarh ln., Kn–Khondagaon ln. Place name abbreviations as in figure 1.

The geological map of the Eastern Ghats (Ramakrishnan, 1998) and Figure 1 show the presence of charnockites to the north of 18.5° but this is not reflected in the magnetic data (Figs. 2, 3, 4). Hence we infer that these charnockites have low susceptibilities and are associated with a different metamorphic history compared to Block-S. Laboratory studies of 220 samples of charnockites from the Southern Granulite Terrane of Peninsular India have established that the charnockites that have undergone retrograde metamorphism have low susceptibilities (Ramachandran, 1990). Schlinger (1988) observed that retrograde metamorphism of intermediate pressure granulites leads to the replacement of magnetite, ilmenite and ilmenite-hematite inter growths by silicate titanite and hematite. From geochronological data and metamorphic P-T trajectories it has been inferred that the Eastern Ghat occurring to the north of Godavari Graben have experienced at least two phases of granulite facies metamorphism and a late amphibolite facies over print (Dasgupta and Sengupta, 2000). For a basic rock carried through metamorphic grades, the transition to lower grade destroys original magnetic minerals, iron being tied up in non-magnetic silicate minerals or weakly magnetic spinels (Mayhew et al., 1991). As Block-N is devoid of any magnetic sources we infer that this block possibly has an over print of amphibolite facies metamorphism and Block-S depicts granulite facies metamorphism.

Conclusions

(1) The Eastern Ghat in the study region is divided into two blocks: Block-N, north of Srikakulam, devoid of any magnetic sources while charnockites are the main magnetic carriers in Block-S to the south. We infer that the charnockites in Block-N have lower susceptibilities associated with a different metamorphic history compared with Block-S.

(2) The exhumation process within the EGMB has undergone differential uplift with the western side having been uplifted to a greater extent than the southeast.

(3) The Sileru Shear Zone has been demarcated as the contact between the Bastar craton and the Eastern Ghat Mobile Belt.

(4) High-grade charnockitic rocks exist in the surface and sub-surface along the shoulders of the Godavari Graben, which provides a new insight into evolution of the Godavari Graben vis-à-vis the adjoining cratons.

References

Acharya, K. (1997) Evolutionary characters of the Gondwanaic Indian crust. Ind. Minerals, v. 51, pp. 1-24.

Anand, S.P. and Mita Rajaram (2002) Aeromagnetic Data to Probe the Dharwar Craton. Curr. Sci., v. 83, pp. 162-167.

Chetty, T.R.K. and Murthy, D.S.N. (1994) Collision tectonics in the Eastern Ghats Mobile Belt: mesoscopic to satellite scale structural observations. TERRA NOVA, v. 6, pp. 72-81.

Dasgupta Somanath and Pulak Sengupta (2000) Tectonothermal evolution of the Eastern Ghats Granulite Belt, India: a metamorphic perspective. Geol. Surv. Ind., Spl. Publ., v. 55, pp. 259-274.

England, P.O. and Thompson, A.B. (1984) Pressure temperature paths of regional metamorphism heat transfer during the evolution of regions of thickened continental crust. J. Petrol., v. 25, pp. 894-928.

Geological Survey of India. (2000) Seismo Tectonic Atlas of India and its environs, 1:1 million scale, Bangalore.

Geological Survey of India. (2001) Tectonic Map of India, 1:2 million scale and its explanatory brochure (compiled by Sarkar, A.N).

Geosoft. (1999) Oasis Montage Data Processing and Analysis (DPA) systems for Earth science applications (ver 4.3), Geosoft Inc., Canada.

Harikumar, P., Rajaram, M. and Balakrishnan, T.S. (2000) Aeromagnetic study of Peninsular India. Proc. Indian Acad. Sci. (Earth Planet. Sci. Lett.), v. 109, pp. 381-391.

MacLeod, I.N., Jones, K. and Dai,T.F. (1993) 3D Analytic Signal in the interpretation of total magnetic field data at low magnetic latitudes. Explo. Geophys., v. 24, pp. 679-687.

Mayhew, M.A., Wasilewski, P.J. and Johnson, B.D. (1991) Crustal magnetization and temperature at depth beneath the Yilgran block Western Australia inferred from MAGSAT data, Earth Planet. Sci. Lett., v. 107, pp. 515-522.

Mishra, D.C., Gupta, S.B. and Venkatarayudu, M. (1989) Godavari rift and its extension towards the east coast of India, Earth Planet. Sci. Lett., v. 94, pp. 334-352.

Murthy Radhakrishna, I.V. and Rama Rao, P (2001) Magnetic anomalies and basement structure around Vizianagaram, Visakhapatanam and Srikakulam districts of Andhra Pradesh, India, Gondwana Res., v. 4, pp. 443-454.

Rajaram Mita and Anand, S.P. (2003) Central Indian tectonics revisited using aeromagnetic data, Earth Planet Space, v. 55, pp. e1-e4.

Rajaram Mita, Anand, S.P. and Vinit C. Erram (2000) Crustal magnetic studies over Krishna-Godavari basin in Eastern continental margin of India, Gondwana Res., v. 3, pp. 385-394.

Ramachandran, C (1990) Metamorphism and magnetic susceptibilities in South Indian granulite terrain, J. Geol. Soc. Ind, v. 35, pp. 395-403.

Ramakrishnan, M., Nanda, J.K. and Augustine, P.F. (1998) Geological Evolution of the Proterozoic Eastern Ghat Mobile Belt, Geol. Surv. India, Spl. Pub., v. 44, pp. 1-21.

Reddy, A.G.B., Mathew, M.P., Singh, B. and Naidu, P.S. (1988) Aeromagnetic evidence of crustal structure in the granulite terraine of Tamilnadu-Kerala. J. Geol. Soc. India, 32, pp. 368-381.

Reid, A.B., Allsop, J.M., Granser, H., Millett, A.J. and Somerton, W.I. (1990) Magnetic interpretations in three dimensions using Euler deconvolution. Geophys., v. 55, pp. 80-91.

Roest, W.E., Verhoef, J., and Pilkington, M.(1992) Magnetic interpretation using 3D analytic signal. Geophys., v. 57, pp. 116-125.

Schlinger, C.M. (1985) Magnetization of Lower crust and interpretation of regional aeromagnetic anomalies: example from Lofoten and Vesteralen, Norway, J. Geophys. Res., v. 90, pp. 11484-11504.