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Mapping of magnetic basement in Central India from aeromagnetic data for scaling geology

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ABSTRACT

The Central Indian region has a complex geology covering the Godavari Graben, the Bastar Craton (including the Chhattisgarh Basin), the Eastern Ghat Mobile Belt, the Mahanadi Graben and some part of the Deccan Trap, the northern Singhbhum Orogen and the eastern Dharwar Craton. The region is well covered by reconnaissance-scale aeromagnetic data, analysed for the estimation of basement and shallow anomalous magnetic sources depth using scaling spectral method. The shallow magnetic anomalies are found to vary from 1 to 3 km, whereas magnetic basement depth values are found to vary from 2 to 7 km. The shallowest basement depth of 2 km corresponds to the Kanker granites, a part of the Bastar Craton, whereas the deepest basement depth of 7 km is for the Godavari Basin and the southeastern part of the Eastern Ghat Mobile Belt near the Parvatipuram Bobbili fault. The estimated basement depth values correlate well with the values found from earlier geophysical studies. The earlier geophysical studies are limited to few tectonic units, whereas our estimation provides detailed magnetic basement mapping in the region. The magnetic basement and shallow depth values in the region indicate complex tectonic, heterogeneity, and intrusive bodies at different depths, which can be attributed to different thermo-tectonic processes since Precambrian.

Key words: Aeromagnetic data, Central India, Magnetic basement, Fractals/scaling, Spectral method.

INTRODUCTION

Aeromagnetic data provide good coverage of an area and are useful for delineating structural patterns, magnetic basement depths, geotectonics, and thermal status of a region (Nabighian *et al*. 2005). The basements are complex granitic or metamorphic rocks below sedimentary rocks that are important for hydrocarbon as well as mineral exploration. The aeromagnetic data have an advantage over other surface geophysical data in detail mapping of the basement as the data coverage is uniform. The basement and tectonic structures can be obtained from magnetic data using various methods, e.g., qualitative analysis of magnetic anomalies, Euler deconvolution, Werner deconvolution, wavelet transform, Naudy method, analytic signal method, etc. (Nabighian *et al*. 2005).

The interpretation of aeromagnetic data in the frequency domain is simple and frequently used since 1970 (Spector and Grant 1970). The Spector and Grant (1970) method has become an important tool for estimating depth to the top of the anomalous ensemble of sources from magnetic data in which top depth is simply related to the power spectrum of the magnetic field. The top depth values may be interpreted in terms of the depth of various geological features in the sub-surface. Spector and Grant (1970) assumed statistical ensemble of prisms having frequency-independent source

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distribution equivalent to white noise distribution. The random and uncorrelated distribution of sources is assumed due to mathematical simplicity and unavailability of detailed information about this distribution with depth.

From acoustic, density, resistivity, gamma-ray, and susceptibility borehole data, the source distribution is found to be random and correlated, which corresponds to scaling noise (Pilkington and Todoeschuck 1990; Maus and Dimri 1994; Bansal, Gabriel and Dimri 2010). The power spectrum of scaling noise is defined mathematically as

$$\varphi(k) \propto k^{-\beta}, \tag{1}$$

where φ is the power spectra of the magnetic source (magnetisation) distribution, k is the wavenumber, and β is the scaling exponent. The scaling exponent controls the appearance or degree of correlation that quantifies the spatial statistical distribution of physical parameters within the crust, e.g., zero, negative, and positive values correspond to uncorrelated, anti-correlated, and correlated distribution of sources, respectively (Pilkington and Todoeschuck 1993).

To overcome the assumption of uncorrelated sources, the scaling distribution of sources is introduced in the Spector and Grant method for finding the depth of anomalous sources, and the method is known as the scaling spectral method (Maus and Dimri 1995, 1996; Fedi, Quarta and Santis 1997; Bansal and Dimri 1999). The estimated depth values for scaling distribution of sources are closer to realistic depth values (Maus and Dimri 1996). The scaling spectral approach has been applied successfully to various field examples from many parts of the world (e.g., Maus and Dimri 1996; Bouligand, Glen and Blakely 2009; Bansal *et al.* 2016; Salem *et al.* 2014, etc.).

In this paper, we applied the scaling spectral method to compute the depth to the top of the causative sources from aeromagnetic data of the Central Indian region and interpret the estimated depth values in terms of the basement and shallow magnetic sources.

GEOLOGY OF THE STUDY REGION

The study region comprises major geological units, e.g., the Bastar Craton (BC), the northern part of the Singhbhum Orogen (NSO), the eastern fringe of the Deccan Trap (DT), the eastern Dharwar Craton (EDC), the Eastern Ghat Mobile Belt (EGMB), and other tectonic zones (the Godavari Graben [GG], the Mahanadi Graben [MG], the Central Indian Tectonic Zone [CITZ]) within latitudes 17–23°N and longitudes 78–85°E (Fig. 1).

The Achaean basement of the GG is composed of granite and gneisses covered with a huge amount of sediments of the Purana (Proterozoic) alongside the graben, the lower and upper Gondwana (largely comprising shale, sandstone, and limestone) in the central part of the graben bounded by normal fault (King 1881). The Proterozoic rocks of the GG consist of Pakhal, Albaka, and Sulavai series. The BC, lying to the south of the CITZ, is separated from the Dharwar and the Singbhum Craton, respectively, by northwest–southeast-trending younger rifts the GG and the MG. The BC consists of the Dongargarh Granite (DG), the Kanker Granite (KG), the Kondangaon Granulites (kg), the Khariar Basin (KB), and two major Proterozoic basins: The Chhattisgarh Basin (CB) and the Indravati Basin (IB) (Meert *et al.* 2010). The basement of the CB comprises granites and gneisses of Archaean age with associated metavolcanic–metasedimentary belts (Krishna 1968). The Central Indian Suture (CIS) is a collisional suture, represented as a strike–slip fault and separates the BC from the Bundelkhand Craton (Yedekar *et al.* 1990). The Deccan flood basalt (Cretaceous–Eocene volcanic episode) covers the northern part of the Godavari Prahnita valley and the northwestern part of the study area. The NSO is mainly made up of the Archaean rocks (iron ore group, Singhbhum Granite, older metamorphic group). The CITZ falls on the northwest of the study region and to the north of CIS. The CITZ consist of several sub-parallel east-northeast-trending faults: Narmada, Tapti, Gavilgarh and Tatapani fault, Tan shear, and Bamni-Chilpa fault (Yedekar *et al.* 1990). The study region also covers a small portion of the EDC, which lies to the southwest of the BC, is characterised by voluminous late Archaean granitoids with minor tonalite–trondhjemite–granodiorite gneisses and thin volcanic dominated schist belts (Geological Survey of India 2010). The EGMB, to the east of the BC, consists mainly of granulite facies rocks (charnockites, khondalites, migmetites, etc.) (Chetty 2001). The EGMB have a network of ductile shear zones both within and at the margins, which divided the EGMB into distinct heterogeneous terrains with extensive tracts of foliated mylonitic gneisses and ultramylonites (Chetty 2001).

METHODOLOGY

The Spector and Grant (1970) method is mostly used for finding the depth to the top of anomalous sources from magnetic field data for the statistical assemblage of sources. The depth to the top of an assemblage of magnetic sources and thickness of magnetic body are related to the 2D power spectrum of the

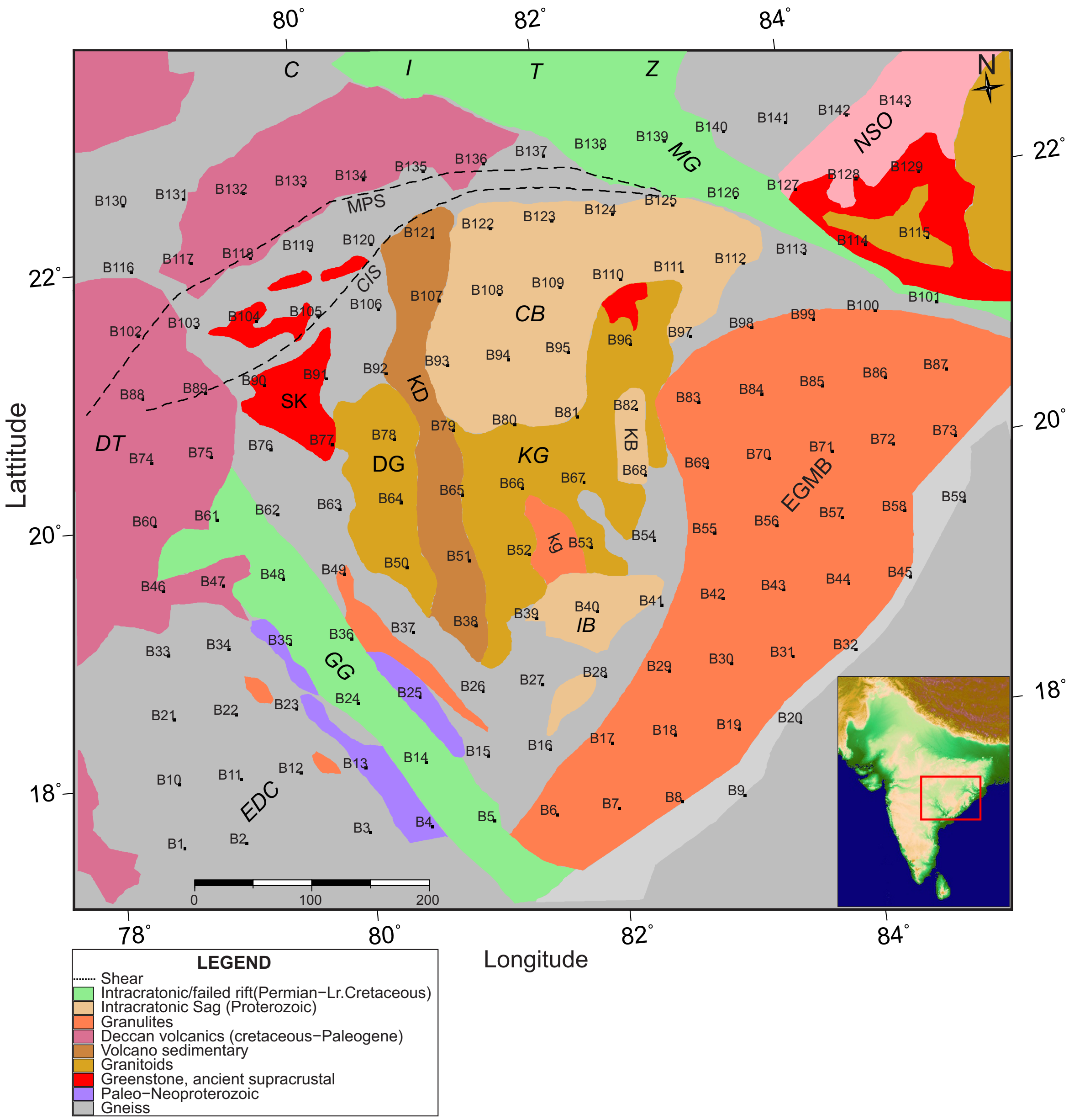

Figure 1 The sketch map of the study region (Geological Survey of India 1993). The black dashed lines represent the shear zones. Black square points show the centre of the blocks (B1, B2, B3, etc.) used in this study. Key to marked features: CB: Chattisgarh Basin; CIS: Central Indian Shear; CITZ: Central Indian Tectonic Zone; DG: Dongargarh Granites; DT: Deccan Traps; EDC: Eastern Dharwar Craton; EGMB: Eastern Ghat Mobile Belt; GG: Godavari Graben; IB: Indravati Basin; KB: Khariar Basin; KD: Kotri-Dongargarh Orogen; kg: Kondangaon Granulite; KG: Kanker Granites; MG: Mahanadi Graben; MPS: Main Peninsular Shear; NSO: Northern Singhbhum Orogen; SK: Sakoli Supracrustal Belt.

magnetic field as (Blakely 1996)

$$P(k_x, k_y) = 4\pi^2 C_m^2\, \varphi_m(k_x, k_y) \left|\Theta_m\right|^2 \left|\Theta_f\right|^2 \mathrm{e}^{-2|k|z_t} \times (1 - \mathrm{e}^{-|k|(z_b - z_t)})^2, \quad (2)$$

where C_m is a constant of proportionality; φ_m is the power spectrum of the magnetisation; Θ_m and Θ_f are the directional factors related to the magnetisation and geomagnetic field, respectively; k_x and k_y are the wavenumbers in the x and y directions; Z_t and Z_b are the top and bottom depth of the magnetic sources.

The 2D power spectrum is converted to 1D by radial averaging where directional terms Θ_m and Θ_f become constant. The assumption of random and uncorrelated distribution of

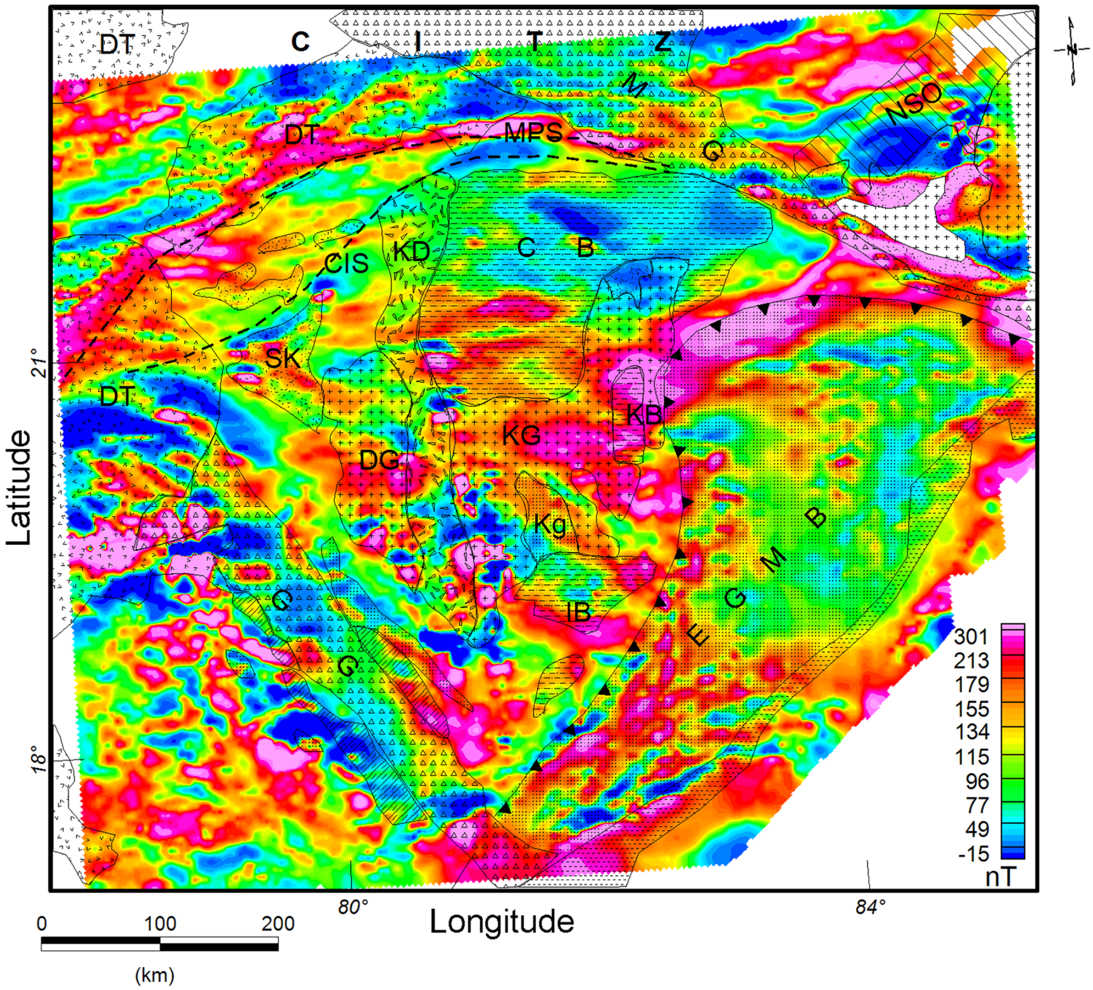

Figure 2 Aeromagnetic map of the Central India overlain by the main geological and tectonic units. Geological units are shown by different symbols, whereas abbreviations of the geological units are the same as described in Figure 1 (Geological Survey of India 1995; Rajaram and Anand 2003).

sources further reduces the power spectrum of the magnetisation (φ_m) to a constant value, and in that case, the power spectrum of the magnetic field is expressed as

$$P(k) = A_1 \mathrm{e}^{-2|k|z_t} (1 - \mathrm{e}^{-|k|(z_b - z_t)})^2, \tag{3}$$

where A_1 is constant; for a very thick magnetic body, the above equation leads to the simplest form as

$$P(k) = A_1 \mathrm{e}^{-2|k|z_t}. \tag{4}$$

In case of random and correlated (scaling) distribution of sources, the power spectrum of magnetisation (φ_m) is expressed by equation (1), and by combining equations (1) and (4), the power spectrum of the magnetic field is expressed as (Maus and Dimri 1995, 1996; Fedi *et al.* 1997; Bansal and Dimri 2014)

$$P(k) = ck^{-\beta} \mathrm{e}^{-2kz_t}. \tag{5}$$

The unknowns, constant (c), and two parameters top depth (z_t) and scaling exponent (β) can be estimated using a nonlinear inversion method (Dimri 1992) where L2-norm is used for minimizing the errors using the Levenberg–Marquardt algorithm (Levenberg 1944; Marquardt 1963).

APPLICATION TO THE CENTRAL INDIAN AEROMAGNETIC DATA

The aeromagnetic data (Geological Survey of India 1995) presented here were collected in a reconnaissance mode during

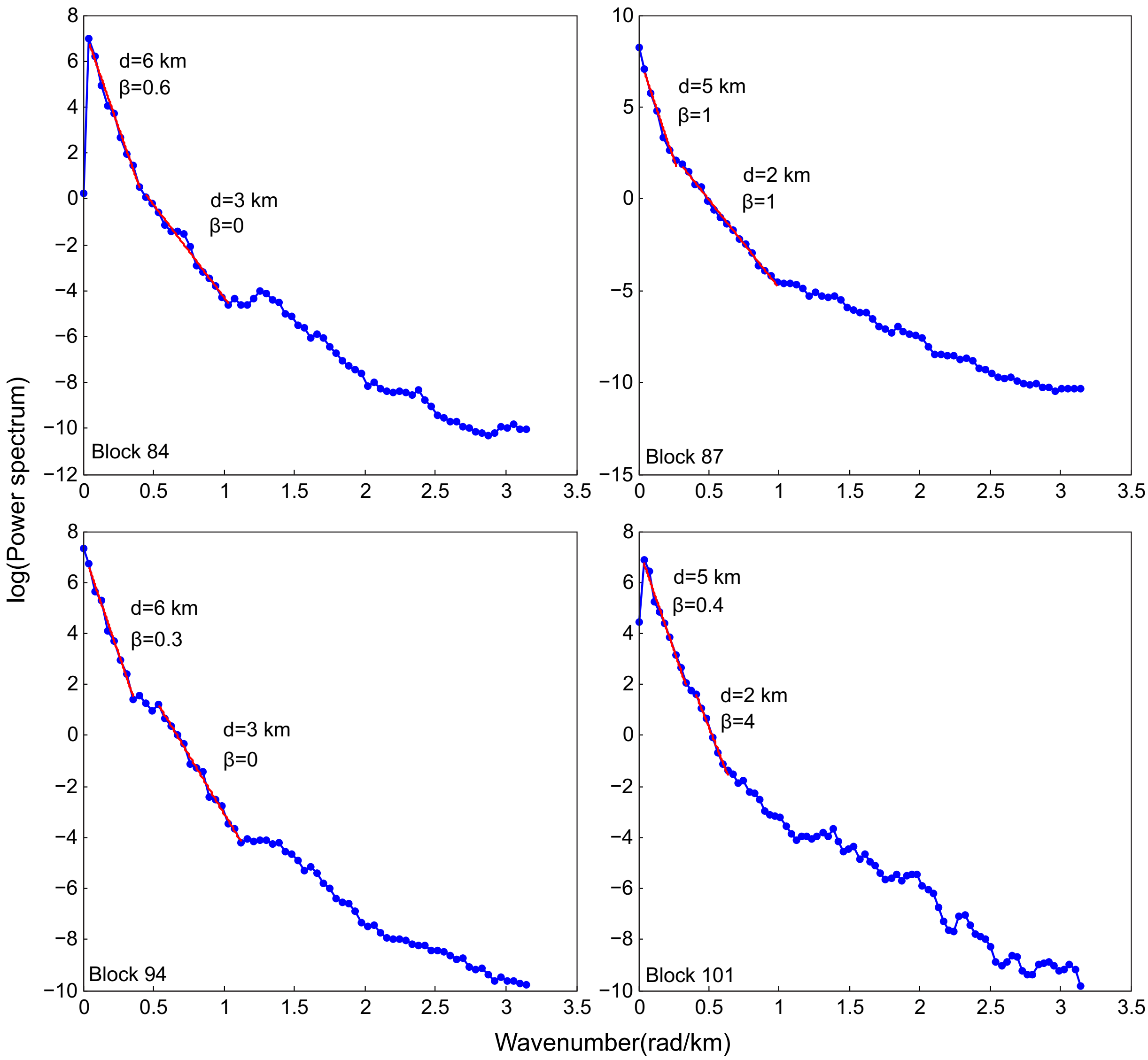

Figure 3 Plots of power spectrum versus wavenumber for blocks 84, 87, 94, and 101. The red lines are the best fit to the power spectrum for estimating depth and scaling exponent. The estimated depth and scaling exponent values are also shown.

the period ranging from 1983 to 1992 along north–south lines spaced 4 km apart at different altitudes. A crustal anomaly map of Central India was generated by Rajaram and Anand (2003) continuing all datasets to a common elevation of 1500 m and applying necessary corrections including the removal of the main field contribution (outer core effect) by using appropriate IGRF models. The crustal anomaly map generated after gridding the data at 1 km interval, represented in Fig. 2, is found to depict signatures of major geological and tectonic units of Central India (Rajaram and Anand 2003). We used these data and selected 143 blocks of dimension 100 km × 100 km with an overlap of 50 km. First-order trend was removed, and each grid was expanded by 10% using the maximum entropy method. A radially averaged power spectrum for each block has been generated using the Fast Fourier Transform (FFT). Equation (5) is applied to the power spectrum of aeromagnetic data to estimate the scaling exponent and depth values using the non-linear inversion method. The estimated depth values are interpreted in terms of magnetic basement and shallow magnetic bodies. The power spectrum of eight representative blocks along with the estimated depth values (with respect to mean sea level) and scaling exponents are shown in Figs. 3 and 4, whereas estimated depth and scaling exponent values for all the blocks are presented in

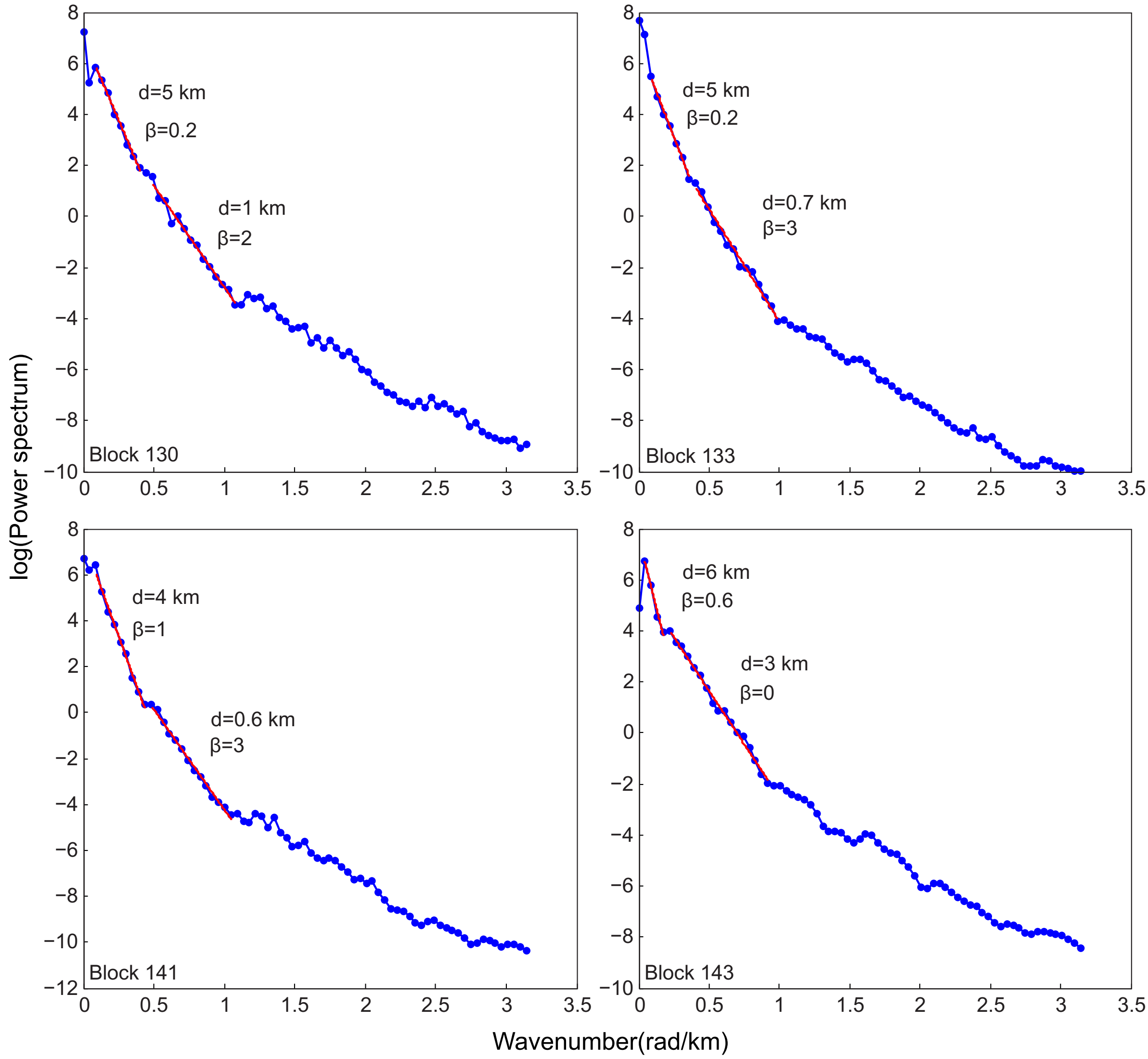

Figure 4 Plots of power spectrum versus wavenumber for blocks 130, 133, 141, and 143. The red lines are the best fit to the power spectrum for estimating depth and scaling exponent. The estimated depth and scaling exponent values are also shown.

Table 1. The basement depth found from earlier geophysical studies are compared with those from the present study (Table 2). Estimated basement and shallow depth values are superimposed on the geotectonic map (Fig. 5). In Fig. 5, we presented shallow depth ≥1 km since estimated depth values, lower than 1 km, are not reliable because of large statistical errors in their estimation and use of sampling interval of 1 km. A 3D map (Fig. 6), along with the contour map, of the estimated magnetic basement is represented.

Below, we discuss in detail the depth to basement obtained from aeromagnetic data, its significance and comparison with previous geophysical studies, which are mainly limited along few profiles. We interpret our results with respect to different geological units.

RESULTS

Godavari Graben (GG)

The GG mainly contains the Godavari Prahnita Basin having Gondwana sediments (Upper and Lower) and Neo-Proterozoic sediments. The magnetic basement depth values in the GG were found to vary between 3 km and 7 km, and depth to shallow magnetic sources vary from 2 to 3 km (Figs. 5 and 6). A basement depth of 7 km is found at the

Table 1 Estimated depth and scaling exponent values for different blocks

Block No.	Depth 1 (km)	$\beta 1$	Depth 2 (km)	$\beta 2$
B1	5	0.2	1	1
B2	5	0.2	1	1
B3	4	0	0.4	0.3
B4	6	0	1	4
B5	4	0.8	2	0
B6	3	0.7	3	0
B7	4	0.2	0.5	3
B8	4	0.2	1	0
B9	4	0.2	2	0
B10	6	0	0	3
B11	5	0	1	2
B12	4	0.3	3	–
B13	4	0.3	–	–
B14	5	0.6	3	3
B15	3	0.8	0.2	3
B16	5	0.4	2	0
B17	4	0	–	–
B18	–	–	–	–
B19	7	0	2	1
B20	5	0.4	2	3
B21	4	0	1	2
B22	5	0	1	2
B23	4	0	1	0
B24	6	0	2	1
B25	4	0.6	2	0
B26	3	0.6	0.4	4
B27	5	0.1	–	–
B28	3	1	2	0.8
B29	5	0	3	0
B30	4	0.2	0.1	3
B31	4	0.2	–	–
B32	6	0.5	3	0
B33	4	1	–	–
B34	3	0	0.7	3
B35	7	0	2	0
B36	5	0	0.7	0.9
B37	4	0	1	2
B38	3	0.6	0.5	3
B39	–	–	–	–
B40	7	1	1	2
B41	1	2	1	2
B42	5	0.2	3	0
B43	7	1	1	2
B44	3	1	1	4
B45	9	0.8	3	0
B46	4	0	1	0
B47	5	0	2	0
B48	5	0	3	0
B49	3	0.4	2	4
B50	4	0.1	1	2

(*Continued*)

Table 1 Continued

Block No.	Depth 1 (km)	$\beta 1$	Depth 2 (km)	$\beta 2$
B51	3	0	0.2	4
B52	3	0.1	0.5	2
B53	4	0	2	0
B54	3	0.3	0.7	0
B55	4	0	–	–
B56	3	0	1	0.8
B57	4	0	–	–
B58	3	0.6	0.9	0
B59	9	0	0.9	4
B60	3	0	0.1	1
B61	3	0	0	0
B62	6	0	1	3
B63	7	0.1	3	0
B64	3	0	1	0
B65	4	0	2	0
B66	4	0	0	4
B67	2	2	–	–
B68	2	1	0.1	1
B69	4	0.4	0.4	3
B70	4	0	2	1
B71	3	1	2	1
B72	4	0	0.2	4
B73	8	0	2	2
B74	5	0.1	0.4	2
B75	5	0	0.3	3
B76	3	0.6	0.2	2
B77	3	1	0.9	4
B78	4	0.2	0.4	4
B79	4	0	2	0
B80	3	0	0.8	0
B81	2	3	0.6	3
B82	4	3	1	2
B83	6	0.7	1	2
B84	6	0.6	3	0
B85	4	0.6	0.8	3
B86	4	0	0.5	4
B87	5	1	2	1
B88	6	0.2	3	0
B89	4	0.6	0.5	4
B90	6	0	3	2
B91	3	0	2	0.5
B92	3	0.1	3	0
B93	3	0.6	2	2
B94	6	0.3	3	0
B95	4	0	1	3
B96	5	0	3	0.2
B97	7	1	2	3
B98	6	2	1	3
B99	4	0	0.7	0
B100	5	0.2	3	0
B101	5	0.4	2	4

(*Continued*)

Table 1 Continued

Block No.	Depth 1 (km)	$\beta 1$	Depth 2 (km)	$\beta 2$
B102	4	0	1	2
B103	3	1	0.6	4
B104	4	0.5	1	0
B105	3	0.2	2	0.2
B106	3	0.3	–	–
B107	6	0	2	0.1
B108	6	0.3	3	0
B109	5	1	0.8	3
B110	3	1	0.3	2
B111	3	2	1	2
B112	4	1	1	3
B113	6	0	2	0.6
B114	7	0	2	2
B115	4	0.5	2	0
B116	4	0.6	1	2
B117	5	0.4	2	2
B118	5	0.5	0.4	3
B119	6	0	2	0.2
B120	4	0.7	0.5	2
B121	5	0.6	0.4	3
B122	4	2	1	2
B123	4	1	1	4
B124	7	0	1	0
B125	5	0.3	0.4	3
B126	6	0	2	2
B127	6	0.3	0.2	2
B128	4	1	1	3
B129	4	0	–	–
B130	5	0.2	1	2
B131	4	0.3	1	2
B132	3	0.9	1	2
B133	5	0.2	0.7	3
B134	4	1	0.4	2
B135	5	1	0.6	4
B136	8	0	0.7	4
B137	8	0	3	2
B138	6	0	0.9	3
B139	5	0.5	3	1
B140	4	0	–	–
B141	4	1	0.6	3
B142	5	0.8	3	0
B143	6	0.6	3	0

centre part of the basin, which is interpreted as the thickness of the Gondwana sediment, whereas the basement is shallower to 3 km towards the northwest in the region covered by the DT flows. The magnetic basement depth values of 4 to 6 km are found in the region occupied by the Neo-Proterozoic sediments.

The basement depth values are comparable with earlier geophysical studies (Mishra, Gupta and Venkatarayudu 1989; Raju, Rajesh and Mishra 2003; Sarma and Rao 2005; Sushini *et al.* 2014). Mishra *et al.* (1989) reported a maximum sedimentary thickness of 5–6 km (Table 2) in the Godavari Prahnita Basin (B35, B36, B24, B14, Fig. 1, Table 1) using the principal harmonic inversion method on the Bouguer anomaly. Raju *et al.* (2003) found 5 km (Table 2) thickness of Gondwana sediments (B5, B14, B48, B36, Fig. 1). Sarma and Rao (2005) presented the comprehensive basement picture of the GG using gravity and magnetic data and estimated the thickness of Gondwana and Proterozoic sediments as 7 km in the centre of the graben. Sushini *et al.* (2014) estimated sediments thickness of the Godavari Basin from broadband seismic station as 4.32 km (Gondwanas), which lies between blocks B14 and B15 (Fig. 1). Therefore, our estimation of magnetic basement depths of 3–7 km in the region correlates well with the earlier geophysical studies in the region. Moreover, we provide a detailed basement map of the GG. The shallow magnetic anomalies at a depth of 2–3 km found in the present study may be representing magnetic bodies at shallower depth.

Bastar Craton (BC)

Chhattisgarh Basin (CB)

In the CB, part of the BC, the magnetic basement depth values vary from 3 to 5 km, and shallow magnetic bodies occur at 1 to 2 km depth (Figs. 5 and 6). Srinivas *et al.* (2004) estimated maximum sediment thickness of the Chhattisgarh and the Indrāvati Basins as 3 and 2.5 km, respectively, using 2D modelling of the total magnetic field data. Singh, Singh and Singh (1997) estimated the sedimentary thickness varying from 3 to 3.5 km in the CB (B108, B109, B122, Fig. 1, Table 1) from total magnetic data using the 2D inversion method. They also reported the presence of dikes at the depth of 0.28 and 1.26 km on the Archaean basement. Singh *et al.* (2006) found sedimentary thickness around 3.5 km near the Bilaspur (B123, B110, Figs. 1 and 5) and the Raigarh (B124, B111, B125, Figs. 1 and 5) from modelling of gravity data. The gravity modelling has shown the variation of sedimentary thickness to 3–4.2 km (Ramakrishna 1995). The magnetic basement depth of 3–5 km found in this study somewhat correlates well with the sedimentary thickness of 2.5–4.2 km found from the earlier studies (Srinivas *et al.* 2004; Singh *et al.* 2006; Singh *et al.* 1997; Ramakrishna 1995). We also found some deeper magnetic bodies at the depth of 6 to 7 km. These

Table 2 Comparison of estimated basement depth with earlier geophysical studies

	Depth values from our study (km)			
Region	Magnetic Basement	Shallow Source depth	Depth values from other studies (km)	References
GG	3-7	2-3	5-6 (Gravity)	Mishra *et al.* (1989)
			5 (Gravity)	Raju *et al.* (2003)
			7 (Gravity and Magnetic)	Sharma and Krishna Rao (2005)
			4.32 (Seismic)	Sushini *et al.* (2014)
CB	3-5	1-2	3.0 (Magnetic)	Srinivas *et al.* (2004)
			3.5 (Gravity)	Singh *et al.* (2006)
			3.5 (Magnetic)	Singh *et al.* (1997)
SK	2-6	2	2-5 (Gravity)	Rao (2007)
KG	2-5	1-3	–	–
KD	3-5	2	–	–
DT	3-6	1-2	3-4 (DRS)	Veeraiah and Babu (2014)
			5 (MT)	Azeez *et al.* (2011)
EGMB	3-7	1-3	3.5-4.5 (Magnetic)	Swami *et al.* (2008)
EDC	3-6	1	5.1 (Magnetic)	Ramdas *et al.* (2004)
NSO	3-6	1-3	6-7 (Gravity)	Verma *et al.* (1978)
MG	5-6	2	5 (Magnetic)	Anand and Rajaram (2007)
			5.1 (Gravity)	Mallick *et al.* (2012)

deeper bodies are in the northern and the central portion of the CB. The northern portion of deeper bodies in the CB is close to the Central Indian Suture (CIS). The aeromagnetic data of 100 km × 100 km, used in this study, might have also effects of adjacent geological units. In the centre of the basin, a depth of 6 km might be indicating deeper magnetic basement in that region. In the CB, our estimate of shallow magnetic bodies at a depth of 1 to 2 km matches well with the depth of 1.26 km (Singh *et al.* 1997) and 1–3 km (Murthy and Mishra 1989) for the intrusive bodies. A small variation in depth values estimated by us and earlier studies (Singh *et al.* 1997; Murthy and Mishra 1989) is quite obvious due to the use of different methodology and error involved in each estimation.

Sakoli Supracrustal Belt (SK)

The SK Belt is also a part of the BC where our estimated basement depth values vary from 2 to 6 km, and the deepest depth of 6 km is found in the western part of the belt near the CIS (Fig. 5). These estimated depth values are at the border of the SK belts, i.e., containing the effect of adjacent geological units. Rao (2007), from gravity data modelling, found high-density bodies at the depth of 2–5 km (B90, B91, B76, B77, Fig. 1, Table 1). Rao (2007) also pointed out these high-density bodies may be representing "pounding of mantle-derived material in the upper crust". Therefore, these bodies may have different susceptibilities than the surrounding, and our estimated depth values may represent these anomalous bodies.

In other parts of the BC, the magnetic basement depth values are found to be varying from 2–4 km (Khariar Basin [KB]), 7 km (Indravati Basin [IB]), 3–4 km (Dongargarh Granites [DG]), 3–5 km (Kotri-Dongargarh Orogen), and 2–5 km (Kanker Granites [KGs]). The shallow magnetic source depth values in these regions are 1 km (KB, IB, and DG), 2 km (Kotri-Dongargarh Orogen), and 1–2 km (KGs).

Deccan Trap (DT)

In the DT, we found variation of the depth values from 1 to 6 km (Figs. 5 and 6). The shallow depth values of 1–2 km are found close to Main Peninsular Shear (MPS) and Gavaligarh fault. These depths are deeper than the trap thickness of 200 m found from the geophysical investigations in the Wardha Valley (78–79°E and 21–22°N) (Nascar and Saha 2015) and bore wells drilled (Madhnure 2014) in the Nanded area (immediate west of the study region). The depth of 1–2 km is shallower than the basement depth of 3–4 km found from the deep resistivity sounding (little west of the blocks B46, B60, B74, Fig. 1, Table 1) (Veeraiah and Babu 2014). These shallow depths may be representing the magnetic bodies within the sub-trappean sediments. Azeez *et al.* (2011), from the magnetotelluric study, estimated a basement depth of 5 km, slightly

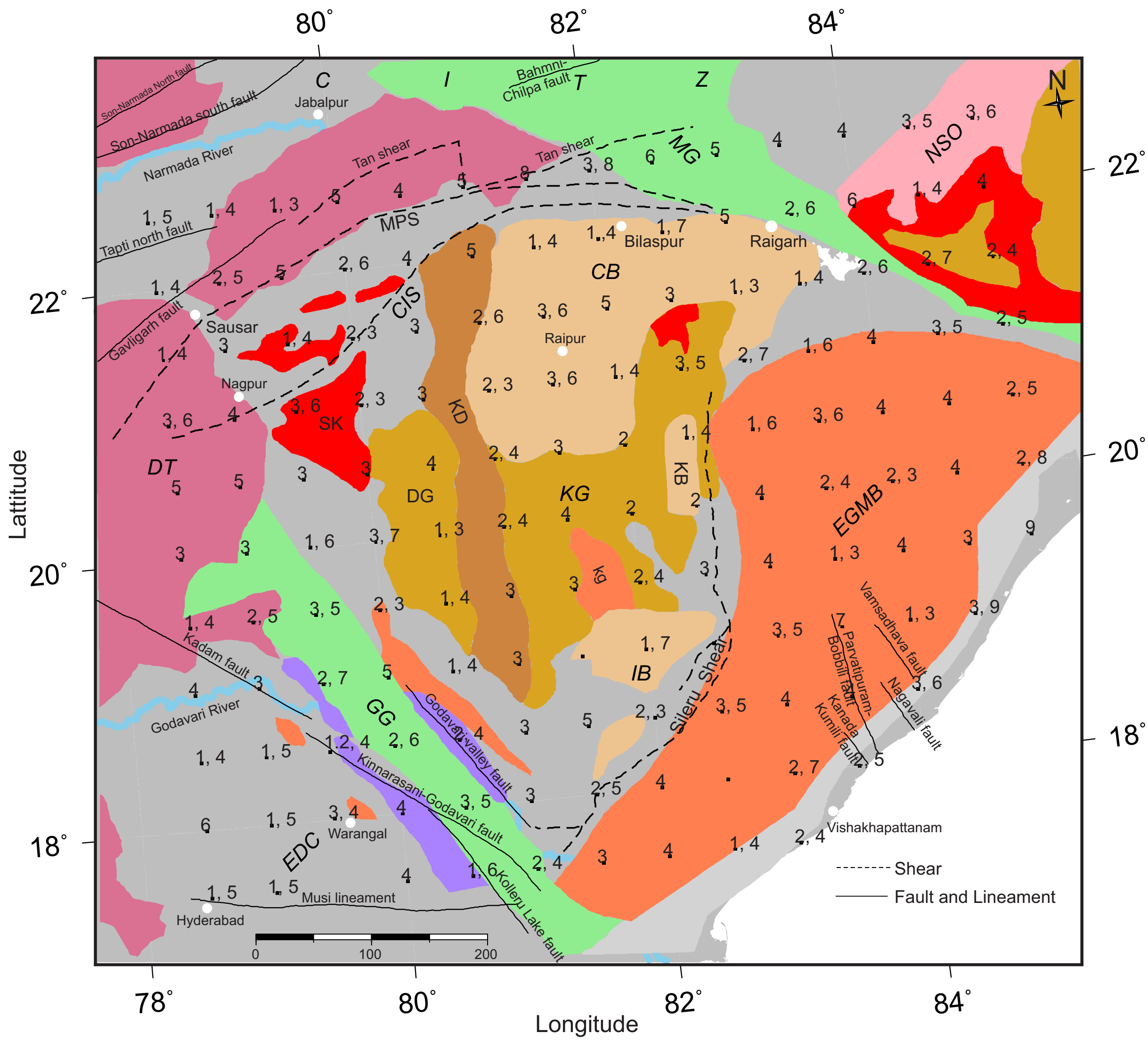

Figure 5 Geotectonic map of the region with magnetic basement and shallow source depth values (km).

to the west of the blocks (B130, B116, B117, B102, Fig. 1, Table 1), i.e., the nearby region of Narmada river, Tapti North fault, and Gavligarh fault. In the present study, in the northern portion of the DT, basement depth values are found to vary from 3 to 5 km, whereas in the southwest, these varies from 3 to 6 km.

Eastern Ghat Mobile Belt (EGMB)

In the EGMB, we found variation of depth of anomalous magnetic sources from 1 to 7 km (Figs. 5 and 6). Swami *et al.* (2008) estimated two basement depths at 1.9–3.0 km and 3.5–4.5 km from magnetic data (south of the blocks B6, B7, B8, and B9, Fig. 1, Table 1) corresponding to granulitic (granitic–gneiss) and charnokitic basement, respectively. The depth values we got may represent a change of lithology from khondalitic (less susceptibility, i.e., 100 orders of magnitude less than charnockite) to charnokitic through granitic–gneissic facies. Therefore, our shallow depth of 1–3 km and deeper depth of 3–4 km (B6, B7, B8, and B9, Fig. 1, Table 1) represent granite–gneissic and charnockitic basement depth, respectively. We found somewhat deeper depth of 6–7 km (near blocks B32 and B43, Fig. 1, Table 1), which may be probably due to the presence of the Kanada-Kumli fault and the Parvatipuram Bobbili fault (Fig. 5). The region to the north of these faults has undergone a different metamorphic

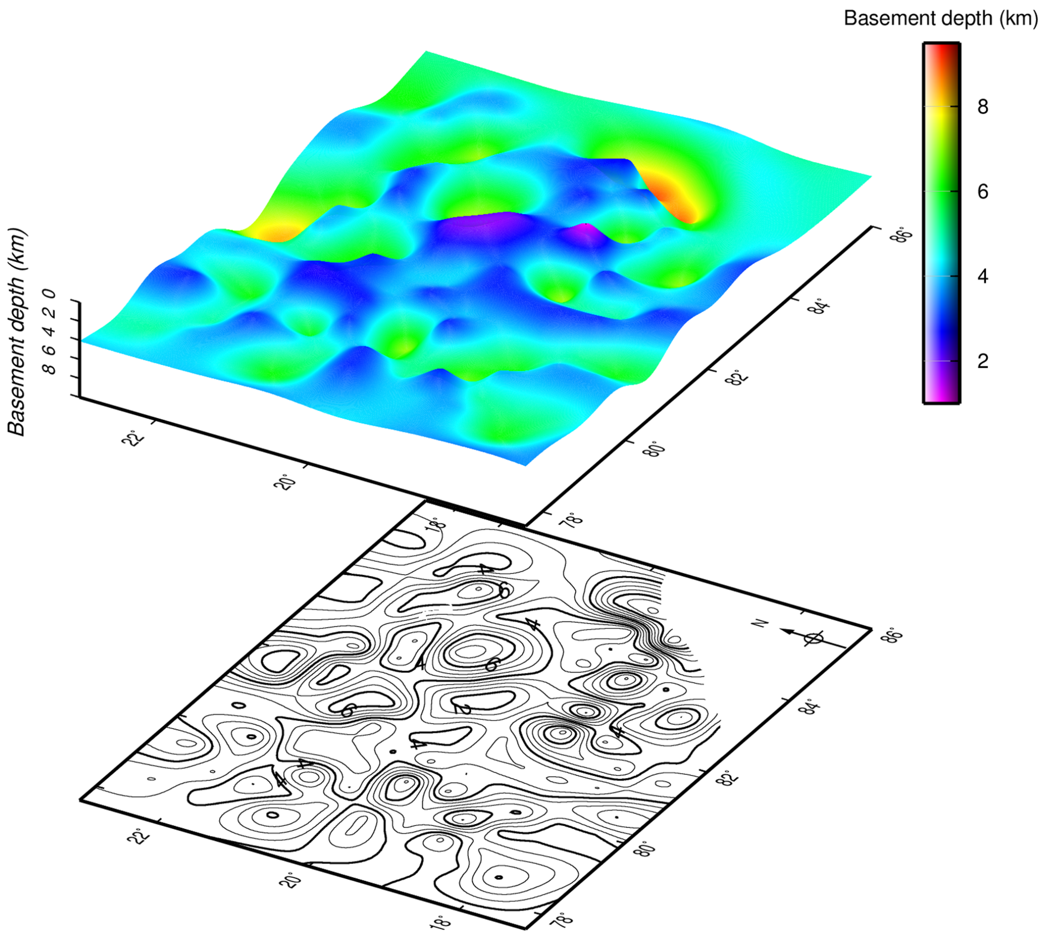

Figure 6 3D map, along with contour map, of the estimated basement of the region.

history, compared with the south (Anand and Rajaram, 2003), with the northern block having an overprint of amphibolite facies metamorphism compared with granulitic facies in the south. Dasgupta and Sengupta (2000), from geochronological and metamorphic *P*–*T* trajectories, inferred that the Eastern Ghat occurring to the north of the GG have experienced at least two phases of granulite metamorphism and a late amphibolite overprint. The depth that we got thus represents granulite facies, the high-susceptibility charnockites in the sub-surface below the amphibolite rocks.

Eastern Dharwar Craton (EDC)

In the EDC, we found depth variation from 1 to 6 km (Figs. 5 and 6). Ramadass, Himabindu and Ramaprasada Rao (2004), from the quantitative analysis of the regional total magnetic field, estimated the average basement depth of 5.1 km assuming susceptibility contrast of 0.012 cgs to the little southwest of the blocks (B1, B2, Fig. 1). In this region (near blocks B1, B2), we divide our depth values as shallow magnetic bodies at a depth of 1 km and basement depth 5 km. The magnetic basement depth may be further divided for northern, central, and eastern EDC as 4–5, 5–6, and 3–4 km, respectively.

Northern Singhbhum Orogen (NSO)

The depth of anomalous magnetic sources in the NSO (blocks B128, B143, Fig. 1) are found to lie between 1 and 6 km. Verma *et al.* (1978), from 2D modelling of gravity data, estimated the sedimentary thickness of 6–7 km (near the blocks B142, B143, B129, Fig. 1, Table 1). They also reported the Dalma lavas at the depth of 2.5 km and found the presence of the large plutonic granite within the Singhbhum batholith. Verma, Sarma and Mukhopadhyay (1984) interpreted the residual gravity anomalies and found iron ore groups and underlying Koenjhargarh volcanic rocks of 4 km thickness (near the blocks B127, B113, B115, B128, Fig. 1, Table 1).

Mahanadi Graben (MG)

The magnetic basement depth of the MG varies from 5 to 6 km (Figs. 5 and 6), which is comparable with the basement depth of 5 km obtained using Euler deconvolution (near blocks B126, B139, Fig. 1) (Anand and Rajaram 2007). Rao *et al.* (1982) from aeromagnetic data found the depth of 4.5 km near the shelf margin in the offshore area. Behera *et al.* (2004), from seismic and gravity data, estimated maximum depth of 3 km (near blocks B101, B115, Fig. 1). Mallick, Vasanthi and Sharma (2012) remodelled the gravity data of MG and estimated the basement depth values ranging from 1 to 5.1 km southwest of the study region. The deepest basement depth of 5.1 km is found slightly to the west of the blocks B101 and B115 (Fig. 1).

The basement depth values are found to vary from 2 to 7 km, whereas shallow sources are found in the range of 1 to 3 km (Table 1) for the study region. The scaling exponent values are found to vary from 0 to 4 in the region (Table 1), indicating a complex nature of the crust. The values of scaling exponent are not found constant for geology and same depth in different geological units. These types of scaling behaviour may arise due to the very complex history of the formation of the Central Indian region.

DISCUSSION AND CONCLUSIONS

We estimated the depth of magnetic interfaces and scaling exponents from aeromagnetic data of Central India using the scaling spectral method. This depth and scaling exponent values are optimised by L2-norm using the Levenberg–Marquardt algorithm. The deeper depth values are interpreted in terms of the depth of magnetic basement. The basement depth in the study region varies from 2 to 7 km. The shallow magnetic basement of 2 km is found in some part of the Bastar Craton (Dongargarh Granite, Kanker Granite), and the deepest basement depth values are found correspond to Godavari Graben and the Eastern Ghat Mobile Belt. The depth of shallow magnetic bodies in the region varies from 1 to 3 km.

The scaling exponent values corresponding to the magnetic field and magnetisation are related (Maus and Dimri 1994) and can explain the lithology (Pilkington and Todoeschuck 1993; Maus and Dimri 1995) and the heterogeneity (Bansal *et al.* 2010) of the region. Maus and Dimri (1995) performed source depth estimation using a scaling exponent of 2.4 and 1.5 for the metamorphic and sedimentary rocks, respectively. Some authors are of the opinion of assigning a fixed value of scaling exponent ~ 3 for a region (Fedi *et al.* 1997). Bansal and Dimri (2014) summarised the values of scaling exponent for the source distribution as 2.4 to 4.6 for 3D sources, which will be lower for 2D and 1D distribution of sources. A recent study by Salem *et al.* (2014) has shown the β value variation between 0 and 1.7 in the Central Red Sea region. Bouligand *et al.* (2009) tried different values of β in the estimation of the Curie depth and finally fixed values between 2.5 and 3.5 for 3D distribution of sources. In the present study, we found β variation between 0 and 4 for 2D distribution of sources. These values are very scattered and not found correlated with depth and geology. Such a large variation in β values may indicate a complex tectonic nature of the region.

The Central Indian region has a complex geological history as some earlier studies suggested plume activities (Curray and Munasinghe 1991). Due to plume activities, reworking of the crust must have taken place due to shallower and deeper intrusive bodies. This phenomenon may be very common during plume activities. There are enough evidences of the existence of plumes and collision history right from the Proterozoic to recent times (Rao 2002). Disturbed tectonic activity due to plume-related bodies might have also affected the basement depth in the region.

The process of underplating has been invoked for rift formations worldwide. The underplating is also a common phenomenon in the old cratons and basins due to the differentiation process in the formation of the continental crust in the geological past. Underplating caused by plume events (Cretaceous–Tertiary) in the Indian shield and its imprints are possibly affected in many geological units of the upper crust, reflected in the form of magnetic sources. The occurrences of the intrusions in the upper crust affected by the various tectono-thermal events in the geological past, since Precambrian plate tectonics, must have changed the composition of the initial crustal rocks (Rao 2002). Kroner (1977) is of the view that the Pan African tectonogenes have led to the crustal evolution as evidenced by the modern theory of global tectonics. All the processes discussed above led to the formation of present-day crustal structure in the different geologic segments of the Central Indian region.

In the present study, we are able to map magnetic interfaces using the scaling spectral method applied to reconnaissance-scale aeromagnetic data. Detailed mapping of the magnetic basement using high-resolution aeromagnetic data will be useful for mineral and hydrocarbon exploration in the region.

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