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Crustal structure of the western part of the Southern Granulite Terrain of Indian Peninsular Shield derived from gravity data

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ABSTRACT

The Southern Granulite Terrain (SGT) is composed of high-grade granulite domain occurring to the south of Dharwar Craton (DC). The structural units of SGT show a marked change in the structural trend from the dominant north–south in DC to east–west trend in SGT and primarily consist of different crustal blocks divided by major shear zones. The Bouguer anomaly map prepared based on nearly 3900 gravity observations shows that the anomalies are predominantly negative and vary between −125 mGal and +22 mGal. The trends of the anomalies follow structural grain of the terrain and exhibit considerable variations within the charnockite bodies. Two-dimensional wavelength filtering as well as Zero Free-air based (ZFb) analysis of the Geoid-Corrected Bouguer Anomaly map of the region is found to be very useful in preparing regional gravity anomaly map and inversion of this map gave rise to crustal thicknesses of 37–44 km in the SGT. Crustal density structure along four regional gravity profiles cutting across major shear zones, lineaments, plateaus and other important geological structures bring out the following structural information. The Bavali Shear Zone extending at least up to 10 km depth is manifested as a plane separating two contrasting upper crustal blocks on both sides and the gravity high north of it reveals the presence of a high density mass at the base of the crust below Coorg. The steepness of the Moyar and Bhavani shears on either side of Nilgiri plateau indicates uplift of the plateau due to block faulting with a high density mass at the crustal base. The Bhavani Shear Zone is manifested as a steep southerly dipping plane extending to deeper levels along which alkaline and granite rocks intruded into the top crustal layer. The gravity high over Palghat gap is due to the upwarping of Moho by 1–2 km with the presence of a high density mass at intermediate crustal levels. The gravity low in Periyar plateau is due to the granite emplacement, mid-crustal interface and the thicker crust. The feeble gravity signature across the Achankovil shear characterized by sharp velocity contrast indicates that the shear is not a superficial structure but a crustal scale zone of deformation reaching up to mid-crustal level.

1. Introduction

The continental blocks of the granulite grade Precambrian Terrains and the associated shear zones play an important role in the reconstruction of the East Gondwana (Janardhan, 1999). Peninsular India is considered as a part of East Gondwana during Pan-African orogenic assembly (ca. 500–700 Ma) (Bartlett et al., 1995) and the well-exposed Precambrian Terrain of South India occupies approximately the center of the eastern Gondwanaland (Miller et al., 1996). Because of its closeness to Sri Lanka, southern Madagascar and east Antarctica during late proterozoic (Kriegsman, 1995; Collins and Windley, 2002), tectonic evolution of the Peninsular India has relevance to modeling of the continental assembly (Ramakrishnan, 2003). The terrain is broadly a composite of an exposed upper crust of Greenstone–Granite Domain (GGD) in the Dharwar Craton (DC), exhumed lower crust of High Grade Domain (HGD) in the Southern Granulite Terrain (SGT), Eastern Ghats Mobile Belt (EGMB), and the Karimnagar Granulite Belt (KGB) (Drury et al., 1984; Mahadevan, 2003; Ramakrishnan, 2003). The DC is separated from the SGT by the orthopyroxene isograd (Fermor Line)

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identified by Fermor (1936), which essentially separates the charnockitic and non-charnockitic terrains in the shield (Figs. 1 and 2). The south Indian Shield, therefore, provides an oblique cross section across the continental crust (Fountain and Salisbury, 1981).

The SGT extending from 8° to 12°N latitude of south Indian shield (Fig. 1) is one of the ancient shield areas characterized by extensively exposed exhumed deep crustal rocks (Mahadevan, 2003). The SGT, Kapuskasing structural zone of Canada and the Arunta Block of Australia are few examples for the Archean high-grade granulite terrains in the world (Percival and Card, 1983). Structurally, the SGT is dissected into three major blocks by the prominent E–W trending Bavali–Moyar Shear Zone (BMSZ) and Palghat–Cauvery Shear Zone (PCSZ), and the NW–SE trending Achankovil Shear Zone (ASZ) (Ramakrishnan, 1993; Chetty, 1996). Occurrence of a number of plateaus, viz., Mysore, Wayanad, Nilgiri and Periyar are generally identified with regions of high relief and plain areas of considerable elevations (⩾500 m) are characteristic of the SGT (Radhakrishna, 2001).

To understand the mechanism of crustal evolution and tectonic history, it is necessary to know the characteristic features of the lower crust. The SGT represents a Precambrian Terrain of lower crustal origin, believed to have been formed by the accretion of various crustal blocks during the mid-Archean to Neoproterozoic (Radhakrishna, 1989; Harris et al., 1994; Jayananda and Peucat, 1996). Several structural and isotopic investigations have tried to link up shear zones in the SGT with the separated parts of the Gondwana (Drury et al., 1984; Harris et al., 1994; Bartlett et al., 1995; Yoshida et al., 1999; Bhaskar Rao et al., 2003; Ghosh et al., 2004; Chetty and Rao, 2006) and also suggest different models of orogeny to explain the Neoproterozoic evolution of southern India and its amalgation within the Gondwana assembly (Collins et al., 2007; Santosh et al., 2009). In addition, the gravity, magnetic, resistivity, magneto-telluric and seismic data interpretation across major shear zones and plateaus of the SGT have provided valuable insights towards understanding the domain boundaries, crustal dynamics, crust–mantle interactions and lithospheric structure (Gupta et al., 2003; Rajaram et al., 2003; Mishra and Vijaya Kumar, 2005; Harinarayana et al., 2006; Rajendra Prasad et al., 2006; Singh and Stephen, 2006; Vijaya Rao et al., 2006; Kumar et al., 2009). In this study, we present a detailed analysis of gravity anomalies in the central to western part of SGT by utilizing nearly 3900 gravity observations in terms of deep continental crustal structure and mass anomalies across several segments of shear zones and plateaus and their contribution to the tectonic history of the SGT.

2. Regional geology

Geological correlation between the south Indian Shield and other Gondwana fragments is hampered due to lack of coherent

Fig. 1. Map showing various geomorphic features such as plateaus, coastal plains, trends of major shears, lineaments (L), faults (F) and plateaus (P) in the Southern Peninsular India. The inset shows the study area located in the southwestern part of the Southern Peninsular India.

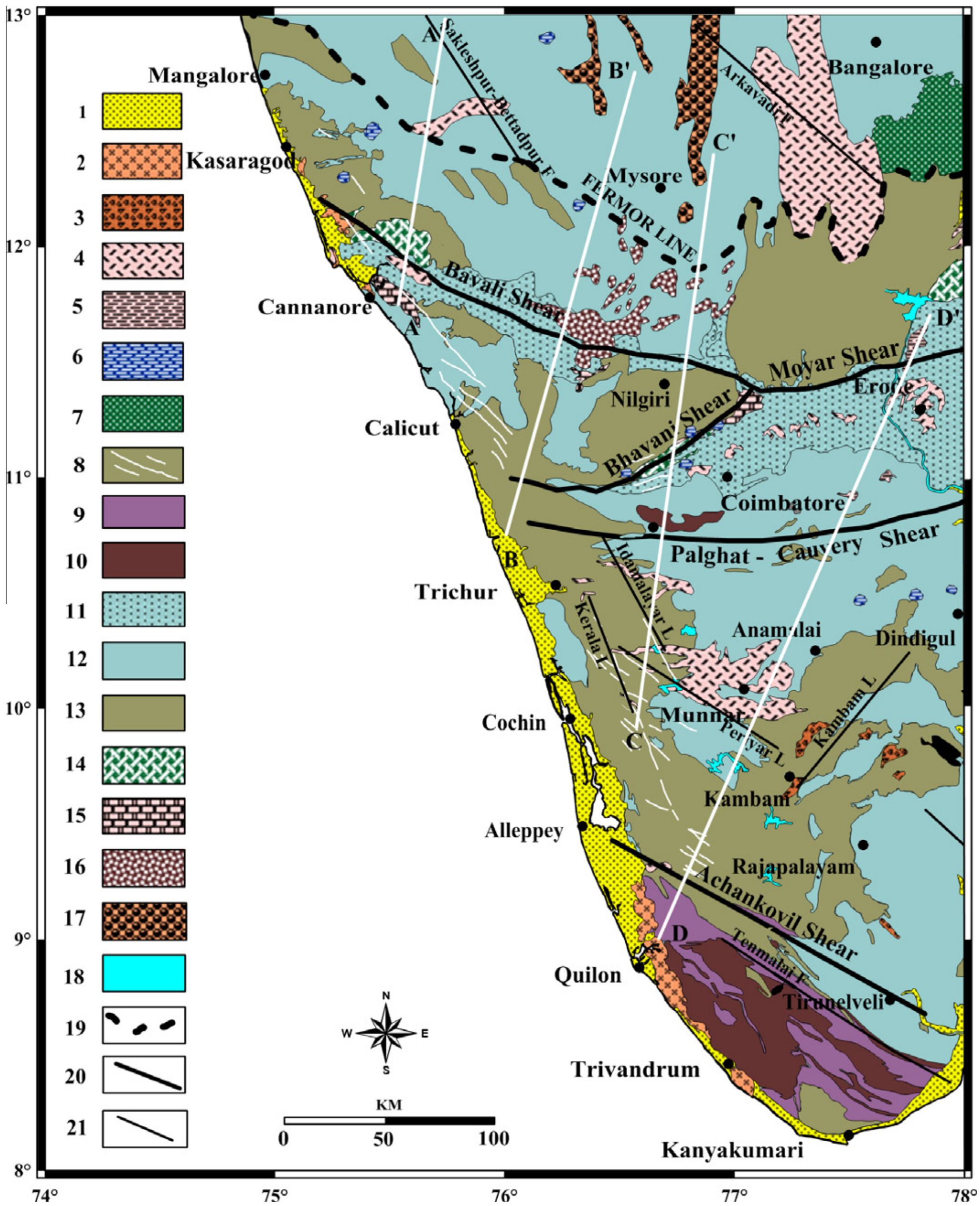

Fig. 2. Detailed Geological map of the study area (after Geological map of Kerala, Karnataka and Tamil Nadu, Geological Survey of India, 1995). The rectangles indicate: 1. Alluvium, 2. Sandstone, 3. Laterite and Bauxite, 4. Granite unclassified, 5. Syenite, 6. Anorthosite, 7. Alkaline complex, 8. Dolerite and Gabro dykes, 9. Garnet–biotite gneiss, 10. Khondalite, 11. Hornblende–biotite gneiss, 12. Hornblende gneiss, 13. Charnockite, 14. Pyroxene granulite, 15. Quartz–mica schist, 16. Sargur supracrustals, 17. Dharwar supracrustals, 18. Water reservoirs, 19. Fermor Line, 20. Major shear zones, 21. Major lineaments/faults. The profiles AA′ through DD′ indicates location of four regional gravity profiles selected for modeling the crustal structure below the region.

structural framework for the SGT (Cenki and Kriegsman, 2005). The SGT has a complex evolutionary history from early Archean to late Neoproterozoic (3500–550 Ma) with repeated multiple deformations, anatexis, intrusions and polyphase metamorphism (Bartlett et al., 1998; Bhaskar Rao et al., 2003). Major outcropping rock formations in the SGT (Fig. 2) mainly consists of number of large charnockitic massifs, khondalites, supracrustals, gneissic complex intruded by mafic/ultramafic rocks, granites and alkaline complexes (Mahadevan, 2003). Late Mesozoic intrusives consisting of alkaline plutons and dykes indicate the long-lived magmatic activity in the time span from late Proterozoic to early Paleozoic (Rajesh and Santosh, 2004). They are also broadly contemporaneous with Pan-African events in other fragments of the Gondwana Supercontinent (Kroner, 1981; Santosh et al., 1994) and emplacement of mafic dykes in early mid Proterozoic and late Phanerozoic time in the high-grade region. Neogene and Quarternary sedimentary sequences are seen exposed mostly in the southern and northern part of coastal SGT (Radhakrishna and Mathew, 1995).

Number of shear zones of Neoproterozoic age with a marked change in their structural trend from the dominant N–S in DC to E–W in the SGT divides the entire region into three different blocks: the northern, central and southern blocks (Drury and Holt, 1980). The northern block consists of DC with low-grade metamorphic rocks of greenschist to amphibolite facies and granulite massifs. The northern block is separated from the central block by Bavali–Moyar Shear Zone (BMSZ) where the region divides the shield into Archean terrains in the north and the Neoproterozoic mobile belt further south (Gopalakrishnan, 1996). The central block named Nilgiri–Madras Block consisting of gneisses lies between BMSZ in north and PCSZ in south defines the transition between low and high grade terrains. The southern block located south of PCSZ consists of two blocks, viz., Madurai Granulite Block (MGB) in north composed of charnockitic massifs, amphibolite facies gneiss and supracrustal rocks and Kerala Khondalite Belt (KKB) in south separated by NW–SE trending ASZ (Drury et al., 1984; Srikantappa et al., 1985; Yoshida et al., 1999). The MGB is also characterized by its ultrahigh temperature metamorphism and multi-stage exhumation history and the presence of recently defined Karur–Kambam–Painavu–Trissur Shear Zone (KKPTSZ) (Raith et al., 1999; Satish Kumar 2000; Ghosh et al., 2004). The important rock types within the KKB are garnet–biotite–sillimanite gneiss (khondalites) and garnet–biotite–quartzofeldspathic gneisses with associated migmatites and charnockites (Guru Rajesh and Chetty, 2006).

3. Gravity data and analysis

For the present study, we used about 3900 gravity observations (Fig. 3, inset) collected over a long time span by using different gravimeters. Out of this, around 1000 gravity observations were acquired by National Geophysical Research Institute (NGRI, 1978) to study the relationship of gravity field to broad structural provinces in Peninsular shield of south India (Subrahmanyam, 1978). Prior to the present study, the authors at Cochin University of Science and Technology (CUSAT) had collected 1750 gravity observations (Kurian et al., 1999; Arts et al., 2003; Radhakrishna et al., 2003) using the W. Sodin gravimeter (model No. 100) having a dial constant of 0.24 mGals or the Lacoste and Romberg gravimeter (model G-1042) having a worldwide range of 7000 mGals. Though these stations are closely distributed in some parts, large data gaps still existed particularly in the regions of Moyar–Bhavani Shear

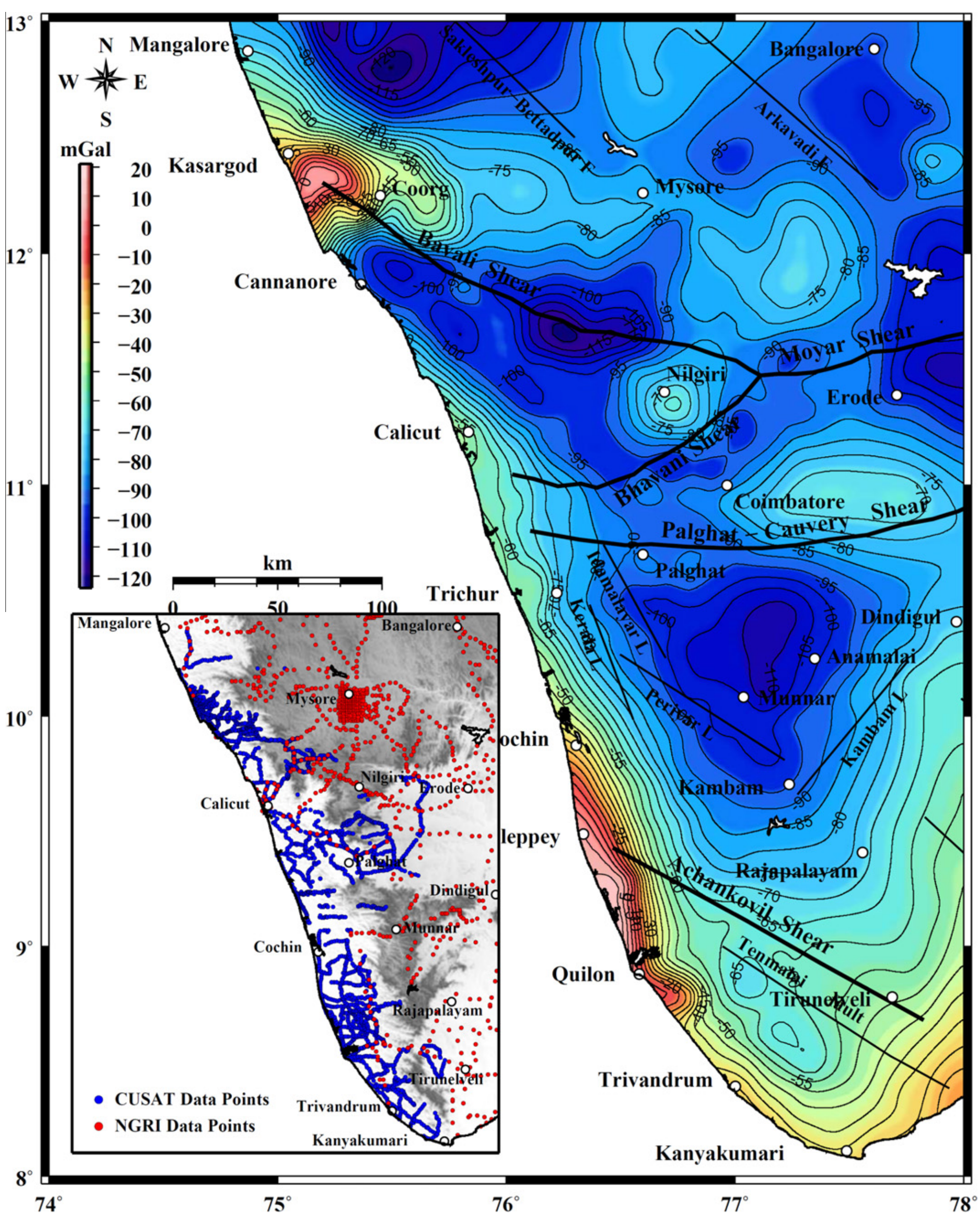

Fig. 3. Bouguer anomaly map of south western part of SGT prepared at 5 mGal contour interval. Shear zones, lineaments (L) and faults (F) are shown for comparison. The inset represents the distribution of gravity data points in the area.

Zone (MBSZ), along Palghat gap, parts of Central Kerala and Periyar plateau area and the eastern part of ASZ. To fill the data gaps, an additional data of nearly 1150 gravity observations were made at 1–2 km data spacing using Lacoste and Romberg gravimeter along all available motorable roads to have a better and uniform coverage. This is achieved by establishing several secondary bases utilizing the already available base stations (Singh et al., 1985; Radhakrishna et al., 1998) through forward looping method. The elevation data has been considered from altimeter, benchmarks, toposheets and Global Positioning System. The maximum error involved in elevation measurements is around 3–4 m giving rise to an error of less than 1 mGal in the reduced gravity values. The normal correction was made based on the 1930 International gravity formula and the Bouguer correction was made using the density of surface rocks as 2.67 g/cm^3. Terrain correction has been computed by approximating the topographic masses using a high resolution regional Digital Elevation Model (DEM) from Shuttle Radar Topography Mission (SRTM) 90 m sampling data that covers the study area (Hinze et al., 2005).

4. Analysis of gravity anomaly maps

4.1. Bouguer anomaly map

The terrain corrected Bouguer anomaly map prepared at 5 mGal contour interval is shown in Fig. 3. The contours have a typical NNW–SSE to E–W trend and display several gravity highs and lows of varying dimensions. The Bouguer anomalies are predominantly negative and vary between −125 mGal and +22 mGal. The trends of these anomalies follow the structural grain of the terrain and exhibit considerable variations within the charnockite bodies. The most pronounced anomaly in the region is a broad gravity low of −115 mGal centered over the Periyar plateau covering the gneiss and charnockite out crops and exposed Munnar granite body in the south-central part of the study region. Another interesting anomaly seen on the map is the relative gravity high closure of around −65 mGal over the Nilgiri plateau which is surrounded by gravity lows. It would be worthwhile to examine the causative factors for these two contrasting anomaly pattern over the highly elevated peaks in the Western Ghats. The map in general shows positive anomalies in the coastal areas that decrease towards the interior all along. Between Mangalore and Cannanore, a localized gravity high with maximum Bouguer anomaly value of +5 mGal is observed at the coast near Kasargod. Near Alleppey, another pronounced gravity high of around +20 mGal is observed hugging the coast within the sedimentary basin. In the central part of the study area, the Palghat gap is characterized by a long wavelength E–W trending gravity high though the anomalies are not well expressed in the western part of the gap. This E–W trending gravity high coincides with the gap (Mishra, 1988), while gravity anomaly low zone is observed coinciding with the region sandwiched between the PCSZ and MBSZ with charnockite hills on either side (Subrahmanyam and Verma, 1986). A gravity low occurs over the Wayanad plateau along BMSZ and is seen located between the two gravity highs over Nilgiri and Biligirirangan hills on either side. The Bavali Shear Zone in the NW part of the study area is seen correlating with a gravity high gradient in the north. However, the ASZ, a major suture belt in the southern part of the study area does not show up well on the Bouguer anomaly map.

4.2. Geoid-Corrected Bouguer Anomaly (GCBA) map

Observed Bouguer anomaly is the ensemble of all the subsurface source horizons. In the Indian shield region, the striking factor that emerged from the satellite derived gravity models is the influence of long wavelength Indian Ocean Geoidal Low (IOGL) (Kahle et al., 1978). The causative factors of the IOGL have been inferred variously to the lithosphere and mantle processes or to the core–mantle boundary features (Chase, 1979; Hager et al., 1985). The IOGL centers a little north of equator and south of Kanyakumari at the southern tip of Indian shield. This is the longest wavelength feature on the surface of Earth with a geoidal depression of about 110 m and a lateral extent of about 4000 km. The influence of the IOGL on gravity field based on the Goddard Earth Model 10 (GEM-10) (Marsh, 1979) is between −45 mGal at the southern tip of India to −31 mGal

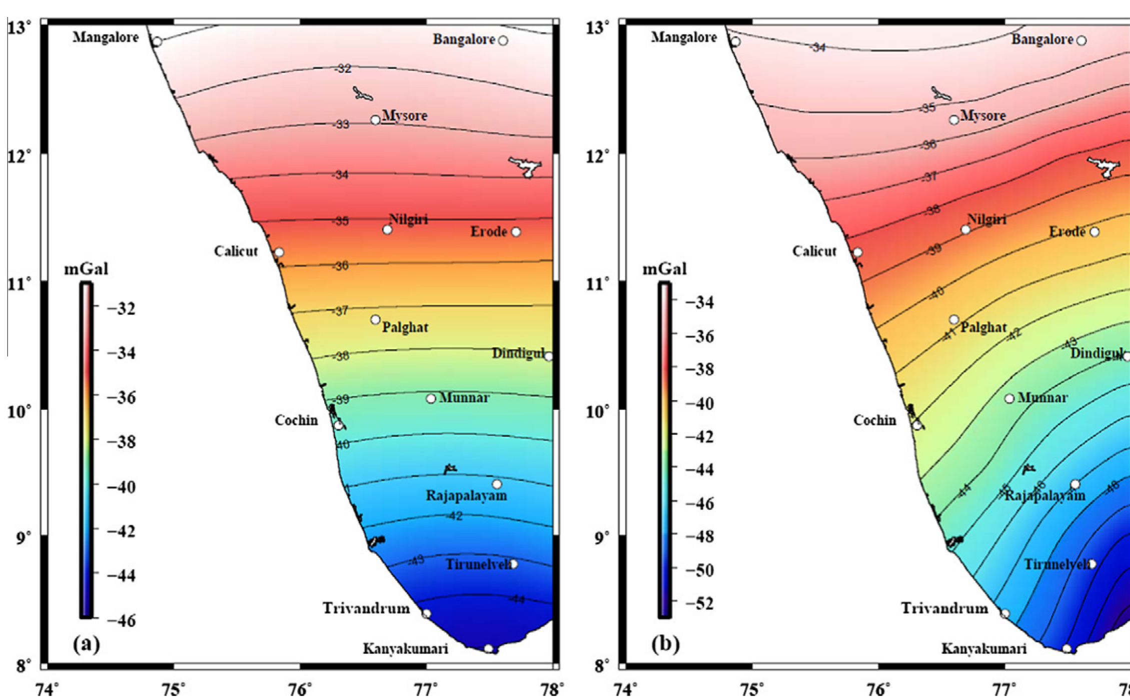

Fig. 4. Indian Ocean Geoidal Low (IOGL) on gravity field in the study region. (a) IOGL effect from GEM-10 model (after Marsh, 1979) and (b) IOGL effect from GEM-T3 model (after Lerch et al., 1994).

at 13°N in the South Indian shield region (Fig. 4a). The improved model of IOGL based on Earth's gravitational field GEM-T3 (Lerch et al., 1994) gives rise to variation between −50 mGal in the southern tip of India to –34 mGal at 13°N (Fig. 4b). For continental scale crustal studies, the gravity anomalies should be corrected for this effect because of its large amplitude and deeper source. In the present study, the Bouguer gravity map is corrected for the IOGL effect (shown in Fig. 4b) based on the GEM-T3 model of Lerch et al. (1994) as this model provide a better resolution. Fig. 5 shows the Geoid-Corrected Bouguer Anomaly (GCBA) map of the region. The resulting GCBA map reflects most of the anomalies as in the original Bouguer anomaly map (Fig. 3) except change in their amplitudes.

4.3. Regional and residual anomaly maps

In order to ascertain the depth and extent of various subsurface masses causing the gravity anomalies, two-dimensional wavelength filtering (Zurflueh, 1967) and Zero Free-air based (ZFb) (Subba Rao, 1996) methods have been adopted. In wavelength filtering, by progressively increasing the cut-off wavelength of a low-pass filter one can observe the trends existing in the anomaly map (Lefort and Agarwal, 2000). In order to avoid the edge effect, a cosine tapering was given at the cut-off wavelength. Thus the gridded data have been filtered with a low-pass filter for different cut-off wavelengths ranging between 25 and 150 km for identifying various trends and distribution of subsurface sources that may be lying at different depths. Low-pass filtered map (Fig. 6a) of wavelength >150 km reflect sources at Moho depths (Chakraborty and Agarwal, 1992; Lefort and Agarwal, 1996) and this map has been considered as the regional map in the wavelength filtering analysis. The wavelength filtered regional map (Fig. 6a) when subtracted from the GCBA map (Fig. 5) gave rise to filtered residual anomaly map (Fig. 6c) of the region. According to the ZFb method, the compensated continental topographic masses will have zero free air values

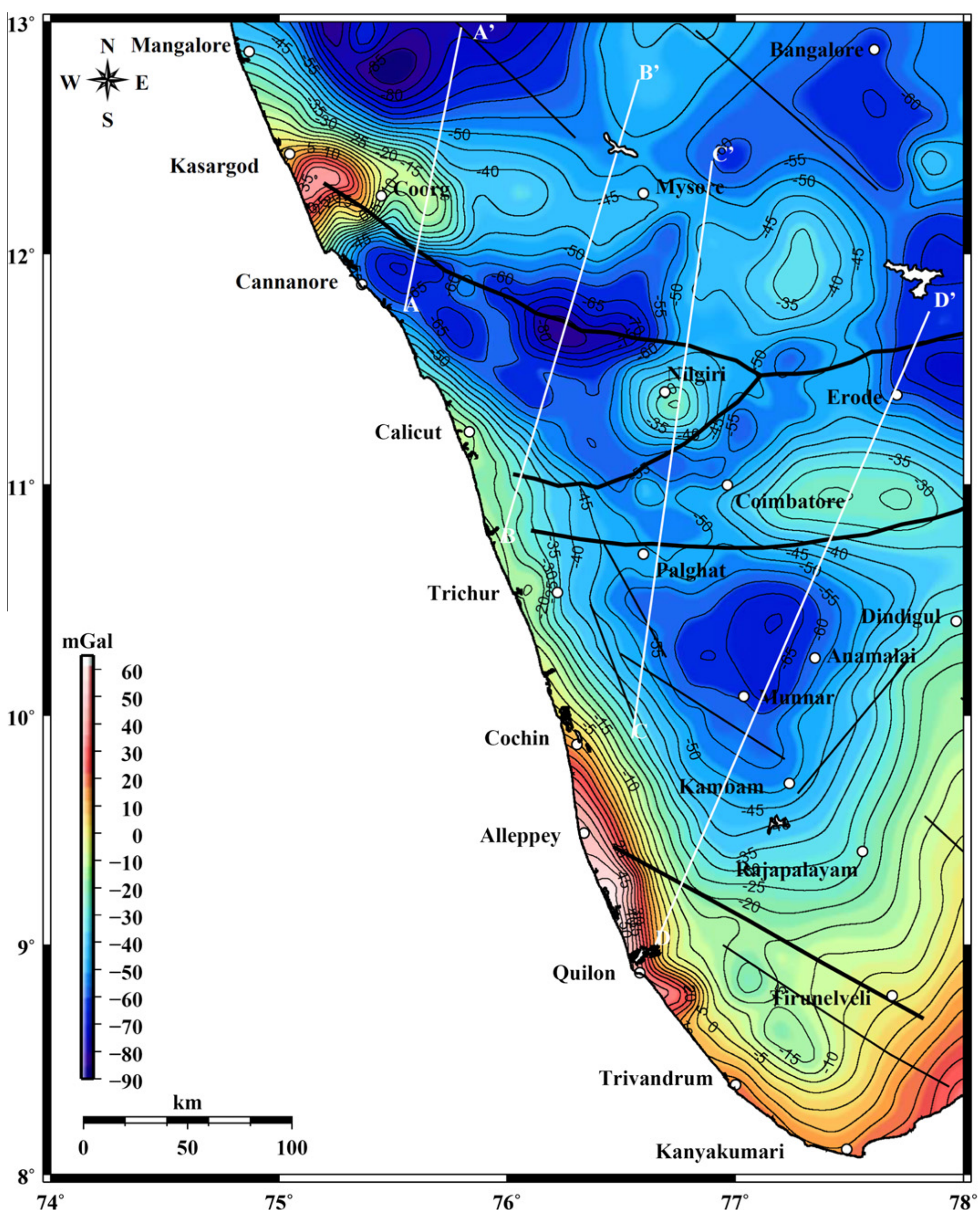

Fig. 5. Geoidal Corrected Bouguer Anomaly (GCBA) map of the study area. Contour interval 5 mGal. Lines AA′ through DD′ represents profiles selected for two-dimensional gravity modeling.

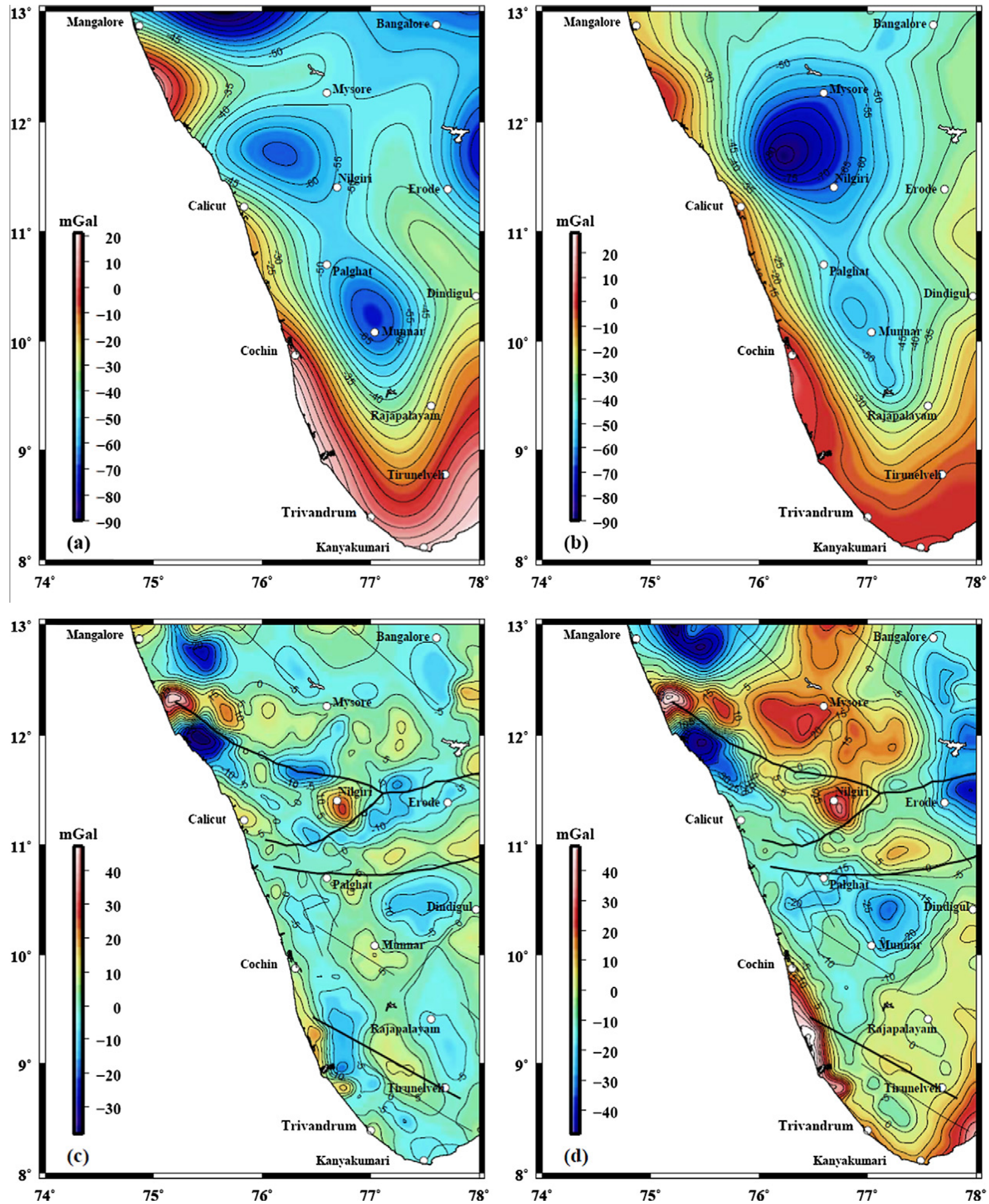

Fig. 6. Regional and residual maps prepared using two-dimensional wavelength filtering and ZFb methods. The top side figures (a and b) represent the low-pass-filtered regional anomaly map and topography compensated negative-bias regional anomaly map, respectively. The bottom side figures (c and d) represent the residual maps prepared after subtracting the low pass-filtered regional anomaly map from the GCBA map and ZFb residual anomaly map after subtracting the negative-bias map from the GCBA map, respectively.

at different elevations. These elevations when used in the computation of Bouguer correction give rise to negative Bouguer anomalies. This negative bias in Bouguer gravity corresponding to zero free air values is considered as ZFb regional gravity field (Fig. 6b) equivalent to conventional regional anomaly map, and when removed from GCBA map (Fig. 5) will give rise to ZFb residual anomaly map (Fig. 6d) which is nothing but the conventional residual anomaly map (Subba Rao, 1996).

The regional anomaly maps (Fig. 6a and b) prepared from the above two methods show similar trends. The gravity lows over Periyar and Wayanad plateaus and the two coastal gravity highs at Kasargod and Alleppey observed in these maps indicate deeper mass anomalies at Moho level. A comparison of wavelength filtered and ZFb residual anomaly maps (Fig. 6c and d) indicate that both the maps correspond well and correlate with the geological structures and major shear trends, though minor variations exist in their amplitude. The gravity high in the less elevated region of Palghat gap and the coastal gravity highs near Alleppey and Kasargod indicate that the gravity field is partly contributed by mass heterogeneities at shallow levels also. Both residual maps show gravity low over Periyar plateau and have anomaly trends correlating well with major shear zones like Bavali, Bhavani, Moyar, Palghat–Cauvery as well as other prominent lineaments in the region.

5. Gravity modeling

The crustal density structure/configuration in the SGT is investigated along four regional gravity profiles AA′–DD′ (see Figs. 2 and 5 for profile locations) cutting across major shear zones, plateaus and other important geological structures. For this purpose, the GCBA map is used for interpreting gravity anomalies in terms of 2D-crustal models using the GM-SYS software. The available seismic data, one in the north of SGT (Kavali–Udipi Transect) (Reddy et al., 2000) and the other two, (Kuppam–Palani Transect) (Reddy et al., 2003) and (Vattalkundu–Kanyakumari Transect) (Rajendra Prasad et al., 2006) within the SGT have been utilized to constrain the density structure. All four profiles (AA′–DD′) have a NNE–SSW alignment running from near the coast into the interior and essentially cover the charnockite and gneissic provinces in low, mid as well as high land areas. Profile AA′ starts from the west coast in the NW part of the study region cuts across the Bavali Shear Zone and extends into the DC almost closer to the Kavali–Udipi Deep Seismic Sounding (DSS) profile. Profile BB′ starts from the western extension of the PCSZ, cuts the BMSZ and Wayanad plateau in the central part and extend up to the Mysore plateau. Profile CC′ passes through the Palghat gap (Palghat wide shear), cuts across the major structures like PCSZ, Bhavani, Nilgiri plateau, Moyar Shear Zone and finally terminates at the Mysore plateau. Profile DD′ is the longest of all profiles which covers most part of the study area from southwest to northeast by ASZ, KKPTSZ, Periyar plateau, PCSZ and Moyar shear.

5.1. Constraints on crustal densities and its structure

The SGT being an exhumed lower to middle crustal rocks, the occurrence of formations above the Conrad discontinuity in this region will depend on the levels of exhumation of the deep crust (Mahadevan, 1994). Such a scenario can be realized from the fact that exposed major rock types in the SGT such as charnockites and gneisses give rise to densities dominantly above 2.73 g/cm^3. The average densities of the surface rocks in the SGT region (Table 1) have been compiled from Radhakrishna et al. (2003) and Ajayakumar et al. (2006). Also, the seismic velocities compiled by Reddy et al. (2003) provide valuable information on variation in crustal configuration between DC and SGT region.

Table 1
Density values of major rock types in the study area (after Radhakrishna et al., 2003 and Ajayakumar et al., 2006).

Sl. no.	Rock type	No. of samples	Mean (gm/cc)	S.D.	Range (gm/cc)
1	Granite	81	2.67	0.0385	2.57–2.78
2	Gabbro	18	2.99	0.140	2.64–3.14
3	Diorite	7	2.75	0.0811	2.68–2.92
4	Anorthosite	13	2.77	0.0940	2.67–3.01
5	Dolerite	6	3.02	0.1231	2.87–3.21
6	Granulite	12	2.75	0.0928	2.64–2.98
7	Charnockite	41	2.76	0.0730	2.60–3.00
8	Gneiss	56	2.73	0.1061	2.57–3.16

Based on the four layered velocity structure obtained along the Kuppam–Palani seismic section (Reddy et al., 2003; Singh et al., 2003) divided the 20 km thick upper crust into two crustal layers of 2.71 g/cm^3 on the top and 2.76 g/cm^3 layer at the bottom. Below these two layers, the mid-crustal low velocity layer (LVL) with a low density of 2.70 g/cm^3 and lower crustal layer with a high density 2.89 g/cm^3 have been considered by them. Here, the density configuration considered by Singh et al. (2003) has been slightly modified because of the following facts: (i) the Kuppam–Palani geotransect mainly passes through a belt of E–W trending shears with unclassified gneisses as dominant outcrops and (ii) higher surface rock densities (for charnockites 2.76 g/cm^3 and 2.73 g/cm^3 for gneisses) have been estimated from a good number of rock samples in the region. It is possible that wherever gneisses occur, charnockitic rocks may be extending at depth practically making them as two different layers (see Fig. 2 for surface geology), but the massive charnockitic rocks extend into deeper depths, in which case the first two layers of Singh et al.(2003) become a single layer. Such a distinction has been made in the present study. Other surface rocks such as granite (2.67 g/cm^3), anorthosites (2.77 g/cm^3), and mafic granulites (2.75 g/cm^3) have been considered as small layers/bodies. The mid-crustal low velocity/low-density layer (2.65 g/cm^3) considered here could be due to granitic intrusions (Krishna Brahmam, 1993), metasomatic activity or presence of fluids or 750 Ma alkaline activity related to intra plate rift (Reddy et al., 2003), or crustal melting (Janardhan et al., 1979; Newton et al., 1980). The crust underlying the low velocity zone is assigned a density of 2.85 g/cm^3 and the upper mantle with a density of 3.3 g/cm^3.

The velocity structure compiled by Reddy et al. (2003) suggests an average Moho depth of 37–40 km in the DC region and 42–45 km below the SGT. Based on the isostatic compensation achieved at the level of Moho, Singh et al. (2003) indicate the undulations with maximum thickness of 42 km beneath the western DC and Moho depth ranging from 39 to 40 km in the SGT region. Apart from such direct information on Moho depth, the crustal thickness map has been prepared for the whole of Peninsular India by inverting gravity anomalies based on 3-D fit (prism shape) by Subba Rao (1988) and based on ZFb Bouguer anomaly data assuming a mean sea level crustal thickness of 33 km and density contrast of 0.45 g/cm^3 between crust and mantle by Subba Rao (2002). The Moho depth map prepared by him indicates crustal thickening of 37–44 km in the interior of the SGT.

Though the crustal thickness estimates from different methods mentioned above vary in their values, the results show similar trends and thickened crust in the SGT. The differences are due to the fact that the methods are addressing different properties of the lithosphere and also they have their intrinsic limitations (Rai et al., 1993). Using more closely spaced data generated in the present study, a refined picture of the crustal thickness could be obtained from IOGL corrected ZFb Bouguer anomalies assuming a standard crustal column thickness to be 38 km, density of regional topographic mass as 2.75 g/cm^3 and the density contrast at the crust–mantle interface as 0.4 g/cm^3. The crustal thickness map presented in Fig. 7 shows that the Moho undulations are evidently due to the deep-seated compensation of the regional topography. It shows the crustal thickness ranging from 37 km to 44 km with a maximum depth of around 41 km and 44 km below the elevated regions of Periyar and Nilgiri plateaus, respectively. A comparison of the crustal thickness values obtained from the Kavali–Udipi and Kuppam–Palani DSS profiles suggest a general agreement of Moho configuration in the area. Thus the thickness map shown in Fig. 7 is taken as the basis for the present modeling.

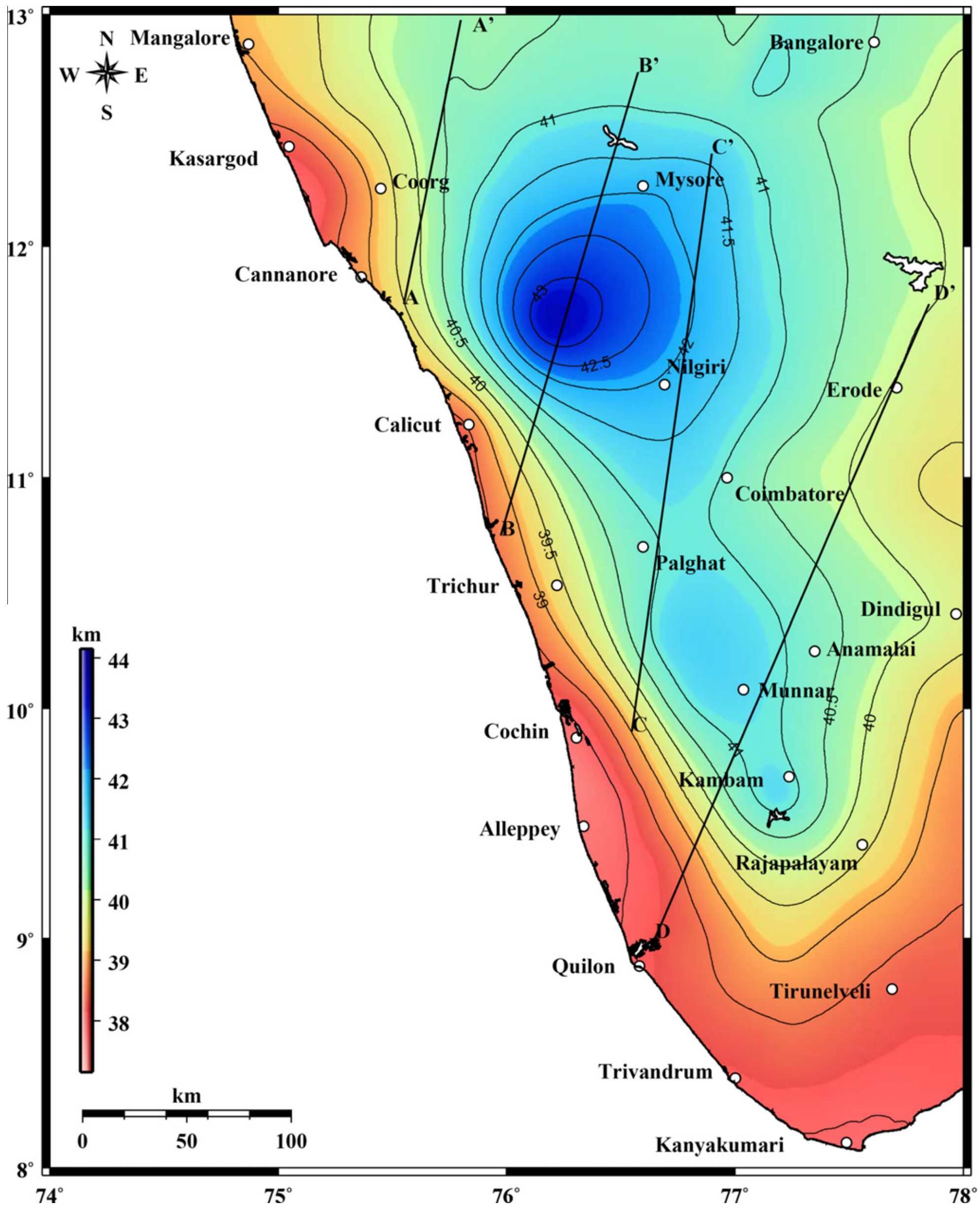

Fig. 7. Crustal thickness map for fully compensated regional topography assuming 38 km as standard crustal column thickness at sea level, 0.4 g/cc as density contrast of crust with mantle and density of regional topographic mass as 2.75 g/cm^3. The contours represent the Moho depth in km. Lines AA′ through DD′ represents profiles selected for two-dimensional gravity modeling.

5.2. Gravity derived crustal models

Two-dimensional gravity models along the four profiles (AA′–DD′) cutting across the major structural features of the SGT are presented in Figs. 8–11 and salient aspects of each of these modeled profiles have been discussed below:

5.1.1. Profile A–A′

The profile A–A′ (Fig. 8) has a length of 125 km and cuts across the Bavali shear and charnockite massifs of Coorg. It can be seen from the model that the Bavali shear delimits the thick upper crust and juxtaposes it against the high-grade granulite. Since the profile is situated in the boundary of SGT and DC the noticeable feature is that the four-layered crustal structure with mid-crustal low-density layer in SGT is getting transformed towards a three-layered crust below DC. The presence of mid-crustal low velocity layer in the SGT part of the profile and its attenuation towards the DC has been constrained from the available DSS information so as to model rest of the features. The model indicates the presence of a high-density (2.98 g/cm^3) intrusive body in the lower crust below the Coorg, which contributes significantly to the gravity high over the charnockitic province. In the SW part of the profile, Bavali shear takes major role for the separation of the outcrops of pyroxene granulite towards north and granite and quartz-mica schist in the southern part which is extending down to depth of 2.5–5 km. The Moho is at a more or less uniform depth of 40–41 km along the entire profile.

5.1.2. Profile B–B′

Profile model B–B′ (Fig. 9) with a length of 200 km also crosses the BMSZ and Wayanad plateau indicates slight thickening of the crust below the shear zone. This model also brings out the presence of high-density (2.98 g/cm^3) material in the lower crust below the western part of Nilgiri Plateau. The Moho is present at a depth

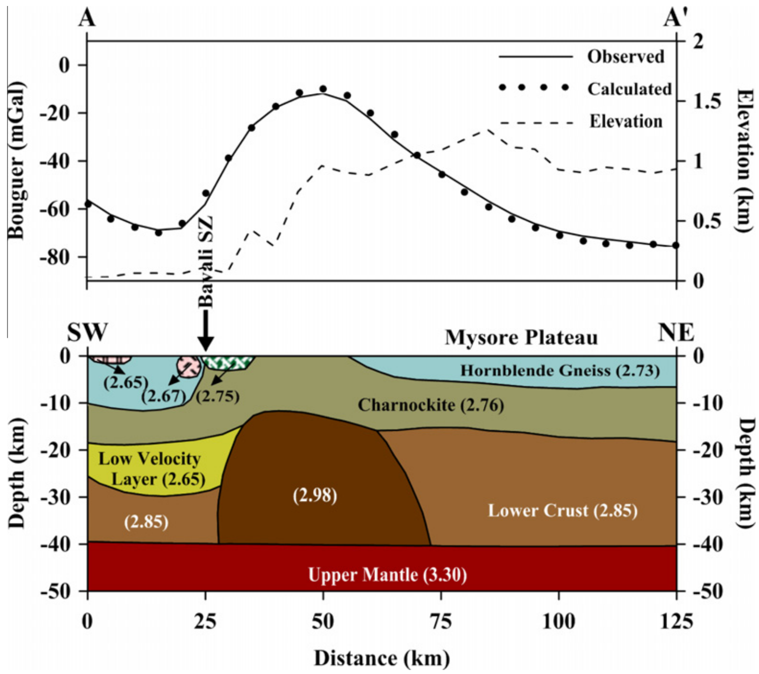

Fig. 8. Gravity derived crustal model along profile AA′. The values represent densities in g/cm^3. SZ: shear zone; L: lineament.

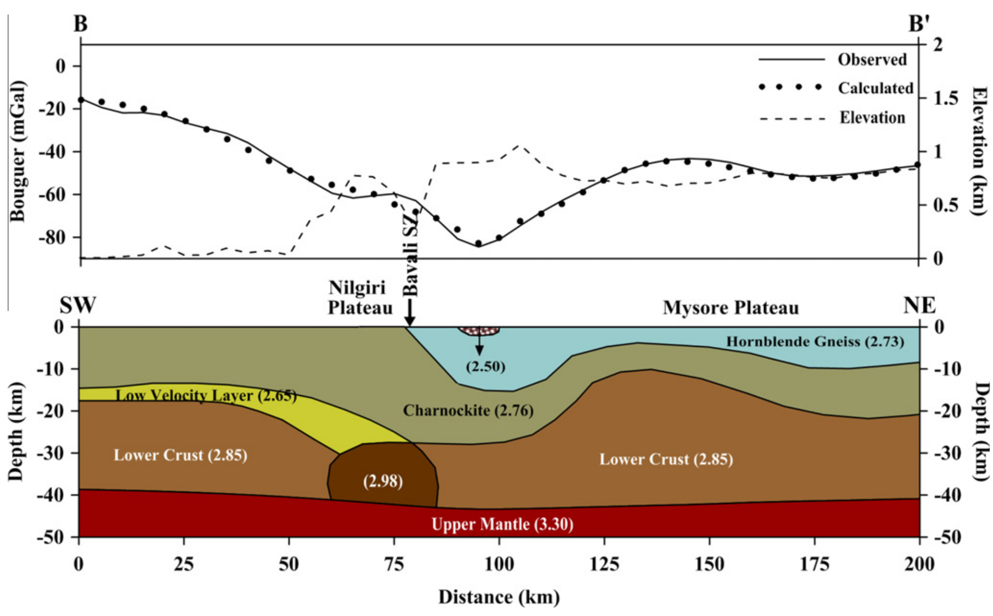

Fig. 9. Gravity derived crustal model along profile BB′. The values represent densities in g/cm^3. SZ: shear zone; L: lineament.

of 38 km at the coast and deepens up to 42 km below the Wayanad plateau. The Sargur supracrustals also partially contribute to the gravity low in the central part of the profile where Wayanad plateau located.

5.1.3. Profile C–C′

Profile C–C′ (Fig. 10) covers a length of 250 km cutting across most of the prominent features like Periyar lineament, Palghat–Cauvery, Bhavani and Moyar shears, Nilgiri Plateau and finally enters into the DC. The model indicates that the crust below Nilgiri plateau and Palghat gap is highly heterogeneous in nature and is characterized by prominent gravity highs. While the Nilgiri plateau is associated with sharp and large amplitude gravity high, the gravity high over Palghat gap is broader and of smaller amplitude. The model shows that the plateau is characterized by a thicker crust (~44 km) and the presence of intrusive body of 2.98 g/cm^3 in the lower crust. On either side of the Nilgiri plateau southerly and northerly dipping fault structures are present along Bhavani and Moyar shears, respectively. The model over Palghat gap indicates the presence of a body of intermediate density (2.80 g/cm^3) where the mid-crustal low velocity/low-density layer is absent between PCSZ and Bhavani Shear Zone. The upper layer below PCSZ shows

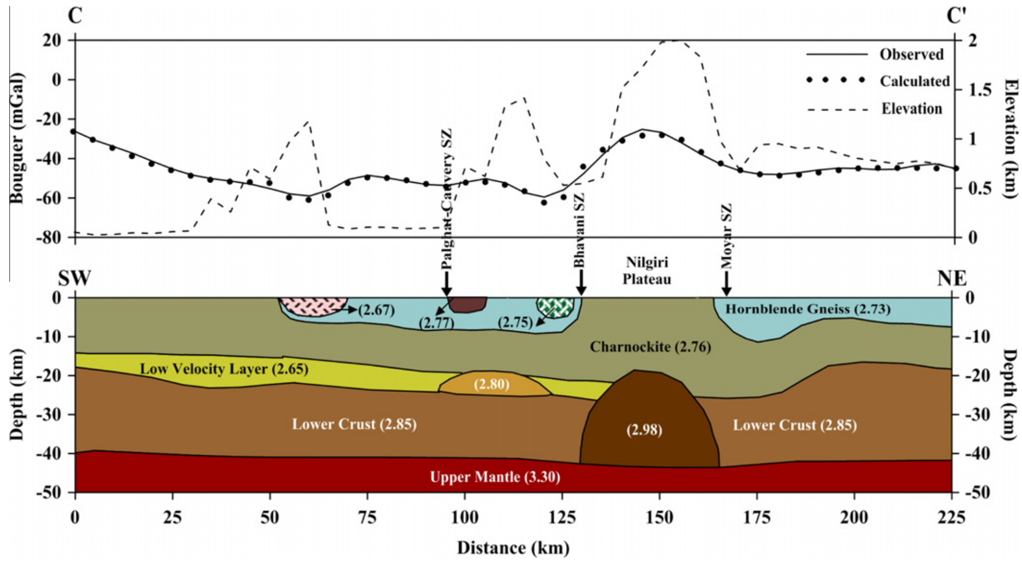

Fig. 10. Gravity derived crustal model along profile CC′. The values represent densities in g/cm^3. SZ: shear zone; L: lineament.

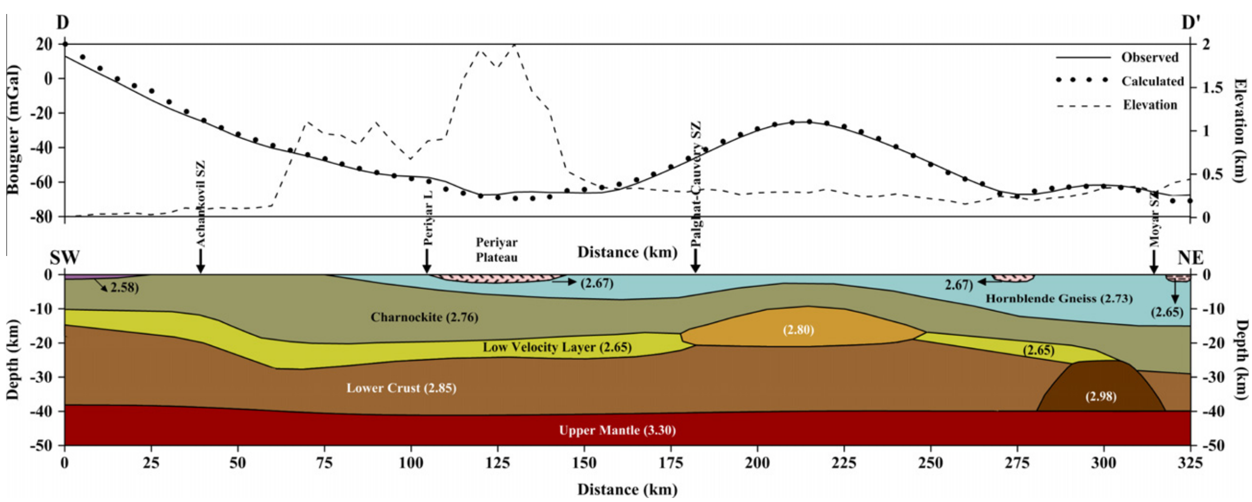

Fig. 11. Gravity derived crustal model along profile DD′. The values represent densities in g/cm^3. SZ: shear zone; L: lineament.

the presence of granite pluton extending to a depth of 5 km and out crops of khondalite and alkaline bodies extending to depths of 4 and 5 km, respectively.

5.1.4. Profile D–D′

Profile D–D′ (Fig. 11) is of 325 km long cutting across the ASZ in SW to KKPTSZ, PCSZ and Moyar shear towards NE. The profile has been partly constrained by the Kolathur–Palani DSS profile (Reddy et al., 2003) as it passes very close to it in the NE. The ASZ which is considered as the terrain boundary between MGB in north and KKB in the south (Kumar et al., 2009) is situated in the SW part of the profile. The model indicates presence of large granite bodies in the upper part of the crust below Periyar plateau and north of Palghat gap and high density rock mass at a depth of 10 km–20 km beneath the Palghat gap. The Moho is seen to be varying from 37 km at the coast to 41 km below Periyar plateau and 40 km below the PCSZ. The maximum occurrence of the intermediate density (2.80 g/cm^3) body with a thickness of ~10 km and the termination of the low velocity layer towards Moyar shear are very clear in the model. Below ASZ, the model reveals the presence of relatively thin upper crust in south and thicker upper crust north of the shear zone.

6. Discussion

The SGT is made up of several litho tectonic units and crustal scale lineaments that are characterized by the different periods of crustal evolution and exhumation process. The four gravity models (AA′–DD′) presented here provide insight into the deeper crustal architecture across the shear zones and plateaus in the SGT. Radhakrishna et al. (2003) carried out gravity modeling across the Bavali Shear Zone considering a generalized two-layer crustal configuration. However, the models presented in the present study (AA′–DD′) took into account the four layer crustal configuration for the whole SGT proposed by Reddy et al. (2003). It is observed that inclusion of an additional low-density layer did not alter the modeled features significantly. The Bavali shear is manifested in the Bouguer anomaly map by a steep gravity gradient towards northwest part of the study region. The gravity derived crustal structure along profile AA′ (Fig. 8) support the high density mass (2.98 g/

cm^3) of mafic/ultramafic components in the lower crust below high grade charnockite massif located in Coorg (Radhakrishna et al. 2003). The presence of high density mass in the lower crust would correspond to seismic velocity of nearly 7.2 km/s and is consistent with the existence of such velocities in many Proterozoic crustal segments of major Precambrian cratons elsewhere (Christensen and Mooney, 1995). The gravity models along profile AA′ also indicates that the Bavali shear extends at least up to 10 km depth with southerly dip and separates two contrasting upper crustal densities. The gravity profile model BB′ (Fig. 9) also across the part of Nilgiri plateau and BMSZ also brings out the presence of high density body of 2.98 g/cm^3 below the Nilgiri plateau which is located in south of the BMSZ. It is clear that, the gravity highs on either side of the BMSZ contribute by two different high density bodies situated in the lower crust below the Nilgiri and Coorg which are separated from each other by the BMSZ. It is debated whether the shear zones in the SGT result from collision of micro continents or due to differential exhumation of high-grade domains (Mahadevan, 2003). Fountain and Salisbury (1981), based on some typical gravity profiles across known granulite provinces of the world, suggested subduction in a continent–continent collision as the primary process to bring down the material to intermediate crustal levels and subsequent erosion to expose them at the surface. Nambiar et al. (1997) studied the P–T estimates of metamorphic rocks on either side of the Bavali Shear Zone suggested that the northern part of the Bavali shear recorded 10–12 kb pressures while the rocks south of the Bavali shear registered 6–8 kb pressures. The exhumation levels inferred for the northern block is ~35 km and the southern block is ~25 km, implying differential uplift of the two blocks.

The profile CC′, which is cutting across the Palghat–Cauvery, Bavani and Moyar shears with a sharp localized gravity high over the Nilgiri plateau encircled by gravity low characterize the third model (Fig. 10). The Bouguer anomaly map shows the high and lows coinciding with the charnockitic rocks on east and west and the shear zones on north and south of the Nilgiri plateau. The gravity derived crustal model indicates a thick crust (44 km) followed by a body of high density 2.98 g/cm^3 in the lower crust below the plateau with presence of major shear zones on northern and southern part of Nilgiri plateau. This supports the presence of intermediate rock type in the lower crust below Nilgiri plateau as suggested by Gupta et al. (2003). However, the depth to the Moho inferred in this study is about 44 km, which contrasts with the 60 km Moho depth proposed by Gupta et al. (2003). Narayanaswami (1970) has suggested that the Nilgiris represent a folded belt with its axis trending in a NE–SW direction. Subrahmanyam and Verma (1986) inferred that the gravity high over Nilgiri plateau is a result of the up thrusting of high-density pyroxene granulites in such a folded belt. However with the presence of high density material of density 2.98 g/cm^3, between PCSZ and MBSZ supports Qureshy (1981) who suggested that the uplift of the Nilgiri hill was caused by thickening of the crust through incorporation of heavy material moving from upper mantle into the crust. The increase of Bouguer anomaly with increasing elevation of the plateau indicates densification of the crust. The presence of major shears on either side (i.e., southerly dipping Bhavani shear on south and northerly dipping Moyar shear on north) of the Nilgiri plateau support the block faulting mechanism that might have given rise to the plateau uplift. The gravity low just south of the Bhavani shear correlates with the alkaline and granite bodies, which were intruded along the shear zone.

The other prominent feature along the models CC′ and DD′ is the presence of high-density (2.80 gm/cm^3) body at intermediate depth of 10–20 km beneath the Palghat gap with a Moho depth of 39 km. Singh et al. (2003) and (2006) proposed a similar crustal model for the Palghat gap along Kuppam–Palani seismic section based on gravity modeling. They suggested that the gravity high anomaly over the region is due to the 10 km mafic/ultramafic mantle material together with crustal upwarp which are controlled by the shear zones and thrust in this region. The nature and origin of Palghat gap has been a controversial issue. Various processes proposed for the origin of the gap include, fluviatile action (Jacob and Narayanaswami, 1954), structurally controlled marine and fluviatile erosion (Arogyaswami, 1962), repeated uplift (Nageswara Rao and Srinivasan, 1980) and crustal upwarping (Subramanian and Muraleedharan, 1985). This major structure is considered as a ductile shear zone by Drury and Holt (1980), as a crustal suture zone (Radhakrishna, 1989; Ramakrishnan, 1993), a zone of intense crust–mantle interaction (Singh et al., 2003, 2006) and as a region of extensive belt of tectonic exhumation (Ravindra Kumar and Chacko, 1994). Geophysical evidences indicate the extension of the structure on either side towards east and west coast (Bose and Kartha, 1977; Reddy et al., 1988) characterized by 1–2 km crustal thinning (Srinagesh and Rai, 1996). Structural studies in a part of gap region by D'cruz et al. (2000) favor the Palghat gap being treated as a sub-vertical ductile shear zone and the gap topography is a product of shearing and erosion. The gravity based crustal models presented here also support the view that the Palghat gap with a width of 80–100 km appears to be related to recent tectonic activities resulting in an upward Moho in this region.

In model DD′ the other conspicuous anomaly in the region south of Palghat gap is the broad gravity low over the Periyar plateau with a thick crust of 42 km. Krishna Brahmam and Kanungo (1976) suggested that a considerable part of this gravity low is caused by granite batholiths at depth. Santosh (1986) pointed out that a number of granite and syenite intrusives puncture the granulite facies rocks and these intrusives have a spatial relation to lineaments/faults. Ajayakumar et al. (2006) explained the gravity low due to large variations in intracrustal layers, highly weathered top layer and surface as well as concealed granite bodies. However, the granite body with a depth of 3–4 km, the ~41 km thick crust, and the deformation along the number of Neoproterozoic shear zones KKPT (Ghosh et al., 2004), in this region are mainly contributes the gravity low over the Periyar plateau. Along the profile DD′ the southernmost existing feature is the ASZ which is considered as a terrain boundary between the two contrasting geological domains MGB and KKB (Guru Rajesh and Chetty, 2006; Kumar et al., 2009). The southerly thinning and northerly thickening of the upper crust on either side of the ASZ shows the extension of the shear zone up to mid-crustal level beneath ASZ (Guru Rajesh and Chetty 2006) suggesting the contrasting nature of tectonic regime in the region which is characterized by sharp velocity contrast (Rajendra Prasad et al., 2006).

7. Conclusions

The detailed analysis of the Bouguer anomaly map and the gravity derived models along the four profiles bring out the four layer structure with an addition of mid-crustal low-density layer/low velocity in the whole SGT. Crustal thickness estimates based on regional gravity anomalies give rise to the Moho at a depth of 37–44 km in the SGT. The gravity derived crustal models confirm that BMSZ is manifested as a plane separating two contrasting crustal blocks with a high density (2.98 gm/cm^3) masses at the base of the crust below Coorg and Nilgiri, which are intruded due the incorporation of high density material moving from upper mantle into the crust. The steepness of the Bhavani and Moyar shears towards south and north, respectively, on either side of Nilgiri plateau indicates uplift of the plateau due to block faulting and its extension towards deeper level manifests the intrusion of alkaline and granite rocks into the top crustal layer. The gravity high over

Palghat gap is due to 10 km thickness mafic/ultramafic material at an intermediate together with crustal upwarp of 1–2 km. The gravity high over Palghat gap indicates the presence of a body of intermediate density (2.80 g/cm^3) reflecting upwarp of the lower crust to mid-crustal levels. The Periyar plateau is seen to be lying over a thicker crust and the gravity low is due the thick crust with granite emplacement in upper crust and variations in the intracrustal layers with the spatial correlation of KKPTSZ. The terrain boundary ASZ between MGB and KKB indicates the contrasting nature of tectonic regime which is characterized by the thinning and thickening of upper crust on either side of the ASZ and sharp velocity contrast.

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