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Deep Resistivity signatures across the Chitradurga shear zone of Dharwar craton, India

B. Veeraiah[1] and G. Ashok Babu*[2]

[1]Department of Geophysics, University College of Science, Osmania University, Hyderabad-500007, Telangana, India
[2]CSIR-National Geophysical Research Institute, Uppal Road, Hyderabad -500 007, Telangana, India
*Corresponding Author: ashokbabug@ngri.res.in

ABSTRACT

The deep resistivity signatures of the crustal scale Chitradurga shear/fault zones, which divide the Dharwar craton of peninsular India into two major crustal blocks, are investigated. Deep Resistivity Sounding (DRS) data acquired at twenty-nine locations spread in a near SW-NE direction across the craton yielded significant insight into the resistivity distribution within the N-S trending Chitradurga shear zone and adjoining major geological features. A major resistivity transition observed in the interpreted geo-electrical section is depicting a clear separation between the eastern and western parts of the Dharwar craton. The eastern part of the Chitradurga schist belt is indicated by high resistivity compared to the western part. This can be attributed to younger intrusive (Closepet Granite). The study has further indicated the extension of the shear/fault zone at depth and is characterized by low resistivity. The presently obtained electrical depth section prepared up to about 1500m bears correspondence with the available gravity variation along the traverse.

Key words: Deep Resistivity soundings, Dharwar craton, shear/fault zone.

INTRODUCTION

The Dharwar craton occupies a major part of the south Indian Precambrian shield and consists of different geological blocks joined together along or bounded by the major faults/shear systems. These crustal scale faults/shear systems have attracted the attention of many geoscientists to study the mechanism relevant to the evolution of the Dharwar. Most of the surface manifestations due to the shear/fault zones can be understood through geological studies. However, the subsurface information, especially regarding the nature and extent of shear/fault zones at depth can be obtained only from geophysical studies. The efficacy of the Deep Resistivity Sounding (DRS) study in investigating the nature of shear/fault zone was reported earlier by Singh et al., (2003) and Singh and Stephen (2006). The associated mineralogy, stress, fluids etc. influence various physical parameters of the litho units in the shear/fault zone at depth. In the present study, the DRSs were carried out along a 220 Km long SW-NE trending profile from Chikmaglur to Bhadrapur in southern India, cutting across all major geological units of the Dharwar craton. This study lays emphasis on the resistivity signatures of the shear/fault zones associated with the Chitradurga schist belt and adjoining structures (Figure 1) (Ramakonda Reddy et al., 2010; Veeraswamy et al., 2010). The earlier study associated with Dharwar craton on major shear/fault systems (Chardon et al., 2008), deep faults (Grady, 1971) and sub-surface layer velocity variation observed between Western Dharwar Craton (WDC) and Eastern Dharwar Craton (EDC) (Rai et al., 2003) indicate the plate tectonic-type of activity having operated as far back as Archean.

Geological setup

The Dharwar Craton (DC) is one of the best-studied geological terrains renowned for its Greenstone schist belts, grey Gneisses, Charnokites and younger Granites (Naqvi and Rogers, 1987) in Peninsular India. Areas to the east and south of DC covered by the metamorphic/igneous bodies and structure are related to the Pan-African assembly of Gondwana. Most of these assemblages are restricted to the central part of the craton, which are not visible due to erosion and morphological changes. Proterozoic sedimentary rocks conceal the northern margin of the craton and by Deccan traps, whereas the eastern margin is overlain by the Meso-Neoproterozoic Cuddapah basin. Late Archaean metamorphism in much of the western part of the DC varies from low thermal Green schist to Amphibolite facies in contrast to the high thermal Greenschist to Amphibolite facies on the eastern part related to the emplacement of voluminous granite (Naqvi and Rogers, 1987).

The craton was divided into two tectonic blocks (Swami Nathan et al., 1976) viz., the Western Block and the Eastern Block. These blocks were later, renamed (Rogers, 1986) as the Western Dharwar Craton (WDC) and Eastern Dharwar Craton (EDC), respectively (Figure 1). It is believed that the WDC and EDC are separated by the shear/fault zone at the eastern margin of the Chitradurga schist belt and western margin of the Closepet Granite (CG) (Subrahmanyam and Verma, 1982). The contact between the WDC and EDC is not sharp, and there is a transition zone between the Chitradurga Shear/fault zone (CSz) and CG.

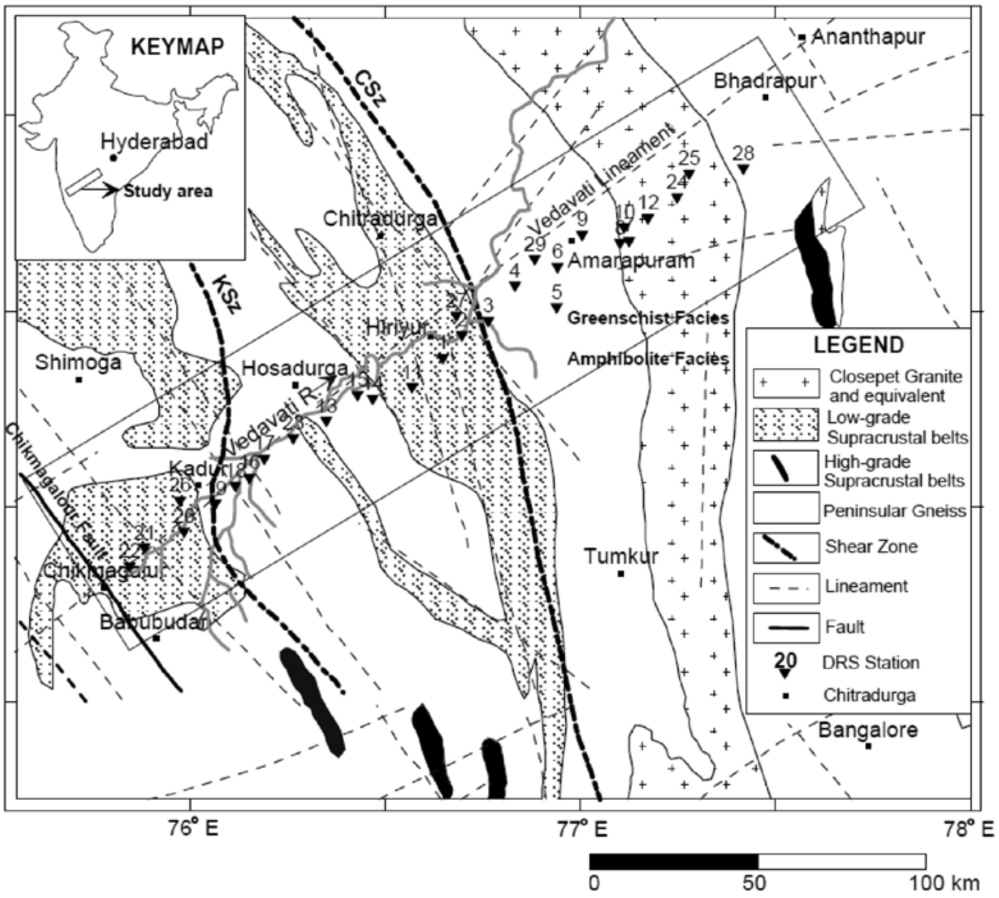

Figure 1. Geological map of the study area (modified after Sharma (2010) showing the locations of deep resistivity soundings across the Dharwar Craton).

In the present study, DRS measurements were carried out at 29 stations with interval varying between 5 to 8 km along a 220 km long SW-NE profile from Chikmaglur to Bhadrapur across the DC (Figure 1). At each station, measurements were made at 48 half-current electrode spacing (AB/2) starting from 1.5 m and increasing up to 5000 m with Schlumberger array, using high power electrical exploration system.

Equipment, Data Acquisition and Interpretation

The high power electrical exploration system used in the present study for acquiring DRS data consists of three major units viz., i) 30 kW Generator (ZMG30) ii) High Power Transmitter (GGT30) and iii) Multi-function Receiver (GDP32II). The 30kW generator produces a three-phase regulated voltage of 115V (400Hz), which is the input for transmitter. The transmitter is capable to produce source signal from DC to 10 kHz for both time and frequency domain measurements with a maximum output of 1000V and 40 A. In the present study, the source signal of 8-second period (0.125 Hz) was used. For deeper penetration a maximum spacing of 10 km was chosen between the current electrodes with the Schlumberger electrode configuration adopted in this study.

A deep resistivity sounding curve is obtained by plotting the apparent resistivity (on y-axis) versus half-current electrode spacing (on x-axis) on log-log scale. The DRS station locations were chosen (Figure 1) to have nearly a uniform station spacing all along the profile and covering all geological features of the study area. The observed DRS data for typical soundings are presented in Figure 2. The observed resistivity for all electrode spacings (AB/2) near CSz at DRS02 from shallow to deep is relatively low compared to all other soundings on the profile. The DRS data (DRS28, 25 and 12) on the east of CSz show comparatively higher resistivity than the data (DRS14,13,18 and 20) on the west for all electrode spacings.

It is conventional to interpret resistivity data in terms of thickness and physical property (electrical resistivity) of horizontal layers. However, 1D model in general, cannot adequately describe the geology often, particularly when there are near surface lateral resistivity variations causing distortions in resistivity data. It is possible to

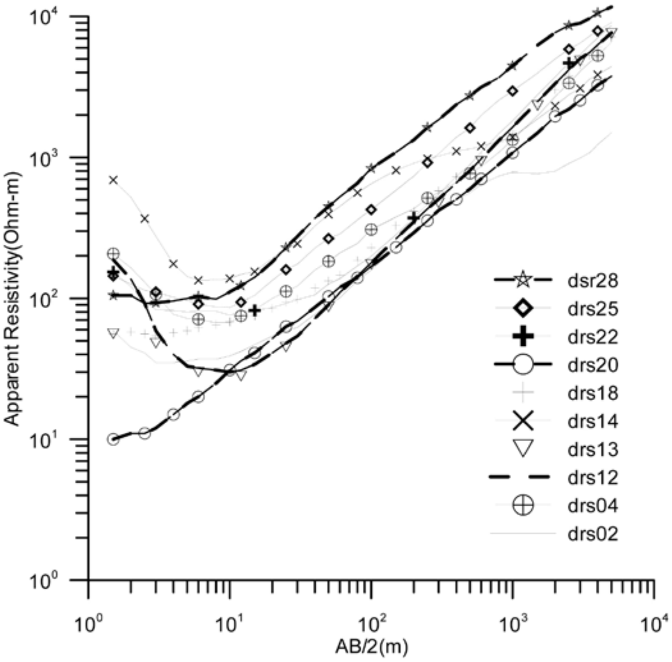

Figure 2. Typical Deep Resistivity Sounding curves observed along the profile in the Dharwar Craton.

deduce different models from the same DRS data due to principle of equivalence in resistivity method (Keller and Frischkeicht, 1966). Most of these ambiguities have been resolved largely with the help of constraints from other geophysical/geological studies (Reddy et al., 2000, 2003; Ramprasadrao et al., 2003; Ramadass et al., 2005 and 2006; Veeraiah et al., 2009 and Veeraiah, 2011).

The inversion program of Jupp and Vozoff (1975) modified by Verma and Pantulu (1990) is used for deducing the layer parameters from the DRS data. The iterative method successively improves a current model until the error measure is as small as ±5%, and the parameters are stable with respect to reasonable changes in the model. The model parameters after subjecting the DRS data for 1D inversion are shown in Table 1.

RESULTS AND DISCUSSION

The models obtained for DRS 11, 01, 02 (Table 1) indicate the probable continuation of relatively conductive zones (427 - 4125 Ωm) at a depth of 40 - 400 m with a thickness between 468 – 980 m. This low resistivity zone does not extend further to the NE of the CSz (e.g., DRS04). However, the models obtained from the DRS04 to 28 on the north-eastern part of the profile indicate the probable continuation of NW-SE near surface conductive zone (17-97Ωm) with a thickness of 2 - 58 m. The layer parameters (Table 1) indicate that the thickness of low resistivity (6-98Ωm) zones varies from few hundred meters (at DRS14, 11, 01, 02, 27, and 03) to >1000 m, which correlates with the shear zone observed as a relative gravity high (Figure 3) between the Chitradurga Schist Belt and the Closepet granite (Mishra, 2011).

The resistivity and thickness (Table 1: minimum no. of layers 3 and maximum no. 6) as derived from the 1D inversion are represented in the geo-electrical section (Figure 3). The resistivity of different layers varies from few tens to few Kilo Ωm. A thin (1 m) top layer of resistivity 10-460 Ωm (except 990 Ωm at DRS14) is observed along the profile. The resistivities of the first and second layers are not showing any significant subsurface resistivity variation except over the Closepet Granite. In general, the low resistivity is present in first and second layers, which diminishes with depth. These low resistivity variations could be attributed to the uppermost weathered zone as well as fractures in the bedrock, which control the movement of groundwater. However, there is a clear indication of low resistivity from the third layer onwards near the major geological features i.e., at CSz and Kadur shear zone (KSz).

A relatively low resistivity feature is observed in 5th layer (1681 Ωm) and in 6th layer (427 Ωm) at about 100 m depth at DRS 1 (near Hiriyur) along the profile, which is bounded by the two high resistive zones (>10000 Ωm). This low resistivity is depicting direction of the major geological feature of the region i.e., CSz. The other low resistivity (62-150 Ωm) zone observed (2nd and 3rd layers) at DRS 02 and DRS 3 could be attributed to the groundwater movement due to the River channel near (Figure 1) these two stations. All along the profile, the resistivity increases with depth. Similar trend is observed near CSz (DRS 02, 27 and 03), but the resistivity here is relatively low from surrounding stations up to the basement

Table 1. Modeled layer parameters of deep resistivity sounding measurements across Dharwarcraton, India.

S. No.	DRS No. (from SW-NE)	Position of DRS (decimal degrees)	Layer Resistivity (Ωm)							Layer thickness(m)						Total Depth	Itera-tions	Mean % Error
			1	2	3	4	5	6	7	1	2	3	4	5	6			
1	22	N13.34E75.85	184	59	78	105	5050	73817	-	1	1	7	36	129	-	175	18	3.16
2	21	N13.39E75.88	58	44	113	1745	54486	-	-	5	11	30	134	-	-	180	13	2.29
3	20	N13.43E75.98	11	178	2487	10000	-	-	-	3	63	636	-	-	-	702	4	4.21
4	26	N13.51E75.97	91	11	97	31669	-			1	12	12	-	-	-	25	8	3.40
5	19	N13.50E76.03	150	40	137	2788	31143	-	-	1	11	49	317	-	-	378	6	2.07
6	18	N13.55E76.12	56	77	129	2075	1697	44309	-	4	7	31	150	225	-	417	6	1.74
7	16	N13.57E76.15	138	38	4029	2065	26828	-	-	1	56	310	380	-	-	747	6	2.23
8	17	N13.62E76.19	460	2001	201	4490	2284	62024	-	6	7	37	313	585	-	948	8	2.94
9	23	N13.67E76.26	110	38	1977	1733	6367	81422	-	1	2	64	454	321	-	842	4	1.54
10	13	N13.72E76.35	59	18	13283	9269	66710	-	-	2	9	343	422	-	-	776	5	4.29
11	15	N13.78E76.43	56	22	210	11198	76751	-	-	2	74	196	461	-	-	733	7	2.51
12	14	N13.77E76.47	990	119	1213	1406	786	52873	-	1	10	21	317	458	-	807	6	1.66
13	11	N13.80E76.57	104	37	17013	4125	10361	14766	-	1	1	40	468	642	-	1152	24	2.72
14	01	N13.88E76.65	57	23	29733	3195	1681	86711	-	2	6	97	214	980	-	1291	7	3.35
15	02	N13.93E76.70	54	30	40	298	2076	427	39603	1	1	15	53	311	892	1273	14	2.17
16	27	N13.99E76.68	71	62	153	5531	2550	17897	-	1	9	15	330	860	-	1215	2	2.92
17	03	N13.97E76.76	353	65	150	1606	46531	-	-	1	42	226	556	-	-	831	9	2.70
18	04	N14.06E76.83	253	58	231	799	80923	-	-	1	8	25	386	-	-	420	7	2.31
19	05	N41.01E76.94	42	17	36	3929	37561	-	-	1	2	25	395	-	-	423	11	1.92
20	29	N14.23E76.88	112	20	141	5025	10544	-	-	1	4	44	369	-	-	418	6	2.92
21	06	N14.11E76.94	28	18	21180	42613	-	-	-	2	58	243	-	-	-	273	10	2.60
22	09	N14.21E77.11	100	37	465	1425	45874	-	-	1	4	33	272	-	-	310	10	2.22
23	08	N14.17E77.10	112	23	54	4204	65375	-	-	1	29	112	276	-	-	418	12	2.53
24	07	N14.18E77.12	161	56	1700	2409	29685	-	-	2	16	129	348	-	-	495	5	2.21
25	10	N14.21E77.11	129	28	13632	430000	-	-	-	1	24	423	-	-	-	448	6	2.06
26	12	N14.23E77.17	196	26	99	5299	47663	-	-	1	9	17	413	-	-	440	6	2.22
27	24	N14.29E77.25	46	37	211	5286	60903	-	-	1	2	15	394	-	-	412	10	2.60
28	25	N14.35E77.28	145	97	56	574	3756	17902	-	1	2	6	57	291	-	357	13	2.84
29	28	N14.36E77.42	111	94	2085	6090	17627	-	-	1	8	88	274	-	-	371	8	3.54

as shown in Figure 3. The resistivity variations observed along profile (Figure 3 and Table 1) with depth correlates with a major geological feature (shear/fault zones) of the study region, which may be attributed to the occurrence of Archaean Supracrustals (Drury et al., 1984).

A clear separation of eastern and western regions of the study area is observed at depth (DRS02) by relatively low resistivity in third layer onwards (Table 1 & Figure 3). Considering that the Chitradurga schist belt occurs along the shear zone (CSz) in the Archaean host rock, the contrast can be explained by the Archaean rocks possessing a relatively higher resistivity than the schistose rocks. However, it is possible to visualize resistivity distinction from a depth of 1000 m and below from 5th layer (Table 1), as evidenced from the basement resistivity. Gravity model along Kavali –Udipi profile (Singh et al., 2004; Mishra, 2011) also shows a high-density steeply inclined ridge like body under the Closepet Granite. Surface projection of the western boundary, which coincides with the mylonitic shear zone at the eastern margin of the Chitradurga Schist Belt (Abhinaba Roy et al., 2008) can be inferred as the boundary between the two cratons WDC and EDC. The relatively high resistivity observed in the present study below EDC and the low below WDC is matching with the results of receiver function analysis by Kiselev et al., (2008) based on Poissions ratio which suggested, a felsic crust under the EDC and mafic crust under the WDC.

This boundary was also delineated by magnetotelluric investigations as a deep vertical divide between the two Dharwar cratons (Gokaran et al., 1998a), across which there

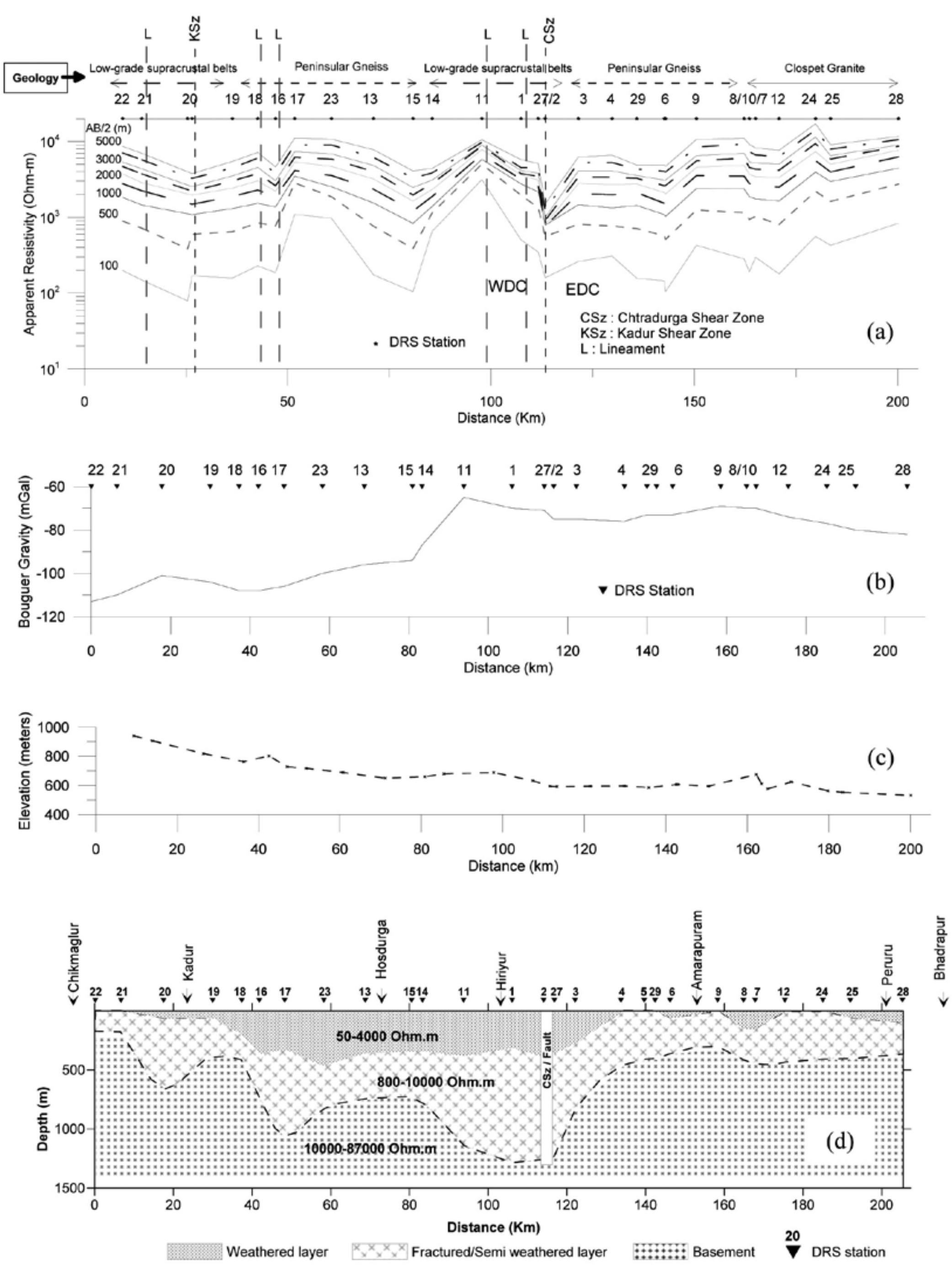

Figure 3. Along the SW-NE profile in Dharwar craton (a) Observed Resistivity at different electrode spacing (b) Bouguer Gravity data (GMSI, 2006) (c) Elevation (d) Geo-electrical section based on 1D models.

are appreciable conductivity changes. High-grade gneissic terrain of the EDC, exposed to the east of this boundary forms the basement rocks brought up to the surface through thrusting, followed by erosion (Kaila et al.,1979). The deeper layers (5th layer onwards-Table 1) also show relatively low to moderate resistivity trends compatible with NW-SE shear systems. The low resistivity observed on the west of the profile between DRS20 and DRS19 is associated with Kadur shear zone (KSz). This zone is similar to the low resistivity zone (comprising DRS01, 02 and 03) in the center of the profile within the CSz system. The structural trends in the shear system follows NW-SE (Figure 1), in contrast with the general N-S and NE-SW trending structural fabric observed in other regions of South India (Roy et al., 2008).

The observed resistivity plot along the profile at different electrode spacings (AB/2= 100, 500, 1000, 1500, 2000, 2500, 3000, 4000 and 5000 m) is shown in Figure 3(a). This plot clearly indicates a sharp decrease in resistivity near CSz and KSz and comparatively high resistivity in east of CSz than the west. The bouguer gravity anomaly along the profile (Gravity Map Series of India (GMSI), 2006) is shown in Figure 3(b). The data clearly indicates gravity rise from about -110 mGal in the west to -80 mGal on the east. Over this deep crustal feature relatively shallow crustal lithological, structural features like the schist belts, lineaments and younger basic and acidic intrusives are pronounced, which have correspondence in the electrical resistivity profiles and the depth section shown in Figure 3. The boundary between the WDC and EDC is clearly visible in the gravity as is noticeable in the electrical signatures also. Subrahmanyam and Verma (1982) reported higher density values for schists and hence the relative gravity high on the Chitradurga schist belt.

The bedrock topography is clearly brought out by the geo-electrical section (Figure 3d) obtained from 1D inversion of DRS data along the profile up to a depth of 1500 m across the Dharwar craton. In general, the low resistivity zones are observed at varying depths in the middle part of the profile. In the south western part of profile up to 35 km (between DRS 22 and 18) a thin top weathered layer is observed, whereas the same layer is thicker further between DRS18 and 03. Further from DRS03 onwards the top weathered zone is very thin except near DRS08, 07 and 28. Another deep low resistivity feature is observed on this profile between DRS16 and 23. The resistivity transition observed at the eastern boundary of the CSz coincides with Chitradurga boundary fault at a distance of about 115-120 km on the profile. The resistivity signatures derived from the wide band MT investigations in the Dharwar craton also indicated low resistive features pertinent to the shear zones and major faults (Gokarn et al., 1998b). The near- surface conductive (low resistive) zone matches with the features in the vicinity of faults and in CSz as reported by Chardon et al., 2008. 2D models of deep crustal layers are reported with resistivity in the order of 5000 Ωm and 100 kΩm for the Pan-African and Archaean terrains, respectively (Singh and Jimmy, 2006).

CONCLUSIONS

The sub-surface resistivity variations from the present DRS study associated with the major shear system of the Chitradurga and its environs in the DC, revealed possible extensions of shear zone to a depth of 1300 m, while the resistivity variations observed up to 100 m for the overlying layers reflect the nature of surficial weathering, basement fractures, shallow groundwater movements, etc. The geo-electrical signatures are clearly distinguishing the WDC and EDC by relative low and high resistivity from the west to east along the profile. There is recognizable correspondence between the electrical resistivity derived depth section and the shallower gravity variations in revealing the effects of supra-crustal lithologic units and structures and also the marked difference between EDC and WDC.

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Compliance with Ethical Standards

The authors declare that they have no conflict of interest and adhere to copyright norms.

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