Research Paper

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Structural Appraisal of the Gravity Map of Dharwar Craton, India Through Gradient Techniques

Geography

KEYWORDS : Dharwar Craton, Faults, Vertical derivative, Tilt derivative, Synclines and Anticlines.

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ABSTRACT

An attempt has been made to understand the complex nature of the new Bouguer gravity anomalies over Dharwar Craton in relation between geology, structure and tectonics in the study region bounded between 73° 30' E -78° 30' E Longitudes and 12° N-17° N Latitudes. Disposition of Schist belts, Younger Granites and Various Faults (f1-f12) and other gravity lineaments, (9-Gravity Highs (H1-H9), 7 Gravity lows (L1-L7)) were delineated. These signatures are also observed in vertical and tilt derivative maps. The structures are identified for the Dharwar formations are alternating bands of Synclines and Anticlines with dense greenstone rocks, and separated by anticlinal ridges of low density younger granites. These findings are significant in view of the paucity structural data in the Dharwar Craton and form a Geostructural data base.

1.0. Introduction :-

The Archean-Protozoic Dharwar Craton in the Pre-Cambrian Indian peninsular shield extended over 400,000 Km^2 lies between the longitude 73°30 E' to 78° 30' E and latitude 12° N to 17°N (Ramman and Murthy, 1997; Dhevaraj et al., 2009). It is characterized by a complex geological history while the southern and central parts of the Craton are well investigated, the northern part received relatively lesser attention though the Dharwar Craton has being attracting the attention of geoscientist for several years now.

Geologically the Dharwar Craton well documented (Naqvi & Rogers, 1987; Rajamani, 1990; Chadwick et al., 2000). Earlier geophysical studies in the region include gravity (Subrahmanyam, 1978; Hari Narain and Subrahmanyam, 1986; Krishnabrahman, 1993; Mishra and Rao, 1993; Magsat (Mishra and Venkatarayduu, 1985). Gravity and Magnetic (Qureshy et al., 1967; Kaila & Bhatia, 1981; Babu , 2001; Mishra & Prajapati, 2003), deep seismic soundings (DSS) (Kaila et al., 1979; Reddy et al., 2000), Aeromagnetic Reddy et al.(1988) and tomographic (Srinagesh & Rai, 1996; Gupta, 2003), Magneto- telluric (Gokarn et al., 1998, 2004), Petrophysical and crustal configuration (Ramadass et al., 2002, 2006), and heat flow (Gupta, 1982) investigations. They gave an indication of variation in the crustal thickness and suggested the operation of vertical tectonics in the region. However, most studies so far have consisted of large area (small-scale) investigations directed towards regional appraisal.

The tectonic framework of south Indian shield region (SISR) has been studied by various geological and geophysical methods and reviewed by various workers (e.g. Mishra, 2011; Drury and Holt, 1980; Drury et al., 1984; Radhakrishnan, 2003; Santosh et al., 2003, 2005). Here, an attempt has been made combining the all available gravity data sets for consensus on the configuration of the craton emphasis the need for investigations oriented towards understanding the tectonics and structure in the Dharawa craton. With this in mind the Jadcherala-Goa and Udipi transect and 2D gravity data sets in the dharwar craton has been integrated.

2.0.Geological setup of the Dharwar Craton :-

In Indian scenario, Peninsular India is a Mosaic of pre-Cambrian continental crust shown variety of geological features manufactured at different times by different geotectonic processes, exhibits low to high grade crystal in rocks, surrounded by mobile belts with varied lithologes, tectonic styles and evolutionary history that have been brought into juxta position and sutured together during different epochs.

The study area up to 17°N Latitude the total area is 25,000 Km^2 lies in Dharwar craton. The Dharwar craton originally named as Pichamuthu (1962) has gained wide acceptance. The Dharwar craton occupies an area of 400,000 Sq Km lying between the longitude 73°30 E' to 78° 30' E and latitude 12° N to 17°N (Devaraj et al., 2009) is bounded by Arabian sea to the west of the middle proterozoic mobile belt (MPMB) to the east and south. The study area up to 17°N latitude is composed mainly of the Dharwar Craton and a part of the Bastar Craton separated by the Godavary Gondwana graben. Toward the east of the Dharwar and Bastar Cratons is the Eastern ghat mobile belt, the junction between them being the sileru shear zone. South of the Dharwar Craton is the Southern Granulite Terrain (SGT). Fig. 1 gives the generalized geology and tectonic map of the study region redrawn from Ramakrishnan and Vaidyanadan (2008), GSI (2001, 2010); Sentil Kumar et al., (2007) (Fig 1).

The difference in regional facies in terms of lithology, volcanic-sedimentary environment, metamorphism, and magmatism suggest a possible division of the Dharwar Craton into a Western Dharwar Craton (WDC) and Eastern Dharwar Craton (EDC) separated by the Closepet Granite (Vishwanath and Ramakrishna, 1976; Swaminath and Ramakrishna, 1981; Naqvi and Rogers, 1987; However, Chadwick et al.(1996) suggested the eastern high temperature metamorphic terrain). Based on differences in the Metomaphic phases of the schist belt, their inter relationship with the surrounding gneisses and granites and limited. Geochronological data and distinct crustal evolution patterns (Swaminath et al. 1976; Chadwick et al. 2000; Vaidyanadhan and Ramakrishnan, 2010). The Dharwar Craton it is sub-divided into Western Dharwar Craton and Eastern Dharwar Craton (WDC and EDC). It is debated whether the Chitradurga boundary shear (Swami Nath and Ramakrishna, 1981; Anand and Rajaram, 2002; Gokarn et al., 2004) are the closepet granite is the divided between the western and eastern Dharwar cratons (Ramakrishnan and Vaidyanadhan, 2008).

The geological map of Dharwar craton shown in Fig.1 A major part of the exposed Western Dharwar Craton (WDC) is occupied by largely unclassified gneissic granitoids termed as 'older gneissic complex (Radhakrishnan and Vaidyanadhan. 1997; Dey, 2013).

The Western Dharwar Craton (WDC) contains two types of supra crustal groups of the WDC, the oldest recognized Sargur group occurs as widely dispersed enclaves within the gneisses where as the younger supra crustals (3 to 2.5 Ga old i.e. essentially late Achaean) of the Dharwar supergroup, namely the Bababudhan, Shimoga and Chitradurga groups, occur as large belts comparable to proterozoic basins and geosynclines.

The Dharwar type of schist belts on the other hand occur in the older peninsular gneisses complex, west of the Chitradurga thrust fault and ranging in age from 2900-2600Ma, are younger than their eastern counterparts. Bruce Foote (1886) first gave the name 'Dharwar' to this highly altered crystalline schist. These belts have a large sedimentary component with considerable development of quartzite, argillaceous and carbonate sediments that rest unconformably on the older gneissic basement (Chadwick et al., 1991, 1992; Nutman et al., 1996 and Kumar et al., 1996) are recognized as a super group. The intrusion of the younger Chitradurga granite around 2600 Ma has set an upper limit to sedimentation in the Chitradhurga basin.

Thus the stratigraphic succession of the Dharwar supergroup has two main divisions the older mainly igneous, Bababudan group that hosts the main iron formation and the overlying 'Chitradurga Group' of schistose rocks, that are largely sedimentary in character, composed of conglomerates, quartzites, Limestones, greywackes and associated manganitferrous cherts. The Older Gneissic Complex (OGC) and Younger Genissic Complex (YGC) are sheared along the Chitradurga boundary thrust (CT). Similarly the Dharwar schist belt is shears with the OGC along the Bababudhan Nellur (BN) shear.

The southern part of the Western Dharwar Craton (WDC) contains a number of metamophished ultramafic bodies, many of which form large intrusive complexes. The Eastern Dharwar Craton (EDC) composed of a linear N-S to NNW trending belts of Neoarchean (3.3-3.0 Ga) gneissic rocks (younger gneissic complex) and granites interleaved with narrow ~2.7 Ga, greenstone belts (Chadwick et al., 2000; Jayananda et al., 2000; Vaidyanadan and Ramakrishnan, 2008). The major type granites suite is closepet granite. These greenstone belts, termed as Kolar type schist belt are mostly made up of green schist to Ambhibolite facies, meta-basalts with Komatites, felsic volcanic and meta sediments like iron formations, greywackes and pelites (Vaidyanadan and Ramakrishnan, 2010). The granitoid rocks of the eastern Dharwar craton are predominantly quartz, monozodiorite to granodiorite in composition with minor granites that are younger than the former. They have major and trace element and Sr and Nd isotope characteristics consistent with their derivation from either mantle or short lived mafic sources (Balakrishnan and Rajamani, 1987; Krogstad et al., 1989, 1995, Peucat et al., 1990). These granitoid rocks surrounding the greenstone belts are not genetically related to the amplibolites of the belt. The available age information indicates that they are all juvenile additions to the continental crust during the 2650-2500 Ma periods (Chadwick et al., 2000), grouped the entire plutonic complex under the term 'Dharwar Batholith' due to the close lithological similarity, structural coherence and emplacement of imperative lithologies between 2700 Ma and 2500 Ma.

An interesting feature observed in the schist belts of the Dharwar craton is that they are generally associated with shear zones. All the eastern schist belts except for the Kustagi belt have shear zones on their western side and the western schist belts have shear zones on their eastern sides. Most Eastern Dharwar Craton (EDC) schist (Green Stone) belt have sheared intrusive contact with syntectonic Neo-Archaean plates are dominated by volcanic rocks and BIF (Jayahanada et al., 2013). These zones have considerable width and depth extents and mark the boundaries of the schist belts within which a thick series of volcanic rocks/sediments were deposited (Chadwick et al., 1985 a & b, 1991 &1992).

The crescent shaped proterozoic Cuddapah basin consists of highly metamorphosed sediments while the Godavari graben forming the northern limit of the Dharwar Craton comprises Gondwana Sediments high grade granulite rocks of Karimnagar (Rajesham et al., 1993) and Bhopalpatnam are reported along the shoulders of the Godavari graben (Anand and Rajaram, 2003). The eastern ghat mobile belt toward the east of the Dharwar craton, is a granulite terrain composed mainly of Charnockites, khondalite, quartzite, calc-granulite, pyroxene granulite and lethynites (Ramakrishnan et al., 1998) trends in NE -SW trend EGMB is separated from the Dharwar, Bastar Cratons by the Sileru shear zone (Chetty and Murthy, 1994).

3.0.Gravity Data Base :-

New gravity data was collected along > 600 Km from Panaji to Jedcherla transect and 941 gravity observations were acquired with a station interval of 1 Km with a Lacoste-Romberg (Model-G-940) gravimeter with an accuracy of 0.1 mGal. In order to minimize the error due to drift in the instruments, secondary bases were established all along the profile, which were tied to the Muddanuru base (Qureshy and Krishna Brahmam, 1969). As the gravity value for the Raichur Railway station calibrated according to the ISGSN-71 System (Morelli et al., 1974; Krishna Brahmam, 1993 and Chapin, 1996) is 978,270.05 mGals, the values obtained for the sixteen base stations the along the transect with respect to the old value of 978,285.02 gravity values of all the new base station, were reduced by 14.97 mGals to bring them into the ISGSN network. After all corrections applied to data and it was concentrated in filling the gap and merging new observations with existing data from NGRI (Singh et al., 2003, 2004) and GSI (Keshawamani, 1996, 1999; Appa Rao, 1995) and CEG (Ramdass et al., 2003, 2006). In fact, a further increase in the density and accuracy of observations might provide more information about the structure of the Craton**.**

4.0.Qualitative analysis of the gravity map of the Dharwar Craton :-

The Part of the Bouguer gravity map of India Shield (Singh et al., 2003,2004; Keshawamani, 1996, 1999; Appa Rao, 1995; Ramdass et al., 2003, 2006; Mishra, 2011), on 1:100,000 scale is presented in Fig 2, between longitude 73°30 E' to 78° 30' E and latitude 12° N to 17°N. Interpretation of the Bouguer gravity data of South India correlating all the geologically provinces has been carried out by many workers, in particular Subrahmanyam (1978). In this paper an attempt is made to discuss the salient structural features (gravity lineaments) inferred from the Bouguer gravity map. To retain the clarity of the map, only a few lineaments trending NW-SE, NE-SW, near E-W and N-S were shown (Fig. 2, 3 & 4) indicating mega faults (F2 to F3) and minor faults f1 to f12, have been identified. Steep gradients of gravity with isolated flexures are indicative of the possible faults. Several flexures with different gradients are located near Panjim, and Magalore on the west coast, while only two broad flexures south and north of Madras corresponding to the Cauvery basin and Cuddapah thrust zone f3 and f5 respectively

Over the Dharwar craton, the gravity anomaly varies from a maximum value of – 20 mGals in the south western part to a minimum value of -130 mGals in the around the Hassan. Prominent gravity highs and lows are traced as H1 to H9 and lows L1 to L7.

The south western margin of the Craton is characterized by a sharp gradient (marked F1) in Fig.2 of gravity, which separate the H1 and H2 gravity high zones with a f2 fault, gravity H2 is falling western boundary tending NW-SE direction. The Dharwars and the Charnokites are separated by F1 deep seated fault and SGT is continuous with the Dharwar greenstone terrain further north, forming a single crustal block which may be called the Dharwar Crustal Block (Radhakrishnan and Naqvi, 1986). South of F1 has not yet been well defined, both the two provinces appear to be related by a continual progression in metamorphic grade, also exhibit considerable variation over the charnokites (Subramanyam, 1986) is continues westwards into the Arabian sea.

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The entire west coast particularly between Mangalore and Cannaore with gravity H2 high looking at the short wavelength nature of inferred coastal anomalies the gravity highs is attributed to the emplacement of high density ultrabasic rocks at shallow depths (Subramanyam and Verma 1986; Kirshnabrahmama, 1993). Contrary to which Mishra and Rao (1993) attributed to the coastal gravity highs to deep faults along which Moho up warped along the west coast.

The gravity low L1 is located in south of Bangalore the maximum response of bouguer anomaly is -110 mGal and trends in EW direction. The gravity Low L2 over the Shimoga basin were thought to be due to presence of low density material beneath the basin. This is the largest part that covers in the western part of Deccan craton. It extends in a north –northwesterly direction for a length of 250 km and has a maximum width of 120 km at Dharwar, bounded by deep seated Fault F2 trends in EW direction. The extension of the basin further north and west is obscured by the cover of Deccan Traps and the Arabian sea. The western margin of the basin is marked by large domal masses of basement gneiss which occur in the form of islands surrounded by platformal sediments and volcanics. The eastern margin is faulted Bababudan-Nallur Fault (BN).

The absence of significant positive anomalies within the schist belt may be attributed to its relatively small thickness under a major portion of its outcrop, except near areas of anomalies moderate highs, where the schists probably attain considerable thickness. Further south, a pronounced negative anomaly, delineated by gravity lows is observed. This is an almost circular feature with tounge-like projections towards the north, on either side of Shimoga might be a thickest accumulations of partly sub aerial mafic volcanic are centered round Bababudan and Kudremukh.The anomaly has a large areal extent covering several thousand square kilometers.

A significant gravity low (Fig.2) of -110 mGal centered above Londa near Kharwar is either a granitic body at depth whose cupolas are exposed around Londa and also at Marmugoa,or thickening of the crust, or a combination of both (Krishna Brahmam, 1993).

In the northern part of the belt, a prominent oval- shaped negative anomaly (L4) demarcated by -115 mGal closure near Belgaum may be noticed. This anomaly is directly attributable to a granite body intruding the greenstone belt but outcropping over a limited area. The magnitude of this gravity low is about 25-30 mGal below the background level. The extension of contours beyond the outcrop of the granite over the schistose rocks clearly indicates its subsurface extension under a thin cover of high-density schist. The gravity contours show a tendency to continue southward and merge with the northerly extension of gravity low L7, there by suggesting the southerly continuation of the granite body giving rise to L2.

This H6 gravity zone is falling in the Chitradurga -Gadag schist belt zone, situated to the north-east of the Shimoga belt. It has a linear extent of more than 300 km. The belt is quite narrow, just about 50 km wide and elongated accurately in a almost N-S direction (Subramanyam and Verma, 1982). On Bouguer gravity map (Fig. 2) has brought out the Chitradurga fold closures is very well expressed as a positive axis flanked on either side by a gravity low. The gravity low may be suggest that the schistose formations have relatively shallow depth continuity within in the gneissic basement. Interestingly, the younger Chitradurga granite forming the core of Chitradurga closures is characterized by a gravity low. The region has an overall Bouguer gravity relief of approximately 40 mGal with Bouguer amplitudes increasing from -100 mGals to -60 mGals .This distinct feature of this map is the elongated, slightly arcuate, N-S trending high zone (H6) that corresponds to the Gadag Schist. Further, the fault F2 is abutting the gravity high.

The eastern margin is a thrust Fault (CT) marked (Fig 2, 3, & 4), whose marked by a strong mylonite zone, Schist belt primarily consist of mafic and ultramafic rocks with meta sediments (Greywacke, Conglramerate and banded iron formations) and granite intrusive (Mishra, 2011) along margins of Chitradurga schist belt (CT).They usually show gravity highs and lows related to mafic and felsic intrusive and crustal thickening. Auriferous shear zones are also present in this belt

The closepet batholiths, earlier believed to be the boundary between the eastern and western Dharwar Craton is represented by a fall in Bouguer gravity from -80 to 95 mGal. Over the closepet granite a general increase in values is observed towards west with different gradients. However, at the eastern contact, a few gravity low closures indicating the low density granite intrusive have been brought out. The long wave length gravity high H4 may be correlated to deep seated structural high with a number of mafic inclusions. Gravity highs encountered in to regions where greenstone belts are absent can reasonably be attributed to high density intrusives and/or thinning of the crust. On the other hand, gravity lows are normally due to granitic intrusions and/or thickening of the crust

The Closepet granite forms a long linear belt of younger Pottassic granites extending over a length of nearly 500 km. However, between the latitudes 13° and 14.5° N it is flanked on its west by gravity high, whose axis closely follows the trend of the Closepet granite (Fig. 2). South of 13° latitude it is flanked on its east by abroad star shaped gravity low.

H7 is faulted along the west coast northern part of the study area. This high probably due to rise in the moho towards the west coast. Krishna Brahmam et al. (1993) argued this high is most probably due to emplacement of high density ultrabasic rocks at comparatively shallow depths.

The gravity high flanking the western side of the Closepet granite (north of 13° latitude) is cause by emplacement of heavier material probably along a zone of weakness related to the major geo-suture suggested by Swami Nath et al.(1976) which demarcates the grarrnite-greenstone terain into two distinct blocks. From western part of the Closepet granite and uplifted crustal block have been emplaced.

The Kusthagi schist belt has small gravity high (H4) with Bouguer gravity values ranging from -95 mGals to-83 mGals. The younger granite intrusions separating Kusthagi and Sindhanur schist belts contribute to significant anomalies of about 4 mGals in Bouguer gravity. The eastern part of Sindanur schsit belt reflected as a prominent gravity high zone , values increases from -91mGals to 66 mGals., trending WNW-ESE, with two closures of echelon pattern, lying south of Bellary.

The Sindhanur, Hutti maski and Kusthagi schsit are bounded by the Peninisual Gneiss (PG) in the east and west. Geologically these belts clearly delineated the schist-granite boundary and confirming the faulted nature and intense folding at the contacts and dominated by the presence of meta basalts and meta sediments. The Deccan traps and Kaldgi sediments cover the N-W extension of the Kustagi belt.

Penukonda-Ramagiri-penakacherla Schist belt (H4) is traced as narrow zone indicated by steep gradients from Gudibanda in south, forming the eastern margin of the gravity high zone (H4) at Hindupur. A significant gravity high zone with two closures, one west of Penukonda and the other east of Ramgiri forming the Penukonda-Ramgiribelt and juxtaposed by prominent lows has been identified. Further north, the belt splits into two branches. The western branch is brought out as steep gradients from Ramagiri to north of Atmakuru and then appears to merge

with the eastern margin of gravity high zone of Sandur schist belt up to south of Vidapanakallu exhibiting gravity high zone,

Prominent among the gravity anomalies corresponding to the E-W trends is a gravity 'high'(H4) encompassed by the -80 mGal contour located north of Bangalore, enclosing the Veligallu, Kolar-Kadari, Ramgiri and Chitradurga greenstone belts, cutting across the closepet granites (Fig. 2). This anomaly zone is identical with that of the Kapuskasing gravity high, Superior Province, Ontario, that cuts across the regional structural trends, which has been interpreted as an ancient rift system (Innes & Gibb, 1967). This zone appears to be a major fold, trending NW-SE to E-W with an abrupt change in the trend along the closepet granite axis, possibly indicating a fault. It is not unlikely that the -80 m gal contour broadly defines the folded pattern of the entire greenstone-granite terrain from south to the flexure observed near Bombay under Deccan Trap cover. The revised stratigraphy of the Chitradurga and Kolar greenstone belts (Ramakrishnan, 1990) shows that in the basal parts, the Sakarsanahalli Formation of the Kolar belt are recognized as equivalents of vanivilas Formaion of Chitradurga and the remaining succession of Kolar is equivalent to Ingaldhal Volcanics. This broadly suggests that the arcuate gravity high represents a fold thrust zone.

The Kolar schist belt is brought out a prominent gravity high (H3) zone near Srinivasapur, the kadiri belt is representing a feeble high zone, superimposed on N-S gravity gradients ,extending from Kandakur in the south to the Pranap in the north with isolated high (Kesawamani, 1996) near mudigubba and Dorigal. It then joins the western margin of Cuddapah Basin in between Kolar and Kadri belts, a moderate gravity highs zone.

The Raichur and Gadwal shcist belt, a high density granodiorites exposures and a couple of younger granite intrusion, characterized by mafic and felsic rocks and is intruded by granites anmdgranitoids at places indicated by a gravity highs of about 4 mGals.

The contact of PGC with Cuddapah basin is brought out as an arcuate steep gradients with increasing values towards east in the basin, with a prominent gravity low zone (L3) in the form of low closures all along the margin due to the presence of younger granites and basal quartzites of Cuddaphas .The highs and lows alternate and extend up to the margin of the Cuddapah basin in the east. The western part of the Proterozoic Cuddapah basin shows relative gravity high of -60 mGal (H5).

The gravity H8 is falling NE part of the study area, Madhunnar, Mahabhubnagar having an gravity anomaly of 40 mGal and is characterized by Kimberlite emplacement.

A prominent regional gravity lows, one L7 oriented along NW-SE direction. From Pune-Koyna- to Kurudwadi, known as Koyna low and the other L5 is trending N-S from Pune to north of Sholapur, these two lows are meeting at north of Pune. These two gravity lows are falling in between F3 and f12 faults. There is a steep gradient in the Bouguer gravity anomaly near the west coast. The origin and characteristics of these large gravity lows (Harinarayana et al., 2007) and highs have been a matter of debate. The steep gravity gradient anomaly from west to east coast (3-4 mgal/km) has been interpreted as due to deep seated faults (F3 & f12), these faults are believed to be the cause for the western Ghats scarp. From the Bouguer gravity contour map, a gravity highs (H9) is falling under kurudwadi rift zone. These features have been interpreted as zones of marked subsidence and uplifts of deep seated nature. The gravity high (H9) suggest (Pathro & Sharma, 2007) a domal structure near Nasik, called the Nasik dome which is consider to be a primary volcanic structure related to volcanic shield.

A NW-SE trending lineament, kurudwadi lineament enters Deccan traps near Gulbarga passing through kurudwadi and extends to north of Mumbai. Structural distributions at deep crustal depths are speculated along this lineament from satellite imageries and its field verification.

5.0.Derivatives of Bouguer Anomaly:-

Gravity data are often useful in defining the lateral extent of geological bodies such as plateaus and sediment filled valleys. For near surface bodies with near vertical contacts the maxi/min. Gradients of the observed anomalies help in estimating the depth of the source body and the location and dip of its edges.

Vertical derivatives are a measure of the difference in gravity value at a point relative to its values at neighbouring point. The Z-gradient is thus a measured of the change in the gravity field with depth. Derivative maps are based on the concept that the rate of change of gravity with elevation is much more sensitive to changes in rock densities near the ground surface than at depth. Therefore such maps are a useful technique for demarcation of geological boundaries details of which are observed in the original map.

In general, the tilt derivative enhances the high frequencies relative to low frequencies and eliminates the long wave length regional component and effectively resolves the adjacent anomalies. Millar and Singh (1994) introduced the tilt angle method for one dimensional magnetic data and Veroduzco et al., (2004) extended it to two dimensional gridded data. Oruc and Keskinsezer (2008) proved that tilt angle technique is applicable to map the linear geological features from gravity gradient data. Oruc (2010) introduced the new edge detection technique based on the first vertical gradient of gravity anomaly. Tilt angle is the ratio of the vertical derivative to the absolute amplitude of the total horizontal derivative. Also, it produces positive and zero values over as well as edge of the source region respectively whereas, negative values outside the source region. The mathematical expression of tilt angle is given by

Tilt Derivative (TDR) =$\tan^{-1}$ (VDR/THDR)

Where,

VDR is vertical derivative [dT/dz]

THDR is total horizontal derivative [sqrt $((dT/dx)^2 + (dt/dy)^2]$

T is the gravity field

The vertical gradient (Fig. 3) and tilt derivative (Fig. 4) maps are seams conjunction with bouguer gravity map. The correlation between gravity trends, vertical gradient, tilt derivative and structure of the Dharwar Craton (Fig. 5) are brought out both the general trends as well as geology of the formations.

There are H1 to H9 gravity high trends are observed that that the axis of positive anomalies, these are associated with synclinal schist belts filled with high density rocks (Greenstones). The negative axis (gravity lows) on the other hand L1 to L7 characterized the anticlinal structures. In the present study apart from this three major faults F1 to F3 and minor faults f1 to f12, Bababuden-Nallur Shera (BN), Chitradurga trust (CT), Closepet Granite (CGG) observed signatures in all the derivative maps and bouguer maps. The identified small faults in the Dharwar craton essentially represent contact between the supra crustals, schist and younger granites in the region.

6.0.Summary of the Gravity Interpretation :-

New gravity investigations were carried out between the 73° 30' E -78° 30' E Longitudes and 12° N-17°N Latitudes in the Dharawar craton from qualitative analysis (Bouguer gravity, Vertical derivative and tilt derivative) several faults/lineaments are determined

The gravity over the Dharwar Craton has range of -20 mGal to -130 mGal near Hassan it is characterized by conspicuous highs and lows alternating and trending NE-SE direction. The gravity high (positive) in most cases are invariably with greenstone belts, while gravity lows (negative) optional occur over granite outcrops and younger granites. The Dharwar, Shimgoa, BN belts is a wider and shallower basin; it is representing in Bouguer anomaly, vertical and tilt derivative chitrdurga, Sandur, betls, Hutti-Maski Raichur deep troughs established by gravity highs.

Further, north of the study area DVP also brought out the structural configuration of the region. Broadly all lineaments appear to follow the preferred direction NW-SE, NS and NE-SW, the major structural features over the NW-SE Western Ghats (F3) and Kurdwar low (L7) was identified.

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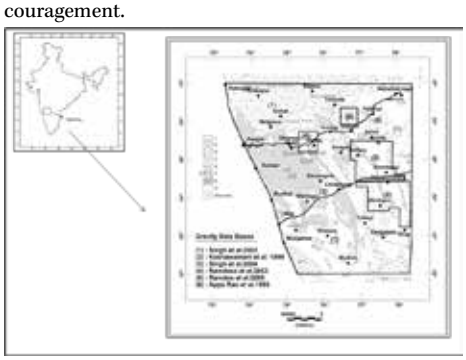

Figure 1. The geological map of southern India showing the location of Dharwar Craton. The rock types: (a) gneisses, (b) schist belt rocks, (c and d) medium to high-grade metamorphic rocks, most of them are granulites, (e) granites, (f) alkaline rocks, mostly of syenites, (g) Proterozoic sedimentary rocks, (h) Deccan basalts, and (i) alluvial sediments (after Ramakrishanan and Vaidyanadan, 2008; GSI, 2001, 2010; Senthil Kumar et al., 2007).

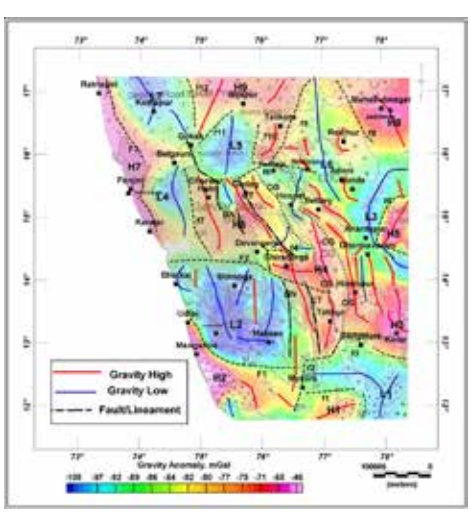

Figure 2. Bouguer Gravity Anomaly image of the Dharwar Craton between longitude 73°30'E to 78° 30' E and latitude 12° N to 17° N (Singh et al., 2003; Singh et al., 2004; Ramdass et al., 2003; Ramdass et al., 2006; Keswamani et al., 1999; Appa Rao et al., 1995)

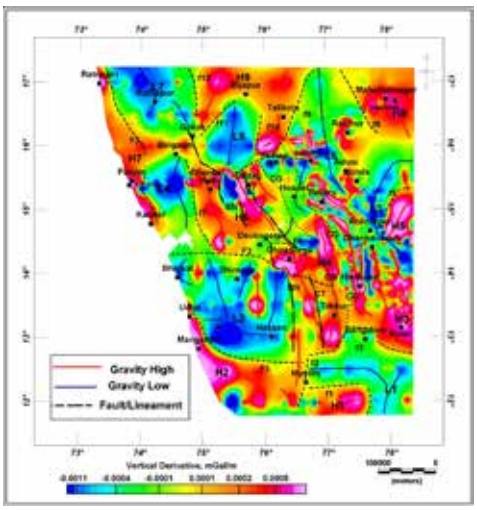

Figure 3. Vertical Derivative map of the Bouguer anomaly of Study area

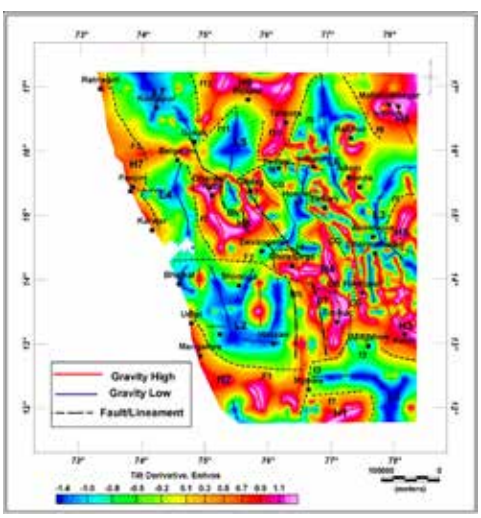

Figure 4. Tilt Derivative map of the Bouguer anomaly of Study area

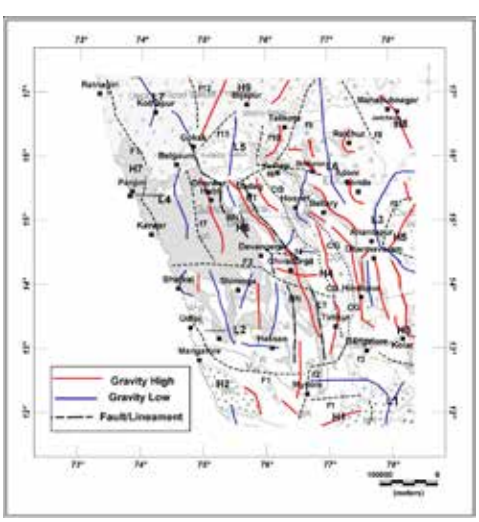

Figure 5. Structural map of the Study area

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