

Integrated Remote Sensing and Gravity based analysis of southern part of Deccan Syneclise for delineating promising areas of exploration

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Keywords:

Deccan Syneclise, Subtrappean structural architecture, Koyna Rift, Kuruwadi Rift

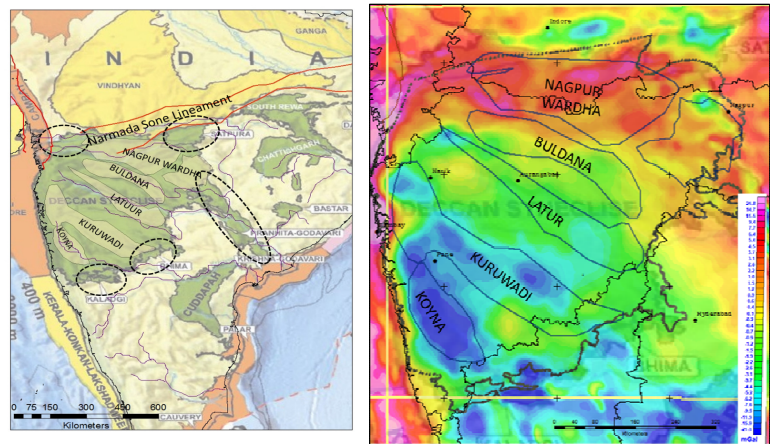
Summary

The Deccan Syneclise is assumed to host a substantial thickness of Proterozoic, Gondwana and Mesozoic sediments covered by Deccan traps. This paper is an attempt to develop a sub-trappean structural model of the southern part of Deccan Syneclise and delineate promising areas for exploration integrating gravity, magnetotelluric and remote sensing studies validated with field evidences. Results of the studies indicate NW-SE oriented Archean shear zones exposed south of Deccan Syneclise continue under the traps forming the primary structural elements in the sub-trappean basement. These undergo multiple reactivations to form a number of lows for sediment accumulation. The Kaladgi sediments are found to continue in the southern part of the Koyna Rift as scattered zones of about 2.8 km thick Proterozoic sediments that are associated with adsorbed gas anomalies. The northern part of the Koyna Rift is devoid of any sediment. Kuruwadi Rift, though forming another gravity low doesn't contain sediments. However, it is probable that the Kuruwadi- Latur gap and the Latur rift together form a fault bounded depression that hosts a thick layer of pre-trappean sediments of probable Mesozoic-Gondwana affinity. Based on gravity modelling, about 2 kms of sediment is inferred below 400-500m of trap thickness in areas around Shrirampur-Aurangabad and Ahmednagar with indications of presence of a thermogenic petroleum system in the area making it promising.

Introduction

Deccan Syneclise forms a large depression in the western and central part of the Indian plate with an area of about 273000 km² (Kumar et al., 2004). Tectonically, it is considered as an intracratonic sedimentary basin hosting a substantial thickness of Proterozoic, Gondwana and Mesozoic sediments that are covered by lava flows of the Deccan basalts of Late Cretaceous- Paleocene time. This intracratonic

depression is bounded to the north by the Narmada-Son rift whereas in south and east, it is limited by the Archean metamorphic exposures that form the basement of the Syneclise. The boundaries of the Deccan Syneclise are also characterized by exposures of a number of smaller independent basins consisting of Proterozoic-Cambrian and Gondwana sediments. These basins in an anticlockwise order, from south to north are i) Kaladgi Basin (ii) Bhima Basin (iii) Pranhita Godavari basin (iv) Satpura Basin (v) Vindhyan Basin and the (v) Narmada basin all of which are partially covered by the Deccan Traps (Fig 1a). In the perspective of gravity data implying subtrappean layout, a number of concealed grabens/ rifts have been indicated below trap. These gravity derived rifts have a general NW-SE trend supposedly containing Mesozoic to Proterozoic sediments coinciding with regions of low regional gravity anomaly (Kumar et al., 2004). These rifts from north to south are Nagpur-Wardha, Buldana, Latur, Kuruduvadi and Koyna (Fig 1b). The alignments of these rifts spatially correlate with the outcrops of the Mesozoic and Proterozoic basins exposed along the rim of the Deccan Syneclise.



1: a Map of Deccan Syneclise area with surrounding basins and grabens delineated from gravity data (Source: DGH, India) b: Rifts delineated based on regional gravity signatures

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Based on this correlation, it is premised that surface outcrops of the surrounding basins continue as subtrappean sediments below Deccan Traps in these probable rifts. Considering probability of diverse presence of subtrappean sediments in the basin, it is considered a potential area of hydrocarbon exploration and categorized as Category IV basin. Since these sediments are rift related, their disposition below the Deccan Trap is controlled by the sub-trappean structural architecture of the basement of the Deccan Syncline. Thus, analysis of sub-trappean structural architecture becomes a significant exploratory input. The present paper is an attempt to determine the sub-trappean structural architecture in the southern part of the Deccan Syncline to identify such rift related sediments.

Methodology

In the present approach, it is assumed that deep seated structures resulting from an earlier phase of tectonics and constituting the basement of the Deccan Syncline had been reactivated by a later phase of tectonics. These reactivated structures propagate upward within the trap with each phase of reactivations. Such structures reactivated by neotectonic deformations result in formation of structures in the trap top. Since, these structures are associated with a predominantly vertical component of deformation, these are imprinted on the surface especially in sensitive elements like drainage, lineaments and topographic derivatives (Fig 2) as per principles described in Mazumder et al.(2016).

Fig. 2: **a and b:** Lineaments and faults delineated from AWiFS and LANDSAT ETM+ image data **c:** Drainage based faults manifested in anomalous drainage geometries and **d)** Slope breaks (in brown) derived from DEM of the area

Other than geomorphic analyses, field based remote sensing studies help to identify structures observed directly in the outcrops like shear zones, faults and dykes that form an integral part in surface structural interpretation. Features extracted from these data sets can be considered as surface representations of small parts of subsurface faults. As such, they can be regarded as micro elements or building blocks of larger faults and hence referred as Micro-Faults or Micro-Linears and are subsequently joined based on their apparent continuity and trend to generate regional faults following law of convergence (Fig 3).

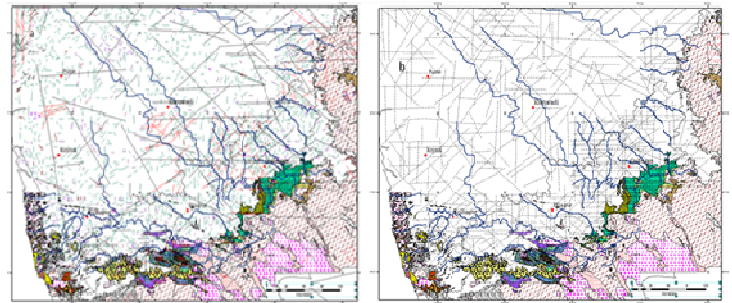
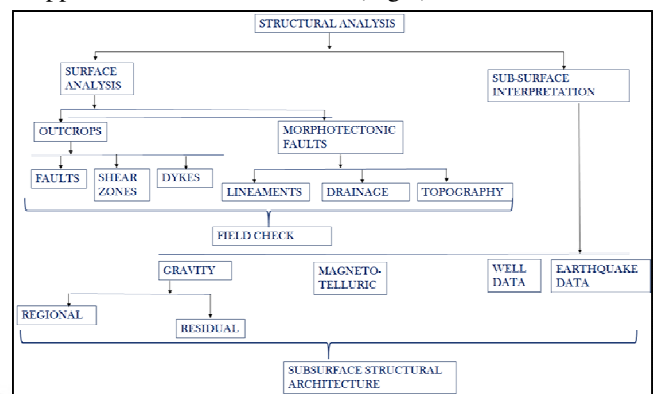
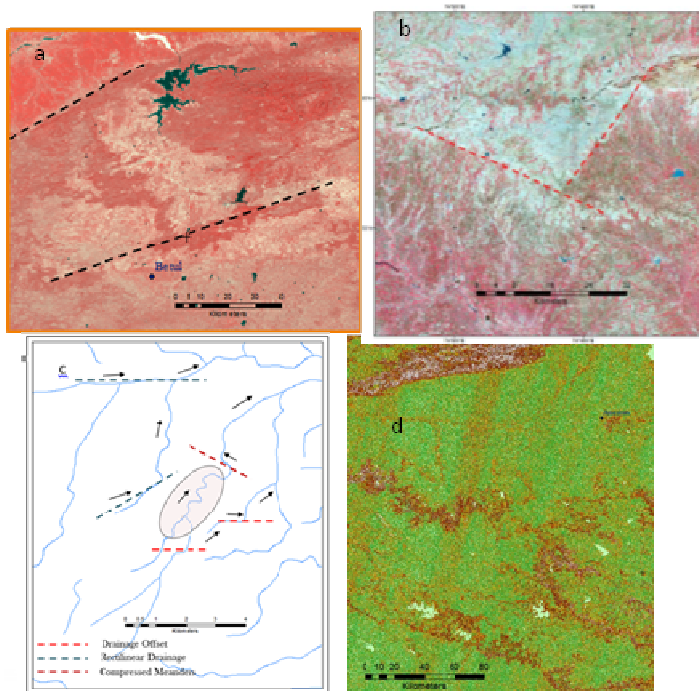


Fig. 3: **a:** Elements of surface faults derived from components like anomalous drainage geometries, lineaments, slope breaks, dykes and exposed faults in outcrops. White area indicates trap covered Deccan Syncline **b:** The elements are joined based on their apparent continuity and trend to form a morphotectonic fault network

The subsurface structural study is based on gravity and available MT data, well data and earthquake epicenter data that helps to determine subsurface structural layout in a regional scale. Both remote sensing based data and geophysical data are integrated in a GIS platform to derive a model of sub-trappean structural architecture (Fig 4).



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Fig. 4: Workflow for determining subsurface structural architecture based on integration and analysis of surface and subsurface data.

Data Analysis and Discussion

a) Dominant Subtrappean Structures

Regional gravity studies in the Deccan Syneclise indicate prominent gravity low in the Koyna and Kuruwadi areas that are separated by Sangole uplift. This implies the existence of low density material below the traps pointing to the possibility of subtrappean rifts. A correlation of the Bouguer gravity data with reconstructed surface regional faults indicate that morphotectonic features broadly correlate with regional sub-trappean features (Fig. 5a). This implies that the sub-trappean features may have continued through trap due to neotectonic reactivations and are manifested on surface as morphotectonic faults. Trend analysis of the surface reconstructed faults in the Deccan Syneclise indicates a dominant NW-SE trend along with subsidiary N-S, NE-SW and E-W trends. These NW-SE trends also appear to be the oldest since it offsets the N-S and E-W trends in outcrops of gneisses exposed in the southern boundary of the Deccan Syneclise (Fig 5b). These NW-SE trends are found to be associated with the development of Archean shear zones exposed in the area south of Deccan Syneclise (Chardon et al., 2008). These shear belts (Fig 5c) form the main tectonic "grain" of the Southern Granulite Terrain forming the primary structural elements in the sub trappean basement. These structural elements thus may act as the zones of weakness and as a result of multiple reactivations may form the grabens and horsts in the region. The high concentration of the E-W trends in the southern part of the Deccan Syneclise is probably associated with the deformations associated with the Mesoproterozoic cover rocks of the Kaladgi basin (Fig 3b). The deformational structures define a zone of E-W trending axial planar cleavages and thrusts in the south-central part of the basin and a zone of extension in the northern parts of the basin. (Mukherjee et al, 2016). GIS based correlation indicates that the shear zones are found to continue as NW-SE morphotectonic faults in the trap top along with E-W trends exposed on the Deccan Syneclise.

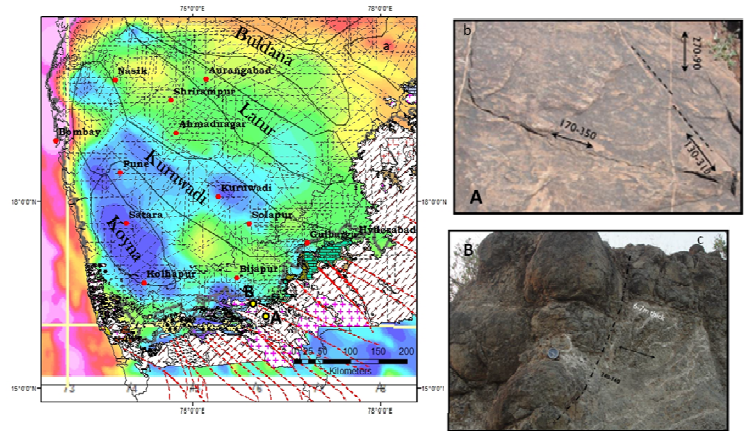


Fig. 5: Correlation of the Regional gravity features with surface morphotectonic faults. Both the gravity and morphotectonic features appear to be the continuation of NW-SE Pre-Cambrian shear zones b) NW-SE trend appears to be the oldest trend offset by a younger E-W and N-S trend in gneisses exposed in the rim of Deccan Syneclise at Pt. A c)

b) Koyna and Kuruwadi Rifts:

As per DGH, the Koyna rift and the Kuruwadi rift, about 540 km and 390 km in length respectively, appear to merge in the region north of Pune. These rifts possibly originated during the Precambrian period and were subsequently deepened and extended in length by a second phase of crustal disturbances. Deep seismic studies in the Koyna region revealed two low velocity layers in the crust, one in the upper crust and the other in the lower crust (Vasanthi and Kumar, 2016). The shallower low velocity may be due to the presence of the sedimentary formations, below the Deccan volcanics suggesting northward extension of the Kaladgi Basin far beyond the exposed outcrops. Separation of the residual lows over in scattered zones surrounding Kolhapur on northwest and south of Belgaum (Fig 6 a) also indicates the extension of Kaladgi sediments towards north-west (Mallick et al., 2012). These sediments are accommodated below a trap thickness of around 600m-800m and overlying an approximate basement at a depth of 3.6 km. These residual lows are found to correlate with surface hydrocarbon anomalies recorded by Kalpana et al., 2010 implying existence of petroleum system in these sediments making them prospective. However, further north of this region, two core boreholes drilled to depths of 1,522 and 1,196 m (KBH-1 and KBH-2) have penetrated the Deccan Traps (Fig 6) and found no sediments

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between the thick lava pile of Deccan ranging in thickness between 933 and 1,185 m and the underlying granitic basement (Gupta et al, 2015). Cores recovered have revealed flood basalt piles with lava flows, each being characterized by a vesicular and/or amygdaloidal layer which may have resulted in low gravity zones in the area (Roy et al., 2013). Magnetotelluric profile across Koyna Rift (Fig 6) also implies that the traps lie directly on a high resistive granite-gneissic basement (Sarma et al., 2004). This implies that though the southern part of the proposed rift may contain subtrappean sediments, the northern part of it appears to be devoid of any. One of the NE-SW faults may have acted as a barrier between these two parts.

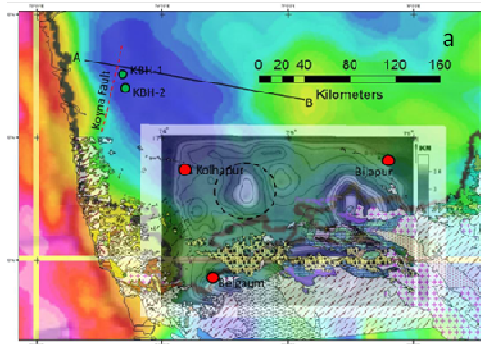


Fig. 6 Residual lows indicate extension of Kaladgi sediments NW (after Mallick et al., 2012) correlating with surface hydrocarbon anomalies making sediments in the south of Koyna Rift prospective. Positions of core holes KBH1 and KBH2 along with profile AB demarcated

Kuruwadi rift suggested along the Nasik-Kurduwadi axis forms a predominantly negative Bouguer anomaly and is postulated as a major rift. This zone is aligned in the trend of the exposures of the Bhima Group (Fig 7a), implying Bhima Group of sediments continuing below the trap as infra-trappeans. However, dip data measured in the Bhima Basin indicates that the dip of the formations varies from 2° to 5°(Fig 7b) (horizontal to sub-horizontal). As such the Bhima Group of sediments may not be continuing below the enormous thickness of traps to such an enormous distance. Magnetotelluric studies carried out across the Kuruwadi rift (Fig 7c) indicate that the Deccan basalts in this area are observed to be about 500 m thick directly overlying the granitic crust.

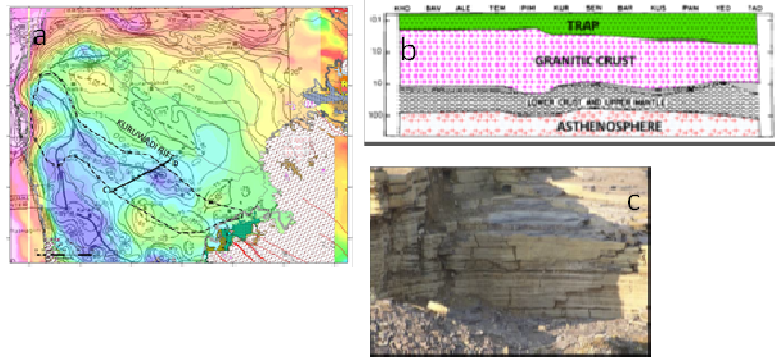


Fig. 7a) Kuruwadi rift based on gravity data found aligned along outcrops of Bhima group of sediments b)MT data along profile CD across Kuruwadi rift indicates Deccan Trap directly overlying granitic basement (after Gokarn et al., 1992) c) Field based measurements of formations in Bhima group indicate that the dip amount varies from 2° to 5°

c) Area North of Kuruwadi Rift

In the area north and west of the Kuruwadi rift, MT data shows an area of high trap thickness in a NW-SE trend (Fig 8a) aligned between the earlier premised Kuruwadi and Latur rift (Patro and Sarma, 2007). The same area is found to show an anomalous tonal signature in the AWiFS data, which probably is a manifestation of some structural variation in the area (Fig 8b). This area when correlated with geochemical adsorbed gas anomaly shows higher signature of C2+ (Rasheed et al, 2012) aligned along the trend (Fig 8c). The C2+ signature in geochemical data indicates the presence of a thermogenic petroleum system in the area. Intensity of the C2+ signature is found to increase further north-west ward indicating that the thickness of sediments may increase in that direction. Integrated together, these observations point out to the probability of a rift system underlying this area, hosting sediments thick enough to generate hydrocarbons that is deepening westwards. This NW-SE trending zone extends from Gulbarga in the east to Dahanu in the coastal tract in the west. Remote sensing based studies indicate that all along this zone, a dominant NW-SE lineament pattern could be recognized. Field studies have established that most of the interpreted lineaments along this sector represent regional fracture zones which can be traced

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across distances of more than 20 - 30 km. Magneto-telluric profiles along Sangole to Partur also indicate thin patches (300 m) of pre-trappean sediments (Fig 8d) occurring as conductive layers (approx 10–20 ohm-m) in the region between SP34 and SP37 that correspond to the southern part of the area (Patro and Sarma, 2007). This thickness of sediments might increase in areas underlying higher intensity of geochemical signatures further NW. Harinarayana et al., 2007 had also analysed two basement faults from the magneto-telluric signatures implying a deep seated rift like feature in this area which may house these probable sediments. One of the NE-SW basement trends may be instrumental in this case to cause a variation of thickness across the proposed rift.

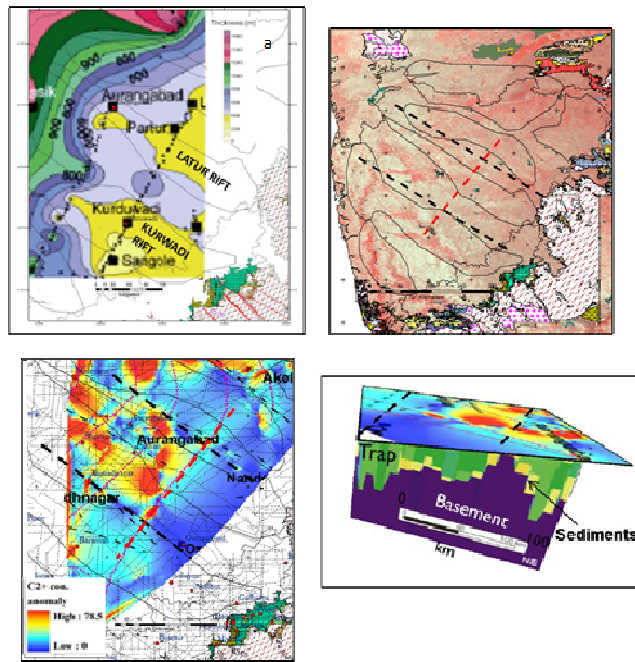


Fig. 8a) MT data shows a NW-SE area of high trap thickness between Kuruwadi and Latur rift (after Patro and Sarma, 2007) b) Tonal anomaly derived from AWiFs data between Latur and Kuruwadi rift implying some structural variation in the area c) C2+ adsorbed gas anomaly observed aligned between these two rifts implying sediments underneath with the NE lineament instrumental in causing a probable thickness change d) Thin layer of sediments observed below trap in the area (after Patro, 2007).

Modelling along a number of gravity profiles in this area also indicate the presence of sediments below the Deccan Trap. Modelling along a northward E-W oriented profile BB' indicates about 1.5-2 kms sediments below 400m of trap (density= 2.75) in the region between Kuruwadi and Latur rift in the northern part. This area is found to correlate with a very prominent geochemical anomaly that reiterates the presence of the sub-trappean sediments. In the area further eastward of the Latur Rift extending on to the southern part of the Buldana rift and beyond, the trap thickness is found to abruptly increase to more than 2 kms and sediment thickness is also found to decrease correspondingly.

Gravity modelling along another EW profile CC' further southwards indicates that in the western part from Pune to Kuruwadi area, trap directly overlies the basement having a density of the 2.67. However, further west of Kuruwadi, a thin layer of sediments with a thickness of about 300-400 m is found to occur in between the basement and the traps. The area corresponding to the Kuruwadi Rift and area further eastwards of it shows a high trap thickness of about 1.5 kms. The notch like area preceding the sediment layer may be a deep seated structural element which probably controls the boundary of sediment deposition in this area.

A NE-SW gravity profile AA' cutting across the earlier two EW profiles shows that area corresponding to the Latur rift and the Kuruwadi-Latur gap has an infra-trappean sediment thickness of about 300-400 m below about 200 m of trap sequence.

However, well Killari-1 drilled near Latur in Latur-Buldana rift, encountered basement after drilling only 6m of sediments below the trap cover (Nandi et al., 1999).

Based on the above analysis, it is probable that the Kuruwadi- Latur gap and the Latur rift together form a fault bounded depression that hosts a thick layer of pre-trappean sediments. Considering the parallelism in alignment with the PG rift exposed northward, it is probable that Mesozoic-Gondwana sediments are housed in this rift. In terms of sediment thickness, it appears that the NW part near Aurangabad, Ahmednagar and Shrirampur may be more interesting than the SE part of the proposed rift. The sediment thickness is found to abruptly decrease eastwards probably due to the effects of a NE-SW oriented fault.

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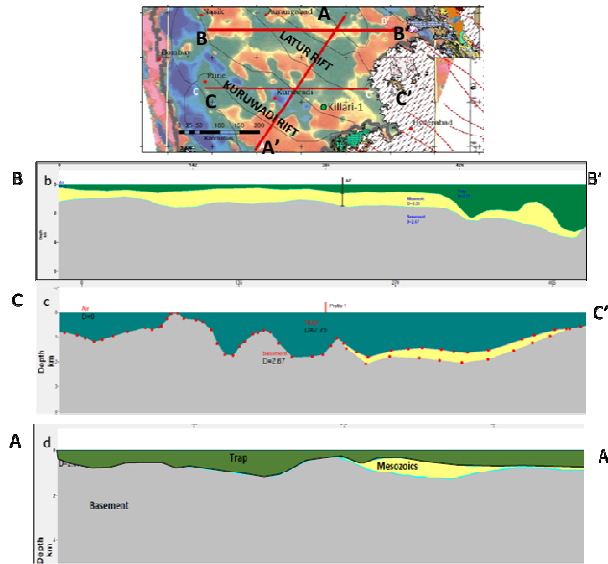


Fig. 9a) Gravity profiles AA', BB' and CC' overlain on the residual gravity map shown in Figs d, a and b

Conclusions

The subtrappean structural architecture in the southern part of the Deccan Syneclise is dominantly controlled by NW-SE trending shear zones which form the primary fabric of its basement. These structures were reactivated during later tectonic regimes resulting in the probable formation of a number of NW-SE oriented rifts. Based on this premise, two areas can be considered as apparently interesting from exploration point of view

1. Area south of the Kolhapur where about 2.8 km Proterozoic Kaladgi-Badami subtrappean sediments may exist associated with adsorbed gas anomalies
2. Area around Shirampur-Aurangabad and Ahmednagar where based on gravity modelling 2 kms of sediment is inferred below 400-500m of trap thickness with indications of presence of a thermogenic petroleum system in the area.

ACKNOWLEDGEMENTS

The authors express their gratitude to Director (Exploration), ONGC and ED-HOI-KDMIPE Dr. D.N.Singh for their permission in presenting and publication of this manuscript.

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