

Infra-trappean sediments in Deccan Syncline: New Insights

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Deccan Syncline, infratrappean sediments, Seismic and gravity profiling, subtrappean depocentres.

Abstract

Sub/infra-trappean Proterozoic-Mesozoic sediments can be possible areas for future hydrocarbon exploration. The vast Deccan trap cover in the central and south-western part of Indian peninsula has remained a barrier for such endeavors for long. This study attempts to unravel the distribution of infra-trappean sediments lying below Deccan Trap by integrating various geological and geophysical tools i.e. 2D Seismic profiles, Gravity data, well data, geochemical data etc. Study led identification of sediment depocenters below the Deccan Traps. There was congruity of Gravity and Seismic data at most places, however incongruity was observed at places.

Introduction

The Present study covers Deccan Syncline, Narmada, Bhima-Kaladgi and northern part of Pranhita-Godavari Basin comprising an area of ~3, 58,815 Km². This area lies between 22° 45' 00" N to 27° 00' 00" N latitude and 74° 15' 00" E to 78° 30' 00" E longitude (Fig.1). Earlier Geological investigation of subtrappean sediments in this area was conducted utilizing various tools, viz. gravity surveys, electrical resistivity surveys, scanty DSS survey and MT Surveys. Earlier initiatives and status of geological understanding of the study area is presented in details in the following paragraphs.

a) Earlier exploratory initiatives: Geological investigation of the basins exposing at the fringe of trap covered Deccan Syncline was carried out by ONGC in seventies. Geological survey of India (GSI) has conducted regional gravity surveys over the Deccan trap in the western and central India. These regional gravity studies are supplemented by spot refraction seismic soundings at number of selected points. These soundings have revealed that the trap is thin in the southern and eastern fringes and thick in the western and north-western parts. GSI also carried out deep electrical resistivity soundings.

In order to study the nature of the crustal structures, configuration, thickness of the Deccan traps and the underlying sediments over the basement, National Geophysical Research Institute (NGRI) conducted DSS and refraction seismic work sponsored by GSI. Both the electrical soundings and seismic refraction/DSS methods have indicated the presence of Gondwana sediments below the trap in the Nagpur-Amravati-Akola area.

ONGC initiated geophysical investigations in Nagpur-Pusad-Betul area with the aim of delineating the thickness of the Deccan traps and the underlying sediments, if any. Under this programme, the gravity-magnetic surveys were conducted during 1984-85 (Ghildyal N. D. 1985). Broad conclusions derived from this survey were that the thickness of sediments is about 2.1 Km in the west of Wardha town and 4.17 to 5.74 Km (approx.) near Katol (Nagpur District).

b) Present Geological Understanding: In India, Deccan volcanic province of Late Cretaceous to Paleogene period covers large parts of the western India forming Deccan Syncline. The main rock exposures in the basin consist of a number of basaltic lava flows which have been poured on to earth's surface during Cretaceous-Paleocene period, blanketing all pre-existing rocks ranging in age from Precambrian to Cretaceous. It is bounded to the north by the Narmada-Son rift (even though the lava spread extends much north of Narmada River) and to the south and east by the Precambrian sediment and Archaean metamorphic exposures. The western limit may be defined as the longitudinal fissures from which the basaltic lava erupted and is marked by a highly increased thickness of Deccan volcanic, even though the Trap is known to extend up to the shelf margin of Bombay Offshore basin (Fig.1). Generalised stratigraphy of Deccan Syncline Basin after, Deshpande.1998 is presented in Fig-2.

Better geological understanding of the Deccan Syncline were only at the margins where lava

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flows extend over Precambrian to Early Cambrian rocks, Gondwana and Cretaceous sediments found in the (1) Kaladgi and Bhima depressions along the southern margin. (2) Pranhita-Godavari graben on the east and (3) Narmada graben on the north.

The Proterozoic Kaladgi–Badami and Bhima basins are intra-cratonic basins occurring over the Archaean Dharwar craton. Inadequate data exist on the age of the basin fills, the deep basinal architecture, subsidence history and tectonic controls for both of the basins. The Kaladgi–Badami Basin, covering 8300 km², consists of three quartzite-shale-limestone cycles with an aggregate thickness of 4500 m alongside minor cherts and conglomerates deposited in continental, transitional and shallow-marine environments presumably during the late Palaeoproterozoic / Mesoproterozoic to Neoproterozoic. The lower part of the succession (Bagalkot Group) is deformed into east–west-trending elongated doubly plunging synclines and anticlines. The upper part of the succession (Badami Group) is undeformed and unconformably overlies the lower part.

Geophysical surveys by NGRI for DGH also indicate a number of concealed grabens/ rifts below trap, having a general NW-SE trend supposedly containing Mesozoic sediments. These rifts from north to south are Nagpur-Wardha, Buldana, Latur, Kuruwadi and Koyna rifts which basically coincide with regions of low regional gravity anomaly (Kumar et al., 2004). The alignments of these rifts are found to coincide with the outcrops of the Mesozoic and Proterozoic basins exposed along the rim of the Deccan Syneclise.

The E-W to ENE-WSW trending intraplate Narmada-Tapti rift is delineated by high angle northward dipping normal faults of Tapti rift on the south and southward dipping step like listric faults of the Narmada rift zone (Bhattacharji et al., 1996). The region is completely covered by a thick pile of Deccan lava flows and is characterized by several hidden tectonic structures, magmatic crustal accretion, sedimentary basins and complex geophysical signatures. It is regarded as the northern and NW extension of the Deccan Syneclise basin. The Deccan Trap thickness varies considerably from 100 m in the north-eastern part to more than 1500 m towards the west coast of India.

The Pranhita-Godavari basin is a large intracratonic Gondwana basin located in the eastern part of Peninsular India. It essentially represents a NW-SE trending failed rift and is separated into three sub-basins, viz., Godavari, Kothagudem and Chintalapudi sub-basins, by transverse transfer zones. It is unique as it preserves about 4500m thick sediments deposited in a time span of 200 Ma from late Carboniferous/early Permian to Cretaceous.

c) Present study: The present study focused on deciphering the subsurface disposition of subtrappean sediments/metasediments. The 2D seismic data acquired by DGH under National seismic programme (NSP) along with gravity and magnetic surveys, electrical resistivity surveys and DSS surveys were utilized for developing a better geological understanding and possible depocentres.

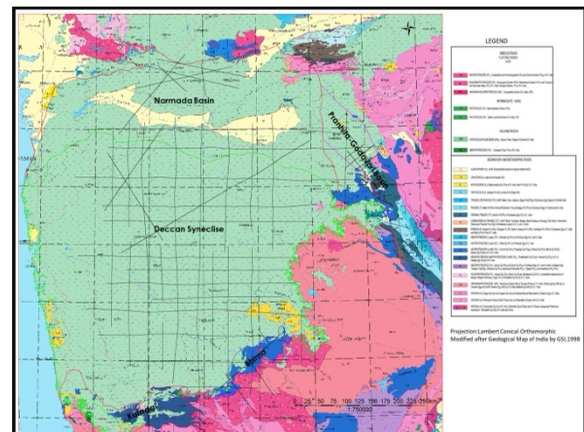
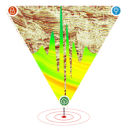


Fig. 1: Geological map showing Deccan Syneclise, Narmada, Bhima, Kaladgi and PG Basins (Modified after GSI map of India). Available 2D seismic data also overlain on the Geological map.

Methodology

In the study following data inputs were considered

- 1) 10945.6 LKM 2D seismic data acquired under NSP in Narmada Basin, Deccan Syneclise, Bhima Basin, Kaladgi Basin, and Northern Part of PG Basin covering total Area of 3, 46, 815 km² were analysed to unravel the subtrappean stratification and structural setup (Fig.1). The available 2D seismic data was scanned and utilized for constructing the profiles and seismic interpretation. The available seismic data is of different



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surveys, varying seismic parameters and record lengths. In the study there are no 3D seismic surveys available. The acquired RMS Velocity data of NSP Surveys were also used for understanding the basin and defining basement top and trap base along with deciphering sediments in between the trap and basement.

Age	Formation/Group	Lithology	Litho-type	Anticipated thickness (km)	Geographic distribution
Recent-Pleistocene	Alluvium Laterite Sand				Nagpur, Bhandara, Chandrapur, Wardha, Jalgaon Kolhapur Satara Thane, etc.
Miocene-Pliocene	Tertiary sediments		Lignites, Shales		Ratnagiri, and Sindhudurg districts
Early Paleocene-Late Cretaceous	Deccan Traps		Basalts	1-2	Most of the state of Maharashtra from west of Nagpur to Arabian sea coast
Unconformity					
Late Cretaceous	Lametas Bagh beds		Arenaceous Limestone, Sandstone, Shale	2-3.5	Nagpur, Chandrapur, Dhule, Gadchiroli, and Yavatmal districts
Middle Triassic	Upper Gondwana		Sandstones Shales		
Unconformity					
Triassic-Carboniferous	Lower Gondwana		Sandstones & Shale interbedded with coal	1.5	Nagpur, Chandrapur, and Yavatmal districts
Proterozoic	Penganga Beds Pakal Kaladgi		Limestones Shales Conglomerates, Sandstones Shales		Gadchiroli, Ratnagiri, and Sindhudurg districts
Unconformity					
Archean	Sausar Nandgaon Sakoli Bailadila Amagaon Unclassified gneisses				Nagpur, Bhandara, Chandrapur, Gadchiroli, Ratnagiri, and Sindhudurg districts

Fig. 2: Generalised stratigraphy of Deccan Syncline Basin (Deshpande.1998)

- Four velocity surfaces were created by taking the velocities of Deccan Trap around 5000m/sec, sediment velocity surface to be 4300m/sec, (i.e. between Trap Base and Basement top) and basement velocity taken as per DSS study to be 5500m/sec and beyond 4000m depth the velocity were taken as 6000m/sec. These four layer velocity model has been utilized for time to depth conversion.
- There are no wells drilled in the study area however, information regarding subsurface disposition of Gondwana and Mesozoic sediments in the peripheral regions of Deccan Syncline were incorporated by integrating well data of Lodhika-A, Dhanduka-A(Saurashtra Basin), Wbla-A, Anand-A & Dabka-B (Cambay Basin), Jhirna-A (Satpura Basin) and Aswaraopeta-A, Endamaru North-

A & Lamellapadu-A (southern part of PG Basin), as presented in (Fig-3).

- Earlier recorded Bouguer Gravity Anomaly & magnetic data analysis was incorporated in the study which greatly aided in understanding the basin and defining depth to basement in the areas with seismic gaps.
- GSI data like electro-resistivity soundings, drilled boreholes in Koyna region and northern part of PG Basin were used for horizon interpretation of basement and trap base.
- DSS and MT surveys of NGRI have been utilized for the interpretation of basement. Boreholes of CGWB at Kuruduwadi area and Killari-1 well drilled by AMD/NGRI were also utilized for understanding the basement and trap base.
- DEM profiles were utilized for viewing as well as analysing the surface exposures in depth sections. Along with this Geological Map, Trap Thickness, Surface seepage maps, Surface lineament map etc are integrated in the study.

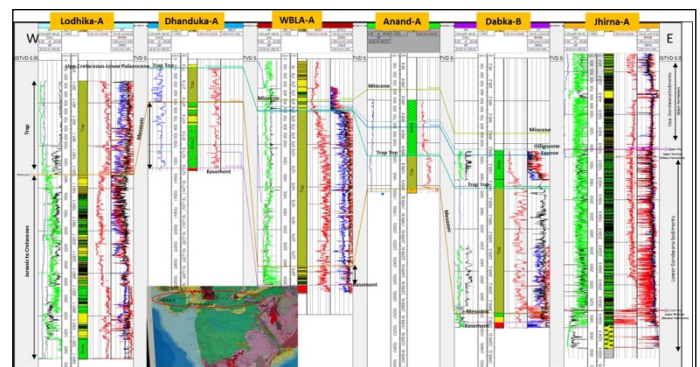


Fig. 3: E-W Electrolog correlation along Dip direction showing wells Lodhika-A, Dhanduka-A, WBLA-A, Anand-A, Dabka-B and Jhirna-A

Adopted workflow for this study is given below:

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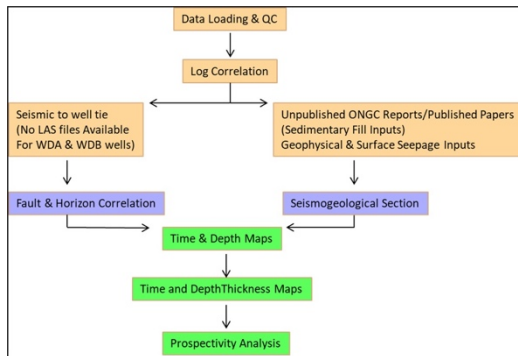


Fig. 4: Adopted workflow

Analysis and major findings

Seismic Data Analysis:

The seismic lines when plotted on geological map of India, it came to notice that the seismic line DSN-B, near to PG Graben, is passing through the outcrops of Proterozoic, Archean basement and trap. Hence, the Seismic signatures of these formations were used as reference at outcrop points and utilised along with Bouger anomaly map for correlating the seismic horizons in all the area. Also, the RMS velocity data of these seismic lines were constrained between 2500 m/s to 6500m/s, considering 5000+ m/s velocity for Basement, below 3500 m/s velocity for sediments and between 4000 to 5000 m/s velocity for Deccan trap. These gives near matching correlation for Proterozoic, Archean basement and trap on seismic signature as per DSN-B line (Fig-5).

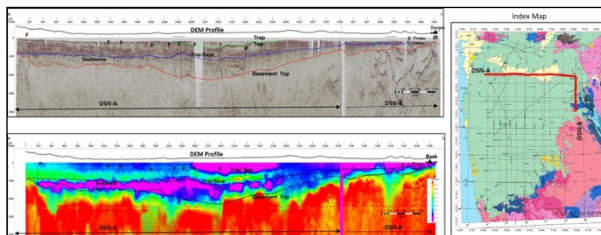


Fig. 5: RC Seismic Line DSN-A & DSN-B Interpreted & RMS Velocity Sections

The seismic horizon boundaries were correlated in the entire area of study. At first interpretation were carried out covering northern part of Deccan Syncline (DSN 2D lines), followed by southern part of Deccan Syncline (DSS 2D lines), PG Basin 2D Lines, Bhima and Kaladgi basin lines, Narmada Basin 2D lines.

Deccan Trap Base/Bottom is marked and correlated w.r.to bright amplitude in seismic along with RMS Velocity values of respective lines. The horizons that has been marked in DSN, DSS lines of Deccan Syncline area are Deccan Trap top, Deccan Trap Base and Basement top and at places alluvium/recent sediment bottom is also marked again w.r.t RMS velocity and seismic amplitude. Whereas, in Bhīma, Kaladgi and Narmada Basins, the marked and correlated horizons are Trap Top, Trap Base and Basement top. In PG Basin along with Trap base, the Gondwana sequences and Basement top has been correlated and marked. The structural configuration, thickness variation, fault pattern of the formations have been analysed in detail in study area.

Gravity Data Analysis:

Bouger Anomaly Map of study area (ONGC) were analysed to the understand the basement configuration and expected sediment thickness below the Daccan cover. This analysis were corroborated with the seismic analysis to enhance horizon identification confidence.

Megnatotelluric (MT) Data Analysis:

Interpretation of MT Data (NGRI) facilitates the understanding of lateral subsurface heterogeneities reflecting possible rheological changes that are known to be closely linked to the seismogenic processes (Jones, 1992). Thus MT data helps to identify different lithological variations as well as different structural elements like faults and dykes. In this study MT data was utilized to infer the thickness variation of the Deccan traps and compared with the thickness variation deduced from the seismic. The MT investigations carried out after Latur earthquake along three profiles in the study area, viz, Guhagarh-Sangole (GS), Sangole-Partur(SP), Edlabad-Khandwa (EK) and one short profile along Nanasi-Mokhad. The results shows that the Trap lies directly over high resistive basement in all profiles except along Edlabad-Khandwa profile Where huge thickness of sediments has been delineated. (Fig. 6).

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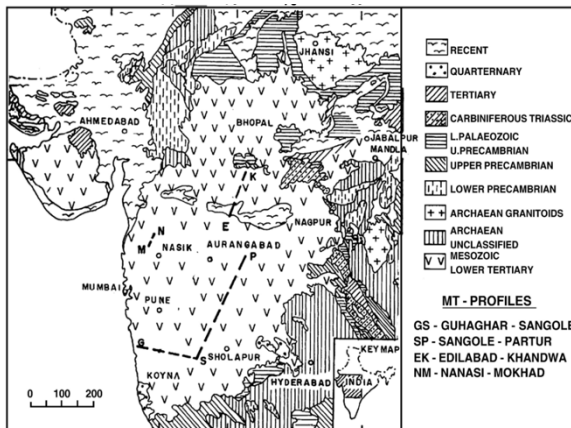


Fig. 6: Simplified geological map of the area with locations of four MT profiles, (T. Harinarayana,2007,NGRI)

Geochemical Data Analysis:

Mainly two types of Geochemical studies were carried out in the study area by NGRI, viz, Soil sample surveys and surface seepages. The Soil samples were collected from favorable areas identified by integrated geophysical studies. The compositional and isotopic signatures of adsorbed gaseous hydrocarbons (methane through butane) were used as surface indicators of petroleum micro-seepages. An analysis of 75 near-surface soil-gas samples was carried out for light hydrocarbons (C1 to C4) and their carbon isotopes from the western part of Tapti graben, Deccan Syneclise, India. The geochemical results reveal sites or clusters of sites containing anomalously high concentrations of light hydrocarbon gases. High concentrations of adsorbed thermogenic methane (C1 $\frac{1}{4}$ 518 ppb) and ethane plus higher hydrocarbons (SC2p $\frac{1}{4}$ 977 ppb) were observed. Statistical analysis shows that samples from 13% of the samples contain anomalously high concentrations of light hydrocarbons in the soil-gas constituents. This seepage suggests large magnitude of soil gas anomalies might be generated/sourced from Mesozoic sedimentary rocks, beneath Deccan Traps. NGRI Report (Rasheed, 2012) may be referred for the location of hydrocarbon seepages.

Remote sensing:

The Lineament analysis of the study area generated by ONGC through Remote Sensing has been used to demarcate the discontinuities in the subsurface from surficial impression. The data strengthen our understanding of the subsurface from seismic and other geophysical studies (Fig. 7).

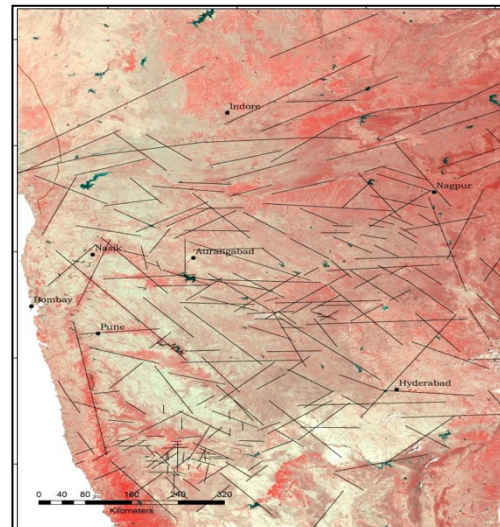


Fig. 7: Regional Lineaments delineated from AWiFS image data in the study area (Source: Remote sensing Division, KDMIPE)

Well Data Analysis:

The few Boreholes drilled by GSI (Fig.8) in late 1980s encountered Archean Basement directly after Deccan Traps in the Koyna Region and the boreholes drilled in the Nagpur-Wardha region of PG graben area encountered Gondwana as well as Neo-Proterozoic sediments after Deccan Trap. ONGC drilled two core wells namely WDA and WDB in northern part of PG graben, where formations of Lower Gondwana have been encountered. CGWB (Central Ground water Board) drilled few boreholes in Kuruduwadi Rifts area (Fig-9), where basement was encountered after Trap, Similarly one well was drilled in Killari area by NGRI/AMD as well Killari-1, here also basement was encountered after drilling 8m of sediments comprising 1-2 m oxidised shaly section followed by a conglomeratic grit-sandstone section and Trap at the top. Accordingly, while making the depth sections and maps from seismic, these well data were utilized to calibrating the depth surfaces along with the basement configuration and sediment thickness.

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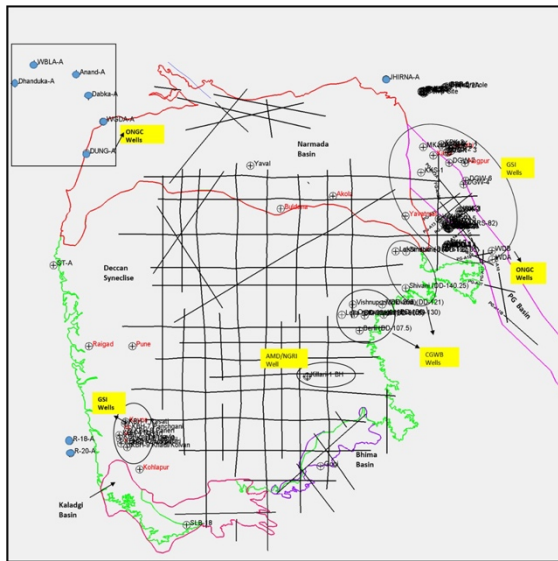


Figure 8: Location map of shallow boreholes drilled by GSI, Central Ground Water Board & AMD in Deccan Syncline, Bhima, Kaladgi, Narmada and PG Basins

Major Findings

Basement Configuration:

The deepest depth of basement is observed in Narmada basinal area at two places. In some areas basement high are observed as per bore holes drilled by CGWB/ AMD in Killari-1 and

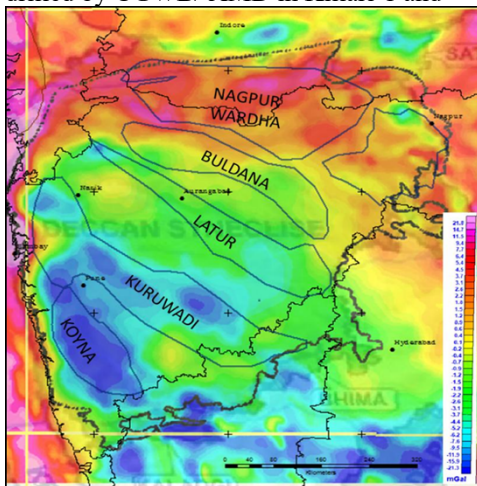


Figure 9: Rifts delineated based on regional gravity signatures (Source: ONGC)

Vishnupuri borehole on eastern flank of Deccan Synclinal area. The basement is exposed in Kaladgi basinal area which is also corroborated as per seismic. Presence of the rift area viz, Koyana, Kuruduwadi, Buldhana and Nagpur-Wardha can be confirmed from the time relief and depth structure map of basement. The trend of basement shows

that the basin is deeping towards north, north-west in the study area (Fig-10).

Thickness of Infra-trappean Sediments:

Thickest sediments are observed in Narmada Basin. In northern PG basin area around too thickest sediments were observed. Between Killari-1 borehole and Vishnupuri borehole, approx. 1600m thick sediments is there showing basinal low area.

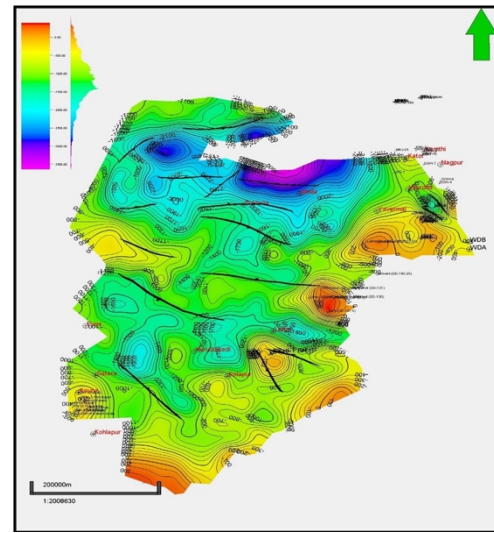
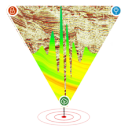


Fig.10: Depth Structure Map (Basement)

Correlation between gravity data and seismic:

The basement configuration interpreted on the seismic 2D data after integration of the well/borehole data drilled by GSI, NGRI/AMD and electro resistivity sounding data of GSI matches with the Bouger Anomaly Map of ONGC particularly in the Buldana Ridge, Latur Rift, Kuruwadi Rift and PG Graben portions. However, Narmada and Koyana Rift portion the Basement configuration is not matching with the Anomaly map. The GSI drilled wells in the Koyana rift portion encountered granitic basement immediately after the exposed Deccan Trap (Fig-11). The Mesozoic as well as Gondwana/ Proterozoic sediment thickness are anticipated to be more in the Narmada basin, Latur Rift, Kuruduwadi Rift and PG Graben areas. One North-South Geological profile passing through the Narmada basin, Latur Rift, Kuruwadi Rift where Killari-1 is drilled provides evidence of basement high. The borehole Killari-1 falls in between Kuruduwadi rift and Latur rift (Unpublished ONGC report) Proterozoic sediment deposition in the Kuruduwadi rift is assumed based on geological datasets integrated with seismic data. The Deccan



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trap cover exists almost along the entire length of the profile. Similar to this, it is assumed that Gondwana sequences have been deposited in the Latur rift, Buldana ridge part, and Narmada Basin in addition to Cretaceous Lameta beds that are infratrappean which truncate at Killari-1 basement high (Fig-12).

Conclusion

The Deccan Syneclise is an intracratonic Basin, covering an area of 273000 km² in the western and south-central part of India. Most of the basin is covered under the lava flows of the Deccan basalts of Late Cretaceous - Palaeocene age, below which substantial thickness of Gondwana–Mesozoic sediments may exist. The presence of Mesozoic sediments under the volcanic rocks has been revealed by deep wells drilled by ONGC in Kutch and Saurashtra Basins (Fig-3). With the increase in demand for petroleum products and diminishing indigenous production, it has become necessary to look for probable potential zones even in locales that were hitherto known as bleak prospects. Paleozoic & Mesozoic sediments throughout the world are known for hydrocarbons and are well established source rocks in prolific hydrocarbon bearing sedimentary basins around the world. In India, significant hydrocarbon finding has not yet been established within Paleozoic-Mesozoic sequences, as the major parts of these sediments are overlain by the Deccan Traps. Detection and mapping of these sediments below the Deccan Trap has been a long-standing complex geophysical problem facing the oil industry.

Based on all the integrated approach has been used to identify areas with possible Paleozoic-Mesozoic sedimentation beneath the Deccan trap. The sandstone reservoirs of sub-trappean Mesozoic and Gondwana Sequences are the likely petroleum productive zones. The probable source rocks are the lower Gondwana (Barakar formation) and the cap rock might be the intraformational shales and the Trap flows. High geothermal gradient and the tectonic history of the basin indicate the thermal subsidence and burial to be significant enough to cause the maturation of organic-rich sediments and, most likely, the generation and expulsion of hydrocarbons. Also, the inter-trappean sediments within the Deccan trap may be promising reservoirs as hydrocarbon generated in Proterozoic / Gondwana sediments may be migrated into the sandstone reservoirs within the

inter-trappean and the Deccan trap above may act as seal. Fig.13 shows sediment thickness map overlain on C2+ anomaly map and promising depocentre.

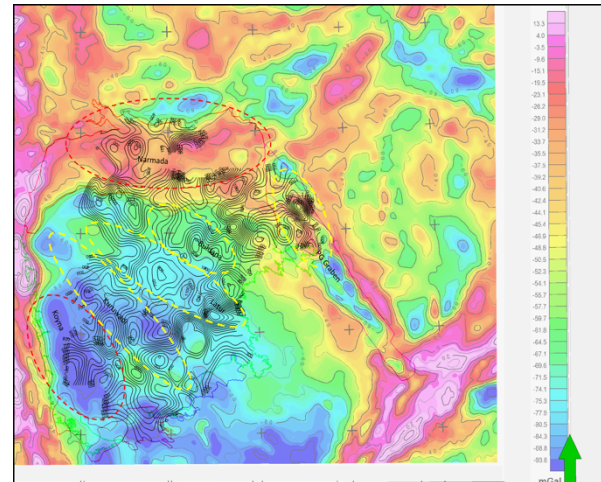


Figure 11: Bouguer Anomaly Map where red oval corresponds to unmatching highs & lows and yellow oval corresponds to matching high and lows.

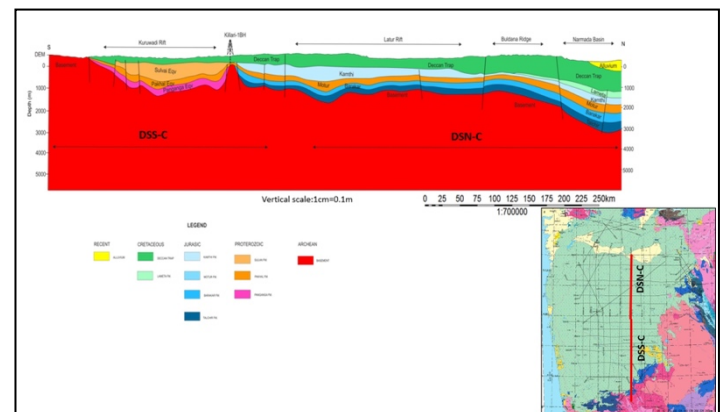


Figure-12: Seismo-Geological Section DSN-C & DSS-C RC line

