GEO India 2018

PaperID **AU414**

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Mesozoic Basin configuration and possible Prospective locales for future exploration in Kutch, Saurashtra, Cambay and Narmada area

Abstract

Mesozoic rocks contribute ~ 50% of Oil and ~ 40% of gas reserves world-wide. India has 26 sedimentary basins with basinal area of ~ 1.79 x 10^6 sq. km of which Mesozoic basins occupied area of 4.0 x 10^5 sq. km. Recent hydrocarbon discoveries from Mesozoic sediments in Kutch-Saurashtra offshore in western India proved that the potentiality of Mesozoic hydrocarbon cannot be ruled out further in less explored onland part of Kutch, Saurashtra, Cambay, and Narmada area. Present study pertains to understand the extension of Mesozoic basin across Kutch, Saurashtra, Cambay and Narmada area and find out the possible areas for exploration of Mesozoic sediments focusing on onland part by integrated approach using seismic, well, gravity and outcrop data. Gravity modeling has been carried out integrating all G & G data. The study reveals that, Mesozoic sediment thickness is maximum of ~ 9000 m in Kutch offshore and decreases to ~ 4000m in Saurashtra offshore. The thickness is gradually reducing towards the onland part. In Kutch onland, thickness of Mesozoic sediments is between 200- 5000m. However, in Saurashtra onland, the thickness varies between 500m to 4000m. The Cambay area however has relatively lesser thickness around 400-800m, probably due to its close proximity to the provenance or erosion/ uplifting experienced prior to Late Cretaceous rifting whereas Narmada area experienced between 200- 3000m Mesozoic thickness at places.

The possible prospective locales for future exploration of Mesozoic basin have been brought out across the study area, where, substantial thickness of Mesozoic sediment, fair reservoir occurrence, adequate source and effective seal is envisaged.

Introduction

The Kutch-Saurashtra, Cambay and Narmada Basins are peri-continental rift basins in the western margin of the Indian Craton (Biswas, 1987) and occupy area more than 250000 sq.km. The study area is confined to the western part of India comprising of Kutch, Saurashtra, Cambay and Narmada area within Latitude 19^o 30' N and 25^o 00' N and Longitudes 67^o 10' E and 75^o 10' E. These basins were formed by rifting along Precambrian tectonic trends i.e. Dharwar (NNW-SSE), Aravalli-Delhi (NE-SW) and Satpura (ENE-WSW) by sequential reactivation of primordial faults which controlled the structure and style of the basins. The evolution of the western continental margin of India commenced in Late Triassic–Early Jurassic time with the breakup of Gondwanaland, India and Madagascar separated during Late Cretaceous while Seychelles rifted out subsequently and the western continental margin began to evolve to its present structure (Norton et.al., 1979). By Late Miocene, India attained its present position, following collision with Eurasian plate in Eocene.

Structural imaging in Trap-covered regions is a complex geophysical problem. Near-vertical seismic reflection studies have not been successful in trap-covered regions due to the combined effect of multiple generation, mode conversion, scattering and absorption leading to poor signal-to-noise ratios beneath and within the trap. Deep seismic sounding (DSS) and Non seismic Geophysical technique such as Gravity, Magnetic and Magneto-Telluric (MT) are very powerful geophysical technique for delineating the deep feature of the earth's crust. Several DSS survey carried out in NGRI by Kaila et.al. in 1976, 1979, 1981, 1990 in Western India along various profiles. Gravity, Magnetic and MT studies in Kutch-Saurashtra area has been carried out in NGRI by various workers (Mishra et al., 2000, 2004 and Chandrashekhar et al., 2002, 2005). In present study these results has been incorporated.

The gravity modeling has been considered as one of the most suitable technique to understand sub basalt imaging.The Bouguer anomalies are principally related to deep compensating masses which are associated with changes in crustal structure and composition (Woolard, 1959). The observed Bouguer anomaly is the cumulative effect of attraction due to sources lying at different levels and can be classified into two broad components (i) residual anomalies due to shallower sources, and (ii) regional anomalies due to deeper sources. The Bouguer anomaly helps in identification of major structural highs and lows in the study area. The 2D density model of Bouguer gravity along selected profiles integrating with conventional seismic, well, DSS and Outcrop data has been accomplished which resulted into demarcation of Basement top, Mesozoic top, & Trap top.

Geology, Tectonics & Mesozoic petroleum system

The Kutch–Saurashtra is contiguous basin extending from land to offshore. Kutch onland has the classic Jurassic - Cretaceous exposures and the vast plains of alluvium covering Rann, and extend into offshore with a wide shelf platform. In Saurashtra onland, most of the area is covered by Deccan Trap (fig: 1) with limited Mesozoic exposures in Dharangdhara area in the Northern vicinity; however, coastal areas are marked by presence of Cenozoic and Quaternary sediments. The northern limit of Kutch-Saurashtra basins extends beyond the Indo-Pakistan border and southern extent of the basin is contiguous with the Mumbai offshore basin. Cambay Basin situated towards east of Kutch-Saurashtra is a narrow

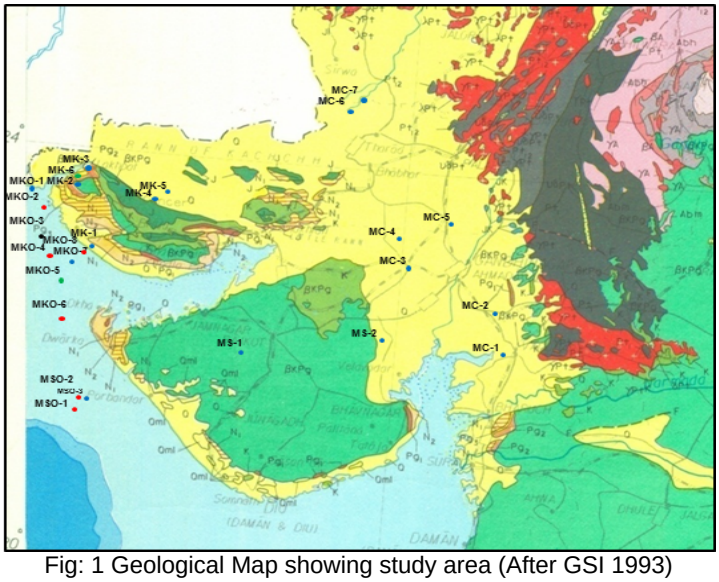

Fig: 1 Geological Map showing study area (After GSI 1993)

NNW -SSE trending elongated intracratonic rift graben, extending from Luni River in the north to Tapti River in the south. In the north, the basin narrows and tectonically continues beyond Sanchor to pass on to Barmer basin of Rajasthan while in the south, the basin merges with the Tapti Daman extent of Mumbai offshore basin. Limited occurrences of surface and subsurface Mesozoic rocks have been observed in margins of Cambay basin. The Mesozoics comprises essentially of shallow marine Jurassic succession in Kutch area (both in outcrops and subcrops), shallow shelf to continental facies of Cretaceous in Kutch - Saurashtra with a limited presence of Cretaceous rocks of continental origin in subsurface in the basin margins of Cambay Basin. Frequent Cretaceous exposures across Narmada area are of marine to continental origin.

The occurrences of hydrocarbons with in Jurassic wells MSO-1 (4058-4172m) and MSO-2 (4422-4483m) in Saurashtra offshore, Early Cretaceous well MKO-5 (2840-2845 m) and Late Cretaceous well MKO-4 (3440-3446 m) in Kutch offshore sediments indicate the presence of Mesozoic Petroleum system. Most probably the organic rich syn- rift sediments in Kutch Basin may be Early Cretaceous sediments deposited in fluvial to shallow lacustrine settings having mainly terrestrial organic matter as observed in a

drilled well MKO-3 wherein, the possible source rock of the Mesozoic petroleum system has been studied. The reservoir rock corresponds to Early Cretaceous which is very thick in Kutch Basin.

Data Input

Various workers have studied these areas time to time to demarcate the extension of Mesozoic basin pertaining to above cited areas. However, G & G data used in the present study is being discussed selectively herein, for convenience.

Outcrop Data: Surface Geological map of Basin prepared by GSI in 1993 has been taken into account for surface geological exposures. **Well Data and log correlation:** Total 42 Mesozoic wells have been drilled in Kutch, Saurashtra and Cambay. Of these 42 wells 6 wells in Kutch-Saurashtra offshore are hydrocarbon bearing & one well in Kutch onland has shown hydrocarbon indication from Mesozoic sediments. Log correlation along four profiles has been incorporated in studies. One of the profiles has been shown in fig-3 which is passing through three Mesozoic wells in Saurashtra offshore, two in Saurashtra Onland and one trap & one Mesozoic well in Cambay. **Seismic Data and Horizon correlation:** More than 200 seismic 2D lines have been used in present study. Trap top & Mesozoic top are well delineated in offshore seismic (fig: 4) compare to onland part where only trap top can be interpreted due to poor seismic signature for sub-trappean event. The input from seismic was further used for gravity modeling. **DSS and seismic Refraction Data:** NGRI had recorded two NS DSS profiles in Cambay i) Mehmadabad – Billimora in south, ii) Dharimanna- Mehmadabad in North Cambay (Kaila et.al., 1981, 1990) and one EW DSS profile (Navibandar to Amreli) in Saurashtra onland (Rao & Tiwari 2005). Seismic refraction studies were also carried out by NGRI along five profiles Jodiya-Ansador, Tikor-Mangrol, Jogvad-Junagadh, Kurunga-Latipur & Dwarka-Porbandar-Madhavpur in Saurashtra peninsula. The velocity-depth section interpreted along these DSS and Seismic refraction profile has been incorporated in present study. **Gravity Data:** The Bouguer anomaly map (fig: 2) has been prepared using vintage ONGC gravity data and published NGRI gravity data 2012. The Bouguer anomaly map shows major structural highs and lows in the study area. A part from this, recently gravity data along two NS profile had been acquired by ONGC in 2015-16 in Narmada area which is also incorporated in the present study. Major gravity Highs and Lows has been shows on map by H1-H21 & L1-L21 respectively.

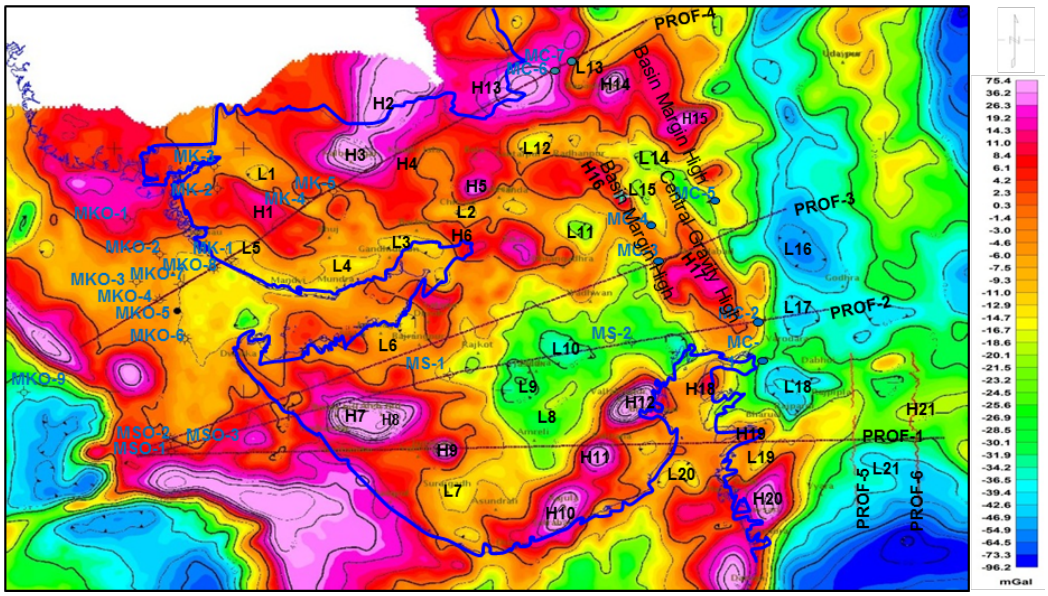

Fig:2 Bouguer gravity anomaly map with major gravity high H1- KMU (Kutch Mainland Uplift), H2-Nagar parker Ridge, H3-H6 Pachham, Khadir, Bela & Wagadh uplift, H7- H9 – Barda, Alech & Junagadh Volcanic plug, H10 - H12-

Rajula, Palitana & Vallabhipur Volcanic Plug, H13- Basement High in Cambay, H14- Tharad Ridge, H15- Eastern Basin Margin High Cambay, H16- Radhanpur Ridge, H17-Central gravity high, Cambay, H18- Devla High, H19- Ankleshwar High, H20- Intrusive. & Major gravity low L1-L5- Depression, L8-Large wavelength Jasdan Plateau gravity low with low wavelength L9 & L10 due to Mesozoic sediment. L11-L12- Depression at basement level. L13 –L15- Sanchor, Patan & West margin depression in Cambay.

Methodology

To bring out a meaningful understanding of basinal configuration and preparation of maps, gravity modelling has been done integrating all G & G data in GM-SYS software. The point data from the gravity model has been extracted along three horizons Trap, Mesozoic and Basement top and have been used for map preparation using Decision space Geoscience software at grid interval of 2500m. For integration of tectonic elements, the major faults already identified on the basis of surface geological mapping in Kutch, Saurashtra, and Narmada area has been taken into account, while in Cambay area, already established major faults at Trap Top level on the basis of 2D/3D seismic has been considered. However, in Trap/ alluvium covered Saurashtra areas, faults on the basis of gravity and seismic data, obtained from earthquake intensity have been taken into account (Bhattacharya et.al. 2004). Integration of all the data has led to formulate structure and style of Mesozoic basin of Western India.

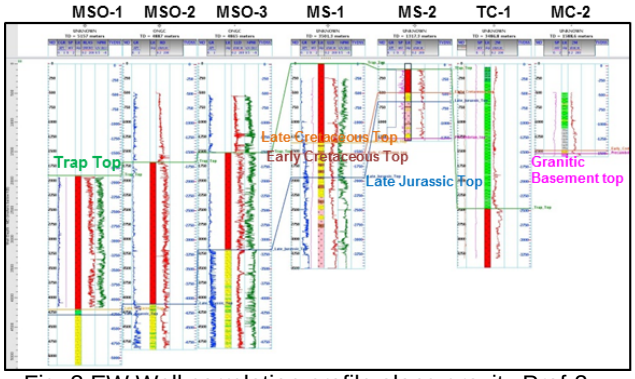

Fig: 3 EW Well correlation profile along gravity Prof-2 through Saurashtra Offshore, onland and Cambay

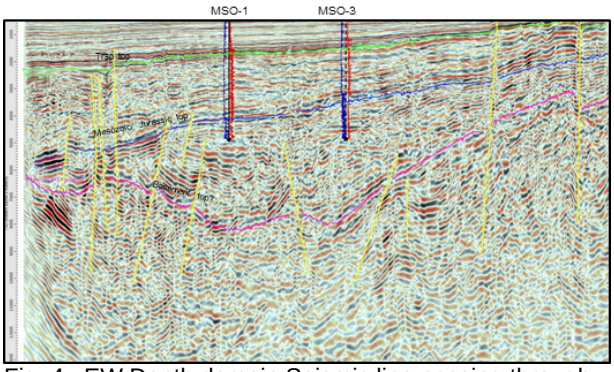

Fig: 4 EW Depth domain Seismic line passing through gravity Profile-2 in Saurashtra Offshore

Gravity Modeling

To bring out meaningful subsurface scenario, available gravity modeling along 25 profiles in Cambay and 12 profiles in Kutch-Saurashtra offshore and onland was further integrated with 4 regional E-W gravity profiles extending for more than 500 km covering Kutch- Saurashtra offshore upto Cambay and 2 N-S profiles across Narmada –Tapti area (Fig-2), a representative 2D gravity model (Profile-2) passing through wells MSO-1,3 MS-1,2 and MC-2 is shown in fig:5a &5b. The observed gravity anomaly taken from Bouguer gravity map shown by dot and computed anomaly of subsurface model by continuous line. Herein, average density for Deccan trap, tertiatry sediments, mesozoics, and basement has been taken as 2.75-2.8 gm/cc, 2.35-2.5 gm/cc, 2.35-2.55 gm/cc and 2.69-2.72 gm /cc respectively for gravity modeling which has been computed from the well log data of well MSO-1 and MS-1. Density of Volcanic plugs and Mantle has been taken as 2.9 gm/cc (Chandrashekhar & Mishra, 2002) and 3.3 gm/cc respectively. The large wavelength regional anomaly has been satisfied by deep crustal and sub-crustal feature such as Underplating at lower crust & Moho. Low to medium wavelength anomaly adjusted by shallow feature such as Mesozoic sediments and Basement variation. The low wavelength high amplitude anomaly of magnitude +30 mGal near Barda in Saurashtra onland is adjusted by volcanic plug present in the area (Chandrashekhar & Mishra 2002). Large wavelength Jasdan plateau gravity low in Saurashtra onland is satisfied by more crustal thickness for isostatic compensation. An under plating layer has been introduced to satisfy the central gravity high of Cambay. Such type of underplating is also seen in other rift basin such as Baikal Rift zone in Siberia (Thybo and Nielsen, 2009), Southern Kenya Rift centre, (after Birt et al., 1997) and Thybo et.al. 2013. Moho configuration however, has been integrated with Mehmedabad- Billimora DSS profile. The modeling shows that mesozoic thickness is increasing up to 4

km towards western side in offshore and less than 4 km in Saurashtra onland part as compare to the eastern side, in Cambay, where maximum thickness of 400m is observed along this profile.

Mesozoic basin configuration

The comprehensive studies integrating the available data & earlier understanding, the basin architecture of Mesozoic basin has been firmed up. The gravity modeling has been used to prepare map close to Trap, Mesozoic and Basement top (Fig-6) and further to envisage Trap & Mesozoic sediment thickness. The Mesozoic basin configuration is well explained by the Messozoic thickness map (fig-7) which indicates increasing Mesozoic thickness towards western side i.e. Kutch-Saurashtra offshore wherein, thickness of more than 9 km is observed in NW side as compared to eastern side where 400m to 800m Mesozoic thickness has been observed in Cambay which may be due to its closeness to the Provenance. However, in Narmada area, more than 2 km Mesozoic sediments have been envisaged in southern side. Based on analysis of thickness map and well data, a contour value of 1200 m has been envisaged as tentative shore line prevailing during Mesozoic time and shown in red color (fig-7).

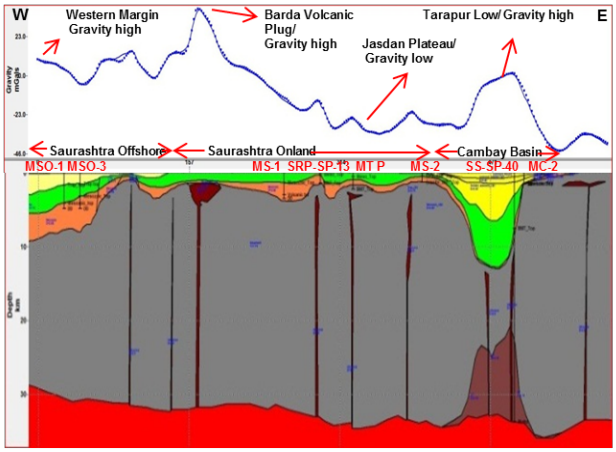

Fig: 5a Gravity modeling along Prof-2 showing deeper features.

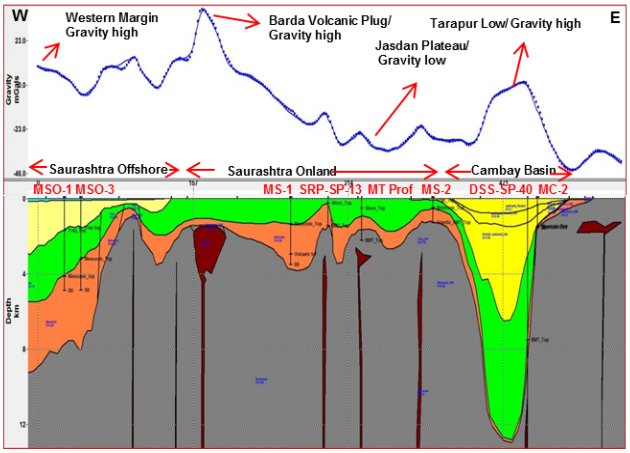

Fig: 5b Gravity modeling along Prof-2 showing shallow features.

Mesozoic Prospectivity

The present study culminated into identification of prospective areas for future exploration based on Mesozoic sediment thickness, the area falling in Gulf of Kutch and adjacent onland part, such as Jamnagar, Rajkot and Dwarka depression, appears most promising from the hydrocarbon point of view. The NW part of the Kutch onland is expected to have more than 4 km Mesozoic thickness, may also be prospective. In Saurashtra onland area, around Manglore depression, more than 2km Mesozoic sediments is expected which may be promising because of its close proximity to the source as nearby well MSO-1 & MSO-2 in Saurashtra offshore are hydrocarbon bearing. In Cambay area around Surat depression and Viramgam (west of well MC-3) seems to be prospective. In Narmada area around Nandurbar depression shows more than 2km Mesozoic sediment thickness which may be potential area from hydrocarbon point of view.

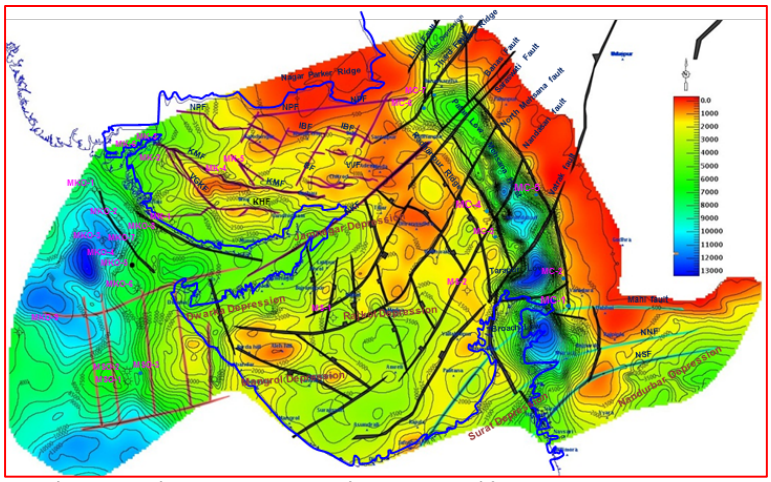

Fig:6 Depth Structure Map close to Granitic Basement top

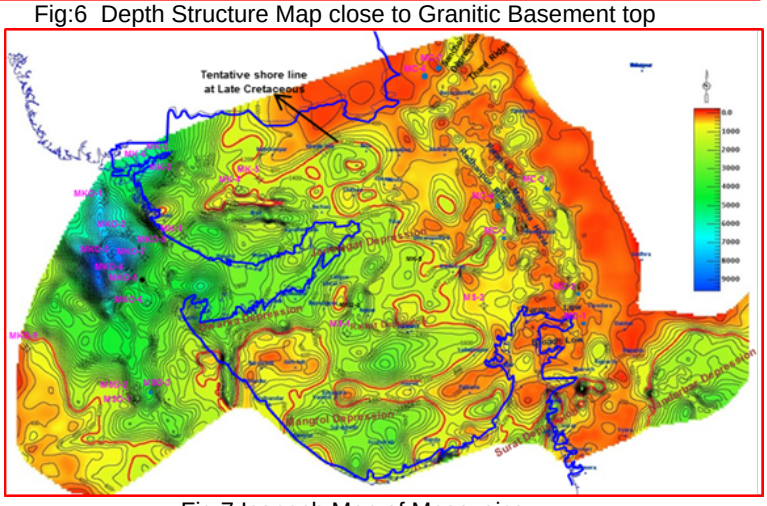

Fig:7 Isopach Map of Mesozoics

Conclusions

The study is an attempt to integrate all the available G & G data, published / public domain and the work carried out during last three /four decade on the Mesozoic of Kutch, Saurashtra, Cambay and Narmada. The study reveals that Mesozoic thickness (~9 km) is well prevalent in western areas as compared to easternmost part, where Precambrian rocks of Delhi, Aravali & Erinpura granite are exposed which is the main provenance for deposition of Mesozoic sediment in Kutch-Saurashtra & Cambay area. Enormous Trap thickness (~8 km) in Cambay area is quite conspicuous.The source potential in the offshore area is well established which further cannot be ruled out towards the onland part of Kutch and Saurashtra. Possibility of marine transgression is quite evident in the well MS-1, cutting samples of which indicate upper Dhrangadhra Member as the most favorable candidate for occurrence of hydrocarbon habitat. These sediments display fair source potentials albeit good organic richness with moderate source potential and possible development of oil prone facies. The possible prospective locales for future exploration of Mesozoic basin have been brought out across the study area, where, substantial thickness of Mesozoic sediment, fair reservoir occurrence, adequate source and effective seal is available.

Acknowledgements

Authors expressed gratitude to Shri A.K.Dwivedi, Director (E) for his kind permission to present this paper. Sincere thanks to Dr. Hari lal, HOI, KDMIPE for his support to write this paper. Authors are also thankful to Dr. Ashesh Siawal for their guidance and support. All the members of Basin Research Group are highly acknowledged for their kind co-operation.

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