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Assessing the Hydrocarbon prospectivity of Mesozoics in South Cambay-Western Narmada basin

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ABSTRACT

As exploration for hydrocarbon resources continues to move into non-traditional areas, geologists are targeting Frontier areas and Probable Plays not usually associated with known / established habitats that are typical in a well explored sedimentary-basin. An attempt has been made to construct a conceptual geological model, taking lead from Field geology and Outcrop studies, well, seismic and gravity data. Around the periphery of Cambay Basin, 6 wells that have drilled through Deccan basalts having encountered Cretaceous sequence, thus establishing the presence of a sub-basalt Mesozoic depositional system. Though there is little improvement of sub basalt events but few lines reflect the Mesozoic events and are utilized for mapping. The geological model postulated here, envisages the existence of speculative Mesozoic petroleum system in the study area with Lower Cretaceous Himmatnagar and Nimar Sandstone as reservoir rock and organic rich layers in Cretaceous Lameta and Bagh Beds with Nodular Limestone as source rock with favorable juxtaposed entrapment.
Comprehensive data sets have been integrated to bring out a likely Petroleum System model that was simulated to test Mesozoic prospectivity in the area. On basis of the study, Petroleum System Modelling was carried out and few speculative prospective locales have been perceived in the eastern basin margin, to suggest the existence of Mesozoic petroleum system in South Cambay- western Narmada Basin.

1. Introduction

Basin Architecture

The western continental margin of Indian plate has evolved as a result of rifting along major Precambrian trends (Biswas, 1982). The Kutch, Cambay and Narmada basins are the three major marginal rift basins bounded by intersecting sets of faults whose trends follow the three important Precambrian tectonic trends viz. the Aravalli, Dharwad and Satpura trends . The Narmada and Cambay rift systems cross each other in the Gulf of Cambay region and together with the west coast fault define an area which has been identified by many as a triple junction (Burke and Dewey, 1973; Bose, 1980). These basins opened up one after another from north to south as the subcontinent drifted northward at an increasing pace and rotated counter-clockwise during the Mesozoic (Biswas, 1987). The basins developed serially, starting with the Kutch basin in the early Jurassic, Cambay basin in Early Cretaceous and Narmada basin in late Cretaceous. These three periods of basin formation are correlatable with 3 important stages of the drift history of the Indian subcontinent (Biswas, 1982).
The Cambay basin is a narrow elongated (NNW-SSE) rift basin located in the north-western margin of Indian Peninsula. Structural grain of Precambrian basement exposed in the vicinity of Cambay basin- a complex of igneous and metamorphic rocks controlled the architecture of the basin. The principal lineaments in the basin are aligned NESW, ENE-WSW and NNW-SSE. Major tectonic lineaments expressed as faults, flexures and dikes on the surface, as fault zones in the Cambay basin, and as structural features in the Tertiary sediments are aligned mainly in two directions- NNW-SSE and ENE-WSE. It is evident that these two major trends extend into the Cambay basin, and are manifested both on the surface and in the subsurface.
In the southern part of the basin, the ENE-WSW trending Satpura Orogenic belt extends under the basin between the Narmada and Tapti Rivers and continues into the offshore They appear to follow the fracture and lineament trends (Deshmukh, 1988). There, a number of structures (Ankleshwar, Kosamba, Olpad and Hazira) are associated with this trend. The Satpura orogenic trend continues into the offshore south of the Saurashtra craton, where it constitutes a part of the Mumbai offshore basin. The eastern extension of the Satpura orogenic trend in the Cambay basin is a natural tectonic boundary. It divides the Cambay basin and separates it from the Mumbai offshore basin. Tapti and Narmada Rivers limit the Narmada block to the south and north respectively. Similarly, the Mahi Sagar River defines the northern boundary of the Broach-Jambusar block

JAMBUSAR - BROACH BLOCK

This block is a deep syncline containing more than 6000m of Cenozoic sediments (including more than 3500m of Neogene) and lies between Mahi sagar and Narmada River. The syncline is an asymmetric sag with the depocentre immediately to the north of the Narmada River, with sedimentary thickness decreasing rapidly to the south-toward the ENE-WSW aligned Narmada fault and rather gently in all other directions.

NARMADA - TAPTI BLOCK

Lying between Narmada and Tapti Rivers, the Narmada –Tapti block is an eastern continuation of ENE-WSW striking Satpura-Son lineament which is an important geological boundary in the Indian shield- the boundary which no

Gondwana rocks occur and south of which no Vindhyan rocks occur (West, 1962). The sediments are resting over Deccan trap in the outcrops of Narmada-Tapti area. The lineament is defined by relatively straight course and co-linearity of west-flowing Son-River. Parallel linear ridges further enhance the lineament. The Narmada-Son lineament is a zone of high tectonic activity (Choubey, 1971). This resulted in an ENE-WSW alignment of early structures and faults - including the Narmada fault (Dhar and Singh, 1993).

Infra-Trappeans

Lying unconformably over the Champaner Group of rocks is a sedimentary sequence viz. the Bagh formation and Nimar Formation are exposed as inliers within Deccan Trap. The rocks are characterized by heterogeneous composition including charts, marls, limestone, quartzitic sandstone, conglomerate and varigated shales. The beds strike in a NE-SW to NNE-SSW direction with low angle dips towards SE and ESE directions. High angle joints are normally seen in NW-SE and NE-SW directions. These rocks are exposed around Sankheda, Kawant, South of Chota Udaipur and Garudeshwar. These infra trappeans rock are sedimentary in nature comprising sandstone and cherty limestone with numerous fracture and joints.

2. Geology of Study Area:

The Mesozoic exploration is a tough challenge in Cambay basin as Mesozoic basin paleogeography and its extent is little understood in light of scanty well data and poor seismic imaging below basaltic flow of Deccan Trap. The present study targets the Mesozoic prospectivity in the south-eastern part Cambay basin.Mesozoic rocks unconformably overlie Precambrian rocks of Aravalli supergroup (Merh, 1995) and occur as isolated exposures around Narmada valley and trappean upland areas, east of the Kim river basin. The constituent rocks are mainly sandstone and fossiliferous limestones which have been designated as Bagh Formation. Deep Seismic Sounding studies by Kaila et al. (1981) have revealed the presence of Mesozoic rocks below Deccan traps further west. (Fig.1).

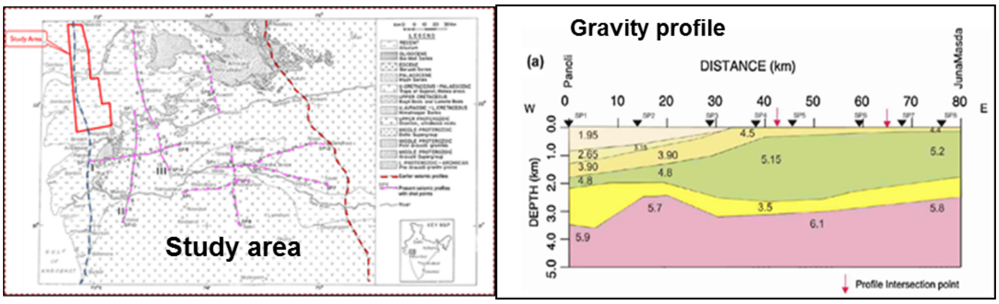

Fig.1 Study area showing GM profile

The basin type, sedimentary fill and the structural styles in the pre Cretaceous basin are completely masked by thick Deccan trap volcanic flows (Fig.2). The earliest appearance of the basin seems to have been during upper Jurassic – lower Cretaceous time when the area was a gentle shelf bounded on the east by the Indian shield. Mesozoic strata may be observed at the surface as a discontinuous band of outcrops around the Cambay basin. These include the Himmatnagar Sandstone and Balasinor Limestone on the eastern margin of the basin, the Nimar group sandstone and Bagh group Limestone on the eastern Narmada river, and the Dhragandhra and Wadhwan sandstone in the northeastern corner of Saurashtra craton. The thickness of the Mesozoic increases from 100-150m on the eastern margin of the basin to more than 750m in wells on the western flank of the basin. Along the Narmada River, thickness increases from 15-30m in the outcrops in the eastern part to about 150m towards the west.

A geological cross section was prepared integrating the gravity, magnetic, seismic, reflection, refraction and DSS data. As interpreted from available GM data, approx. 2km of low density layer, inferred as likely Mesozoic sedimentary sequence is observed in the EW & NS trending GM profiles in the area. (Fig.2). Presence of Cretaceous Himmatnagar/ Nirmar Sandstone, Lameta and Bagh Beds as outcrops in the adjacent area indicate that the area acted as a depocentre during later part of Mesozoic period.

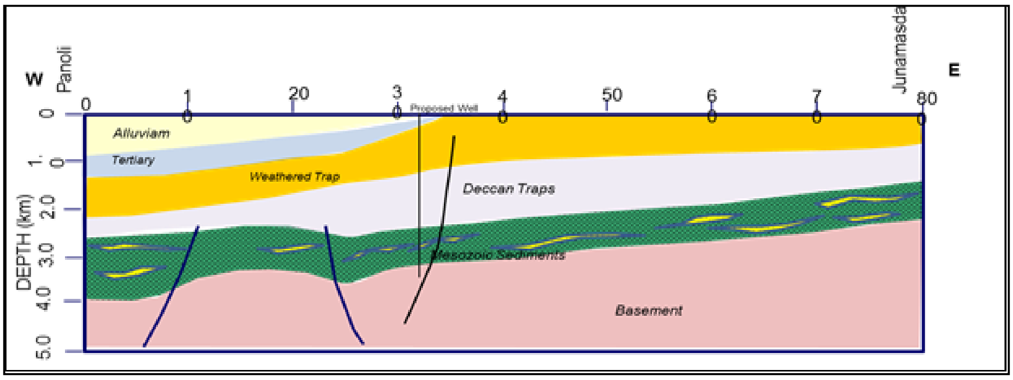

Fig.3 Conceptualized Geological section

The established Mesozoic stratigraphy and litho columns of surface and subsurface are given in (Fig.5). The Pre-Cambrian Basement (Granites and Metamorphics) is exposed along the eastern margin. While the overlying Mesozoics are exposed to the east and west of Basin margin faults. Besides these a few exposures are also seen as detached inliers in Narmada valley near Rajpipla in southern part as well as near Barmer basin in the northern part. The Mesozoic sequence unconformably overlies the Granitic / metamorphic basement and are unconformably overlain by Deccan trap. Marine fossils (fauna and flora) are reported in surface exposures of Bagh and Lameta beds. The Himmatnagar, Songir and Dhranghadhra formations are equivalent to Gondwana and assigned upper Cretaceous age (Krishnan 1982). In the southern margin (Narmada valley) Nirmar group has been assigned lower Cretaceous age, Bagh group – lower to upper Cretaceous and Lametas – upper Cretaceous age.
In subsurface, Mesozoic sequences are reportedly encountered in wells DH-A, VG-A, S E-A, DT-D, in the western part and in A-D, D-B and CR-B in the eastern part of Cambay basin. The genesis and accumulation of hydrocarbons in a basin requires the existence of one or more potential source rocks which must have undergone sufficient burial to attain thermal maturity so that a part of kerogen gets converted to hydrocarbons.

2D Petroleum System Modelling was carried along an 80km E-W profile, considering the Nirmar formation(fluvial lacustrine) and sands within as reservoir, Lameta Formation and Bagh group (transgressive) along with Early Cretaceous shale (? older than Barremian) as speculative source rocks. These constituted the PSE of the conceptualized Mesozoic sequence.
Taking this as a likely scenario it is observed that deeper sequence is attaining maturity within the low that falls west and south of D-B. This low may have functioned as the hydrocarbon kitchen area for the available sub-trappean reservoirs fulfilling entrapment requirements. Therefore, with the presence of speculative source, based on modeling results, there may be possibility of presence of a speculative petroleum system (.) for Mesozoic sequence in the area.

3. 2D-Modeling in the Study Area:

2D-modeling handles mass transfer, both in vertical and lateral directions, hence constructs the GME cycle and leads to better understanding of hydrocarbon generation, expulsion, migration and accumulation/loss through geologic time. A 2D- Petroleum system modeling (PSM) study along one Conjectural geological cross section (approx. 80 km), largely based on 2 wells drilled–east of Cambay Basin, along with limited seismic interpreted data, geological outcrop studies and Gravity-Magnetic modeling profiles (Fig.2), has been undertaken to model paleohistory reconstruction and to assess hydrocarbon generation and migration to evaluate the possible hydrocarbon prospectivity in this area.

2.1 Input Data: One conjectural composite W-E geological was used as input for building the model. The geometry of modelled section with initial horizons is shown in (Fig.3). Each formation/layer is assigned with its relevent lithologies and facies pertaining to Petroleum system elements (Fig.4).

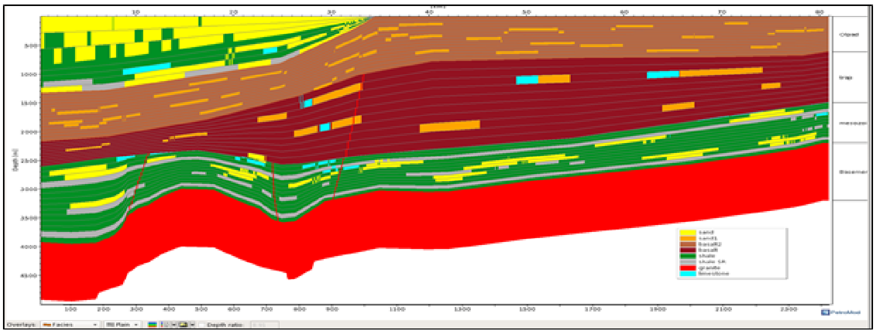

Fig.4. Lithological section depicting layer splits

The lateral variation of facies across the section was taken into account. Geological age of deposition, facies and lithology assignment is given in Table-1, based on the drilled wells data and seismo-geological interpretations.

	Age [Ma]	Horizon	Pre-grid Horizon	Gridded Horizon	Erosion Map	Layer	Event Type	Facies Map	No. of Sublayers	Max. Time Step [Ma]
1	0.00	Horizon_1	Alluvium	Horizon_1_Map						
2						Alluvium	Deposition	FaciesMap_68	3	10.00
3	5.00	Horizon_3	Tertiary top	Horizon_3_Map						
4						Tertiary	Deposition	FaciesMap_10	5	10.00
5	56.00	Horizon_4	Weath trap top	Horizon_4_Map						
6						Olpad	Deposition	weathered basalt	15	10.00
7	65.00	Horizon_5	DT top	Horizon_5_Map						
8						trap	Deposition	FaciesMap_58	10	10.00
9	69.00	Erosion_13_Top								
10						Erosion_13	Erosion			10.00
11	79.00	Horizon_6	mesozoic top	Horizon_6_Map	Erosion_Map_meso					
12						mesozoic	Deposition	FaciesMap_62	15	10.00
13	99.00	Erosion_15_Top								
14						Erosion_15	Erosion			10.00
15	499.00	Horizon_7	basement	Horizon_7_Map	Erosion_Map_bsmt					
16						Basement	Deposition	basement	1	10.00
17	500.00	Horizon_8	Model base	Horizon_8_Map						

Table – 1 : Age Assignment

The lithological facies definition, with assigned petroleum system elements are indicated in Fig.5. The geochemical parameters across the modelled section assigned are listed. The default physical properties (like density, permeability, thermal conductivity, heat capacity etc of standard lithologies) are provided in PetroMod software.

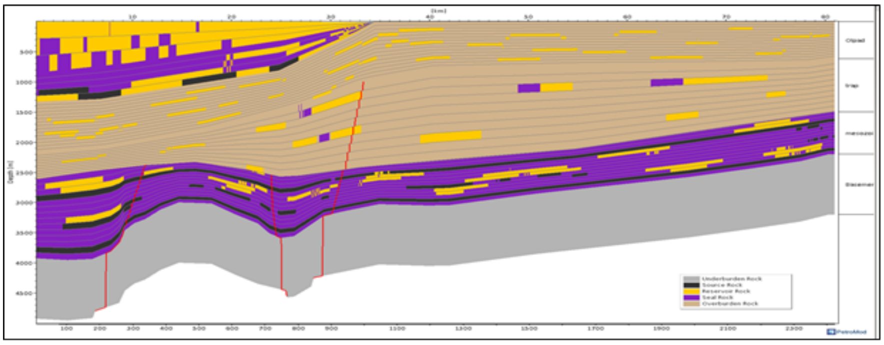

Fig.5. Petroleum system elements

2.1.1 Source Rock: The argillaceous units of Lameta and Bagh Beds Formation within Early - Late Cretaceous Rift Sequence may be considered to be a primary source in the Mesozoic Cambay-Narmada Basins. Envisaged source facies are generally confined within the transgressive sequences belonging to Early and Late Cretaceous periods. Based on numerous published literature (references there-in) regarding hydrocarbon occurrences and reported geochemical studies, a single Total Petroleum System (TPS) with mature source rocks limited to Mesozoic succession deposited in Late Jurassic (?) to Late Cretaceous age may be present in Cambay-Narmada Basin as Cretaceous(?)-Cretaceous (?) TPS. The present day TOC and HI values are taken from drilled well Dabka-2 and are calculated to the original values (TOCo and HIo)**.**

For Cretaceous lower source rock, a Type-III kinetics based on Burnham(1989)_TIII was assigned, where activation energy is 50-62 K cal/mole with maxima at 54 K cal/mole and HI is 200 mg HC/g TOC. For Upper Cretaceous source rock a type-III kinetics based on Burnham(1989)_TIII was assigned, where activation energy is 50-54 K cal/mole with maxima at 52 K cal/mole and HI is 200 mg HC/g TOC

2.2 Heat Flow : The transfer of heat to the sediments is controlled by thermal conductivity (k=W/mK) of the formation and thermal boundary conditions at top and bottom of the model. The resulting heat flow (Q=gradT X k) is derived by multiplication of thermal gradient and rock conductivity. Thermal calibration of present day heat flow regime

was made using observed corrected BHT values from wells Dabka-2 and Anand-D, to calibrate temperature and thermal history.
The subsurface heat flow was varied (keeping thermal conductivity and other physical rock properties constant) to achieve best fit with present day BHT and VRo. A good calibration of BHT and modeled temperatures was observed by setting the present day heat flow to 45mW/m^2. Two paleo heat flow peak of 80 mW/m^2 were assigned for the rifting period and Deccan volcanics**.** The sediment-water interface temperatures (SWIT) are assigned based on Wygrala (1989) Auto SWIT in PetroMod. (Fig.6)

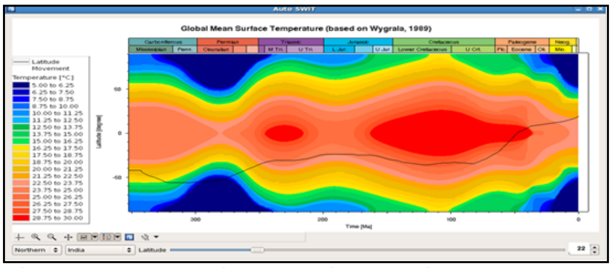

Fig 6. : SWIT trend for Cambay Basin

2.3 Simulation:

The 2D-modeling studies were carried out on integrated 1D, 2D, 3D Petroleum System Modeling software Petromod (Version 17.2) from M/s Schlumberger. The model is simulated with hybrid petroleum migration which is integration of Darcy and flow-path migration methods.

3. Results and Discussion

3.1 Maturity and Transformation Ratios of Source Rocks

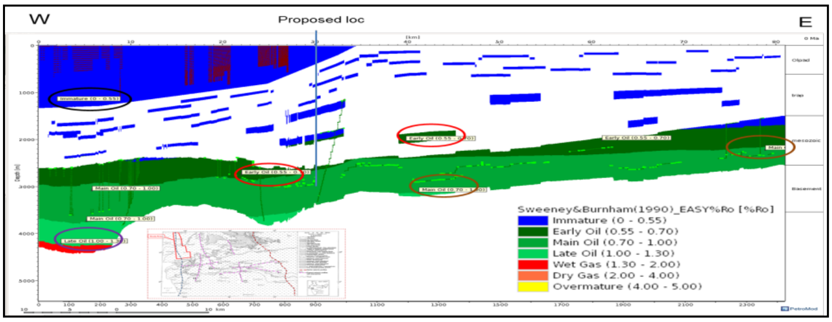

Fig.7. Rock Maturity

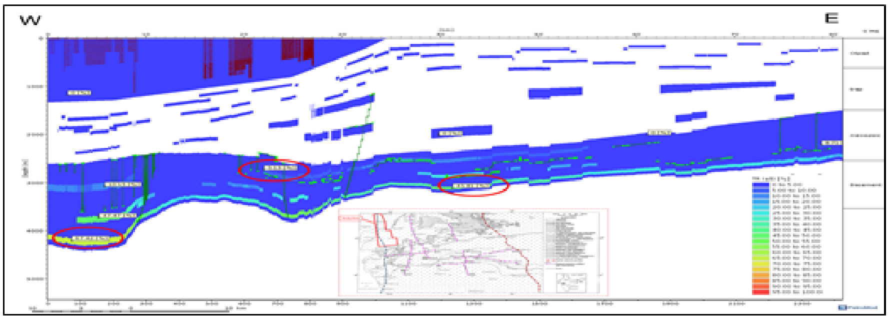

Fig.8 Transformation Ratios

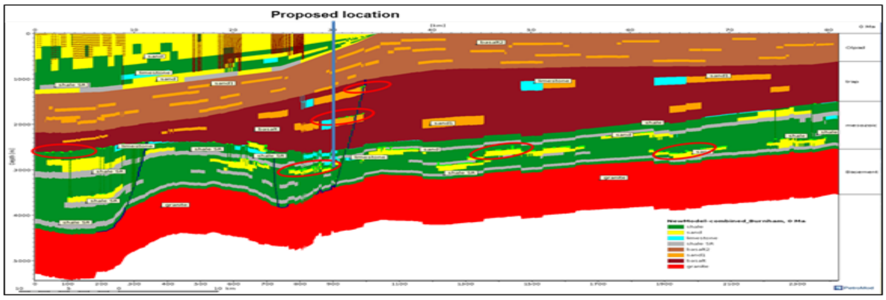

Fig.9 Hydrocarbon Locales within modeled Speculative Mesozoic Petroleum Systems

- Source rock layer in Upper Cretaceous formation falls within early oil to late oil maturity window and attained critical moment around 15 Ma in deepest part of modelled section with present day transformation ratio (TR%) in range of 35% to 05%.(Fig.7)

- In the deepest part of modelled section, Lower source rock layers are in main oil to wet gas maturity window and have attained critical moment approximately at 45 Ma and 10 Ma, with present day transformation ratio for Lower Cretaceous source rock is in range of around 67% and 8% respectively. (Fig.8 & 9)

The present day Source Rock Maturity and Transformation Ratios are shown in the final output of modeling results are summarized in the Events Chart. (Fig.10). It shows the temporal relation of assigned Petroleum System elements and processes of modelled petroleum system. This events chart is to compare different times that the processes occurred vis-a-vis the times that the PS elements formed. It shows entrapment formation at 56 Ma and the preservation of hydrocarbons with critical moment at ~35 Ma for the system.

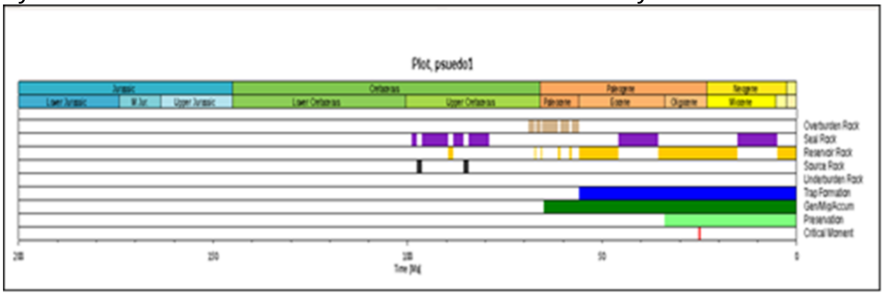

Fig.10. Events Chart

3.2 Modeled Petroleum Accumulation in Studied Section

Through Petroleum System study paleohistory reconstruction and assessment of hydrocarbon generation and migration simulated to evaluate the possible hydrocarbon prospectivity in S Cambay- western Narmada area. Following conclusions can be drawn from extensive discussions on 2D-modeling.

Source rock layer in Upper Cretaceous formation falls within early oil to overmaturity window and attained critical moment around 15 Ma in deepest part of modelled section. Present day transformation ratio (TR%) in range of 35% to 05%.In the deepest part of modelled section, Lower source rock layers are in main oil to wet gas maturity window and have attained critical moment approximately at 45 Ma. Present day transformation ratio for Lower Cretaceous source rock is in range of around 67% and 8% respectively.Hydrocarbon accumulations observed in Deccan Trap basalts flows are within modeled intra-trappeans, which have been charged through the open faults.In 2D modelled section Hydrocarbon accumulation observed is due to structural as well as stratigraphic entrapment.

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