A relook into the Mesozoic Sequence in Kutch-Saurashtra Basin, India

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Abstract

Kutch Saurashtra Mesozoic (~252Ma to ~66 Ma) sequences are overlaid by Deccan trap basalt and Tertiary sediments. The basin has undergone multiple volcanic and rifting processes resulting in intricate basin geometry, flood basalt, volcanic structures and intrusions. Deccan trap basalts are thickening towards the southeast in the Saurashtra Arch area in the Kutch Basin. The sub-basaltic, sub-carbonate imaging, intricate Tectonic settings and varying lithology and unconformities result in the Mesozoic exploration challenging even after multiple discoveries. There are two sets of fault orientation in the Mesozoic sequence, coast parallel and cost perpendicular in which the coast parallel faults are formed by the passive rifting process of the continental margin and failed rift process in the Kutch-Saurashtra Basin resulted in the coast perpendicular fault system. The main ENE-WSW faults are expected in Saurashtra Arch, Gulf of Kutch and KD-KI areas. The rift-related clastic sediment accumulation may be expected thicker in the Saurashtra Arc area and the Gulf of Kutch area due to underlying Mesozoic grabens and hence more interesting. The Early Cretaceous sandstone having on land exposure (Bhuj Sandstones) is extending to Kutch Shelf up to a certain distance from the coastline and sand facies abruptly change into limestone facies. The Mesozoic sequence exhibit half-graben geometry and process syn-rift and post-rift sediments. The uplifted areas of half grabens are shallower and have a high chance of accumulating the Hydrocarbon from the Mesozoic petroleum system. The seismic facies interpretation may help to find out the gross lithology of the Mesozoic sequence where drilled well results are not available.

Introduction

The western continental margin of India is a volcanic passive continental margin. Mantle plume interaction with lithosphere left volcanic flood basalt Deccan trap and Somnath Volcanics (Chatterjee et al., 2013) and several volcanic structures including volcanic plugs (Chandrasekhar et al., 2002), intrusives & sills in the crust. The Kutch basin formed as a part of the earlier rifting process when Greater India (India and Madagascar together) separated from eastern Africa. The continental margin off Kutch-Saurashtra is older Compared to other parts of the western continental margin of India as Kutch-Saurashtra Basin is conjugate with the Somali Plate (Corfield et al., 2010) whereas the rest of the continental margin had rifted subsequently from Madagascar, Seychelles and Laxmi Ridge (Yatheesh, 2020).

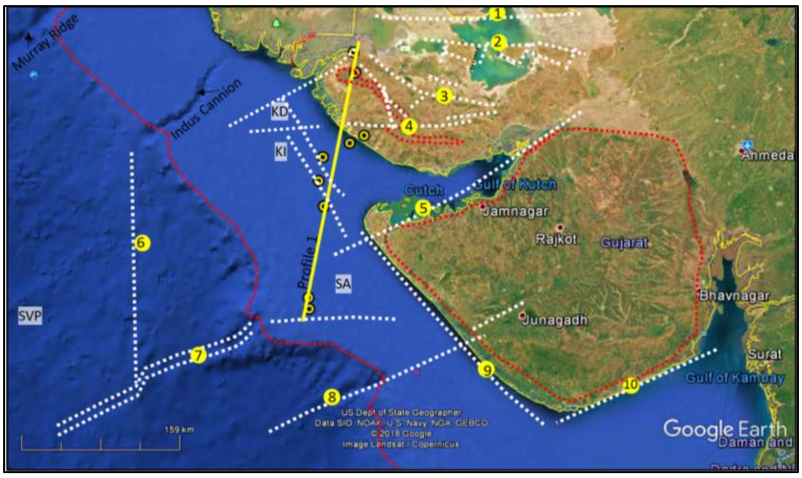
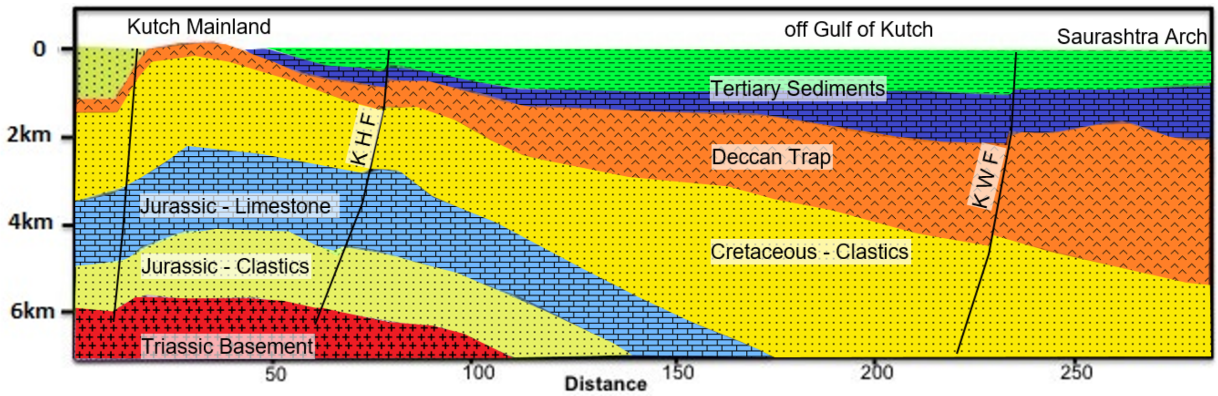


Figure 1: Structural elements overlaid on Google Earth image showing the major fault systems prevalent (Modified after ONGC & Biswas, 2005) in the basin depicted by white dotted lines, The possible extension of Deccan trap in the continental shelf and the surface exposure of the Deccan trap in on land Kutch and Saurashtra peninsula is depicted in red dotted lines. Saurashtra Volcanic Province (SVP) and Saurashtra Arch (SA) and Kutch D and I structures (KD and KI) are important features. 1) Nagarparker Fault, 2) Island belt fault, 3) Kutch mainland fault 4) Katrol Hill fault, 5) Kathiawar fault 6) Dwaraka fault, 7) Central Meridian faults of Saurashtra Arch 8) Girnar fracture zone 9) Coast bounding fault of Saurashtra / Kim Fault 10) SE Coast bounding fault of Saurashtra are important faults;

The Kutch basin is a peri-cratonic basin situated in the state of Gujarat in the northwestern continental margin of India (Biswas, 2005). The basin extends from on land to offshore from Nagar-Parkar Fault in the North, the Radhanpur-Barmer Arch in the East, Saurashtra Peninsula and Saurashtra Arch in the south& southeast extend to the deep water towards the ocean basin and India-Pakistan political boundary in the west and northwest (Figure 1). From the Saurashtra Arch (Sriram et al., 2006) to the Diu Arch off the Saurashtra peninsula is known as the Saurashtra basin. Most of the Saurashtra peninsula is covered with Deccan Trap volcanics. Deccan trap spreads across onshore and offshore areas of peninsular India. The thickness of the trap varies from ~150m, north in the Kutch shallow water to ~2800m in the south on the western flank of the Saurashtra Arch. KI structure, paleo-high on the Kutch shelf is devoid of Deccan Trap. A thin layer of Deccan trap extends probably up to the Murray Ridge in the lower Indus basin of Pakistan indicated in the drilled well results off Karachi (Gong et al., 2020).



A geological cross-section from north to south connecting Lakhpat of Kutch mainland to the Saurashtra Arc in the off-Saurashtra Peninsula depicting lithological and trap thickness variation is presented in Figure 2. The length of the profile is about 260km and covers most of the important features of the basin. Due to the tilt in the basin, the trap is exposed in the Kutch on land. The Katrol Hill (KHF) and Kathiawar fault (KWF) cut across the area. Mesozoic sediment thickness increases toward the south in the Saurashtra Arc region. The section shows the basin is tilted towards the southeast towards the Saurashtra Arch region resulting in a higher thickness of Trap and Mesozoic sediments.

Figure 2: Geological cross-section (Profile 1) depicting the lithology and trap thickness variation in N-S direction from Kutch mainland to Saurashtra Arch. The profile location is shown in Figure 1. The lithological variation is interpolated from the nearby wells and is represented as yellow dots in Figure 1.

Geo-potential data modelling will help us to identify crustal heterogeneities and depth to the basement.

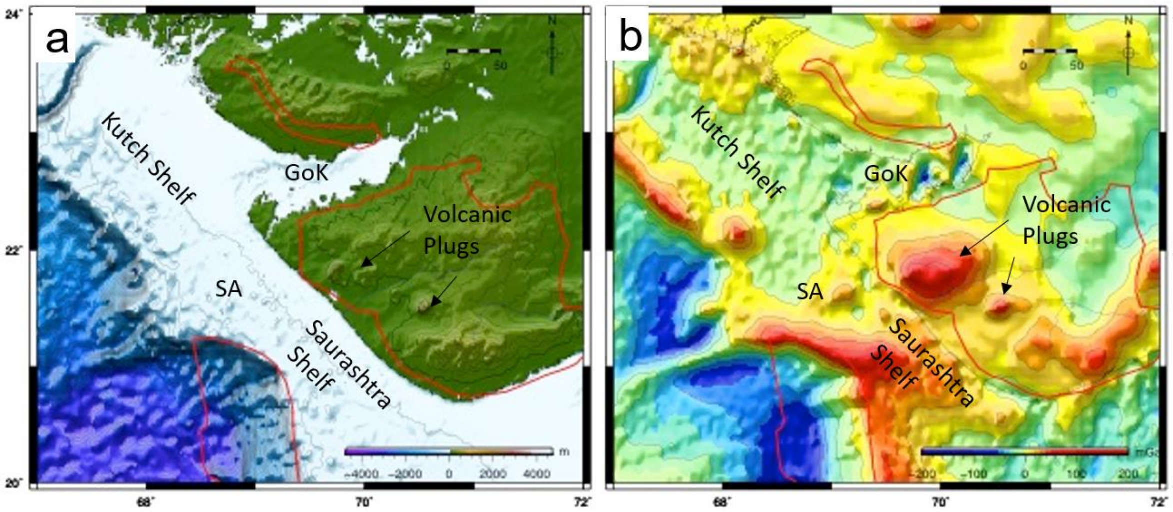


Figure 3: a)Topography and Bathymetry b) free-air gravity Kutch/ Saurashtra sub-basins.

Figure 3 shows the comparison between the topography versus the free-air gravity anomaly (Sandwell & Smith, 1997). The volcanic plugs and southern part of Saurashtra Arch (SA) show high gravity anomaly and the basinal areas show moderate gravity anomaly. The Saurashtra Arc signature can be seen in the topography as well as in the Gravity.

In the Kutch shallow waters, hydrocarbon plays are established in the Tertiary as well as in the Mesozoic sequences. The Tertiary plays are not extensive and limited to isolated structures compared to other producing hydrocarbon fields. The carbonate sequences in the Kutch Basin hardly acts as reservoir except in very few wells and the porosity development is limited. The carbonates are generally denser and nonporous in most parts. The sandstone is the primary reservoir rock and producing sands are available mostly in the Early Eocene and Miocene in the Tertiary. The main sand sources in the Kutch shallow water Tertiary sequences are from either bar complexes or the fluvial channel systems and are limited compared to deltaic sands. Whereas the Mesozoic encompass thick clastic sediments for example alternate sand shale sequence in the Early Cretaceous. The reservoir pressure is also higher than the Tertiary because the depth and extent of the structures are also sizeable.

Sub-Basaltic Imaging and seismic velocity profile

Many exploratory wells have drilled through the trap establishing the Mesozoic pay but the success wasn't consistent due to poor seismic imaging. Reservoir characterization of the Mesozoic sequences is the most challenging problem. Mesozoic clastics are below the carbonates & basaltic sequence of high velocity and a very feeble amount of seismic energy reaches to Mesozoic after traversing through the high-velocity medium. The Kutch basin is having unconformities including angular unconformities and hiatus sequences that make the interfaces irregular and the seismic waves get scattered and dissipated. Multiples including peg leg multiple mask the primary reflectors and create coherent reflectors below Basalt.

The trap has high velocity than that of the surrounding sediments. The low-velocity zone that gets shadowed is one of the major problems in sub-basalt imaging. Moreover, these shadowed zones are mainly clastics and are zones of interest. The Mesozoic sediments have lower velocities than the overlying trap. Velocities from the Vertical Seismic Profile (VSP) data were analyzed from drilled wells that penetrated through the Mesozoic sequences in the Kutch shallow water area (Figure 4). The VSP derived interval velocities range from 2200m/s to 6000m/s. The interval well velocity in the trap ranges from 4000- 5800m/s in the Kutch Basin and in which the thick and weathered Deccan trap sections show a high range of velocities. The tight limestone also exhibits high velocity as in the Deccan trap. Whereas the clastics, marl or porous limestone below displays the low-velocity zone (LVZ) below the trap. This LVZ becomes a problem while seismic data processing and acts as a shadow zone.

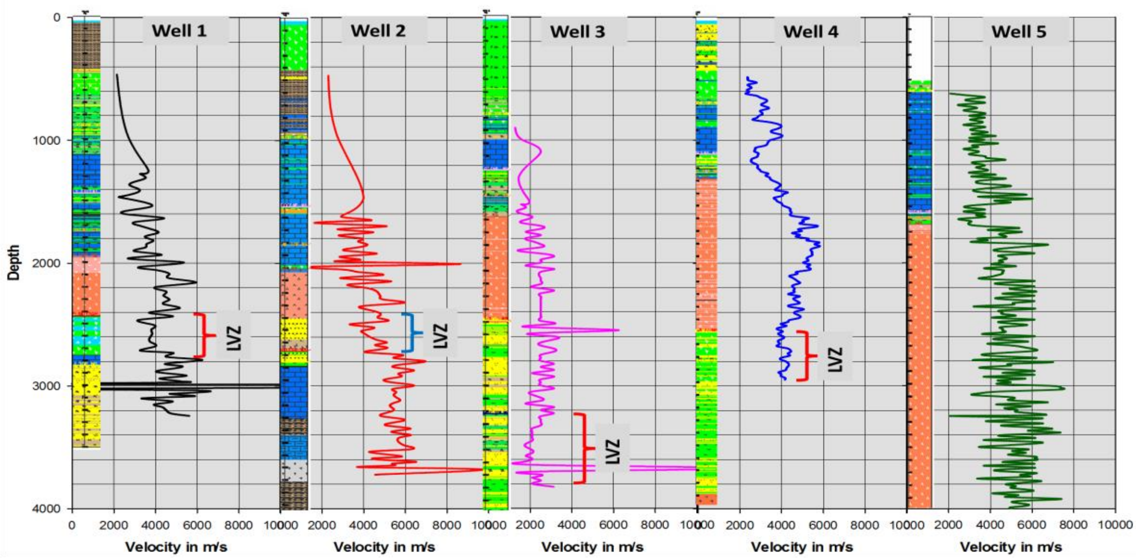


Figure 4: Comparison of interval velocities derived from vertical seismic profile (VSP) of Mesozoic wells taken from different parts of Kutch Kutch basin shown against the lithology.

Most of the Mesozoic sequences get masked by the multiples. Low-frequency data enhance the mappable events but the identification of inter bed multiple from the primary becomes challenging for the interpreter. In general ‘Water Bottom Multiple’ is one of the strong multiple found in the offshore data and is easily removed while processing. Whereas in the Kutch shallow water we can find the strong inter bed/peg leg multiple from the major lithological boundary which mimics the primary reflection in the Mesozoic. The high impedance contrast within the Tertiary layers due to Early Miocene and Paleocene Carbonates result in the interbed reflections and is seen in the Mesozoic level in the poorly processed seismic data. The Early Miocene top portrays the change of the claystone-dominated lithology to Limestone and the Early Eocene clastic to thick Paleocene Limestone is another dominating event.

Fault Structure

The Mesozoic Fault system is assumed to be rift-related and these faults are parallel to the coastline formed in the passive margin set up and there are cross faults in the Saurashtra Arch area, Gulf of Kutch area and the KD-KI area (Figure 1). These cross faults are parallel to the Kutch-Saurashtra Failed rift system. The KD-KI area is highly transformed and forms broad inversion structures.

Basin geometry

The Mesozoic sequence below basalt constitutes a syn-rift and post-rift sequence. The formation dips and the geometry of the Tertiary sequence are distinctly different from the syn-rift sequence of the Mesozoic. The Tertiary sequences dip towards the ocean basin whereas the Mesozoic sequence exhibit dips like that in a horst graben sequence (Figure 5).

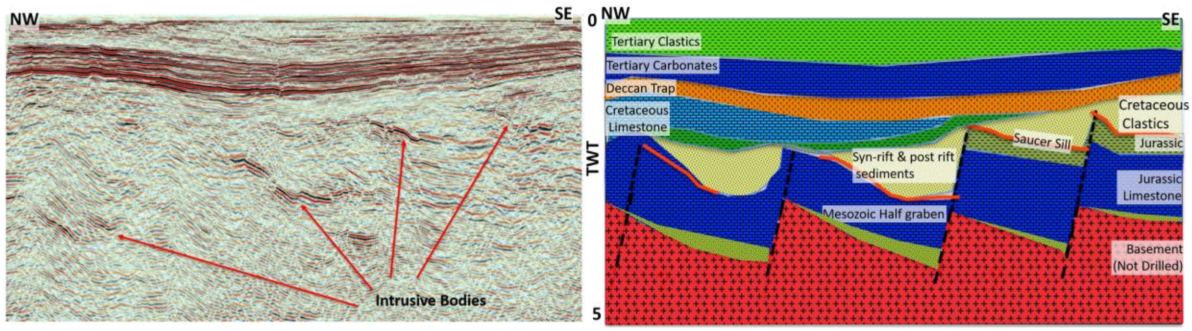


Figure 5: Seismo geologic section depicting the Mesozoic basin geometry in the northwest-southeast direction with interpreted rift-related horst- graben basin geometry in the Mesozoic and syn-rift sediments

Litho stratigraphy of Mesozoic Sequence

There was a global transgression in the Early Jurassic and major deposition started in Kutch from Middle Jurassic in Early Cretaceous the regression started. The main lithology in the Mesozoic sequences contains limestone and clastics (Figure 6).

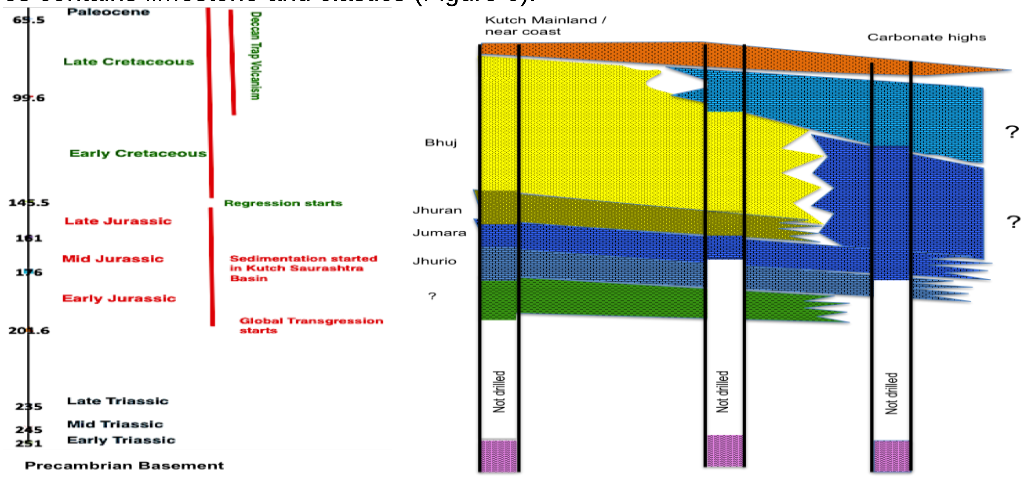


Figure 6: Lithostratigraphic variation Kutch mainland from Kutch mainland to shallow water carbonate highs (KD High) along with the age and major events

In the Late Cretaceous Sequence, Limestone & Marl is not found in the coastal belt of Kutch but are found after a certain distance of ~ 25 nautical miles from the coastline. The Cretaceous Bhuj Sand is exposed in Onland and Kutch Saurashtra on land areas and extends to a limited area of the shelf the Early cretaceous facies map is depicted in Figure 7. The Jurassic of Kutch is mainly Limestone at the top and clastic in the lower section.

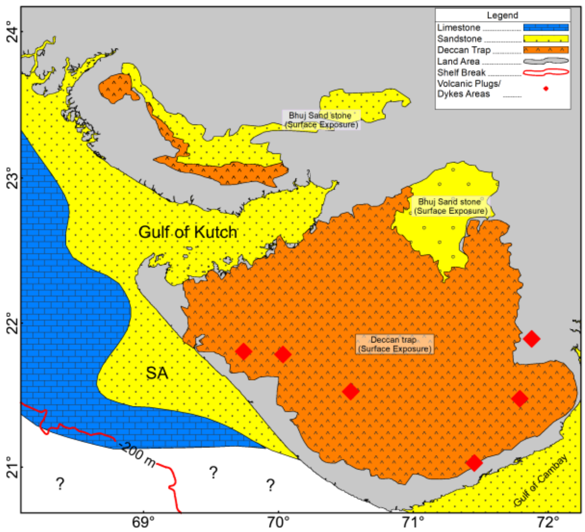


Figure 7: Early Cretaceous facies map showing sand to limestone variation in the Kutch Saurashtra Shelf area along with the on-land exposure of Deccan trap and Bhuj Sandstone

Litho-Facies identification in the Mesozoic sequence through Seismic facies.

Litho-stratigraphic information below basalt is vague due to poor seismic quality and less number of wells that were drilled in the Mesozoic. Mesozoic Sequences in the basin are having horizontal as well as vertical variations in the lithology and half-graben geometry. In the Sub-Basaltic sequences the Gross Litho- facies is directly correlatable with the Seismic facies after reprocessing. The gross lithology of the Mesozoic sequence can be identified from the seismic facies.

The Carbonate sequences are seen with continuous high amplitude reflectors while clastic sequences with thick Sand dominated areas are characterized by less continuous low amplitude events and alternate sand shale sequences are more continuous with low amplitude events (Figure 8). The typical angular and high amplitude events (Figures 5& 8) which cut across the sequence, are intrusives in the area. These bright events help to visualize the fault displacements easily in the deeper section. Some of the extremely low amplitude events seen in the seismic sections may be due to low impedance monotonous shale packs

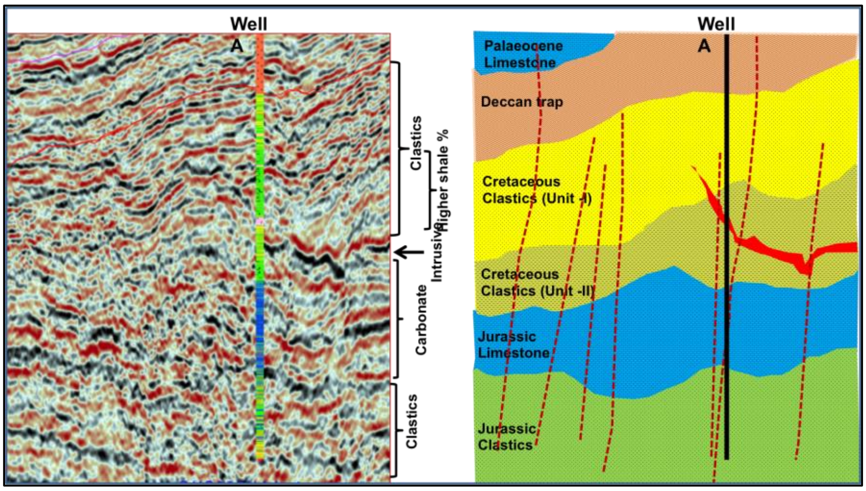


Figure 8: Reprocessed seismic section with drilled well lithology plotted against inferred lithology distribution

Petroleum system

There are three types of petroleum systems expected in the Kutch basin. Tertiary petroleum system, Mesozoic petroleum system and Tertiary-Mesozoic petroleum system. In the Mesozoic petroleum system source, reservoir and seal will be of the Mesozoic age. Shale in the lower unit of Early Cretaceous and Jurassic sequences in the Kutch may possess the source potential (Biswas, 1982), Early Cretaceous (Bhuj) sands are good reservoirs rocks and the alternate shale in the same sequence may act as the seal. The Mesozoic petroleum system is established in Kutch shallow water from the inferences drawn from the significant discoveries in the Kutch Shallow waters and Saurashtra Arch areas.

Conclusion

Many exploratory wells in the Kutch have booked success in the Tertiary as well as the Mesozoic sequences. For converting the Kutch-Saurashtra Basin from Category II to Category I Basin, the Mesozoic prospects will take a lead role over Tertiary as Mesozoic plays have a comparatively better reservoir, extensive structure and high reservoir pressure. Seismic processing exclusive for sub-basaltic imaging will give better results. Interpretation integrating regional information on rift-related and paleogeographic, structural and litho and facies information as well as in the prospect level structure and reservoir information give desirable results in finding the hidden prospects. Unmasking the effects of the Deccan trap is inevitable for success in the Mesozoic which holds huge prospects to be discovered.

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