Prospectivity of Engimatic Paleocene Razole Trap and Inter-Trappean Sediments of KG Basin, India – A Way Forward for Unconventional Play Prospect

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Abstract

In the process of hydrocarbon accumulation in many parts in KG Basin, the Razole Trap actually plays a positive role, including promoting the maturation of source rocks or providing shelter for hydrocarbon accumulation. This article discusses the prospectivity of Hydrocarbon accumulation in the Razole Trap of KG basin. The Razole Trap, laid down by multiple lava flows during the Paleocene to Upper Cretaceous, are extensive in the KG- Basin. The Razole Trap are overlain and underlain by a thick sedimentary succession of clastic reservoir rocks and shale barriers including the Raghavapuram shale-–the major source rock. Several faults are cutting across the Cretaceous sediments upto the Razole Trap basalts, which can act as the conduits for migrations of the hydrocarbons. This article presents the results of an integrated study carried out to identify and evaluate the hydrocarbon-bearing intervals of the basaltic trap which can be used as unconventional play system in this part of the study area.

Introduction

Oil and Gas has been obtained from many volcanic naturally fractured reservoirs around the world. Jatibarang field in Indonesia is an example where production has been obtained from Eocene and Oligocene lavas. Similarly, in the Jatibonico pool in Cuba more than 1200 wells were drilled in fractured serpentines and the Pina reservoir in Cuba where production has been achieved in Upper and Lower Cretaceous tuffites. The Hilbig pool in Texas also produced from Cretaceous palagonites whereas the McArthur River field, Cook Inlet in Alaska produced oil from Jurassic tuffites and volcanic sands. The Kora oil field in New Zealand also found producible oil in an Upper Miocene volcanic zone (Aguilera 1995). In recent years, the basaltic basement has become a proven hydrocarbon producer in some fields such as Padra and Gamji of the Cambay Basin (Kumar et al 2002, Kumar 2006).

In the process of hydrocarbon accumulation in many parts in KG Basin, the Razole Trap actually plays a positive role, including promoting the maturation of source rocks or providing shelter for hydrocarbon accumulation. This article discusses the prospectivity of Hydrocarbon accumulation in the Razole Trap of KG basin. The Razole Trap, laid down by multiple lava flows during the Paleocene to Upper Cretaceous, are extensive in the KG- Basin. On the basis of outcrop studies, core studies and formation evaluation studies carried out in the KG Basin, Razole trap can be classified into three categories: massive basalt, fractured columnar basalt, highly altered vesicular basalt depending on the flow characteristics. In between the flows are present inter-trappean sediments comprising of Sandstone, Claystone and Limestone.

Many wells were drilled to target the hydrocarbon accumulations in the Razole Trap and the results have indicated that the fractured columnar basalt facies host effective porosity and permeability and are the probable reservoir rock. The Razole trap are overlain and underlain by a thick sedimentary succession of clastic reservoir rocks and shale barriers including the Raghavapuram Shale-–the major source rock. Several faults are cutting across the Cretaceous sediments upto the Razole Trap, which can act as the conduits for migrations of the hydrocarbons. This article presents the results of an integrated study carried out to identify and evaluate the hydrocarbon-bearing intervals of the basaltic trap which can be used as unconventional play sytem in this part of the study area.

Geological Setting

The NW-SE trending Godavari Rift and the NNE-SSW to NE-SW oriented KG Basin represents a tectonic junction known as Godavari Triple Junction. This terrane preserves a geological record spanning Mesoproterozoic to Neogene and provides evidences for Gondwana break-up, Cretaceous continental rifting and drifting. Lakshminarayana (1995a) suggested that a series of NE-SW step faults controlled the development of east coast basins since Mesozoic. The blocks from west to east direction are the Mailaram high, Dammapeta Basin, Raghavapuram Basin and Pangidi-Rajahmundry. Basin Rajahmundry Traps' (RT) is a topic of great interest to the geo-scientific community because of its temporal correlation with K-T boundary and geochemical similarities with the Deccan Traps. RT occurs as four major outcrops, two on either side of southerly flowing Godavari River, near Rajahmundry, Andhra Pradesh. They have width of over 2 km and a cumulative length of 80 km. The exposed lava succession consists of flows with thickness varying between 20 and 60 m. In addition, good exposures of infra- and inter-trappean sediments are also seen. The total expanse of RT is much larger (ca. 15000 km2 with thickness over 175 m) with its continuation subsurface below the Tertiary and Quaternary sediments further south of these exposures up to the present shoreline of the Bay of Bengal (Raju et al. 1996). This subsurface occurrence of RT is often referred to as Razole Traps.

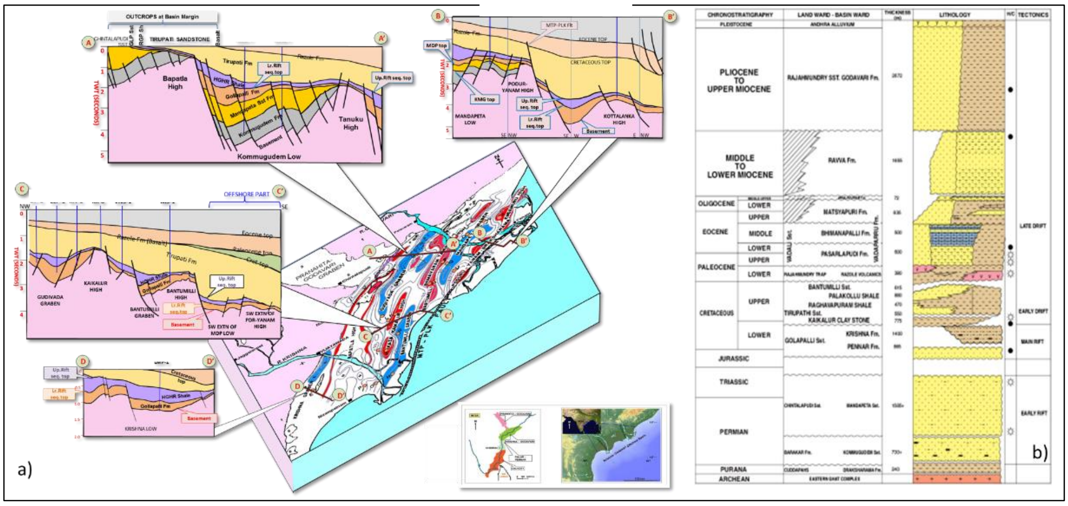

Figure 1) a) Basin fill map of KG Basin super imposed on Geological Map. Seismogeological profiles illustrating the tectono-stratigraphic setup in different parts, b) Stratigraphy of the Krishna-Godavari pericratonic basin. (Source: ONGC Reports)

Outcrop Studies

The outcrop studies carried out during the present study bring out some important characteristics of the Razole Traps. The Razole Trap units here comprise of three distinct basaltic lava flows (lower, middle and upper) separated by two Intertrappean sedimentary horizons identified as Intertrappean I and II. The 20-30 m thick lower flow unconformably overlies the Maastrichtian-Danian Infratrappean bed. The lower basalt flow is characterized by the presence of physical volcanological features such as rootless cones, tumuli and dyke along with prominent development of single to multi-tier columnar and radial jointing. Intertrappean I consists of 2-3.5 m thick clay, marl and limestone intercalations which is sandwiched between the lower and middle flows of RTB. The middle flow represents 6-10m thick, greenish grey vesicular basalt resting unconformably over the clay and limestone of Intertrappean I. This flow is 1-2 m thick and appears to be massive. The middle flow is overlain by Intertrappean II which is made of red clay/red bole. The upper flow (5-17 m thick) unconformably overlies the Intertrappean II and is made of fine-grained vesicular basalt.

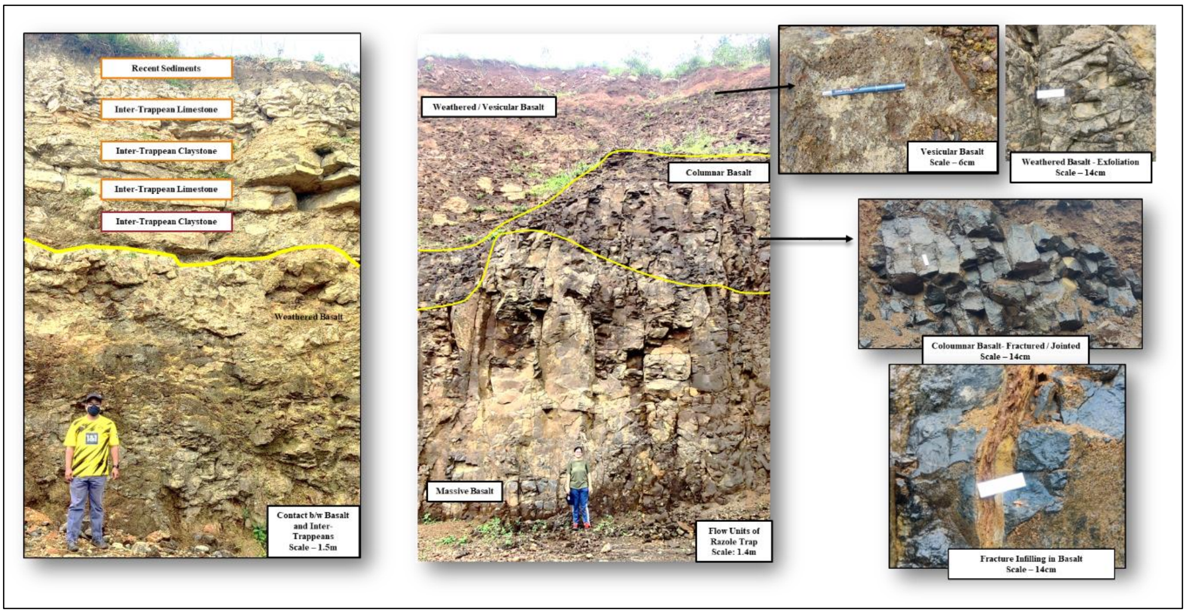

Figure 2 Outcrop images of Razole Trap Volcanics in West Godavari Sub-Basin, KG Basin

Within each basaltic flow, further three distinct units can be identified on the basis of the morphology of the flow caused due to the cooling patterns of the basalt. At the bottom present is the colonnade or massive basalt which is usually one-fifth of the total flow thickness and is characterised by 4 to 6-sided, 0.5-1 m wide vertical columns. The middle part is the columnar basalt or the entablature zone is typified by curved or radiating prisms of lava and accounts for about half of the flow thickness. The columns of this zone aretypically narrower than the colonnade; usually less than 0.5 m in width. At the top is the vesicular crust of the flow is dominated by mm to cm size, spherical vesicles; a few being larger (tens of cm in size) and relatively flattened. The vesicles of the vesicular zones are often filled with zeolites and other secondary minerals. The vesicles in the lava core are fewer in number, larger in size (often over 10 cm) and relatively flattened.

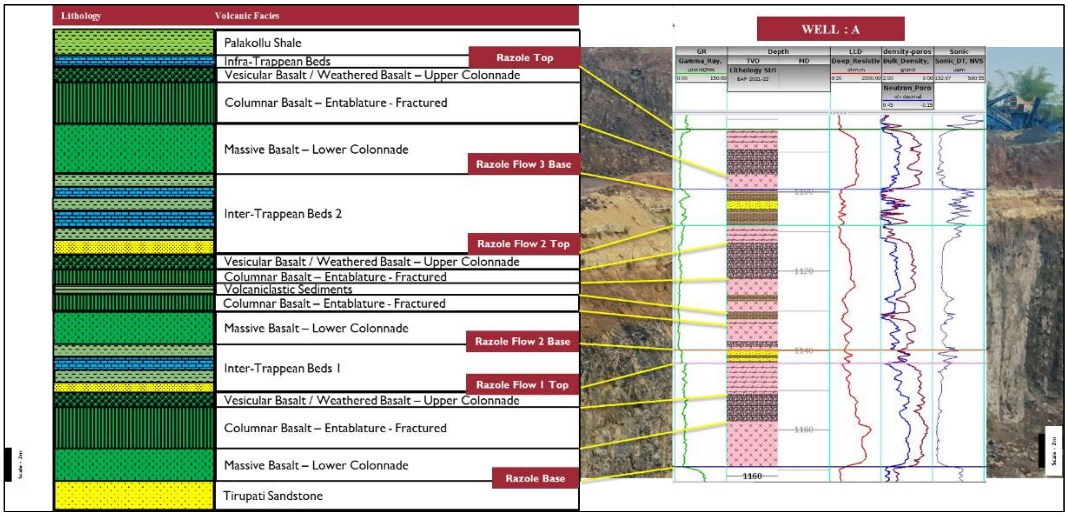

Figure 3 Razole Trap Formation - Volcanic Facies classification correlated with well log and outcrop

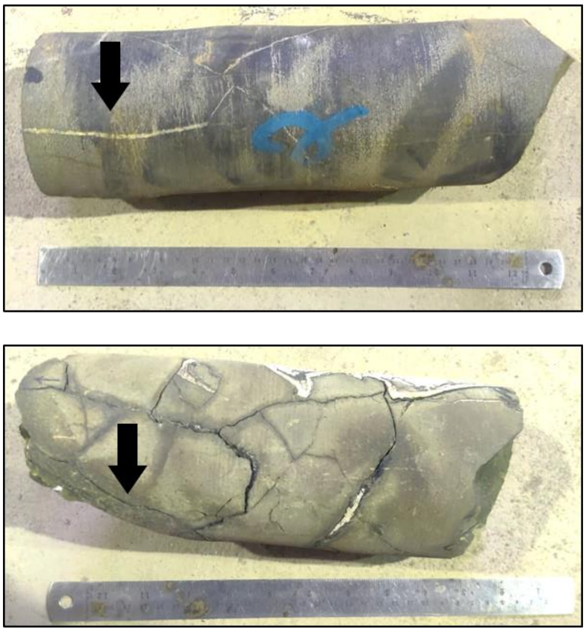

Figure 4 Cores of Fractured Basalt of Razole Formation

Seismic Data Studies

A 3D post-stack seismic cube was analyzed to study the general structural features of the Razole Trap Formation in the KG Basin. Several 2D interpreted seismic sections (inline and crossline) were constructed. In addition, detailed subsurface structural mapping was generated for the top of the Razole Formation.

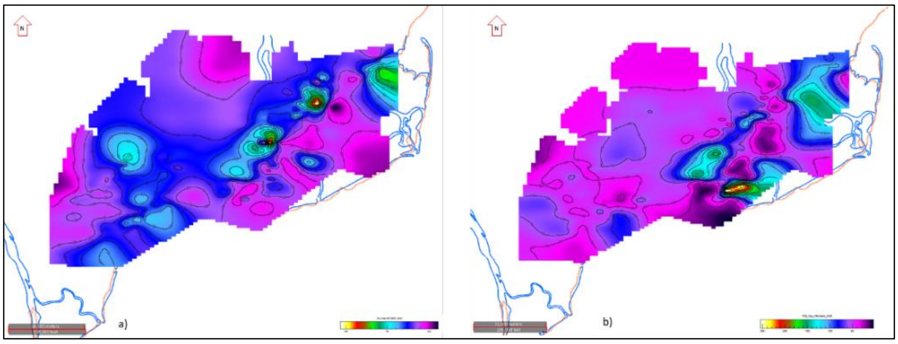

Figure 5 a) Razole Trap Inter-Trappeans Gross Thickness Map, b) Razole Trap Basalt Gross Thickness Map

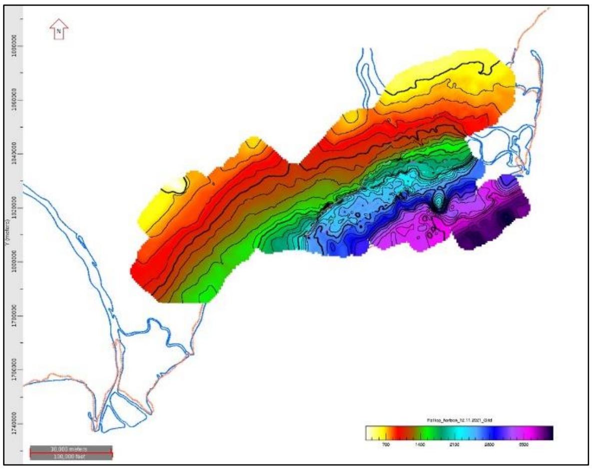

Figure 6 Depth Structure map of Razole Trap Formation

The gross thickness map of inter-trappeans and trap basalt were prepared using well log data by demarcating the different flows by log characteristics as shown in Fig 5. These maps give an overall understanding of the variable thickness distribution of intertrappeans and trap basalts throughout the basin. The Razole Formation separates the Mesozoic petroleum systems of KG basin from the Cenozoic Petroleum systems and is marked at the top by a contrasting high amplitude at the top. The depth ranges from 100 m above sea level to 3500 m below sea level across the basin. The Razole Formation offers a regional seal of the whole Mesozoic petroleum system of the KG Basin. The NW-SE fault systems are more developed than the NE-SW ones, especially in the middle area where the two prospective basement horst blocks are separated by a deep half graben created during the Late Jurassic rifting. The Tanaku and Kaza uplifts are of interest for further drilling and development activities. Most oil producing wells are drilled through these two uplifts; however, another uplift with good potential was detected in the south-eastern part of the study area.

Well Log Data & Formation Evaluation

Mafic igneous lithologies produce characteristic wireline log signatures which can be used to indicate rock types in wells without core data. Logs used for lithological interpretation of igneous rocks in this study include gamma ray, deep and micro-resistivity, density, neutron porosity, acoustic travel time, caliper and photoelectric factor, though in some wells only a partial log suite is available. Basaltic material produces typically low gamma values (15-60 API) due to the low abundances of U, Th and K in early crystallising minerals from mafic melts. Tabular lavas (individual flows comprised of singular cooling units) are characterised by blocky log motifs – often with asymmetrical bell-shaped profiles (Planke 1994) – with high resistivity (20-200 ohm.m), high density (2.7-3.1 g.cm-3) and fast acoustic travel times (40-60 µs.ft-1 or 5.1-7.6 km.s-1). Inter-Trappean sedimentary rocks have lower densities (2.3-2.5 g.cm-3), resistivities (1-10 ohm.m) and acoustic travel times (60-80 µs.ft-1 (5.1-3.8 km.s-1)) than subaerial lavas, exhibiting high neutron porosity due to the presence of clay-bound water, and display a wide density-neutron separation similar to that of shale.

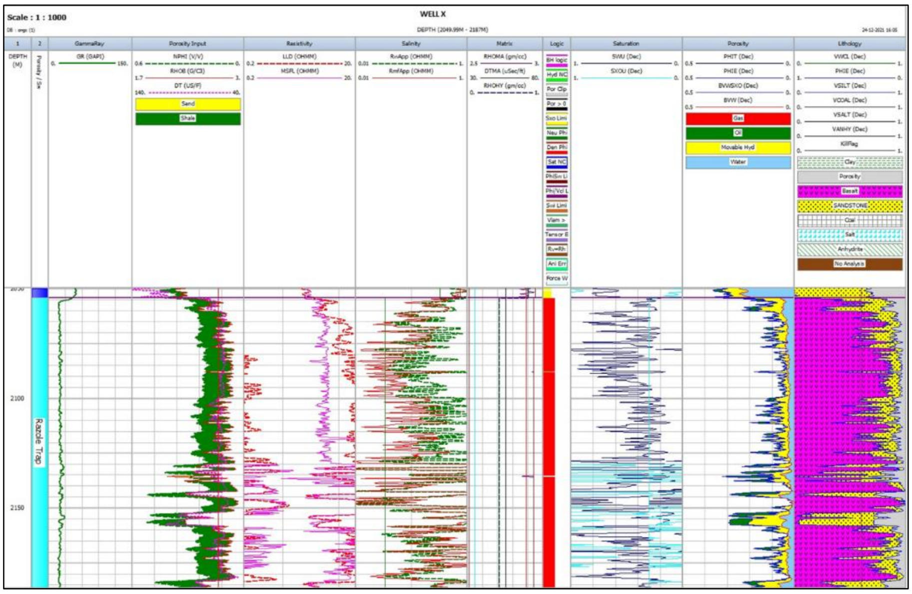

Figure 7 Formation Evaluation of Well X which has produced from Razole Trap Formation

The formation evaluation of the well shows that there a number of fresh and weathered basalt intervals are identified from well logs The logs also show the above interval as moderately weathered basalt. The total porosity estimated from PHIE is displayed in the last track. There are some good porosity intervals where the porosity is ranging from 15-20%. In weathered basalt, it varies from 10 to 25% and water saturation varies from 30-50%. One object was tested in the interval 2055m-2189m and the well flowed gas and water at 1,34,940 m3/day & 22 m3/day respectively at FTHP: 2960 psi through 20/64” choke. During drilling, Gas kick at 2071m was observed during drilling the basalt section in this well and the sample cuttings showed specky GYF and mild positive cut.

Play Prospectivity Analysis

The Razole Play can be divided into two separate play systems having different reservoirs: 1) Fractured Basalt Play system and 2) Inter-Trappean Play system. Known reservoirs in the area are the fractured basalts and the sandstones in the inter-trappeans. The organic rich formations of Late Paleocene Palakollu shales and Upper Cretaceous Raghavapuram/Chintalapalli shales serve as the primary source rock. This sequence comprises four lithofacies-highly carbonaceous shale, medium grained sands, limestone and silty shale, the last one constituting the major part of the sequence. The organic matter in the sequence is dominantly type III and III B. Contribution of type II was reported in a few wells. The maturity level varies between catagenetic to inadequately mature in different parts of the basin. The basalts are themselves acting as the seal for these plays and at times, intervening shales also act as local seals for the reservoirs. The paleontological data and the presence of marine limestones indicate the deposition of these lava flows in sub-marine conditions and the following deposition of the inter-trappean sediments in shallow-marine conditions. Faults cutting across from the Cretaceous sedments and extending upto the Paleocene sediments serve as the conduits for the migration of hydrocarbons. The fractured basalts are the primary gas reservoirs in the Razole area besides the Paleocene Sandstones. Generally, the presence of hydrocarbons in these unconventional reservoirs could be detected from the indications during drilling or by production testing. The possible fracture zones can be identified mostly on the basis of qualitative interpretation from PE curves, low densities within the volcanic flows, high neutron porosities, low resistivity within the within the flow and shear wave analysis.

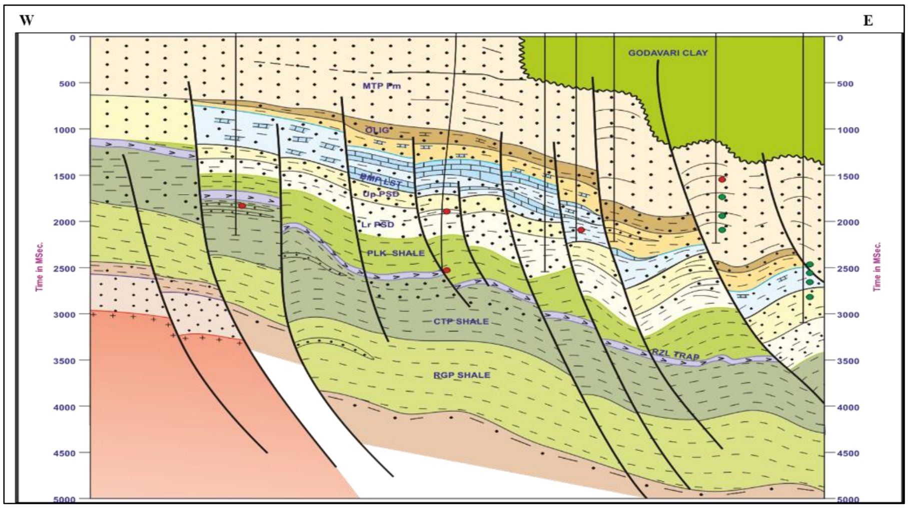

Figure 8 Seismo-geological cross section along W-E of KG Basin depicting the Razole Petroleum System

Several fault propagated folds and domal strucutres are identified via the seismic data analysis. Few folds are juxtaposed against faults originating from the Cretaceous sediments and can probably host hydrocarbons. Other features include domal structures in the basin-ward part of KG Basin. The past exploration efforts in the Razole Trap play have been mainly focused in the Razole and Ellamanchili area on the Fractured Basalts and Inter-Trappeans. Seismic surveys have brought out well defined structural closures at horizon-II & horizon-III levels in Razole area which correspond to Eocene Limestone and Paleocene volcanic flows respectively. Based on time structure maps, different fault blocks have been identified in the Razole area. Three wells drilled on the southernmost fault blocks have produced commercial quantities of gas in Paleocene volcanic flows and inter-trappean beds. The well drilled on the northern side of fault block also indicated presence of gas in volcanic flows and inter-trappean beds of Paleocene age. Elamanchili prospect was mapped as fault closure at Lower Eocene and Paleocene level. One Elamanchili well was drilled on these prospects and they have shown presence of hydrocarbons within Razole Trap sections.

Conclusion

The multi-study approach for the prospectivity of Paleocene Razole play shows that the seismic sections and depth structure maps reveals that the Razole Trap Formation is primarily dissected by several NW-SE step-like normal faults and, to a lesser extent, by NNE-SSW faults. Fractures are clearly identified using the integrated logging plots and the resistivity ratio method. The fractures are also observed on the outcrop level and core data. Most of the reservoir clusters are located within the hydrocarbon-bearing fractures, while a considerable amount of data is available for the massive featured hydrocarbon zones. Hydrocarbon saturation in the Razole Play is associated with highly fractured. Fracture porosity reaches 12%, while average reservoir porosity is less than 5%. The dominant lithology is Basalt and Inter-Trappean Sandstone, Claystone and Limestone. Traps are created by the basalt flow units within the Razole Formation. Hydrocarbon emplacement is through fault juxtaposition of the fractured Razole Trap blocks against the organic-rich shale of the Raghavapuram Formation. Hydrocarbon charging occurred through lateral or up-dip migration of hydrocarbons from the Raghavapuram Formation in nearby structural lows. The uplifted and fractured reservoir blocks are of prime interest in terms of hydrocarbon accumulation and production.

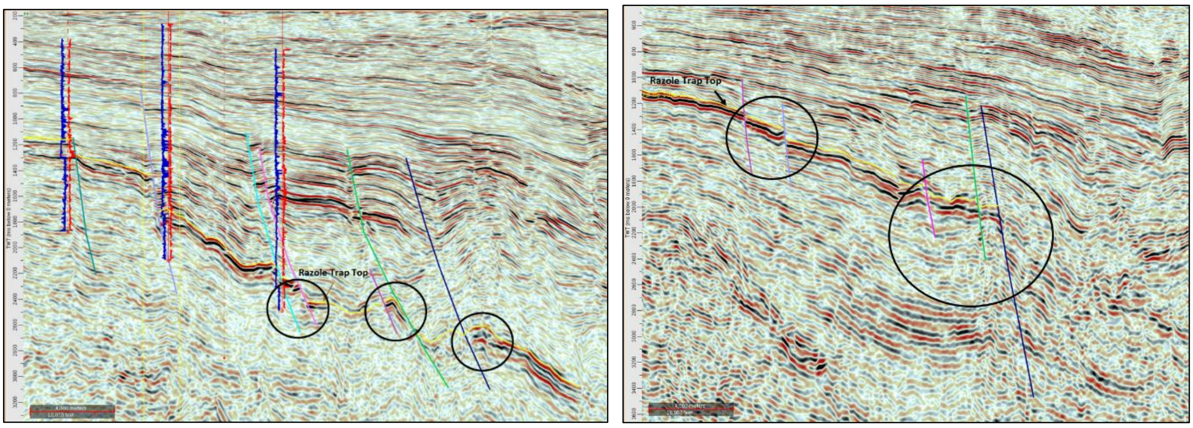

Figure 9 Seismic Sections showing Play set up of Razole Play along with some prospective areas

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Reference

1. Aguilera R. Naturally Fractured Reservoirs. Tulsa, OK. Pennwell; 1995.
2. Pendkar, N., Kumar, A., 1999; Delineation of Reservoir Section in Deccan Trap Basement, Example from Padra Field, Cambay Basin, ONGC Bulletin, V.36, No.1 (June 1999), p. 83-88.
3. Kumar, A., Narayan, J.P., Pabla, S.S., Mahanti, S., Lakhera, S., 2004; Formation Evaluation of Kalol, Chhatral, Olpad and Deccan Basement Reservoirs of Gamij Field, Cambay Basin, ONGC, KDMIPE, Dehra Dun, Unpublished Report.
4. Raju, D.S.N., Jaiprakash, B.C. And Kumar, A. (1996) Palaeoenvironmental set-up and age of basin floor just prior to the spread of Deccan volcanism in the Krishna-Godavari Basin, India. Mem. Geol. Soc. India, no.37, pp.285-295.
5. Sen, B., Sabale, A.B., Misra, K.S. And Lakshminarayana, G. (2007) Morphology and internal heterogeneity of flows of Rajahmundry Traps, West Bank of the Godavari River, Andhra Pradesh (abstract). Workshop and Group Discussion on Cretaceous Volcanicity: Its petrologic and geodymanic implications; SDM College of Engineering and Technology, Dharwad, India, pp.10-11.
6. Lakshminarayana, G., Manikyamba, C. and KHANNA T.C. (2010) New observations on Rajahmundry Traps of the Krishna-Godavari Basin. Geol. Soc. India. v.75, pp.807-819.