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An analysis of synrift exploration in South Cambay Basin with associated challenges and rewards

Abstract:

Cambay Basin, a rich petroliferous province, has largest contribution in onshore oil and gas production of India. The basin is producing hydrocarbons on commercial scale from the year 1960. With more than five decades of exploration and production activities, the main producing Middle Eocene Hazad sands of South Cambay Basin have been highly exploited and thus the fields have been shifted to the category of Brown field. In this scenario, for maintaining the pace of hydrocarbon production in the country, there is need for exploring new and challenging hydrocarbon bearing horizons in the basin. In this paper, a detailed discussion has been made on hydrocarbon exploration in Synrift Olpad Formation of South Cambay Basin in light of successful exploratory leads obtained from synrift sand LS-1 in Ankleshwar field. Sand LS-1 is having highly heterogeneous lithology like volcanic sandstone, trap-wacke, trap conglomerate, variegated claystone and epiclastic sandstone. The source rock potential of Olpad Formation has been established by various geochemical studies of drill cuttings, conventional cores and side wall cores. Reservoir characterization at the slope of fan deposits with proper entrapment is major exploration challenge for synrift pays. Deeper subsurface positions of synrift sands in Jambusar-Broach block demand higher geoscientific understanding. Associated significant CAPEX for drilling presents a challenge on techno-economic viability front. If we are able to overcome these challenges, then, we may be looking at plays which have already awarded explorers worldwide with significant reserves in synrift depositional regime.

Keywords: Synrift facies, sand LS-1, Olpad Formation, fan deposits, CAPEX, infrastructure support

Introduction

Cambay Rift Basin is producing hydrocarbons in commercial quantities since the discovery of hydrocarbons in its southern part from Ankleshwar anticline in exploratory well Ankleshwar#1 (1960), though hydrocarbon was discovered even before in Lunej structure in exploratory well Lunej#1 (1958). Since then extensive exploratory efforts have been made throughout the basin to explore all possible locales of hydrocarbon accumulation. Concerted efforts have been done to monetize the hydrocarbon discoveries through extensive production activities. In the initial stage of exploration, the understanding of basin configuration wrt hydrocarbon accumulations was limited. With due course of time, Middle Eocene sands (Hazad sands of Ankleshwar Formation in South Cambay Basin) were found to be main hydrocarbon bearing sands. The exploration and production activities became more systematic and focused for these Middle Eocene pay sands which produced hydrocarbon on commercial scale to immediately cater country's oil demand. Over the time of more than five decades of hydrocarbon production, now these Eocene pays have been highly exploited. Thus, Cambay Basin has been matured for these pay sands. In future, for maintaining the momentum of hydrocarbon production in the country, a shift in exploration objective is needed for finding out new hydrocarbon bearing horizons.

After exploitation of Middle to Late Eocene pays which are continuously producing hydrocarbons as prolific producers in Cambay Basin since last more than five decades, the other exploration objectives are shallow Miocene and deeper Paleocene sands. The hydrocarbon prospectivity of shallow Miocene sands has already been worked out by recording open-hole logs in the wells at the time of drilling. Several Miocene hydrocarbon reservoirs in Ankleshwar, Kosamba and Olpad fields of South Cambay Basin have been identified and are producing hydrocarbons. Attempts have also been made for exploring hydrocarbon prospectivity of Paleocene Olpad Formation which deposited during syn-rift phase. Few successes in syn-rift Olpad Formation have been achieved in Ankleshwar field, where sand LS-1 at the top of Olpad Formation is producing hydrocarbons. Other areas of South Cambay Basin have not been much explored for ascertaining syn-rift prospectivity. Exploratory leads obtained from LS-1 sand of Olpad Formation may act as key to further synrift exploration in South Cambay Basin.

Cambay Basin

Cambay Basin is narrow, elongated, intra-cratonic rift basin located on the western margin of Indian plate. The general basinal axis is sigmoidal NNW-SSE, but swings are noticed across major lineaments/faults. The entire basin is divisible into five tectonic blocks (Fig-1) based on the rift associated transverse fault system, and the associated depocenters are governed by rifted basement (Mishra and Patel, 2011). The complex network of these transverse faults compartmentalizes the whole Cambay basin into five major tectonic blocks from north to south as under:

- Sanchor-Patan Block
- Mehsana-Ahmedabad Block
- Tarapur-Cambay Block
- Jambusar-Broach Block
- Narmada-Tapti Block

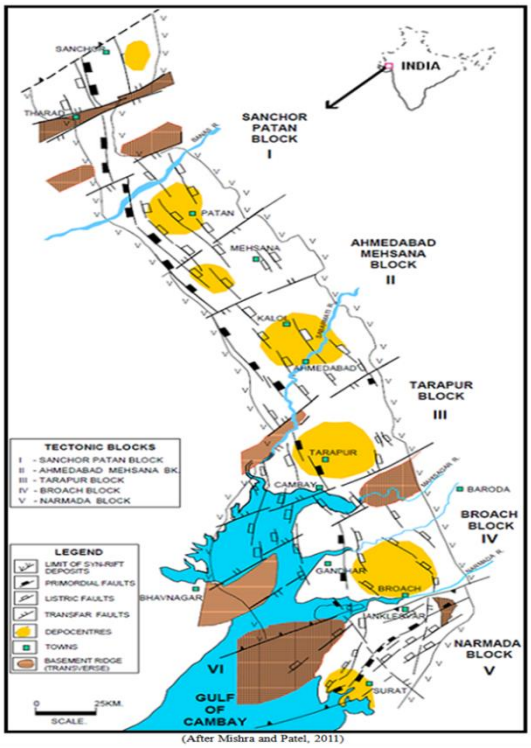

Fig-1: Tectonic blocks of Cambay Basin

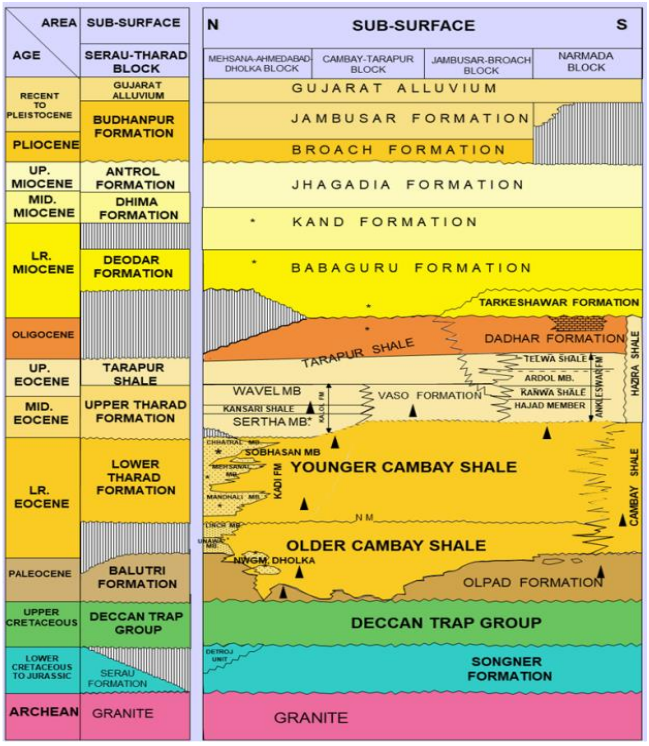

Fig-2: Stratigraphy of Cambay Basin

Narmada-Tapti and Jambusar-Broach blocks together constitute South Cambay Basin. The tectonic evolution of the basin has been categorized into three prominent phases; Synrift phase, Post rift sag and Post rift Inversion. In Synrift phase, mainly basalt derived materials were deposited as cones and fans under aerial to fluvial environment which constitute Olpad Formation. In Post rift sag, flexural subsidence occurred due to thermal cooling and heavy sediment loading. Thick deposition of Cambay Shale took place in Late Paleocene to Early Eocene as a result of widespread marine transgression. This was followed by number of regressive and transgressive cycles which caused the deposition of sandy and shaly facies, respectively. During Late Miocene to Early Pliocene, Cambay Basin witnessed mild inversion activity related to Himalayan Orogeny which caused the reactivation of pre-existing faults in the basin and ultimately resulted in the evolution of inversion structures, viz., Ankleshwar and Kosamba structures in South Cambay Basin.

Source potential vis a vis hydrocarbon generation

A thick column of Upper Paleocene to Middle Eocene fine grained clastic sediments termed as 'Cambay Shale' has been proved as an excellent source rock for generation of oil and gas in the basin (Mishra and Patel, 2011). As per the studies undertaken by KDMIPE-ONGC, Dehradun for Quantitative genetic modeling, Olpad and Cambay Shale Formations have generated 29.04 and 26.31 Billion Tonnes of Oil + Oil Equivalent Gas (O+OEG), respectively (GK Ray et al, 2001). According to another study undertaken by KDMIPE-ONGC for Hydrocarbon Resource Assessment of Cambay Basin, 20 MMt OE & 15 MMt OE are the hydrocarbon resources for Olpad & Cambay shale sequences respectively in Narmada-Tapti Block. The geochemical studies carried out in the deepest well of Cambay Basin (drilled depth 5716m) in Ankleshwar field (referred as ANK-A) shows that about 150m thick section in Olpad Formation possesses fair to excellent source potential. Total Organic Carbon (TOC) in Olpad section has been found to be in the range of 3-18.8%, S2 >2.5mgHC/g rock with VRo data (Fig-3&4) suggesting beginning of oil window zone at 1700m and gas generation zone at 2650m (D. K. Ralli et al, 1988). Thus, synrift sediments of Olpad Formation may have two modalities for hydrocarbon source; from Cambay Shale as Cambay Shale-Olpad petroleum system or from Olpad itself as Olpad-Olpad petroleum system.

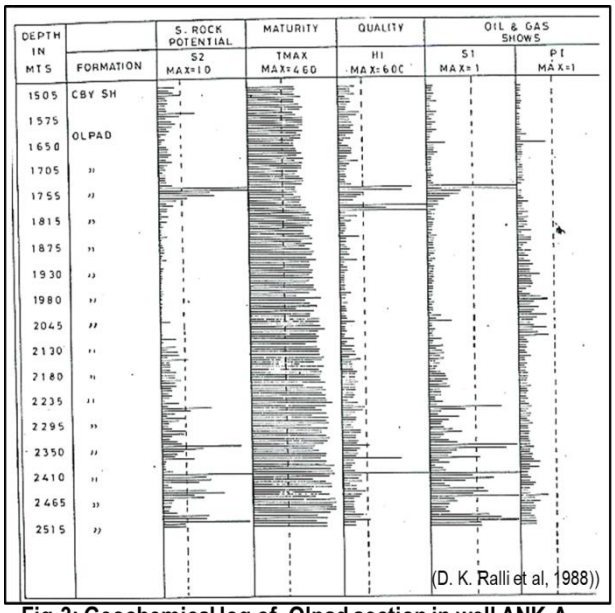

Fig-3: Geochemical log of Olpad section in well ANK-A

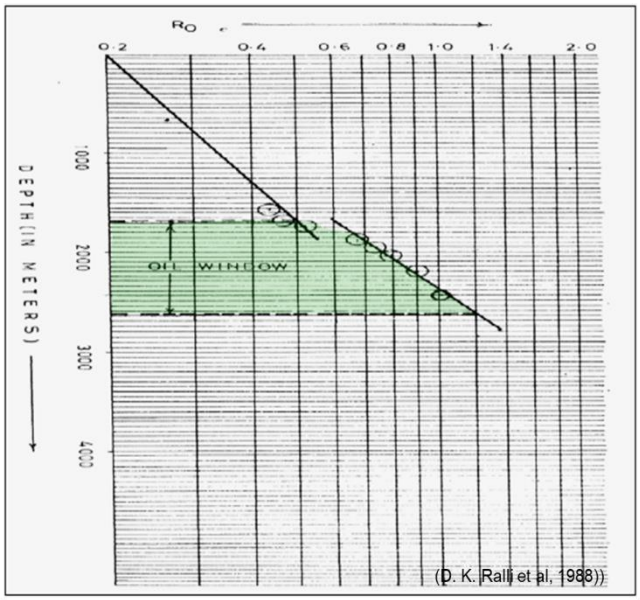

Fig-4: Maturation profile of well ANK-A by Vitrinite Reflectance

Reservoir potential vis a vis hydrocarbon production

Pandey et al. (1993) and later on Anima Saikia et al (2013) have subdivided Olpad Fm into three distinct litho-facies. These are weathered Trap, Claystone and Trap conglomerate/Trap wacke from bottom to top. These litho-facies are well preserved in grabens as a result of weathering of Trap from nearby highs. In North Cambay basin, Nawagam, Dholka, Gamij, Sanand, Mansa & Charada are some of the major oil producing fields from Olpad reservoir. At eastern margin of Broach depression, Padra field produces oil from Olpad sands and weathered trap. The topmost unit trap conglomerate (LS-1 reservoir), formed due to locally dumping from Ankleshwar High by feeder channels, having fair to good porosity produces oil in Ankleshwar field. These basalt derived detritus have deposited in the form of cones, fans and gravel beds under sub aerial to fluvial conditions. (Anima Saikia et al, 2013)

Synrift prospects in Narmada-Tapti Block

It is southernmost tectonic block lying in south of Narmada River. Ankleshwar field, one of the oldest oil and gas field of the country, falls in this block. Motwan, Kosamba, Kim, Olpad are other major oil and gas producing fields lying in the block. All of these fields are producing dominantly from Middle Eocene Hazad sands of Ankleshwar Formation. Moreover, Ardol sands of Ankleshwar Formation, sands of Dadhar,

Tarkeshwar, Babaguru and Kand Formation are also producing hydrocarbons. Two Paleocene syn-rift sands, LS-1 at the top of Olpad Formation and LS-2 in Older Cambay Shale (OCS) are also well established in these fields. Sand LS-1 is producing oil in few areas of Ankleshwar field only. Whereas sand LS-2 is not yet found hydrocarbon bearing anywhere in the block. Both of these sands are less explored, as the major exploration focus has been given on Middle Eocene sands and very few wells have penetrated these synrift sands.

Hydrocarbon prospectivity of sand LS-1

LS-1 unit is present at the top of Olpad Formation. It is the deepest hydrocarbon producing unit of Ankleshwar field having highly heterogeneous lithology like volcanic sandstone, trap-wacke, trap conglomerate, variegated claystone and epiclastic sandstone, cemented by calcareous and ferruginous material. The prospectivity of sand LS-1 and other synrift sands of Olpad Fm is under exploration in other fields of South Cambay Basin. In comparison to Hazad sands, the LS-1 is having low productivity. The oil has 36 - 41 API gravity, higher pour point 33-39:C and high wax content 14-16 %. Because of the origin from volcanic material, the cavities formed due to dissolution, unfilled amygdules or intergranular pore spaces constitute the porosity of the reservoir. In Ankleshwar field, the LS-1 reservoir is generally found to be overlain by a thin coal layer.

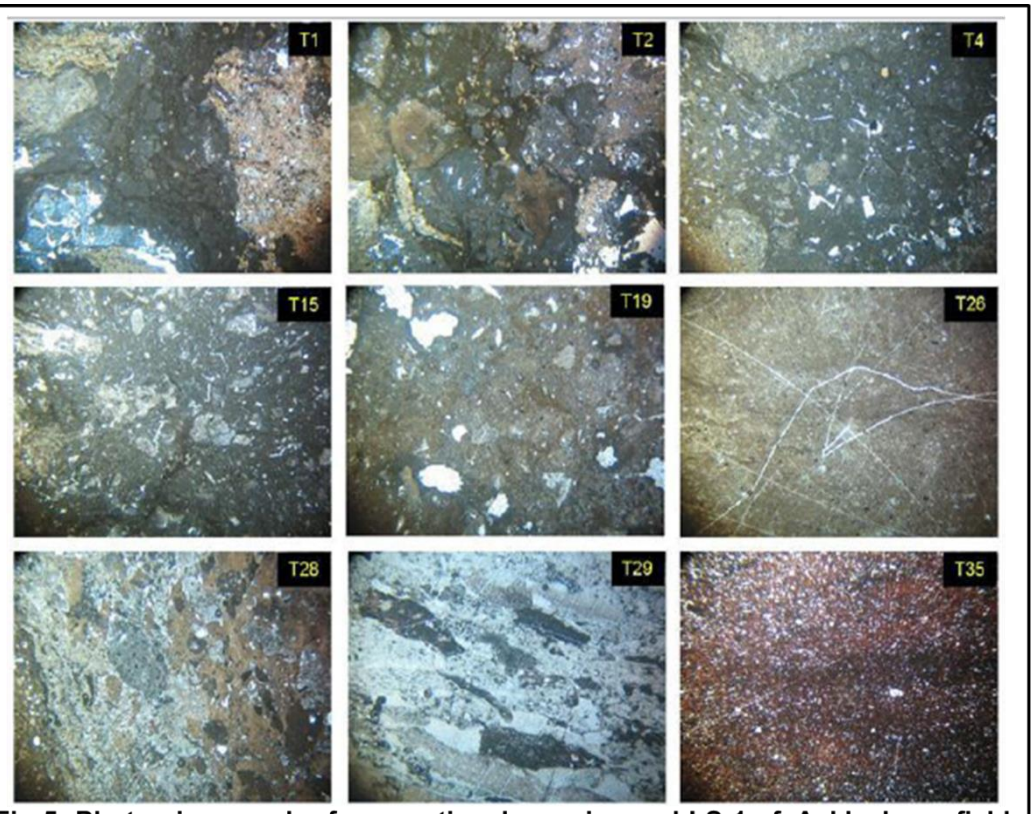

Fig-5: Photomicrograph of conventional core in sand LS-1 of Ankleshwar field
T1, T2 & T4: Trap conglomerate- sand to gravel sized weathered basaltic fragments
T15 & T19: Trapwacke- sand sized weathered basaltic fragments within argillaceous matrix
T26, T28, T29 & T35: Claystones with micro fractures
Source: Sedimentological studies of conventional core at ONGC-RGL, Vadodara

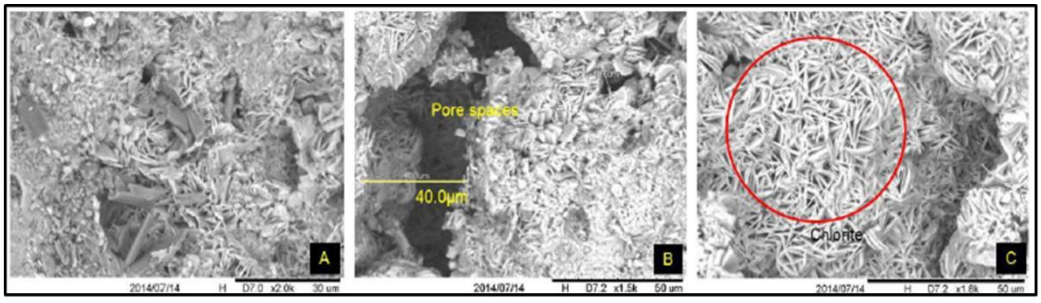

Fig-6: SEM image of a segment of conventional core in sand LS-1 of Ankleshwar field

The presence of commercial accumulations of hydrocarbons in LS-1 reservoir was established in the year 1964, in an exploratory well in central-eastern area of Ankleshwar field. Till date, 17 wells have produced oil from sand LS-1 with a cumulative oil production of around 0.33MMt. It is found that wells drilled on the slope have better development of reservoir facies and thus better commercial hydrocarbon accumulations. Many wells, even after falling within Lowest Known Limit (LKL) of oil, are devoid of reservoir facies due to their structurally higher positions. It is also seen that the lithological heterogeneity is the main controlling factor for fluid distribution in LS-1 reservoir. Therefore, identification of potential reservoir facies on slops of fan deposits hints for locating the hydrocarbon reserves in synrift sand LS-1.

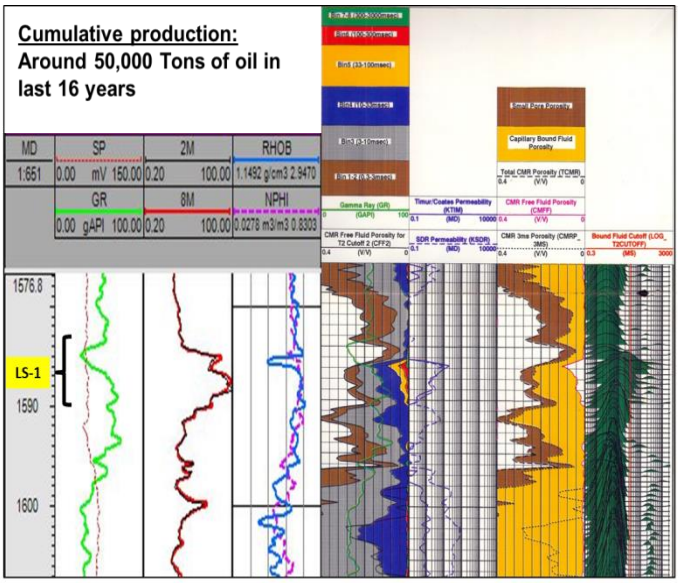

Fig-7: Petrophysical signatures of HC producing LS-1 in Ankleshwar

Synrift prospects in Jambusar-Broach Block

This block is demarcated by Mahisagar river in the north and Narmada river in south. Gandhar, Dahej, Pakhajan, Jambusar, Nada, Dabka, Matar and Padra are the main fields of this Block. Gandhar is the largest onshore field of country. Deepest low in Cambay basin, the Bharuch Depression lies in this block and is main kitchen for South Cambay Basin. Almost all wells in this block produce hydrocarbons from Hazad sands, except Padra field which produces oil from Olpad & fractured Trap and a single well in Malpur area from sands within Older Cambay Shale (OCS). Only few wells in Jambusar, Uber and Dabka areas have penetrated Olpad Fm. Hydrocarbon indications in drill cuttings of Olpad Fm have also been reported in some of these wells. Only 05 wells in Gandhar field, including 04 shale exploration wells have partially penetrated Olpad Fm because of deeper depth, below around 3600m. The thickness of Olpad Formation has been estimated around 2200m in Tankari depression. Dabka and Kural fields, towards eastern margin of the basin, are under exploration to locate potentially prospective zones in Olpad Fm.

Challenges-favors and rewards for Synrift exploration in South Cambay Basin

- Reservoir characterization and proper delineation of fan deposit morphology are major geo-scientific challenges associated with Olpad Fm in South Cambay Basin.
- Drilling of very deep wells (4000m - 6000m) with minimum complications in Jambusar and Gandhar areas is further a technological challenge.
- Around 40% hike in exploratory drilling CAPEX wrt. conventional HC plays in Jambusar and Gandhar areas causes main challenge for techno-economic feasibility in these fields.
- A large number of existing wells in different fields is favorable to ONGC for synrift exploration. Deepening/ side-tracking of existing low potential or non-flowing wells to explore the Olpad Fm at potentially prospective areas may reduce the drilling CAPEX and thus synrift exploration may be boosted to mitigate the associated risk.
- Existing ONGC infrastructure and pipeline network in available Petroleum Mining Leases (PML) supports synrift exploration without any additional increment in OPEX and cost of production.
- By mitigating the associated risks with optimum utilization of available resources and infrastructure, we may be looking at plays which have already awarded explorers worldwide with significant reserves in synrift depositional regime.

Conclusion

- Synrift Olpad Formation composed of mainly basalt derived materials viz. weathered Trap, Claystone and Trap conglomerate/Trap wacke, deposited as cones and fans under aerial to fluvial environment.
- Hydrocarbon generation potential of Olpad Fm. has been established by previous researchers.
- In North Cambay basin, Nawagam, Dholka, Gamij, Sanand, Mansa & Charada are some of the major oil producing fields from synrift Olpad reservoir.
- In Narmada-Tapti block, synrift unit LS-1, at the top of Olpad Fm has produced around 0.33MMt of oil in central-eastern part of the Ankleshwar field.
- Exploratory drilling efforts for synrift prospects are very sparse. Only few wells in Jambusar-Broach block have completely penetrated Olpad Formation.
- Taking the analogy from oil producing synrift pay LS-1 in Ankleshwar field, reservoir characterization may be attempted at favourable structural positions ie. at the slop of fan deposits. This may act as the key for further synrift exploration in other areas of South Cambay Basin.
- Technical efficiency for drilling upto 4000m to 6000m depths with minimum complications and maintaining CAPEX within the limits of techno-economic viability are major challenges.
- Deepening/ side-tracking of existing low potential or non-flowing wells to explore the Olpad Fm at potentially prospective areas may reduce expenditures for synrift exploration in challenging oil pricing regime.
- Existing ONGC infrastructure and pipeline network in available Petroleum Mining Leases (PML) supports synrift exploration without any additional investment.
- Establishing prospectivity of synrift Olpad Fm may open up new HC bearing horizons in brown fields of Cambay Basin to cope up the ever raising oil demand of our country for maintaining the pace of development.

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(Views expressed in this paper are of authors only)

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Well Completion Reports (WCR) and Formation Evaluation Reports (FER) of respective wells.