Biogenic Petroleum System of India’s East Coast Deep Water Basins

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Summary

Exploration and production in deep water (500-2000m) and ultra deep water (>2000m) have expanded greatly during the past 15 years, to the point at which they are now major components of the petroleum industry’s annual upstream budget. Globally deepwater remains relatively unknown frontier, with many deepwater sedimentary targets being only lightly explored. Deepwater discoveries account for less than 5% of the current worldwide total oil equivalent resources, thus deepwater represents an important component of the world’s future oil equation. Gas exploration in deepwater is also destined to become a major focus in the future. Most current deepwater hotspots are located along passive margins. The Indian east coast exhibits a variety of geologic plays and is highly prospective for future exploration. Hydrocarbon system for both rift related and other structural styles using high quality 2D and 3D seismic imaging integrating with geological inputs has generated a large portfolio of play types e.g. channel-levee complex, basin floor fans, lobes, syn-rift structural closure, wedge out against basement highs, which are the likely potential targets for exploration. Timing of petroleum generation and migration is a crucial factor in deepwater and is highly variable depending on the margins’ geologic evolution, basin heat flow history and the distribution of the fetch areas in space and time. Indian east coast is bestowed with two different petroleum systems. (i) a shallow Oligocene to Recent biogenic gas system and (ii) a gas/oil late Cretaceous to Eocene thermogenic system. Strati-structural global biogenic entrapment in late Mio-Pliocene CLC is considered being potential play fairways. Most of the discoveries made in Pliocene reservoirs are gas. Paleo-hydrate dissolution yielding enormous amounts of methane is likely to be trapped in strati-structural combinations in the upper slope regime. All accumulations are in close proximity to the MTC and reservoirs are connected to the MTC by faults. In the Cretaceous-Paleocene system generated hydrocarbons get concentrated within the rift grabens. The Cretaceous play is governed by initial rift architecture. Both the systems are believed to be separated by highly shaly/clayey Paleogene section. Attempt has been made to bring out the possible biogenic systems operating in the east coast of India in Mio-Pliocene section.

Introduction

The ability to identify hydrocarbon bearing sediments beneath the ocean’s floor at extreme water depths continues to improve. In recent years the industry has been successfully making discoveries, appraising and evaluating them; and developing those that can pass the rigorous tests necessary to justify high cost deepwater projects. India has not been exception to this global phenomenon. With the introduction of New Exploration Licensing Policy (NELP) by the Government of India in 1997, the country has seen the entry of multiple players into the deep water sedimentary basins of eastern coast of India (Fig-1) in particular. With the state-of-the-art seismic data acquisition-processing-interpretation, it is becoming certain that further exploration potential exists in deepwater depositional complexes of eastern coast of India.

Figure-1. The study area (East coast of India)
Regional geology and tectonic setting.

All the basins (Mahanadi, Krishna-Godavari, Cauvery) developed along the eastern passive continental margin of India resulted from rifting and breakup of Gondwanaland during the Jurassic period. During the Oligocene, a major hinge developed all along the coast, resulting in thick Neogene sediments along the basinward side of the hinge. This hinge marks a facies change from platform carbonates to basinal siliciclastic rocks, thus delineating a possible Eocene continental shelf break. During this time, large sedimentary basins formed at the deltas of the major rivers.

Mahanadi basin is one of the passive margin basins located along the east coast of India. It is located between hydrocarbon producing KG basin to the southwest and Bengal basin to the northeast. Mahanadi graben was an intra-cratonic basin, with NW-SE trending graben in the then Gondwana land, which was initiated during Permo-Carboniferous time. During Middle to Late Cretaceous, Indian plate first drifted towards north and after collision with Eurasion plate it drifted towards east. Due to this movement a new ocean floor was created. During this period paleo-coast was tilted towards east, which resulted in the development of rejuvenated drainage systems into the newly formed ocean floor. Overlying Neogene sequence comprises of clastics in the form of channel-levee complex, fans and mass transport systems in a deep-sea setup. Expected total sedimentary thickness is of the order of 5 km. Deep water blocks of Mahanadi basin witnessed the presence of ENE-WSW trending horst-graben structures that are located to the northwest of shelf break.

The KG basin, formed during the break-up of Gondwana supercontinent is situated in the eastern passive continental margin of India. The basin trends NE-SW parallel to the Pre-Cambrian Eastern ghat trend. The basin extends from the onshore to the offshore deepwater. The deepwater portion provides a unique province for the study of depositional systems resulting from the interplay of dynamics of Krishna and Godavari delta progradation, gravity-induced processes and relative sea level changes.

Cauvery basin contains a series of horst graben features that are oblique to the coast. The grabens are filled with Mesozoic rocks. Tertiary sediments accumulated as a thick wedge on a uniformly eastward-sloping platform. Many modest accumulations of oil and gas have been discovered on the flanks of these grabens.

Petroleum System And Play Types

Two different petroleum systems are operating in the east coast of India (i)A Late Cretaceous Paleocene thermogenic system relying on a potential mature source pod down dip, most of the generated hydrocarbons get concentrated within the rift grabens, vertically sealed by Late Cretaceous - Paleogene transgressive shales. Aerial extent of the Cretaceous play is governed by Initial rift architecture. Source rocks are mainly lacustrine to restricted marginally marine. Reservoirs consist of synrift sand dumps and incipient channel deposits. This Petroleum System has both oil and gas.

(ii) Pliocene Gas system: These are Late Miocene – Early Pliocene global biogenic activity related pools, with basin wide occurrence, initially trapped in the form of Methane hydrates and buried with contemporaneous sedimentation. Subsequent dissolution by changing stability zone, has liberated gas (in 1:154 ratio), which migrated upwards. Their concentration is largely governed by fetch areas, reservoir availability, trap geometry and fault connectivity. Miocene to Pleistocene sequence show development of abundant channel-levee system with associated mass transport complex operating in the east coast (Fig.2,3) and other places of the globe (Fig. 4). Abundant thick pelagic shales serve as regional cap facies. Entrapment conditions envisaged are mainly stratigraphic and strati-structural in nature. The upward migration of the hydrocarbons is envisaged through the fault conduits. Mahanadi and KG area is proven to contain biogenic gas accumulations as discovered in wells.

Figure-2. Pliocene CLC discoveries sitting above MTC.
Deep Water sedimentation

Deepwater sedimentation is likely to be most rapid during periods of sea-level lowstand, because depocenters are most likely to be located at or near the shelf edge. During early lowstand, because of sea level fall, shorelines tend to prograde rapidly across the shelf, forcing depocenters to reach the shelf edge. This results in the accumulation of large volumes of sand and mud at the shelf edge. Rapid sedimentation of the shelf edge and upper slope gives rise to frequent slumping which can generate sediment gravity flows into the deep basins. However, deepwater sedimentation also occurs during highstands of sea level. Canyons that extend across the shelf and capture fluvial flow are active feeders as deepwater systems formed during relative sea-level highstands (as in case of Congo River).

Biogenic Gas

Biogenic gas is formed at shallow depths and low temperatures by anaerobic bacterial decomposition of sedimentary organic matter. Biogenic gas is very dry, consisting almost entirely of methane. Biogenic methane, on average, contains lighter carbon isotopes than thermogenic gas.

Presence of a commercially significant biogenic gas petroleum system in a deep marine environment requires rapid sedimentation. Organic matter rapidly moves from the near-seabed oxidizing zone to the deeper anoxic zone, and probably also inhibits replenishment of sulphates from overlying seawater; biogenic gas generation occurs in an anoxic, sulphate-reducing, environment and requires a minimum TOC of > 0.5%. Biogenic gas is produced by the metabolic activity of anaerobic bacteria. Methane generation by bacteria can take place in temperature ranges between 0°C and ~75°C, but particular microbes may perform optimally within a narrow temperature band. If we assume a sediment water interface temperature on the slope of ~5°C and a geothermal gradient of ~3.5°C/100 meters, then theoretically, based on temperature criteria alone, biogenic gas could be actively formed from the seabed down to ~2.0 km in deep-water setting s in the Mahanadi offshore.

Edman et al. (2001) discusses a biogenic gas field (Mississippi Canyon 348) in a distal, deepwater, low net sand setting in the Gulf of Mexico (2,200 m bathymetry). He suggests that the gas was first generated in turbidite sands, then concentrated by the formation of gas hydrates. Once the gas hydrates were buried deeply enough to become unstable, they would then have sublimated and exsolved methane which would have migrated laterally and charged updip reservoirs.

Observation and Discussion: Alternate explanation for the Pliocene Gas System

In both Mahanadi and KG basin the Pliocene discoveries are characterized by discrete reservoir bodies associated with high amplitude on seismic, restricted to CLC. Such bodies are typically expressed as DHIs. In most of the cases, the discoveries are resting just over the MTC (Fig. 5, 6, 7, 8, 9 & 10) and invariably connected through faults (Fig. 11, 12 & 13). On seismic MTC exhibits chaotic reflection characteristics. It has also been observed from the drilled well logs (Fig. 14). Most of Pliocene faults sole out within MTC. These coarser clastics associated with CLC are actually charged with dry methane accumulations.
The entire Mio-Pliocene section is thermally immature. The obvious question then is where from the dry gas has come? It is believed that an enhanced biogenic activity exists during Early Pliocene. The methane generated by methanogens and sulphate reduction got trapped in the form of gas hydrates. These hydrate layers were subsequently buried by shales/clays and remained stable within high stabilized
zone (HSZ) limits at ambient pressures & temperatures. The continuous burial induced changes in the isotherm profiles leading to dissolution of Gas hydrates at their bases. Once the base of hydrate layers got destabilized, it led to mass movements of catastrophic dimensions, triggering further instability of hydrate beds. The cumulative effect witnessed complete destruction and collapsing of the hydrate mass, liberation of methane in very large amounts, fracturing, folding and faulting of the overlying sediments. The liberated gas migrated upwards through faults and gets concentrated in the form of dry gas pools within Pliocene. So the Mio- Pliocene gas pools could be a product of gas hydrate dissolution.

**Conclusion**

It is now believed that the paleo hydrate dissolution yielding to release of enormous amount of methane entrapped in the strati-structural combinations in the upper slope region. High resolution 3D campaigns provides extraordinary opportunity to examine the distribution of dry gas entrapment through identifying MTC, micro faults and associated DHIs. East coast in particular KG and Mahanadi is emerging as a hotspot for future exploration. The present assessment for gas in east coast is in the order of 25 TCF (DGH, 2006). However the trend of success indicates this to be of much higher order.

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