Reassessing the Hydrocarbon Potential of Bengal Basin, India in light of recent Discovery

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Abstract

The history of petroleum exploration in Bengal Basin started in late 1940's by Stanvac Oil Company through geological and photogeological surveys. Subsequently, in 1958, a joint venture project Indo-Stanvac Petroleum Project (ISPP), drilled first set of exploratory wells. Oil indications in Ichapur-1 from basal Oligocene sands and Golfgreen-1 from fractured Eocene carbonates added certainty to the existence of petroleum system elements in the Bengal Basin. However, due to stratigraphic nature of these oil indication and paucity of structural entrapment, these leads could not be replicated. A series of studies, conducted in recent years led to the first commercial hydrocarbon find in the Mio-Pliocene sequence of well Discovery-1. Further, success of well Discovery-2, aimed to chase the lead provided by well Discovery-1 adds confidence to the envisaged model and provides a fresh vigour to exploration. A basin scale petroleum system modelling provided the key insights about the existence of petroleum system in the basin, and it highlighted the corridor along the Hinge zone as most prospective locale for hydrocarbon entrapment. Subsequently, a smaller area near the hinge zone was studied in detail for firming up of prospects. Seismic characterization helped in delineating the Proto Damodar and Proto Ganga-Brahmaputra channel system trends. It was found that relatively weaker Proto-Damodar channel system with possibility of isolated reservoir lobes were represented by dim amplitudes on seismic. Proto-Ganga Brahmaputra channel system, with bright amplitudes on seismic, dominates the Mio-Pliocene sequence with connecting latero-vertical stacking causing top loss of migrating hydrocarbon. Spec-D and Pre-stack inversion was carried out to identify the proto-Damodar trend channels. The shifting channels in time and space created an environment where multiple reservoir and cap rock facies would be stacked both laterally and vertically. The multiple stacking of reservoir and cap rock facies creates favourable conditions for HC entrapment. One layer of relatively high impedance shale with thickness >200m was identified to be draping proto-Damodar sand lobes over a large area. Seismic scale cross plots of lead wells showed that gas can be characterized with P-Impedance and Vp-Vs. Drilling of location Discovery-2, targeting isolated sand lobes in Proto-Damodar trend produced commercial gas and this maiden success of model based subtle trap exploration will rejuvenate the exploration in Bengal Basin.

Introduction

Bengal Basin witnessed start of one of the earliest HC exploration campaigns in India, due to discovery in genetically related Assam & Assam Arakan Basin. Geological and Photogeological surveys started in 1940s resulting in generation of enormous amount of sub surface data by drilling of first set of 10 wells with no success. After a drilling holiday from 1960 to 1976, there was an aggressive drilling of 33 wells from 1976 to 1995 resulting in two oil indication wells, from Basal Oligocene sand and fractured Eocene limestone (Fig.1) respectively. This HC indication suggested the existence of working petroleum system within Bengal Basin.

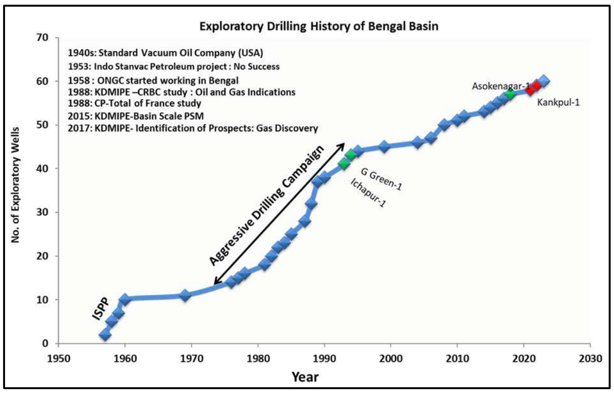

Fig.1: Exploratory drilling history of Bengal basin

Tectonic evolution of the Basin started with creation of accommodation space within grabens/half graben of Gondwana intracratonic failed rift (Dubey et al., 2019). Subsequently, Late Jurassic to Early Cretaceous break up, and the rifting signatures of Indian Plate from Australia are not conspicuous in the basin. However, it caused reactivation of existing Gondwana graben forming faults. Post Rajmahal volcanics basin remained in passive margin set up. Colossal amount of clastic input due to Himalayan orogeny starting from the Oligocene led to flexural deformation within Eocene carbonates around the hinge zone. These fracture around the hinge zone act as charge conduit from Paleocene kitchen to shallower reservoirs. Post Oligocene period was relatively stable in terms of tectonics, although differential compaction-related folding occurred during the Miocene.

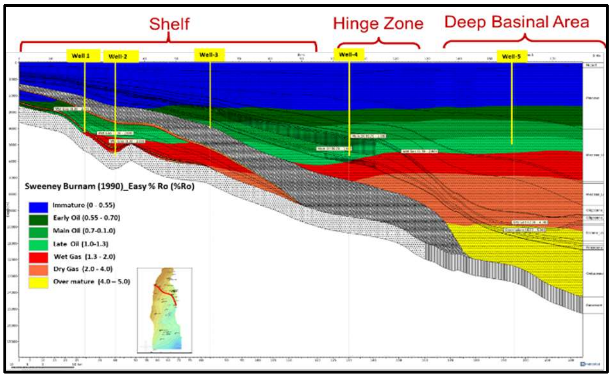

Fig.2: NW-SE section passing through Bengal Basin showing modelled maturing.

Source rock data indicates that the Lower Gondwana coal and coal-shale sediments are mature source rocks in the basin, however its presence is limited to the shelf area. Jalangi shale of Paleocene and Hoogly shale of Eocene are the major Type-III kerogen source rock within the basin extending from shelf to deep offshore. The geochemical analysis of oil from discovery well in the basin suggests generation of hydrocarbons from source rocks of Late Cretaceous or younger age. Kaur et al., 2020, demonstrated through Petroleum system modelling results, that source rock within Paleocene, Eocene and Oligocene formations attained peak oil generation window in the areas around and east of hinge zone and achieved more than 50% transformation. The critical moment for the Paleocene source rocks in the modelled area is 14Ma, Eocene source rocks 10Ma and Oligocene source rocks is 4 Ma (Fig.2). It also suggested, shelf contribution to hydrocarbon charge is minor and major charge contribution is from the east of hinge zone. Further, at hinge zone alternate, repetitive proto-Damodar and proto-Ganga-Brahmaputra channels system create an environment for multiple stacking of reservoir and cap rock facies both laterally and vertically which provided conduits for hydrocarbon accumulation in the shallower Mio-Pliocene sequences (Fig.3).

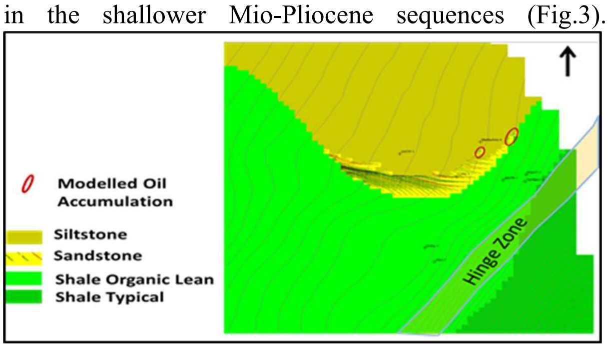

Fig.3: Modelled accumulations in stratigraphic entrapment conditions near Hinge Zone.

Geology of Bengal Basin

The Bengal Basin, located in northeastern India, is a polycyclic basin that evolved through two distinct tectonic episodes. It was initiated as an intracratonic rift basin within Gondwanaland during the Paleozoic–mid-Mesozoic time. This phase ended with widespread Rajmahal volcanism during the Early Cretaceous. The second phase of basin formation took place when the Indian Craton separated from Gondwanaland and started drifting northward. During this journey of the Indian plate, the Bengal Basin received colossal volumes of sediments from Late Mesozoic through Tertiary to recent times. During Eocene–Oligocene, a hinge zone was formed due to flexure caused by differential subsidence along the shelf break. The Eocene period witnessed carbonate deposition followed by drowning due to transgression, inhibiting the development of secondary porosity in the carbonate deposits. Neogene collision of Indian Plate resulted in the southerly tilt of the Bengal Basin with cessation of carbonate built-up and influx of terrigenous sediments from the Indian craton side. Mio-Pliocene sequence represents the foreland deposits with dominant influence of Ganga-Brahmaputra River system. The study area that is the subject of this paper is part of a regional study being pursued based on indications that the hinge zone area is prospective for hydrocarbons.

Recent Bengal discovery and future hydrocarbon exploration

Oligocene witnessed increased sedimentation rate which is continuing till recent due to Himalayan Orogeny. Proto-Damodar River system was the dominant sediment input system prior to initiation and dominance of proto-Ganga-Brahmaputra River systems. Seismic signature of proto-Damodar is moderate amplitudes and erosional features with channel cuts can be best ascertained at the end of Late Oligocene (Fig.-4). In Miocene, Himalayan orogeny led the birth of

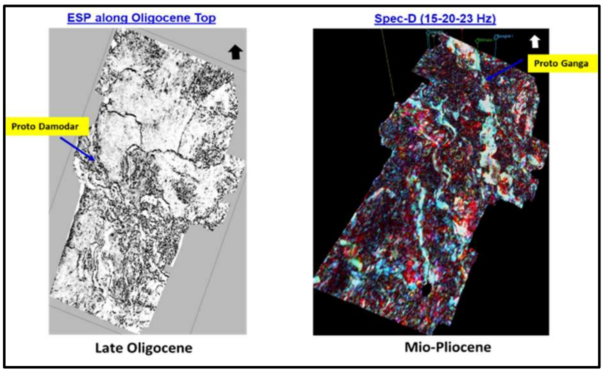

Fig.4: Proto-Damodar Channel system at the End of Oligocene and Proto-Ganga-Brahmaputra River systems in Mio-Pliocene.

proto-Ganga-Brahmaputra River system that resulted in huge sediments supply. During Mio-Pliocene both channel system i.e., proto-Damodar and proto-Ganga-Brahmaputra were active, but Ganga-Brahmaputra dominated in terms of sediment supply. It was found that relatively weaker Proto-Damodar channel system with possibility of isolated reservoir lobes were represented by dim amplitudes on seismic. Proto-Ganga Brahmaputra channel system, with bright amplitudes on seismic, dominates the Mio-Pliocene sequence with connecting latero-vertical stacking causing top loss of migrating hydrocarbon thus Proto-Damodar channel sands characterisation was preferred. The two different trends of channels were differentiated based on the seismic property and P-Impedance (Fig.-5).

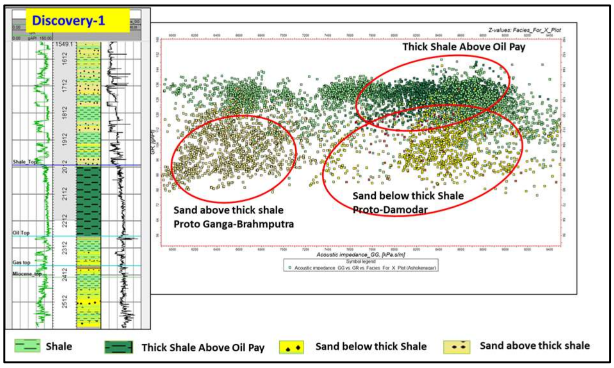

Fig.5: P-Impedance Vs. Gr plot showing relatively low impedance Proto-Ganga-Brahmaputra River sands w.r.t. Proto-Damodar Channel sands.

One layer of relatively high impedance shale with thickness >200m was identified to be draping proto-Damodar sand lobes over a large area. Prospects were prioritised based on relatively High P-Impedance shale layer draping over the discrete sands of proto-Damodar origin (Fig.-6). Inversion study shows low impedance within HC bearing zones of Mio-Pliocene. Oil and gas zone in Discovery-1 well shows the P Impedance of the range 7800 to 8600m/s*gm/cc.

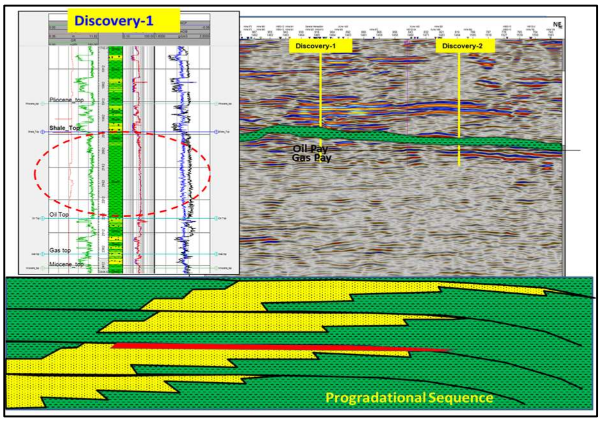

Fig.6: Prospects prioritised based on relatively High P-Impedance shale layer draping over the discrete sands of proto-Damodar origin.

The same has been used to delineate HC bearing sand distribution in time and space. Cross-plot between P-Impedance and Vp/Vs differentiates the gas pay as low Impedance and low Vp/Vs values (Yadav et al., 2020) in log (Fig.7). In case of oil pay zones two zones are

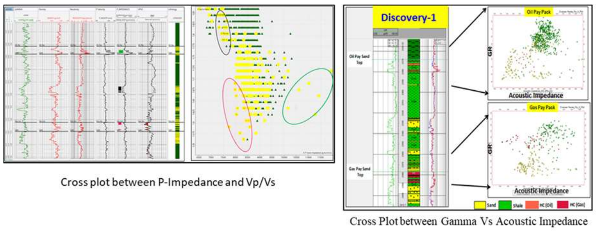

Fig.7: Cross plot between P-Impedance and Vp/Vs, Cross Plot between Gamma Vs Acoustic Impedance.

observed, having different impedance values. (1) Low Vp/Vs and low impedance, (2) Low Vp/Vs and moderate impedance. This plot suggests the presence of two separate lithofacies associated with the reservoir zone. The reservoir facies in the gas zone P Impedance varies from 7500 to 8500 g/cc*m/s and Vp/Vs ratio as low value 1.55-1.65. In contrast to the reservoir facies of the gas pay, the reservoir facies for the Oil pay exhibit high P-impedance and moderate value Vp/Vs (1.65-1.72). Therefore, characterization of only gas pay

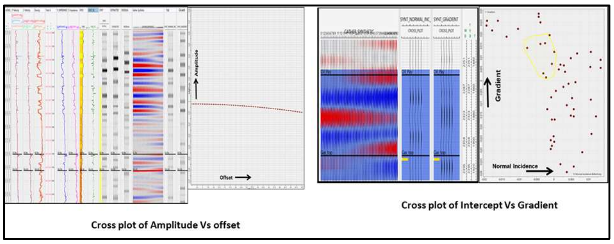

Fig.8: Cross plot of Amplitude Vs offset, and Cross plot of Intercept Vs Gradient.

reservoir is feasible from the inversion study. AVO modelling along the well gives a quick analysis of amplitude response with offset along the gas-pay zone. AVO modelling is carried out using P-wave and S-wave velocity recorded in the well. AVO study along the well shows the amplitude becomes more negative with the offset means amplitude increases with offset. Further intercept Vs Gradient crossplot was prepared to see

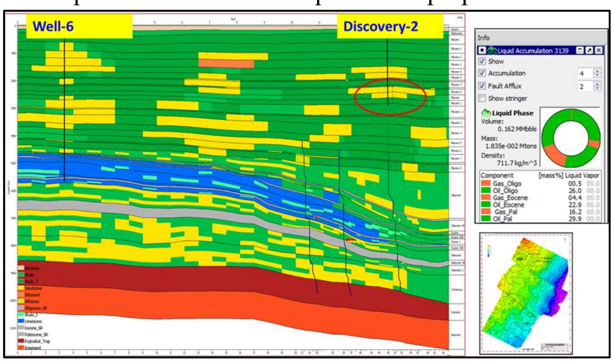

Fig.9: Discovery-2 P-impedance highlighting lower discrete sands.

AVO response of gas–pay sand. Gradient Vs Intercept crossplot shows class-II AVO anomaly (Fig.8). Based on these studies location Discovery-2was prioritised (Fig.9). Further, to de-risk the prospect, a localised 2D

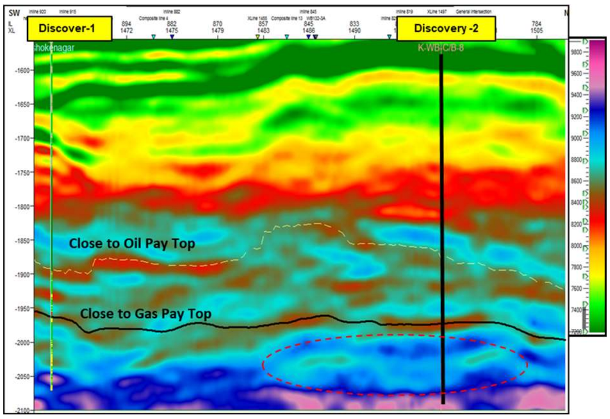

Fig.10: Migration Modelling along Transect Passing through Well-6 and Discovery-2.

PSM Modelling was carried out to assess the charge migration through geological history (Fig.-10). Drilling of location Discovery-2, targeting isolated sand lobes in Proto-Damodar trend produced commercial gas and this maiden success of model based subtle trap exploration will rejuvenate the exploration in Bengal Basin. Results of the Discovery-2discovery, which validates the study, adds confidence to envisaged exploration model. Other interesting deeper stratigraphic prospects like Paleocene Barrier bars (Fig.-11) may be prioritised for exploration in Bengal Basin.

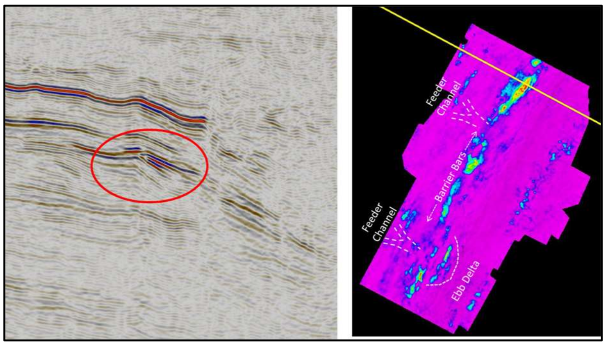

Fig.11: In Bengal basin there are other interesting stratigraphic prospects i.e. Paleocene Barrier Bar.

Conclusion

A working Petroleum System exists in Bengal Basin, however, exploration in Bengal Basin has been challenging due to absence of structures and limited understanding on delineation, characterization and de-risking of the subtle traps. For Mio-Pliocene sequence, identifying two channel trends, isolating discrete sands based on P-impedance below the thick capping shale and further de-risking the study with P-Impedance and Vp-Vs volumes for fluid and 2D PSM for migration and charging helped in successfully striking gas in Kankpul.

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