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Habitat of hydrocarbon occurrence in the Precambrian Basement in Cauvery Basin, India

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Abstract

Cauvery Basin is the southernmost petroliferous basin located in the state of Tamil Nadu in India. It is a rifted passive margin basin originated during Late Jurassic break up of Gondwanaland. This basin is marked by a series of horst-graben setup aligned in a NE-SW direction and extends from onshore to the offshore in the Bay of Bengal. Outcrops of Lower Gondwana to Miocene sedimentary rocks are exposed along the western fringe. More than 8000m thick sedimentary sections ranging in age from Permian (?) to Miocene are expected in the sub-surface. Oil & gas has been discovered in commercial quantities in Precambrian basement, Lower & Upper Cretaceous and Paleogene sections. The basement "buried hills" has emerged as one of the major targets for exploration in the basin. Basement rocks are represented by granite, gneiss and charnockites. Hydrocarbons in the basement have so far been discovered along two prominent basement highs- the Kumbakonam-Madanam ridge which extends eastward into the offshore as the Porto Novo high and the western flank of the Pottukotai-Manargudi ridge. The present study attempts to understand the habitat of hydrocarbon occurrence in the basement in Cauvery Basin. Data available so far from different fields have shown that there are variations in the pattern of the hydrocarbon occurrences in the basement in Cauvery Basin which is found in the weathered / altered zone, fresh basement as well as in fractured zones significantly below the basement top where the upper part is apparently non-hydrocarbon bearing. Although, the migration and entrapment of hydrocarbons into the basement fractures are not very well understood, based on the available data it is opined that accumulations in the basement appears to be through medium to long distance migration from the mature Andimadam source beds abutting against the Basement. It is postulated that in addition to fracture networks and faults connecting the source to the basement reservoirs, the basement-sedimentary beds interface would provide one of the least resistant flow path for the migration of hydrocarbons that are released during primary migration from the Andimadam source pods.

Key words: Precambrian basement, oil & gas, buried hills, back-fills

1. Introduction & Exploration history :

Cauvery Basin is the southernmost petroliferous basin located in the state of Tamil Nadu in India. Exploration for hydrocarbon in Cauvery basin was initiated by ONGC in 1958 starting with geological surveys in the outcrops followed by geophysical survey in 1959 in the onland which was subsequently extended into the offshore area in 1964. The first wildcat well Karaikal-1 was drilled in 1964 have indicated presence of oil and gas. The first onland discovery was made in 1976 (Karaikal-10). Subsequently ONGC made the first offshore discovery, PY-1 in 1980. So far accumulations of oil and gas have been established in the Archaen-Proterozoic crystalline basement, Lower and Upper Cretaceous, Palaeocene, Eocene and Oligocene. This paper is intended to deal in greater details about the occurrence of oil & gas in the basement rocks which has emerged as one of the important target for exploration in this basin (Fig-1).

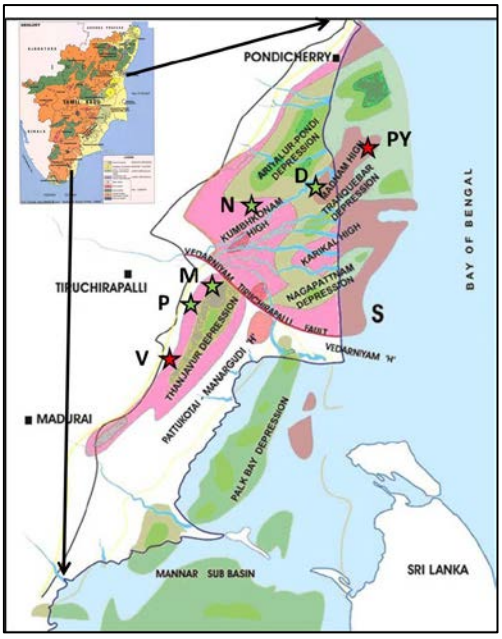

Fig-1: Tectonic map of Cauvery Basin showing horsts & graben structures. Tentative locations of the oil & gas discoveries from basement are shown.

Oldest sedimentary rocks belonging to the Upper Gondwana outcrops in the western margin of the basin. In the sub-surface more than 8000m thick sedimentary column ranging in age from Permian (?) to Miocene have been encountered. Generalized stratigraphy of the basin is given in Fig-2.

Evolution of the Cauvery basin is genetically linked with the other simultaneously evolving extensional basins of East Coast of India, viz. Palar, Krishna-Godavari, Mahanadi and Bengal Basins (Rangaraju et al, 1993). These basins were formed as a result of fragmentation of Gondwanaland during Late Jurassic- Lower Cretaceous and it continued to evolve till the end of Tertiary through rift, pull-apart, shelf sag and tilt phases during which many episodes of transgression, regression, erosion and deposition took place to fill the basin (Prabhakar and Zutshi, 1993).

The basement rocks of Peninsular India consist of complexes of Archaen-Proterozoic igneous and high-grade metamorphic rocks. Tectonically the crystalline basement falls within two major terrains, a greenstone-granite terrain (Dharwar Craton) in the north and a granulite terrain in the south. Dividing the two crystalline terrains is what is known as the Palghat-Cauvery shear zone (PCSZ) which was originally recognized by ONGC field geologists and was named as Cauvery Fault. This shear zone has been recognized as the boundary between two geological domains (Fig 3a & 3b).

2. Petroleum System :

Laboratory geochemical investigations have established the Andimadam formation having TOC ranging from 0.56 to 10.7 %, HI ranging from 40 to 416 mgHC/g TOC as the main source rock in Cauvery Basin. Bhuvanagiri formation (in Bhuvanagiri Field) also exhibits intervals with good to excellent organic matter richness and fair to good generative potential (Neeraja P, et al 2013). The generation threshold (VRo 0.5%) varies from 40 to 72 Ma from one sub-basin to other sub-basin. Computation of critical moment, the time of filling of the primary trap has been equivalent to 0.70 % VRo based on Methyl Phenanthrene Index (MPI). The critical moment in Cauvery basin becomes younger from north to south. It is 50 Ma in Ariyalur-Pondicherry sub-basin, 25 Ma in Tranquebar, 15 Ma in Nagapattinam and 3 Ma in Ramnad sub-basins (Chandra et al 2001).

3. Hydrocarbon Occurrence in Basement:

The Precambrain basement topography in the sub-surface of Cauvery Basin is undulating in nature with ridges and intervening depressions (Fig-4). Hydrocarbons discovered so far in basement are

located along one of the prominent basement ridge which appears as a ‘’buried hill”. Wells drilled along its flank as well in the crestal part have proved to be hydrocarbon bearing. Establishing the

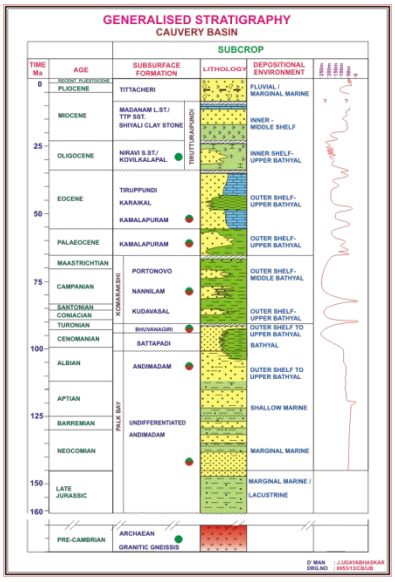

Fig-2: Generalised sub-surface Stratigraphic column of Cauvery Basin.

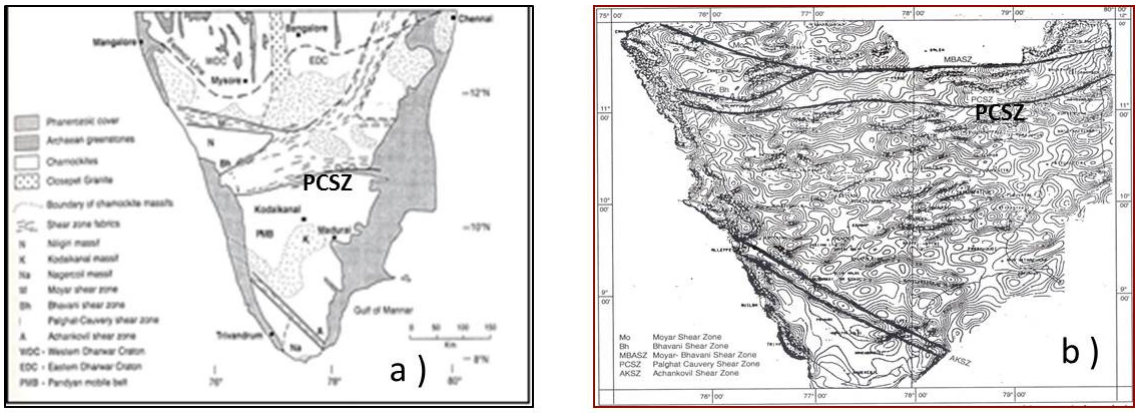

Fig-3a: Southern part of Peninsular India showing various shear zones and position of Cauvery Basin. b) Aeromagnetic map India showing crustal scale shear zones marking terrain boundaries, position of the Palghat Cauvery Shear Zone (PCSZ) is shown (after Reddi et al, 2008) Source: Geology of India, Vol-1 edited by Ramakrishnan M & Vaidyanadhan R., 2008.

controlling factors for hydrocarbon accumulations and its localization has proved to be a challenge. First commercial oil discovery in fractured/weathered basement was made in 1980 in the PY-1 field located about 50 km SSE of Pondicherry offshore on the eastern most part of the Kumbakonam-Madanam-Porto Novo High. This offshore field was later operated by private operator for development and production. In the following years oil & gas was discovered in the onland part of this prominent basement high in M (1994) and P (1995) both located in the western part of the Kumbakonam-Madanam-Porto Novo High and field V (2003) on the Pattukotai-Manargudi ridge (Fig-1). Following these early successes many exploratory wells drilled subsequently in this area targeting basement prospect did not yield the desired results.

Revisit to some previously explored structures (D & N) located along the Kumbakonam-Madanam-Porto Novo High has resulted in two important oil & gas discoveries. These recent discoveries have given new insights about the hydrocarbon occurrences and its habitat in the Precambrian basement.

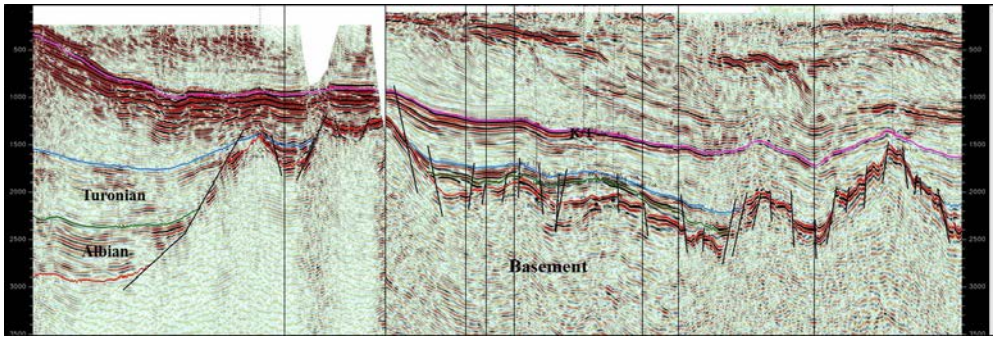

Fig-4: Arbitrary seismic section across Cauvery Basin showing the undulating topography of the Precambrian Basement.

Consequently new strategy towards exploration for oil & gas in the basement has been undertaken. Presence of hydrocarbon is seen from the top of the basement which is capped by shale of the overlying formation. Interestingly in the latest discovery N, the top 90m of the basement was found to be practically devoid of any hydrocarbon shows, and then upon further penetration into the basement presence of hydrocarbon started showing (Fig-5). Resistivity image log run in this well do not conclusively ascertain fracture pattern in the basement section probably due to very rugose nature of the borehole. The surprise in this well was followed up by barefoot testing of the basement which flowed oil @ 30m3/day and gas @ 18500m3/day. This recent find have necessitated a renewed approach to explore hydrocarbon accumulation deeper into the basement by a few hundred metres and not merely drilling few metres which may lead to missing of a potential accumulation like in N (Fig-5 & 6).

4. HC accumulation models in basement

Worldwide there are 30 different countries having production of oil & gas from the basement. Some of the largest fields are located in Vietnam and Yemen (Geoscience Ltd, 2012). In the recent years Hurricane Energy, a company dedicated to basement exploration has reported major discoveries in the UK continental shelf. The focus of the company is on the, Rona Ridge trend, West of Shetland where the extremely old (2.33 – 3.2 Ba) and fractured Lewisian Basement forms extensive ridges and localised highs which are the focal point for charge from the prolific Kimmeridge Clay source rock in the area *(source : http://www.hurricaneenergy.com)*. Hurricane has modelled accumulation and migration (which it calls as “Jelly Fish”model) as the result of basement up warping forcing basement by few kilometres above the prolific Kimmeridge clay. Upward movement of the basement resulted in extensive faulting and fracturing in the basement. As the oil producing rock forces out hydrocarbons, they move up the flank and into the basement through the fracture network. Oil migrated into the trap which is overlain by thick seals of mud and clay. Oil also backfills down through the highly permeable fracture network. In the basement there is no permeability in the rock, so the oil cannot escape but is trapped (Fig-6).

In case of Cauvery Basin somewhat similar accumulation and migration model is proposed in the present work. The sub-surface Kumbakonam-Madanam basement ridge appears to have remained exposed to sub-aerial weathering and erosion till the end of Turonian whereas sedimentation continued in the intervening depressions. Analogues of such exposed hills are still prevalent throughout the state of Tamil Nadu as inselbergs (Fig.7). These basement ridges were subsequently covered during Cenomanian-Tertiary sedimentation as “buried hills”.

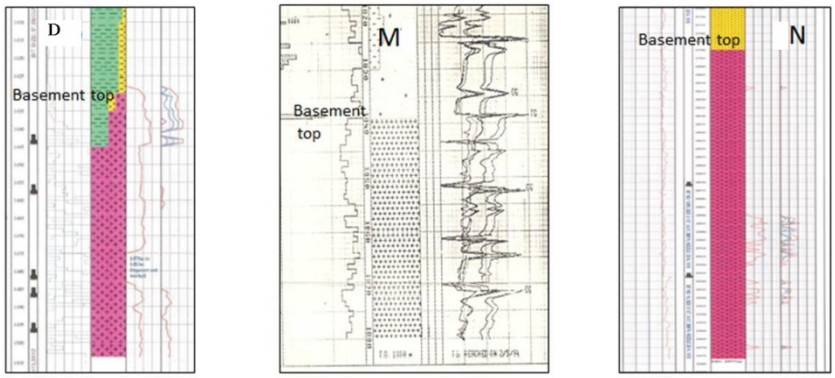

Fig-5: Mud logs of three drilled wells D, M & N. In both D & M gas shows encountered right from top of basement. Whereas, in well N top 90m in basement was practically devoid of gas shows then presence of hydrocarbon started showing, signifying a different hydrocarbon habitat from the former two wells.

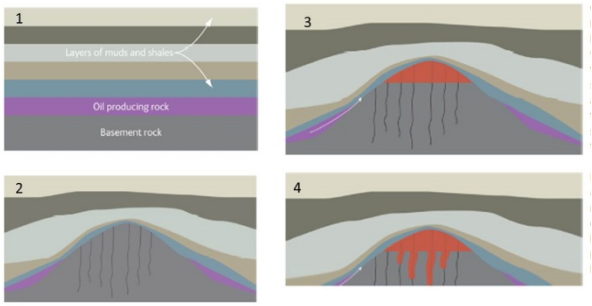

Fig-6: "Jelly Fish" model for the Basement oil accumulation in UK Continental Shelf, West of Shetland devised by Hurricane Energy (after www.hurricaneenergy.com).

In addition to lateral filling of hydrocarbons expelled from the source beds abutting against the basement, it is postulated that the sediment and basement interface (i.e, flanks of the basement) will provide less torturous migration pathways for the migrating hydrocarbons. Also once exposed and now buried, fractured basement will have lesser fluid pressure than the fluid filled sedimentary strata surrounding it, providing thus, favourable conditions for oil migration into the permeable fractures and fissures in the basement. A sealing cap of shale or clay will trap the hydrocarbons.

Fig-7: Photograph of basement near the town Yanaimalai meaning "Elephant Hill" in Tamil, exposed as inselberg having steep sides rising abruptly from the surrounding area. (source : http://geographyoftamilnadu.blogspot.in)

Upward migrating oil along the basement-sediment interface & fractured networks may find its way and get trapped into the fractured portions which in turn may not be inter-connected further upward leading to accumulation as encountered in field N (Fig-8).

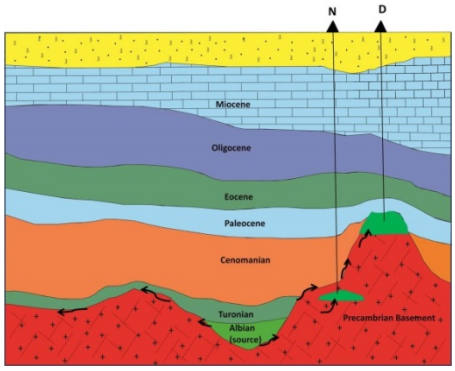

Fig-8: Schematic model to depict hydrocarbon migration and accumulation into the basement in Cauvery Basin.

5. Conclusion:

- Hydrocarbon accumulations in the Precambrian basement in Cauvery Basin occur in two distinct habitats.
- The sediment and basement interface / flank of the basement will provide a less torturous migration path for the migrating hydrocarbon. Also once exposed and now buried fractured basement definitely will have far lesser fluid pressure than the fluid filled sedimentary strata surrounding it, providing thus favourable conditions for oil migration into the permeable fractures and fissures in the basement. A sealing cap of shale or clay will trap the hydrocarbons.
- The exposed basement topography of Peninsular India adjacent to the Cauvery Basin can form a quality analogy area for understanding the basement in the sub-surface.
- Effective exploration in basement may require penetrations of a few hundred metres into the basement and not overlook its prospectivity by merely tagging it which may lead to missing of potential accumulations deeper in the basement.

Acknowledgement

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