Summary

KG-PG Basin has been established as a polycyclic intracratonic rift basin which hosts petroleum systems ranging from Permian to Pliocene and offers a target for aggressive exploration. As the imprints of at least two major tectonic events are clearly evident, the possibility of basement to be fractured is very high. Established Basement lineaments also support the existence of more than one trend of fractures. Although the basement configuration and its juxtaposition with the source rocks in West Godavari as well as East Godavari areas give sufficient clue for existence of basement HC, but due to various reasons its systematic exploration has been overlooked. Although approximately 56 wells have been terminated in basement but none of them aimed basement as prospect. Only a handful of them have been tested which turned out to be dry. The Recent HC finds in synrift sediments flanking Bantumilli high demands detailed exploration of Basement highs. Recent basement finds of Cauvery basin as well as the established ones from Western Offshore and Assam discoveries highlight some of the important criterion which may form the basis of an aggressive systematic basement exploration campaign. Current article draws a comparison of geological disposition of basement highs of KG Basin with those of the recent ones. An integrated gravity – seismic mapping of the area may bring out new locales for detailed exploration. Some possible locales are indicated.

Keywords: Basement, KG Basin, characteristics, petroleum system, status

The commonest quote

Commercial oil deposits in basement rocks are not Geological ‘accidents’ but are oil accumulations which obey all the rules of oil sourcing, migration and entrapment; therefore in areas of not too deep basement, oil deposits within basement should be explored with the same professional skill and zeal as accumulations in the overlying sediments.” -K.K. Landes et al (1960 AAPG)

The KG Basin

KG Basin is a polycyclic peri-cratic passive margin rift basin located on the east coast of India and extends both onland and offshore. The onland part covers an area of app 28,000 sq km and the offshore part including deep waters covers an area of about 1,45,000 square km. The characteristic feature of his basin is the presence of enechelon system of basement horsts and grabens filled with thick pile of Permian to recent sediments. The Basin show two prominent structural grains of NW-SE older Gondwanic Pranhita-Godavari trend and the NE-SW horst graben trend of passive margin rift system related to Jurassic-Cretaceous breakup of the Greater Indian sub-continent from Antarctica.
Composite Bouguer Anomaly map, Residual Gravity map and the seismic data indicate the presence of linear subsurface basement highs and lows. The KG basin is divided into Krishna, West Godavari and East Godavari depressions separated by basement highs named as Baptala and Tanuku ridges. The prominent cross trends of Pithapuram and Chintalapudi define the main Godavari basinal area. The Chintalapudi cross trend divides the West Godavari into Bhimadolu depression towards the north and Gudivada and Bantumali depressions separated by Kaza ridge to the south. The average thickness of the sediments over the ridges varies from 0.5 km over the Baptala ridge to 2.5 km over the Tanuku ridge. In the depressions, thickness varies from 3 km in Krishna depression to over 7 km in Godavari depression.

Generalized Geology

All the depressions in the basin are filled up with sediments ranging in age from Late Paleozoic to Late Mesozoic to Recent. The PG graben, which evolved as a pull apart intracratonic basin, till the Jurassic, and then due to the break-up of Gondwanaland, became peri-cratonic basin, preserves Permo-Jurassic sediments of Kommugudem Fm, and Mandapeta Fm along with the Red Bed. These remnants of early rift system are overlain by Fluvial/Fluvio Marine synrift sediments of later cycle which commenced with the NE-SW rifting in cretaceous, known as Gollapalli Fm in East Godavari and Nandigama Fm in West Godavari. These are overlain by transgressive shale dominated sediments of Raghavapuram Fm which mark the first marine flooding in the entire basin. Lower part of this Raghavapuram Fm shows a High Gamma High Resistivity event in the northwestern part, however not seen in the basin, has been named as HG-HR marker. Raghavpuram Fm is conformably overlain by Sand rich Tirupati Fm representing the transgressive episode. Widespread volcanic activity occurred early Cretaceous to Eocene. The oldest flows are dated by Ar-Ar method to be 100-105 my (Rajmahals) and the outcropping basalts of Krishna-Godavari basin are believed to be of Palaeocene.

Fig-2 Basin Fill map showing highs and lows in KG Basin, Karuppusway,2013

Fig-3 Generalised Stratigraphy of KG Bsin, Source - DGH

The Tertiary period is marked by several cycles of transgression and regression and rapid progradation of the deltaic domain. This led to narrowing of the basin shelf and the deposition of sediments associated with growth faults and roll over anticlines.

Characteristics of the Basement Rocks

The Precambrian igneous metamorphic complex of the Eastern Ghats which forms the basement in KG-PG Basin is comprised of high grade metsediments known as Khondalites with Charnockites having intrusive relationship with former. The original structural trend is NE-SW which has been related to a remnant mega fold of Archean times(Krishnan, 1960). The Magnetic methods have established the presence of Charnockites as part of the basement of KG Basin (Murthy, 2006). Mineralogical composition of these igneous - metamorphic complex may be considered during fracture modeling. As the area has experienced at least two sets of extensional tectonism and led to two orthogonal sets of fractures- the older NW-SW and younger SE-NW, The basement is likely to be fractured. Active subsidence along normal fault system, parallel to Precambrian Eastern Ghat trend, developed during rifting, gave rise to horst graben setting. These synrift extensional faults were reactivated in several stages. Due to tectonic activities in several stages, in
addition to the major linear horst and grabens, existence of a number of isolated buried hills is very likely. The sedimentation pattern has led to the juxtaposition of source rich sediments with basement horst. The phenomena is well evidenced in Gudivada, Mandapeta and Kakinada low areas.

**Basin Evolution**

The basin evolved through four tectonosedimentary phases including the initial rift phase, followed by Synrift phase, the Drift Phase and the Late Drift phase (DGH). The northeastern part of the present onland basin was part of an intra cratonic rift set up till Jurassic that constituted the southeastern extension of NW-SE trending continental rift valley slopping northward. The present KG basin got initiated through rift / syn-rift tectonics between Permo-Triassic to Early Cretaceous. In the synrift stage, the sediments were deposited during early subsidence by tectonic fault systems. Basin subsidence continued along basement bound fault system accommodating synrift sediments of late Jurassic to early Cretaceous. Rift to drift transition in the Drift stage marks a southerly/southeasterly tilt of the basin leading to widespread marine transgression during Cretaceous and deposition of marine shale sequence followed by onset of overall regressive phase during Late Cretaceous. During Maastrichtian-Danian, the basin experienced major volcanic activity (Razole Volcanism) covering 1600 sq. km. area and having span of 5.5 million years. Soft collision between the Indian and Eurasian Plates and initiation of Matsyapuri-Palakollu fault appears to have greatly influenced the Paleogene and younger tectonic regime and the consequent sedimentation pattern. During Later drift stage sediment induced neogene tectonics has been the most significant phenomena. Increased gradients for the river systems and increased sediment load coupled with significant sea level falls during Neogene had triggered sediment induced tectonics in the shelf and slope parts of the basin creating highly prospective exploration locales.

**Petroleum Systems**

KG Basin is a unique basin where hydrocarbon accumulation is seen in the traps of all ages viz from Permian to Pliocene. It is quite evident that the basement highs developed in the extensional regime created isolated sedimentation systems and thus separate petroleum systems in the different parts of the basin (Table-1). An estimate says that the Permian source rock started expulsion at around 110 Ma and reached the critical moment at around 90 Ma. Mature cretaceous source rocks present over a large geographical area in onshore as well as offshore started expulsion at 40 Ma and their critical moment reached at around 1.3 Ma. Condensates of Eocene, Paleocene, and Upper Cretaceous reservoirs correlating to Cretaceous sources indicate that the traps in their migration path should be filled. Due to continued oil/gas generation in the Cretaceous source rocks, Eocene and older reservoirs in existing oil field areas in shallow offshore, Mori, Chintallapalli, Modi, Narsapur, Velpuru and Tanuku areas have excellent prospect of being filled. The Eocene source rock recently started expulsion (6 Ma) and has not reached the critical moment.

<table>
<thead>
<tr>
<th>Area</th>
<th>Petroleum System</th>
<th>Source</th>
<th>Reservoir</th>
<th>Seal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manapeta-Endamauru</td>
<td>Permian – Up Jurassic Cret system</td>
<td>Kommugudem Fm. Max TOC: 6.5%, HI: 155</td>
<td>Mandapeta-Golapalli Set</td>
<td>Red Bed, Argillaceous on top of MDP Fm. RGP Shales</td>
</tr>
<tr>
<td>West Godavari</td>
<td>Aptian-Albian TST</td>
<td>Gajulapadu Shales TOC: 1 to 8.4</td>
<td>Karukollu Formation</td>
<td>RGP Shales</td>
</tr>
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<td></td>
<td>Aptian-Albian HST</td>
<td>RGP Shales TOC: 0.8 to 3.4%, HI: 1.40</td>
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<tr>
<td></td>
<td>Up Cret Chintallapalli-Tirupati System</td>
<td>Chintalapalli Shale TOC around 2%, HI:25</td>
<td>Tirupati Set throughout the basin</td>
<td>Traps/Tertiary Shales, RGP and CTP Shales</td>
</tr>
<tr>
<td>South of MTP-PLK Fault Zone</td>
<td>Upper Cretaceous-Eocene-Pliocene</td>
<td>Chintalapalli Shale: RGP Shale TOC: 2%, HI:25</td>
<td>Sands within RGP, CTP and TPT Fm.</td>
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<tr>
<td></td>
<td>Paleocene</td>
<td>Palakkollu Shale TOC: 1.2 to 2.8, HI: 1.50</td>
<td>Pasarlapudp Formation</td>
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<tr>
<td></td>
<td>Eocene</td>
<td>Vaddapura Shale of Oligocene TOC: 1.4-5.1%, HI: 290</td>
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<tr>
<td>Offshore Area</td>
<td>Pliocene</td>
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Indian Basement Discoveries

Recent successes in Cauvery Basin along with the Western offshore, Cambay and Assam brings out some common patterns which are supported by the global occurrences of basement hydrocarbons. In addition to the other elements of petroleum system viz source, seal, reservoir, migration pathway, the relief of the buried basement hills is a very important factor. Majority of the global discoveries come from the buried hills having prominent relief along with the juxtaposition of source sediment along the flanks. Structural map of Borholla of Assam reveals an antiformal structure at basement level. In the Mumbai offshore major fractures are vertical to sub vertical and are genetically linked to Dharwar trend. The Aravalli and Satpura trends have offset these fractures and created the fracture mesh. In the Bassein field Basement high juxtaposed against kitchen to the east has been observed. Recent finds in Cauvery basin also point towards the occurrence of basement HC nearby the fault zones on the isolated basement hills where suitable source and cap exist. In the Mattur area the fractures are induced by the extensional faulting related to rift and wrenching during drift phase. The rift related faulting in this basin has a major NE-SW trend which is offset by younger NW- SE trend.

In the Pandanallur area fractures area observed in specific intervals much below basement top and Borehole breakouts correspond to highly weathered zones. In the Madanam and Pundi areas, the discoveries lie on the top of the basement hill the close proximity of a fault/ fracture zones. Again in cauvery basin only, the efforts taken to explore the fractured basement at shallow level which do not have considerable relief show only indications, viz Krishnapuram area of Tanjavur sub basin.

Status of Basement Exploration

In KG basin, although 56 wells have penetrated the basement but none was planned to probe a basement prospect. Only five were tested, out of which, one well showed HC indication and rest four were proven to be dry. Majority of the wells entering into basement have been drilled on the Kaza – Kaikalur high, Bantumilli high and Endamuru high. Some of the wells have been drilled in Krishna sub basin, PG basin, Kakinada high also. As most of the locations targeted the shallower prospects in the overlying sediments, the suitability of basement prospects were largely ignored and the basement drilling was done in order to enhance the geological understanding of the basin. The basement prospects have never been delineated or attempted. In most of the wells, penetration in the basement are negligible or are not in proximity of fault zones. Hence it can be said that the basement plays of KG Basin remain a virgin prospect and yet to be explored.

Envisaged Prospectivity

Gravity data analysis based on the inversion of residual gravity
anomalies, after removal of regional component from the Bouguer anomalies over the onshore and offshore part of KG basin indicate the presence of a number of basement depressions as deep as 7.5 km and ridges as shallow as 1.0 km which corroborate well with borehole and seismic results. (Singh et al 2009). High resolution gravity mapping combined with seismic reflections may reveal the existence of small basement highs with considerable relief. Petroleum system modeling studies indicate that the generation of HC in a huge quantum occurred with their critical moments after the attainment of structural positions of the basement highs and hence in those areas where source rock is juxtaposed with fractured basement highs should be taken as high priority areas for basement exploration. Detailed regional geological studies indicate towards the existence of quite a good number of such locales where source rocks are juxtaposed with the basement highs and forms ideal sites for basement HC exploration. The recent exploratory activities further provide some leads in this direction. At location Laxminarasimhapuram, which lies above a basement high, presence of oil at the bottom of Raghavapuram Fm has been discovered. Raghavapuram Fm, which forms a prolific source and flank the Bantumilli high producing source as well as seal. Further on the eastern flanks of Bantumilli high, Gollapalli Fm has been found to hold huge gas reserves at very pressure in a recently declared discovery as Bantumilli h South. The geological set up of these locations (Fig) point towards the generation and migration of HC in the close proximity of the fractured Basement highs which increases the possibility of the basement to be charged.

In the Malleswaram area where Oil and Gas deposits have been discovered from Nandigama Formation, basement highs offer lucrative exploration targets.

**Conclusion**

KG basin has already been proven as a prolific HC producer where HC has been located in various plays ranging from Permian to Recent. Basement plays of KG Basin are largely unexplored. In the wake of recent successes in Cauvery Basin and other parts of India, the plausibility of basement reservoirs of KG basin demands a systematic exploration campaign. Recent Indian discoveries highlight some strong clues for the identification of the targets. Disposition of Source rich sediments deposited in the lows juxtaposed with fractured basement highs make suitable conditions for the development of charged reservoirs. The configuration of basement, evidences of existence of secondary reservoir development processes, juxtaposition of source rocks vis-à-vis basement highs and proximity to the proven fields in KG Basin offers lucrative target for HC exploration. Recent synrift discoveries on the flanks of Bantumilli high
further strengthen the cause Locating isolated fractured basement hills juxtaposed with source rocks and sufficient drilling depth within basement section in the proximity of fault/fracture zone has proved to be successful. The geophysical and geological data point towards the presence of a number of buried basement hills in KG Basin. Integration of Seismic and Gravity based studies may bring out suitable locales for further exploration.

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