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Exploration of Prerift & Synrift Plays in KG Basin – Unfolding a New Chapter

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Abstract

KG-PG basin is a pericratonic rift basin on the east coast of India. It is a polyhistory basin with at least two known phases of tectono-sedimentary cycles and are known for their hydrocarbon occurrences. Imprints of various phases of tectonics are preserved in the form of various weak zones and lineaments in the Basement. An analysis of the Basement relief map prepared using 3D seismic data of KG Basin has been attempted which bring out different set of lineaments in different parts of the basin. It suggests that entire KG Basin can be divided into different sectors on the basis of NS trending regional structural elements. Presence of a NW-SE trending lineament, parallel to Pithapuram cross trend is identified which is envisaged as an important tectonic element which divides KG Basin into two parts. It is proposed to name this as **Penugonda Lineament**. Integration of bio stratigraphic studies suggests that in the northeast of this lineament, Permo-Triassic prerift sediments are overlain by early cretaceous Raghavapuram Sediments. Synrift Gollapalli sediments are not present in this area. In the south-east of this lineament, Permo Triassic sediments are overlain by Jurassic sediments. It is interesting to observe that Jurassic sediments are present in east Godavari as well as Gudivada Graben but absent in the Bantumilli Graben which lies between the two areas. On the integrated relief maps of Prerift top and Synrift top, extent of prerift and synrift plays in different sub basins are delineated.

Introduction

With unique characteristics of coexistence of seven petroleum systems ranging in age from Permian to Recent, KG-PG Basin located on the east coast of India, having an aerial extent of 230000 SKM extending from on land to deep offshore, preserving a sediment thickness up to 10 kms, has been attracting explorationists since 1950s. Tectonically, the onland part of the Basin has been divided into different sub basins viz Krishna Sub basin, Gudivada Graben, Batumilli Low, Bhimadolu Graben, Kavitam-Mandapeta Low, Narsapur Sub basin (South of Poduru Yanam High).These sub basins are restricted by the basement highs viz Baptala high, Kaza-Kaikalur high, Tanukku High and Poduru Yanam high (Fig-1). A deep-seated fault, extending across the KG PG Basin features prominently on the tectonic map

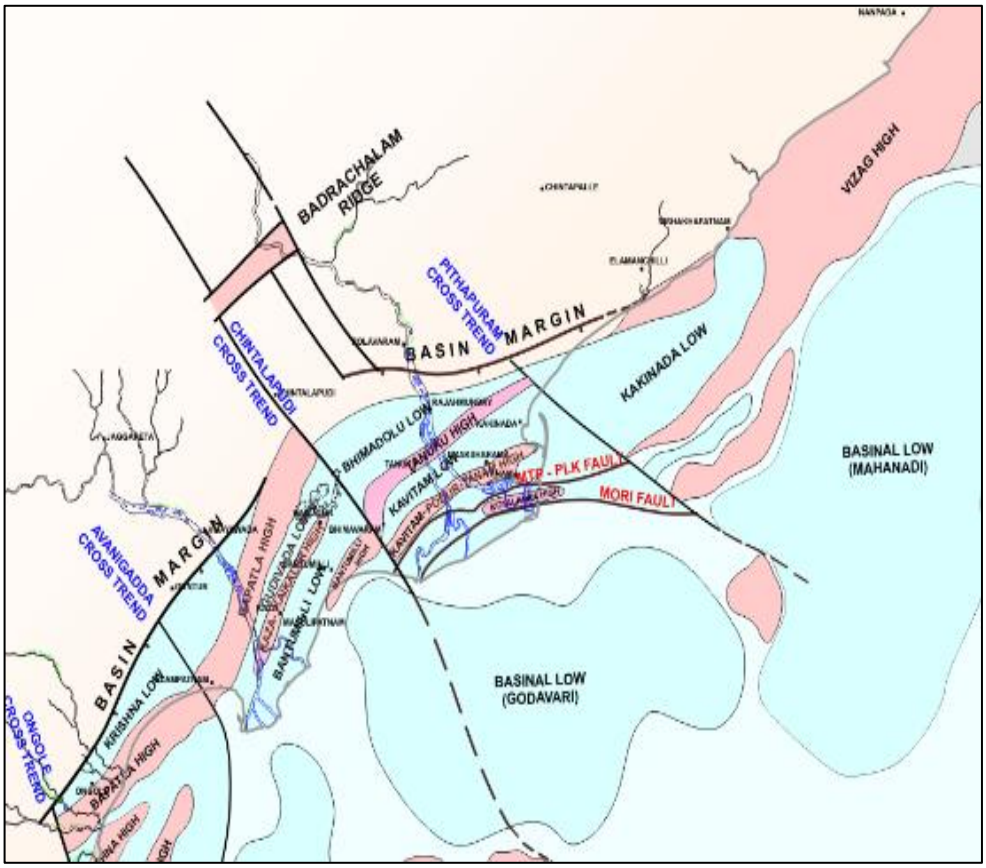

Figure 1 Tectonic Elements of Krishna Godavari Basin (Karuppuswamy, 2013)

known as Matsyapuri Pallakollu Fault, is an important tectonic feature. The first phase of intracratonic rifting within Gondwanaland led to the Permocarboniferous sedimentation in NW-SE trending PG graben which preserves Kommugudem, Mandapeta and Red Bed formations, deposited mostly in continental environment. This rift cycle of sedimentation continued till early part of late Jurassic and is being referred as Pre rift sedimentary rocks.

The second tectonosedimentary cycle begins in Late Jurassic-Early Cretaceous, was associated with the fragmentation of Gondwanaland. Previous studies indicate (Mohammed Ismael et al 2019) that the rift fill sediments of NW-SE trending PG Graben were subjected to continental stretching across the north east-south west strike of primeval structural grain (Eastern Ghat Orogeny) and led to the development of NE-SW trending rifted pericratonic passive margin KG Basin. This led to the deposition of early Cretaceous synrift sediments known as Nandigama Formation in West Godavari sub basins and Gollapalli Formation in East Godavari sub basins.These are overlain by post rift rift Raghavapuram Formation which occur as blanket sedimentation in the entire KG Basin. Both synrift and prerift sediments have been identified as hydrocarbon plays. Generalized stratigraphic column is provided as Fig-2. The later tectonic event of passive margin pericratonic basin trending NE-SW is superimposed on the earlier intracratonic rift set up trending NW-SE and the two trends are nearly orthogonal to each other. KG-PG basin is marked by the presence of some well-established coast perpendicular cross faults (Fig-1). Associated seismic activities suggest that these cross faults are still tectonically active (Ramkumar et al 2016). Prevailing concepts suggest that entire KG basin, delimited by Ongole cross trend in the south and Pithapuram cross trend in the north, evolved due to Cretaceous rifting and the entire basin preserves a huge thickness of synrift sediments distributed across various sub basins. Similarly, it is also understood that subsurface occurrence of Prerift sediments is restricted within the established limits of PG graben, between Chintalapudi & Pithapuram cross trends. In the present paper, assimilating the various geological aspects, an effort has been made to identify important lineaments which are envisaged to act as boundaries of different tectonic regimes and hence bring out new understanding of the regional set up. Integrating regional setting with seismic data, biostratigraphy, electrolog interpretations and laboratory

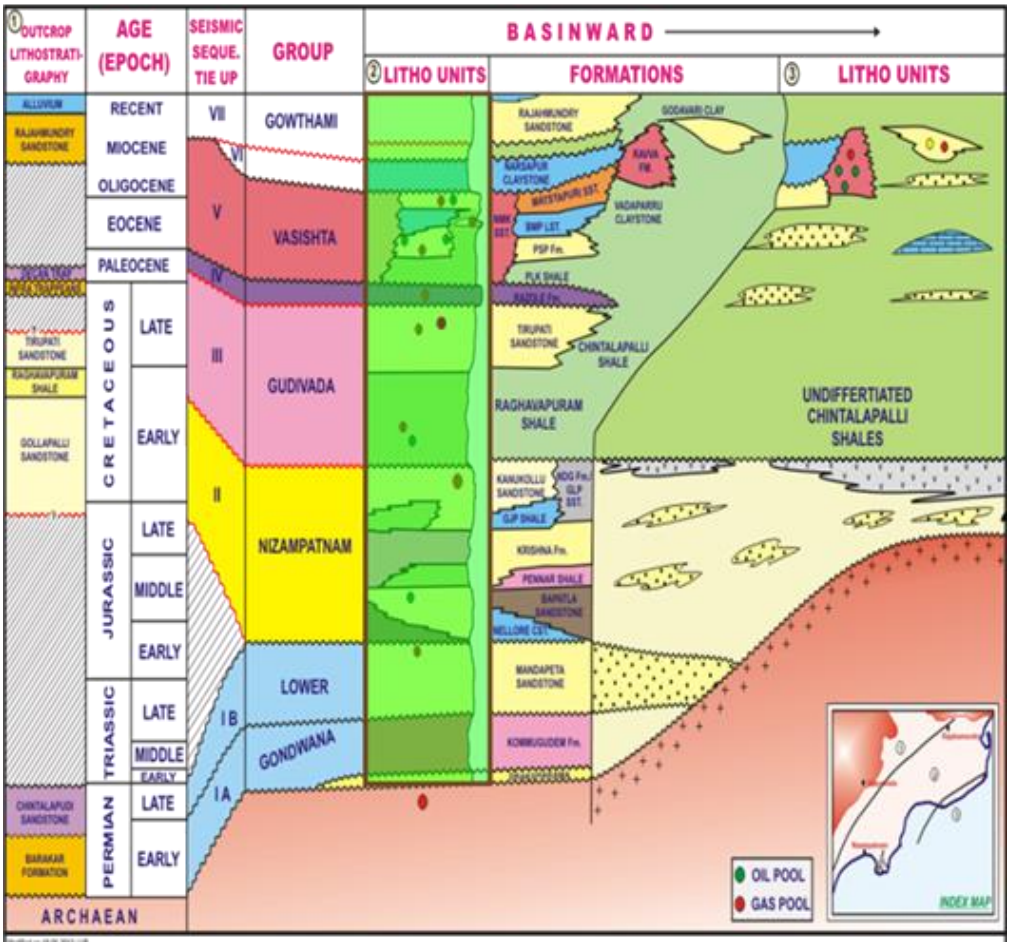

Figure 2 Generalised Stratigraphy of KG Basin (Karuppuswamy, 2013)

analyses of the rock cuttings, geological distribution of synrift and pririft plays in a regional framework have been attempted.

Sectors at Basement Level

Time relief map close to the top of Basement in different parts of KG-PG onland basin indicates presence of four sets of linear trends. These trends are marked as lineaments (Fig-3). Presence of NS trending lineaments1-8, appears to be present in the entire basin. These lineaments are apparent on the relief map as well as on seismic sections. Some of these are indicated in figures 4 & 8. In the southeast of Kaikalur Horst, it appears as a prominent feature which also marks the southern limit of Gudivda graben as well as Bantumilli Low. Eastward, as evident on the map, presence of NS lineament appears to mark the sharp change in relief of Bantumilli horst. Parallel occurrence of this NS lineament is observed in the East Godavari region also where it appears to affect the disposition of Tanuku High as well as Poduru Yanam high. Further, it appears to divide Kavitam Low into two parts - Kandepudi Low and Penugonda Low. Another parallel NS lineament is observed to be present between Mandapeta high and Penugonda Low. Similarly, it appears that Mandapeta High is bound towards east by a NS lineament. Trends of Gudivada graben, Kaza-Kaikalur Horst, Bantumilli Graben and Bantumilli horst follow similar NE-SW trend and terminate against a NW-SE trending lineament AA'. It is apparent that this lineament marks the southern limit of Tanuku Horst as well as Poduru Yanam High and can be Identified as the boundary of east and west Godavari sub basins.- This lineament coincides with Chintalapudi cross trend and does not appear to extend south of MTP-PLK Fault. Parallel to this, another NW-SE lineament XX' is

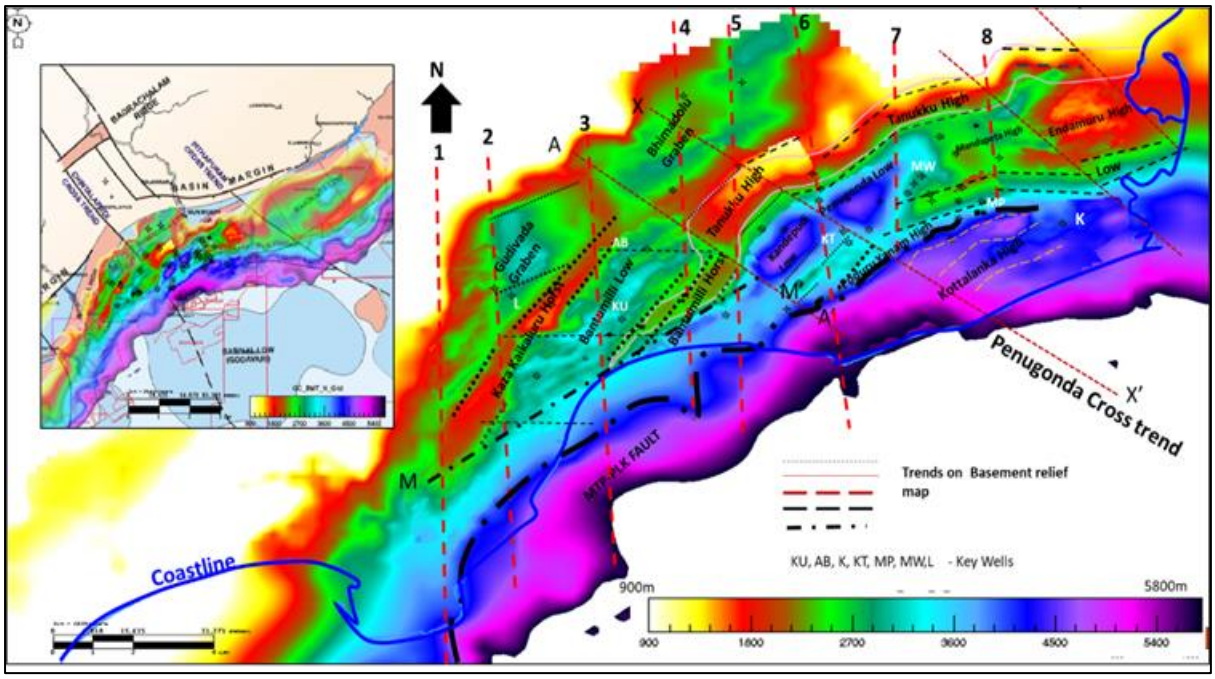

Figure 3 Time relief map near Basement Top of KG-PG Basin indicating different set of lineaments on the basis of the disposition of relief features. INSET- Time relief map near Top of Basement superimposed on Tectonic map of KG-PG Basin.

marked. This lineament shows parallelism with Pithapuram Cross trend. NW-SE oriented regional structural trends of west Godavari appear to prevail in the area between lineaments AA' & XX'. In the east of the lineament XX', a change in the trend of highs and lows are observed as evident from the trends of Tanuku high, Penugonda low and Poduru Yanam high. It is envisaged that the lineament XX' is an important tectonic element which divides KG-PG basin into two parts. Towards south west of this lineament, well developed NW-SE trending highs and lows are present having similar trend. In the north of this lineament, the trends as well as shape of the highs and lows are different. It appears to separate the Penugonda low from the .Kavitam low in the south of Tanuku horst. Further, in the south of Poduru Yanam high, it provides a sharp boundary between the north eastern part where horst and grabens are present from the SE part where a deep low is evident. In the SE of lineament AA', a NE-SW trending lineament MM' is observed to be present as a major

structural feature. This marks the limit of Bantumilli graben. In the southeast of lineament MM' no horst and graben structures are present (Fig-4a). It can be envisaged that XX' is a transform zone which probably marks boundary of two tectonic regimes.

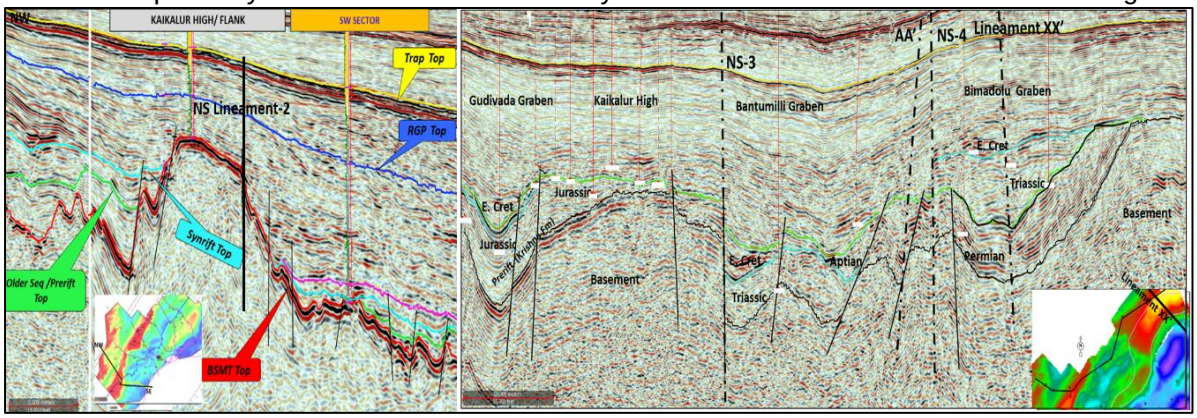

Figure 4 a NW-SE Seismic line showing absence of prominent horst and graben structure in the south east of lineament MM' (refer Fig-3),also NS lineament 2 is shown here. b. Seismic line passing through Gudivada Graben Kaikalur High, Bantumilli Graben & Bhimadolu Graben showing the disposition of Basement, Prerift & Synrift sediments. Lneaments XX', AA,, NS-3 4 are shown in the section.

Prerift Plays

In KG-PG Basin, Prerift sediments are primarily referred to the Gondwana sediments. Earlier, the occurrence of these sediments was considered to be restricted within Pithapuram and Chintalapudi Cross trends. However, In the recent years, in the wells drilled beyond these cross trends also have encountered Permian and Triassic sediments(Fig-6 inset, Shandilya et al 2017) It suggests the possible extension of Gondwana depocentre in NE-SW direction also. However, configuration of the extended permotriassic basin need to be brought in detail. Theoretical models of synrift sedimentation suggest that, in principle, an angular relationship exist between the attitude of Synrift rocks and that of the pre rift rocks. In the Gudivada Graben, a very thick sequence comprised mainly of arenaceous clastics of Late Jurassic age, known as Krishna Formation is unconfirmably overlain by early Cretaceous shales known as Gajulapadu Shale and exhibit an angular relationship. This arenaceous pack(Krishna Formation) is referred here as older sequence. The disposition of the older sequence and its parallelism with that of the Basement clearly points towards its Prerift affiliation (Fig-4b). It points towards post Jurassic tectonic upliftment of the area. Bantumilli graben is fully covered with 3D seismic data and around 90 wells have been drilled to explore the deeper plays. In the Bantumilli graben, earlier, it was considered that the Basement is overlain by Synrift Sediments. A close observation of the lithology encountered in different wells revealed that Basement is overlain by a pack of red claystone (Shandilya et al 2019), which in turn is a part of thicker sequence identified and mapped as older sequence. Palynological studies in a couple of wells in Bantumilli graben suggest Permo Triassic age of this older unit. Although, this is a clastic fluvial sequence, it possesses poor reservoir properties from hydrocarbon accumulation point of view. Since, this pack is overlain by synrift sequence and no active petroleum system is known to charge these reservoirs, no well through

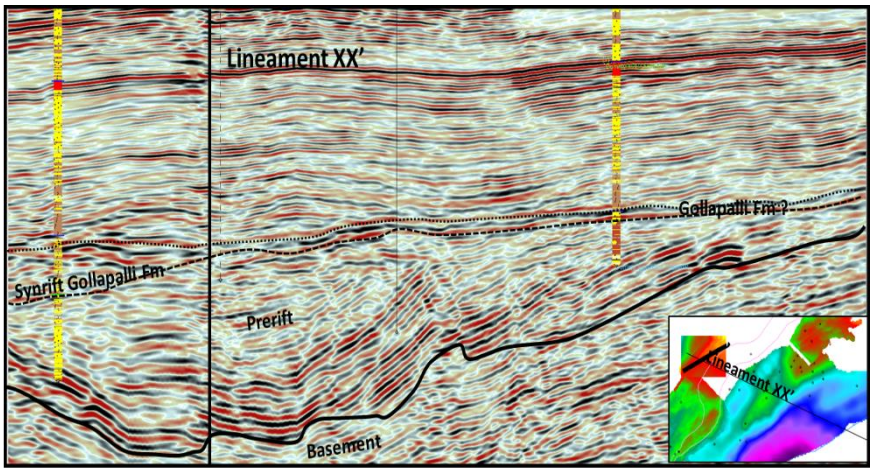

Figure 5 NE-SW seismic line in Bhimadolu Graben showing thickness variation of Gollapalli Fm across lineament xx'

unit has shown any hydrocarbon accumulation. Hence, although the prerift sequence is present in Bantumilli Graben, its occurrence is indicative only of restricted prospectivity. It is interesting to note that late Jurassic sediments are absent in Bantumilli Graben and Triassic sediments are overlain by early Cretaceous sediments. It suggests that probably this graben was a positive area during Jurassic and the graben formed during tectonic movement at the end of Jurassic. In the Bhimadolu Graben, it is well established that Mandapeta and Kommugudem formations of Gondwana supergroup overlie Basement. It is observed that lineament XX' divides Bhimadolu graben into two parts. In the SE part, thick prerift sediments along with synrift sediments are present while in the NE of this lineament, Basement is overlain by Raghavapuram Fm of Aptian. It is shown in the seismic section fig-5. A thin pack of synrift Gollapalli Formation (30-80m) is also considered to be present, however it can be envisaged that this pack is not Gollapalli but the basal part of Raghavapuram Fm. In the NE of line AA', south of Tanuku horst, lies the Kavitam-Mandapeta Low which is flanked in south by Poduru Yanam High.

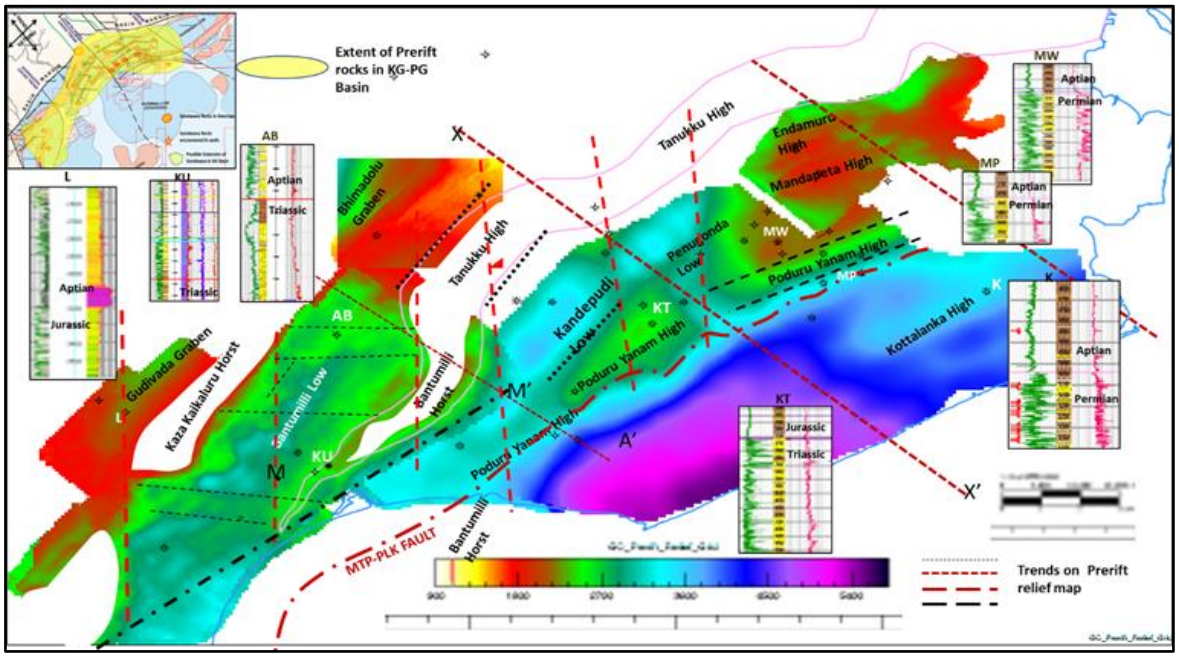

Figure 6 Time relief map near Prerift Top of KG-PG Basin indicating its extent as well as depth of occurrence. INSET- Possible extent of prerift rocks on the Tectonic map of KG Basin(Shandilya et al 2017)

As indicated over the basement map, the area can very well be divided into two parts by NW-SE lineament XX'. In the northern part of line XX', lies the Mandpeta Low which is well known for its Mandapeta Field, gas producer from prerift Mandpeta Formation. It is a structural high at prerift top which is overlain and juxtaposed by Raghavapuram Formation. Further south of Mandpeta field, prerift plays have been proved to be hydrocarbon bearing, although the reservoirs are tight and require advance stimulation techniques. In the south, lies Poduru Yanam high where basement is overlain by Kommugudem Formation which in turn is overlain by Raghavapuram Shales. In a couple of wells, drilled on the southern flanks of this high, commercial hydrocarbon is encountered from Permian sands. It further strengthens the understanding that wherever suitable entrapment exists within the prerift sands, in the juxtaposition of Raghavapuram Shale, prospectivity gets enhanced. Hence Prerift plays (Mandpeta as well as Kommugudem Formation) are highly prospective between Tanukku High and Poduru Yanam High in the NE of XX' lineament. In the south of this lineament lies Kandepudi low where Prerift sediments are present at depth below 5km. Being in the low, below the synrift deposits, it may be considered to be of low prospectivity, as seen in the Bantumilli graben. Towards south of this low lies Poduru Yanam High. Recent Palynological studies of the well cuttings drilled over the this high suggest that this is a huge structural high of Triassic sediments. Well data on these high indicate the presence of late Jurassic sediments composed chiefly of Shales which overlie Triassic sediments which in turn are overlain by Cretaceous Raghavapuram Shales. This high is juxtaposed with source rich Raghavapuram shales from north as well as south. Hydrocarbon indications from the wells drilled

over this high provides leads for the possibility of a large gas field. Hence for prerift play, this part of Poduru Yanam is highly prospective. In the south of Poduru Yanam High, again the area is bisected into two parts by the lineament XX'. In the NE of this lineament, horst and graben structure at the top of Prerift are evident. As against the prevailing models, present study envisages that no synrift Gollapalli Formation is present in the area. The Permian sediments composed of sand shale alternations serve as the reservoir and is overlain by Raghavapuram Shales of Aptian age. It is confirmed by biostratigraphic studies of the single well drilled in the area over Kottalanka high, a high running parallel to Poduru Yanam high in the area. It flowed gas from Permian sediments. However, the depth of occurrence is more than 5000mt and hence logistically difficult to explore. In the SW of this lineament no highs and lows are present but a broad deep low. Here presence of prerift or synrift sediments are doubtful. It appears that Raghavapuram Fm directly overlies the Basement

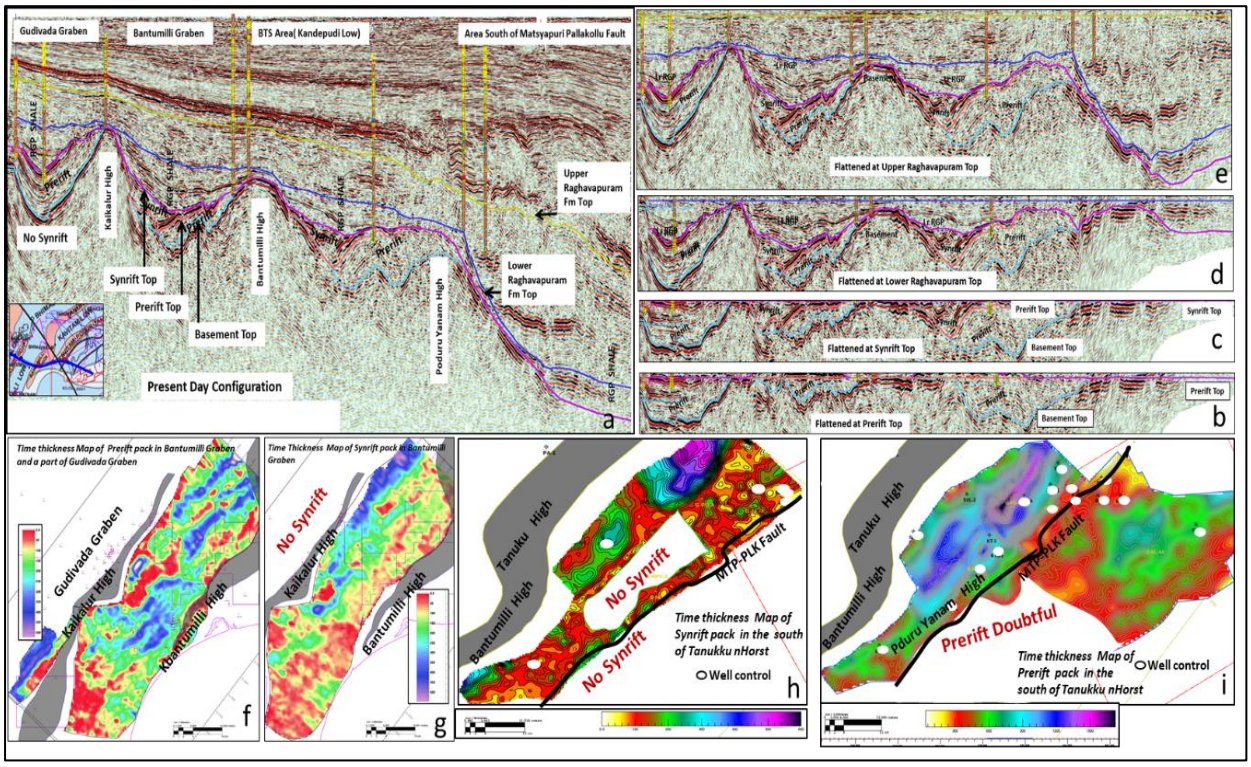

Figure 7 a) A regional seismic section passing through Gudivada Graben, Bantumilli Graben, Kandepudi Low to south of MTP-PLK fault showing present day disposition of Basement, Pririft, Synrift and Post rift (RGP Fm) b, c, d, e.) The section flattened at Prerift Top, Synrift Top, Lower Raghavapuram Top and Upper Raghavapuram Top f) Time Thickness map of Prerift pack in Bantumilli Graben and part of Gudivada Graben g) Time thickness map of Synrift pack in Bantumilli Graben. In Gudivada Graben no synrift is inferred h) Time Thickness map of Synrift pack in south / SE of Tanuku high/Bantumilli high i) Time Thickness map of Prerift pack in south / SE of Tanuku high/Bantumilli high

Synrift Plays

It is envisaged that initiation of rifting during Late Jurassic-Early Cretaceous led to the development of restricted marginal marine environment in the grabens and fluvio marine deposits on the flanks. On the highs, erosion with localised sedimentation might have taken place. Hence majority of the sedimentation appears to have taken place on the flanks and within the grabens. In the Gudivada graben, no clear cut synrift deposits are found. In the drilled wells, it is observed that the Prerift arenaceous pack is directly overlain by Lower Raghavapuram shales which were deposited in restricted marine environment. It indicates that the area came under marine influence concomitant with the tectonic movement in the end of Jurassic and led to shale

deposition. Hence the prevailing understanding of the pattern of synrift sedimentation pattern in Gudivada graben needs to be relooked. In Bantumilli Graben, the synrifts deposits, known as Nandigama Formation has been found to be present in the entire sub basin. Entire Bantumilli graben is envisaged to receive clastic sediments during synrift phase from the adjoining highs viz, Bantumilli high, Kaza Kaikaluru high and Tanukku high. The synrifts here are overlain by lower Raghavapuram shales which facilitate as regional seal along with lateral source. The intercalated shales within synrift Nandigama Formation are also considered as good source rocks. As mentioned earlier, lineament XX' is envisaged to be a major tectonic element which acts as a transform zone.

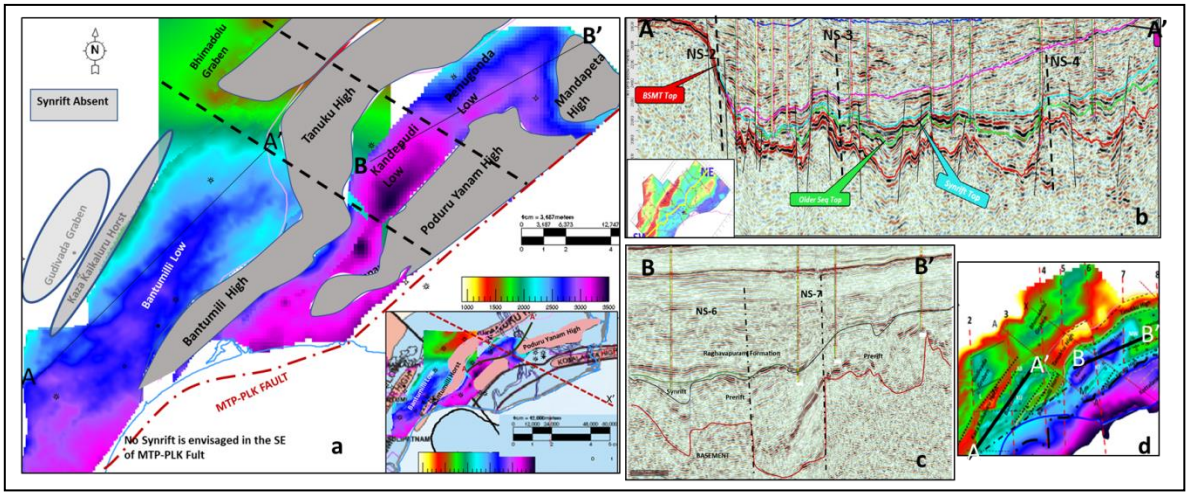

Figure- 8 a. Time relief map near Synrift Top of KG-PG Basin indicating extent and depth of occurrence of Synrift play b. Seismic line AA' showing disposition of Synrift, Prerift and Basement in Bantumilli graben. NS Lineaments 2, 3 & 4 marked in fig-3 are also indicated c. Seismic line BB' showing disposition of Synrift, Prerift and Basement in east Godavari. Lineaments XX' and NS-6 are also indicated. d. disposition of line AA';& BB' on Basement relief map

It has been observed that in the NE of this lineament, synrift sediments are either absent of very thin. In the wells drilled in this area, Gollapalli Fm is represented by a pack of around 60mts of sand shale alternation while in the SW of this lineament, synrift sediments thickness increases appreciably. This phenomenon is observed in the area in the south of Tanukku Horst also. In the North of Tanuku high, in Bhimadolu graben, between lineaments XX' and AA' presence of appreciable thickness of synrift sediments is envisaged. One well has been drilled in this area, in the SW of lineament XX which encountered thick Gollapalii Formation and indicated hydrocarbon shows during drilling. In the NE part of this lineament, where synrift is either absent or represented by a sand pack of nearly 60mts Fig-8c. It may be considered as the basal part of Raghavapuram Formation. A regional understanding about the distribution pattern of this sand may locate the strati structural entrapments in this area. In the East Godavari region, towards south of Tanukku Horst, again this lineament divides the area in two parts. Towards NE, synrift is either absent or very thin. this pack representing Gollapalli Formation may be envisaged as basal part of Lower Raghavapuram. In the Kandepudi Low, appreciable thickness of Gollapalli formation is present, however, it occurs at depths below 5000m and overlain by Raghavapuram Shale. A well drilled in this area reveals the HP-HT-Tight nature of these reservoirs. However, on the northern flanks of Poduru Yanam High, appreciable thickness of synrift sediments lying in juxtaposition of Raghavapuram Shale, appears to be good locales for synrift exploration. Towards south of Poduru Yanam high, no occurrence of synrift sediments has been observed. In SW of lineament XX' Raghavapuram Fm overlies Basement/doubtful Permian sediments while in the NE of this lineament, Raghavapuram Fm overlies thick prerift sediments.

Conclusions

Integrating the recent sedimentological, biostratigraphic and 3D seismic data, maps near the tops of Basement, Prerift and Synrift are prepared and analyzed. At Basement level, four distinct set of lineaments are identified. Based on the N-S trending lineaments, entire KG Basin can be divided into different sectors. Each sector is envisaged to preserve tectonic history in the broad framework of the evolution of KG Basin. A lineament XX' is being identified as an important tectonic element which divides KG-PG basin into two parts. This lineament may be named as **Penugonda Cross Trend as** shown in Fig-3. In the NE of this lineament, occurrence of synrift is not observed while in the sub basins in the SE of this lineament, synrift sediments are present in the grabenal part. The extent and depth of occurrence of Prerift and Synrift sediments are marked.

It is observed that in Gudivada graben, prerift play needs further exploration while synrift prospectivity is doubtful. In Bantumilli Graben, prerift sediments are present but with very poor prospectivity while the synrift prospectivity is higher towards the southern part. In Kandepudi low, thick synrift pack is present but its deep occurrence coupled with unconventional nature lowers its prospectivity and same for prerift play also. On the northern flanks of Poduru high, synrift sediments are juxtaposed with Raghavapuram Shales and hence may be considered to be prospective. In the south of Poduru Yanam High, in the South east of Penugonda Cross Trend, occurrence of both pre rift and synrift sediments are doubtful. In north east of this lineament, Prerift play has been proved to be prospective.

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