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Petroleum System(s) Modeling: An understanding of Syn-rift plays of Bantumilli Graben, Krishna Godavari basin, India

Abstract

Krishna Godavari Basin, located on the eastern Indian passive margin is a poly-history basin having commercial oil and gas accumulations in various stratigraphic levels ranging in age from Triassic to Plio-Pleistocene. In Bantumilli graben, located in West Godavari sub-basin of onland KG Basin, oil and gas has been established in structural and strati-structural plays within syn-rift clastic reservoirs, but a better understanding is required to realise the full potential of this play. This study integrates all known data-sets to highlight the key exploration challenges by carrying out a comprehensive 3D Petroleum System(s) modeling. Late Jurassic and Early Cretaceous source sequences are the main source layers in the Bantumilli graben. Late Jurassic and Early Cretaceous source layers in the study shows a diverse rock maturity ranging from early oil to dry gas window with a high transformation ratio of 70-98%. Based on Source Rock tracking, multiple Petroleum Systems are observed ranging from Late Jurassic to Late Cretaceous. Modeling elucidates the charging type to be of thermogenic origin and corroborates with known discoveries so far.

Introduction:

The Krishna-Godavari basin, a pericratonic basin, located in the central part of the eastern passive continental margin of India lies between Kakinada in the northeast and Ongole in the Southwest. This is a typical passive margin basin and has a dual-rift evolution history in the eastern continental margin of Indian plate. It comprises of sedimentary facies from Early Permian through Mesozoic and Cenozoic interrupted by a volcanic episode in the Early Paleocene. The characteristic feature of the study area of Bantumilli graben is the presence of en-echelon system of horsts and grabens filled with thick pile of Mesozoic to Recent sediments. Commercial accumulation of hydrocarbon is established in sediments ranging in age from Late Jurassic to Early Cretaceous.

Tectonics:

Major tectonic elements present in this area are horst-graben morphology that includes Kaza Horst, Kaikalur-Lingala Horst, and SW plunge of Bantumilli - Bhimavaram high and Bantumilli grabens. Bantumilli high rising towards NE takes a NW swing at Suryaraopeta, Mahadevapatnam area Figure 1.

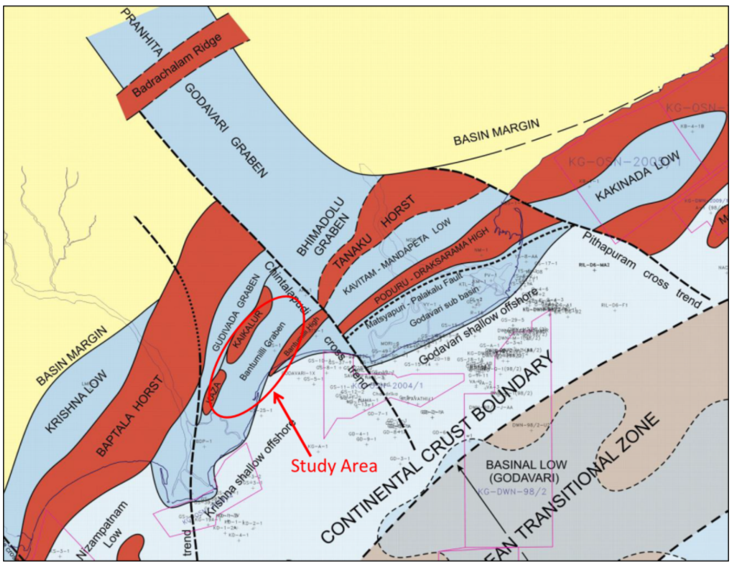


Figure 1: Tectonic Map of KG Basin showing study area

The NW flank of Bantumilli high is gentler as compared to the SE flank towards Lakshmipuram. Similarly the Kaikalur high has steeper SE flanks as compared to gentler NW flanks where Kaikalur - Lingala fields are located. The SE faults extend from Basement to Razole levels suggesting continued tectonic activity till Palaeocene (Sastri V.V., et. al, 1973). Bantumilli graben is filled with coarser to finer clastic rocks of fluvial to marginal marine environment of Nandigama/Kanukollu Formation overlying Archaean basement. With breaking up of continents marine transgression had taken place with Aptian-Albian sediments of HG-HR sequence of Lower Raghavapuram Formation, bounded by regional unconformities at top and bottom and overlies the rift fill. The basin tilt 'towards SE' facilitated open marine conditions resulting in deposition of transgressive shale with minor sands in the near shore/shallow water environment. This Raghavapuram litho unit is overlain by Tirupati sandstone prograding towards SE and grade into prodelta/deep marine Chintalapalli shales beyond Matsyapuri Palakollu fault (Venkatarengan R., 1993).

The oil discovery from syn-rift sediments in Malleswaram area in Bantumilli graben provided significant impetus to the exploration of hydrocarbon within syn-rift sequence in Bantumilli graben. Syn-rift is also promising for gaseous hydrocarbon for Nandigama and Bantumilli south prospects.

Petroleum Systems:

The potential source rocks are shales within rift fill sequences (Kanukollu/Nandigama/Gollapalli formations) which display TOC in the range of 4 to *9%* having Type-Ill Kerogene source at places. The shales within Raghavapuram Formation display TOC in the range of 1 to *7%* having Type-Ill Kerogene (Sethi S., et. al., 2014). Geochemically the source rock in syn-rift sequences has better potential than the source rock in post rift Raghavapuram Shale Formation in terms of quality and quantity. The Oil-source correlation studies indicate the existence of two petroleum sources in West Godavari with sources being Late Jurassic-Early Cretaceous and Early Cretaceous (HG-HR) shales. Both the sources have a number of overlapping geochemical characteristics and correlate well in environment of deposition and type of organic matter. For both Nandigama and Raghavapuram plays, the entrapment model is Strati structural. The well log correlations and other well data indicated that, thick arenaceous unit consists of mainly sandstone with minor shale alternations are deposited within Nandigama Formation. Laboratory study reveals that the clastics deposited within Nandigama Formation are generally poorly sorted with wide variation in grain size. This indicates that the provenances of sediments are very nearby without much transportation and winnowing and the adjoining Kaikalur-Lingala and Bantumilli Highs might have sourced these sediments at the early rift stage in the form of Alluvial Fan/Fan delta and Braided fluvial system towards the Bantumilli graben. The reservoir is generally tight in nature and hydrofracturing improves permeability. Raghavapuram Formation deposited in fluctuating sea level condition and reservoir facies developed within this formation are mainly discontinuous.

Model Building:

Static model (depth surfaces of key stratigraphic horizons and Faults) and their corresponding facies model form the primary inputs for building a petroleum system model (Figure 2). Data obtained from wells drilled within the Bantumilli graben and information available in public domain has been integrated.

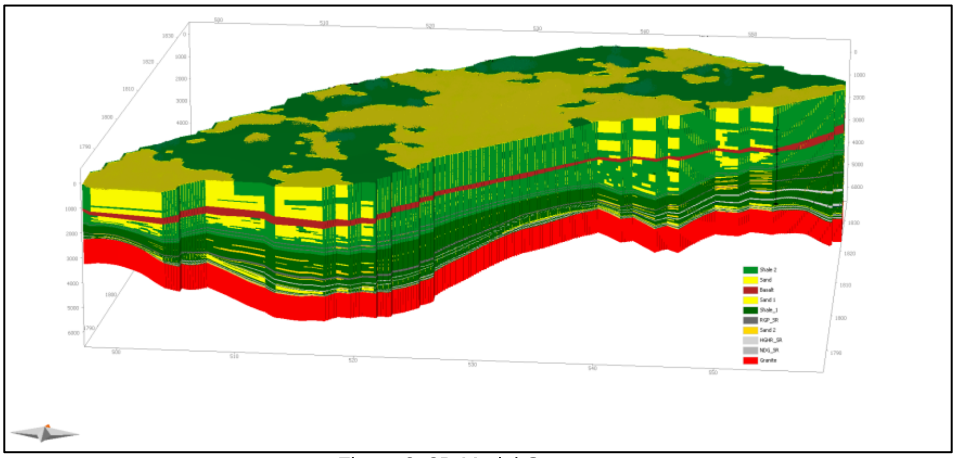


Figure 2: 3D Model Geometry

The final static geometry of the 3D Model is built up on the PetroMod platform, comprising all the fault incorporated depth maps, erosion map, geochemical data and facies with corresponding layers imparted within it.

Boundary Conditions

Boundary conditions need to be defined for the heat, pressure and fluid flow analysis through the entire simulated geologic history. The usual boundary condition data for the heat flow analysis are temperature maps on sediment-water interface (SWIT) and the basal heat flow maps for the respective events.

i) Sediment-Water-Interface-Temperature and Paleo-Water-Depth:

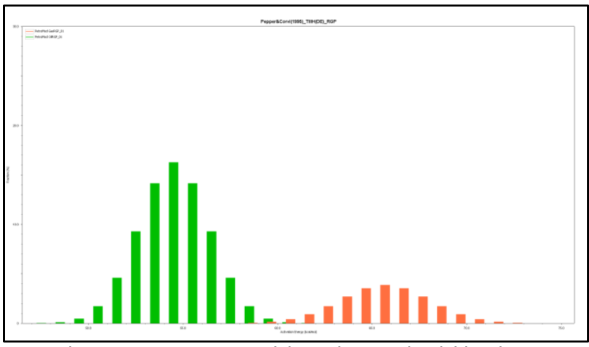
This is the upper boundary condition for the modeling process, defining the surface temperatures through geological time. Paleo Water Depth (PWD) data were prepared through analyzing biostratigraphic data and lithological composition.

ii) Basal Heat Flow:

Generated Heat Flow trends are calibrated for present day with the help of VRo and BHT data. Two HF peaks have been assigned i.e. one at the Tithonian age, which marks the rifting events in Bantumilli Graben and the second at Razole Volcanics event. Heat Flow ranges from ~85mW/m2 during Tithonian age and ~75mW/m2 during Razole Volcanics of Early Paleocene and gradually decreasing through time as the KG basin enters passive margin set up.

Source Rocks and Kinetics

Total four source rock layers have been assigned in the model. First in Late Jurassic Nandigama Formation, second one in Early Cretaceous HG-HR within Raghavapuram Formation, third and fourth in Early Cretaceous Raghavapuram Formation. Two default Type III kinetics from PetroMod Software, Peper & Corvi (1965)_TIIIH(DE) and Burnham(1989)_TIII have been used in the model. For all source facies, activation energy of Peper & Corvi (1965)_TIIIH(DE) ranges between 47.5 -61.5 Kcal/mol for oil with maximum distribution from 54.5 (21.14%), 53.5 & 55.5 (18.37%) Kcal/mol and 56.68-74.68 Kcal/mol for gas with maximum distribution from 65.68 (16.87%), 64.68 & 66.68 (15.43%) Kcal/mol (Figure 3). in the ratio of oil: gas 77:23 and for Burnham(1989)_TIII activation energy is distributed 48 to 68 kcal/mole with a maxima in 52 (32%) Kcal/mol (Figure 4).



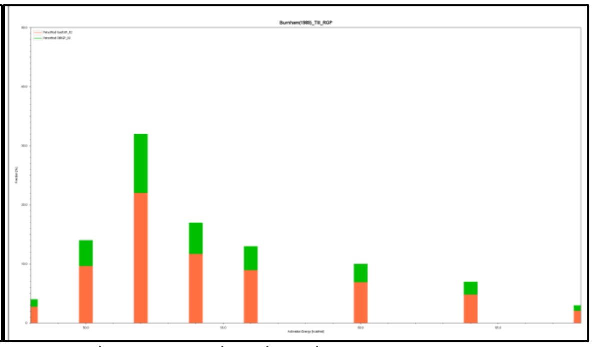


Figure 3: Peper & Corvi (1965)_TIIIH(DE) kinetics Figure 4: Burnham(1989)_
TIII kinetics

Maturity and Transformation Ratio:

Maturity overlay shows that main hydrocarbon generation window falls below 2400 m approximately (Figure 5). The maturities of different source rock layers were calculated in PetroMod based on the Easy-Ro% vitrinite reflectance kinetics by Sweeny & Burnham (1990).

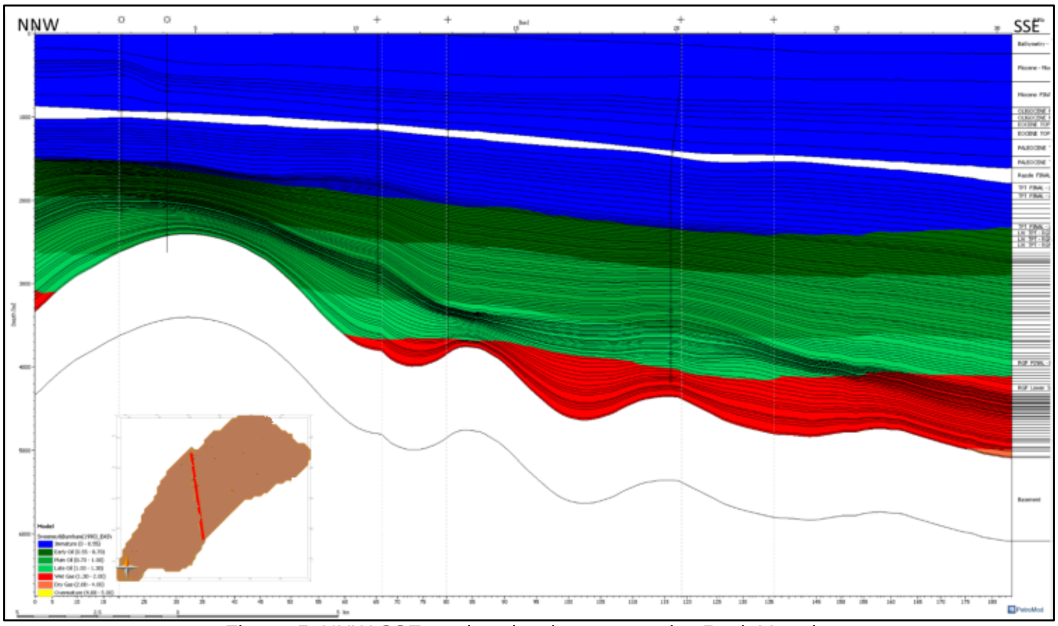


Figure 5: NNW-SSE section showing present day Rock Maturity

Rock maturity for Late Jurassic (Nandigama Formation) source rock layer shows a very diverse maturity ranging from early oil to dry gas window (Figure 6). Deeper grabenal areas are mainly in wet gas to dry gas window and shallower flank areas are in early oil to late oil window.

Transformation ratio (TR) for Late Jurassic (Nandigama Formation) source rock layer shows a very high transformation (upto 98%) which may be attributed to more thickness of sediments and deeper depth of burial of the sediments (Figure 7), whereas shallower grabenal area shows moderately high transformation (<60%).

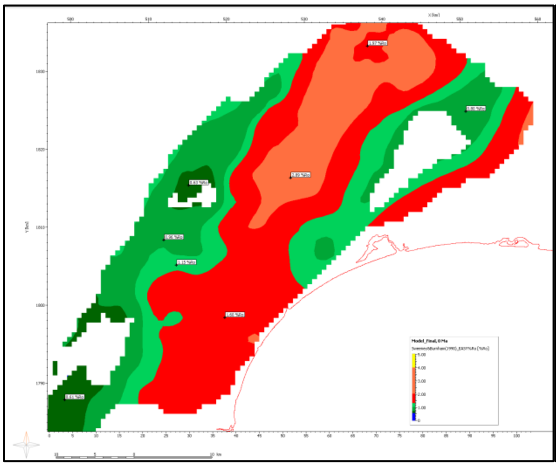


Figure 6: Rock Maturity of Late Jurassic Source Rock Layer

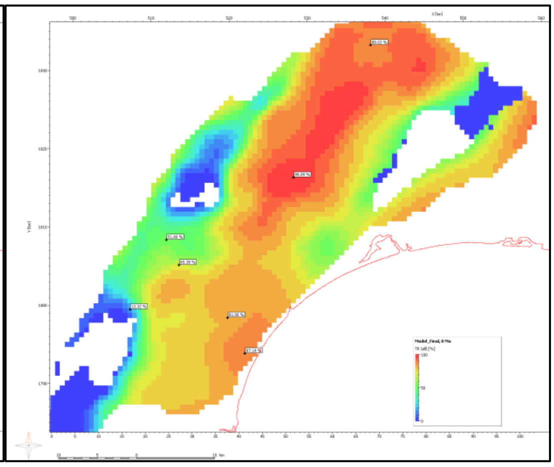


Figure 7: Transformation Ratio of Late Jurassic Source Rock Layer

Rock maturity for the Early Cretaceous (HG-HR within Raghavapuram Formation) source rock layer is also diverse ranging from early oil to wet gas window (Figure 8). Deeper grabenal areas are mainly in main oil to wet gas window and shallower flank areas are in early oil to main oil window.

Transformation ratio (TR) for Early Cretaceous (HG-HR within Raghavapuram Formation) source rock layer shows a high transformation (upto 75%) over most of the area. Shallower areas (w.r.t. depth) over Kaza-Kaikalur high and Bantumilli high show either very less or no transformation as observed in the Figure 9.

Early Cretaceous Raghavapuram lower source rock layer is in immature to early oil window and shows either no or very less transformation.
Similarly Early Cretaceous Raghavapuram upper source rock layer is also in immature to early oil window and shows either no or very less transformation.

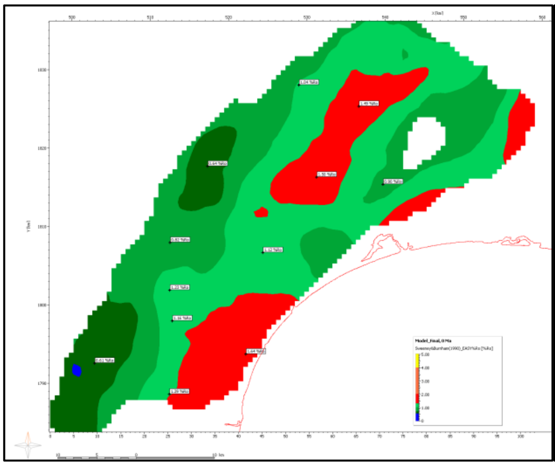


Figure 8: Rock Maturity Early Cretaceous Source Rock Layer

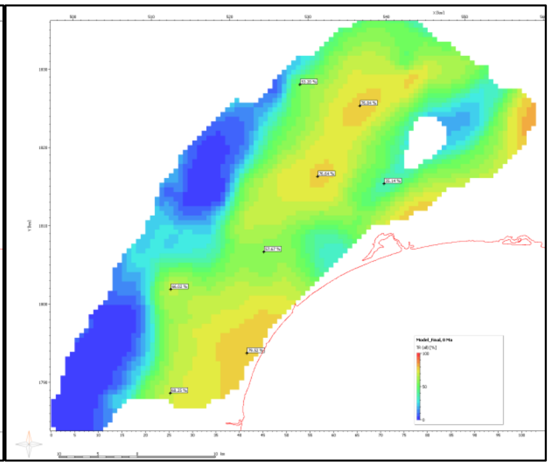


Figure 9: Transformation Ratio of Early Cretaceous Source Rock Layer

Generation and Expulsion

Late Jurassic source rock layer attained critical moment around 114 Ma in deepest part of Bantumilli graben whereas in shallower grabenal it attained critical moment by 50 Ma. Early Cretaceous source rock layer attained critical moment around 80 Ma in deeper parts, in shallower area it is yet to attain critical moment. Early Cretaceous Raghavapuram lower and upper source rock layers show either no or very less transformation, therefore yet to attain critical moment.

Accumulation and Origin of Charge in Different Reservoirs

Although most of the structures were available during critical moment, a sizable amount of the hydrocarbon generated and expelled from source layers, is lost as side and top flow losses prior to accumulation in reservoirs as depicted by migration vectors (Figure 10).

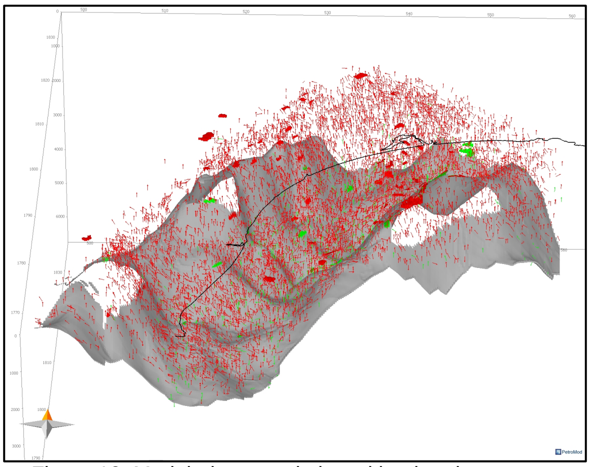


Figure 10: Modeled accumulation with migration vectors

The origin of charge in different reservoirs is analyzed through source rock tracking. It is observed that most of the reservoirs are fed from Late Jurassic Nandigama to Early Cretaceous HG-HR source rocks in the area.

Analysis of various elements of Petroleum System(s) and oil to source correlation study indicates the presence of two Petroleum Systems i.e.

1. Late Jurassic - Late Jurassic/ Early Cretaceous/ Late Cretaceous (!),
2. Early Cretaceous – Early Cretaceous/ Late Cretaceous (!),

Conclusions

The Late Jurassic source rock has achieved 50 % of Transformation ratio at 114Ma in deeper parts of graben, therefore major part of generated hydrocarbon has been lost prior to the formation of favourable entrapment in Cretaceous sequences. Early Cretaceous source rock has achieved 50 % of Transformation ratio at 80Ma in deeper parts of graben, therefore large part of generated hydrocarbon entrapped in favorable locales available during Cretaceous age. The study brings out two main Petroleum Systems viz., 'Late Jurassic' – 'Late Jurassic/ Early Cretaceous/ Late Cretaceous'(!) and 'Early Cretaceous' – 'Early Cretaceous/ Late Cretaceous'(!). The study identifies YTF potential mainly in the Syn-rift plays of Bantumilli Graben, particularly the western flank of Bantumilli High can be potential target for synrift exploration.

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