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High Resolution Sequence Biochronostratigraphic Analysis of Late Jurassic – Cretaceous, Raghavapuram - Golapalli – Tirupati – Razole Petroleum System, Onland Krishna – Godavari Basin, India

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Krishna-Godavari Basin is a continental passive margin pericratonic basin. It contains about 5 km thick sediments with several cycles of deposition, ranging in age from Late Carboniferous to Pleistocene. The basin came into existence following rifting along eastern continental margin of Indian craton in early Mesozoic. Krishna-Godavari basin (Fig.1) is a proven petroliferous basin with commercial hydrocarbon accumulations in the oldest Permo-Triassic Mandapeta Sandstone onland to the youngest Pleistocene channel levee complexes in deep water offshore. The basin has been endowed with four petroleum systems, which can be classified broadly into two categories viz. Pre-Trappean and Post-Trappean in view of their distinct tectonic and sedimentary characteristics. The Pre Trappean Petroleum systems comprised of two systems viz. (1) Permo-Triassic Kommugudem-Mandapeta-Red Bed Petroleum System and (2) Late Jurassic-Cretaceous Raghavapuram-Gollapalli-Tirupati-Razole Petroleum System.

The present study is concentrated on Late Jurassic-Cretaceous Raghavapuram-Gollapalli-Tirupati-Razole Petroleum System. The main objective of dinoflagellate cyst based high resolution sequence biochronostratgraphic analysis (Fig.2) is to establish age range of Golapalli, Raghavapuram and Tirupati formations for biochronostratigraphic applications and sequence stratigraphic interpretations to fully understand this petroleum system in the onland part of the basin.

For age assignment in outcrop section first appearance datum (FAD) and for subsurface sections last appearence datum (LAD) or disappearance level of globally recognized dinoflagellate cyst biochronohorizons have been considered. The age dates are based on the work of Haq et al. (1987), Helby et al., (1987), Williams et al., (1993), Stover at al., (1996), Williams and Bujak (1986) and Aswal and Mehrota (2000, 2002). The terminology for sequence boundaries representing unconformities viz. Early / Late Jurassic boundary i.e. M I 30; Early / Late Cretaceous boundary i.e. M I 60; Valanginian / Hauterivian boundary i.e. M II 70 and Cretaceous / Tertiary boundary (K/T) i.e. C II 10, have been adopted from Petroleum Systems Sequence Stratigraphy handout (unpublished ONGC report)

Raghavapuram Shale, being the source rock and Golapalli, and Tirupati formations mainly representing reservoir facies and Razole Formation acting as regional seal. Raghavapuram Shale of Cretaceous age is considered as the principal source rock not only for this system but also for the onland part of the basin. Lenticular sands within Raghavapuram Shale are one of the potential exploration targets. Sands within Gollapalli Formation of Late Jurassic-Early Cretaceous in Mandapeta-Endamuru area and its time equivalent Kanukollu Formation in Lingala-Kaikalur area are another potential target in this petroleum system. A northeast southwest trending corridor of Upper Cretaceous Tirupati Sandstone between south eastern side of Tanuku Horst and MTP (Matsyapuri) fault is emerging as another important target. Raghavapuram Shale acts as effective seal for both Gollapalli reservoirs

and for the sands within Raghavapuram. Shale intercalations within Tirupati Formation appear to act as seal for the accumulations within the Formation and Razole Formation (Deccan Basalt) acts as a regional cap for the Pre-Trappean hydrocarbon accumulations.

Lithologically Golapalli Formation in general, comprises of medium to very coarse grained occasionally pebbly, micaceous and glauconitic Sandstone. The formation is unconformably overlain by Raghavapuram Shale Formation. In type section (outcrops) Raghavapuram Shale unconformably overlies the conglomeratic grit and sandstone of the Golapalli Formation and measures about 75m in thickness. The lower half (40m) consist mainly of white to pale earthy shales and claystone and contains at least two thin seams of light buff to grayish, white, medium grained, gluconitic sandstone. The upper half comprises reddish to purple sandy shale and claystone with red ferruginous claystone and thin sandstone. In subsurface reference section (subsurface) in well Tanaku-A the formation is 800m thick and is represented by grey, calcareous shale and has been divided in to two lithounits based on electrolog motifs. The lower High Gamma – High resistivity (HG-HR) claystone unit is unconflormably overlain by upper, High Gamma – Normal Resistivity (HG – NR) sandy claystone which in turn is conformably overlain by sandstone unit of Tirupati Formation.

The oldest sediments of the petroleum system, are deposited on undulated surface created due to sub-aerial unconformity that manifests a long hiatus. The present study based on dinoflagellate cyst events from well RCP-A suggest that this unconformity is represented by *Sverdrupiella* sp.– *D. priscum* Zone dated as Rhaetian to Sinemurian unconformably overlain by *L. deflandrei – N. pellucida* Zone dated Middle to Late Oxfordian. The unconformity represents absence of Late Sinemurian to Early Oxfordian (193-161Ma) sediments, suggesting a hiatus of approx. 33Ma span. The unconformity represent the dismemberment of Gondwana land that led to the formation of pericratonic rift basin during Late Jurassic, is designated as M I 30 representing I order sequence boundary. This period of non deposition is followed by deposition of synrift sediments. These early synrift sediments in Krishna-Godavari Basin are represented by **Golapalli Formation.** Biostratigraphic study based on dinoflagellate cyst suggest that these sediments are represented by *Lithodinia deflandrei – Nannoceratopsis pellucida* Interval Zone, *Nannoceratopsis pellucida – Oligosphaeridium patulum* Interval Zone, *Oligosphaeridium patulum – Omatia montgomeryi* Interval Zone, *Omatia montgomeryi – Rigaudella apiculata* Interval Zone, *Rigaudella apiculata – Kalyptea wisemaniae* Interval Zone, *Kalyptea wisemaniae – Egmontodinium torynum* Interval Zone, *Egmontodinium torynum – Aprobolocysta variegranosa* Interval Zone, *Aprobolocysta variegranosa – Dollidinium sinuosum* Interval Zone (Aswal & Mehrotra, 2002). The oldest interval zone recorded above the M I 30 i.e. *L. deflandrei – N. pellucida* zone is dated 161 – 156Ma, while the youngest zone recorded from Golapalli sediments i.e. *A. varigranosa – D. sinuosum* zone is dated 138 – 137Ma. Thus, based on the dinoflagellate cyst chronohorizons the Golapalli Formation is dated Oxfordian – Late Valanginian (161 – 137Ma) in age.

The above *Aprobolocysta variegranosa – Dollidinium sinuosum* Interval Zone representing 138-137Ma i.e. Late Valanginian in the subsurface is unconformably overlain by *Muderongia simplex – N. kostromiensis* Interval Zone representing 133-131 Ma i.e. Hauterivian. The unconformity represents a hiatus of approximtley 4 Ma (137-133Ma) spanning Late Valanginian – Hauterivian. This unconformity, in out crops is represented

by conglomeratic grit and boulder beds in Raghavapuram type section near Raghavapuram village, and Narsinghpuram hill section near Narsinghpuram village in western part of the basin. This unconformity has been considered as II order sequence boundary and is designated as M II 70. The sediments (Golapalli Formation) in between M I 30 to M II 70 are deposited in intertidal environment.

The Golapalli/Golapalli equivalent sediments in the basin are unconformably (M II 70) overlain by Raghavapuram Shale Formation. Eight dinocyst events have been recorded from outcrop sections. Based on dinoflagellate cyst biochronohorizons represented by presence of LAD of *Cerbia tabulata* (111Ma) of Early Albian and LAD of *Pseudoceratium ludbrooki* (99.6Ma) of Early Cenomanian age, a hiatus of approximately 12 Ma (Early – Late Albian) span has been identified across this sandstone. Also based on these chronohorizons the sediments above Golapalli Formation (above M II 70) and below this Albian unconformity are dated Late Hauterivian to Early Albian and the sediments from this Albian unconformity to the base of Tirupati Formation are dated Cenomanian to Early Maastrichtian in age in out crops. In the subsurface sections, the dinoflagellate cyst events recorded from HG–HR unit are represented by *M.simplex - N.kostromiensis* interval zone, *N.kostromiensis – C. magna, C. magna - C.elegantulum, C.elegantulum – L. stoveri, L. stoveri - P.neocomica, P.neocomica - P.pelliferum, P.pelliferum - A.neptunii, A.neptunii - M.australis, M.australis - C.tabulata, C.tabulata - N.monoculatus,* Interval zones. These interval zones suggest Late Hauterivian – Early Albian (133 – 110Ma) age for HG-HR unit. *C. tabulata - N. monoculatus* (111–110Ma) Interval zone representing Early Albian is unconformably overlain by *Discorsia nana – G. tuberculosum,* interval zone representing Middle Albian *(106 -102Ma)* suggest a hiatus of approximately 4Ma. Thus the dinoflagellate cyst events recorded from out crop and also from subsurface indicate a hiatus of varying span from 4 – 12 Ma across first sandstone band in outcrop and across HG-HR/HG-NR unit of Raghavapuram Shale. This regional unconformity has been designated as **M I 60** and is considered as I order sequence boundary.

The dinoflagellate cyst events recorded form upper unit of Raghavapuram Shale (HG–NR unit) is represented by *Discorsia nana – G. tuberculosum, G. tuberculosum - Protoellpsodinium sp., Protoellpsodinium sp. - P. ludbrooki, P. ludbrooki - L. arundum, L. arundum - K. williamsii, K. williamsii - E. spinosa, E. spinosa - P. parvispinum, P. parvispinum - C. edwardsii, C. edwadsii – F. mantellii, F. mantellii - S. anthophorum, S. anthophorum-O. porifera, O. porifera - P. deflandrei, P. deflandrei - N. tuberculata, N. tuberculata - S. longifurcatum, S. longifurcatum - T. castanea, T. castanea - O. costata, O. costata - H. pulchurum., H. pulchurm - O. operculata, O. operculata - X. asperatus* interval zones. These dinoflagellate cyst interval zones suggest Late Albian–Early Maastrichtian (106 – 69Ma) age for the upper unit of Raghavapuram Shale.

The HG-NR member of the Raghavapuram Shale which is dated Late Albian – Early Maastrichtian, has a gradational conformbale upper contact with Tirupati Formation. The Tirupati Formation is represented by *X. asperatus - C. utinensis, C. utinensis - C. distinctium,* and *C. utinensis - Dinogymnium spp.* Interval zones. Based on these dinoflagellate cyst chronohorizons the formation is dated Maastrichtian (69 – 66) in age. The sediments represented by HG-NR unit and Tirupati Formation dated Late Albian to Maastrichtian are overlain by Early Paleocene volcanics represented by Razole volcanics in the onland part and towards south / south east it is directly overlain by Paleocene shale

i.e. Pallakulu Shale. The unconformity represented by Razole volcanics across Cretaceous / Tertiary boundary (K/T) is designated as C II 10.

The study concludes that the oldest sediments of the petroleum system represented by Golapalli Formation of Oxfordian – Late Valanginian age is deposited unconformably on M I 30 which represents a hiatus of 33Ma (Late Sinemurian to Early Oxfordian i.e. from 193 to 161 Ma). The hiatus may relate to dismemberment of Gondwana land and formation of pericratonic rift basin along east coast during Late Jurassic followed by deposition of early synrift sediments in intertidal environment. This dominantly arenaceous facies in Golapalli Formation hosts oil and gas accumulations in Kaikalur-Lingala area in west Godavari subbasin and Mandapeta area and also possesses source rocks in Kaikalur and Endamuru-Mandapeta areas.

In both outcrops and subsurface the Golapalli Formation and its equivalent, are unconformably (M II 70) overlain by HG-HR unit of Raghavapuram Shale Formation, having a hiatus of approximately 4Ma spanning Late Valanginian – Hauterivian a II order sequence boundary. The HG-HR unit represents late synrift phase dated Late Hauterivial – Early Albian is relatively a good source rock with 'Type II/III organic matter. The HG-HR unit is unconformably (M I 60) overlain by the HG – NR unit dated Late Albian-Early Maastrichtian (106 – 69Ma). The unconformity (M I 60) represent a hiatus of varying span from 4-12Ma and has been considered as I order sequence boundary. The HG-NR unit has a marginal source rock with type III OM. The study suggests that the HG-NR unit is conformably overlain by Tirupati Formation of Maastrichtian (69–66) in age.

According to Hussain et al., (2000), the sediments above M I 60 become sandier towards the top due to shallowing caused by southeasterly tilting of the basin that continued till Early Maastrichtian and finally ended with the commencement of deposition of Tirupati Formation in marginal marine to coastal environment. The inferences are corroborated by the present study which suggest that in eastern most part of the basin in Kakinada trough only HG-NR member of Raghavapuram Formation is present and is dated Hauterivian – Early Albian i.e. 133-110Ma. In other areas viz. Endamuru, Ramchandrapuram, Mahendravada, Draksharama and Mandapeta graben the age of the formation ranges from Barremian to Cenomanian – Santonian suggesting presence of HG-HR unit and lower part of HG-NR unit. In the west of Mandapeta subbasin represented by the wells Kavitam and Velpuru it ranges Late Hauterivian to Early Albian suggesting presence of only lower HG-HR unit. In further west represented by Viravasaram it ranges Early Barremian to Early Campanian (both HG-HR and HG-NR units). In Bantumilli graben in wells Bantumilli and Nandigama, Kaikulur – Lingala area and Nizamapatnam subbasin it ranges from Early Cenomanian to Early Maastrichtian (HG-NR unit).

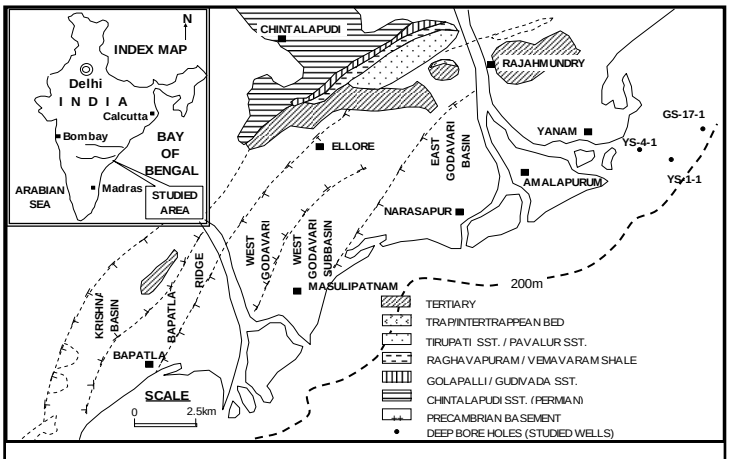

FIG. 1. GEOLOGICAL MAP OF KRISHNA-GODAVARI BASIN (after Shastri *et al*., 1981), SHOWING WELL LOCATIONS.

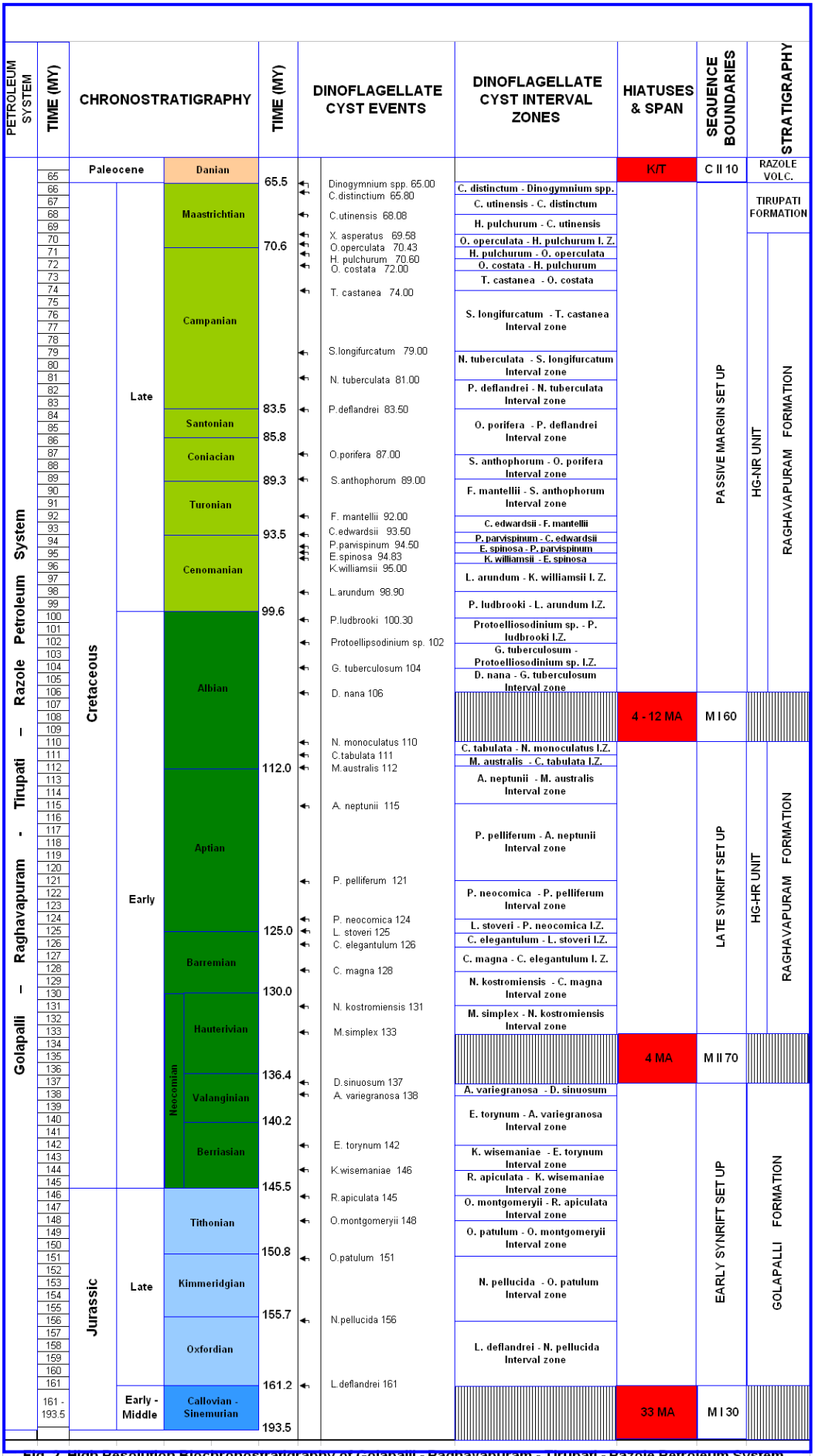

Fig. 2. High Resolution Biochronostratigraphy of Golapalli - Raghavapuram - Tirupati - Razole Petroleum System