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Pennar Basin : A Potential Spot for Synrift Exploration

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Summary

Pennar Basin aligned along the coastal tract of Andhra Pradesh in India, is juxtaposed with the southern extremity of prospective Krishna Godavari Basin. The basin exhibits extensional tectonic set up with typical half graben geometry and normal listric faulting. The basin underwent two major tectonic cycles during its evolution; one in Early Permian and the other in Late Jurassic. It evolved concurrently with southern Palar Basin, during the initial cycle of Permian, later got more clearly differentiated with the up-liftment of Nayudupeta ridge during Late Jurassic.

To the west, basin is limited to the exposures of Archean gneiss of the Eastern- Ghat massif. To the east, it extends into the Antarctica landmass. The north-south trending on land basin axis of the basin shifts to NNE in apparently due to a cross trend, dividing the basin into basin in the north.

The Bitragunta low in the northern part of Pennar basin hosts around 6 Km. thick Jurassic and Cretaceous sedimentary column, of which the synrift sediments comprise the major fill. This low might act as good kitchen for hydrocarbon generation. The basin margin fault to the west is well defined listric fault covering this low, however towards south this fault is observed as a high angle fault. This listric fault might have played a role in formation of probable hydrocarbon locales in the synrift Jurassic and Lower Cretaceous section. The inverted structures observed at the toe of western margin fault, within the synrift sediments of Jurassic and Lower Cretaceous section form the potential target for exploration in Pennar Basin and demand attention.

Introduction

The Pennar Basin is located in the eastern part of Indian platform adjoining Krishna Godavari basin in the north and Palar basin to the south(Fig. 1). The basin is bound on the northwest by basin margin fault with steep flank and by the gently rising flank on the east, showing typical half graben geometry. The basin fill comprises sediments ranging in age from Permian to Recent. Five wells have been drilled so far in the basin, two in onshore (AON-1 & AON-2) and three in offshore (AOF-1, AOF-2 & AOF-3), without any success. The age dating of various formations has been worked out through palyonological study. The sub surface data of these wells reveals favourable source, reservoir couplet in Jurassic-Cretaceous section. Seismic interpretation of broad grid seismic 2D surveys has been carried out. The mapping of Basement and prominent sequences within Jurassic and cretaceous section could very well bring out the tectonic set up and the depositional history of the basin. The integration of well, seismic, geochemical and Palyonological data could bring out the Petroleum system of Pennar basin and prospective areas for hydrocarbon exploration.

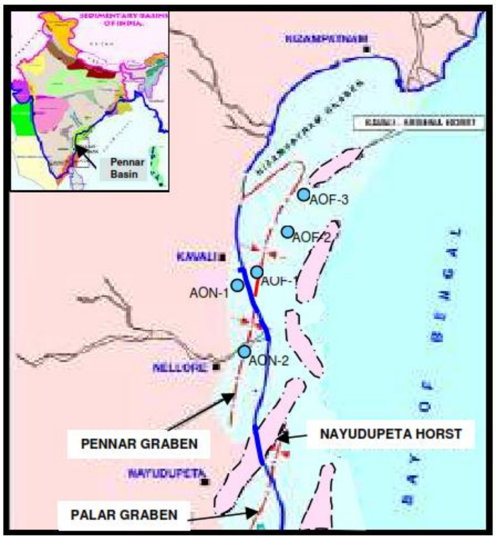

Fig. 1 : Index map

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Discussion

Stratigraphy

Based on the cutting and core informations from different wells, the brief description of the different formations is stated below along with their age (dating through palyonological data). Lithostratigraphic nomenclature of one of the well AON- is shown in table 1.

Basement: In Pennar basin, metamorphic basement of Archean age were encountered in two drilled wells viz AON-1 & AON-2. It is gneissic in nature and defined by dark and light coloured bands in well AON-1. The dark coloured bands constitutes biotite and hornblende while the light coloured band is composed of quartz and feldspar.

Nellore Claystone: This is the oldest sedimentary unit observed in the drilled wells, unconformably overlying the

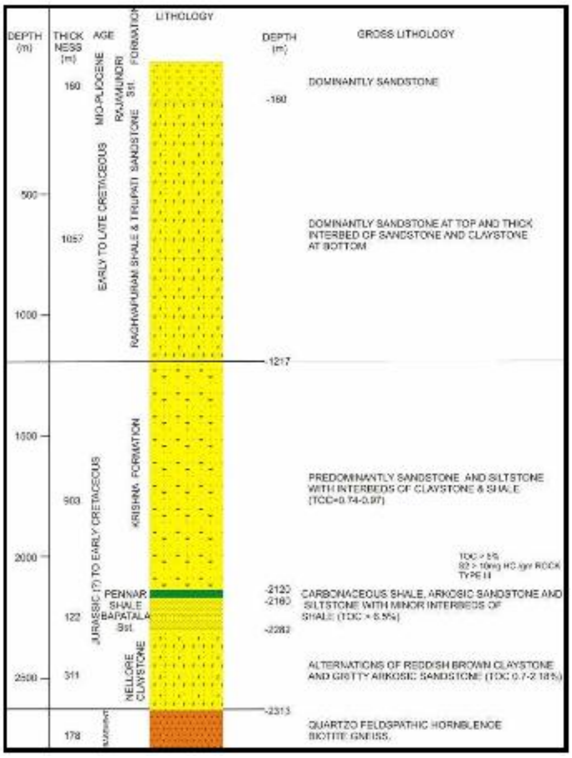

Table 1 : Lithostratigraphy of well AON-1

Basement. This unit is dominantly argillaceous with medium to coarse grained sandstone and minor siltstone. The age of this unit has been worked out to be Late Jurassic (Tithonian).

Bapatla Sandstone: This formation is mainly characterized by arkosic sandstones and siltstones with interbeds of carbonaceous shales. Though the top part of this formation present in all the wells, but the thickest unit has developed in well AOF-1 drilled in relatively basinal part. This thickness of this formation is inferred to be much more in the basinal part of Pennar basin. In well AOF-1, the lowest part of this formation are mainly coarse grained sandstone with minor clay which is dated to be Kimmeridgian –Callovian age (Middle to Upper Jurasic) whereas in well AON-2, the lowest part of this formation is dated Berriasian-Valanginian (Fig. 2) The top part of this formation are mainly arkosic sandstone with dark coloured claystone of Neocomian age. Towards top and middle part of this formation in well AOF-1, gaseous hydrocarbon shows were observed. These sediments were probably deposited in lacustrine environment (Cassa, 1990).

Pennar shale: This sedimentary unit unconformably overlies the Bapatla Formation and underlies the Krishna formation. This unit comprises of shale with sandstone and siltstone interbeds. In well AOF-1, few coal seams are also observed. A Neocomian – Barremian age has been assigned to this formation.

Krishna Formation: The Krishna formation unconformably overlies the Pennar shale which is dominantly an arenaceous unit consisting of sandstone and siltstone with intermittent claystone/shale. Sandstone is predominant in the bottom section. Barremian to Aptian age is assigned for this formation.

Tirupati Sandstone / RaghavpuramShale (Undifferentiated) : TheTirupati/ Raghvapuram formation unconformably overlies the Krishna formation consisting of thick interbeds of claystone/shale and sandstone, without noticeable change in the lithological/log character. Towards top part (in well AOF-1) this section is characterized by abundant quantity of glauconite. Aptian to Upper Cretaceous age is assigned for this unit.

Rajahmundry Sandstone: This is a tertiary section unconformably overlies the Tirupati/ Raghavapuram formation and comprises mainly pebbles, granules and unconsolidated sand with minor siltstone and clay stone.

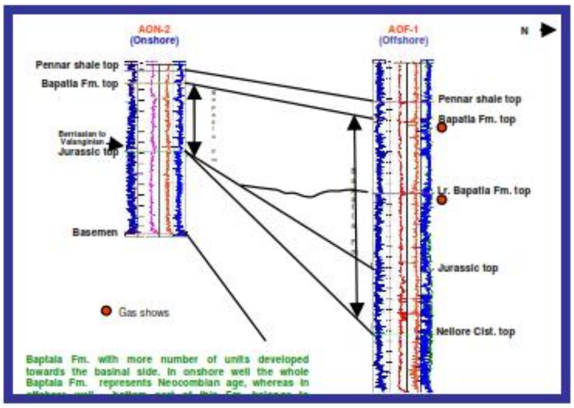

Fig 2 : Log correlation of AON-2 & AOF-1

Source rock analysis

The upper part of **Nellore Claystone Formation** exhibit fair to good TOC value (% TOC 0.7-2.18) with a marginal to fair source potential, in well AON-1.

The overlying **Bapatla Formation** mainly representing arkosic sandstone and siltstone with minor interbeds of shale/carbonaceous shale. In well AON-1, selected shale samples of this Formation exhibit excellent TOC (>3.5%) and good source potential (S2 : 7 -9 mg HC/gm rock). An admixture of type III with nearly 20% type II OM is inferred from HI data (>200 mg/gm TOC). The sequence seems to be mature as indicated by T max data. Further study of ISRAG team reveal that for the well AON-1, the Pennar Shale and Bapatla Formation source sequences are at the threshold of oil window having attained around 0.6% of EVRo and for significant hydrocarbon generation with present day low temperature gradients (0.0275 deg C/m), these sequence require an additional burial of 1000 m or so. In well AON-1, mature, fair quality source rock of Kerogen I, III and IV are observed specially in the intervals corresponding to bottom part of Pennar shale & top part of Bapatla Formation having high quality of OM and quantities of S2 upto 68mg HC /gm of rock . These intervals contain degraded Type I kerogen derived from algae and higher plant organic matter that was deposited in a lacustrine, sub oxic environment. This type of kerogen, having moderate H.I. is capable of generating mixed high wax oil and gas (Cassa,1990). This organic matter might have been better preserved and have higher oil generating potential in the anoxic core at the bottom of the lake depocentre. Further, the present study inferred more thickness of Bapatla Formation as well more number of units towards the basin deep. Cumulative thickness of the argillaceous streaks within Bapatla sand stone Formation would have enough source potential for substantial generation of hydrocarbon.

Pennar Shale Formation consists of mainly shale. Immature- mature fair quality source rock of Kerogen I, III & IV is observed in wells AOF-1 and AOF-2. Hand picked samples of dark grey to black carbonaceous shales in well AON-1 exhibit excellent organic matter richness and very good source potential (TOC > 6% and S2 > 10 mg HC/gm rock). The organic matter is inferred to be an admixture of type III with nearly 20% type II. T max values (~440 deg C) indicate the sequence to be mature. This sequence characterized as good source rock has potential for both oil & gas.

Within Lower Cretaceous section in well SD-1, **Krishna Formation** being dominantly sandy exhibits poor to fair organic matter richness except for few intervals which show good organic matter richness (TOC > 1%). Pyrolytic yields are also very low in the entire sequence baring a few thin streaks. Organic matter in these argillaceous streaks has a well preserved mixture of type III & II (HI ranges 190-360 mg/ HC/ gm TOC) capable of generating both oil and gaseous hydrocarbons.

Petroleum System

Source rock, Migration, Reservoir rock and Trap are the main decisive factors based on which hydrocarbon potential of a basin is established. All these four factors are likely to be present in Pennar Basin.

Source: Bapatla Sandstone Formation, juxtaposed with shale/claystone is interpreted to the main source with sufficient overburden pressure and thermal maturity to generate hydrocarbon. Additionally Pennar shale and lower part of Krishna Formation may act as source rock. The source component of deeper Nellore clay stone formation is speculative as it is mainly consist of reddish/chocolate brown coloured claystone with pebbly sandstone and conglomerate. However in AON-1, the upper part of this sequence exhibits fair to good TOC value with marginal to fair source potential.

Reservoir: Bapatla Sandstone would act as main reservoir specially in the deeper part of Pennar low where the anticipated thickness is much more there. Additionally arenaceous section of Krishna formation (lower part) may also act as reservoir rock.

Entrapment: A number of shale viz shale layers within Bapatla Formation, Pennar Shale, and shale layers within Krishna formation would act as seals in different levels.

Migration : The conduits of migration are deep-rooted faults and unconformity surfaces.

Seismic Data Analysis

Time relief map at Basement (Fig.3)

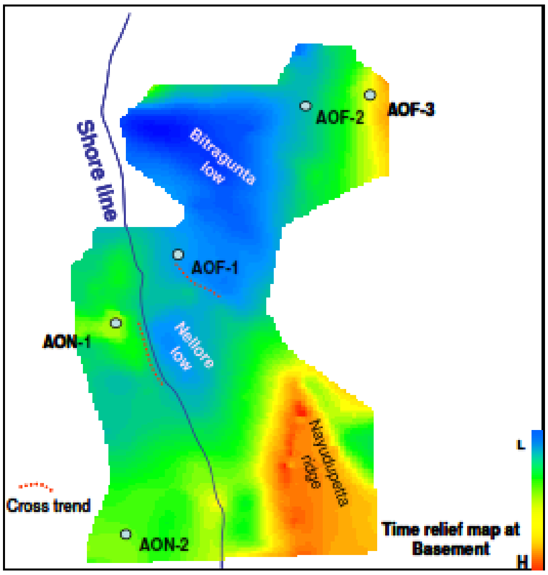

Fig 3

The Nayudepeta ridge, which separates Pennar basin from southern Palar basin, has N-S trend in the north which swings to NNE-SSW to the south near the shore line. To the NW of Nayudupeta ridge, the Pennar graben could be very well brought out at Basement level. This graben consist of two lows, deepest being in the northern part (Bitragunta low) having around 6 km sediments. To the south of this Bitragunta low, another NNW-SSE trending Nellore low having around 5 km sediments is seen with a connectivity to the main low. To the south of Bitragunta low, a NW-SE trending cross trend is inferred from the offsetting in contours pattern. To the western margin of Nellore low, another cross trend oblique to basin opening fault is present.

Further it has been observed that in the northern part (Bitragunta low) the western basin margin fault is listric, however towards south this is observed to be high angle fault.

Time structure map at Jurassic top (Fig. 4)

The time structure map at Juraasic top level indicate that the southern part of Bitragunda low has been obliterated

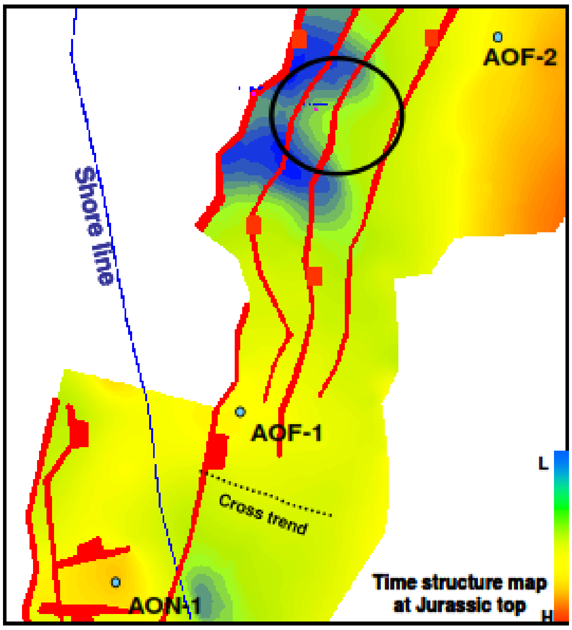

Fig 4

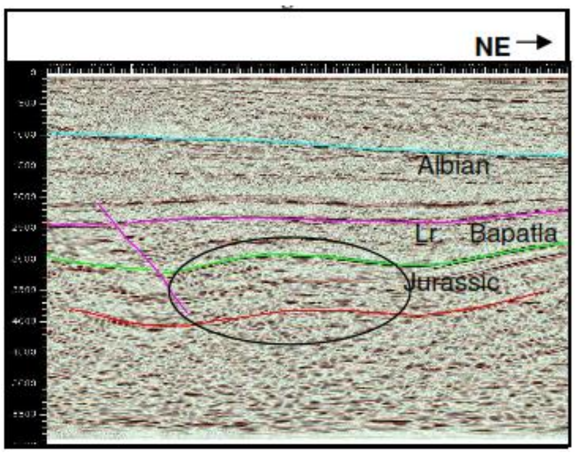

Fig. 4A: Seismic line 1 depicting structurisation

and a SE trending spur/nosal feature emerged out along the cross trend. Well AOF-1 is located on this trend which showed hydrocarbon indication. To the north of the spur, within Bitragunta low, a structural high close to western basin margin listric fault is mapped, which is depicted along seismic line 1 (Fig. 4A). The feature seems to be promising.

Time structure near top of Lower Bapatla Formation (within Neocomian) (Fig. 5)

This is a well correlatable reflector corresponding to Lower Bapatla Formation (within Neocomian).

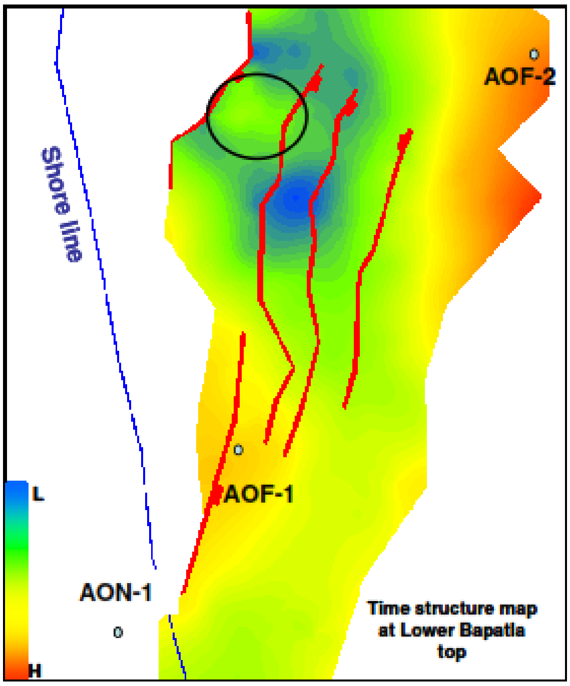

Fig 5

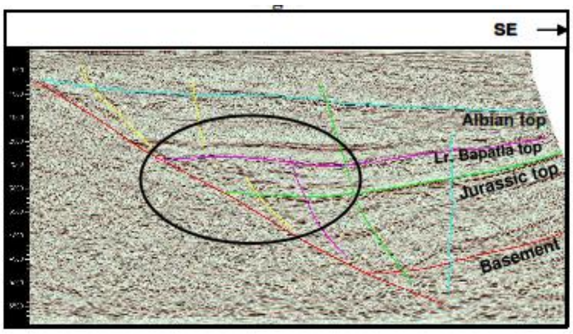

Fig. 5A: Seismic line 2 depicting inverted structure

In AOF-1 well, this reflector is corresponding to a depth of 2800m and the porosity of sandstone in the top part of zone (2804-2850m) is worked out to be 10-13%. Gaseous hydrocarbon shows are also observed upto 2835m. The time structure map at this level indicates that the aerial extend of Bitragunda low is same as Jurassic time but in overall N-S trend of this low, two sub lows separated by a high oriented across the regional trend. This higher area is inferred as an inverted structure at the toe of basin margin listric fault, depicted along seismic line 2 (Fig. 5A). Paleo tectonic analysis confirms the structurisation after deposition of Bapatla Sandstone Formation. The SE trending spur/nosal feature (upon which well AOF-1 is located) observed at Jurassic level has extended its aerial spread towards south.

Time thickness map of Jurassic (Fig. 6)

The map depicting a good thickness of Jurassic and older sediments deposited over the basement low, being maximum sediment thick in Bitragunta low and relatively lesser sedimentation in Nellore low .The sediment entry is appeared to be from western margin but its orientation are different i.e to the northern and southern part of Bitragunta low, the sediment thick are oriented in WSW-ENE and WNW-ESE fashion . But in Nellore low, the major sediment is trending NW-SE. (may be due to cross fault along which river system emerged)

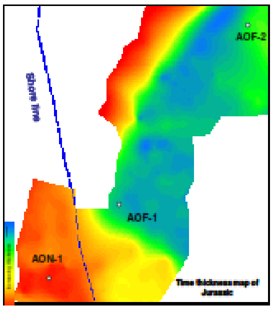

Fig. 6

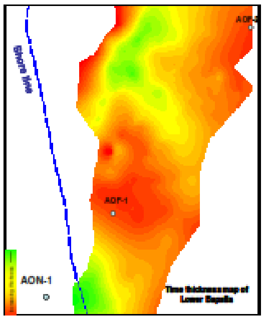

Fig. 7

Time thickness map of Lower Bapatla Formation (within Neocomian) (Fig. 7)

Instead of multi point entry, the main entry of these sediments is from western margin and towards east it bifurcates into NE and SE direction. Maximum sediment thickness for this formation is observed in the inverted structure within Bitragunta low, confirms its later upliftment. The sediment thickness of Bapatla Formation would be much higher compare to the sediments encountered in well AOF-1.

Conclusions

The evolution of Pennar basin witnessed two major tectonic cycles during the early stage. The first, in Early Permian and the second in Late Jurassic.The second episode resulted in upliftment of Nayudupet ridge which differentiated it with the southern Palar basin.

The north-south trending onland basinal axis of the basin shifts to NNE in offshore. The clockwise rotation of the basinal axis is apparently due to a cross trend, dividing the basin into Nellore sub-basin in the south with around 4500 m. and the Bitargunta sub- basin in the north hoisting around 6000 m. of sediments. The Bitragunta low comprises a thick Jurassic and Cretaceous sedimentary column with a major fill of synrift sediments. This low might act as good kitchen for hydrocarbon generation. Hydrocarbon show was reported in the upper part of Lower Bapatla Formation in the Lower Cretaceous section with good to moderate porosity in well AOF-1. Bapatla Formation mainly representing arkosic sandstone and siltstone with minor interbeds of shale/carbonaceous shale. High qualities of organic matter (upto 25% TOC in coaly intervals) and good quantities of S2 hydrocarbons are observed in some intervals within this formation in well AOF-1, containing Type I kerogen , derived from algae and higher plant organic matter that was deposited in a lacustrine, sub-oxic environment and is capable of generating oil and gas. This type of organic matter might have been better preserved and have higher oil generating potential in the anoxic deep basinal area. Bapatla Sandstone would also act as main reservoir especially in this deeper part of Bitragunta low where the anticipated thickness is much more. A number of shale units within Bapatla formation would act as seals.

The inverted structures have been mapped in the deeper part of Bitagunta low, at the toe of western margin within the synrift sediments of Jurassic and Lower Cretaceous section, in the northern part of Pennar basin. They seem to be promising and form the potential target for exploration.

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