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Delineating tight Bhuvanagiri reservoirs in Ariyalur-Pondicherry Sub-Basin using integrated approach to reservoir characterization

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Abstract:

The Bhuvanagiri reservoir in Ariyalur-Pondicherry Sub-Basin of Cauvery Basin, deposited during the early-post rift sedimentation were opined to have been fed from multiple sources down the rift shoulder by various workers based on sparse grid 2D seismic and few drilled wells. (Dr Mani, Moulik et. al 2006).

Seismic attributes when tied to well data are a powerful aid to seismic interpretation. They allow the geoscientist to interpret and recognize the depositional environment. Study integrating 2000 km2 seismic data, electro-logs and other well data to seismic attributes with deterministic inversion has brought out the precise sand geometry of Bhuvanagiri Sands in Ariyalur-Pondicherry Sub-basin. Bhuvanagiri reservoir which were earlier opined to have deposited as multisource debris flow systems can be interpreted as point directional flow unit entering from south-eastern part of the sub-basin and flowing along the axis guided by the antecedent topography.

The Bhuvanagiri reservoirs are moderately hard, very fine to medium and occasionally coarse argillaceous sandstone in a shale matrix with around 500 m thickness occurring at depths ranging from 2400 in the southern part of the sub-basin to 3800m in the northern distal part. The porosity is moderate to poor and permeability is immeasurably low to occasionally 24md and is destructed by diagenesis. Mini Hydro-fracturing Jobs was conducted in few wells have showed a mixed response, while testing with barefoot completion has yielded substantial flow improvement. It was opined that the reservoirs require a massive hydro-fracturing to achieve consistent producibility and a plan is under preparation to drill high angle and drain holes which shall be completed with massive hydro-fracturing based on the extension of this study in Bhuvanagiri field.

The Bhuvanagiri field discovered in 1987 remained as small field with 11 exploratory wells drilled and only four wells under production. Seismic attributes, stratigraphic inversion and pseudo log property mapping helped delineate the precise sand geometry of Bhuvanagiri Sands in Ariyalur-Pondicherry Sub-basin as axial drainage flow unit entering from the south-eastern part of the sub-basin and flowing along the axis of the sub-basin guided by the antecedent topography. The sand maximum is found in the wells drilled along the sand ridge and decreases as we go along the flanks, wells drilled along the flank of the sandy debris flow have very poor sand/gross ratio of 0.30 and 0.04 respectively.

Few recently drilled exploratory wells which did not fall within the sandy debris flow system were devoid of reservoir facies, while three wells drilled based on the work encountered Bhuvanagiri Pay sands as expected with hydro-carbon accumulation leading to proving the model.

Introduction

Bhuvanagiri field has always attracted attention on account of in place reserves in Upper Cretaceous. A total of 11 exploratory wells have been drilled by ONGC in this field out of which 5 wells have struck commercial hydrocarbons, and rest has shown indication of hydrocarbons. Three wells were drilled by Jubliant in their NELP block and two wells drilled within the same reservoir were declared as their discovery wells. Bhuvanagiri formation has also been drilled in 13 wells spread across the Ariyalur-Pondicherry Sub-Basin. These sands are thick with a column of more than 500 m occurring at depths ranging from 2400 in the southern part of the sub-basin to 3800m in the northern distal part and are moderately hard, very fine to medium and occasionally coarse argillaceous sandstone in a shale matrix. The porosity is moderate to poor and permeability is immeasurably low to occasionally 24md. Mini Hydro-fracturing Jobs was conducted in few wells have showed a mixed response. It was opined that the reservoirs require a massive hydro-fracturing to achieve consistent producibility. The reserves in Bhuvanagiri field constitute about 21.1 % of the total prognosticated resources estimated in the Ariyalur Pondicherry sub basin. The reserves converted from inplace accounts to only 2.53 % which is attributed to poor petrophysical rock properties and poor testing/completion methods adopted in production from these tight reservoirs. Drilling through the high pressure tight gas reservoir and successful completion of wells has becomes a major cause of concern, it is the need of the hour to take up this tight reservoir and exploit to help achieve the target set by PP2030. The recent step towards testing and completing one well in barefoot has opened up these tight reservoirs for its producibility.

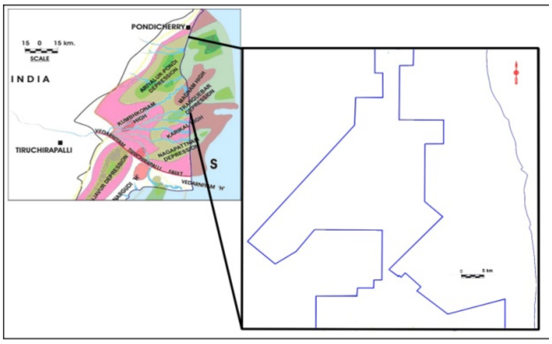

Fig1. Tectonic Map of Ariyalur-Pondicherry Sub-Basin showing study area

Previous Studies

Bhuvanagiri formation were described as having limited aerial extent distributed in scattered fashion as discrete lobes by earlier workers based on the sparse 2D seismic data and few wells that were drilled (S.K.Roy Moulik et.al 2006). Mass transport gravity driven mechanisms, e.g., non-channelized debris flow and sandy slump were identified as the principal depositional processes for Bhuvanagiri sandstone acting under bathymetry ranging from 150m. to 200m+. The present study was carried out to map the extension of Bhuvanagiri play using merged data of 2000 sq. km 3D data covering major part of Ariyalur-Pondicherry Basin. The study has brought a change in geological understanding of the depositional environment.

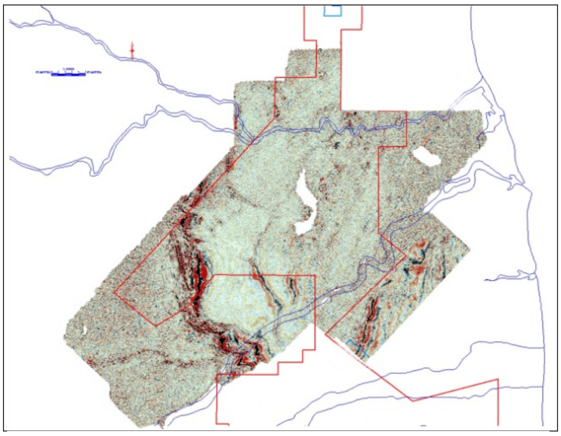
Fig 2. Seismic Coverage Area for study

General Geology

The Cauvery basin was evolved in Late Jurassic-Early Cretaceous time as a result of rift-drift phenomenon of the then Indian plate from East Gondwanaland. Evolution of this basin is genetically linked with the other simultaneously evolving extensional basins of East Coast of India, viz. Palar, Krishna-Godavari, Mahanadi and Bengal basins (Rangaraju et al, 1993).

Ariyalur-Pondicherry depression is the northern most sub-basin of Cauvery basin (Fig 1) and is partitioned by Kumbakonam-Madanam ridge from the adjacent Tanjore-Tranquebar depression. This sub basin, an asymmetric rift graben trending NE-SW, is flanked by outcropping Achaean granite gneisses in the west & northwest, Kumbakonam-Madanam ridge in the south/ southeast and east and extending towards northeast to the present day offshore upto 200m Isobaths into Bay of Bengal.

A series of longitudinal faults trending NE-SW are the main extensional faults associated with the syn-rift phase of basin formation and another orthogonal fault system is trending NW-SE dissecting the older NE-SW

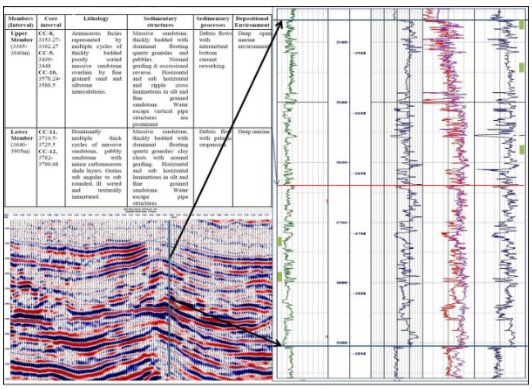
Fig 3. Characteristics of Bhuvanagiri Reservoir

trending fault. This fault system played major role in sediments deposition and hydrocarbon accumulation and migration.

The Bhuvanagiri Field is manifested as crescent shaped sandy ridge with crest centred in the main field where in most of the wells are drilled, few wells drilled in the flank have shown decrease in sand/gross ratio. The present study was focused to map the extension of the Bhuvanagiri reservoir in complete part of Ariyalur-Pondicherry Sub-Basin after a merge volume of 7 campaigns was made available covering the area.

Present Work

A Raw post stack migrated 3D seismic volume covering 2000 km2 containing 2000 traces and 1550 in-lines (Fig 2) spaced at 40m and 20 m respectively was subjected to deconvolution with optimum parameter to maintain the resolution of data and preserve the true amplitudes. The data quality is fair to good, with dominant frequency of around 24 Hz at the reservoir level. The seismic data was calibrated for time-depth with conditioned sonic log of 24 wells. Five seismic reflectors covering the Bhuvanagiri formation and Andimadam formation have been mapped in the study area and seismic attributes were generated for bringing out the reservoir disposition in the area. A part of this data from Inline 3250 to 4500 and Traces 1050 to 2200 was used for deterministic inversion to characterise the reservoir after delineating the reservoir.

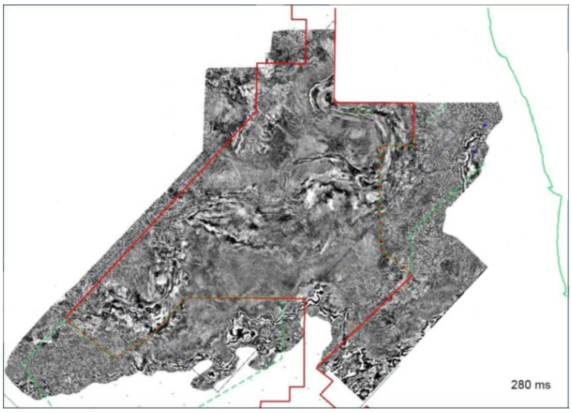

Fig 4. Horizon slice below 280 ms from Turonian Top

Seismic Attributes

The Bhuvanagiri Reservoir is characterized by bi-directional dipping strong seismic reflectors (Fig 3) encased as third order early-post rift sequences between MIII 30 (Turonian) and MI 60 (Albian) sequence. The average thickness of the early post-rift sequence is almost consistent along the basin axis, hence flattened volume of Post Stack Seismic data, sweetness volume and spectral decomposition volume at 24 Hz were computed from M III 30 (Turonian Top) for generating horizon slices. The Horizon slices (Fig 4) between 180ms to 420ms below MIII30 sequence on a seismic grid over the area have brought out a NE-SW trending sinuous trending high amplitude package, along the basinal axis parallel to the basin margin and shoulder of the horst. This zone based on the seismic character and wells drilled is inferred to be the arenaceous facies representing the Bhuvanagiri reservoir.

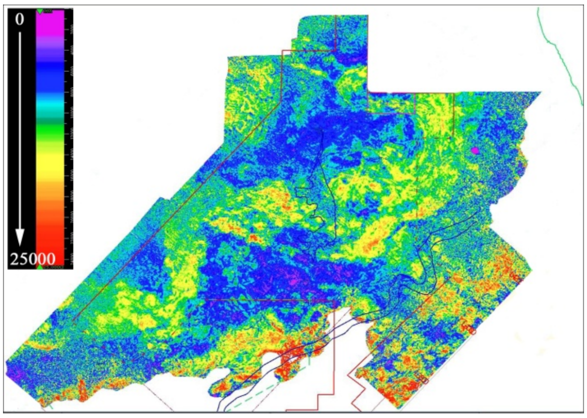

Fig 5. AAA Map between BVG Play Top and Base

Absolute Average Amplitude was extracted between the Bhuvanagiri Formation Top and the base. The AAA distribution (Fig 5) brings out clear expression of the Bhuvanagiri reservoir deposited in the Bhuvanagiri field is a part of a point axial debris flow of the directional sinuous debris flow running down the available slope from SW to NE direction along the basinal axis.

Reservoir Facies & Petro-physical properties

The electro-logs of drilled wells are generally affected by rugosity of the borehole, the sonic and density logs were conditioned for borehole correction, synthetic logs were generated by Multi-attribute analysis using EMERGE software from HRS Suite and the bad/missing data was patched for better consistency. The cross plot of resistivity to sonic (Fig 6) brings out a clear distinction between the shale and sands, the shale is characterized by low resistivity and high sonic travel time while sands are characterized by higher resistivity and slower sonic travel time.

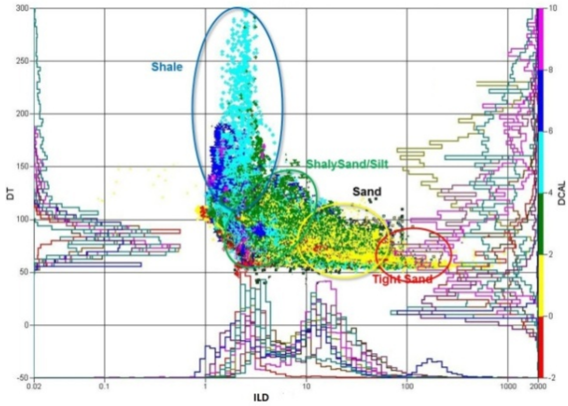

Fig 6. Crossplot of Resistivity to Sonic Travel Time

Since the Neutron porosity and density were affected by borehole damage, weighted average porosity was computed using neutron, density and sonic logs (neutron=5, density=3 and sonic=2).

The acoustic impedance to average porosity cross plot with DT as third axis (Fig 7) brings out distinct four lithological characterization, tight reservoir with very high impedance (44000 to 51000), very low porosity (0 to 0.05) and sonic travel time (40 to 60), reservoir with impedance (33000 to 44000), porosity (0.6 to 0.18) and sonic travel time (60 to 75), silt or shaly sand with (33000 to 27000), porosity (0.18 to 0.22) and sonic travel time (75-80) and rest represented by shale. The Bhuvanagiri reservoir thus has P-Impedance contrast with the shale that occurs below, within and above. The sands have higher acoustic impedance than the shale, the porosity has direct relationship with acoustic impedance, poorer the porosity higher is the impedance. This helped in carrying out deterministic inversion for p-impedance on the seismic data which was good for such studies.

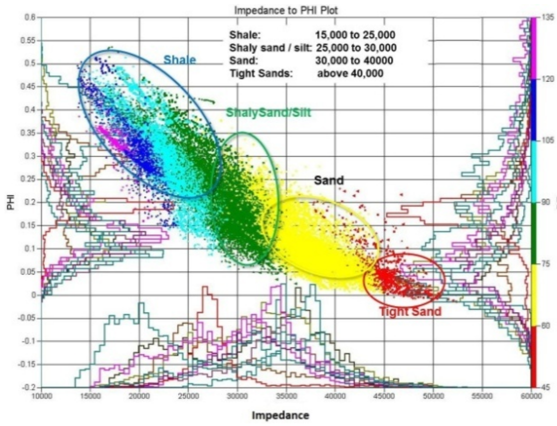

Fig 7. Impedance to Average Porosity Crossplot

Reservoir characterisation

Deterministic inversion was carried out using Strata from HRS and InverTrace from Fugro-Jason. The well-seismic tie and wavelet extraction process produced the synthetic seismogram, time-depth relationship, well log and markers in the time domain. Wavelet was extracted initially using the seismic data and then at each individual well followed by composite wavelet using all the wells. The seismic tie and estimated wavelet at wells are demonstrated in figure (Fig 8).

In order to delineate the sand distribution in the area and to characterise the reservoir sands Acoustic Impedance (AI) inversion has been carried out.

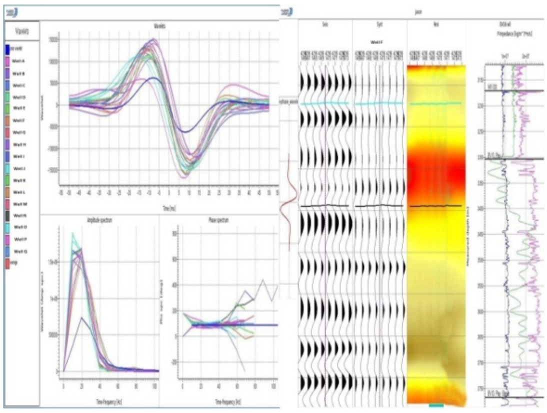

Fig 8. Wavelet extraction and Synthetics

Bhuvanagiri Pay sand has been clearly brought out in impedance section and its impedance value varies from 33000 to 44000. The well derived impedance log to inverted volume impedance log shows a good correlation between the intervals from Turonian to Aptian (Fig 9) at almost all the wells. Three wells out of 25 available were taken as blind wells spaced apart to check predictability of the inversion and were found to be close to 75-85% in wells.

Proportional slices and geobody capture from the Impedance volume brings out the similar disposition (Fig 10) of the sandy flow shown by horizon slices and amplitude extraction.

Conclusion

Stratigraphic inversion coupled with pseudo log property mapping has emerged as potential tool for interpreters to define the reservoir geometry and quality with confidence. Stratigraphic inversion and

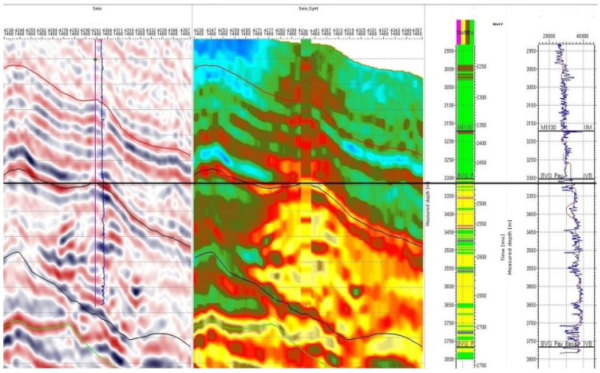

Fig 9. Inverted Impedance Comparison at Well

pseudo log property mapping successfully brought out the precise sand geometry of Bhuvanagiri Sands in Ariyalur-Pondicherry Sub-basin as axial drainage flow unit entering from the south-eastern part of the sub-basin and flowing along the axis of the sub-basin guided by the antecedent topography (Fig 11).

The sand maximum is found in the wells drilled along the sand ridge and decreases as we go along the flanks, wells drilled along the flank of the sandy debris flow have very poor sand/gross ratio of 0.30 and 0.04 respectively, while recently drilled few exploratory wells which did not fall within the sandy debris flow system were devoid of reservoir facies. Three wells were drilled recently along the debris flow system encountered Bhuvanagiri Pay sands as expected validating the reservoir model prepared with integrated data interpretation. Well A (Fig 12) falls in the distal end of debris flow forming the northern arm of Bhuvanagiri Field, Well B is in the main Bhuvanagiri field, Well C is towards the southern arm of Bhuvanagiri field, while Well D and Well E are along the southern proximal part of the debris flow. The electrolog correlation along the wells shows the similar petrophysical properties of the reservoir. A seismic transect (Fig 13) across the debris flow system from the AI volume demonstrates the disposition of the flow unit of Bhuvangiri reservoir extension in the complete Ariyalur-Ponidcherry Sub-Basin as a single point source debris flow system that had the input from South-West part of the graben and was distributed as axial debris flow following the antecedent topography along the basin axis bounded by the Basin margin fault to the West running North-East to South-West and the Madanam-Kumbakonam High to the West also in the similar direction. The study opens up a large upside reserve potential for these reservoirs in Ariyalur-Pondicherry sub-basin of Cauvery Basin.

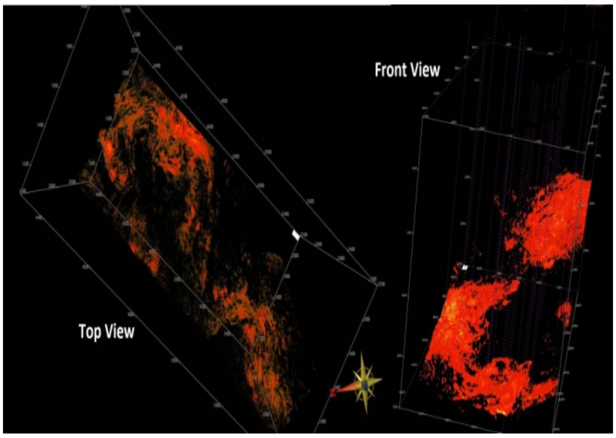

Fig 10. 3D Body capture of the reservoir

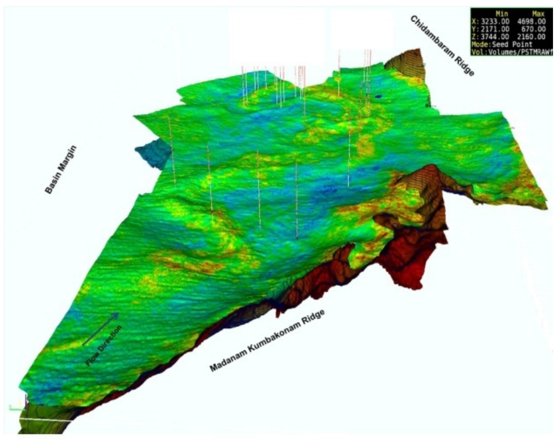

Fig 11. Average Absolute Amplitude on the BVG Play Top

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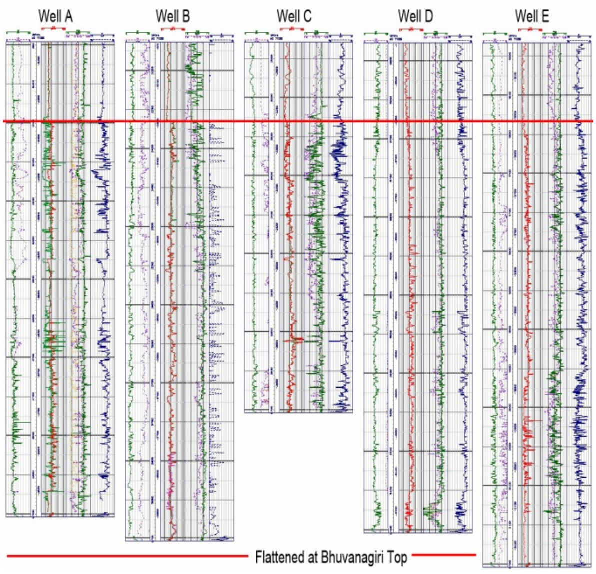

Fig 12. Electrolog correlation along drilled wells

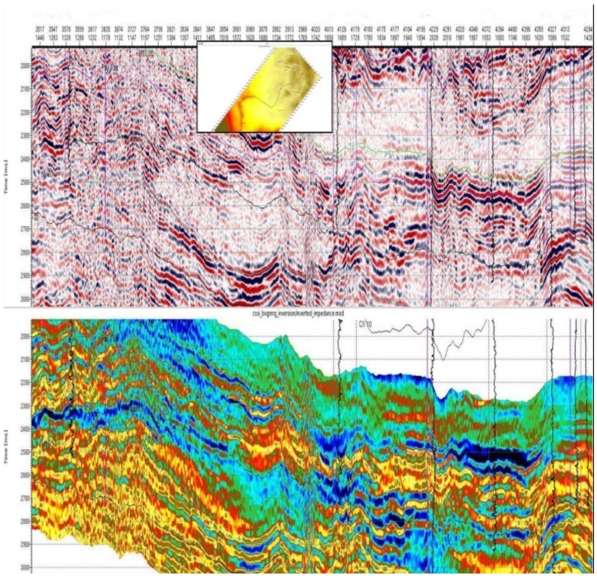

Fig 13. Transect along the Debris Flow

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