PaperID **AU187**

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Deep Water Turbidite Depositional Model and Reservoir Facies analysis of Bhuvanagiri Formation in Ariyalur-Pondicherry Sub-basin, Cauvery Basin

Abstract

Commercial gaseous hydrocarbon has been established from multi layered reservoirs within the Bhuvanagiri Formation in Ariyalur-Pondicherry sub-basin; although, sustained production is obtained from only few wells of Bhuvanagiri Field. This has necessitated developing an integrated depositional model dovetailing distribution of favourable reservoir areas of Bhuvanagiri Formation within the sub basin. The present study incorporating seismic, log and core sample analysis suggest deep water turbidity channel in a slope fan setting from Lower to Upper Bhuvanagiri Formation. Deciphering the facies distribution pattern vertically and laterally within turbidity channel is often highly complex and challenging. Integrated study of available laboratory data and SEM studies indicate poor porosity and permeability on account of clay coating on grains, occurrence of authigenic clay as pore fill. Additionally the reservoir is adversely affected by cementation and other diagenetic changes which has increasingly made the reservoir characterization challenging. Based on the present study, the Bhuvanagiri Formation has been subdivided into four major litho-facies assemblages; basal lags, slumps and debris flows, arenaceous coarse grained stacked channels and fine grained channel levee with characteristic log and seismic responses. The results of drilled wells in the study area has been analysed in light of the aforesaid depositional model and found to be mostly validated. The outcome of the study would facilitate further exploration as well as delineation activities for Bhuvanagiri Formation in Ariyalur-Pondicherry sub-basin.

Introduction

Significant hydrocarbons have been discovered from multiple reservoirs within Bhuvanagiri Formation in Bhuvanagiri and Andimadam Field of Ariyalur-Pondicherry sub-basin of Cauvery Basin. The critical risk for the Bhuvanagiri play is reservoir producibility. Therefore, it was necessary to understand the reservoir facies affecting the production performance and to develop a depositional model of Bhuvanagiri Formation for delineating areas of better reservoir facies. In this paper, a deep water turbidity channel depositional model has been generated for Bhuvanagiri Formation (Cenomanian-Turonian age) and established an important link between primary depositional characteristics and reservoir quality.

Data Input and Methodology

The present study is mainly confined to Ariyalur-Pondicherry sub-basin in the northern most part of Cauvery basin (Fig.1a&b). This NE–SW trending basin is bounded by the granitic outcrop of the Indian shield in the west and by Kumbakonam–Madanam ridge in south and east. Well data of thirty wells, fifteen conventional core data within the Bhuvanagiri Formation, and available 3D seismic data has been interpreted and used for analysis of reservoir distribution in the study area.

Facies Analysis

The Bhuvanagiri Formation is represented by alteration of argillaceous sandstone, calcareous sandstone and calcareous silty clay stone. Top part of Bhuvanagiri Formation is dominated by fine grained silty sediments which is well compacted capping the reservoir units below. The sediments of Bhuvanagiri Formation were broadly divided into two units, namely Upper Bhuvanagiri and Lower Bhuvanagiri based on logs (Fig. 1c), and biostratigraphic data. The Upper Bhuvanagiri unit is biostratigraphically dated as Turonian and Lower Bhuvanagiri top is dated as within Cenomanian and is well calibrated with seismic (Fig 1d). The lower Bhuvanagiri Unit is dominantly arenaceous represented by multiple thick beds of massive sandstone, pebbly sandstone with minor claystone and carbonaceous shale. The upper Bhuvanagiri unit consists of multiple cycles of thickly bedded massive sandstone with floating subangular to subrounded granules. Sand stone is intermittantly layerd with horizontal laminations silt and fine sand along with shale.

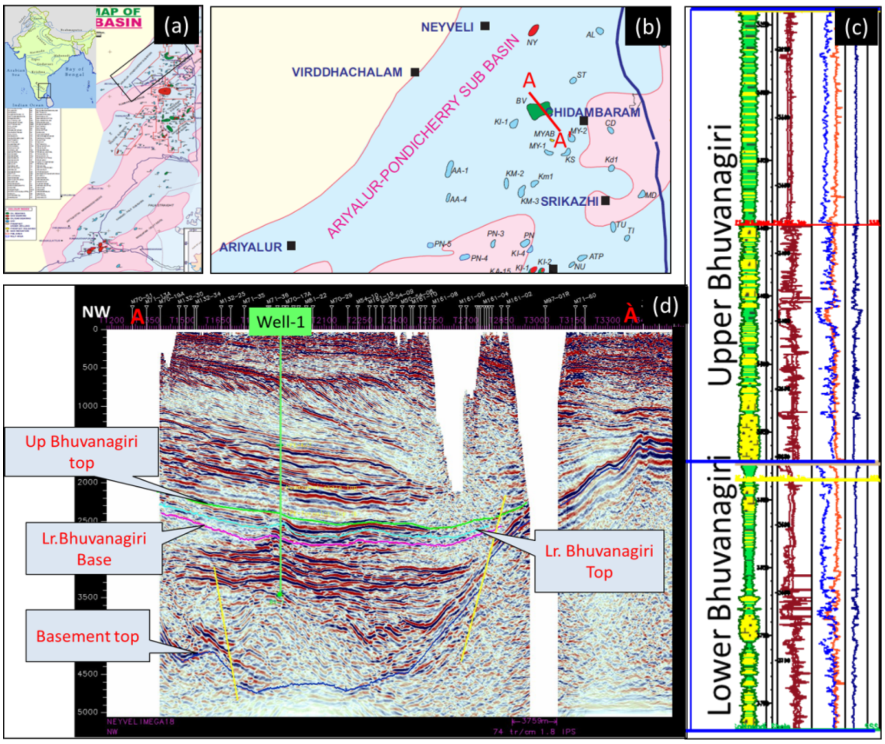

Figure1: Study Area (a)Position of Ariyalur-Pondicherry sub-bain (black rectangle area), (b) Study Area, (c) Upper and Lower Bhuvanagiri units within the Bhuvanagiri Formation and (d) Seismic signature of Upper Bhuvanagiri top, Lower Bhuvanagiri top and base

The megascopic studies of core samples depicts sedimentary structures like graded bedding, truncated Bouma sequence, pene-contemporaneous deformation structures, matrix supported structure-less pebbly sandstone, non-graded and inversely graded sandstone, collectively indicative of deposition of Bhuvanagiri sands by turbidity currents (Fig.2). Foraminiferal evidences shows that the water depth of Bhuvanagiri formation was more than 200 meters during most of the Cenomanian and Turonian sedimentary history.

Isolated sinuous channel has been identified by studying characteristic amplitude slices in 3D seismic within both upper and Lower Bhuvanagiri Formation (Fig.3). Sedimentological and core data and well log data indicate turbidity channel deposited on a slope fan setting. Mutti, 1987 postulated that thick sinuous complexes appear to develop when slope equilibrium is re-established in an area previously starved and over steepened simply as a result of hemipelagite deposition during a period of starvation. This situation very much corroborates with the deposition within the Bhuvanagiri Formation which is underlain by syn-rift Andimadam sediments when the basin was tectonically active and over steepened and underwent a period of starvation. Mayall et.al. 2006 postulated at least four causes of sinuosity of turbidite channels viz. erosion, lateral stacking, lateral accretion and sea floor topography; which is also observed in case of Bhuvanagiri formation in Ariyalur Pondicherry sub-basin.

Sedimentological, log data and core data analysis suggest that the Bhuvanagiri Formation is dominated by a deep water gravity flow deposits system. In the present study an attempt has been made to classify the sedimentary deposits within the Bhuvanagiri Formation into four types of lithofacies:

Litho-Facies A: Basal lag facies within channel: During the early stage of the formation of gravity flow, sediments were transported by gravity flow via deep water channels as the main pathways. During this stage gravity flow had a great erosive force and bypassed the deep water channels forming U or V shaped incised valley features where basal lag deposits are formed. Within the Bhuvanagiri Formation, basal lags deposits consist of Ill-sorted conglomerate, coarse sands and gravels with a matrix of coarse grained sandstone. The sub-angular to sub-rounded pebbles are made up of quartz, rock fragments and clay clasts of coarse sand/conglomerates or mud clasts which show high amplitude seismic response layer at the base of the channel (Fig.2h & 4a).

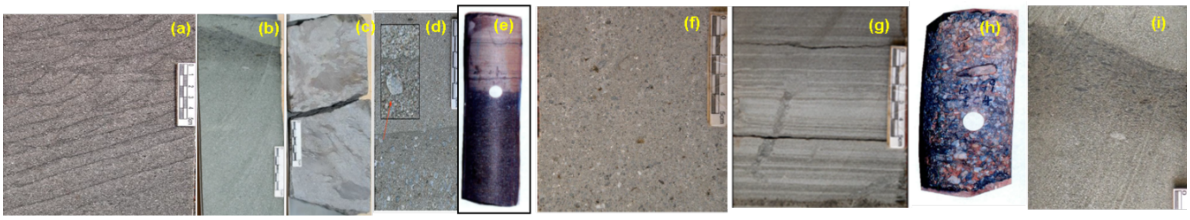

Figure 2: Microfacies core images showing (a) Dish structures (b &c) Penecontemporaneously deformed sandstone, (d) Coarse grained floating poorly sorted sandstone (e) Overall fining upwards cycle with well-defined erosional boundary, the upper part show well-defined bedded sandstone and the lower part is very coarse grained massive sandstone (f) Massive sandstone fine to coarse grained with floating granules (g) parallel & wavy laminations with at places bioturbations (h) Ill-sorted conglomerate with a matrix of coarse grained sandstone (i) Inverse grading

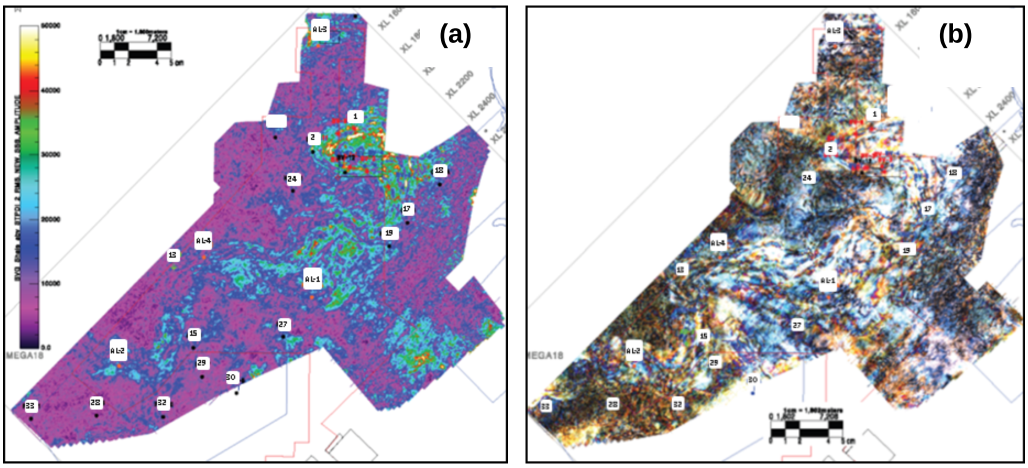

Figure 3 :(a) RMS amplitude Attribute of Lower Bhuvanagiri within thickness range of 40-100 ms ; (b) RGB blended spectral decomposition of Upper Bhuvanagiri Formation

Litho-Facies B: Slump and Debris Flow / Mass Transport Deposits (MTDs): 3-D seismic interpretation results indicate that the study area is located in the proximal to distal part of the mass transport sedimentary system, where sediments are sourced from nearby highs like Madanam high, Kumbakonam high and Western margin of the basin. Within the Bhuvanagiri Formation the MTDs facies is characterised by sharp upper & lower contacts, floating or rafted mudstone clasts, planar clast fabric, dish-pillar & water escape structures, Inverse grading of clasts, basal shear zone, high matrix strength producing a clast rich zone & protruding clasts and chaotic mixture of clasts-matrix (Figs.2a,b,c,d,and i). Slumps and debris litho facies are characterized by blocky nature of logs with sharp top and base and moderate to high amplitude chaotic seismic reflection pattern (Fig.4b). The effect of MTDs system is severe within Upper Bhuvanagiri. Higher amount of gravity related flow encountered in Upper Bhuvanagiri may be due to Late Turonian relative sea level fall which accentuated slope instability. Slumps and debris flows within the channel, in the study area may be locally derived from the collapse of channel walls or from long distance transport from the adjacent highs and are mostly developed at the incised valley bottom.

Litho-Facies C: Arenaceous laterally stacked channel litho facies within deep water channel deposits: During the deep water channel filling period, as the relative velocity of gravity flow decreased, sand rich sediments were deposited, forming high sand to shale ratio. Such High net-gross stacked channels have been drilled within Bhuvanagiri field and have produced hydrocarbon. Such litho facies show massive coarse to fine grained sandstone with floating granules (Fig.2f). In seismic sections, such lithofacies show convex upward mounds and electrolog data show multiple cycles of bell shaped fining upward log curve (Fig.4c)

Litho-Facies D: Fine grained channel levee deposits: As the energy of gravity flow further decreases, fine grained sediments get deposited forming low sand to shale ratio. The levee deposits in the study area consist mainly of mudstone, siltstone and fine sandstone. Low net-gross sinuous channels levee caps the channel fill; seismic response is typical gullwing pattern with levee edging away from channel axis (Fig.4d)

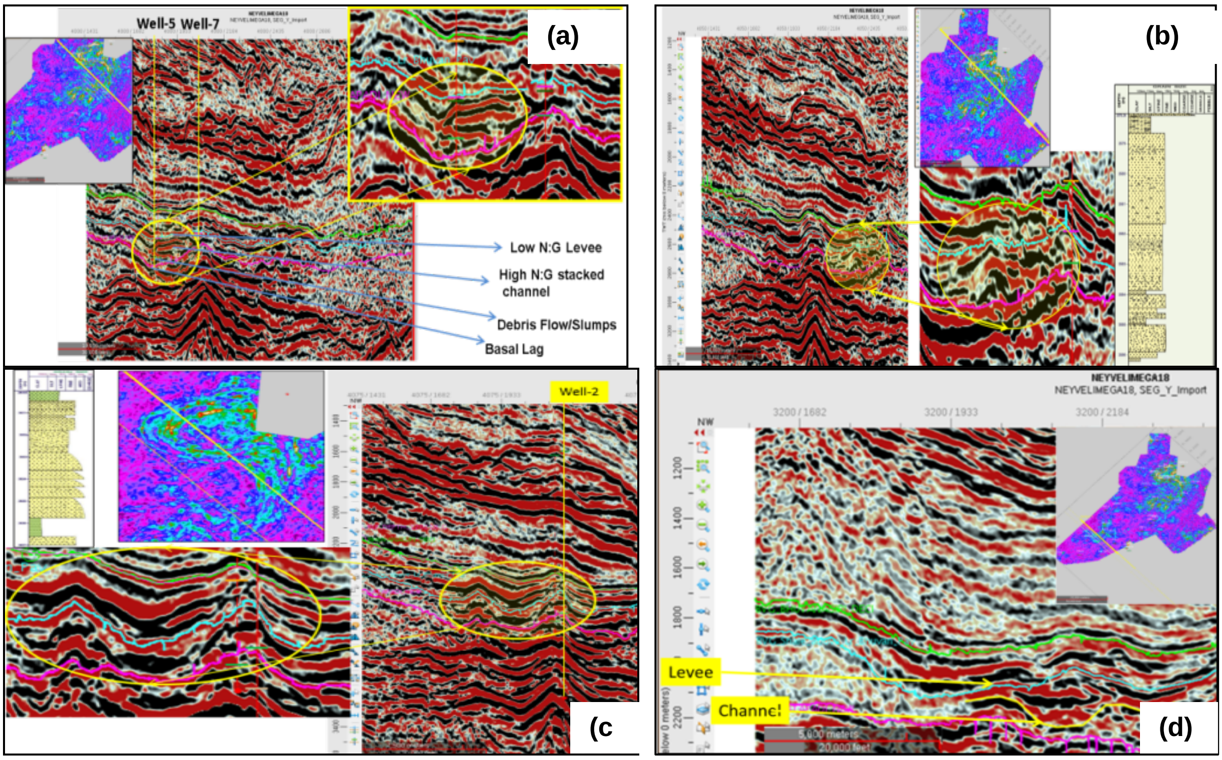

Figure 4: (a) Seismic responses of channel fill litho-facies in Bhuvanagiri Formation of Ariyalur-Pondicherry sub-basin (b) Slump and Debris Flow deposit with chaotic and rotated block mieum to high amplitude and blocky log signature with sharp top and base, (c) Arenaceous lobe at the convex bend of the channel with mounded seismic signature and log showing multiple cycles of fining upward sand, (d) Levee deposit showing typical gullwing pattern with edging away of reflectors from channel axis

Depositional Model

Facies and depositional Model have been conceptualized based on the role of tectonics in sedimentation, and position of relative sea-level. Paleobathymetry map of Cenomanian shows that bathyal regime existed in the deeper parts of Ariyalur-Pondicherry sub basin. Paleo-depth attained its maximum at the end of Middle Turonian, when bathyal realm covered more regions of Ariyalur-Pondicherry sub basin; the deepest portions about 1000m or even more. Sand percentage cum facies maps (Fig. 5a&b) prepared based on log, lithology and RMS amplitude attribute show arenaceous facies within the channel course with more than 30% sand. Sand lobes with more than 40% sand are developed at the convex bend of the channel. Such sandy lobes show convex upward mounded feature within seismic section. These are also known as nested mounds or outer bank bars, a unique feature of submarine sinuous turbidity channel (Kane, et.al. 2008) and show good reservoir characteristics. In wells of Bhuvanagiri field such features show blocky log motifs and also multiple fining upward sands and core shows mainly coarse grained sands and is hydrocarbon producer. Similar sand mounds are observed in fields other than Bhuvanagiri namely Andimadam and Puttur. Besides, slump and debris deposits sourced from adjacent highs is also postulated which are more dominant in Upper Bhuvanagiri compared to Lower Bhuvanagiri (Fig.5a). Shanmugam, 1996 postulated that debris flow deposits can be thick, areally extensive and excellent reservoirs. In the present study however, the drilled well results show that due to intermixing and chaotic nature of such lithofacies, they are not good hydrocarbon reservoir for liquid oil and act as gas reservoir. The petrographic and SEM studies indicate that the reservoir sands of Bhuvanagiri Formation are feldspar rich with presence of biotite mica. Such sandstone is very much prone to diagenesis and has great bearing over reservoir quality. Various diagenetic events such as mechanical compaction, early calcite cementation, alteration of feldspar to sericite and kaolinite which fill the pore spaces, development of clay rims, are responsible for reduced intergranular porosity.

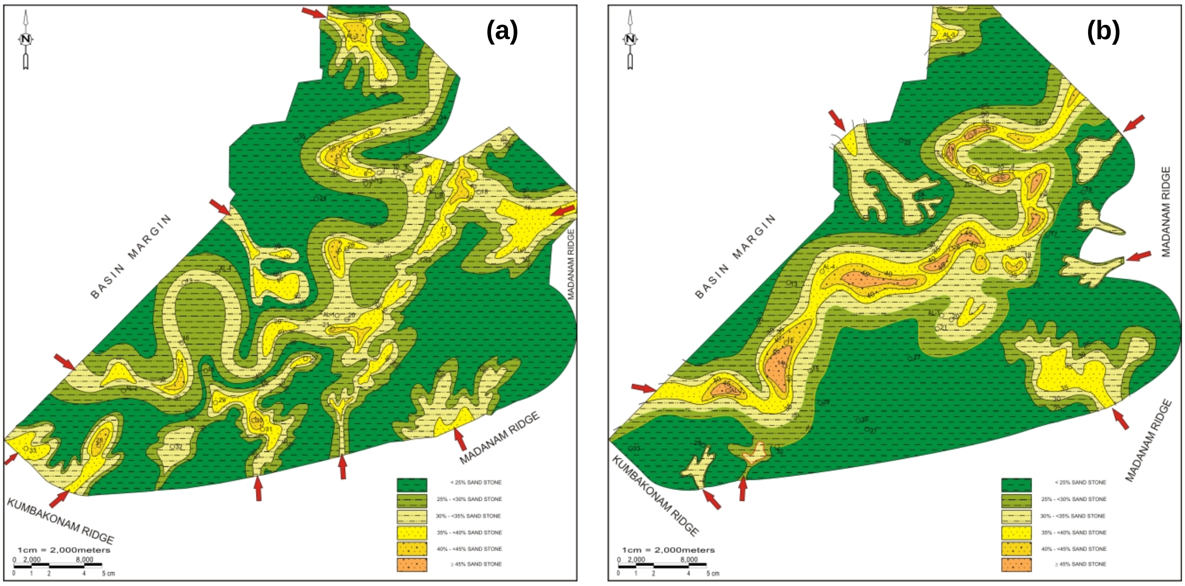

Figure 5: Sand percentage cum facies map of (a) Upper Bhuvanagiri and (b) Lower Bhuvanagiri. Note sandy mounds at the bends of the channel which have produced hydrocarbon from Bhuvanagiri Field in Ariyalur-Pondicherry sub-basin

Combining sedimentological attributes with seismic attribute analysis and seismic responses of litho-facies, conceptual and schematic 3D depositional model of Bhuvanagiri Formation has been prepared (Fig.6) which depicts sinuous turbidity channel running across the entire A-P sub-basin from SW to NE following the basin floor topography.

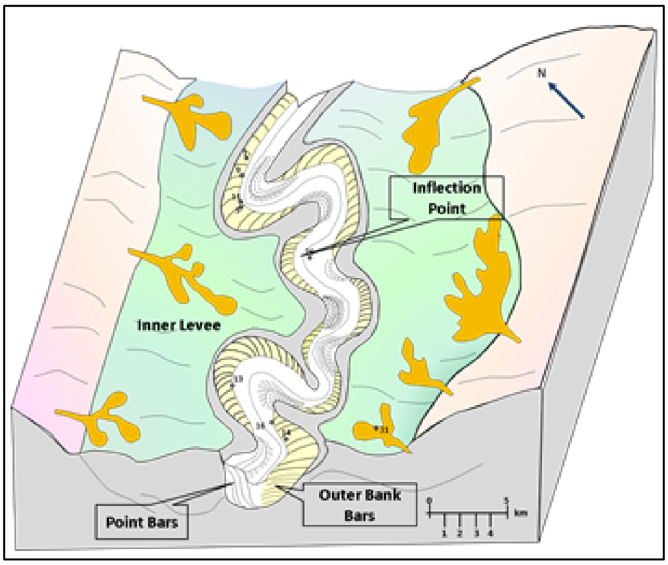

Figure 6: Schematic 3D depositional Model of Bhuvanagiri Formation in Ariyalur-Pondicherry sub-basin showing sinuous turbidity channel along the basin floor topography

Implication on exploration

Analysis show that sand lobes developed at the bends of the channel have better reservoir facies. The results of drilled wells in the study area have been analysed in light of the aforesaid depositional model and found to be mostly validated. Analogous data suggest that such sandy mounds at the convex bend of channels are unique feature of submarine channels also known as outer bank bars. The facies model and depositional model shows that similar sandy lobes within the channel are also developed in other areas besides Bhuvanagiri Field of Ariyalur Pondicherry sub basin and are interpreted to be prospective.

Conclusion

The study has brought out an integrated depositional model illustrating deep water sinuous turbidity channel in a slope fan setting, spanning within the entire Bhuvanagiri Formation in Ariyalur Pondicherry sub basin. It is helpful in identifying spatial distribution of better reservoir facies and will facilitate further exploration as well as delineation activities within Bhuvanagiri Formation in this sub-basin.

Acknowledgement

The authors express their sincere gratitude to the Director (Exploration), ONGC for granting permission to carry out this work. The authors are also indebted to Mr. A.Siawal, GM, KDMIPE and Mr J.Mishra, GM, KDMIPE, ONGC for continuous guidance and supervision while carrying out the work. The authors are grateful to Dr. Harilal, ED-HOI, KDMIPE, ONGC for facilitating this work through support, motivation and guidance. All colleagues and the group members who have contributed in various means and measures to this work are also thankfully acknowledged.

Views discussed in the paper are personal opinions and understandings of the authors and not necessarily be of ONGC's view.

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