Petroleum System Evaluation of Kutubdia Area, Bengal Basin, Offshore Bangladesh

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Abstract

Kutubdia well was the first offshore gas discovery in Bengal shelf, Bangladesh in 1976 and yet the petroleum system of Kutubdia and the surrounding area is still not well understood. This study attempts to integrate all parameters related to the petroleum system to better understand the hydrocarbon generation and migration in the Kutubdia area as well as reservoir distributions and trapping styles. Depositional environments were determined from well log response and seismic facies analysis. Hydrocarbon bearing pay sands were deposited in a deltaic environment determined from well log coarsening upward response and high amplitude parallel reflections on seismic. Seismic facies analysis was used as a significant tool to identify formation boundaries on the seismic. The Top of Bokabil is a significant erosional surface in this area which may correlate with the Messinian regression in the late Miocene times. Horizon interpretation was used to make structural maps of source and reservoir rock intervals. The formation of anticlinal structures was in the late Miocene to early Pliocene evidenced by seismic data which shows thinning over the anticlinal structures during this time. Hydrocarbon bearing pay sands within the Middle Bokabil formation in the Kutubdia well show high gamma ray response due to presence of radiogenic material. High gamma ray and porosity of the hydrocarbon pay sand implies that reservoir sands are poor quality. Source rock for the Kutubdia area is within the underlying Bhuban formation which is located within the gas window and major vertical migration occurred due to the thrusting nature of the structural formation. Reserve calculations were carried out using both shallow-deep resistivity separations and single deep resistivity methods which provide a substantial range of potential reserve estimations for the Kutubdia discovery.

Keywords: Kutubdia, Bokabil Formation, Seismic Facies.

1. Introduction

The Kutubdia study area is located in the south-east part of the Bengal basin which is a complex basin situated to the south of the Himalayas and west of the Arakan-Yoma Range. The Kutubdia anticline is situated in an active structural setting and was the first structure drilled offshore Bangladesh in 1976. It was a gas discovery, but sub-economic and subsequent drilling success in the area has been variable. Uncertainty in the offshore Bengal basin is due to the lower quality sand (arkosic sand) and their discontinuous nature which gives sub-economic reserves. Another uncertainty is source rock potential. The source rock TOC is interpreted to be low and placed in the deeper part of the basin.

The objective of this study is to assess the hydrocarbon potentiality of the Kutubdia structure and the surrounding area by:

1. Defining the controlling factors on the depositional systems and the key events of the structural evolution.
2. Better understanding of the hydrocarbon generation system of the Kutubdia area.

3. Integrating these observations into a petroleum system evaluation.

The study area is located on the shelf of the Bay of Bengal where water depth is very shallow (Figure 1). It is about 70 km west from the east shoreline. Because of the shallow water depths, seismic data is not easy to acquire and the 2D seismic coverage is quite limited and relatively poor quality.

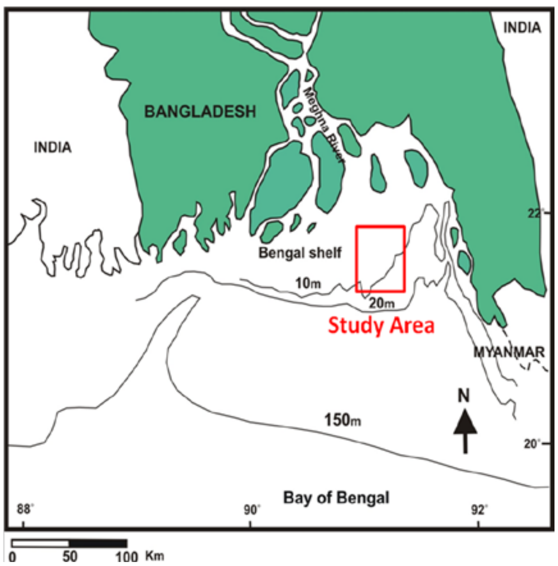

Figure 1: Kutubdia study area located on the Bengal shelf, Bay of Bengal (Modified after Davies et al., 2002).

2. Results

Log Cross Plot Analysis

Gamma ray and shallow-deep resistivity separation cross plots were made which can indicate hydrocarbon bearing reservoir sands (Figure 2). From this cross plot it appears that higher shallow-deep resistivity values indicate gas bearing sands. This cross plot shows greater than 90 API values which mean that the hydrocarbon bearing sands are not clean sands and might be radiogenic.

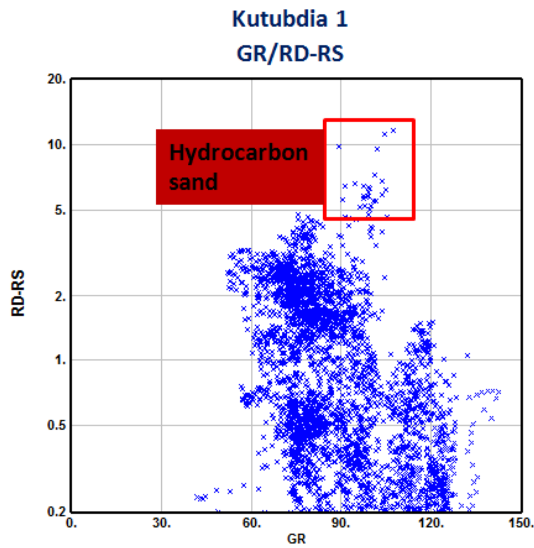

Figure 2: Gamma ray, deep-shallow resistivity cross plot for whole log. RD-RS value for gas bearing sand > 5 ohm-m and gamma ray value > 90 API.

Depositional Environment Interpretation

The Kutubdia study area is situated on the shelf of the Bay of Bengal, offshore the active Bengal deltaic system. The Kutubdia well was drilled only into the early to middle Miocene (Figure 3) because sediment in this southern part of the delta is very thick. Coal bed were encountered near base of the well and coupled with the log character suggests a prograding shelf/coastal depositional environment which could tentatively place it within the Bhuban formation.

Following the Bhuban transgression occurred and a shallow marine shale sequence was deposited over the erosional surface followed by an overall coarsening upward package. Several transgressive and regressive cycles of deposition in alternating high and low energy conditions are interpreted. Log patterns show funnel shape coarsening upward sequences which are interpreted as prograding deltaic deposits in the shelf area of the Bengal basin at this time (Figure 4).

The Middle to Upper Bokabil boundary marks the change from deltaic deposition to interbedded fluvial sand/floodplain deposition. In the Kutubdia well thin sands are observed within the shale and these isolated sands are interpreted as channel fills. The top of Upper Bokabil is marked by a distinct erosional surface on seismic which corresponds on the logs to a change from interbedded fluvial sands and floodplain deposits to predominantly high energy braided stream deposits. An interpretation of this type of progression from deltaic environments to braided streams due to an increase in sediment supply across the shelf is shown in Figure 5.

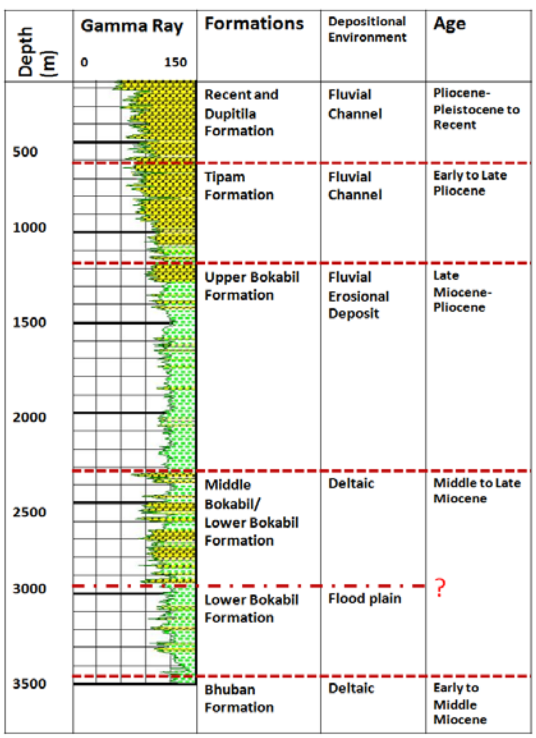

Figure 3: Overall stratigraphy of Kutubdia well.

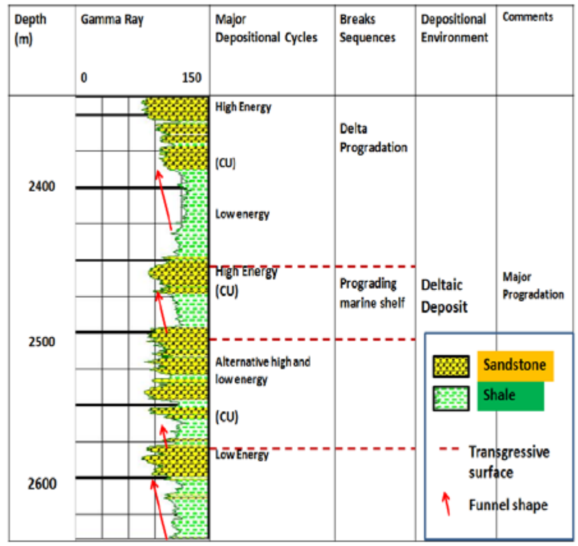

Figure 4: Depositional environment interpretation of Middle Bokabil formation, cyclical deltaic progradation.

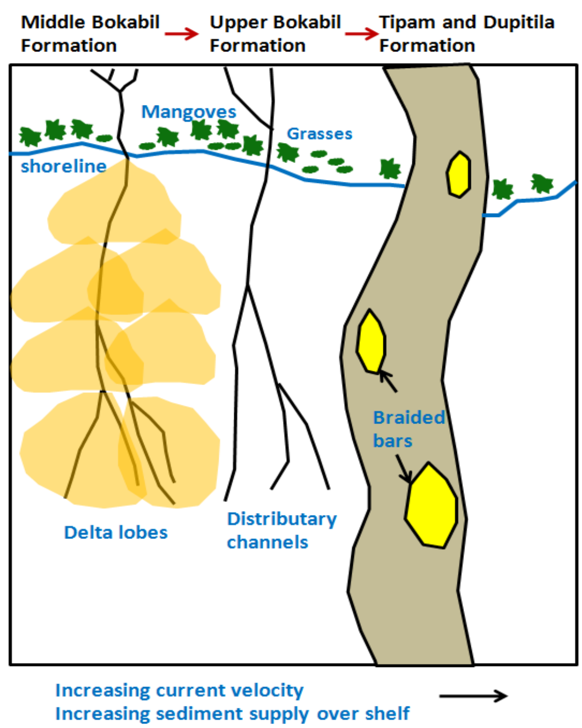

Figure 5: Schematic diagram to show depositional environment of formations in different settings (Modified after Davies et al., 2002).

Seismic Facies Analysis

Horizons were selected from the synthetic seismogram based on abrupt changes in the seismic reflection characteristics and seismic facies analysis was used to differentiate between different units which represent individual formations and sub-formations (Figure 6).

In the deeper part of the seismic data the interpreted Bhuban formation is characterized by alternating high and low energy sand and shale deposits which show medium to high amplitude parallel reflectors. In some seismic sections the top of Bhuban formation is marked as an erosional surface and the boundary is quite distinct. In the Middle Bokabil formation more sandy deposits are observed in the seismic reflections which show amplitudes increasing from less reflection strength at base to higher amplitudes at the top. This indicates alternating sand and shale deposition. The boundary between Middle and Upper Bokabil is quite distinct on seismic and well to seismic tie matches with the seismic response. Distinguishable amplitude differentiates these two sub-formations. The Middle Bokabil parallel reflections change into channelized scattered seismic amplitudes throughout the Upper Bokabil section. A lot of erosional cuts are observed. This dominantly channel cut signature implies lowstand regressive channel-levee complexes.

The most significant horizon in the Kutubdia area is the top of Bokabil which is a prominent erosional surface on the seismic. Above that the Tipam and Dupitila formations are represented by parallel reflections. The Tipam and Dupitila formations can be differentiated on the seismic because Tipam formation shows more parallel reflections than the Dupitila formation.

Structural Interpretation

Depth structural maps and isopachs were generated for intervals of interest using velocity data from the Kutubdia well. Depth structural mapping of top of Bhuban is significant because it represents the depth to the top of possible source rock. The Middle Bokabil depth structural map (Figure 7) is significant because the interval represents the top of the primary reservoir target in this area.

There is no significant difference between top of Bhuban and Middle Bokabil maps because the same tectonic forces created the structuring after deposition. But the top of Upper Bokabil structure is more complex. It shows structural anticlines as in deeper horizons but as well has erosional features with channelized signature superimposed on the anticline structures. There are four distinctive canyons seen on the Tipam-Bokabil isopach map oriented N-S direction. They cut across and pre-date the anticlinal structures.

Structural growth of the Kutubdia and other anticlines started from late Miocene-Pliocene time which is well evidenced on the seismic sections with strata thinning over the top of anticlines and thickening on the flanks between the Tipam and top of Bokabil formation. It is a good indication of the structural timing of these anticlines.

Petrophysical Analysis

The potential reservoirs for hydrocarbons in the Kutubdia well are not good quality. The gamma ray histogram plot (Figure 8) implies significant drops in cumulative frequency where gamma ray values are 100-110 API. Values are too high to show non-radiogenic sand in the log but the reality is those drops do indicate hydrocarbon sands in Kutubdia well which are likely radiogenic.

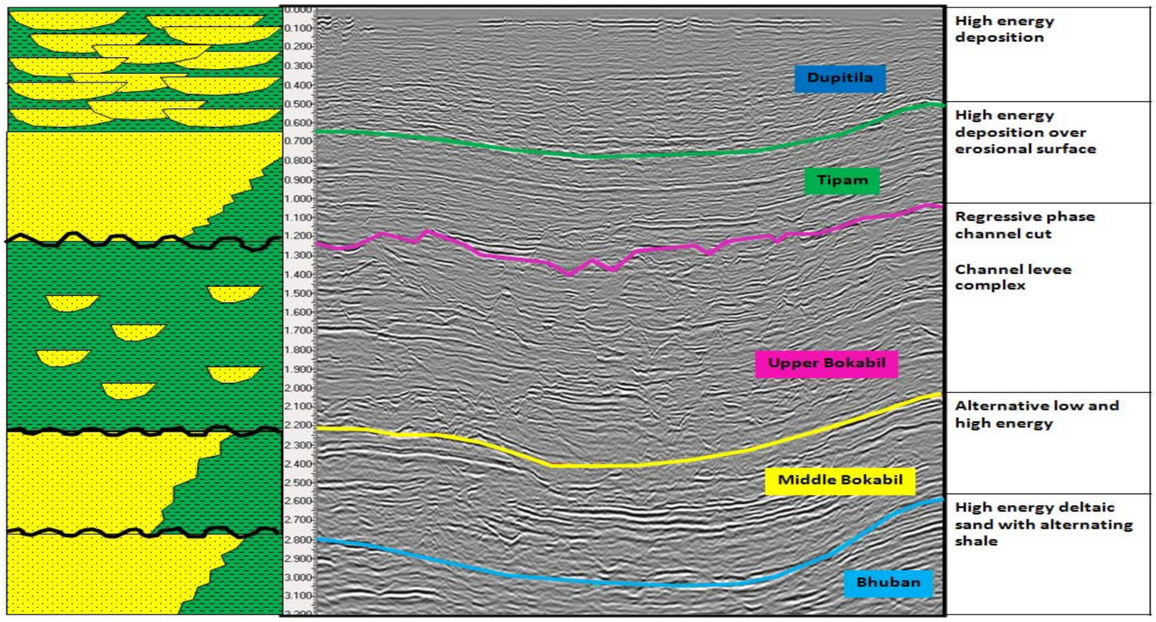

Figure 6: Stratigraphic schematic model relating seismic facies to depositional environments interpreted in the well.

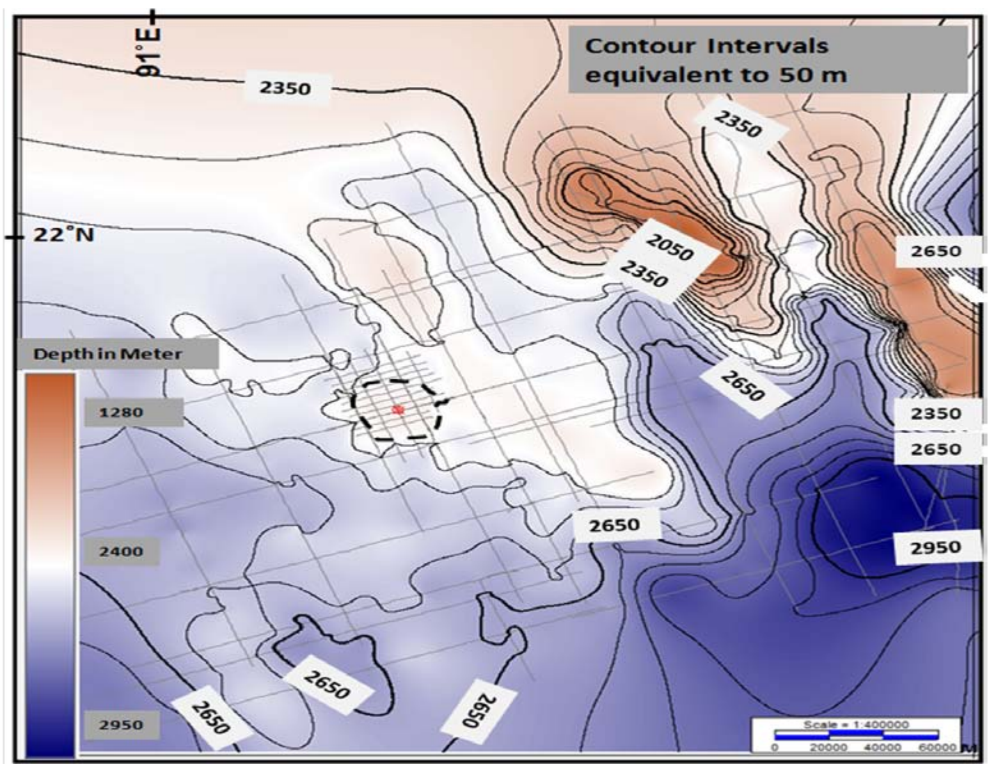

Figure 7: Depth structural map of top of Middle Bokabil formation in meters.

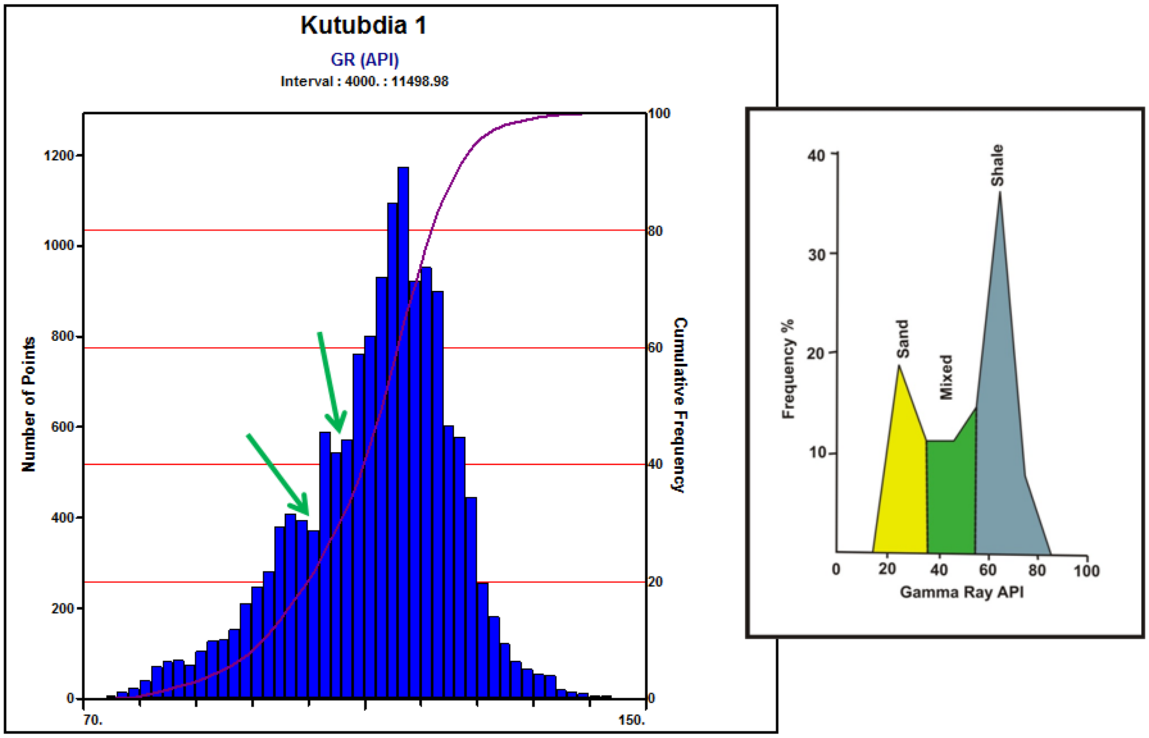

Figure 8: Gamma ray histogram correlated to standard cumulative GR histogram (Rider, 1996).

Reserve Estimate

Strong amplitude sands are difficult to map on 2D seismic so in this case for area estimation the top of Middle Bokabil horizon was chosen to represent the top of the hydrocarbon bearing sands in the well. The vertical closure of the structure is about 30m.

The pay calculation is based on the shallow to deep resistivity separation calculation for pay which gives a reservoir main pay sand thickness of a relatively thin 8m using a S_w cutoff of 60%. Using this type of calculation, the lower pay sand was included in reserve calculations. Estimated reserves are 12.6 Bcm (475 Bcf). In comparison the well completion report gives a net pay calculation of 15m and reserves of 22.5 Bcm (747 Bcf). However, water saturation calculations in this study do not support this (Figure 9).

3. Discussion

Petrophysical analysis shows hydrocarbon bearing sand shaliness is high based on their high gamma ray response. In a QFL plot their place ought to be subarkosic to arkosic range. Some good quality sands are found in Middle Bokabil but the hydrocarbons occur in poorer quality reservoir in the Kutubdia well. The source rock of offshore Bangladesh where geothermal gradients range from 18-22˚C/km (Curiale et al., 2002), is interpreted to be within the Middle Bhuban shale. Based on this data and considering a value of 100˚C for the top of the gas window the maturation depth is about 4000m. During Pliocene time the Kutubdia structure began to trap hydrocarbons within the reservoir sands but only to a limited extent as most of hydrocarbons were trapped in large anticlines to the east (Figure 10).

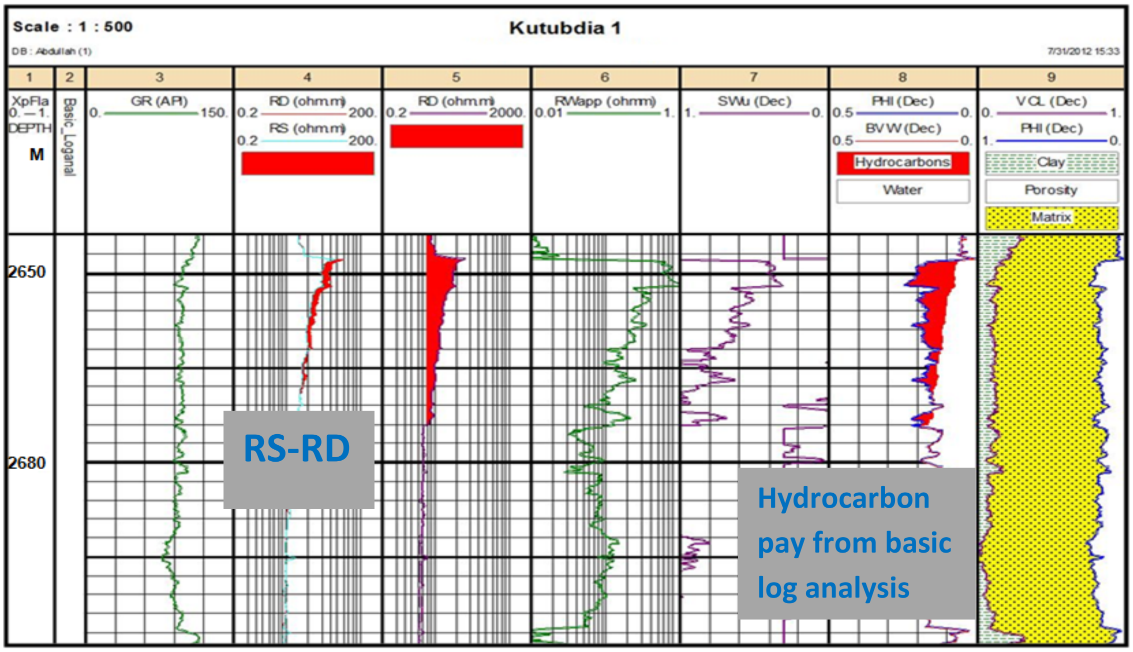

Figure 9: The log analysis shows hydrocarbon pay for shallow to deep resistivity separation compared to well report calculation.

The structural style suggests a fill and spill effect which may limit hydrocarbons migrating into structures like Kutubdia in the west. This may explain lack of hydrocarbons in many good quality sands at Kutubdia. Vertical migration means hydrocarbon escape from deeper to shallower depth occurred due to the thrusting and faulting in the folded structures, and lateral migration took place during the late Miocene.

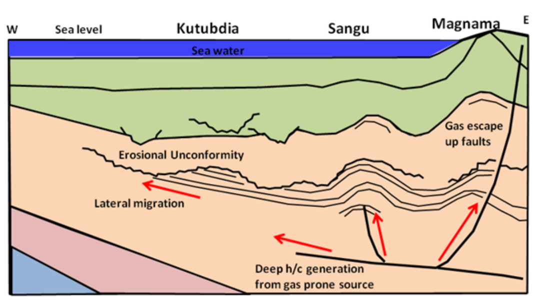

Figure 10: Schematic diagram illustrating possible generation and migration pathways of hydrocarbon in Kutubdia area (Modified after Cairn Energy, 2007).

4. Conclusion

This study addresses the main reservoir at Middle Bokabil formation which is widespread but variable in quality, becoming silty in places. The Upper Bokabil channel deposit could be secondary reservoirs. Source rock is in the Bhuban formation which is interpreted to have fairly low TOC, is not very mature and is grouped into type-III source rock which is common for this area. Maceral are mainly deltaic spore and pollen from mangrove vegetation.

Recent wells drilled in the area have had mixed results and suggest that the main risks are reservoir quality and their distribution, and source rock quality and maturity. To lower these risks, 3D seismic data is a requisite parameter to predict depositional environments and make good interpretation of reservoir distributions. Deeper drilling, coring and acquiring geochemical data could also improve knowledge of the petroleum system.

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