A Reexamination of Exploration Strategy of Lower Bhuban Play in Eastern Tripura, India: A Case Study*

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Abstract

Exploration for hydrocarbons in Western Tripura-Cachar, in India is about 37 years old. However, the quest for hydrocarbon in Eastern Tripura began only in 1991. The drilling of a few wells, mainly over crests, has helped in establishing only hydrocarbon leads within Bhuban reservoirs. Complex geological conditions, a prevalent high pressure regime and subjectivity in delineating exploratory targets from seismic data were significant hindrances in initial phase of exploration in Eastern Tripura. In the later years exploration was shifted towards the synclinal part between anticlines marked by geomorphic highs. Recent discovery of sandstone gas pay within Lower Bhuban Formation in Agartala Dome in Western Tripura and a thick sandstone gas pay within Lower Bhuban Formation in "Khubal Structure" in East Tripura has generated a new impetus to hydrocarbon exploration from Lower Bhuban reservoirs in Eastern Tripura and has helped in establishing Tripura-Cachar region as a part of giant petroleum gas province comprising of Bangladesh-Tripura-Cachar-Mizoram.

This present paper attempts to develop a conceptual geological model for the Lower Bhuban play in East Tripura, demarcate prospective areas for future exploration and delineation of potential reservoir facies. A comprehensive study was undertaken, integrating surface geology, 2-D seismic, drilled wells, petrophysical, sedimentological, geochemical and palaeontological data of Tripura, Cachar and Mizoram to understand the sedimentation history, distribution of reservoir facies and hydrocarbon accumulation pattern in the study area.

Different seismic attributes and AVO studies were undertaken to understand the distribution of pay sands around the Khubal area. Based on this integrated study, seismo-geological cross sections, structure contour and lithofacies maps were generated. Detailed facies analysis was done to reconstruct a suitable geological model. The suggested model is essentially a delta complex. This

integrated study has helped in preparing a Tectono-Sedimentological model of the Lower Bhuban play, identify lead areas and potential reservoir facies for exploration and delineation of Lower Bhuban reservoirs in Eastern Tripura.

Introduction

The Tripura-Cachar region forms a part of the folded foredeep sedimentary prism of the Assam Arakan orogenic belt. The area comprises a series of sub-parallel, long, narrow doubly plunging anticlines arranged in en echelon fashion (Figure 1). Degree of deformation increases due east with progressively older rocks exposed in the core. The sigmoidal shaped Assam-Arakan mountain belt belonging to the Indo-Burma ranges covers most of the northeastern states of India as well as Bangladesh and Myanmar. This province lies between the Indian plate in the west and the Burmese plate in the east. In the northwest, it abuts against Shillong Plateau and in the northeast it wedges towards the Himalayan arc. Southward, the basin extends up to Tripura. The basin extends beyond Nagaland, Manipur and Mizoram into the Arakan coast of Myanmar. The basin also extends southwestward under the alluvial cover of Bangladesh and is contiguous with Bengal Basin.

Eastern Tripura is situated in the eastern part of Tripura Fold Belt in India. The area comprises structures, such as Batchia, Langtarai, Harargaj, Machhlithum, Khubal, Sakhan, Longai and Jampai (Figure 2). It is filled mainly by orogenic sediment derived from the eastern Himalayas to the north and the Indo-Burman ranges to the east. These deposits record uplift and exhumation of mountain belts formed by the ongoing India-Eurasia collision. The bulk of the deltaic deposits are Miocene and younger. Drilling activity had started in western Tripura in 1972 with commercial production from 1975. However in Eastern Tripura drilling had started only in 1991 with few wells drilled in the crestal part of Harargaj and Khubal structures. The major hydrocarbon producing reservoirs are the Upper and Middle Bhuban Formation, although drilling has indicated gas from the Lower Bhuban in Agartala Dome and Baramura structure. In light of discovery of hydrocarbons in the northern plunge in Western Tripura, viz. Kunjaban in northern part of Agartala Dome and Sundulbari in northern part of Tichna structure, it was felt worthwhile to explore the flank and plunge part in eastern Tripura as well for exploration of the Lower Bhuban.

Hydrocarbon exploration in a thrust fold belt is a risky proposition riddled with constraints, foremost being complex geological and tectonic conditions (Figure 3) and mapping of exploration targets from available seismic data. Our experience of drilling in exposed anticlines shows that even anticlines are not always a safe bet on account of structural disharmony well exemplified in the number of structures drilled in Cachar and two structures drilled in East Tripura. Efforts are further compounded due to failure in understanding the distribution of quality reservoirs within the Lower Bhuban.

Reexamination of Exploration Strategy

The frontal folded belt of Tripura-Cachar-Mizoram area shows a progressive eastward increase in structural complexity with wide synclines in between. Evaluation of seismic sections across the Tripura-Cachar area reveals that section across anticlines show chaotic loss of reflection, whereas synclinal part displays well defined continuous reflection characters. It has been observed that many anticlinal crests are dissected by faults that cause drilling complications and possible escape routes for hydrocarbons. It is envisaged that down warping of synclinal flanks in response to tectonic loading may cause upwarping of central portion and readjustments of hydrocarbons towards domal uparching. Although structural amplitude of these structures will be small, their large areal extent and absence of structural complexity make them good exploratory targets.

Objective and Focus Area

The surface geological maps and landsat images indicated presence of the seven exposed structures in Eastern Tripura, and out of them the Khubal Structure is tectonically the least disturbed and gentle structure. Also, proximity to the hydrocarbon bearing structures of Adamtila, Patharia of Cachar and those of Bangladesh makes this area prospective. Collating these facts, the focus of exploration was concentrated on the Khubal-Champabari Manu area. The main objective was to formulate hydrocarbon lead areas for exploration of Lower Bhuban reservoirs.

Breakthrough

Two locations were generated based on integrated studies. Location KHC (Figure 4) was drilled on the eastern flank of Harargaj Anticline. It produced feeble gas from the Upper and Middle Bhuban Formation, but the Lower Bhuban could not be drilled due to complications. Taking lead from the results, another location (KHD, Figure 5) was drilled in a fault closure to the NW plunge of the Khubal structure. The well was drilled to about 3000 m and encountered about 60 m of pay sand in the Lower Bhuban which on testing produced 125,000 SCMD of gas and has resulted in substantial reserve accretion.

Present Study

With the discovery of huge gas reserves in the plunge part of the Khubal structure in Eastern Tripura, the focus has shifted for exploration in Lower Bhuban in adjoining structures. Since the data points were limited, as a first step distribution of Lower Bhuban reservoir was studied, sedimentary structure, petrographic, floral and faunal assemblage study was carried out in the study area to ascertain the reservoir characteristics, sand distribution pattern and depositional environment. Pressure data available for the drilled wells were studied to understand the pressure variation of Lower Bhuban sands in the study area. Surface geological and Landsat data was used to map the subtle structural features and cross faults; from available seismic data AVO was done to map the Lower Bhuban reservoirs around the study area.

Methodology

To follow up the discovery in the Lower Bhuban reservoir, an integrated study has been carried out in selected wells of Western and Eastern Tripura, Cachar and Mizoram where Lower Bhuban is present, to assess the reservoir distribution pattern and sand characteristics. Attempts have been made to integrate lithology, sedimentary structure, petrography, Palaeo floral and faunal studies of Lower Bhuban drilled in the area. A detailed analysis was done to reconstruct a suitable model for the depositional environment resulting in reconstruction of paleogeography. In this study, subsurface lithofacies maps of the Lower Bhuban Formation have been constructed based on analysis of well logs. Finally the model was tested by drilling in one of the identified prospects.

Distribution of Lower Bhuban Formation

Detailed analysis of existence of Lower Bhuban sequence in Tripura-Cachar-Mizoram area has been confirmed by drilled wells in Baramura, Agartala Dome and Rokhia in western Tripura, Khubal and Harargaj in the Eastern Tripura and Adamtila, Badarpur, Hilara, Masimpur, Bhubandar, Chatachura, Chargola, Karalkandi, Patimara, Patharia, Nrayanchara in Cachar and Rengte in Mizoram. The Lower Bhuban is also exposed in the core of the Ataramura structure. Analysis of thickness data compiled from drilled wells and field geological studies and traversing indicates sedimentary thickness pattern of Lower Bhuban Formation (Figure 6).

Petrographic Study

Results of studies of lithological characteristics and sedimentary structures of cores and samples indicate the rock is composed of sub-lithic quartz arenite to lithic quartz arenite of well-sorted grains of quartz, feldspar and lithic fragments (chert, schist and shell fragments) of angular to sub-rounded grains. The sedimentological analysis indicates the sands are dominated by silica with less feldspar content. Among the feldspar, K_2O is dominant which indicates that the sediments were derived from granitic terrain. Increased thicknesses of Miocene strata and the composition of Miocene sandstones of the Surma Group yields a clear record of orogenic unroofing. The sediments were probably fed from the east, from the Burmese shield to the study area. The dominance of quartz with lithic fragments indicates it may also be recycled sedimentary rocks from the Himalayan orogenic belt and from the Burmese plate.

Facies Analysis

Based on lithological study, sedimentary structures, faunal and floral assemblages, several major facies were identified.

Facies X: The most dominant lithology is sandstone, shale/claystone with siltstone layers. Sandstone in the northern part is light to dark grey, mainly quartzose wacke and with micaceous matrix as observed in Hilara, Karalkandi and Badarpur. It is lithic wacke in Narayan chara. Further south the sandstone is medium-grained with improved sorting. Moving further south in Harargaj, Khubal, Baramura, the sandstone is mature fine-grained and silty in nature. Sedimentary structures are ripple laminations, trough cross stratification, slump structures, and lenticular bedding. Based on these, it is interpreted to be deposited in lower delta plain with subfacies of distributary channel levee complex superposed over eroded bar complex.

Facies Y: Lithology is sandstone with minor shale and the environment of deposition is interpreted to be delta fringe with subfacies of distributary mouth bar. It is observed in the Bhubandar, Badarpur, Kanchanpur and East Tripura areas.

Facies Z: Lithology is shale with minor siltstone and sandstone. Sedimentary structures are current ripple, flaser beds, and herringbone structures. Mainly observed in Mizoram, it is interpreted to be deposited in a coastal inter-deltaic environment.

Style of Sedimentation

Surma sediments are believed to be only 2400 m thick in the Sylhet-Chatak area of Bangladesh, 2800 m in North Cachar, and 4500 m in Tripura, while it progressively thickens towards the southeast up to 8500 m in Mizoram where the depocentre of sedimentation is believed to lie. The Oligocene Barail Formation was deposited during a major marine regression that exposed most of the 'Indian Platform' of the Bengal Basin. The Barail Formation comprises a thick sequence of medium- to coarse-grained sandstone intercalated with siltstone and shale. By Early Miocene time, a major phase of sedimentation started and huge amounts of clastic sediment were funneled into the basin from the northeast and were deposited in a rapidly fluctuating condition of deltaic to marginal marine environment that was followed by a major transgression during Early to Mid Miocene resulting in deposition of Lower Bhuban sediments. In the study area during Lower Bhuban time a delta system was prevailing from Oligocene time resulting in deposition of increased sand supply. Major delta system was prograding towards south and southwest, with sediment supply from the rising Himalaya and from Indo-Burman Ranges; sedimentation was in deltaic and open shelf environments along the basin margins. Proto-Bramhaputra River may be oriented NE-SW and N-S and the current course was only configured following Pleistocene uplift of Shillong Plateau. A considerable amount of sediment was also coming into the basin from the northwest and small deltas were building on the western side of the basin (Figure 7).

Depositional Patterns

Sand thickness derived from field traverses and drilled wells suggest the following depositional patterns for the sediments of the Lower Bhuban Formation. The deposits in the northeast are only 500-600 m around Badar pur, Hilara presumably due to limited subsidence in this area. The exposed Indian shield is located not far from here, the thickness in the Mizoram part in the east and Rokhia part towards the west shows an increase in thickness as this part of the basin was affected by tectonic loading, both from the east (Indo-Burman ranges) and the northeast (eastern Himalayas) which caused it to subside further, helping to accommodate huge thicknesses of Miocene sediments of the Surma Group (Figure 8). Trends from the lithofacies maps suggest that deltaic deposits filled the area from the east, and that the source of this sediment included the north-trending Indo-Burman ranges directly adjacent to the east and the eastern Himalayas. The sand/shale ratio has been estimated from various field traverses and drilled wells data. The highest sand/shale ratio for the Lower Bhuban Formation (2.0) is at the Narayanchara and Masimpur area in the northeast, gradually decreasing towards the south in the Chatachura and Mizoram areas. In Eastern Tripura, the ratio is higher in KBA which decreases to 0.33 in LA; further west in RKA it is again 1.33 clearly indicating different sand lobes, which is also confirmed by pressure data recorded in a few wells (Figure 9 and Figure 10). On the basis of integrated studies, different sand lobes have been worked out for the Lower Bhuban and after superimposing sand maps over structures, the following areas are identified as potential exploration areas (Figure 11):

1) Khubal Anticline: To follow up the lead of the discovery well D, the area was studied in detail. Seismic data were tied to well locations and outcrop data. Seismic reflection events corresponding close to the tops of Lower Bhuban Formation have been correlated. Time structure map at Lower Bhuban level (Figure 12, Figure 13) indicate a NW-SE trending prominent cross fault which dissects the northern plunge of the structure into two parts, and an up dip fault closure to the west of the structure. The NW-SE trending fault closure mapped to the west of the Khubal Anticline lies in the vicinity of Machhmara and Champabari synclines. The 2D seismic data acquired over Lines XX4 and XX1 was processed for Pre-stack Time migration. AVO has been used to map the possible extent of the gas producing pay sand. As the subsurface dip recorded is low, about 60 m of sand is expected to extend over a large area, hence all the separate closures in the vicinity becomes good exploratory targets.

2) Manu Syncline: Manu Syncline lies west of Champabari Syncline, in which well KHD was drilled, with the Harargaj structure in between. The seismic data indicates possible continuation of Lower Bhuban Formation towards the west in Manu Syncline. The intervening Harargaj structure (Lower Bhuban) is already proved by drilling. Line XX4 shows a possible turtleback structure within the broad Champabari low, west of which discovery well KBD is drilled. Line AA9 in the Manu area also shows similar minor

inversion/turtle back structure and a fault closure, which could be an ideal locale for entrapment. Moreover, AVO carried out in recently acquired data also indicates possible gas at the Lower Bhuban level (Figure 14).

3) Batchia-Langtarai Anticline: The entire structure is a major anticline with two doubly plunging closed structures. The northern culmination is known as the Batchia Anticline and the southern in known as Langtarai Anticline. The structures are similar to Fenchuganj and Kailash tila structures, which are major gas producers in Bangladesh. The close proximity of the anticline to other gas producing structures in West Tripura also enhances the possibility of presence of hydrocarbons in this area (Figure 15).

To test the conceived geological model, the well LN was drilled on the northern plunge of the Langtarai Anticline. It has encountered Lower Bhuban sand at the expected depth and during drilling 30% to 70% gas was recorded in MLU (Figure 16). Presently it is under production testing.

Conclusions

To follow up the huge gas discovery in Eastern Tripura, a comprehensive study was undertaken, integrating all available geological and geophysical data of Tripura, Cachar and Mizoram to understand distribution of reservoir facies and hydrocarbon accumulation patterns in the area. A detailed analysis was done and a suitable model for the depositional environment was reconstructed. Isopach, sand-shale ratio and lithofacies maps have been prepared. Based on the integrated study, some lead areas have been identified as potential future exploration targets for Lower Bhuban exploration. The model has been tested by drilling a well in one of the lead areas. Drilling has proved the occurrence of Lower Bhuban sand in the area and also the existence of hydrocarbons in the structure.

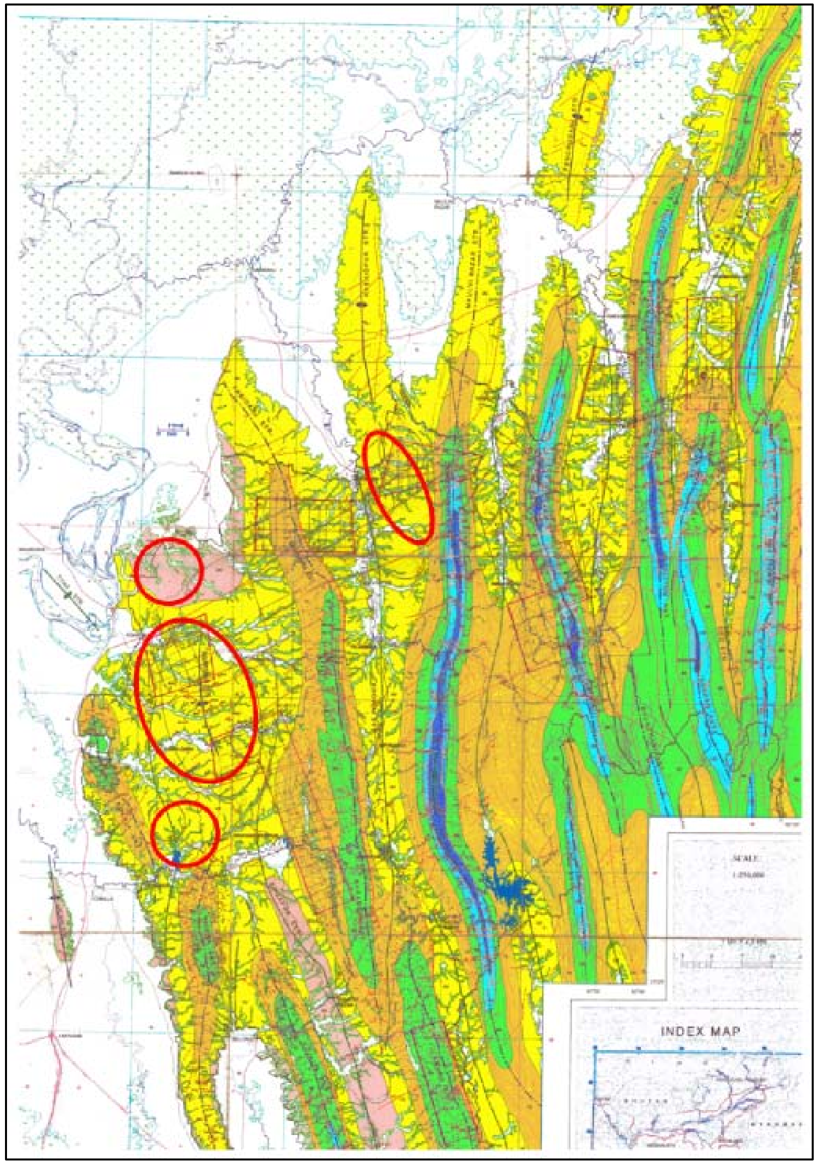

Figure 1. Geological map of Tripura.

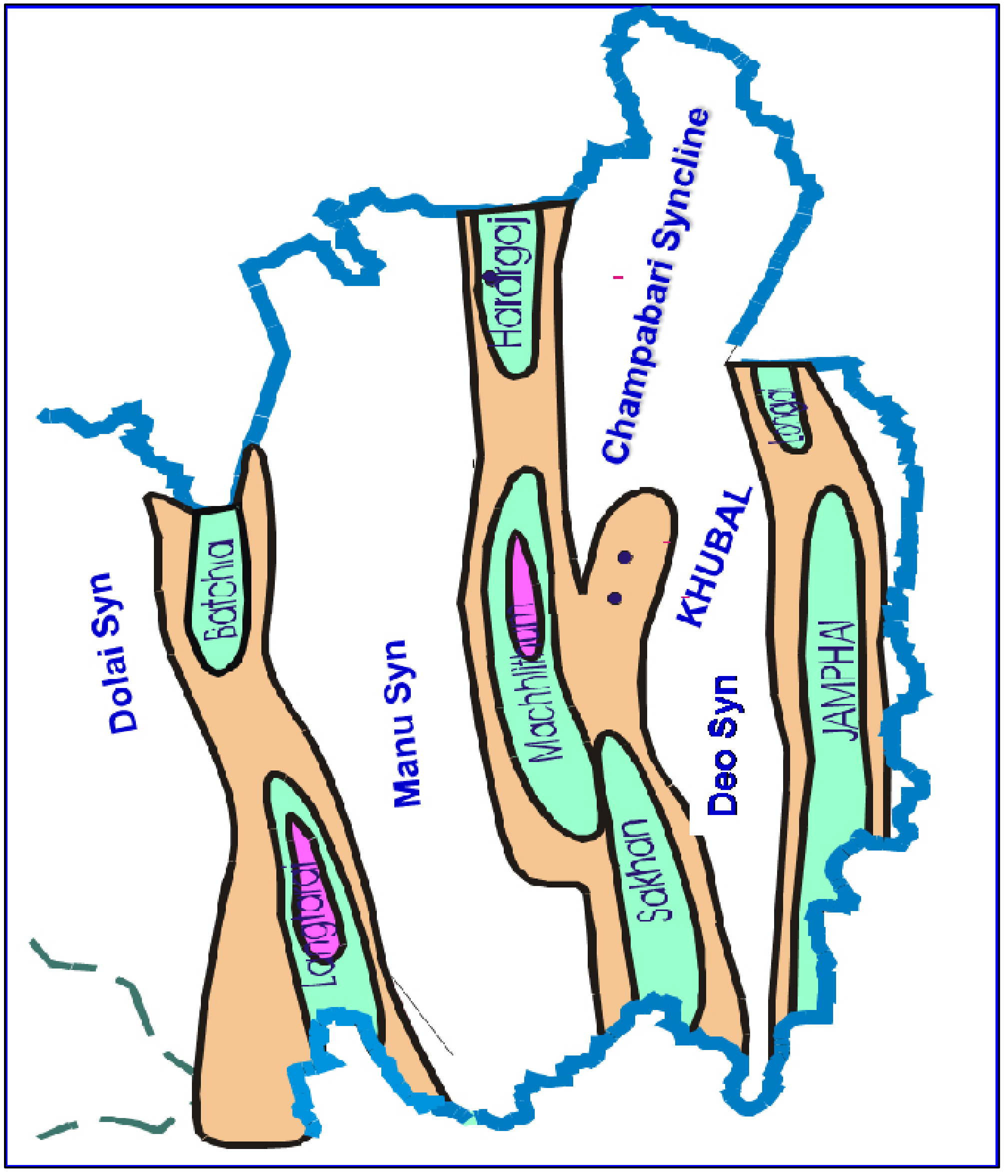

Figure 2. Structures in Eastern Tripura.

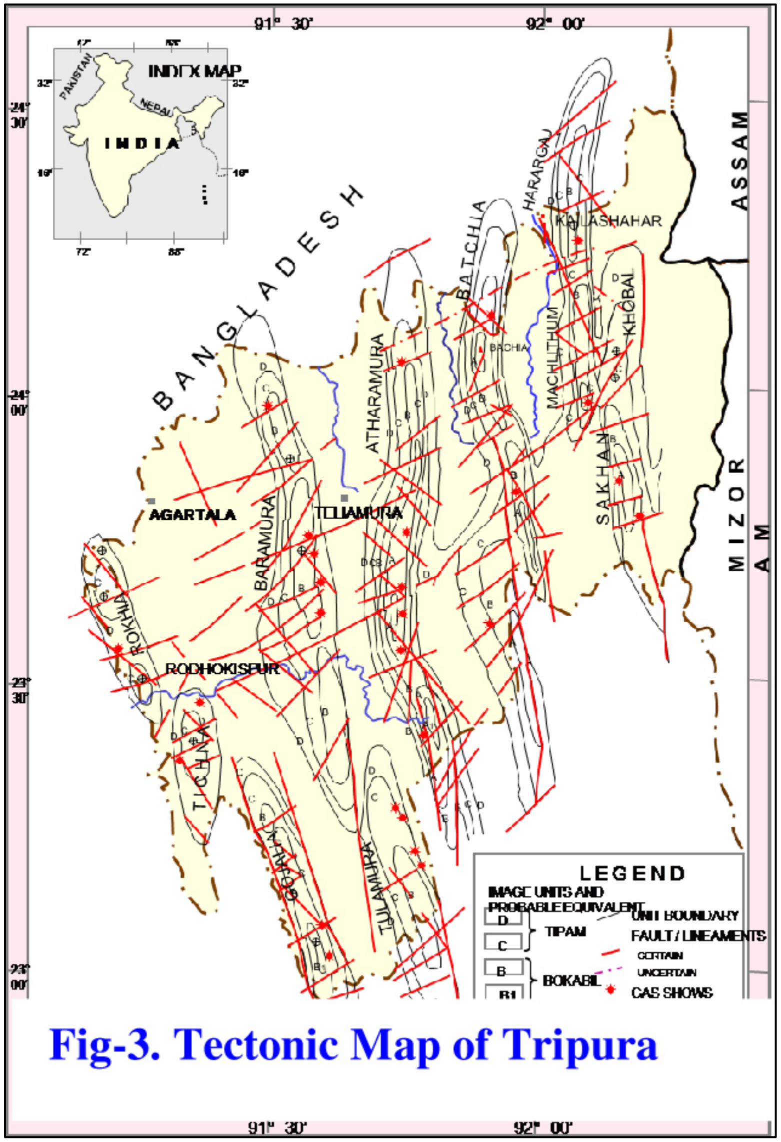

Figure 3. Tectonic map of Tripura.

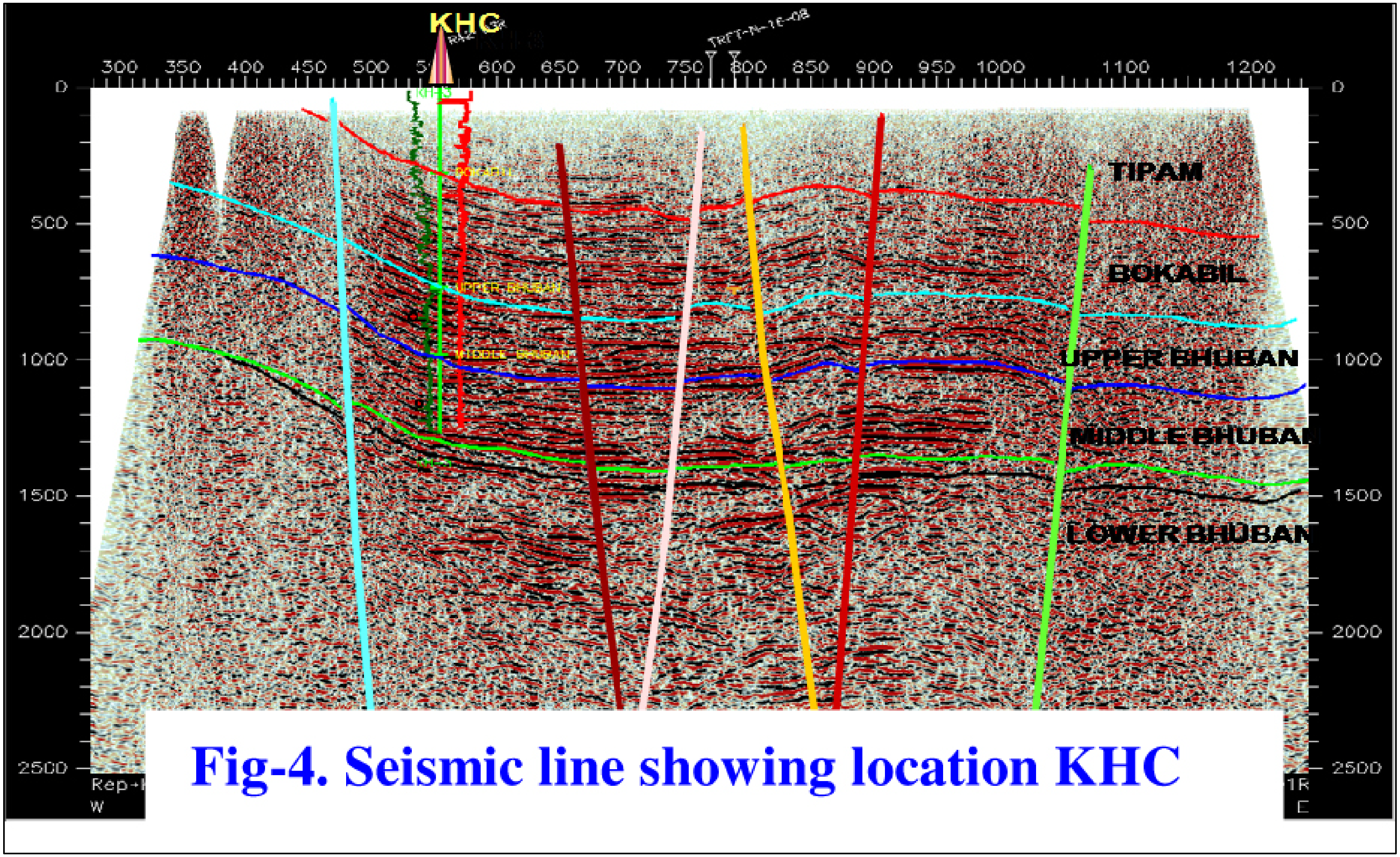

Figure 4. Seismic line showing location KHC well.

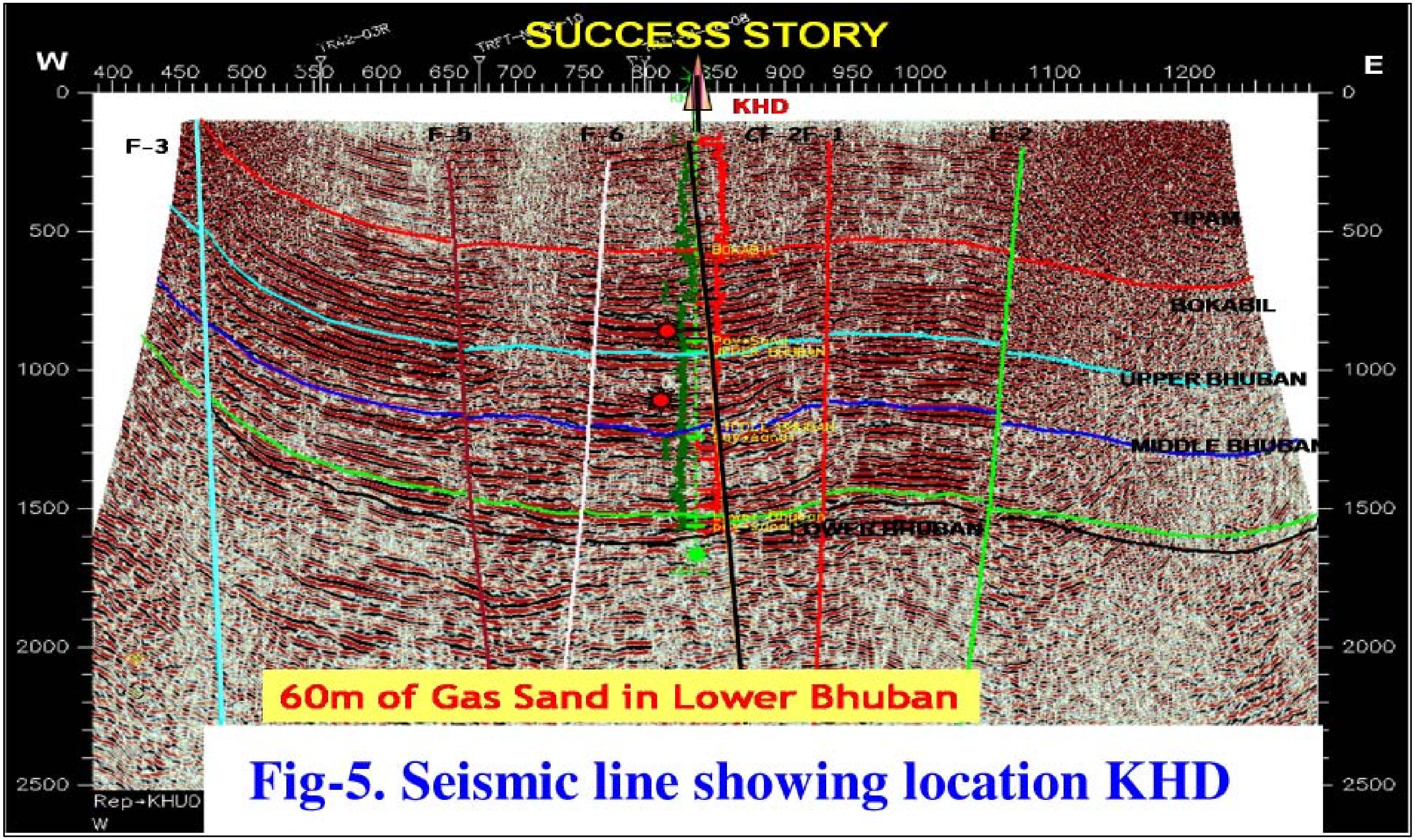

Figure 5. Seismic line showing location KHD well.

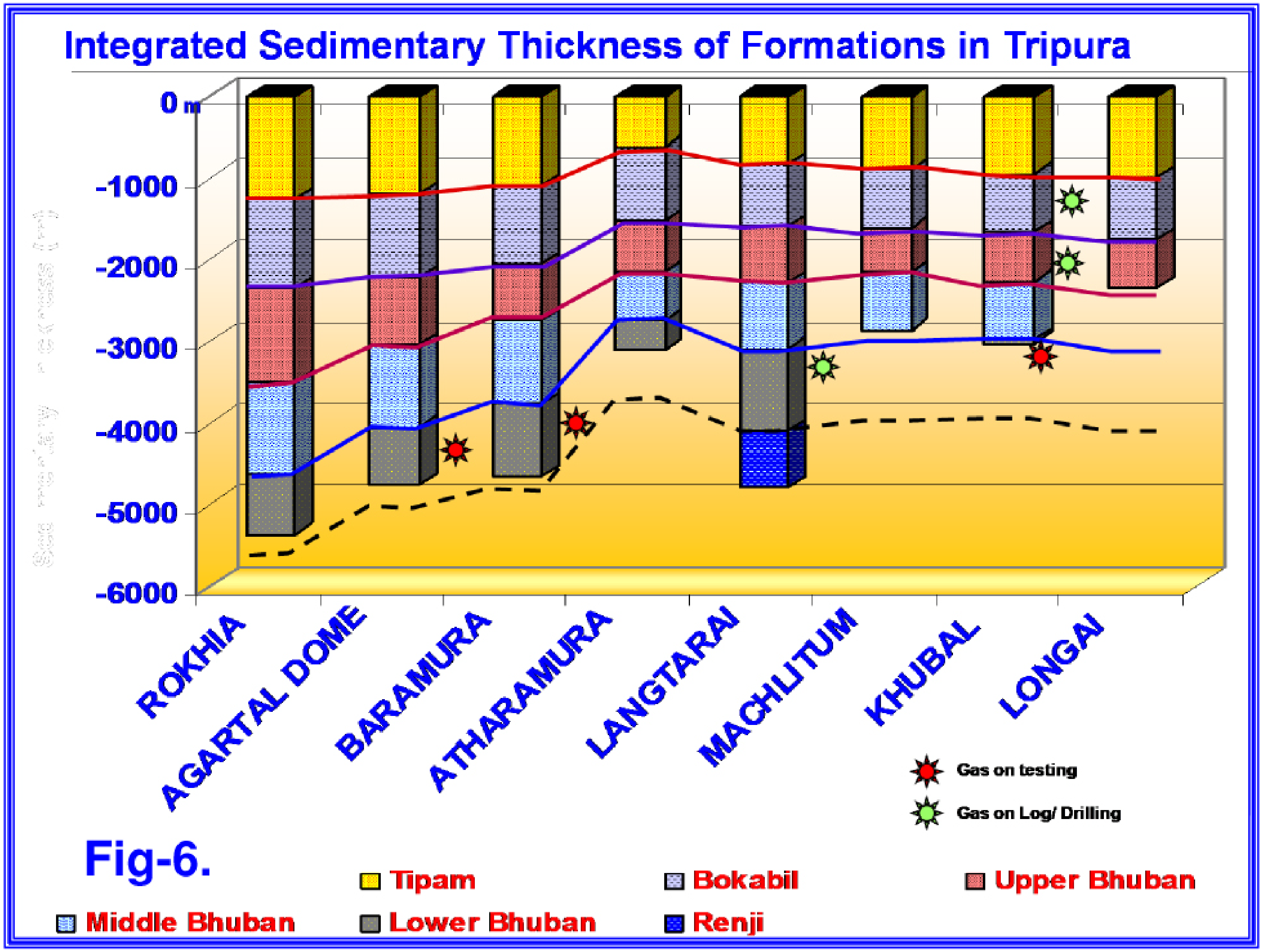

Figure 6. Integrated sedimentary thickness of formations in Tripura.

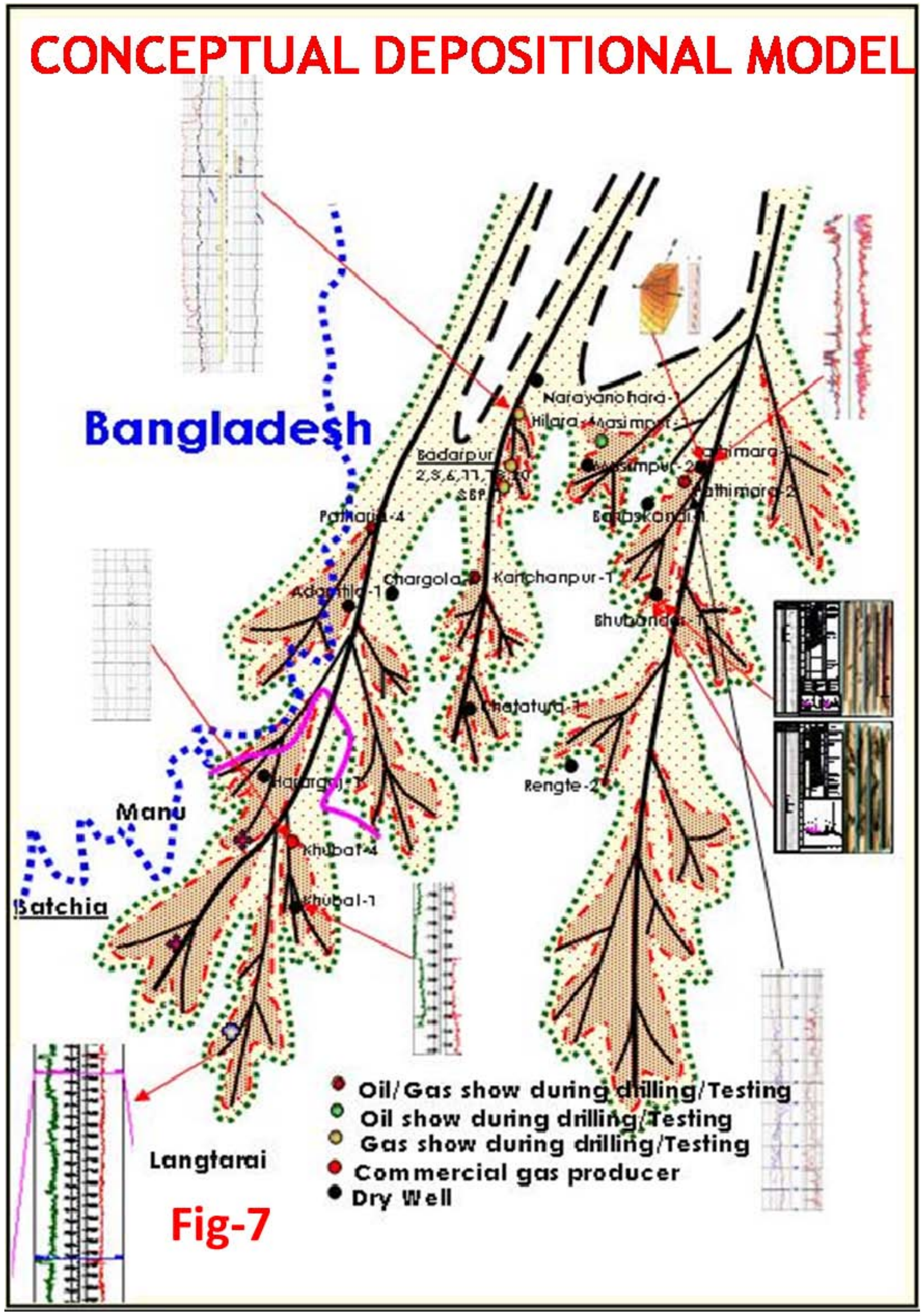

Figure 7. Conceptual depositional model.

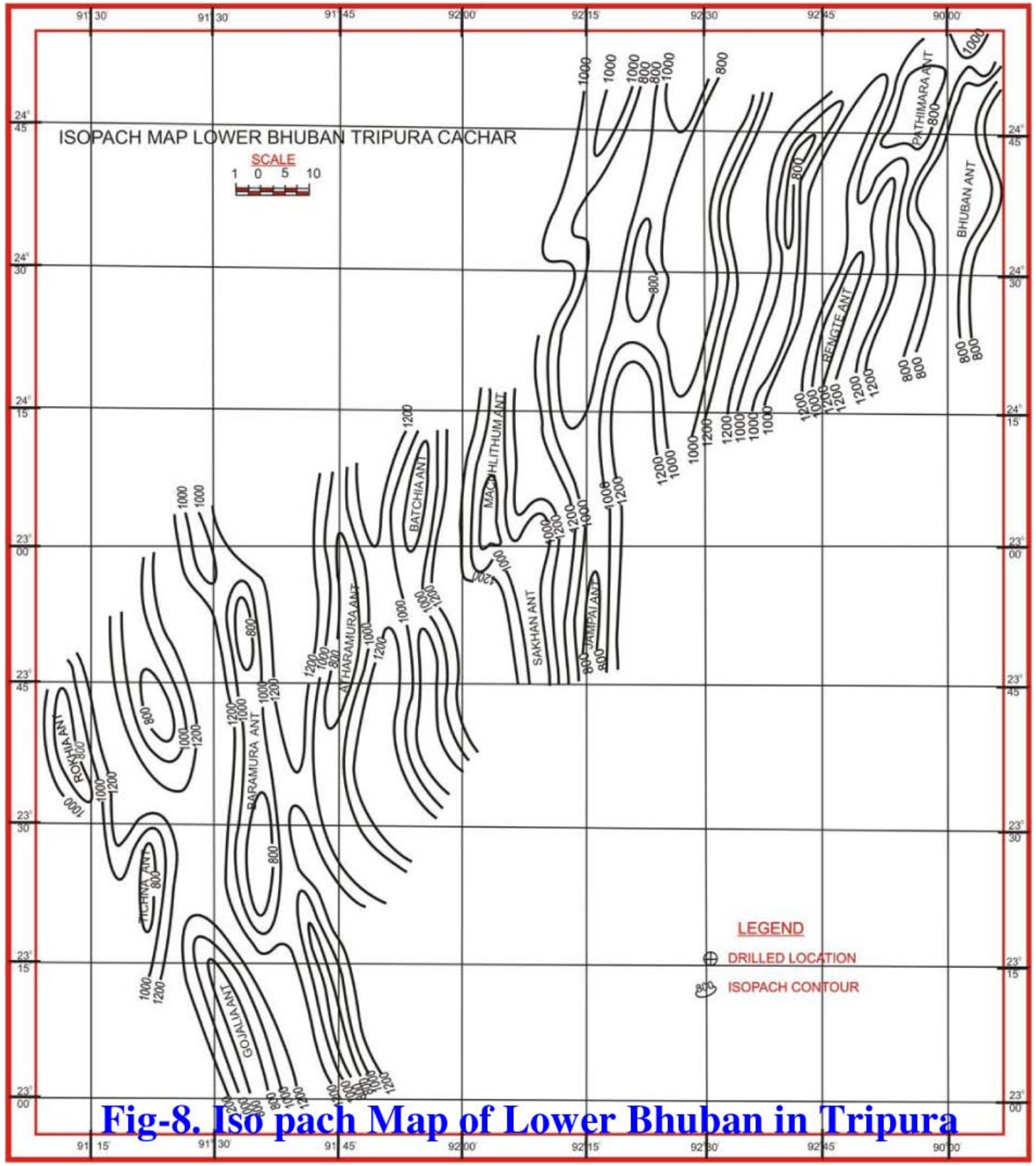

Figure 8. Isopach map of Lower Bhuban in Tripura

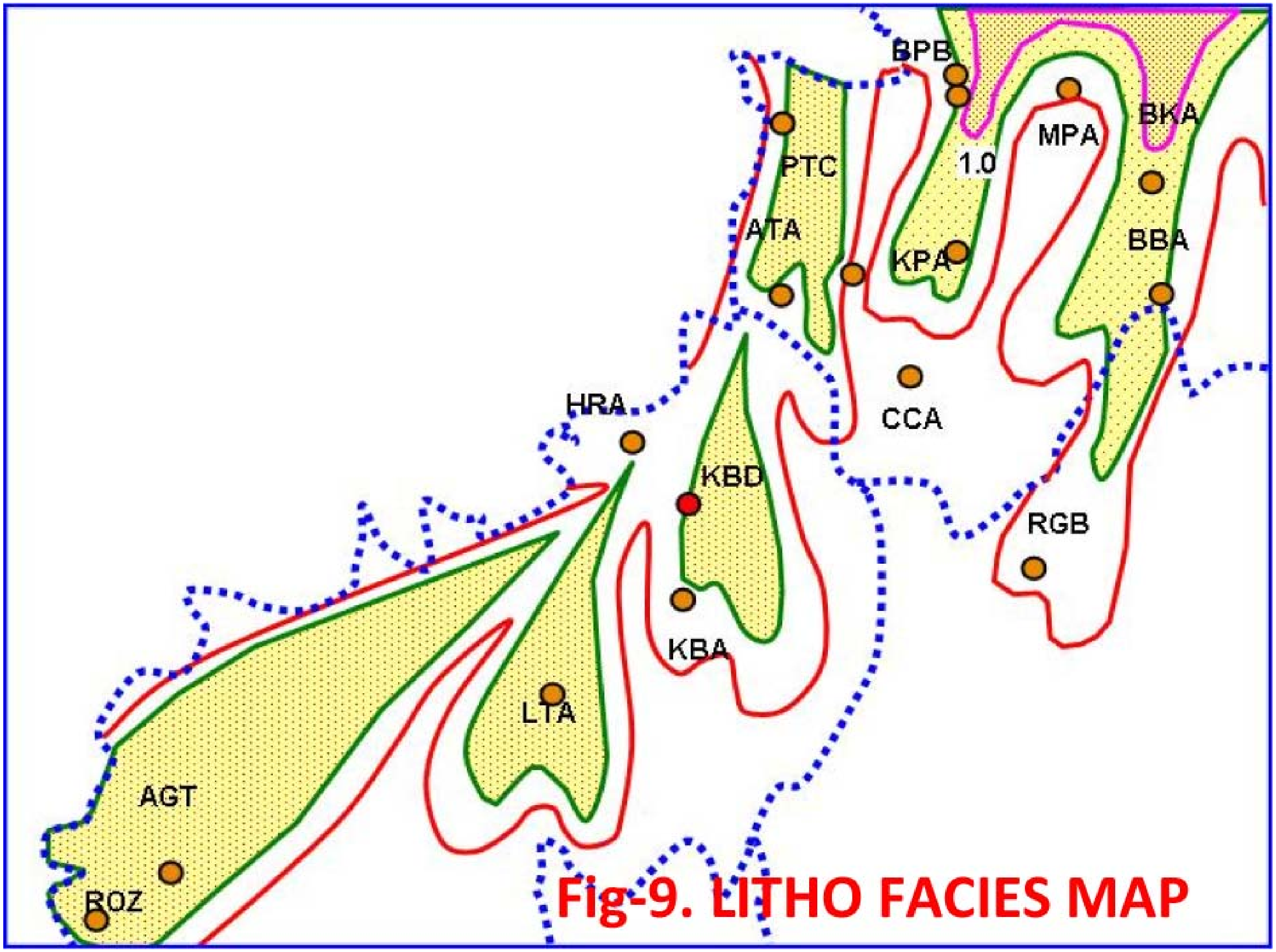

Figure 9. Lower Bhuban Formation lithofacies map.

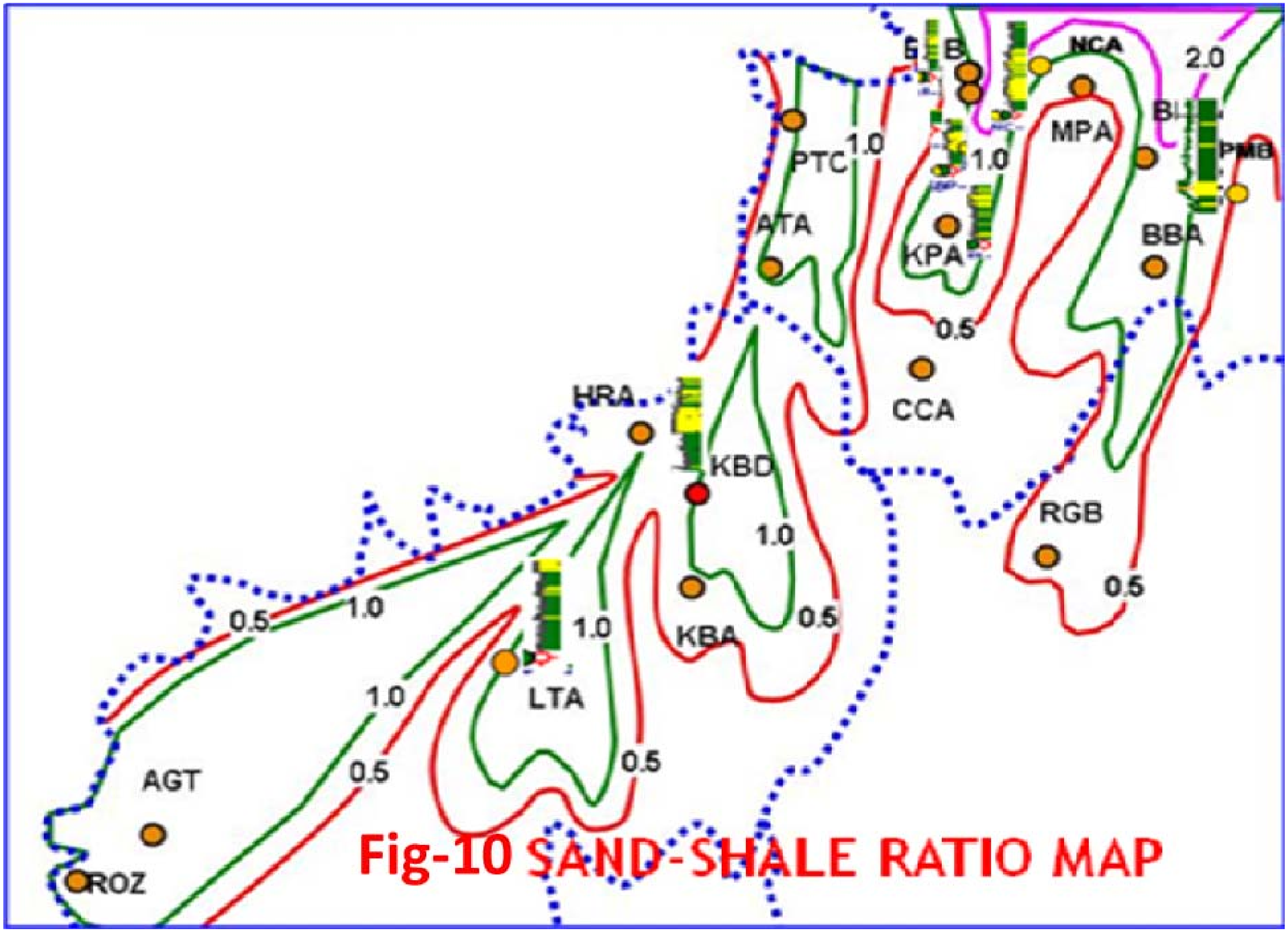

Figure 10. Lower Bhuban Formation sand-shale ratio map.

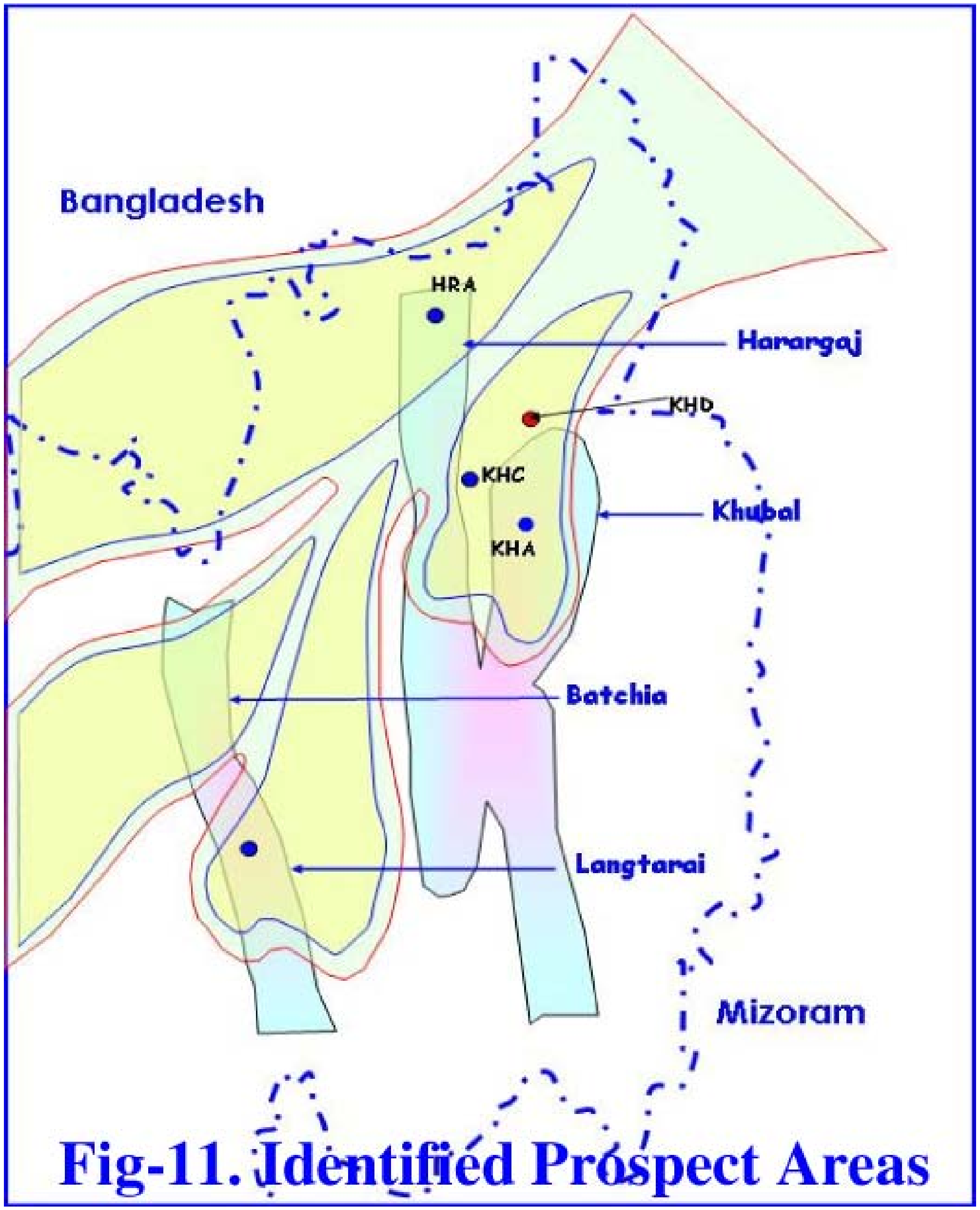

Figure 11. Identified prospect areas.

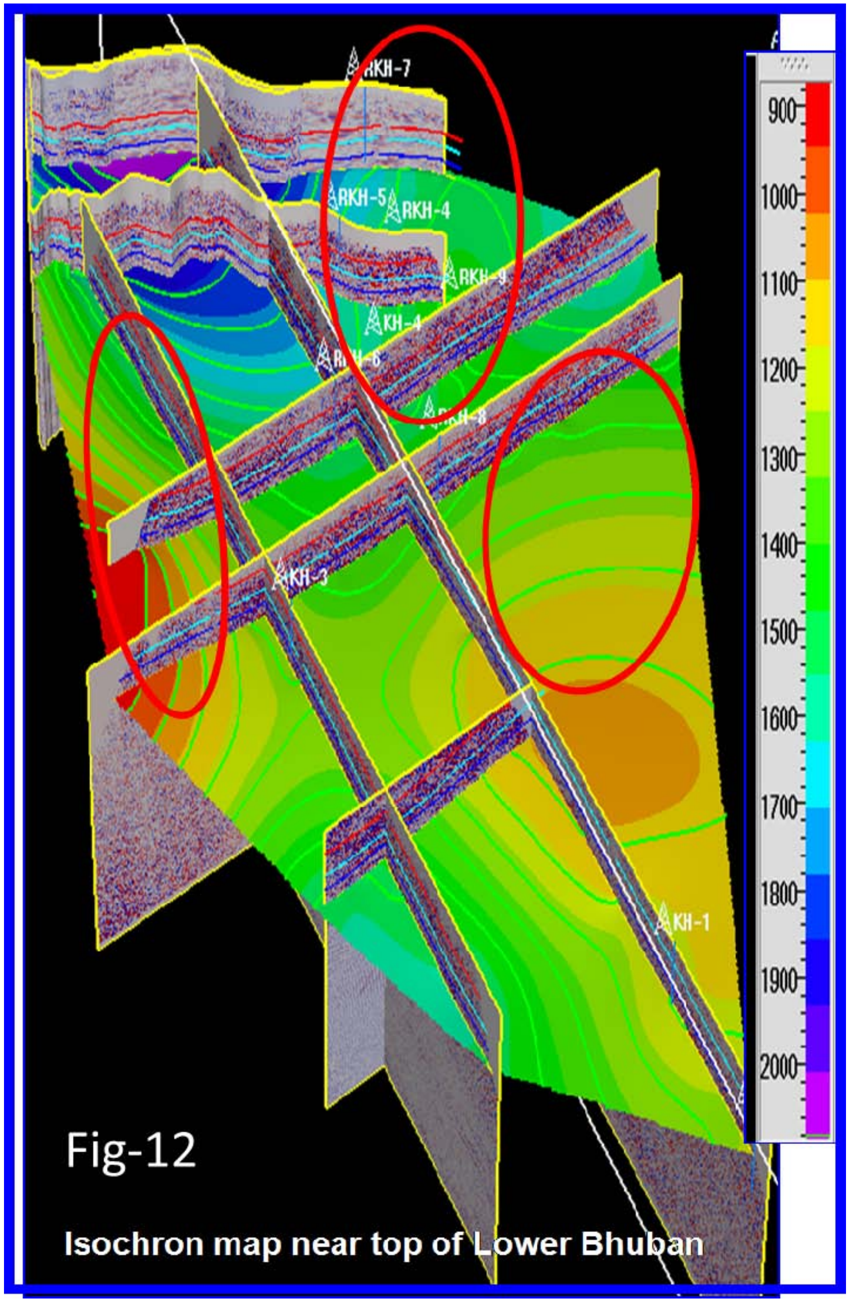

Figure 12. Isochron map near top of Lower Bhuban.

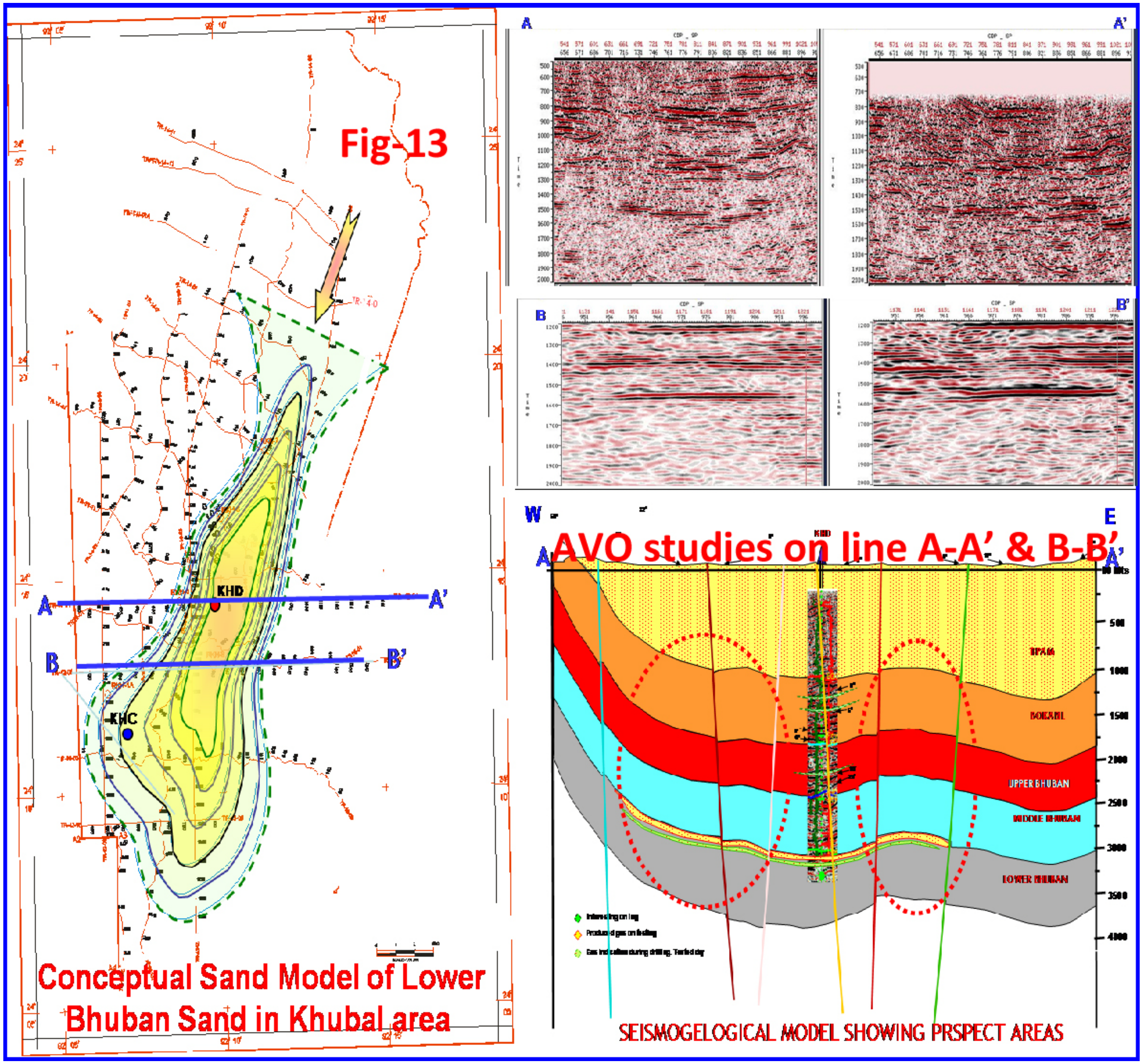

Figure 13. Conceptual sand model of Lower Bhuban sand in Khubal area.

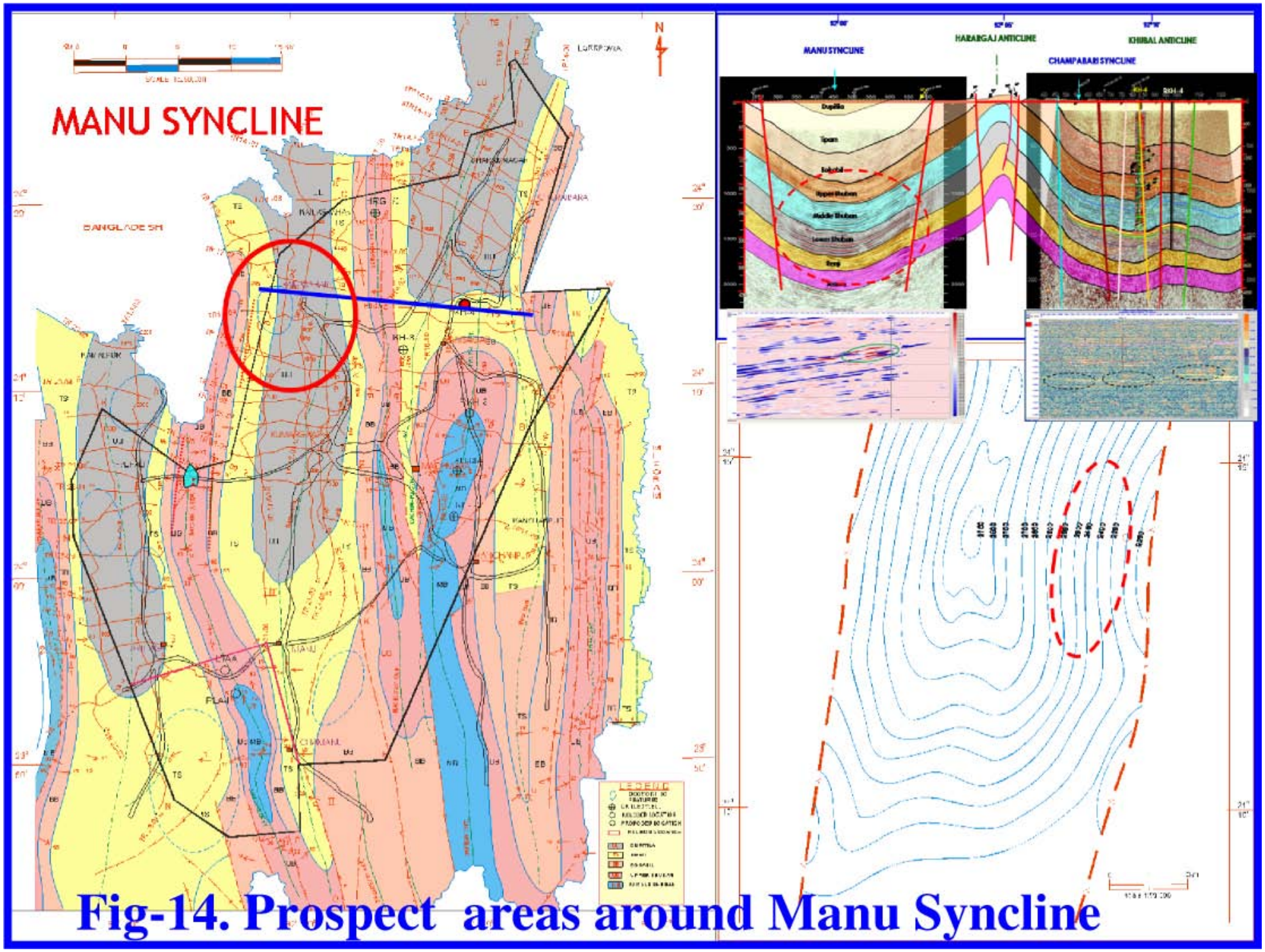

Figure 14. Prospect areas around Manu Syncline.

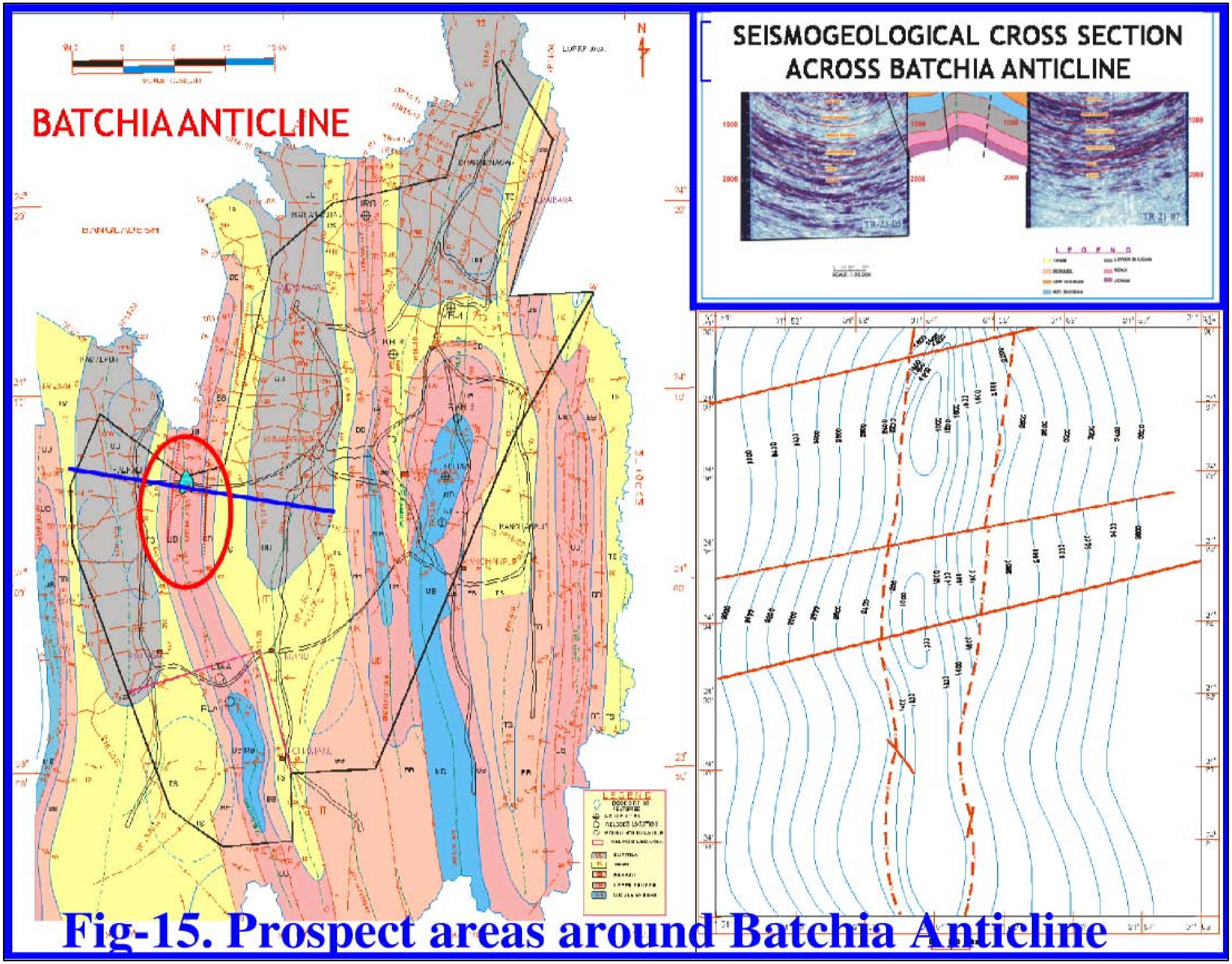

Figure 15. Prospect areas around Batchia Anticline.

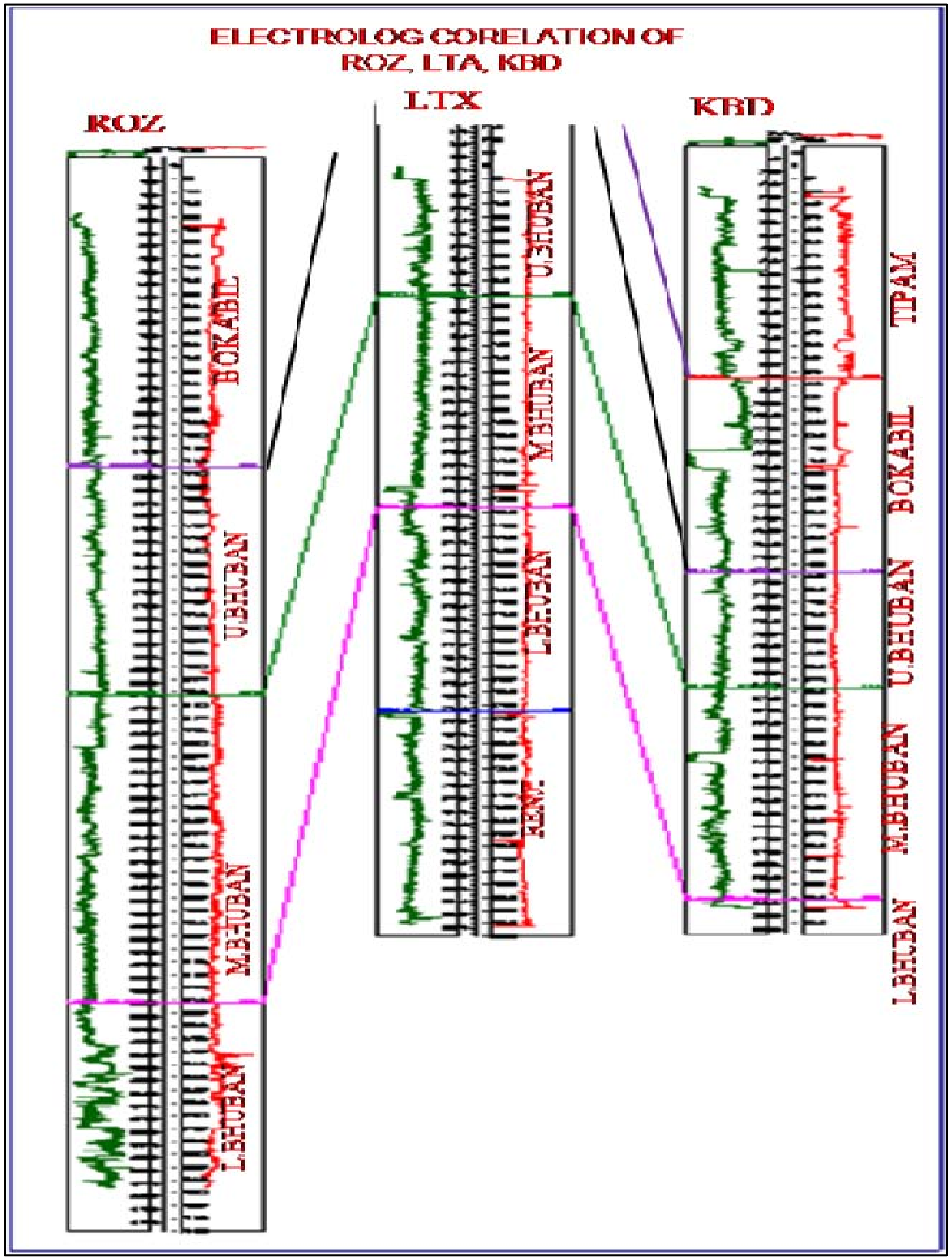

Figure 16. Electric log correlations of wells ROZ, LTA and KBD.