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Exploration in Synclinal Areas of Tripura Fold Belt, India: A Re-found Opportunity*

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Abstract

Recent exploratory successes in synclinal parts of Sundalbari and Khubal structures of Tripura Fold Belt in stratigraphic plays of Bhuban Formation of Miocene age attracts attention of the Geoscientists to think a bit unconventional hitherto being considered as risky. In structures of Tripura Fold Belt, the entrapment of gas is mainly structural and limited to anticlinal highs. Till now, the exploration was mainly limited to these highs only. But a bit deviation from the conventional anticlinal exploration, the adjacent broad flat synclines were targeted for stratigraphic traps with a bit of caution. Thin low resistivity sands belonging to a relict feature of Upper Bhuban Formation in the adjacent eastern synclinal area of Sundalbari structure produced gas @ 1,60,000 m^3/d. Similarly a sand belonging to Middle Bhuban Formation of Miocene age produced gas @ 1,45,000 m^3/d. in Khubal structure, which is also in synclinal area. These successes have come at a right time when the synclinal exploration had taken a back seat after a number of failures in synclinal areas. The thin sands embedded in thick shale sections of Bhuban Formation with small culminations have trapped hydrocarbon. The updip pinchouts in the limbs of the anticlines in adjacent synclinal areas, fault closures in plunge parts of the structures, unconformity related entrapments are the potential targets. The understanding of stratigraphic traps, their trapping mechanism has brought these successes. These discoveries have established that a significant regional potential exists in the synclinal areas of Tripura Fold Belt.

Introduction

The Tripura-Cachar Fold Belt of the Assam and Assam Arakan Basin (Figures 1 and 2) has attracted the attention of Geoscientists for almost a century. The discovery of gas in Mio-Pliocene sands in Rokhia, Agartala Dome, Gojalia, Tichna, Baramura, Kunjaban, Sundalbari and of late Tulamura and Khubal structures have proved the HC potential of the fold belt part of Tripura. The Tripura area has hydrocarbon resources of about 600 MMt (O+OEG). Till now the anticlinal highs were the main target for exploration. Due to rapid latero-vertical facies variation coupled with tectonic disturbances, targeted reservoirs in anticlinal closures sometimes give setbacks. The recent synclinal exploration has got a new vista after success of Sundalbari and Khubal structures where stratigraphic traps in flanks/synclines have proved to be prolific gas producers. The broad flat synclines between anticlines have become target for stratigraphic traps and concealed structures. This paper is an attempt to rekindle the thought process of our Geoscientific community about hydrocarbon plays, entrapment in synclines and the contemporary exploration strategy in Tripura Fold Belt.

Regional Geological Setting

The Tripura-Cachar Fold Belt represents the frontal fold-belt of Assam and Assam Arakan Basin. The belt comprises of long linear tight N-S trending anticlines separated by broad synclinal troughs. To the north the belt is bound by ENE-WSW to E-W trending fold belt associated with Dauki Transfer Fault which passes to the south of Shillong self. The intensity of folding increases from west to east and the tightly folded belt of Mizoram-Manipur, to the east separated from the Tripura-Cachar belt by Kaladan Fault. The Kaladan Fault is interpreted to be the western hinge of the Surma Sub-basin (Jokhan Ram and Venkatraman,1984). The folds decrease in intensity and amplitude towards the west and pass below the Ganges-Brahmaputra Alluvium in Bangladesh. The major anticlinal structures in the area have associated thrusts on their flanks. Regionally it is thought that the thrust fold association has its roots to a décollement surface either within the topmost part of Barail Group or within the Lower Bhubans. Gravity maps suggest a sedimentary fill of more than 15 Km in Surma sub-basin, while seismic studies have been unable to image the ‘basement’ to the sedimentary succession in the area (Kale A.S. et al., 2007)

Stratigraphy

The stratigraphy of Assam and Assam Arakan Fold Belt has been established and revised by a number of workers like Evans (1932), Mathur and Evans (1964), Dasgupta et al (1977). The first attempt to understand the sequence stratigraphy of the basin was made by Despande et al. (1993). The Tripura Cachar Fold Belt exposes different sedimentary units mainly along the narrow linear ranges formed by the anticlines. The cores of the anticlines usually expose the Bokabil or Bhuban Formations flanked by Bokabil and Tipam/Post Tipam Formations exposures. The pre-Surma sediments have not been penetrated in the subsurface and are present beyond this depth. Details of the generalized stratigraphy is given below:

Hydrocarbon Plays and Exploration Strategy

The hydrocarbon plays of some recently discovered structures have been discussed below for a logical analysis and way forward for synclinal exploration strategy till now considered risky.

Sundalbari Structure

Sundalbari Structure was in the news for discovery of gas with well SD#DD in thin sands belonging to a relict feature of Upper Bhuban Formation in the adjacent eastern synclinal part of the main anticlinal high. This discovery has given a new dimension to synclinal exploration in this area. The sand produced gas @ 1,60,000 m^3/d.

Hydrocarbon Plays and Entrapment in Sundalbari Structure

Sundalbari Structure is a separate fault closure in northern plunge of Tichna Anticline (Figure 3). Time Structure Map close to Upper Bhuban Formation shows that the structure is bound by two reverse faults F1 and F2. The northern plunge of the anticline is dissected by a number of NNE-SSW trending strike slip faults (CF1, CF2, CF3) which have compartmentalized the structure to a number of fault blocks.

A *relict feature* is clearly visible in the seismic section AA' below MFS (Figure 4) in the eastern synclinal part of Sundalbari Structure. The relict feature has been mapped as a small amplitude culmination around well SD#DD which can be observed in the time structure map (Figure 5). This relict feature is interpreted as an erosional feature which has arenaceous bands with claystone/shale drapes which act as an effective seal and has trapped hydrocarbons. The arenaceous bands are the low resistivity sands (Figure 6) which have trapped hydrocarbons. So exploration should be for similar relict features/stratigraphic traps in the flat inter-structural synclines. The synclines between Rokhia Anticline (Konaban-Maniyakanagar-Sonamura) and Agartala Dome, Gojalia and Tulamura, Tichna-Gojalia and Baramura etc. should be probed for similar features with 3-D seismic studies.

Sundalbari Structure is in the northern plunge part of Tichna Field and is structurally down w.r.t nearby main Tichna Anticline, the commercial gas production from two Upper Bhuban sands of Miocene age in SD#BB has proved that the structurally lowest fault blocks of Sundalbari Structure have also suitable hydrocarbon entrapment condition in northern most plunge part of structure. These sands pinch out in up-dip direction close to CF2 and absent in SD#AA which is devoid of hydrocarbons. Here the entrapment is a case of *updip pinchout*. This type of entrapment can be visualized in plunge parts of other anticlines like Konaban, Baramura, Tulamura etc. particularly the northern plunge parts in vicinity of Sylhet Kitchen, further north in Bangladesh.

Kunjaban Structure

Kunjaban Structure got its prominence in the year 2007 with significant exploratory lead in KU#A. An Upper Bhuban Sand of Miocene age, Pay-II produced gas @ 2,25,000 m^3/d. In 2008 in well KU#B, further down dip an Upper Bhuban Sand of Miocene age, Pay-I produced gas @ 53,664 m^3/d with water @ 140 m^3/d. Another sand Pay-IV belonging to middle Bhuban Formation of Miocene age produced gas @ 86,350 m^3/d with negligible water in KU#B.

Hydrocarbon Entrapment in Kunjaban Structure

Kunjaban Structure is a concealed structure in northern plunge of Agartala Dome. It is separated from Agartala Dome by a NE-SW trending cross fault F1 (Figures 7 and 8) and cross fault F2 separates well KU#B from KU#A. A separate culmination in the same axial trend is observed around KU#B. From the log correlation profile and sand isolith maps (Figures 9, 10, and 11), it can be observed that Pay-I is present in well KU#B and gas bearing. It is absent in KU#C and its equivalent sands are found to be water bearing in structurally higher KU#A and AD#X. Similarly it can be observed that Pay-II is present in well KU#A and gas bearing and its lower unit is continuous in AD#X as water bearing but upper unit is absent. It is also absent in KU#C and KU#B. The schematic diagram in Figure 12 shows that in NNW direction of Agartala Dome, there are three culminations separated by F1 and F2.The structurally lowest culmination around well KU#B is gas bearing where as in the structurally highest northern plunge part (Figures 7 and 8) the equivalent sands in AD#X are water bearing. Similarly the culmination around well KU#A is gas bearing which are structurally below the equivalent water bearing sands of well AD#X. The preferential charging of the sands through fault conduits/permeable layers has controlled the entrapment. The top part of the structurally lower culminations up to the spill point has been charged with gas while the structurally higher sands in AD#X are water bearing with very gentle dip without any culmination. The charging of the sands is clearly depicted in Schematic Diagram (Figure 12). Log motif of Pay-I (Figure 13) in well KU # B, a thin rim of gas is observed at the top, otherwise the major part of the sand is water bearing. This is also an example of *updip pinchout* close to F2 in the plunge part. The sand pinches out in SSE direction close to F2 and charged mostly with water with a thin rim of gas at top. The sand may be totally charged with hydrocarbons in structurally higher axial part. From sand isolith maps (Figures 10 and 11) another inference is drawn, the portion of the sand away from the axial part are mostly water bearing except *the updip pinchout* situations in limbs and plunge parts. The super charged water bearing layers have encroached the reservoirs with fault conduits/permeable layers which result in early breakthrough of water while on production. Thus clear identification of the axial part and identification of updip pinchouts is very much necessary. So further towards north, in northern plunge part of Kunjaban Structure, similar type of hydrocarbon entrapment in stratigraphic traps cannot be ruled out.

Khubal Structure

Gas discovery in Khubal Structure in eastern Tripura was the biggest news in the year 2009. A 40 m thick sand belonging to Lower Bhuban Formation in well KHU#A produced gas @ 1,54,000 m^3/d through 8 mm bean. It resulted in accretion of a good chunk of gas reserves for the structure and gave a boost to exploratory efforts after failure in three wells.

Hydrocarbon Play and Entrapment in Khubal Structure

Khubal Structure lies east of the Champabari Syncline in eastern part of Tripura east of Machlitum Anticline and Haraganj Structure is NNW part of it. It can be observed in seismic section XX-XX' (Figure 14) that the entrapment is in the synclinal part west of the anticlinal high truncated with a reverse fault to the east. This is also another example of updip pinchout/stratigraphic trap in a syncline.

Barjala Structure

Based on the recently acquired 3-D volume, a new structure called “Barjala” (Figure 15) has been mapped in SE direction of Agartala Dome as a concealed structure. The SE extension of Agartala Dome looks to be much bigger than the earlier conceptualized model. The structure is divided into two parts i.e. Northern and Southern part by a prominent cross fault. This is another example of “small amplitude” concealed structures unidentified so far. The bigger concealed structures like Agartala Dome have been explored. Now it is time to identify small and smaller amplitude concealed structures in the synclines with aggressive 3-D acquisition.

Discussion

Tripura Fold belt has drawn special attention of the Geoscientists with a recent series of discoveries like Kunjaban, Sundalbari, Tulamura and Khubal structures. The structures discussed above are a few selected ones to discuss about their hydrocarbon plays. But there are a number of structures which have evaded the exploratory effort because of gaps in data acquisition due to difficult logistics, environmental problems, etc. For example, except central culmination, the entire Baramura Structure is still unexplored. The SW concealed Baramura western culmination needs attention. Recent discovery of gas in northern plunge part of Tulamura Anticline in a shallow sand has established its prospectivity both for shallow and deeper prospects. Identification of Barjala Structure in southern synclinal part of Agartala Dome is a reminder that similar concealed structures can be searched for in the flat undisturbed synclinal areas. The synclinal exploration has been taken up aggressively from 2007 onwards with drilling of SD#DD with success. Of course, a number of setbacks have been encountered in synclinal exploration for stratigraphic traps in Gojalia, Sundalbari, and Agartala Domes. But these failures should not deter our exploratory efforts in the structures. For example in Khubal Structure, initially three wells eluded us success with little gas shows but the fourth well had a giant success which is also in the flank. Another observation is that almost in all anticlines like Rokhia, Kunjaban, Sundalbari, Tulamura, and Gojalia the northern plunge parts are hydrocarbon bearing irrespective of their structural position. The reason may be its proximity to Sylhet Kitchen in Surma Basin further north in Bangladesh. So far the Badarpur hydrocarbon play which was discovered way back in 1932 could not be traced in eastern part of Tripura. So the understanding of hydrocarbon plays like updip pinchouts in synclinal areas, sealing fault closures in plunge parts even below GWC, unconformity related entrapments, and concealed “small amplitude” structures in flat synclines should be the main targets with a logical and synergic approach.

Conclusions

- Relict features or similar stratigraphic traps in the *synclinal part* of structures of Tripura Fold Belt should be the exploration target after the Sundalbari Discovery in the synclinal part. The synclines between Rokhia Anticline (Konaban-Maniyakanagar-Sonamura) and Agartala Dome, Gojalia and Tulamura, Tichna-Gojalia and Baramura etc. should be probed for similar features with aggressive 3-D seismic studies.

- Updip pinchouts and fault closures in the rising flank of anticlines or *plunge parts* of structures should be probed after success in structurally lower plunge parts of Kunjaban and Sundalbari structures. These types of entrapments can be visualized in the plunge parts of other Anticlines like Konaban, Baramura, Tulamura etc. particularly in the northern plunge parts in the vicinity of Sylhet Kitchen, further north in Bangladesh.

- Multiple GWCs observed in different culminations in the plunge part of structures like Kunjaban Structure necessitates to re-think about the entrapment and going to the lower concealed structures for more hydrocarbons.

- "Small amplitude" concealed structures like Barjala Structure should be identified in flat synclines with aggressive 3-D campaigns for exploration.

- Observations in this study advocate the fact that a significant regional hydrocarbon potential exists in synclinal areas of Tripura Fold Belt.

Acknowledgement

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Figure 1. Geological Map of Tripura.

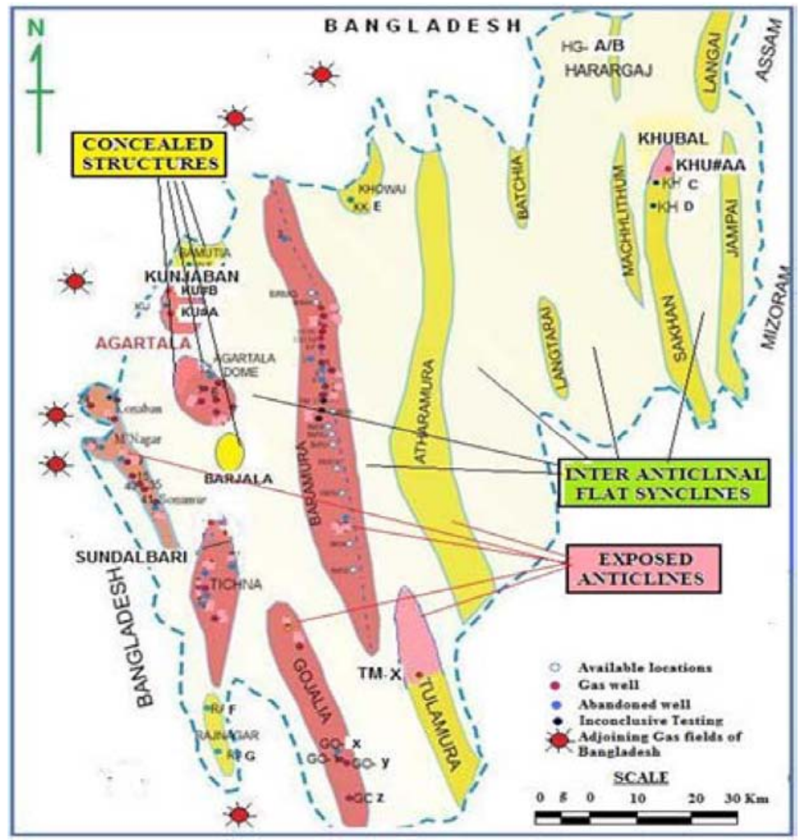

Figure 2. Structures of Tripura Fold Belt.

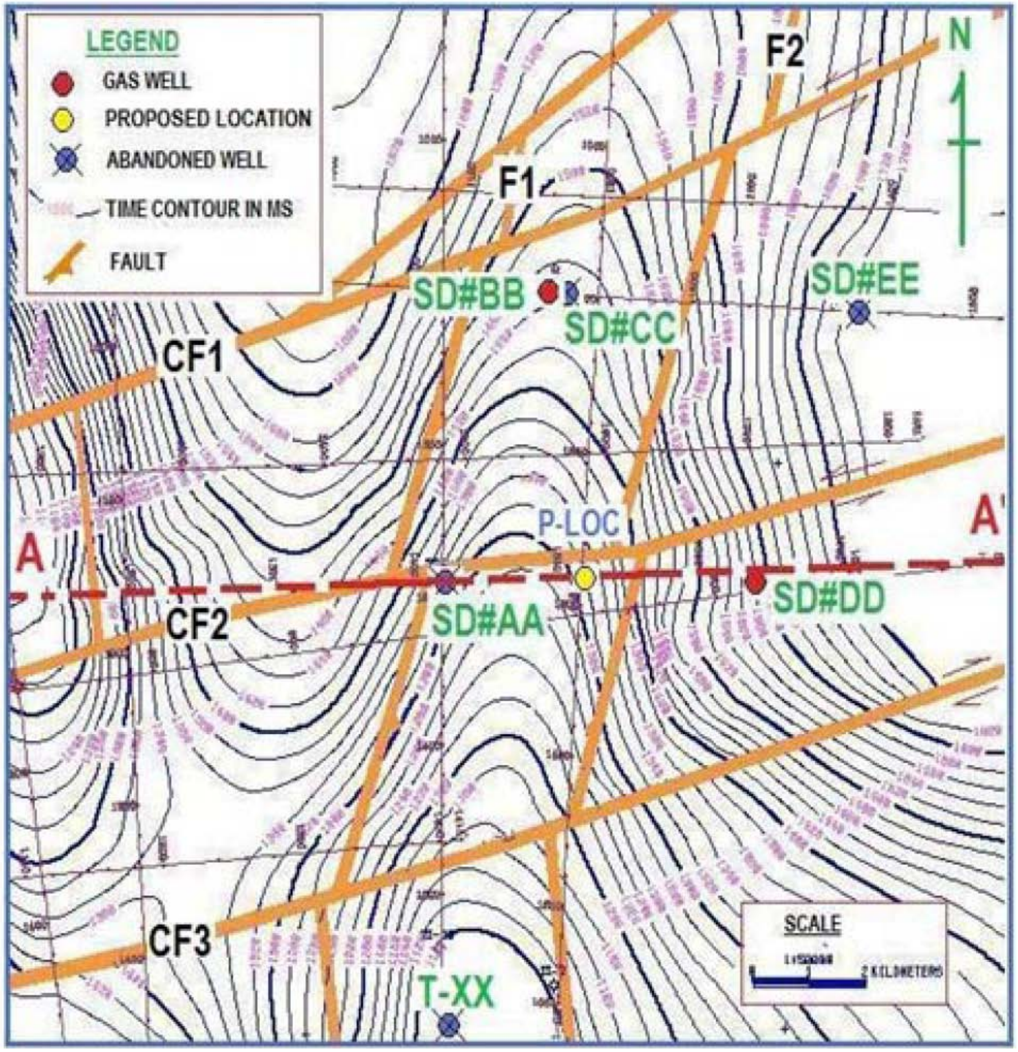

Figure 3. Time Structure Map close to Upper Bhuban Formation (MFS) in Sundalbari Structure.

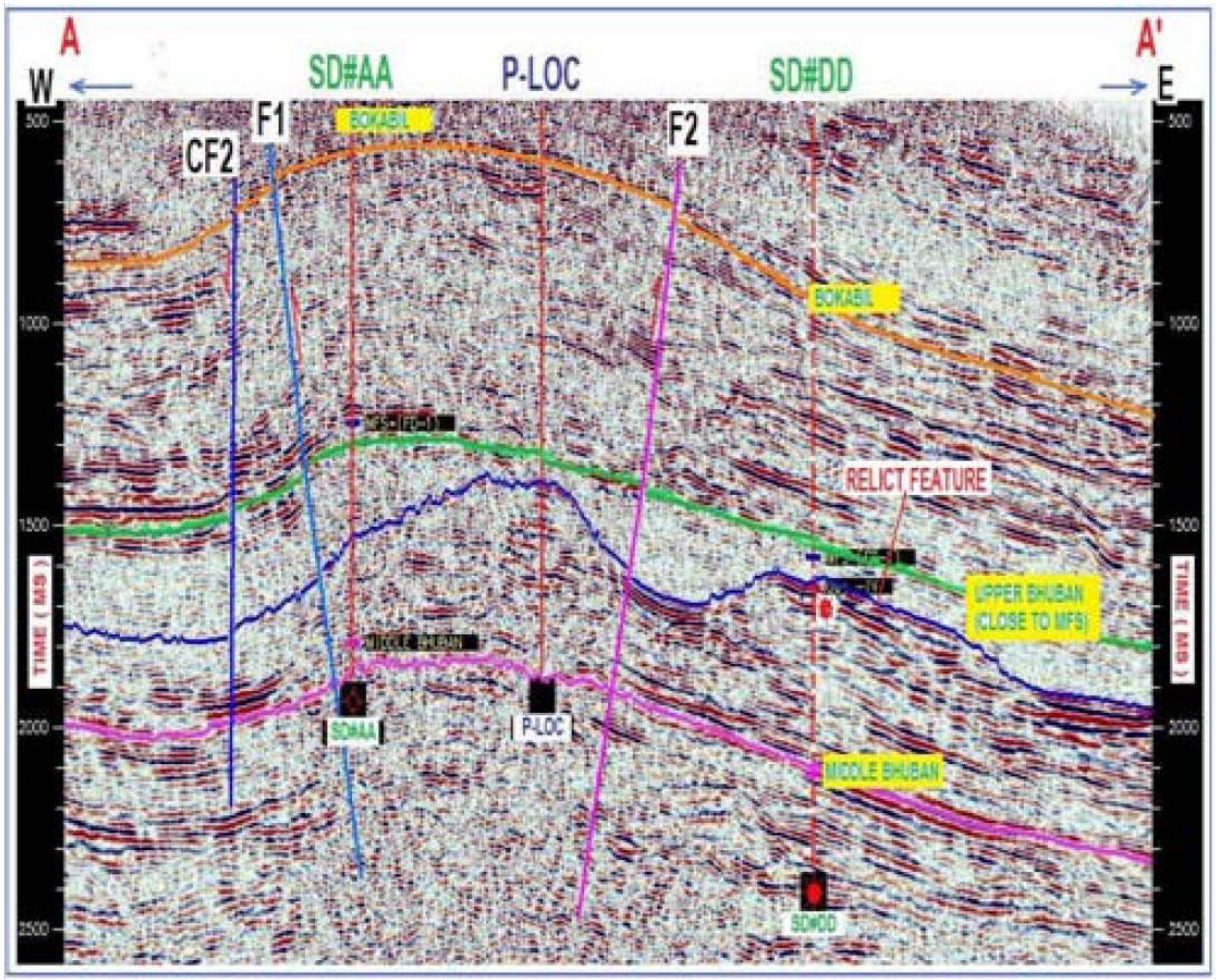

Figure 4. EW Dip Seismic section AA' showing relict feature in eastern synclinal part of Sundalbari Structure which has proved entrapment of hydrocarbon.

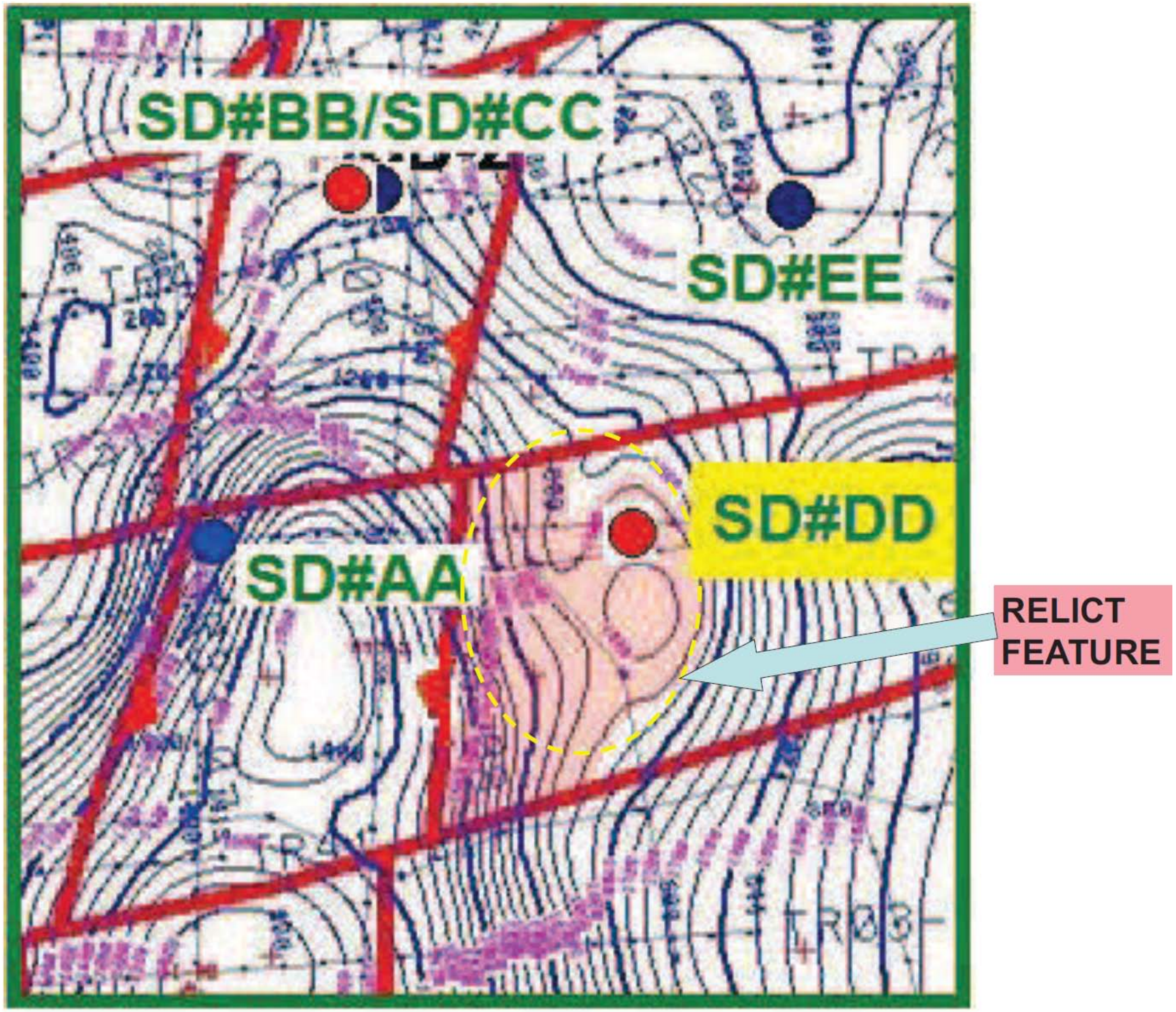

Figure 5. Time structure map of the relict feature in eastern synclinal part of Sundalbari -Structure.

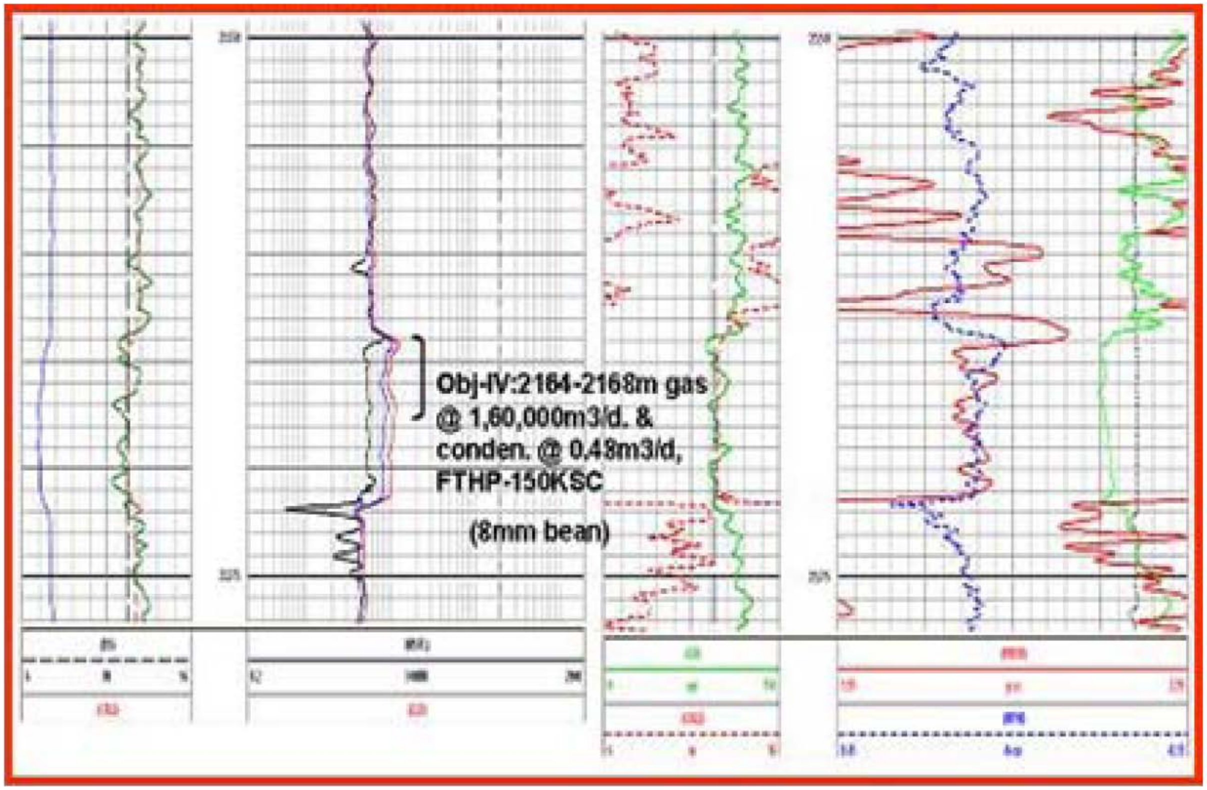

Figure 6. In well SD#DD, sand belonging to the relict feature in the adjacent eastern syncline of Sundalbari anticline produce gas @ 1,60,000 m^3/d.

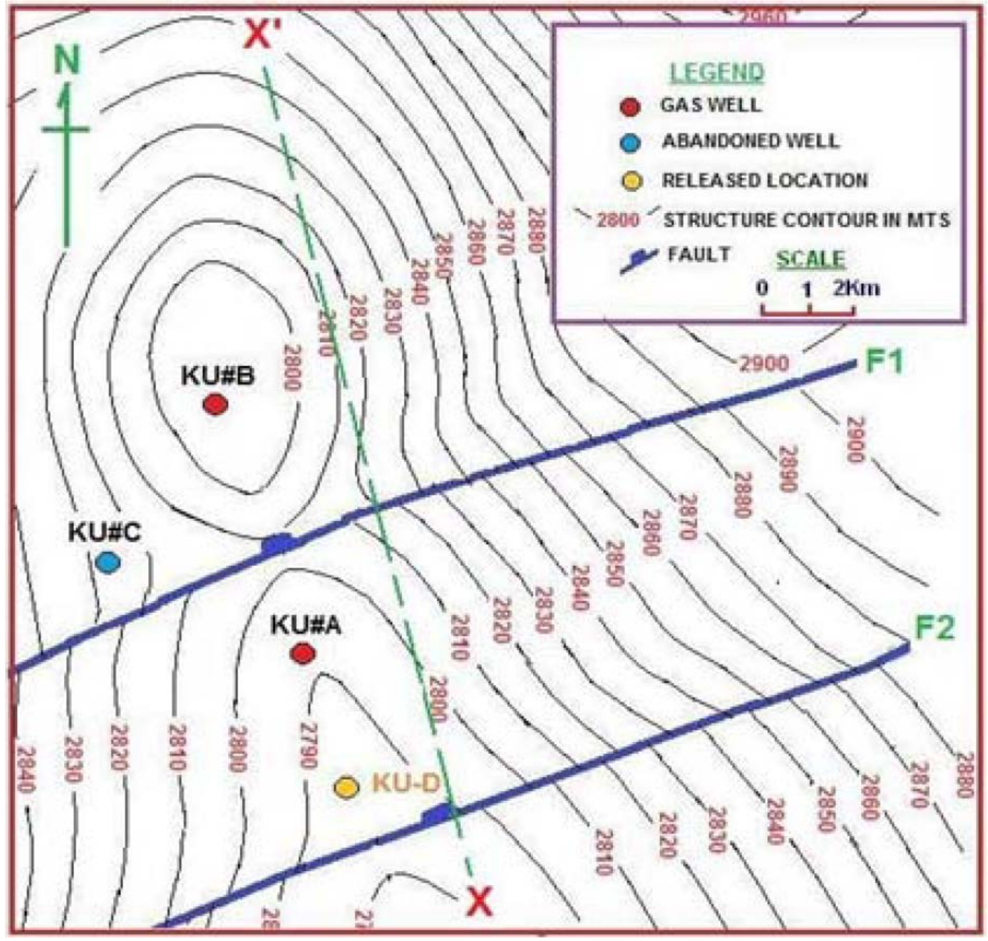

Figure 7. Structure Contour Map close to Middle Bhuban top, Kunjaban Structure.

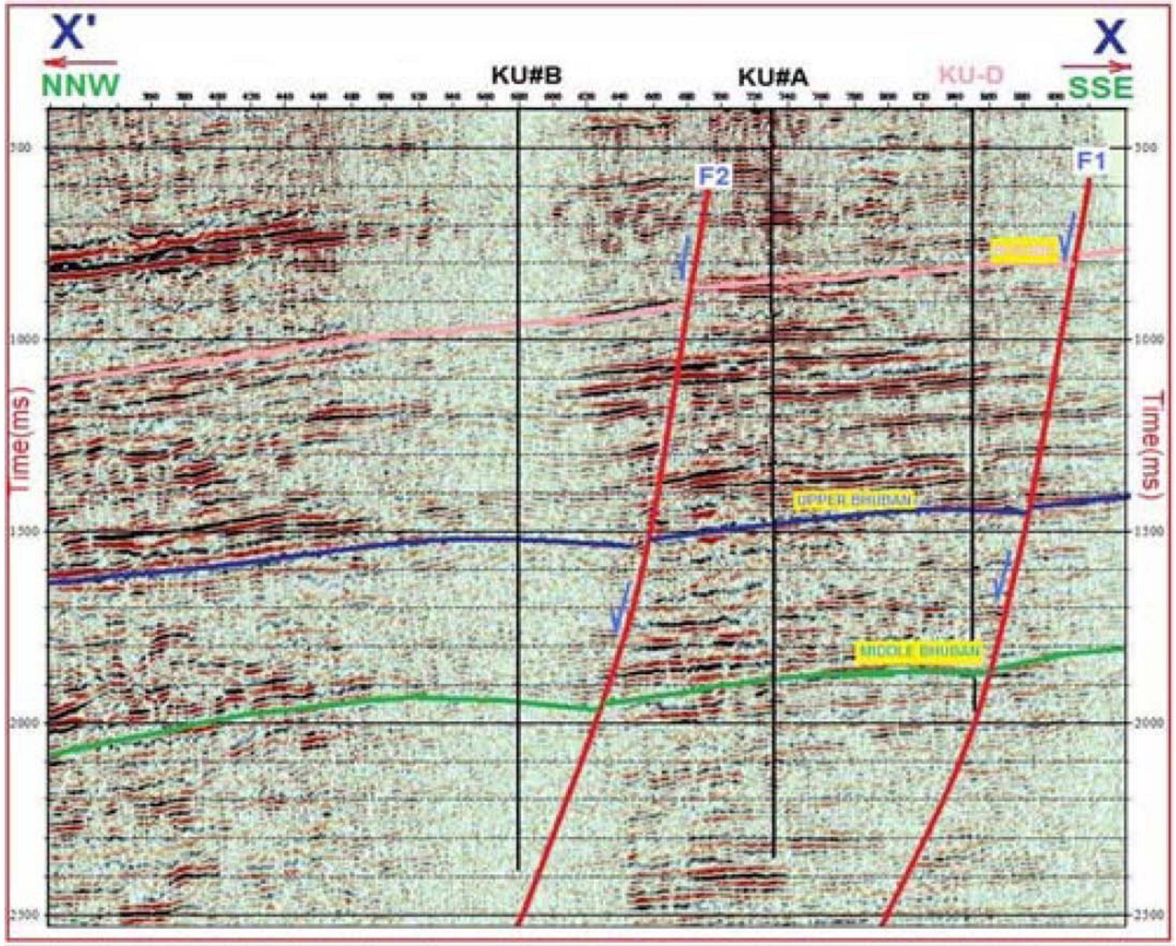

Figure 8. Seismic section XX' showing northern plunge part of Kunjaban Structure.

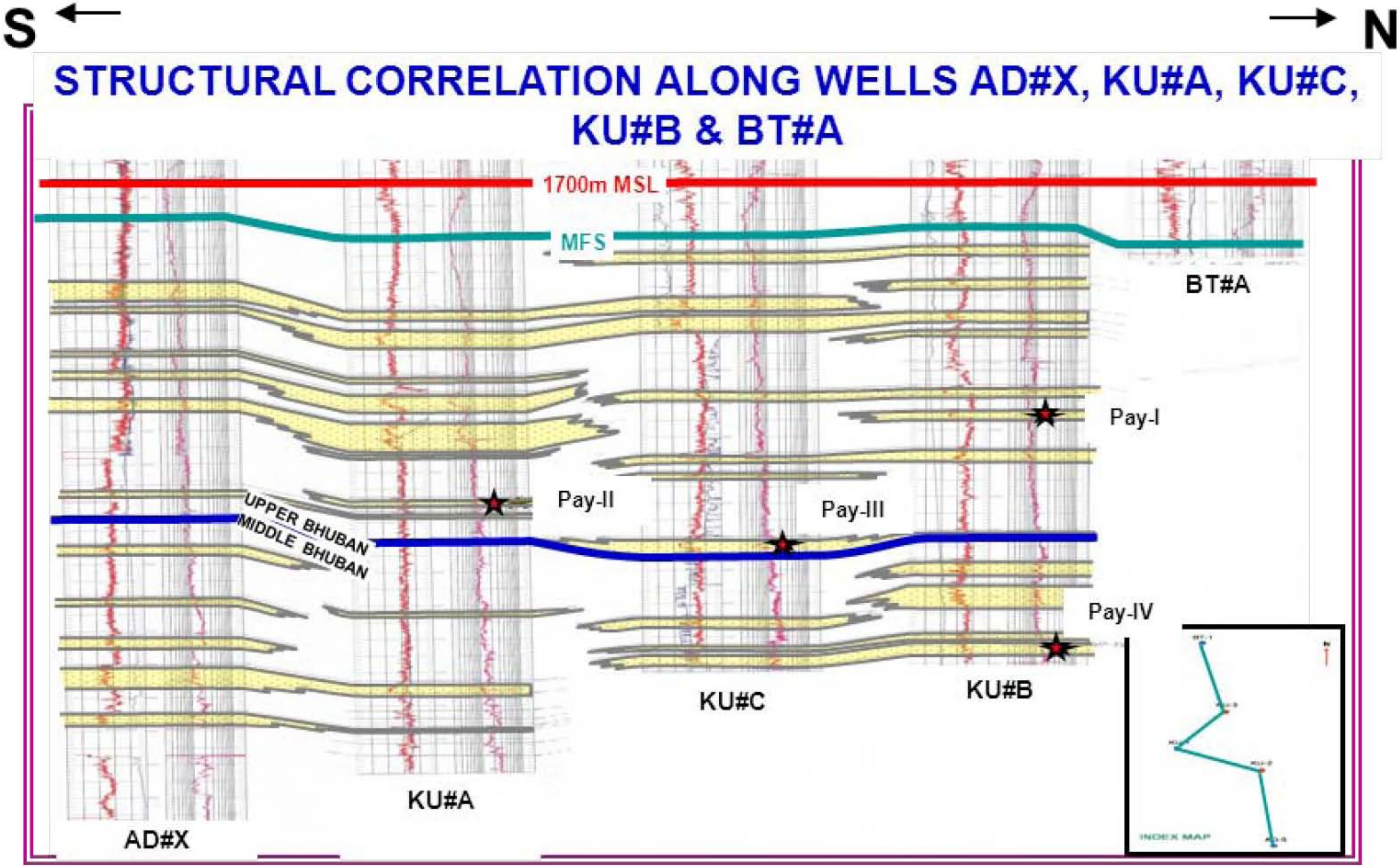

Figure 9. Structural correlation of wells AD-X, KU#A, KU#B, and BT#A.

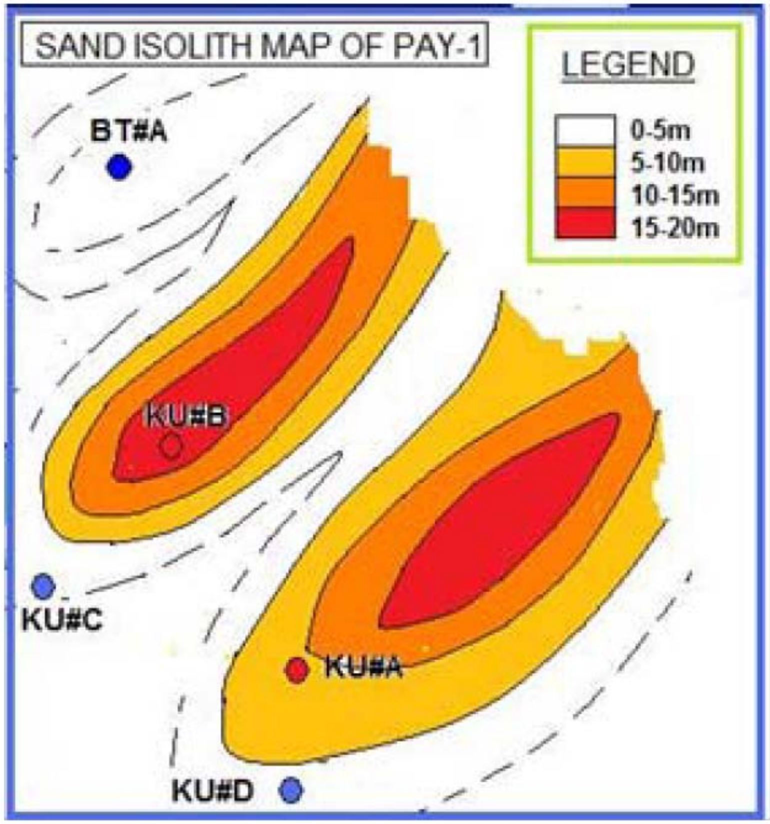

Figure 10. Sand isolith map of Pay-I.

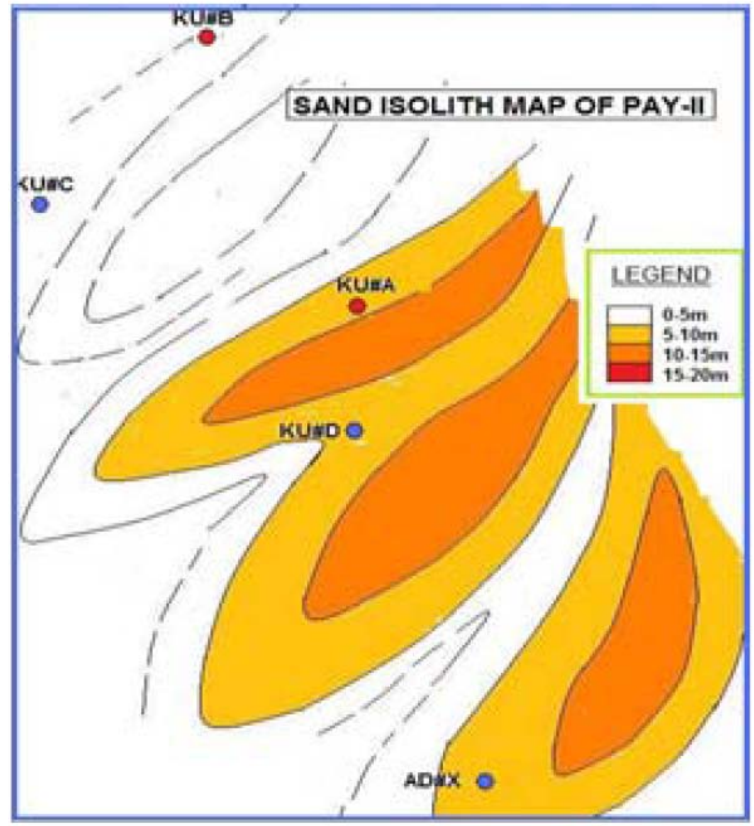

Figure 11. Sand isolith of Pay-II.

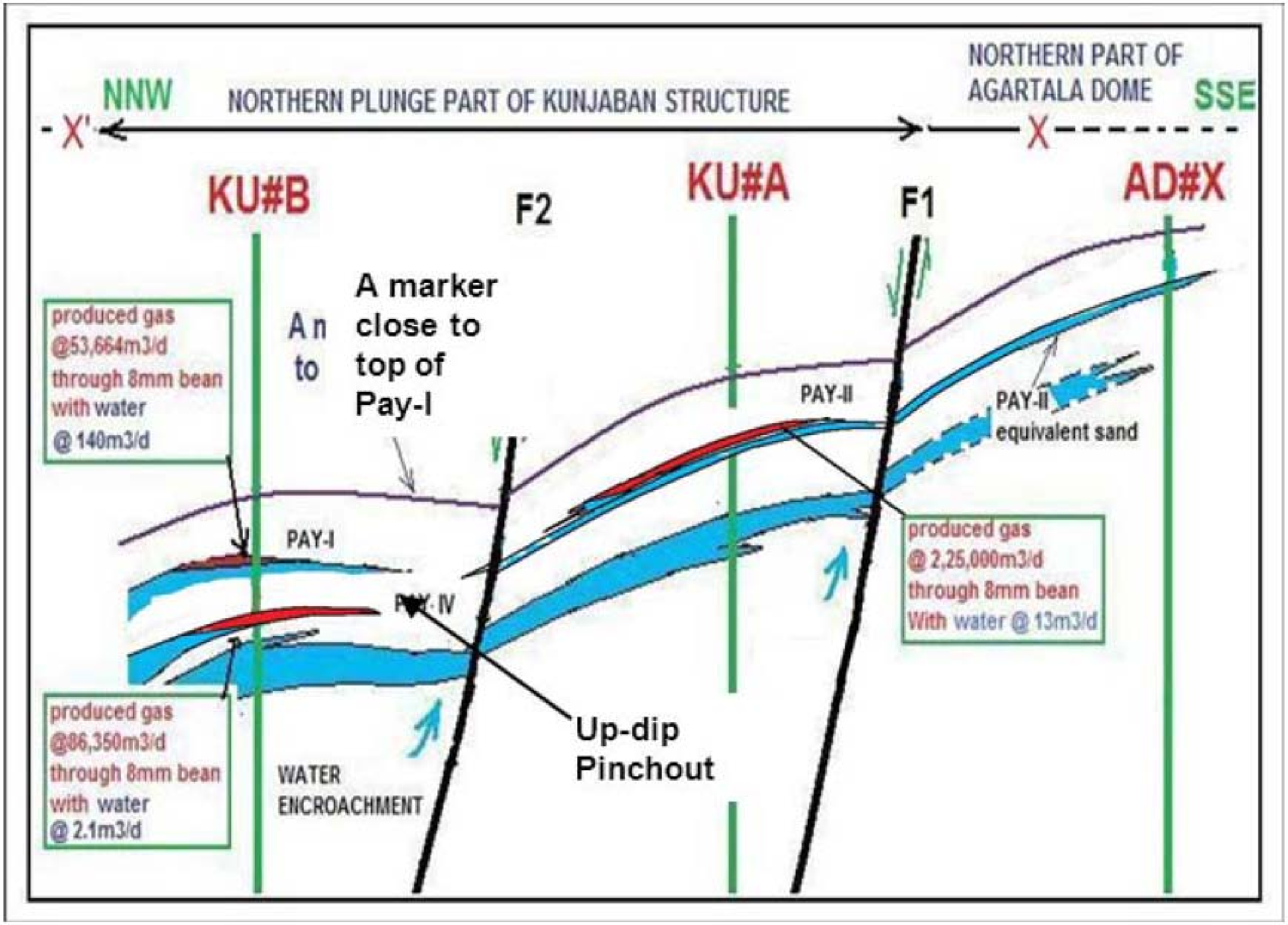

Figure 12. Schematic diagram showing hydrocarbon entrapment in northern plunge part of Kunjaban Structure.

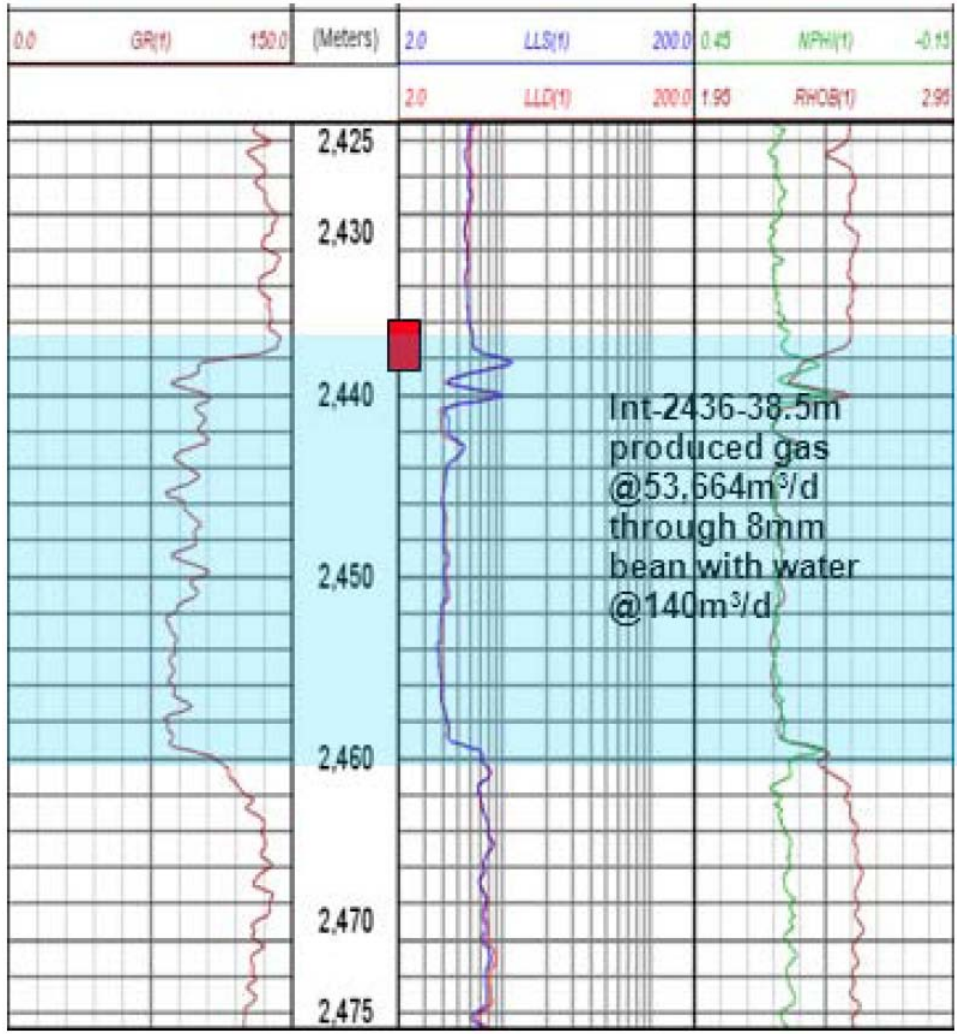

Figure 13. Log motif of Pay-I in well KU#B in Kunjaban Structure. A thin rim of gas is observed at the top otherwise major part of the sand is water bearing.

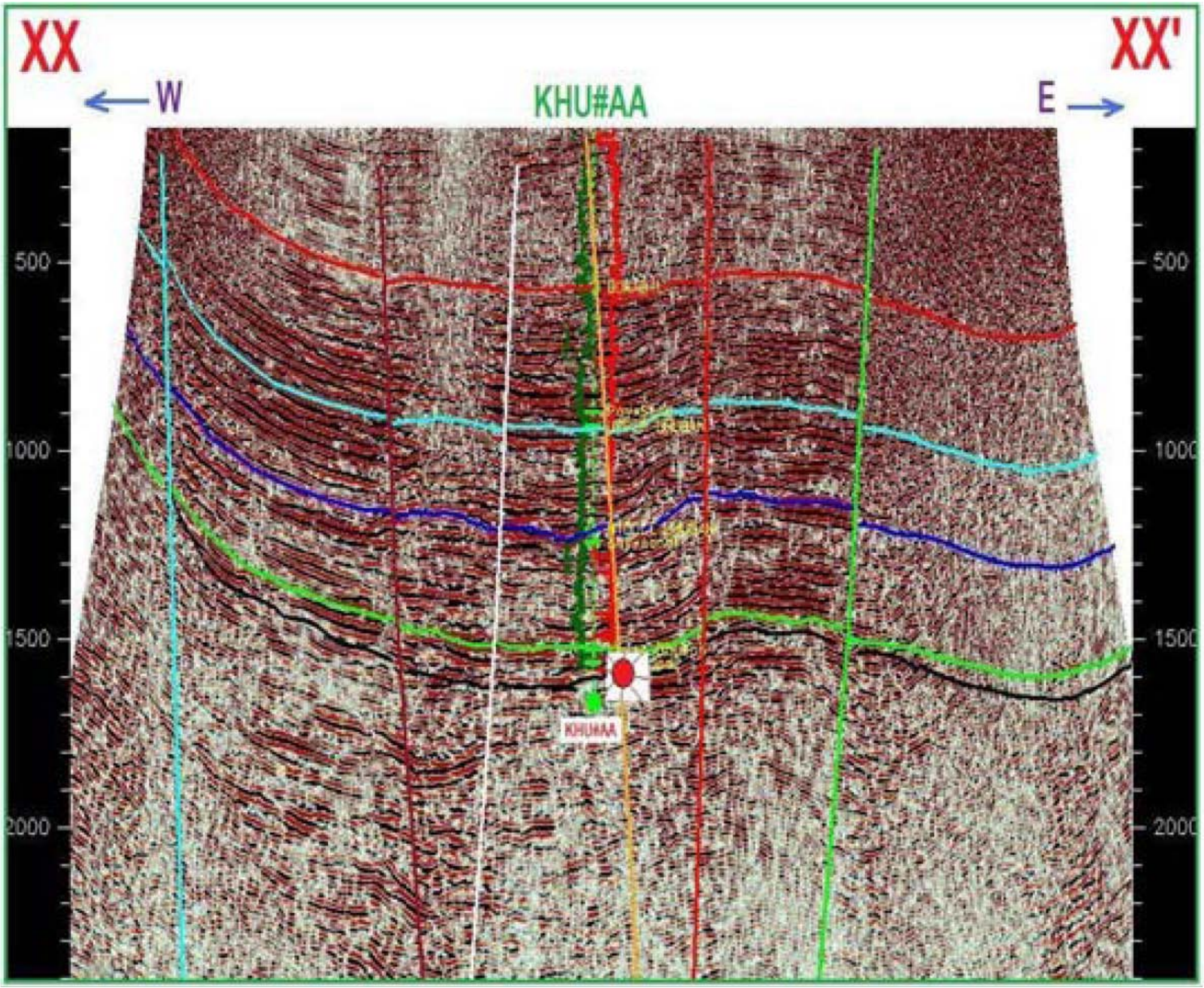

Figure 14. EW dip seismic section XX-XX' showing synclinal part of Kubal Structure which has been proved hydrocarbon bearing.

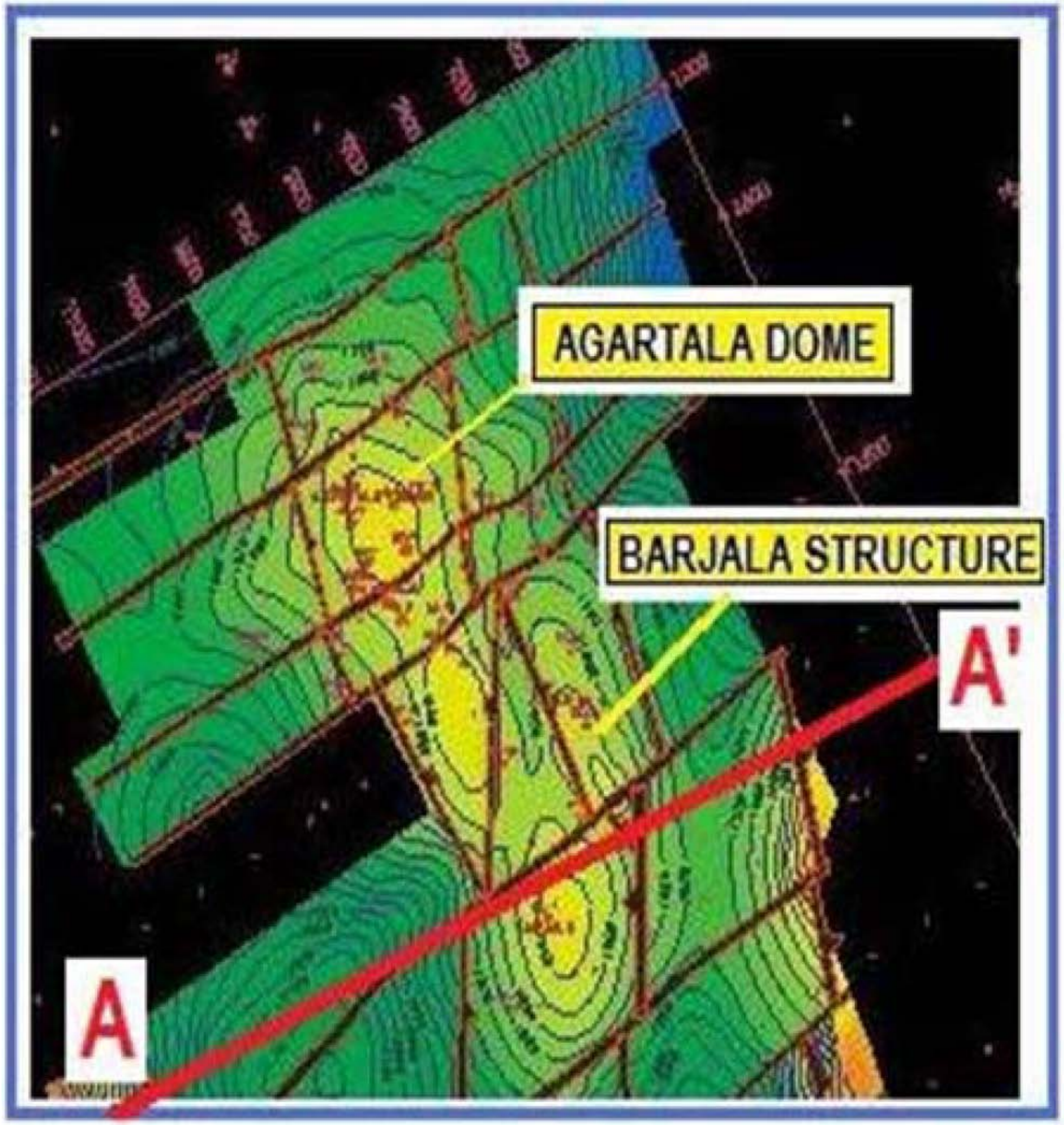

Figure 15. Barjala structure is clearly visible in southern part of Agartala Dome in eastern part of Bishalgarth Syncline.

CHRONOSTRATIGRAPHY		LITHOSTRATIGRAPHY		GENERALISED LITHOLOGY	THICK-NESS (m)	DEPOSITIONAL ENVIRONMENT
	AGE	GROUP	FORMATION / MEMBER			
QUARTERNARY	RECENT TO PLEISTOCENE		ALLUVIUM	Loose sands, silts and clays	400	Fluvial
			DIHING	Pebble beds, conglomerates and sandstones with thin beds of clay		
	^^^ ^^^ ^^^ ^^^^^^^^ U N C O N F O R M I T Y ^^^^^^^^^ ^^^					
NEOGENE	PLIOCENE	DUPITALA	UPPER	Coarse, pebbly sanstone & mottled clays	1000	Fluvial
			LOWER			
	^^^ ^^^ ^^^ ^^^^^^^^ U N C O N F O R M I T Y ^^^^^^^^^ ^^^					
	MIO-PLIOCENE	TIPAM	GOBINDPUR	Varigated soft & sticky clays often silty with Sandstone	1500-1700	Fluvial
			JAIPUR	Mainly sandstone with clays and claystone.		Fluvial
	MIOCENE	SURMA	BOKABIL	Fine grained sandstone/ siltstone with intervene-ing layers of claystone	700-1500	Brakish/Shallow Marine
			UPPER BHUBAN	Sandstone & sandy claystone/ shale layers	650-1200	
			MIDDLE BHUBAN	Shale & occasional Fine grained sandstone	650-1200	Outer shelf/Open Marine
			LOWER BHUBAN	Alterations of sandstone and shale	700-1000	Brakish/ Marginal Marine
	^^^ ^^^ ^^^ ^^^^^^^^ U N C O N F O R M I T Y ^^^^^^^^^ ^^^					
PLAEOGENE	OLIGOCENE TO LATE EOCENE	BARAIL	RENJI	Dominantly sandstone with thin shale layers	700-1000	Brakish/ Marginal Marine
			JENAM	Shale and occasional sandstone	900-1500	
			LAISONG	Alternations of thin sandstone and shale beds	1500-2000	
	EOCENE	DISHANG	DISHANG	Dark grey shale with thin beds of sandstone	1750	

Generalised Stratigraphy of Tripura-Cachar Fold Belt Area