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Prospectivity analysis of Rohtas Formation in Son Valley, Vindhyan Basin, India

Abstract

Recent discovery of significant gaseous hydrocarbon in strati-structural and structural traps within Lower Vindhyan Rohtas Limestone in the Damoh-Jabera-Katni Block of Son Valley, Vindhyan basin has necessitated a relook into the prospectivity of the shallow Rohtas play in a regional perspective beyond the existing acreage limits. The present paper brings out a regional depositional setting by integrating the Gravity and Residual Gravity data and sedimentary thickness distribution from seismic analysis. Major carbonate platformal areas, where favourable reservoir facies can be anticipated, have been demarcated. Suitable structural / strati-structural prospects within these platformal areas, particularly in the vicinity of major depocentres, may form the most prospective targets for future focussed exploration. The established gas bearing reservoirs within Rohtas Limestone manifest in the form of moderate to high seismic amplitude anomalies and low seismic frequencies. Taking lead from this, several similar anomalous features have been mapped in the entire area. Based on the above analysis, five potentially prospective areas have been identified for future exploratory efforts.

Introduction

Hydrocarbon in Proterozoic sediments is known to occur across the globe in many basins like Mc Arthur Basin of Australia, Sichuan Basin of China, Willinston Basin of USA, Sirte Basin of Libya, Lena-Tunguska Basin of Eastern Siberia etc. The Son Valley sector of Proterozoic Vindhyan Basin, in the central part of India, holds promise of emerging as a major hydrocarbon province in view of recent significant gas discovery within Meso Proterozoic Rohtas carbonate reservoirs (Lower Vindhyan) made by ONGC in the Nohta-Damoh-Jabera area within the present exploration acreage. Presence of gas has been established within fractured limestone reservoirs in a number of exploratory wells, although the commerciality is yet to be established. In order to build upon the leads obtained in Nohta and adjoining areas, a holistic review of all available data in the entire Son Valley sector, including areas beyond current exploration acreages, has led to the understanding that a potentially active petroleum system having significant hydrocarbon potential exists over a larger area in this part of the Vindhyan Basin.

Geological Setting

The arcuate-shaped Vindhyan Basin in the central part of India (Fig. 1) covers an area of 162,000 km^2 and contains a thick sequence (2-6km) of shallow marine clastic and carbonate sediments belonging to Meso–Neoproterozoic age. The basin is situated between the Delhi - Aravalli orogenic belt to the north-west and Son-Narmada Lineament (SNL) to the south. The Bundelkhand Massif, located in the north-central part of the basin, divides it into two sectors: Chambal Valley to the west and Son Valley to the east. Stratigraphically, sediments of Vindhyan Super group in Son Valley can be divided into two sequences: the carbonate dominated Lower Vindhyan (Semri Group) and clastic dominated Upper Vindhyan (Kaimur, Rewa and Bhander Groups) sequences, separated by a large hiatus (Fig.2). Evolution of the basin is marked by poly phase tectonic events. Initial structural evolution is controlled by basement related extensional tectonics resulting into formation of horst and graben rifted geometry. This was followed by a phase of compressional reactivation under wrench related movement along Son-Narmada Lineament (SNL) and some oblique faults emanating from SNL forming major inversion structures. There are evidences of an initial compressive pulse during Post-Jardepahar time and finally a major tectonic compressive event in post Rohtas time (end of Lower Vindhyan era). The main depocentres are located close to the SNL, which remained active throughout the geological history, along which relatively continuous subsidence was responsible for deposition of considerably thick sedimentary succession of 3000m to 5500m.

Methodology

To understand the prospectivity of the Rohtas Limestone, detailed structural frame work and the basin configuration has been taken in to account. The regional residual Bouger gravity anomaly map at 2mGal contour interval (source: KDMIPE 2013) along with time and thickness maps derived from 2D seismic data led to the identification of the regional depositional lows and highs. The regional lineament/fault trend was analysed to identify the likely fracture prone areas. Seismic anomalies, similar to the established fractured gas reservoirs in the existing acreage area were used as deterministic tool to identify favourable strati-structural prospects in the areas contiguous to the existing acreages.

Rohtas Play: Regional Prospectivity Analysis

The Lower Vindhyan Rohtas gas play has emerged as the principal play in Son Valley, Vindhyan Basin. Assimilation and synthesis of voluminous G&G data acquired over the area including recent exploratory wells, geological data, gravity magnetic trends, 2D seismic (post stack time and depth migrated) data, source rock analysis of outcrop and well cuttings, surface gas seepage analysis and paleogeographic reconstruction has enabled to understand the key elements of petroleum system occurring in the basin and to build a viable exploration model for this prospective shallow play over a considerably large area.

The Residual Gravity map (Fig.3) indicates that the basin is generally dipping towards south with occurrence of a series of ENE-WSW trending gravity highs and lows between Bundelkhand massif in the north to SNL in the south, mostly parallel to the trend of SNL. These observed gravity highs and lows correlate well with the horst and graben type basement configuration. The main basin is controlled by basement faults and is divided into several sub-basins separated by intervening horst blocks. An ENE-WSW trending regional gravity high belt is seen in the northern part of the area along the southern fringe of Bundelkhand massif (gravity values -16 to -34 mGal). This high trend extends from Narsinghgarh in the west through Bina, Amanganj, Satna to Mirzapur in the east. In the area of present study, this gravity high belt is correlatable with the ENE-WSW trending Singoli-Rajgarh-Banda ridge situated to the north of Hatta. . The gravity lows, corresponding to the major depocentres, occur in the close proximity of SNL. The major gravity low brought out by Residual Bouger Anomaly map is Taradehi-Tendukhera-Jabera Low (-70 to -84 mGal). Additionally, the map has helped in demarcating a number of depositional lows in the area. A prominent low trend extends from Sagar in the west to north of Damoh in the east. The map also brings out a prominent low around Kharkhari, which continues in the northeastern direction upto Mauganj with intervening shallower areas around Rewa and Amarpatan.

A considerable thickness of adequate source rocks is likely to have developed within the grabenal areas in the early rift phase. The available information points to the fact that Vindhyan Basin had potential Petroleum Systems which at present has ceased to generate any further hydrocarbon. Taking into consideration the Mesoproterozoic age and inherent higher heat flow in the rift basin, only gaseous hydrocarbon are expected in this basin. Analysis of surface samples from various localities and subsurface samples from drilled wells show good TOC in Charkaria, Jardepahar and Kajrahat formations. The major half grabens hosting the sediment depocenters have been considered to be the likely kitchen areas. Source rock study of deep wells, particularly Jabera-B located near the Jabera depression has revealed that Arangi Shale, present in the deeper syn-rift sequence is characterized by high TOC values (10.14%). Stratigraphically younger sequences like Charkaria Shale (TOC: 0.42-1.84%) and Basuhari Shale (TOC: 1.14-1.78%), also constitute adequate source rocks. The data from many of the recently drilled wells in Nohta-Damoh area indicated fair to good organic richness in the thick shale section within Middle Rohtas Unit as well as shale layers within the Upper and Lower Rohtas Limestone (TOC: 0.57-4.71%) with presence of algal mats / stromatolites and are considered to be source for both regional as well as in-situ generation of hydrocarbons. Rohtas Formation is envisaged to have a separate shallow petroleum system having adequate organic rich source within middle part of the formation which are envisaged to have charged the gas bearing fractured limestone reservoirs within different units of Rohtas Formation. A number of transgressive shales and intra formational shales act as effective seals.

Since gas accumulation within Rohtas Limestone is primarily controlled by fracture porosity, identification of the major lineament/fault trend and associated fracture prone areas is of paramount importance in demarcating the prospective locale. The regional structural style in Son Valley is governed by two main fault trends, faults parallel to the SNL (E-W to ENE-WSW) as well as along NW-SE aligned oblique faults. Major oblique faults divide Son Valley into a number of tectonic blocks (Fig.4). notable among them are the Udaipur-Tendukhera block, Jabera-Damoh block and Satna-Rewa-Kaimur block (Mahendra Pratap et al., 1999). Among these blocks, the Jabera-Damoh block is tectonically the most disturbed. The major half grabens are located along the down thrown side of these rift related faults. Some of these faults show syn-sedimentary vertical movements. In later phase of evolution, many of these faults got reactivated under inversion related compressional stresses leading to slip reversal during the formation of major inversion structures like Damoh, Jabera and Kharkhari. In the Nohta area, which is located in close proximity to the junction of two major fault trends, a number of closely spaced linkage faults showing sharp change in orientation are observed.

These faults, generated by changing orientation and magnitude of stress distribution due to interaction of two or more fault alignments during different phases of the polyhistoric deformation, have led to intense fracture development. In the areas contiguous to the existing exploration acreages, similar locale having high fracture density have been demarcated around Maihar-Amarpatan, West of Nohta and Tendukhera (Fig.5) on regional lineament intensity map (Banerjee et.al, 2002).

The deposition of the Rohtas Formation was initiated over the basin wide Basuhari marine shale, which provided a gently southerly sloping large inner shelf set up suitable for deposition of a thick carbonate sequence in a quiet water environment. The Upper and Lower Rohtas Units, comprising of dominantly limestone with thin beds of shale were deposited under dominantly regressive phases while the intervening Middle Rohtas Unit is dominated by transgressive shales with thin layers of limestone. The deposition in the large part of the area was in a predominantly sub tidal set up. However, over the prominent ridges, a platformal set up was prevalent during this time. While the limestones deposited in the sub tidal set up mostly represents mudstone, dolomitic mudstone, the limestone in the platformal set up is likely to have a relatively higher energy wackestone facies. The Nohta platform area is found to be suitably located in close proximity to Jabera and Damoh grabens. It is envisaged that hydrocarbon generated within these grabens as well as local depocentres have charged the fractured limestone reservoirs in the adjacent Nohta platform.

Taking analogy from the established hydrocarbon play fairway within the exploration acreage, five prospective blocks have been identified in the contiguous areas of Son valley. The identified areas are depicted on the regional Time structure and Time thickness maps of Rohtas Formation (Fig 6 and 7). Area I comprises the Udaipur-Tendukhera anticlinal structure close to Taradehi-Tendukhera Low in the close proximity of NSL. Area-II is ideally located for exploration of Nohta plays in west of Nohta and Gunjora Structure trending parallel to the NW-SE Chandpur-Jabera fault for structural plays in close proximity of Taradehi-Bahuribund low. Area-III and IV, located to the east of Hatta also appears interesting because of its closeness to a kitchen in South east and known gas bearing wells in the immediate south. Area V, which represents a rising monoclonal terrace around Amarpatan, appears interesting due to its proximity to a significant low in the south. This area is likely to have a platformal set up during deposition of upper Rohtas and likely to have better reservoir development. Moreover, presence of network of faults in the area increases the possibility of better fracture development. Integrated analysis of drilling results and available 2D seismic data suggest that the hydrocarbon bearing intervals established within Rohtas Formation in the area mostly correlate with high amplitude anomalies in seismic events. Presence of similar seismic anomaly has also been observed at several places within the five identified areas (Fig.7) which further corroborates the prospectivity of these areas.

Conclusions

Synergistic interpretation of all available G&G data in and around the current exploration acreages of ONGC in Son Valley, Vindhyan Basin has clearly brought out a large prospective area where the initial leads of Rohtas gas play can be explored in future. Based on geological set up, paleogeography, fault and fracture analysis, seismic facies and other related data, five prospective areas have been identified contiguous to the existing exploration where the shallow Rohtas thermogenic gas play has already been established.

References

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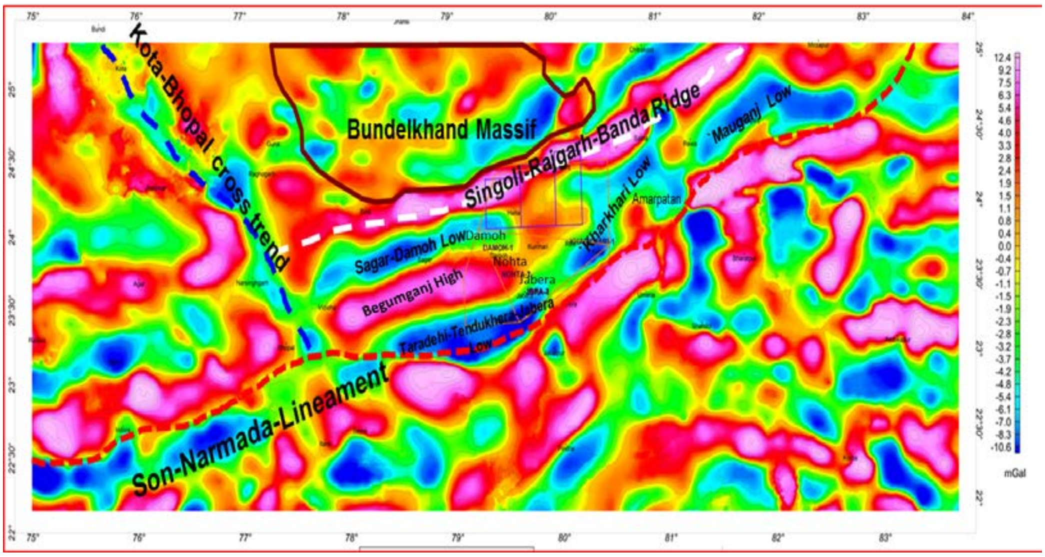


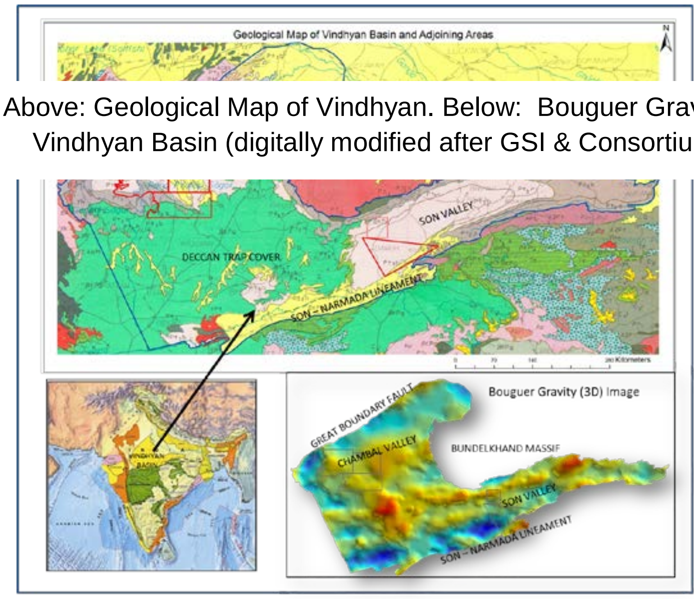


Fig.1 Above: Geological Map of Vindhyan. Below: Bouguer Gravity (3D) Image of Vindhyan Basin (digitally modified after GSI & Consortium, 2006).

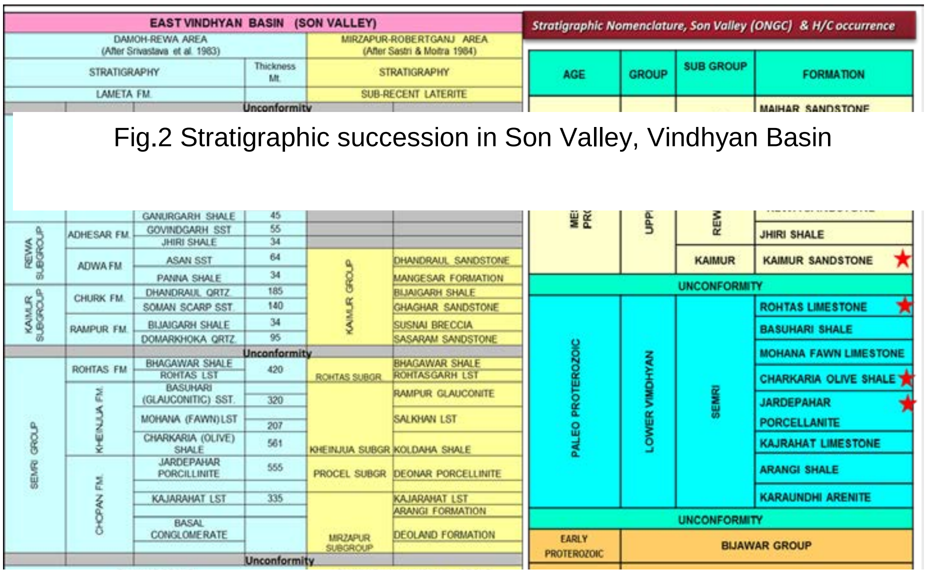
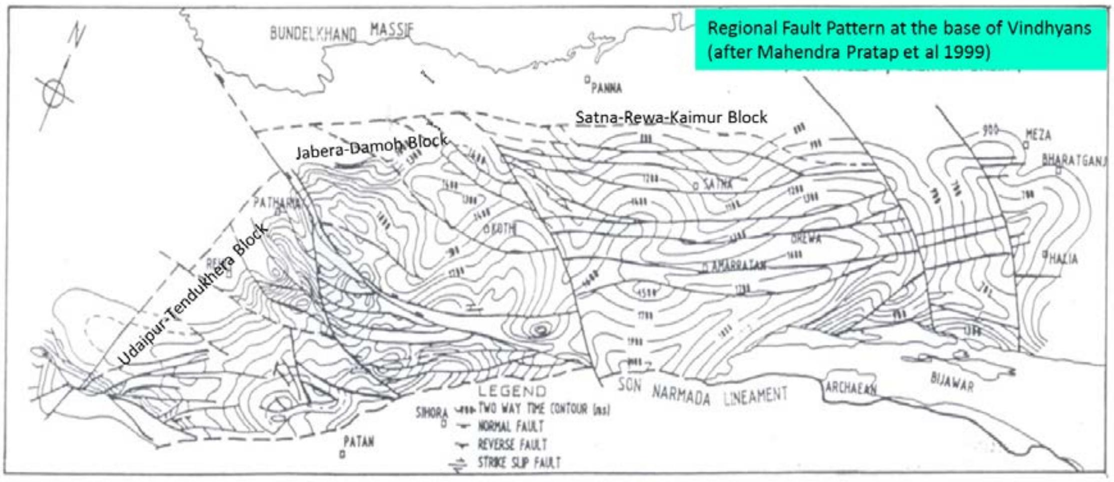


Fig.2 Stratigraphic succession in Son Valley, Vindhyan Basin

Fig.3 Residual gravity anomaly map of Son Valley (Source: KDMIPE, ONGC) with regional lows, highs and tectonic elements superimposed

Fig.4. Regional fault Pattern Map of Son Valley (Mahendra Pratap et al 1999)



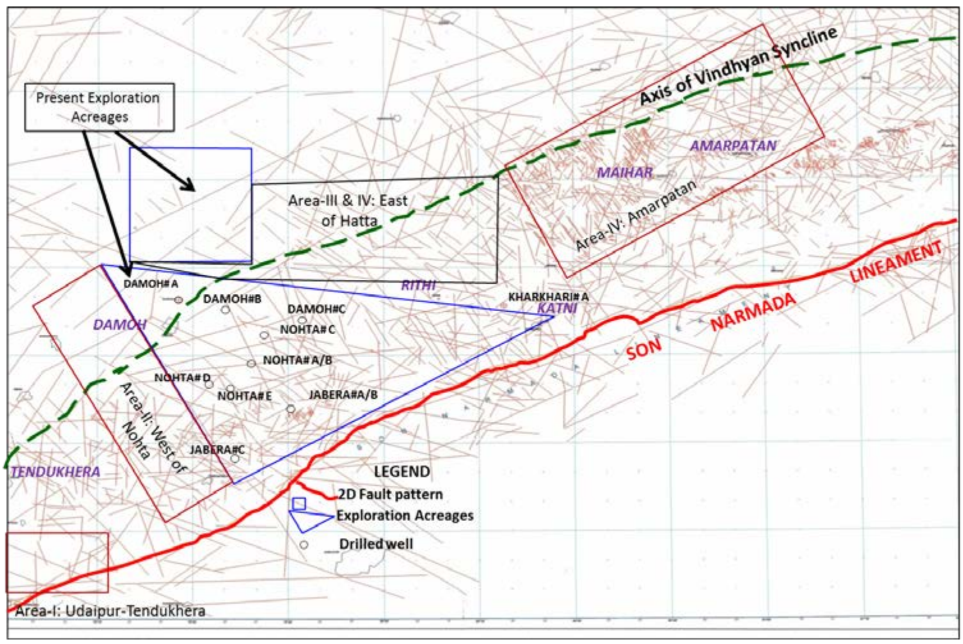


Fig.5. Lineament intensity map of Son Valley (modified after Banerjee et.al, 2002).

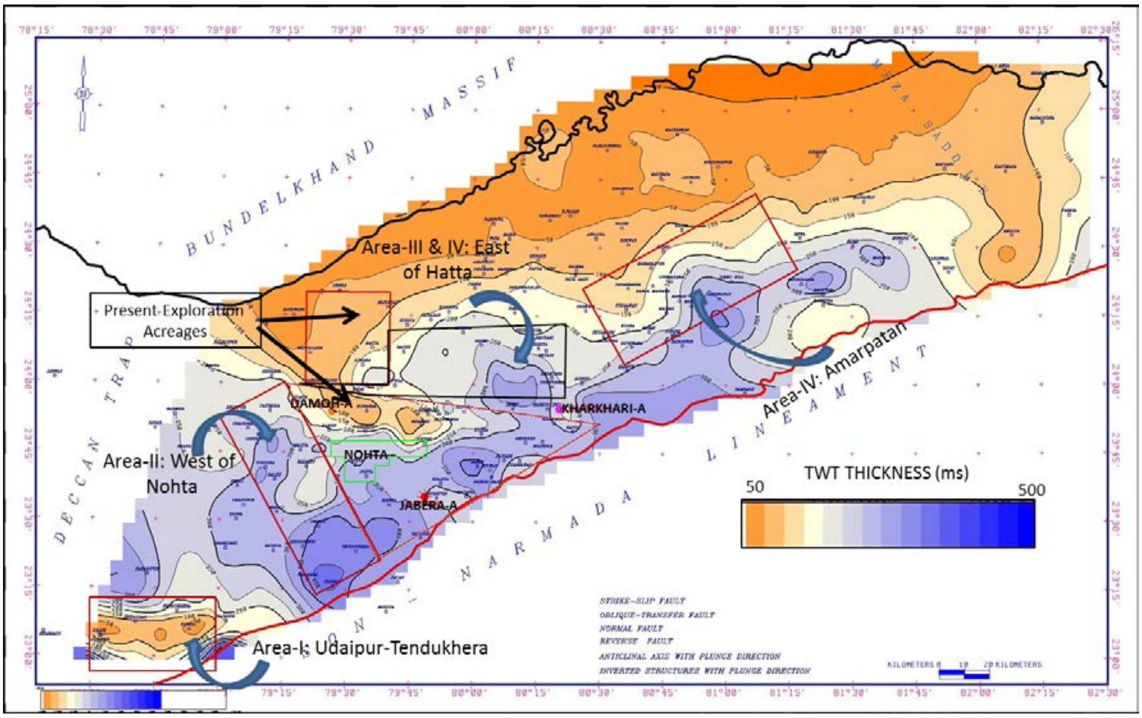


Fig.6. Prospective areas marked on Regional Time thickness map of Rohtas Formation

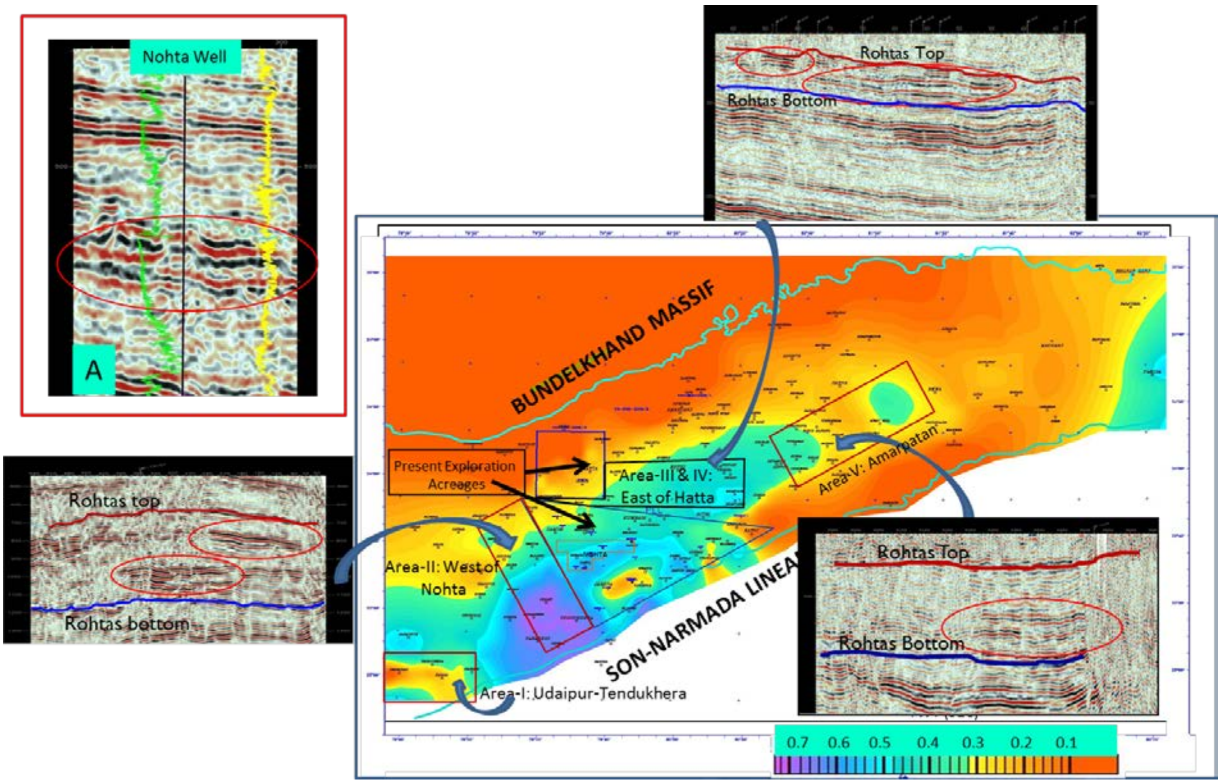


Fig.7. Regional Time structure map of Rohtas Formation showing prospective areas and seismic features similar to anomalies observed in gas bearing fractured Rohtas limestone in Nohta area (A)