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Petroleum Systems Analysis of Rohtas Formation, Son Valley, Vindhyan Basin, India

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Abstract

The geoscientific data generated from recently drilled wells in Son Valley, Vindhyan Basin have facilitated an improvement in understanding the Petroleum systems for the gas discovered within Rohtas Formation, which was hitherto considered to be sourced from deeper syn-rift Arangi / Kajrahat sediments. The present study identifies the presence of viable shallower Rohtas-Rohtas petroleum system within this sub basin, where in the organic rich lagoonal shales within the middle part of Rohtas Formation constitute the principal source with insitu generation of hydrocarbon and migration into the interbedded limestone having fracture porosity. This petroleum system also contributes towards the charging of gas in Basal Kaimur Sandstones due to re adjustment of hydrocarbons as a result of Late Upper Vindhyan compressional tectonics. A number of structural, strati-structural (fractured reservoirs, up dip wedge outs) and stratigraphic (diagenetic and lenticular) traps within Lower Vindhyan Rohtas play and Upper Vindhyan Basal Kaimur play depict the prospectivity of the sub basin.

Key words: Petroleum System, fractured reservoir, stratigraphic traps

Introduction

Recent success in establishing gaseous hydrocarbons within the Rohtas Limestone and Basal Kaimur Sandstone reservoirs in Nohta-Damoh area has added a new dimension to the prospectivity of Son Valley sector of Proterozoic Vindhyan Basin. Presence of gas has been established over a large area extending from the northern most Damoh corridor to the southern extremity of Jabera corridor. However, in view of sub economic flow rates, the commerciality of these shallow gas pools is yet to be established. In the prevalent petroleum system model of Son Valley, the stratigraphically deeper, syn-rift organic rich Arangi shales have been considered as the primary source rock for generation of hydrocarbon in major grabenal areas. However, the insights gained from a number of recently drilled exploratory wells indicates the existence of a viable shallow Rohtas-Rohtas and Rohtas-Basal Kaimur petroleum system, independent from the deeper petroleum system. Thick organic rich shale within Middle Rohtas Unit as well as shale layers within the Upper and Lower Rohtas Limestone are envisaged to be the primary source pods which have charged the gas bearing fractured reservoirs within different units of Rohtas and Kaimur formations. The present paper aims to evaluate the key elements of this shallow petroleum system in Son Valley, Vindhyan Basin.

Methodology

2D seismic data and residual gravity map was used to understand the basin configuration and thickness of sedimentary units. Well log correlations and petrographic studies on cuttings and coreswere used to construct the facies model as well as paleogeographic reconstruction with special

emphasis on Rohtas Formation. Source rock logs and gas composition analysis of drilled wells and outcrop geochemical observations available in public domain were carefully integrated.

Geological Setting

The Proterozoic Vindhyan Basin in the Central part of India is situated between the Delhi - Aravalli orogenic belt to the north-west and Son-Narmada Geofracture 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 (Fig.1). The basin evolved through multiphase geological history starting with an initial rift phase which 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. Residual gravity anomaly map over Son Valley with contour interval of 2mGal (KDMIPE, ONGC unpublished report) reveals the occurrence of gravity lows, corresponding to the major depocentres, in the close proximity of SNL. This lineament remained active throughout geological history and continuous subsidence along this active margin was responsible for deposition of thick sedimentary sequences within these lows. The most prominent gravity low is Taradehi-Tendukhera-Jabera Low. Another 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 up to Mauganj (Fig.2). The basins fill in Son Valley constitutes a considerable thickness (2-6Km) of unmetamorphosed, varyingly deformed sedimentary succession, divisible into carbonate dominated Lower Vindhyan (Semri Group) and clastic dominated Upper Vindhyan (Kaimur, Rewa and Bhander Groups) sequences, separated by a large hiatus.

Petroleum System Analysis

The stratigraphic succession of Son Valley, Vindhyan Basin with key elements of petroleum system is shown in Fig.3. The fractured limestone within Rohtas Formation and Basal Kaimur Sandstone are the principal reservoirs where presence of gas has been established over a large part of the study area. Additionally, Mahona Fawn Limestone, Siltstone within Charkaria Formation, Jardepahar coarser clastics and Kajrahat Limestone are envisaged to be potential reservoirs as well. A number of transgressive shales and intra formational shales act as effective seals. The syn-rift organic rich Arangi shales in the lower part of Semri Group has exhibited good source rock potential (TOC: 0.5-10.14%) in well Jabera-B located near the Jabera Low. 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%). This observation strongly suggests that Rohtas Formation has a separate viable petroleum system having adequate organic rich source which are envisaged to have charged the gas bearing fractured reservoirs within different units of Rohtas and Kaimur formations through short distance migration. Moreover, expulsion of hydrocarbon from the deeper Arangi and Kajrahat sources to the shallow Rohtas and Kaimur reservoirs is not considered as a viable possibility, particularly in view of presence of thick transgressive Charkaria shale sequence, with thickness as high as 600m, in between. The deeper syn-rift source might possibly have charged stratigraphically deeper plays like Kajrahat, Jardepahar and Charkaria, which has not been fully established till date baring flow of gas within Jardepahar Formation and hydrocarbon indications within Charkaria Formation in well Jabera-A. Hence, the following two petroleum systems are envisaged in Son valley:

Rohtas-Rohtas and Rohtas-Basal Kaimur: major petroleum system responsible for the accumulation of gas within Rohtas and Basal Kaimur units.

Arangi-Kajrahat-Jardepahar/Charkaria: secondary petroleum system, yet to be fully established, where the potential source rocks within deeper Arangi/Kajrahat formations might have charged deeper Kajrahat/Jardepahar/Charkaria reservoirs in suitable strati-structural prospects.

Gas composition

The gases from Rohtas and Kaimur reservoirs are similar in composition (82.68-92.39% methane and presence of higher hydrocarbons up to pentane). Stable carbon isotopic values of methane are in the range of -31 to -37.2‰. All these gases have low concentration of C_2+ component, which does not

indicate their association with commercial quantity of liquid hydrocarbon. The carbon isotopic values of ethane and higher hydrocarbons are nearly similar ($\delta^{13}C_2$ -38 to -40‰) and thus are correlatable and point to the same source. In binary plot, these gases fall near condensate associated and dry gas types (Fig.4) indicating thermogenic origin. The gas sample from well Jabera#1 within Jardepahar Formation show lowers methane content (47.29%) and high N2 (41.32%) and is not co-relatable with Nohta wells. The isotopic data ($\delta^{13}C$ of C1: -30$^{o}/_{oo}$) of gas indicate its thermo genic origin, which might have originated from deeper source.

Rohtas-Rohtas and Rohtas-Basal Kaimur Petroleum System

The key elements of the Rohtas-Rohtas and Rohtas-Basal Kaimur petroleum system are as follows:

Source: Fair to good source rock potential has been reported within Rohtas Formation from outcrop studies as well as source rock analysis of well cuttings, particularly in the Middle Rohtas Unit, where thick organic rich shales have been observed alternating with limestone beds. Outcrop based study and source rock analysis (Banerjee et al., 2005; Banerjee and Jeevankumar 2007) suggest high TOC content within black shales within Rohtas Formation (Fig.5). Field evidences of presence of algal stromatolitic mats within Rohtas Limestone having adequate organic richness in the form of fair to good organic richness also corroborate the source potential of Rohtas Formation. Presence of organic rich lagoonal shale within Middle Rohtas Limestone has also been reported in drilled wells (Fig.6). Rock-Eval studies carried out for source rock analysis of Rohtas Formation in drilled wells of Son Valley reveal adequate source potential in Jabera-B (TOC: 1.14-1.78%), Nohta-C (TOC: 0.91-1.84%), Damoh-B (TOC:1.27-4.71%) Damoh-C (TOC: 0.57-1.73%). Although the S2 values indicate low remaining hydrocarbon generation potential (S2:0.01-1.1 mg HC /g rock), these rocks might have generated hydrocarbon in the past.

The thick shale section within Middle Rohtas Unit as well as shale layers within the Upper and Lower Rohtas Limestone envisaged to be the primary source for charging the Basal Kaimur gas play as well. Additionally, shale layers within Basal Kaimur Formation, if having adequate source potential, particularly in deeper areas of Jabera depression, may also act as local source pods.

Reservoirs: Petrophysical studies on available cores as well as electrolog data in Rohtas Formation have indicated 2-4% effective porosity. However, secondary fracture porosity within limestone is found to enhance the reservoir quality. Presences of partially open to open fractures have been interpreted in XRMI logs. Higher fracture porosity is envisaged in areas proximal to major faults and zones of fault intersections. However, the lateral continuity and thickness of the reservoir are an area of concern. In areas nearer to wedge out of shallow limestone sequences within Rohtas Formation, the reservoirs may also have retained frozen primary porosity. These stratigraphic prospects are expected to provide suitable entrapment conditions if migration and accumulation of hydrocarbon occurred prior to significant diagenesis/cementation.

Basal Kaimur gas play was established in well Nohta-C, thereby opening up the prospectivity of this Upper Vindhyan play in Son Valley. Presence of equivalent gas bearing layers have been identified on electrolog evaluation in wells Nohta-A, B, D, E, Damoh-B, C, Jabera-B and C also. Electrolog analysis of this reservoir has brought out porosity of 5% and Sw 50%. A number of open fractures were observed in XRMI log against this interval. The gas bearing sandstone reservoir is present in the bottom most sub-unit of Kaimur Formation overlain by a prominent transgressive shale marker. In this context it will be prudent to say that any sandstone bed within this sub unit may act as a potential gas reservoir, provided they are having secondary fracture driven porosity and suitable strati-structural entrapment condition.

Seal: Intra-formational shales within Rohtas formation, hard dolomitized layer at the top of Upper Rohtas Unit and shale at the top of Basal Kaimur unit are envisaged to have acted as effective seals.

Charging: Elecrolog correlation of Rohtas in wells Damoh-B, C and Nohta-C incorporating source rock log and gas bearing zones clearly shows juxtaposition of source, fractured reservoirs and seal within Rohtas Formation itself (Fig.7). Charging is envisaged through faults and fractures, mainly by short vertical migration. Migration from deeper sources not visualized in view of thick transgressive

Charkaria shale sequence in between. However, where major basement faults extend into the Rohtas Formation, charging of gases from deeper sources is also possible. The Kaimur gas pools are interpreted to be a part of Rohtas-Rohtas-Kaimur petroleum system itself. The gas pool within Basal Kaimur reservoirs have primarily resulted from secondary migration from the Rohtas pools due to post Rohtas tectonic disturbances and subsequent accumulations in suitable strati-structural traps.

Hydrocarbon entrapment styles: The Rohtas and Basal Kaimur gas plays in Son Valley exhibit following entrapment styles (Fig.8):

1. Gas reservoirs in structural traps
2. Gas reservoirs in strati-structural traps: fractured reservoirs in the vicinity of faults and updip wedge out against structural highs
3. Gas reservoirs in purely stratigraphic traps: lenticular reservoir pods and diagenetic traps

Conclusions

Rohtas-Rohtas and Rohtas-Basal Kaimur are the principal working petroleum systems for the accumulation of hydrocarbons within shallow Rohtas and Basal Kaimur plays in Son Valley, Vindhyan The organic rich transgressive shales within Middle Rohtas Unit is the principal source which has likely charged the adjacent fractured limestone reservoirs. Gas accumulation within Basal Kaimur sands are primarily result of secondary migration from Rohtas pools through fault and fracture conduits during post Rohtas tectonic event.

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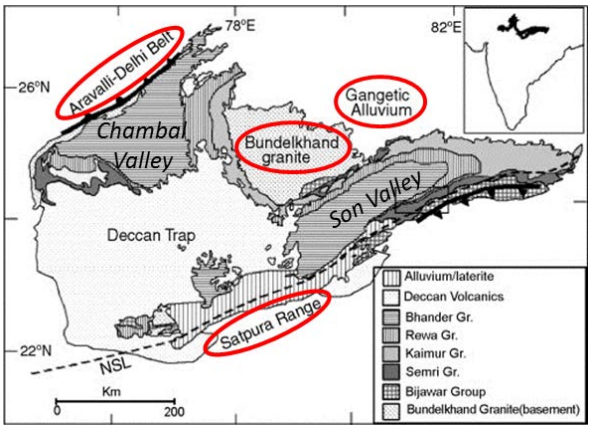

Fig.1 Geological Map of Vindhyan Basin

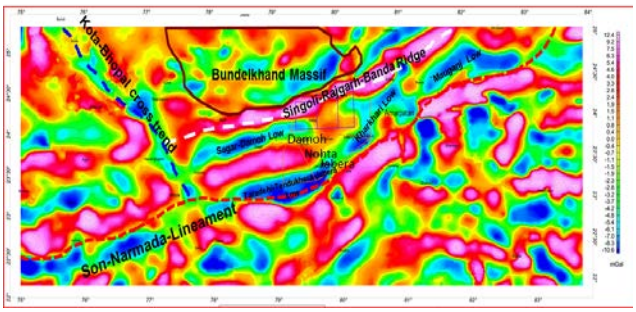

Fig.2 Residual Gravity Anomaly map (2ms contour) of Vindhyan Basin showing major tectonic and geomorphic elements

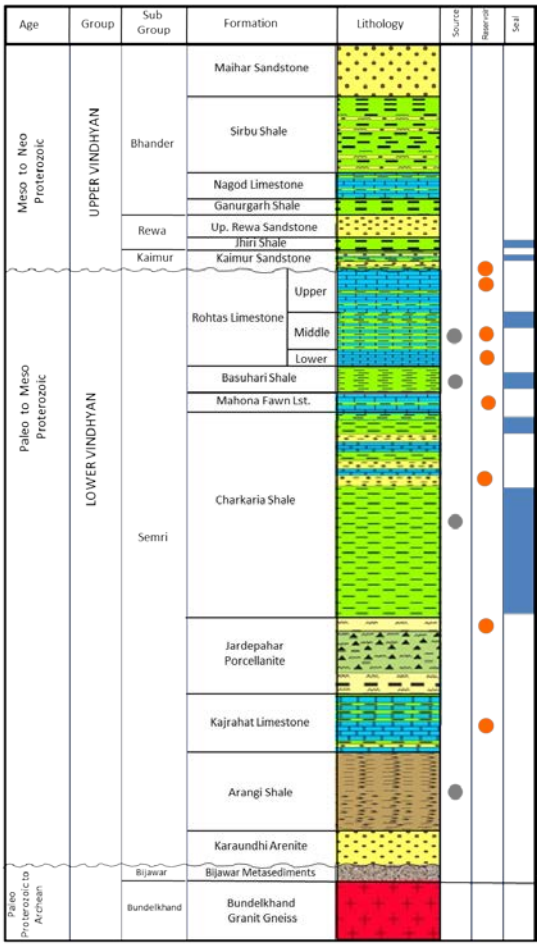

Fig.3 Stratigraphy of Son Valley showing key elements of Petroleum systems

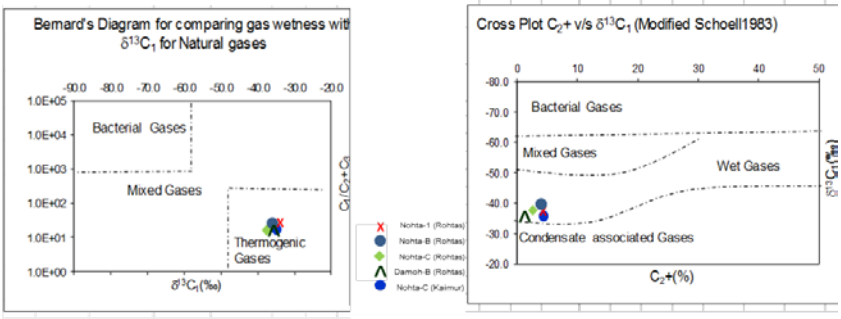

Fig.4. Bernard's and Schoell's cross plot for the Rohtas and Kaimur gases from drilled wells in Nohta-Damoh area (Source: KDMIPE ONGC Reports)

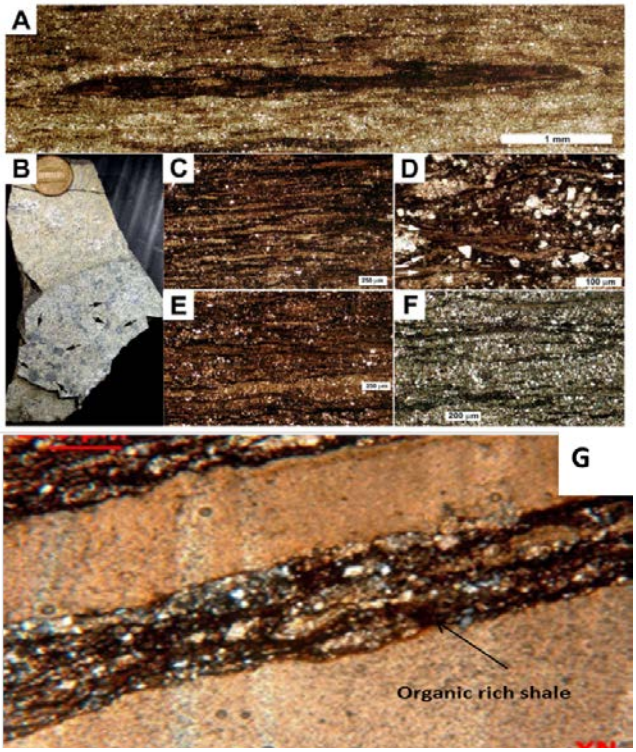

Fig.5. A to F: Field photographs of algal stromatolitic limestone within Rohtas Formation and G: Thin section of Middle Rohtas Limestone of well Nohta-A showing intercalatiions organic rich shales (Source: KDMIPE ONGC Reports)

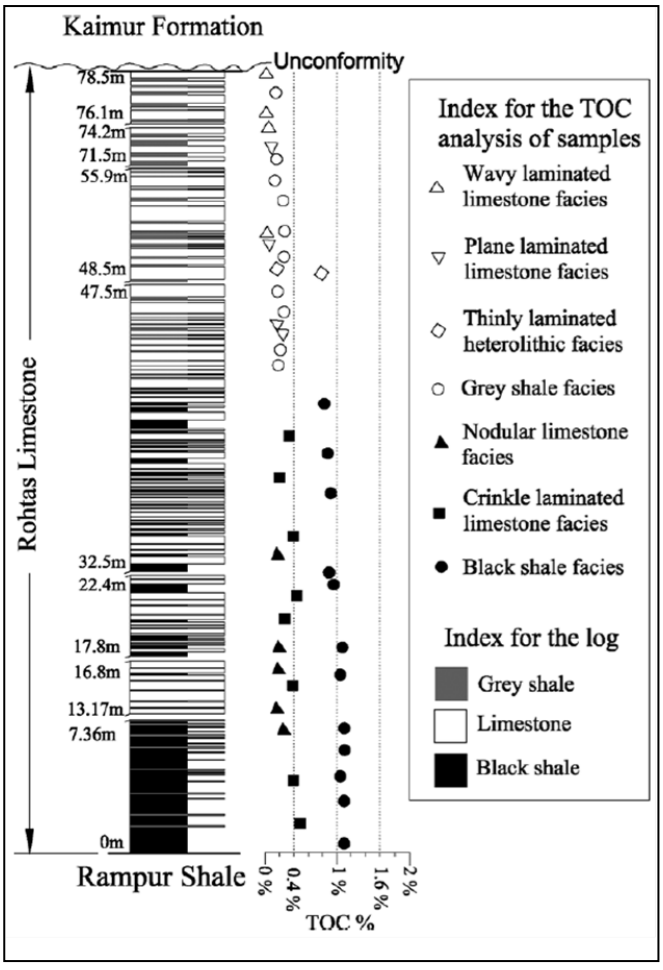

Fig.6. TOC content within Rohtas Limestone from outcrop studies (Source: Banerjee et.al.,2005)

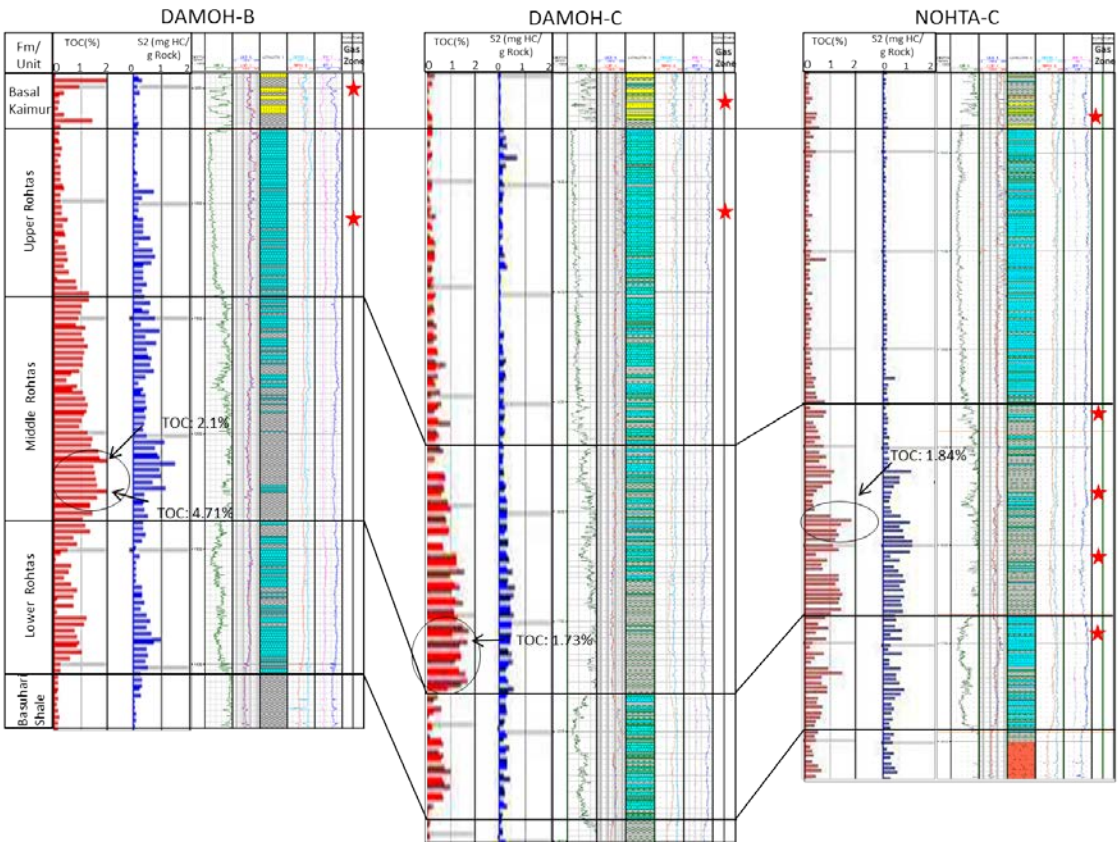

Fig.7. Correlation of wells Damoh-B, Damoh-C and Nohta-C showing juxtaposition of source rock and fractured reservoirs within Rohtas Formation

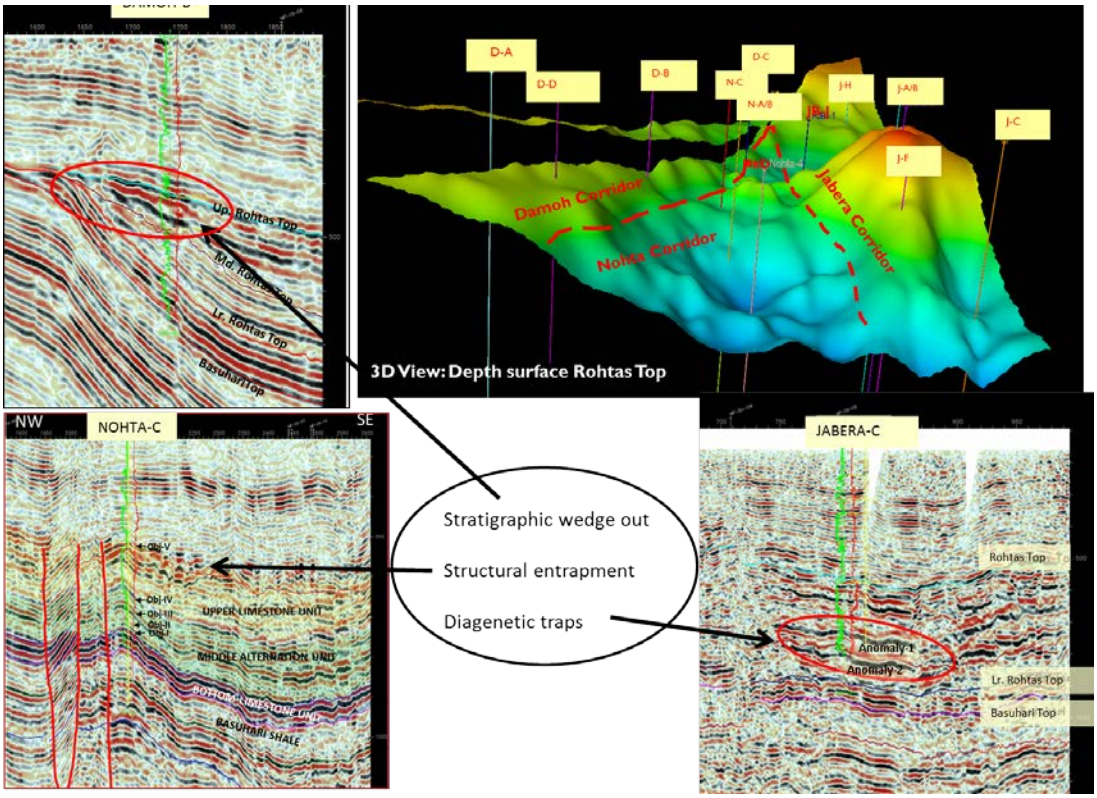

Fig.8. Hydrocarbon entrapment styles in Rohtas and Basal Kaimur gas plays, Son Valley, Vindhyan Basin.