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Higher order sequence stratigraphic (TR cycles) analysis of Rohtas/Kaimur formations in Son Valley, Vindhyan Basin, India

Abstract

Study of higher order sequences (T/R cycles) was attempted to identify the locale having better reservoir facies within Rohtas and Kaimur formations in Son Valley. Fourteen T/R cycles within Rohtas Formation which includes three in Lower, five in Middle and six in Upper Rohtas unit and five T/R cycles within Kaimur Formation have been identified. The analysis of the T/R cycles explains the pulsative transgression and regression witnessed during deposition of these sedimentary units, which is represented by corresponding depositional facies.

The Lower Rohtas unit shows relatively longer regressive pulses resulting deposition of uniformly thick carbonate with intervening short transgressive shale. The Middle Rohtas Unit is dominated by transgressive shale with intermittent smaller pulses of regressive thin limestone. This shales within this transgressive units is envisaged as the major source rock which generated hydrocarbon in around Nohta-Jabera areas. The overlying Upper Rohtas unit constitutes a thick carbonate sequence deposited under a dominantly regressive phase with very short transgressive events. The sandstones within Kaimur Formation were deposited as a tidal channel and tidal bar. Regionally extensive shale representing the transgressive phase demarcates the upper boundary of the Basal Kaimur Sandstones.

The study has brought out a preferential distribution of gas pools within regressive phases of specific T/R units within Lower Rohtas (T/R-3), Middle Rohtas (T/R 5 and 6), Upper Rohtas (T/R 12 and 13) and Basal Kaimur (T/R 1 and 2 of Kaimur cycle).

Introduction

Sequence stratigraphy is the most recent revolutionary paradigm in the field of sedimentary geology and has resulted in fundamental changes in geological thinking and in particular in methods of facies and stratigraphic analysis. The success and popularity of sequence stratigraphy stems from its widespread applicability in both mature and frontier basins where data driven and model driven predictions of lateral and vertical facies changes can be predicted. These predictive models have proved to be effective in reducing lithology prediction risks for hydrocarbon exploration (Catuneanu, 2006). The concept of sequence stratigraphic studies started with the study of transitional environment between the non-marine and marine environment where the relationships of facies and stratigraphic surfaces is easier to observe.

Tectonics and sedimentation

The Vindhyan Basin, a Proterozoic basin in the Central part of India, is located between the Delhi - Aravalli orogenic belt to the north-west and Son-Narmada Geofracture to the south. The Bundelkhand Massif divides it into two sectors: Chambal Valley to the west and Son Valley to the east. The basins fill in Son Valley constitutes a considerable thickness (2-6Km) of un-metamorphosed, sedimentary succession divisible into carbonate dominated Lower Vindhyan and clastic dominated Upper Vindhyan sequences, separated by a large hiatus. The sedimentation started with an initial synrift phase and followed by a post rift phase. During the Vindhyan sedimentation, a shallow eperic sea with maximum water depth of 100m (Chakraborty, 2006) had continued with pulses of subsidence to accommodate the thick pile of sediments spanning a large geological time.

The Vindhyan Basin is genetically associated with two mega tectonic elements: Great Boundary Fault (GBF) to the northwest and Son-Narmada Lineament (SNL) to the south. The Vindhyan sediments of Son Valley define a broad ENE–WSW trending regional syncline in the central part. Several authors; Jokhan Ram et al., 1996, Mahendra Pratap et al., 1999 and Verma *etal*; 2002 have made significant contribution on the tectonic framework including the fault systems, paleo-structures, structural inversion and deformation history of the Vindhyan Basin.

Embry and Johannessen (1992) defined the TR sequence where the sub aerial unconformity as the unconformable portion of the boundary and the maximum regressive surface as the correlative conformity. A T-R sequence is divisible in to a Transgressive System Tract below and a Regressive System Tract above by using the MFS surface as surface of mutual boundary. The Proterozoic Vindhyan Basin is inferred to be a shallow eperic sea with deposition of thick sediment over a large geological time under episodic transgressions and regression. The overall limitation of organic growth during the time makes it difficult to determine the ages of the sediments required for sequence stratigraphic analysis.

The maiden attempt of petroleum systems and sequence stratigraphic analysis of the Vindhyan Basin was carried out by ONGC during 2006-2008 where in first order and second order sequences were identified. Paul *et al* (2013) made detailed study on the sequence stratigraphy of Lower Vindhyan sediments and have identified seven T/R sequences within the 1st order sequence (Fig.1). Subsequent to the above studies, a number of additional wells were drilled in the Son Valley leading to a better understanding of the sub surface geology and petroleum systems.

Methodology

The present study is carried out using mainly the conditioned GR logs from the drilled wells along with integration of laboratory data towards facies, biostratigraphy for the identification of the T/R cycles in each stratigraphic unit.

Identification of Higher Order T-R sequences

In order to correlate the gas bearing intervals within Rohtas and Kaimur formations and the depositional cycles, electrolog correlations were made across the drilled wells in the area (Fig.2). Based on the well, seismic and log data, three distinct units have been identified within the Rohtas Formation. In the present studies, higher order sequences (T/R cycles) were identified within each identified units of Rohtas Formation, Lower, Middle and Upper. Similar exercise has also been attempted for the Kaimur Sandstone. From the analysis of GR log and other log suites, the Maximum Flooding Surfaces (MFS) and the Maximum Regressive Surfaces (MRS) were identified. The sedimentary unit between two such flooding surfaces represents the higher order sequence, a T/R cycle.

Using the above mentioned criteria, fourteen T/R cycles within Rohtas Formation (Lower Vindhyan) have been identified (T/R 1 to 14), which includes three sequences in Lower, five sequence in Middle and six sequences in Upper Rohtas unit. Within the Kaimur Formation (Upper Vindhyan), five T/R cycles have been identified (T/R 1 to 5). Three electrolog correlation profiles along dip and strike directions were prepared to bring out the vertical as well as lateral disposition of these identified T/R cycles in the study area.

The unit wise analysis of the T/R cycles within Rohtas and Kaimur formation explains the pulsative transgression and regression witnessed during deposition of these sedimentary units, which is represented by corresponding depositional facies. The Lower Rohtas unit, which has an overall thickness of 110-130m can be sub divided in to three units, a lower limestone, followed by middle shale and an upper limestone. Three T/R cycles have been identified (T/R-1, 2 and 3) which show shorter interval of transgression while the regressive pulses are of longer duration, which resulted in deposition of thicker carbonate (Fig.3). The Lower Rohtas gas pool encountered in well N#C is within the regressive phase of cycle T/R-3.

The Middle Rohtas Limestone with overall thickness of 200-250m comprises dominantly of shale with interbeds of thin limestone has been categorised under five T/R cycles (T/R-4 to T/R 8) with longer transgressive phase followed by very smaller regressive phase (Fig.4). As a result, large part of the study area was under a relatively deeper bathymetry resulting in deposition of thick shale along with argillaceous limestone. The encouraging source rock geochemical data and presence of organic rich shale layers brought out by petrographic analysis suggest these transgressive units within Middle Rohtas as major source pods which appear to have generated hydrocarbon in depositional lows around Nohta-Jabera areas. Similar source facies within Middle Rohtas unit is also envisaged in the Damoh low. The thin limestone beds juxtaposed with the source pods are potential reservoirs as observed in well N#C, where the gas bearing reservoir is housed within the regressive phase of cycle T/R-5. Another potential gas bearing layer, identified in N#C, and is located within regressive phase of cycle T/R-6.

The Upper Rohtas unit which comprises dominantly of limestone with thin interbeds of shale has maximum thickness (350-400m) with increase in thickness in south west. In Upper Rohtas unit, the regressive phases are of longer duration while the transgressive phases are of relatively shorter spells. From the above analysis it is inferred that the deposition of this unit took place under mainly a regressive phase thus depositing a thick carbonate sequence under a retreating sea. The Upper Rohtas Limestone comprises six T/R cycles (T/R-9 to T/R 14, Fig.5). The Upper Rohtas gas pools, which flowed gas during testing in wells N# A, B, D and D#C are housed within the regressive phases of cycles T/R 12 and 13.

The Upper Vindhyan sedimentation started with the initiation of Kaimur sedimentation under a transgressive regime, resulting in the deposition of shale just above the Lower Vindhyan unconformity surface. Within Kaimur Formation five T/R cycles (T/R 1 to 5) have been identified (Fig.6). Based on lithological and electrolog character, the sandstones within Kaimur Formation are interpreted to be deposited in a tidal channel/ tidal bar environment. Regionally extensive shale sequence (T/R cycle 3), demarcates the upper boundary of the Basal Kaimur Sandstones. The study of the T/R cycles within Kaimur Formation reveals that the gas bearing sandstone reservoirs within Basal Kaimur, which flowed gas in well N#C and similar gas bearing layers identified in wells N#A,B,J#B,C,D#B and C are housed within the regressive phases of cycles T/R 1 and 2. The extensive shale in the lower part of T/R 3 appears to have acted as a regional seal for entrapment of hydrocarbon within the Basal Kaimur sands.

Discussions

Fourteen higher order T/R cycles within Rohtas Formation (Lower Vindhyan) have been identified (T/R 1 to 14), which includes three sequences in Lower, five sequence in Middle and six sequences in Upper Rohtas unit. Similarly five T/R cycles have been identified (T/R 1 to 5) within the Kaimur Formation (Upper Vindhyan).

Conclusions

The gas bearing zones of Upper Rohtas Limestone present most of wells in Nohta-Damoh area was deposited under platformal setup in a regressive phase and is housed within T/R sequences 12 &13. The sandstones within Kaimur Formation are interpreted to be deposited in a tidal channel and tidal bar environment. The extensive shale in the lower part of T/R 3 appears to have acted as a regional seal for entrapment of hydrocarbon within the Basal Kaimur sands. The integration of depositional regime, paleogeography and the T/R cycles helped in understanding the spatial distribution of source, reservoir rocks and seal in the area of study.

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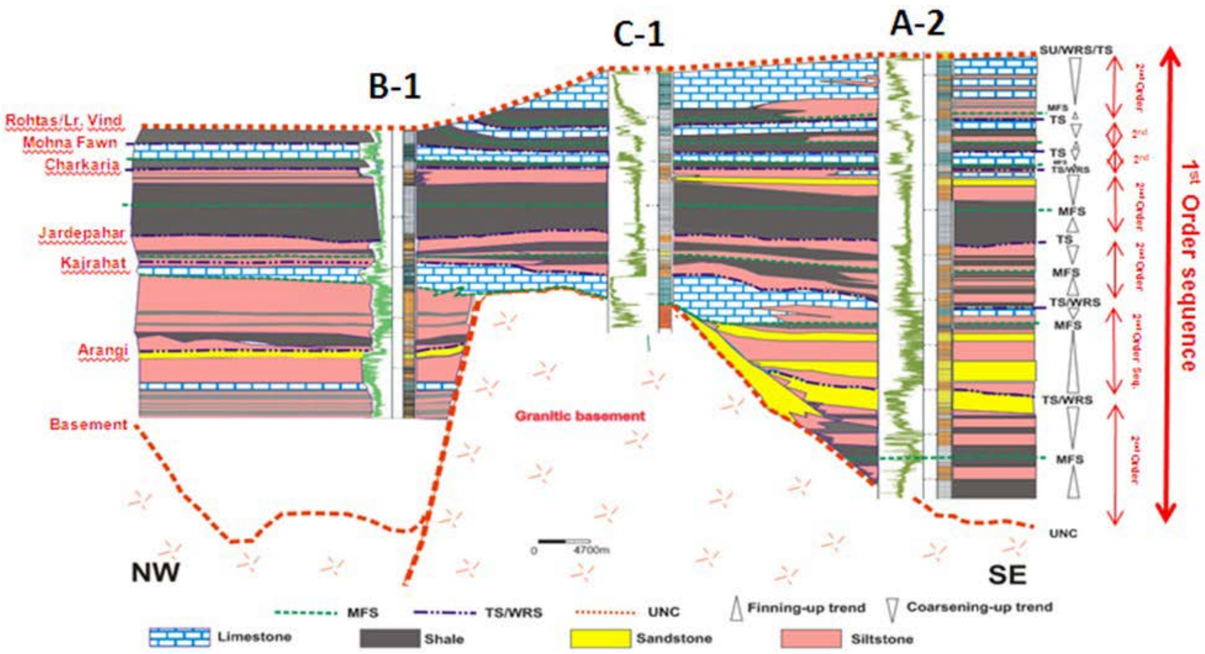

FIG 1: Facies model based on integration of seismic and log data. Sequence stratigraphic framework on the basis of identified surfaces (source Paul *etal* 2013).

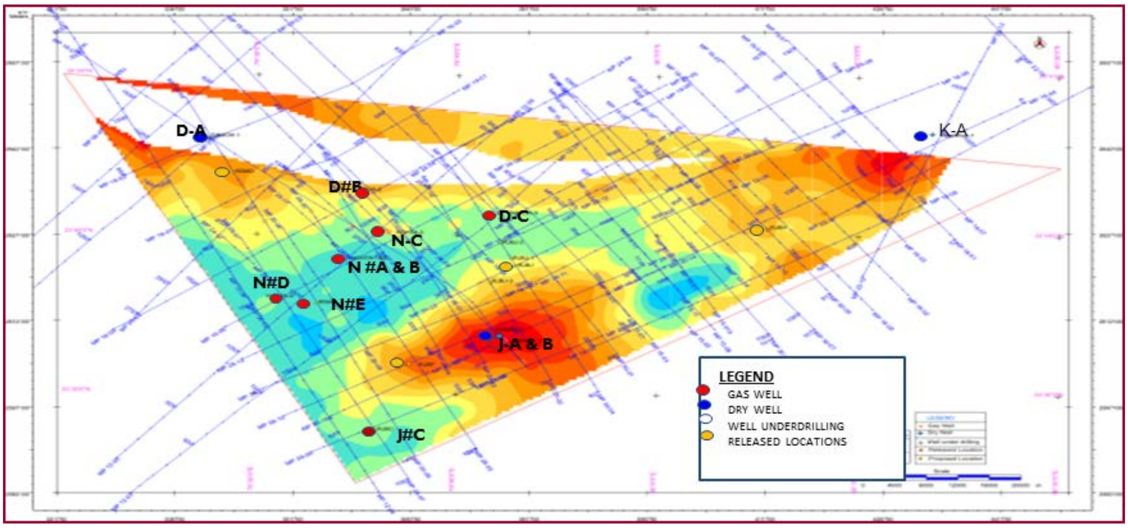

Fig 2. Time relief map on Rohtas Top showing the wells in Damoh-Jabera-Katni block, considered in present studies

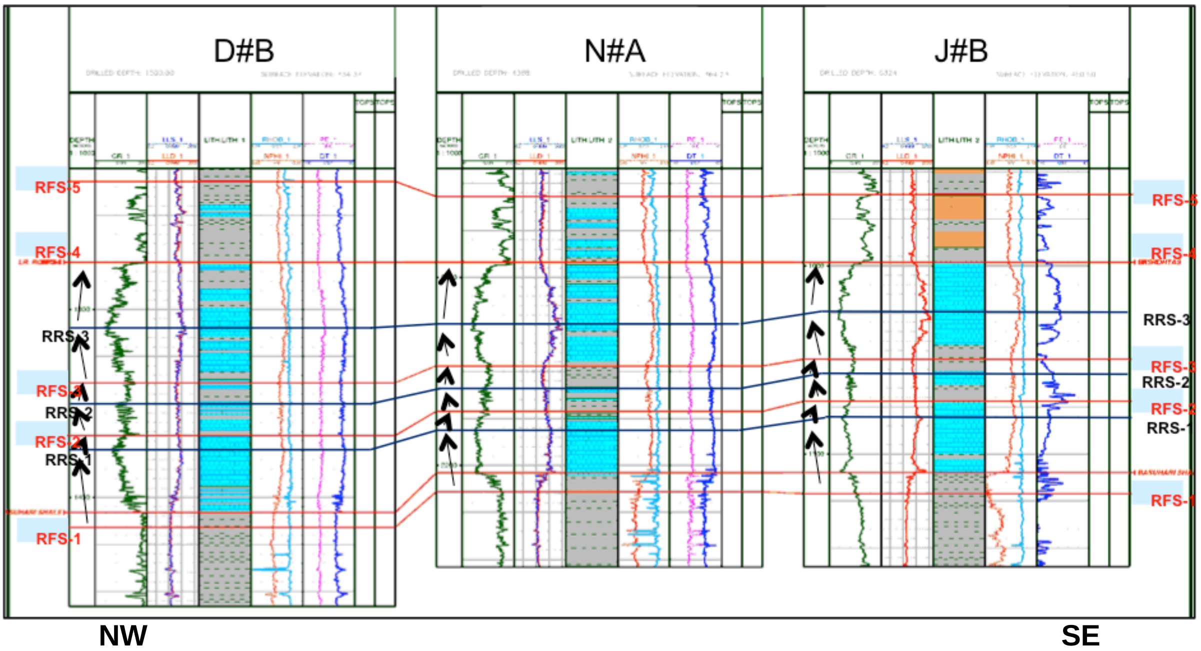

Fig.3. Electrolog correlation through wells D#B, N#A and J#B showing the identified higher order T/R cycle within Lower Rohtas unit.

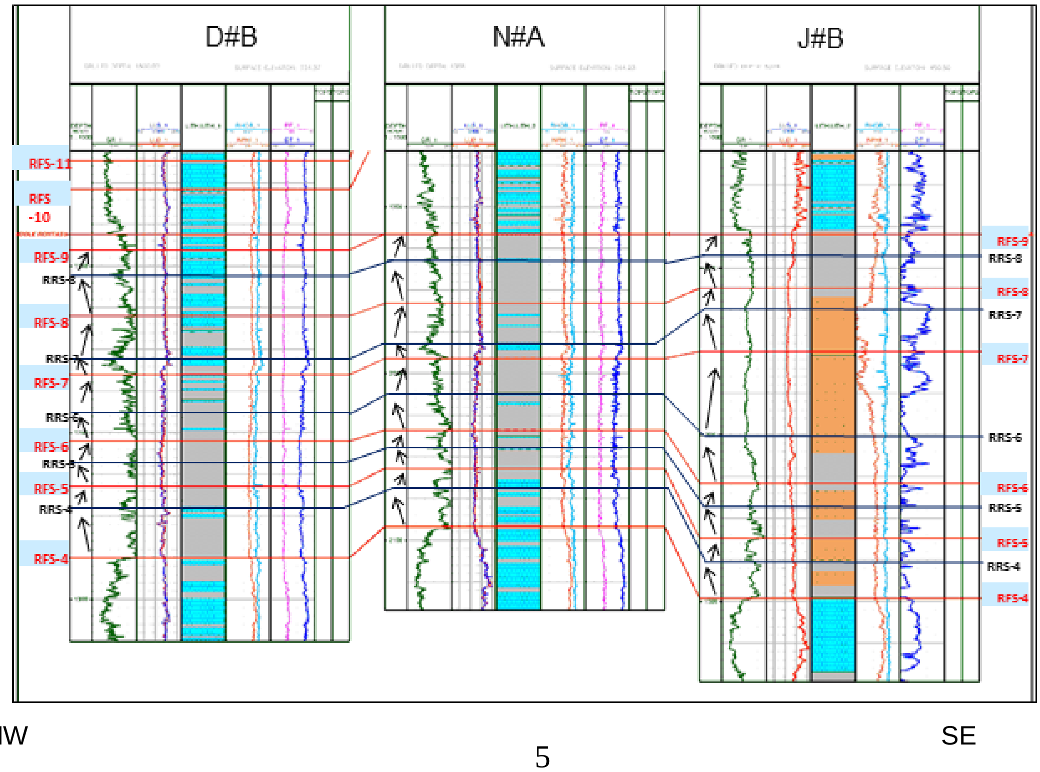

Fig.4 Electrolog correlation through wells B#B, N#A and J#B showing identified higher order T/R cycles within Middle Rohtas Unit.

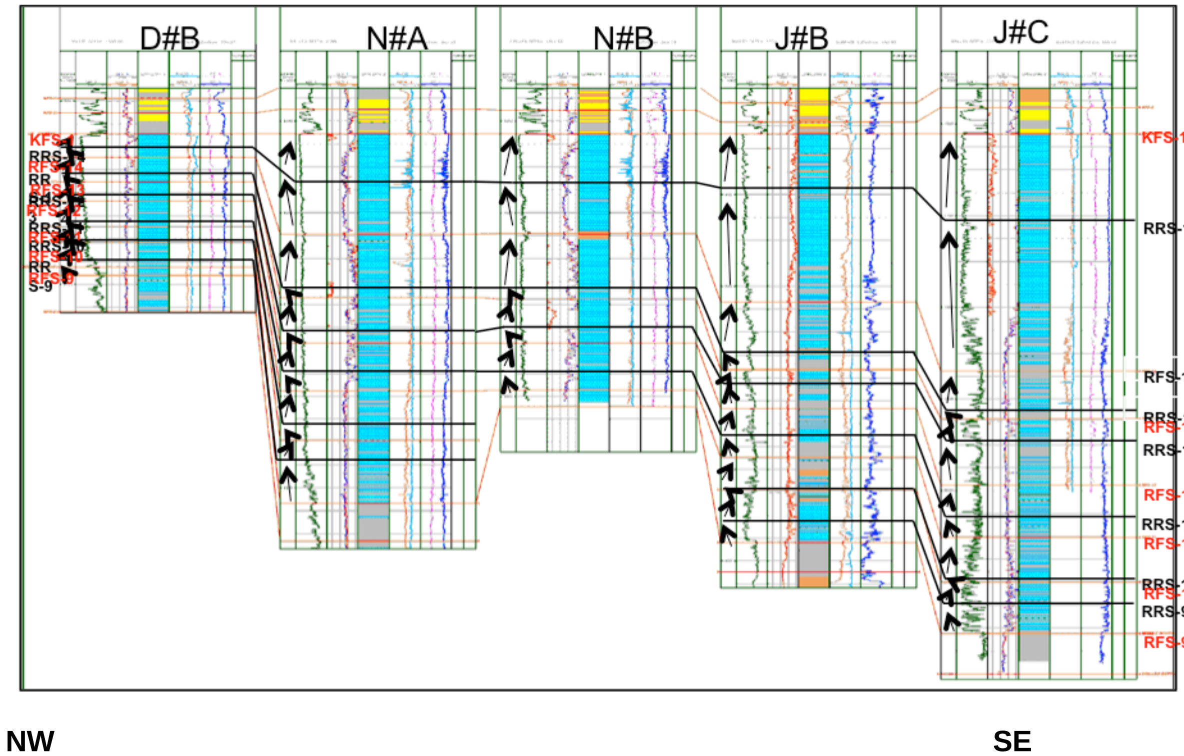

Fig.5. Electrolog correlation through wells D#B, N#A, N#B,J#B and J#C showing the identified higher order T/R cycles within Upper Rohtas Limestone.

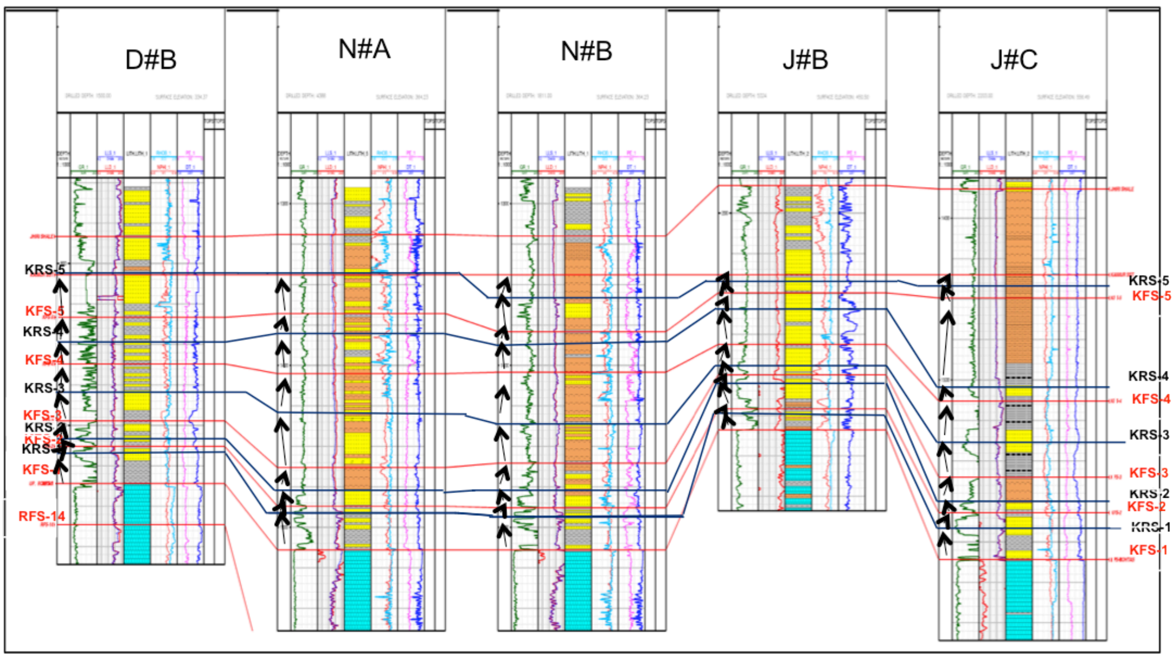

Fig.6. Electrolog correlation through wells D#B, N#A , N#B,J#B & J#C showing the identified higher order T/R cycles within Kaimur Sandstone