Presence of Bijawars in Damoh and Jabera grabens and its implication on hydrocarbon exploration in Son Valley, Vindhyan Basin

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Abstract

Recent discovery and flow of gas from Jardepahar Porcellanite has brought the focus of hydrocarbon exploration in the Paleo-Neo Proterozoic Vindhyan Basin back to the deeper hydrocarbon plays. In such a scenario, the tectono-sedimentary evolution of the major depo-centres, which are envisaged to act as kitchen, plays a very crucial role in decision-making for selection of the sweet spots for future exploratory activities in the Basin. Bijawars have been envisaged to be present below the Lower Vindhyan rocks by earlier workers, however, poor seismic imaging provided very little help in resolving the true picture. Acquisition of new data and advanced re-processing techniques have brought to fore the Bijawars which have recently been mapped regionally. Based on seismic and well data analyses, the present study brings out the evolution of the Jabera and Damoh lows vis-à-vis presence of an unconformity surface transforming into disconfirmity /correlative-confirmity (?) towards the depocentres. The presence of this sequence and it's continuity into the two major depocentres - Damoh and Jabera which have long been envisaged as the major source-pods has a major bearing on the exploratory paradigm and could bring about a major change in the envisaged petroleum system and resource estimation of hydrocarbons in the study area.

Key words: *Vindhyan, Bijawar, Semri, Kajrahat, Jabera, Damoh*

1. Introduction

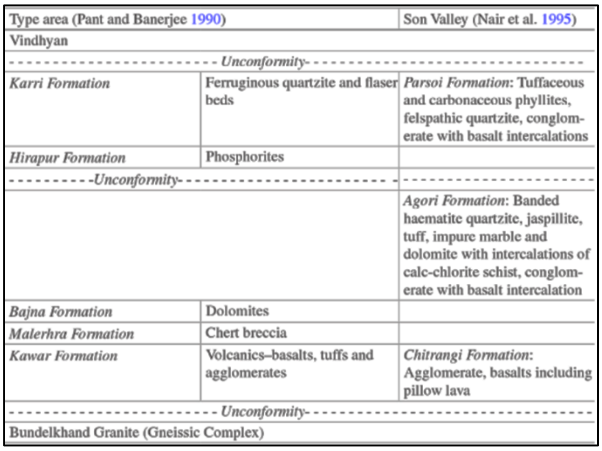
The Palaeo-Neo Proterozoic Vindhyan Basin located in the Central part of India is among the oldest sedimentary basin under active hydrocarbon exploration. The envisaged multiple petroleum systems strengthened with the recent discoveries has further led to aggressive exploratory efforts in the basin. Vindhyans are known to be deposited unconformably over the Paleo-Proterozic Bijawar / Mahakoshal Group of rocks along northern and southern extremities of the Son Valley. These meta-pelites are partially deformed and believed to continue below the Vindhyan package in the area in isolated grabens.

The Damoh and Jabera inversion structures have been of keen interest for hydrocarbon exploration and were among the first structures probed for hydrocarbon presence in the Vindhyan Basin. The inversion structures are representative of the multi-phase evolution of the basin.

New seismic data acquisition and re-processing of existing seismic data has given new in-sight into the understanding of geology of the area, particularly in the two depocentres where differentiation of Bijawars in the package earlier understood as Vindhyans can bring a remarkable shift in our understanding of the GME cycle and consequently the resource estimation.

2. Stratigraphy

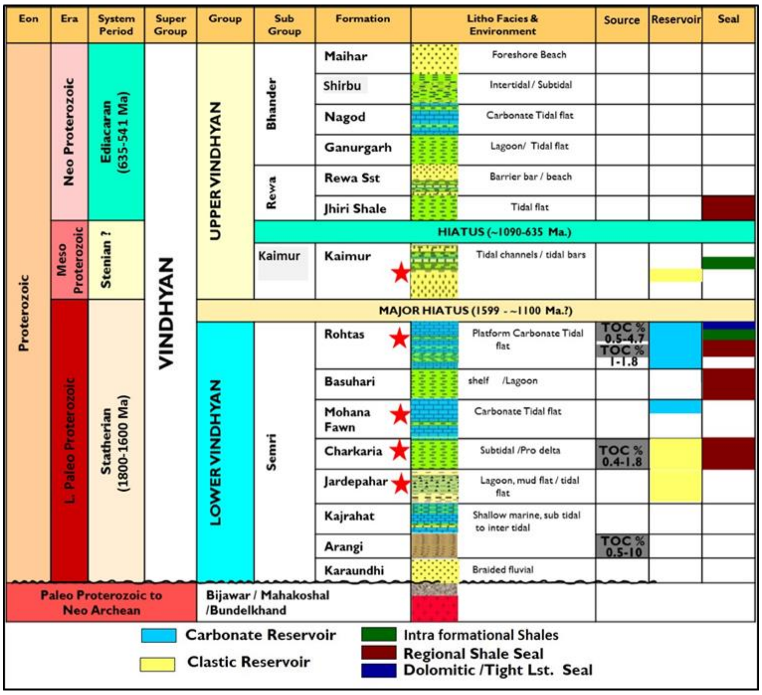
Resting unconformably upon the Archean Gneissic Complex, the Bijawar / Mahakoshal meta-sedimentary succession is somewhat variable in different areas of Vindhyan Basin. The succession broadly comprises of conglomerates, greywackes, ferruginous or locally manganiferous quartzites, dolomitic limestones, chert breccia and basic lavas. The stratigraphic differentiation is more pronounced in eastern Son Valley in Mirzapur, Sonbhadra and Sidhi districts of UP and MP respectively. A brief litho-stratigraphy of Bijawars/ Mahakoshal is given in **Table-1**.



Type area (Pant and Banerjee 1990)		Son Valley (Nair et al. 1995)
Vindhyan		
- - - - - - - - - - - - *Unconformity*- - - - - - - - - - - -		
Karri Formation	Ferruginous quartzite and flaser beds	*Parsoi Formation*: Tuffaceous and carbonaceous phyllites, felspathic quartzite, conglomerate with basalt intercalations
Hirapur Formation	Phosphorites	
- - - - -*Unconformity*- - - - - - - - - - -		- - - - - - - - - - - -
		Agori Formation: Banded haematite quartzite, jaspillite, tuff, impure marble and dolomite with intercalations of calc-chlorite schist, conglomerate with basalt intercalation
Bajna Formation	Dolomites	
Malerhra Formation	Chert breccia	
Kawar Formation	Volcanics–basalts, tuffs and agglomerates	*Chitrangi Formation*: Agglomerate, basalts including pillow lava
- - - - - - - - - - - - *Unconformity*- - - - - - - - - - - -		
Bundelkhand Granite (Gneissic Complex)		

Table-1: Litho-stratigraphy of Bijawar Group

A considerable thickness of shallow marine sedimentary sequence (2-6Km) of Vindhyans is deposited unconformably over the Bijawars/Basement in Son Valley, which is broadly divisible into carbonate dominated Lower Vindhyan (Semri Group) and clastic dominated Upper Vindhyan (Kaimur, Rewa and Bhander Groups) sequences, separated by a large hiatus. Various stratigraphic classification schemes for the Vindhyan sediments in Son Valley have been proposed by different workers. ***Fig-1*** details the stratigraphic nomenclature along with the level wise gas discoveries established so far and the envisaged petroleum system elements.



Eon	Era	System Period	Super Group	Group	Sub Group	Formation	Litho Facies & Environment	Source	Reservoir	Seal
Proterozoic	Neo Proterozoic	Ediacaran (635-541 Ma)	VINDHYAN	UPPER VINDHYAN	Bhander	Maihar	Foreshore Beach			
						Shirbu	Intertidal / Subtidal			
						Nagod	Carbonate Tidal flat			
						Ganurgarh	Lagoon/ Tidal flat			
					Rewa	Rewa Sst	Barrier bar / beach			
						Jhiri Shale	Tidal flat			🟥
					HIATUS (~1090-635 Ma.)					
	Meso Proterozoic	Stenian ?			Kaimur	Kaimur ★	Tidal channels / tidal bars		🟨	🟩
				MAJOR HIATUS (1599 - ~1100 Ma.?)						
	L. Paleo Proterozoic	Statherian (1800-1600 Ma)		LOWER VINDHYAN	Semri	Rohtas ★	Platform Carbonate Tidal flat	TOC % 0.5-4.7 TOC % 1-1.8	🟦	■ 🟩 🟥
						Basuhari	shelf /Lagoon			🟥
						Mohana Fawn ★	Carbonate Tidal flat		🟦	
						Charkaria ★	Subtidal /Pro delta	TOC % 0.4-1.8	🟨	🟥
						Jardepahar ★	Lagoon, mud flat / tidal flat		🟨	
						Kajrahat	Shallow marine, sub tidal to inter tidal			
						Arangi		TOC % 0.5-10		
						Karaundhi	Braided fluvial			
Paleo Proterozoic to Neo Archean				Bijawar / Mahakoshal /Bundelkhand						

🟦 Carbonate Reservoir
🟨 Clastic Reservoir
🟩 Intra formational Shales
🟥 Regional Shale Seal
■ Dolomitic /Tight Lst. Seal

Fig.1: Stratigraphy and Petroleum System elements along with reported gas discoveries in Son Valley sector of Vindhyan Basin

3. Geological setting and present understanding of basin evolution

The arcuate-shaped Vindhyan Basin in the central part of India ***(Fig.2)*** contains a thick sequence of shallow marine clastic and carbonate sediments belonging to Paleo–Neoproterozoic age. The Vindhyan Basin is bordered by Aravalli–Delhi orogenic belt in the west, Son-Narmada- lineament (SNL) in the south-west and Satpura orogenic belt in the south-east. Bundelkhand Massif, occupying the north-central part, divides the basin into two sectors: Son Valley to the east and Chambal Valley to the west.

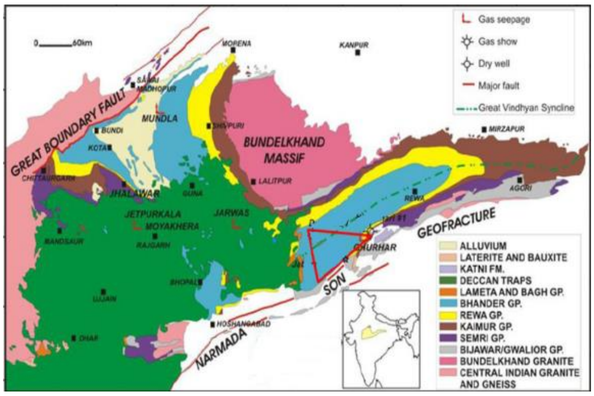


Fig. 2: Geological map of Vindhyan basin showing area of study.

The Vindhyan strata of Son Valley define a broad ENE–WSW trending regional syncline in the central part. The axis of the syncline is slightly curved and plunges gently towards west. The subsurface tectonic configuration brought out from integrated analysis of surface geological maps, residual gravity anomaly maps and seismic data indicates that the basin is generally dipping towards south with the major gravity lows occurring close to the SNL. A series of ENE-WSW trending gravity highs and lows are seen between Bundelkhand Massif in the north and 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.

Tectonic evolution of the basin is evident along key regional seismic section ***(Fig.3)*** from Jabera graben in the SE and passing through Nohta high, Damoh graben and further north-west towards Bundelkhand Massif. The basin has evolved through a poly-phase geological history. Initial tectonic evolution of the basin is controlled by basement related rift tectonics, which formed a number of horst and grabens. This is followed by compressional reactivation of pre-existing extensional faults under the influence of wrench related strike–slip movement from post-Jardepahar culminating at Rohtas which resulted in the formation of major inversion structures.

The Vindhyan group of rocks, interpreted as predominatly marine, were apparently deposited in a roughly E-W elongated basin where an approximate balance between the rates of creation of accommodation space and net sedimentation are apparent as the group is replete with shallow water features.

In the early rift phase, coarser clastic supply from the raised hinterlands and inter basinal highs into the basin margin areas are evident in Karaundhi Formation. In the deeper basinal areas, organic rich source rich shale got deposited as seen in Arangi Formation. Major sediment supply was from the south in the Jabera graben where as it was from the northern side in the Damoh graben. The lower part of Lower Vindhyan (Semri Group) consisting of Kajrahat, Jardepahar and Charkaria formations, overlying the Base of Vindhyans, represent an alternating transgressive-regressive depositional cycles in a shallow Proterozoic sea with carbonate build up (Kajrahat) followed by a period of sub-marine and sub-aerial volcanism (Jardepahar) and overlain by a thick regionally pervasive transgressive, monotonous, drak grey to black Charkaria Shale. This stratigraphic unit represents huge deposition of shale (MFS?) in the available accommodation spaces represented by grabens. By the end of Charkaria, the entire syn-rift set-up was covered by thick argillaceous deposition. The overlying Mohana Fawn Limestone got deposited in an intertidal regime under a carbonate flat set up which witnessed intermittent sea level fluctuations. There was a phase of clastic invasion at the top of Mohana Fawn Limestone leading to the deposition of Basuhari Formation. During this time, clastic input into the Jabera and Damoh graben were from the south and north respectively. Subsequently, a Carbonate platform was extensive during which Rohtas Limestone was deposited all along the basin. There was a hiatus after this, which is marked by a regional unconformity between Lower and Upper Vindhyan.

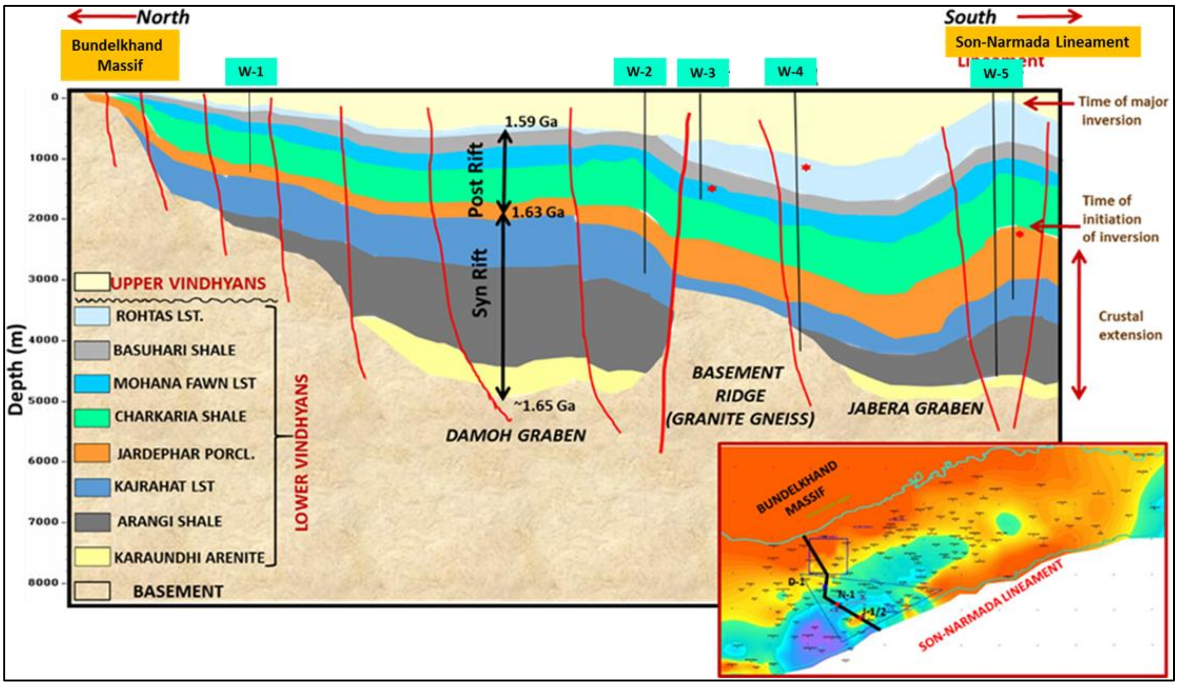


Fig. 3: Seismo-geological section showing present understanding of basin configuration in Son Valley, Vindhyan Basin

4. Details of the present study

4.1 Evaluation of Seismic Data

The newly acquired 2-D seismic in NELP Block VN-ONN-2009/3 and re-processing of older 2-D lines of Hatta area brought out an unconformity below the mapped Kajrahat Top not known previously. This unconformity was mapped based on existing 2-D lines and is found to be extending down not only into the adjacent Damoh graben but further south in the Jabera graben as well as a disconformity(?) as visible based on seismic data ***(Figs. 4 and 5)***. The mapping was initially tried in down-dip direction across wells W-1, W-2, W-4 and W-5 but the Vindhyans are deposited directly on the Basement over the intervening Nohta horst and the Bijawar-Vindhyan unconformity therefore does not continue across the same. Analysis of more dip lines across the Son Valley sector reveals the unconformity again at the Kharkhari high structure which is also a basement high. The unconformity is thus correlatable from Hatta area in North extending down into the Jabera graben in South.

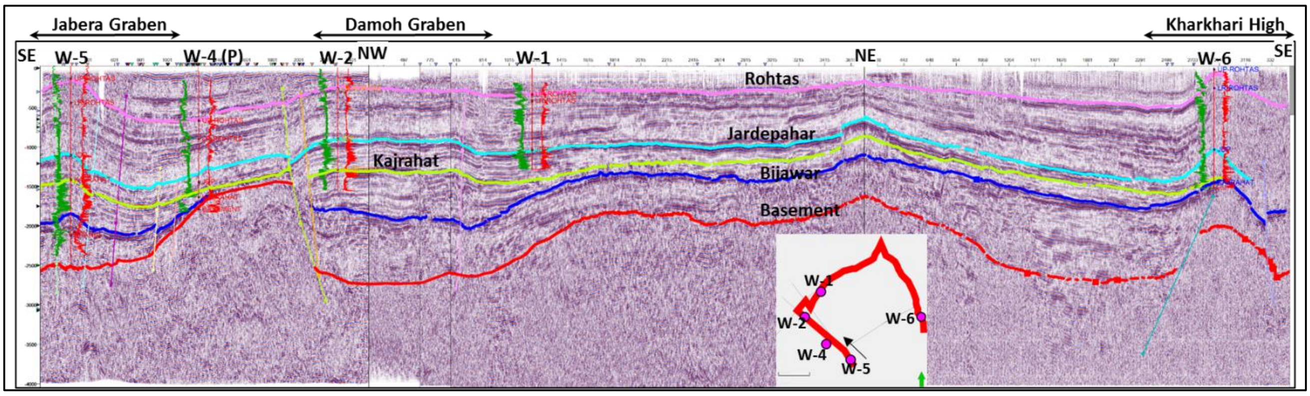


Fig. 4: Seismic section across wells W-1, W-2, W-4, W-5 and W-6 showing configuration of the formations. The Bijawar-Vindhyan unconformity is seen as angular contact below wells W-1 and W-6 (basement highs) and appears as disconformity (?) in the Damoh and Jabera grabens. Note: Well W-4 is projected on the section.

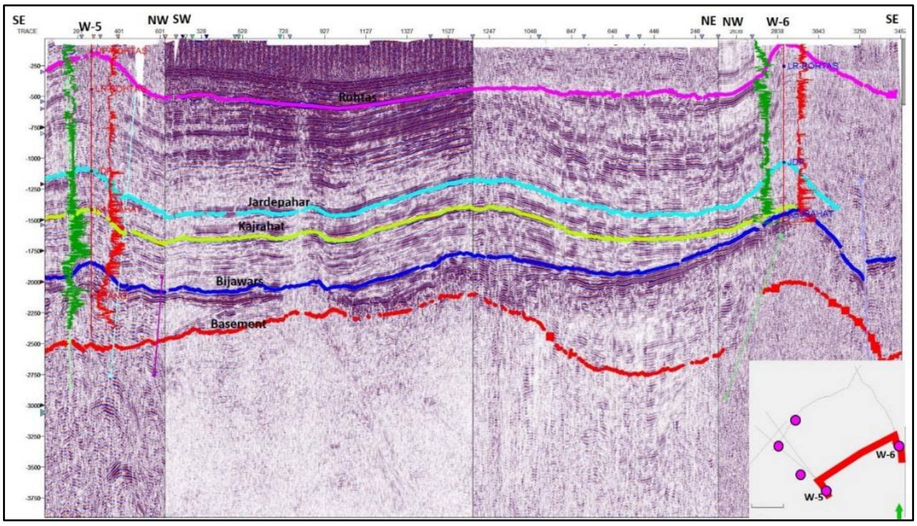


Fig. 5: Seismic section across wells W-5 and W-6 showing the nature of Bijawar-Vindhyan unconformity (blue colour)

Correlation of this mapped level with Well-5, deepest well of the area, shows the layer to be present inside the known Kajrahat Limestone with Arangi shale being encountered further below. Further studies therefore was carried to understand the nature of this unconformity and thereby it’s implication on exploration. Correlation of seismic could not be carried out with surface exposure of Bijawars due to poor data quality towards basin margin areas.

Seismic attribute analysis along 2-D seismic shows continuity of the Reflection Intensity attribute along the mapped Bijawar both in dip and in strike direction, thereby further validating the seismic correlation ***(Fig. 6)***.

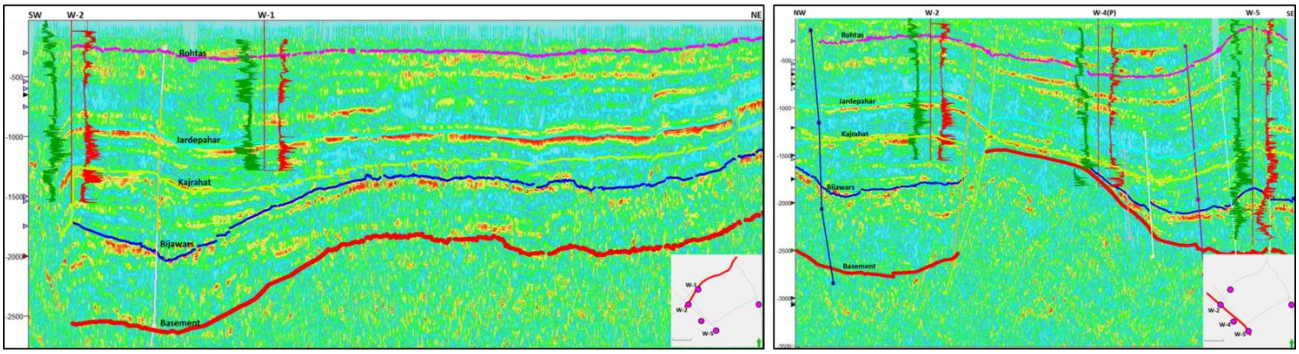


Fig. 6: Reflection Intensity showing continuity of Bijawars along regional strike line (left) and dip line (right).

4.2 Evaluation of Well Data

W-5 is the only well available which has cut across the mapped unconformity surface. Evaluation of this well data reveals further supporting evidences for the mapped unconformity.

a. Sedimentological analysis of drill cuttings

- Drill cuttings in interval 4020 – 4624 m shows carbonised black shale/mudstone in association with Cherty & Ferriferous Cherty Limestone. These limestones at places show evidences of late diagenetic replacement by reddish oxides of iron ***(Fig. 7A).*** The interval marks first occurrence of iron oxides in the sequence characteristic of Bijawars.
- Graded Greywacke-carbonised Shale in the unit represents couplets of shale containing both thermally mature graphite(?) ***(Fig. 7B)*** & immature carbonaceous shale and sandstone.

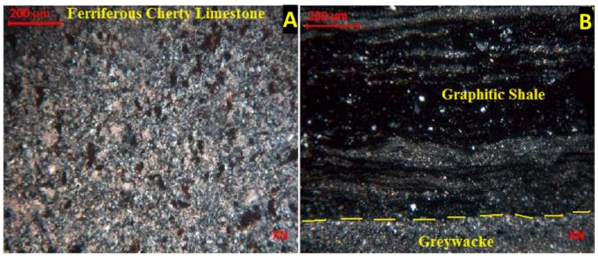


Fig.7: A. Ferriferous Cherty Limestone exhibits late diagenetic replacement by reddish brown oxides of iron; **B.** Parallel laminated couplets of black thermally mature graphitic shale and sandstones.

- Interpreted Arangi Shale (4624-5324m) sequence constitutes a monotonous unit of finer clastics hard, brittle (absence of fissility), non-calcareous claystone containing dark mud flecks, pigments of hematite and disseminated thermally mature organic debris encasing discontinuous lenses of light brown ferriferous siltstone.
- Micro-facies analysis further reveals re-crystallization and modification of clay minerals in which grain size remains microscopic but new preferred orientations develop in response to stresses. Modified fabric thus exhibits preferred oriented sericite clay groundmass containing variable proportions of floaters; such as fused silt grains, carbonized flecks, chert and Fe-claystone clasts which is characteristic of Bijawar metasediments ***(Figs. 8 A & B)***.

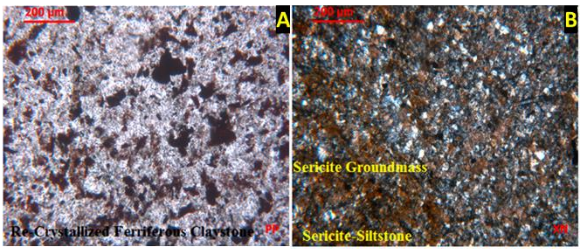


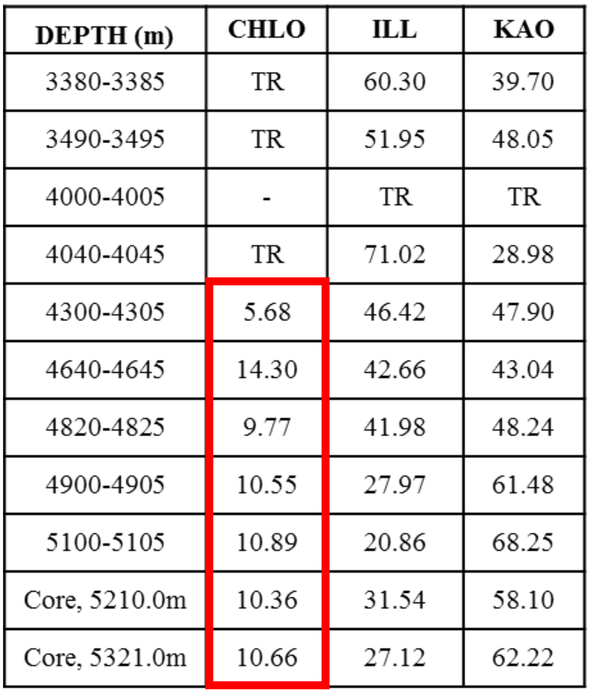
Fig.8: A. Re-crystallized ferriferous claystone containing abundant hematite pigments; **B.** Re-crystallized silty containing fused silt grade quartz grains set in groundmass essentially composed of sericite clay groundmass.

b. Analysis of conventional cores

- Conventional core analysis (5210-5213.50m) shows presence of reddish brown, compact and brittle shale impregnated with dark disseminated thermally mature (carbonized) organic debris and encasing fused silt laminae.
- Micro-facies reveals shale/silty shale contain re-crystallized clay matrix with preferred orientation containing fused silt, chlorite patches, sericite specks and dark hematite pigments imparting red coloration. Sediments were subjected to re-crystallization and modification of textures at greater depth of burial suggesting onset of metamorphism.
- Cored interval (5321-5324m) represents greenish grey, brittle (fissility destroyed) shale exhibiting diffuse laminations and impregnated with carbonized organic debris/pyrite. Silt is grey, very brittle, non-calcareous and displays segregation of dark neo-formed minerals. Relict sedimentary textures visible.
- Petrographically both cores show re-crystallized and modified clay matrix with preferred orientation in which phyllosilicate groundmass transformed from clay minerals to muscovite shreds and chlorite imparting (green coloration) along with tiny dark ferriferous clay clasts.

c. XRD Clay Mineralogical Analysis

- XRD analysis in the interval 4020-5100m indicates ≤10% chlorite, kaolinite and illite almost in the same amount (≥40%) with first appearance see at 4300m from among samples studied ***(Table 2)***.
- Clay and bulk mineral analysis of conventional cores indicates 10% chlorite, 38% illite and its poly-types and 52% kaolinite along with mixed iron-rich phyllosilicate, iron-rich carbonates and Fe-oxides (Figure-18).
- Micro-probing (BSE/EDAX) analysis further corroborates XRD studies and shows high weight percent of elemental Fe, O, Si & Al along with elemental K and Mg both in cores and cuttings below 4020m. This suggests presence of mixed Fe-oxides/carbonates and Fe-phyllosilicate along with chlorite-illite and kaolinite.



DEPTH (m)	CHLO	ILL	KAO
3380-3385	TR	60.30	39.70
3490-3495	TR	51.95	48.05
4000-4005	-	TR	TR
4040-4045	TR	71.02	28.98
4300-4305	5.68	46.42	47.90
4640-4645	14.30	42.66	43.04
4820-4825	9.77	41.98	48.24
4900-4905	10.55	27.97	61.48
5100-5105	10.89	20.86	68.25
Core, 5210.0m	10.36	31.54	58.10
Core, 5321.0m	10.66	27.12	62.22

Table 2: Clay Mineralogical Analysis of well W-5

d. Evaluation of Shale Density and Shale Factor

Shale density is the result of physical, chemical, and mineralogical phenomena in the subsurface and is governed mainly by the burial depth, provided that the fluid pressure is near hydrostatic, or the shales are at near compaction equilibrium. If the fluid pressure is higher than normal hydrostatic, shales are compacted less than those compacted normally under the hydrostatic pressure. When the area being investigated has undergone a significant uplift and erosion, the normal shale compaction trend is shifted to the direction of increased compaction and vice-versa for area which has undergone subsidence and loading, in comparison with the trend in an area of no erosion. The amount of erosion and the maximum burial depth can then be estimated on the basis of shale compaction data (Developments in Petroleum Science, Volume 9, 1978).

Shale factor is a measure of the Cation Exchange Capacity (CEC) of the shale. The CEC of shale increases with the montmorillonite content. This is in turn dependent on the level to which conversion from montmorillonite to illite has taken place. In normal compaction trend line, the montmorillonite should decrease with depth as it is converted to illite. Under-compacted shales are characterized by higher montmorillonite content as compared to normally pressured shales of the same depth. Hence, a plot of the shale factor against depth may show an increase away from the normal compaction trend line across unconformity.

In the well W-5, shale density and shale factor values were continuously monitored along the shale sections from depth of 490m to the drilled depth ***(Fig. 9)***. Both the parameters show similar trends till the upper part of the interpreted Kajrahat Formation. The shift in both shale density and shale factor trends show a sudden change in the compaction behaviour below 4050 which closely correlates to the unconformity correlated on seismic.

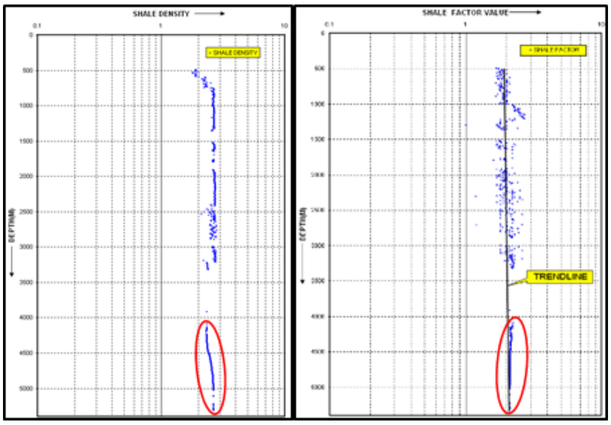


Fig. 9: Shale Density (left) and Shale Factor recorded in well W-5 showing anomalous trend (circled in red)

e. Evaluation of Electro-log Data

XRMI log recorded in well W-5 in the interval 3101.5 – 4102 m and processed/interpreted by the service providers HLS Asia Ltd. indicates unconformity plane at 4020m which is indicated by sudden change in dip amount and direction at the said depth ***(Fig.10)***.

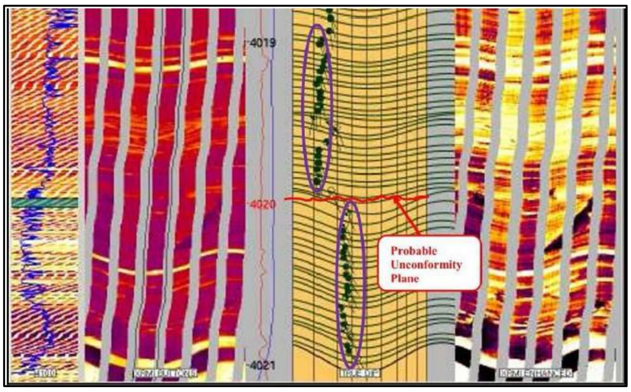


Fig. 10: Processed XRMI log of well W-5 showing sudden change in dip direction and amount.

5. Conclusions

- Presence of an unconformity is seen in seismic at basement highs in Hatta and Kharkhari areas which has been correlated with nearby deeper wells based on available seismic.
- The unconformity layer is found to cut across the known Kajrahat Limestone in well W-5.
- Analysis of cuttings in well W-5 below the mapped unconformity indicates occurrence of iron-oxide and thermally mature graphite (?) which is indicative of the ferruginous quartzites and phyllites of Parsoi Formation of Bijawar meta-sediments.

- The deeper shale sequence shows absence of fisslilty and reveals re-crystallization and modification of clay minerals with development of new preferred orientations in response to stresses. Modified fabric thus exhibits preferred oriented sericite clay groundmass containing variable proportions of floaters; such as fused silt grains, carbonized flecks, chert and Fe-claystone clasts.
- Analysis of conventional cores shows presence of reddish brown iron rich shale encasing diffused silt laminae and shows relict sedimentary textures which is not characteristic of the Arangi shales exposed in Son Valley.
- Micro-facies reveals re-crystallized and modified clay matrix with preferred orientation in which phyllosilicate groundmass is transformed from clay minerals to muscovite shreds and chlorite imparting (green coloration) along with tiny dark ferriferous clay clasts (red colouration) suggesting greater depth of burial and onset of low-grade metamorphism representative of Bijawars.
- XRD analysis for clay mineralogy further corroborates above studies and shows occurrence of chlorite below 4300m.
- Evaluation of shale density and shale factor reveal a clear shift in the trend below 4050m from that observed above which is indicative of change in sedimentation history.
- XRMI log indicates presence of an unconformity at 4020m which is indicated by sudden change in dip amount and direction.
- In the absence of any known unconformity within Semri sub-group, the mapped unconformity and characteristics of the formation encountered below clearly point towards presence of Bijawars in the grabens ***(Fig. 11)***.
- Presence of these meta-sediments in the package earlier envisaged to contain more than 800m of source rock sequence, brings a major shift in the envisaged petroleum plays and estimated hydrocarbon resource.

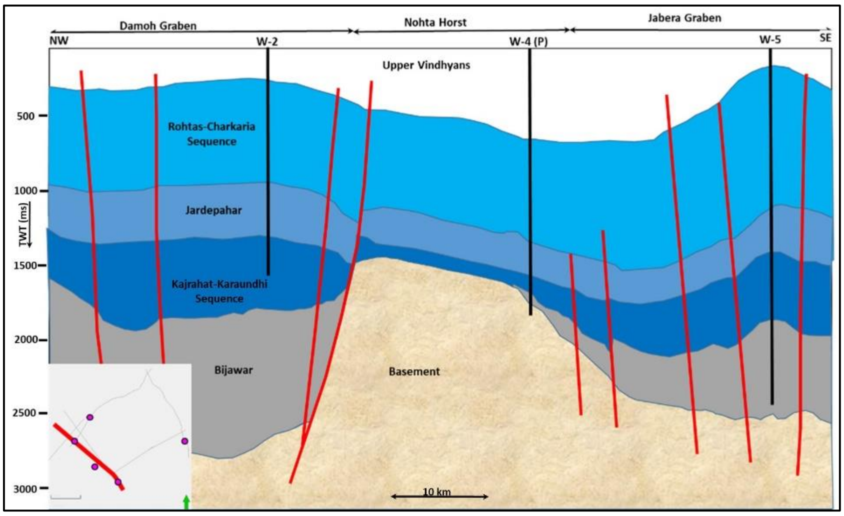


Fig. 11: Seismo-geological section based on present work showing presence of Bijawars in Damoh and Jabera grabens

6. Acknowledgement

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