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Fracture characterization within Rohtas Formation and its role in hydrocarbon distribution in Son Valley, Vindhyan Basin, India

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Abstract

With the days of easy hydrocarbons over, the industry is consciously shifting its focus towards unconventional and tight reservoirs. The present study brings out a detailed model of fracture distribution in tight and low permeability reservoirs within Rohtas Limestone in Son Valley, integrating analysis of fracture type, distribution, intensity and orientation from XRMI logs of drilled wells along with seismic derived fault/fracture patterns as well as outcrop fracture and lineament trends.

The fracture trends within Lower and Upper Vindhyans are broadly similar; however, the Lower Vindhyans exhibit minor variations in stress direction due to episodic compressional events Majority of fractures within Rohtas Formation in the Nohta area in wells Nohta#A, B, C and Damoh#C are either open or partially open. In well Jabera#C, located on the rising flank of Jabera low, almost all fractures are partially open. In wells Damoh#A and B a significant number of closed fractures are observed, which may be attributed to secondary mineralization by diagenetic fluid around Damoh High. Two major fracture trends, viz. ENE-WSW (parallel or sub parallel to Son-Narmada Lineament) and NW-SE (oblique to Son-Narmada Lineament) are observed. The inferred compressive stress direction for Rohtas Formation was ENE-WSW ($\sigma 1$: 80-87.5^{0}) to E-W ($\sigma 1$: 92.5-97^{0}) and tensional stress direction was N-S to NNW-SSE ($\sigma 3$: 350^{0} to 07^{0}). In areas close to intersection of the major faults, a considerable enhancement in fracture corridors over the background fracture are observed.

Since the gas accumulation within Rohtas and Basal Kaimur reservoirs is primarily controlled by fracture driven secondary porosity, a detailed attribute based mapping of the fracture corridors as part of the upcoming 3D seismic interpretation is likely to provide a significant exploratory breakthrough in Son Valley, Vindhyan Basin.

Key words:*Fractures, Tight gas, Stress directions*

Introduction

Presence of gas within Rohtas Limestone and Basal Kaimur Sandstone reservoirs of Proterozoic age in Son Valley, Vindhyan Basin has been established through a number of recent exploratory wells. These are typical *unconventional tight gas reservoirs* having very low porosities, ultra low permabilities (mili-micro Darcy) and low reservoir pressure. Flow of gas from these reservoirs is primarily dependant on the presence of open /partially open fractures. A detailed model of fracture distribution is critically important in such tight and low permeability fractured reservoirs, because even a very small value of permeability is sufficient for production of gas from such reservoirs. It is necessary to relate geometrical information derived from image logs in wells to outcrop geological characteristics and fault/fracture trends mapped through seismic imaging to generate a holistic fracture reservoir model.

Methodology

All the available data pertaining to the intensity, orientation and aperture of fractures within Rohtas Formation in part of Son Valley has been synthesized integrating outcrop, seismic as well as well data. The lineament and fracture data generated on outcrop studies by earlier workers (Banerjee et.al, 2002 and Samal et.al 2005) were plotted as rose diagrams and the principal stress directions were determined within different formations of Lower and Upper Vindhyan. In order to correlate the fracture trends observed in outcrop with the sub surface data, XRMI logs of wells Nohta#A, B, C, Damoh#A, and Jabera#C were studied for determining the fracture intensity, aperture and directions within Rohtas Formation. The results obtained from the above analyses were integrated with the fault and fracture trends mapped in the study area using 2D and 3D seismic data.

Tectonic Framework

The Vindhyan strata of Son Valley define a broad ENE–WSW trending regional syncline. The axis of the syncline is slightly curved (convex towards north) and plunges gently towards west. The tectonic sedimentation limit of Vindhyan Basin in south and south-east is marked by the Son Narmada Lineament (SNL), which is a major geofracture formed along the Archean structural trends and remained active throughout geologic history (Fig.1). Structural modelling through sequential restoration along with a detailed analysis of fault pattern and their genesis suggests a poly phase evolutionary model, beginning with an extensional tectonic regime followed by episodic compressional events. There are suggestions of an initial compressive pulse during Post-Jardepahar time, followed by relative tectonic quiescence during Charkaria, Mahona, Basuhari and Rohtas time and finally a major tectonic compressive event in post Rohtas time (end of Lower Vindhyan era) , leading to the formation of major inverted structures (Damoh, Jabera and Kharkhari).

Outcrop Lineament and Fracture trends

The fracture and lineament data from outcrop studies and remote sensing images reveal two major trends of lineaments: ENE-WSW (Parallel to SNL) & NNW-SSE (Oblique/ cross trends). Very high fracture intensity is observed along axis of Vindhyan syncline. The southern margin close to SNL is tectonically more disturbed and more fractured. Northern limb of syncline shows fewer fractures. Fractures are mostly open on the surface around Jabera and Kharkhari structures, while closing of fractures due to secondary mineralization is seen near Damoh High as well as in close vicinity of SNL. Outcrop data has brought out the presence of conjugate shear fractures as well as tension fractures. Conjugate shear fractures intersect in the axis of intermediate stress (ϭ2) with the axis of greatest principal stress (ϭ1) splitting the acute angle between the conjugate fractures Tension fractures form at right angle to the direction of least principal stress (Fig.2). Details of fracture trends and paleostress directions inferred from outcrop data is shown in Table-1. There are two preferred fracture directions within Kajrahat and Jardepahar formations (almost NE-SW and NW-SE) with the inferred compressional and tensional stress directions being 96^0-97^0 (ϭ1) and 6^0-7^0 (ϭ3) respectively. The fracture trend within Charkaria Formation shows a minor variation with the principal compressional stress direction (ϭ1) being 84^0. This may be attributed to minor fluctuation in stress regime at the end of Jardepahar tectonic event. At Rohtas-Basuhari-Mohana Fawn levels, the fracture trends show a considerable scatter. The inferred mean compressional and tensional stress directions change significantly to 112^0 (ϭ1) and 22^0 (ϭ3) respectively. This may be related to the phase of most intense tectonic pulse at the end of Lower Vindhyans. The fracture trend in the Upper Vindhyans remained almost similar through different formations with maximum compressional stress directions varying between 85^0 and 95^0. Comparison of fracture trends of Lower and Upper Vindhyans for correlating the deformation history reveals that although the trends are broadly similar (almost E-W compressive stress and almost N-S tensional stress), the Lower Vindhyans exhibit minor variations in stress direction corresponding to the tectonic episodes close to Late Jardepahar and post Rohtas times. The Upper Vindhyans, on the other hand, show no significant variation in tectonic stress directions (Fig.3).

Fracture trends from seismic analysis

The fault pattern mapped on the basis of 2D seismic data in the area of present study has brought out two main fault alignments. A number of collinear faults have developed parallel / sub parallel to SNL (E-W to ENE-WSW) which appear to be genetically associated with the major geofracture. Although these faults originated as normal faults during rifting stage, they were subsequently reactivated under inversion related compressional stress leading to slip reversal. Another trend is marked by a series of faults oblique to SNL (NW-SE to WNW-ESE), the most prominent among them being the Damoh fault. Superimposing the mapped fault pattern in the area of present study on the surface lineament map, it is observed that most lineaments and fractures coincide with these two sets of faults. Variance attribute map within Rohtas Formation generated from recently acquired 3D data in Nohta area also corroborates these two major fault / fracture trends (Fig.4).

Fracture trends from wells

Analysis of XRMI logs and cores of drilled wells reveal the fractured zones which acted as conduits for flow of gas (Fig.5 and 6). Fracture intensity within limestone dominated Upper Rohtas as well as shale dominated Middle Rohtas Units are comparable, suggesting fracture intensity is independent of lithology. More than 97% of fractures within Rohtas Formation in wells Nohta#A, B, C and Damoh#C are either open or partially open. In well Jabera#C, almost all fractures are partially open. In Damoh#B, a significant number of fractures (24%) are closed. In the cores of well Damoh#A, almost all the fractures are found to be sealed. Secondary mineralization by diagenetic fluid was more effective around Damoh High. The dominant fracture strike direction in wells Nohta#A and Nohta#B is ENE-WSW *(Mean: 57-227^{0}to 57-238^{0}$\pm$ 5^{0})* which is parallel to the trend of SNL. The second dominant trend is NW-SE *(Mean: 126 -306^{0} to 128 -308^{0}$\pm$ 5^{0}).* The dominant fracture strike direction in wells Damoh#B, C and Jabera#C is NW-SE *(Mean: 123-303^{0} to 134-314^{0}$\pm$ 5$^{0)}$* which is parallel to the trend of Damoh oblique fault. The second dominant trend is NE-SW *(Mean: 41 - 221^{0} to48 - 228^{0} + 5^{0}).* The fracture trend in well Nohta#C shows a variation with the dominant fracture strike direction being W*NW-ESE (Mean: 117-297^{0}$\pm$ 5^{0})* and second dominant strike is NE-SW *(Mean: 43-^{0}$\pm$ 5^{0}).* This may be attributed to changing orientation and magnitude of stress distribution at the intersection of two major fault alignments. This is corroborated by the presence of very high percentage of open fractures in this well. The inferred compressive and tensional stress directions for Rohtas Formation was ENE-WSW (σ1:80-87.5^{0}) to E-W (σ1: 92.5-97^{0}) and N-S to NNW-SSE (σ3: 350^{0} to 07^{0}) respectively**.**

Conclusions

Analysis of stress direction from XRMI logs, and faults trends mapped in seismic data corroborate field observations. The two major structural trends are ENE-WSW (parallel or sub parallel to SNL) and NW-SE (oblique to SNL). The Fracture trends within Lower and upper Vindhyans are broadly similar, however, the Lower Vindhyans exhibit minor variations in stress direction due to episodic compressional events. The inferred compressive stress direction for Rohtas Formation was ENE-WSW (σ1: 80-87.5^{0}) to E-W (σ1: 92.5-97^{0}) and tensional stress direction was N-S to NNW-SSE (σ3: 350^{0} to 07^{0}). In areas close to intersection of the major faults, a considerable increase in fracture intensity and variation in stress direction are observed. Since the gas accumulation and flow behaviour within Rohtas and Basal Kaimur reservoirs in Son Valley is primarily controlled by fracture driven secondary porosity, a detailed attribute based mapping of the fracture corridors using newly acquired 3D seismic data may provide a significant exploratory breakthrough in the area.

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Table 1: Outcrop Fracture trends within Lower & Upper Vindhyan in Son Valley

Group	Subgroup	Formation	Fracture Strike Directions	Inferred Paleo stress directions	
				Compressional	Tensional
UPPER VINDHYAN (MESO TO NEO PROTEROZOIC)	**Bhander**	Maihar Sandstone	NE-SW & NW-SE	E-W (σ_1: 95^o)	N-S (σ_3: 5^o)
		Sirbu Shale	ENE-WSW,WNW-ESE	E-W (σ_1: 90^o)	N-S (σ_3: 0^o)
		Nagod Limestone	ENE-WSW,WNW-ESE	ENE-WSW (σ_1: 85^o)	NNW-SSE (σ_3: 355^o)
		Ganurgarh Shale	-		
	Rewa	Upper Rewa Sandstone	ENE-WSW, NW-SE	E-W (σ_1: 95^o)	N-S (σ_3: 5^o)
		Jhiri Shale	-		
	Kaimur	Kaimur Sandstone	NE-SW & NW-SE	E-W (σ_1: 90^o)	N-S (σ_3: 0^o)
LOWER VINDHYAN (PALEO TO MESO PROTEROZOIC)	**Semri**	Rohtas Limestone	NE-SW, E-W, NW-SE	WNW-ESE (σ_1: 112^o)	NNE-SSW (σ_3: 22^o)
		Basuhari Shale			
		Mahona Fawn Limestone			
		Charkaria Shale	NNE-SSW,NW-SE	ENE-WSW (σ_1: 84^o)	NNW-SSE (σ_3: 354^o)
		Jardepahar Porcellanite	NE-SW & NW-SE	E-W (σ_1: 96-97^o)	N-S (σ_3: 6-7^o)
		Kajrahat Limestone			
		Arangi Shale	-		
		Karaundhi Arenite			
PALEO PROTERO ZOIC TO NEO ARCHEAN	**Bijawar Group**				
	Bundelkhand Gneiss				

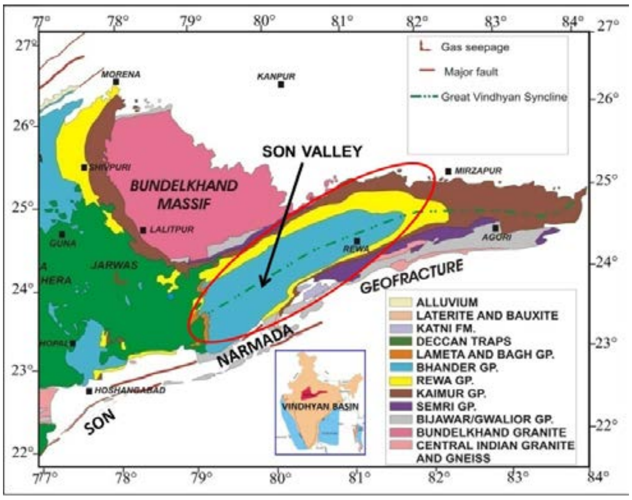

Fig.1 Geological map of Son Valley, Vindhyan Basin

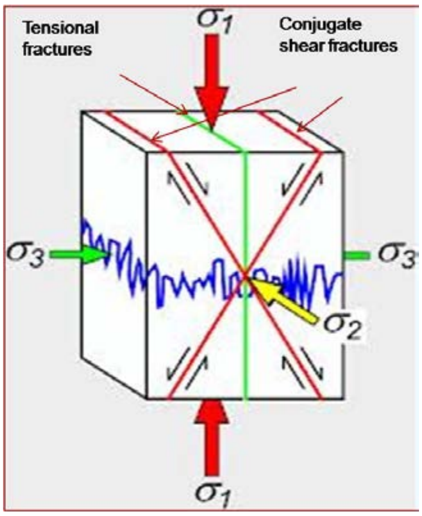

Fig.2 Principal stress directions in tensional and conjugate shear fractures

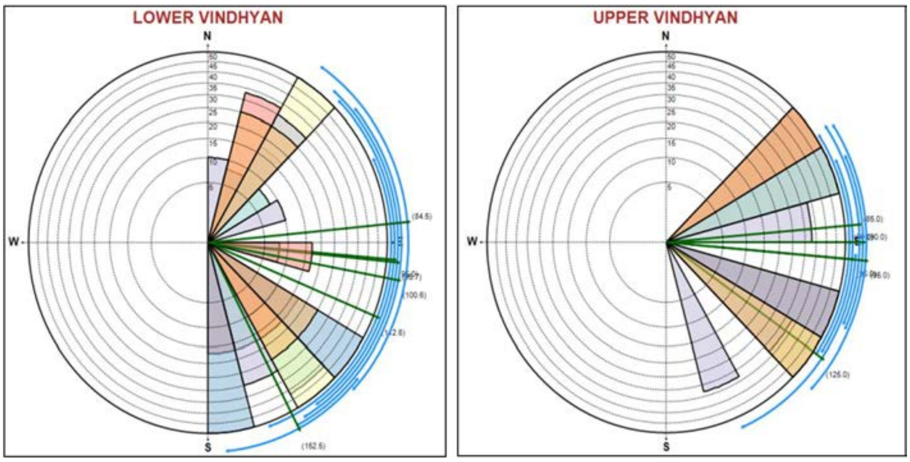

Fig.3 Comparison of outcrop fracture trends and stress directions in Lower and Upper Vindhyan

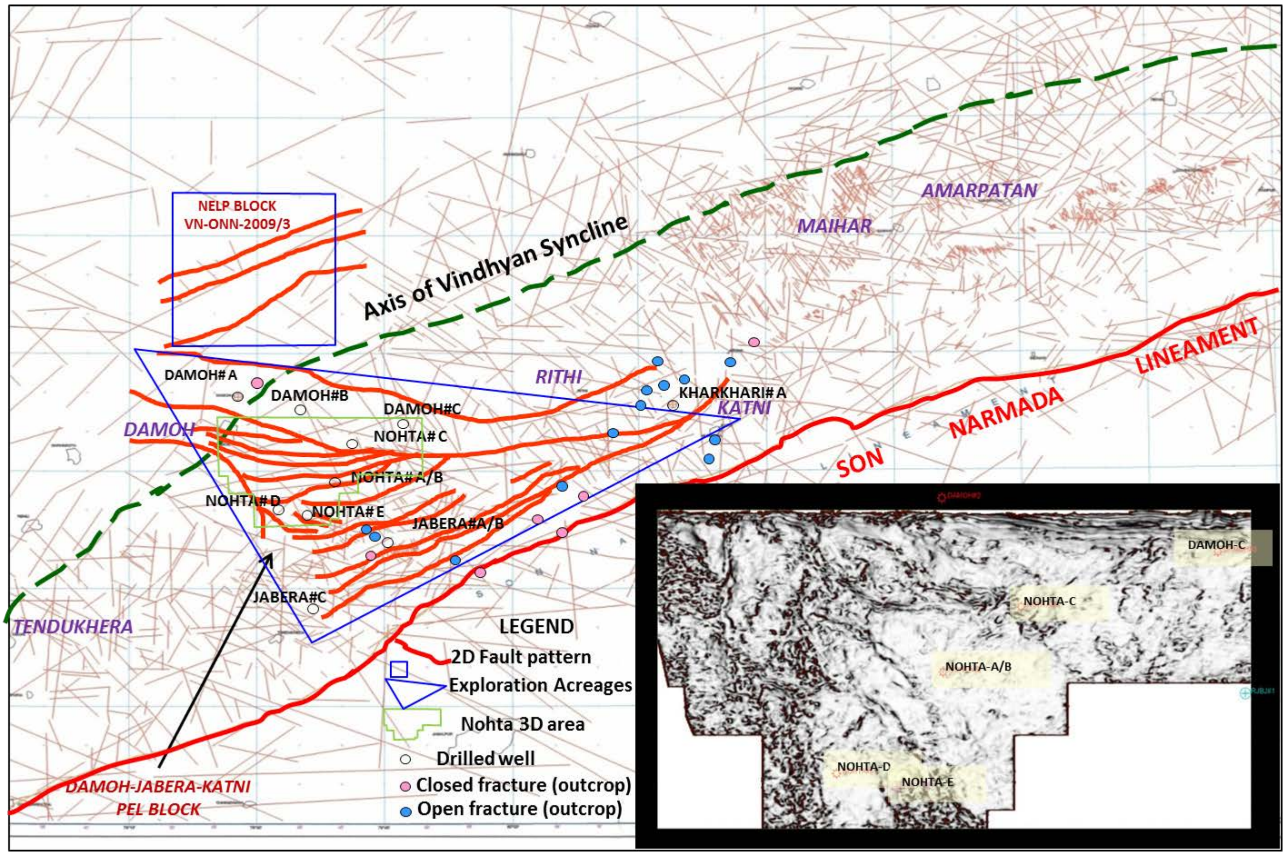

Fig.4 2D fault pattern mapped in the study area superimposed on total lineament intensity map (Banerjee et.al, 2002). Inset: Variance attribute within Rohtas Limestone in Nohta 3D area.

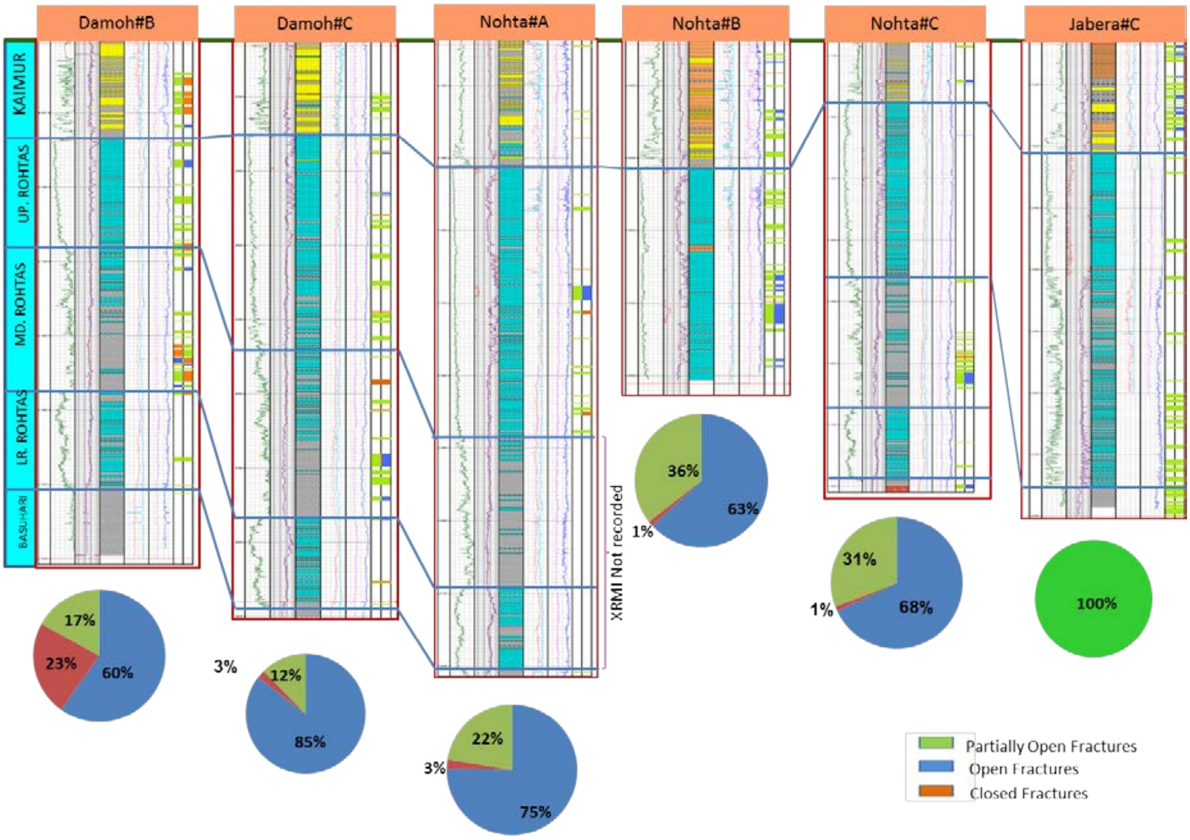

Fig.5 Fracture intensity and aperture within Rohtas Formation in drilled wells of Son Valley

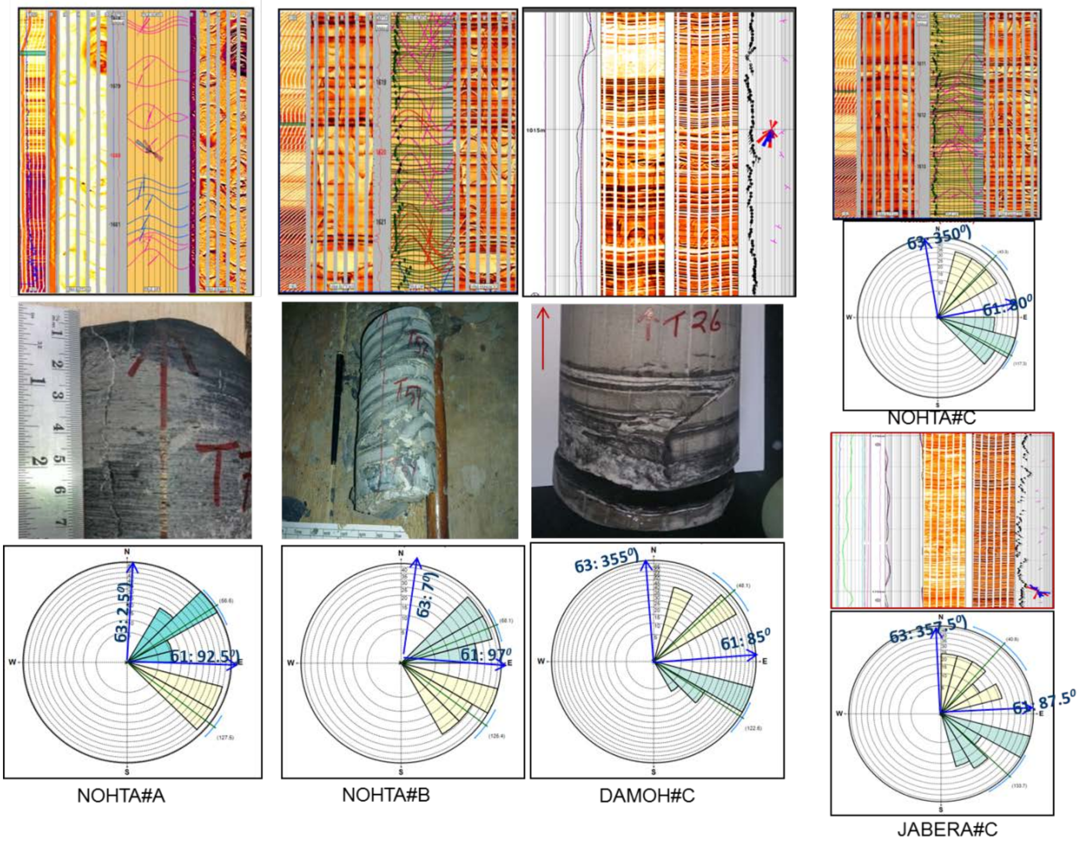

Fig.5 Inferred stress directions from XRMI logs and cores in drilled wells of Son Valley