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Identification of gas bearing zones on logs in tight Rohtas and Mohana Fawn Limestone Reservoirs in Vindhyan Basin, India - A case study

Abstract:

The Proterozoic sedimentary rocks in Vindhyan Basin in central India are extremely tight having very low porosity (~ 1-5 %) and ultra-low permeability (~0.001md). A number of wells drilled in the basin have established presence of gas in carbonate and clastic reservoirs. The cores and well logs have shown presence of fractures which seems to have contributed towards porosity for accumulation of gas. Due to unconventional nature of reservoirs, the task of identifying gas bearing zones by conventional logging methods is very difficult. However, it has been observed that the gas bearing zones can be delineated with the help of acoustic P to S wave velocities ratio (V_P/V_S) and Poisson's ratio (σ) in conjunction with other logs and well data. Remarkably, shear velocity has been derived from conventional 3ft-5ft sonic waveforms since in most of the wells in the beginning only conventional sonic log was available except two wells in which dipole sonic log was recorded. The quality of shear data obtained from conventional sonic is as good as from dipole sonic. The present study gives a brief account of methodology and results for the Rohtas and Mohana Fawn Limestone Formations of Lower Vindhyan Group in Son Valley area. Against the gas bearing zones in Rohtas Limestone, V_P/V_S varies from 1.6 to 1.8 and Poisson's ratio σ from 0.18 to 0.28 whereas in Mohana Limestone more data is needed to arrive at respective ranges. The results are corroborated by well data and testing results.

Introduction:

Vindhyan Basin is an ancient sedimentary basin in the central part of India covering an area of 162000km^2. It is bounded by the Son-Narmada Fault Zone in the south, Great Boundary Fault in the northwest and Bundelkhand Massif in the north-central part. Vindhyan Basin comprises two sectors-Son Valley in the east and Chambal Valley in the west. Stratigraphically, Vindhyan Supergroup can be divided into two sequences-Upper Vindhyan Group and Lower Vindhyan Group. The basin comprises a thick sequence (2-6km) of Proterozoic interbedded clastic-carbonate sediments deposited in predominantly shallow marine environments (D. N. Singh et al., 2013). Even though the Proterozoic rocks have retained their sedimentary character, their porosity and permeability are very low. The sandstone and limestone formations have retained their reservoir character probably due to the presence of fracture porosity. Well data and testing results of drilled wells have established the presence of gas of thermogenic origin in both carbonate and clastic rocks in Vindhyan Basin. In Son Valley area, 16 wells out of the 18 wells drilled and tested so far have given gas indications from different horizons. The Rohtas Limestone, Mohana Fawn Limestone (both Lower Vindhyan) and Kaimur Sandstone (Upper Vindhyan) have flowed non-commercial gas of measurable flow rates during initial testing.

The Vindhyan rocks are generally very hard to drill; particularly the sandstone formations in Upper Vindhyan are so hard that RPM goes as high as 250-300 min/meter during conventional rotary drilling. The drilling of hard surface section has been facilitated by Air Hammer Percussive drilling. Three wells have been drilled entirely by Air Hammer drilling. Flow of formation water during air percussive drilling has been observed in very few cases only.

Due to very tight nature and very low porosity and permeability, the Vindhyan Formations are regarded as unconventional reservoirs wherein the identification of gas bearing zones from conventional logging methods has proved to be a difficult one. In the initial wells, the gas indications provided by mud logging unit (MLU) during drilling and fractures by electrical imaging log (FMI or XRMI) have played a vital role in selection of suitable zones for testing. A study was undertaken to identify gas bearing zones from logs in a more definitive manner, and it has been observed that the gas bearing zones can be delineated with the help of acoustic V_P/V_S and Poisson's ratio in conjunction with other logs and well data. This paper presents and discusses the results of the study for the Rohtas and Mohana Fawn Limestone Formations of the Lower Vindhyan Group.

Rohtas Limestone and Mohana Fawn Limestone characteristics:

Rohtas Formation is the topmost unit of Lower Vindhyan Group in the Son Valley area. It is mostly limestone interbedded with shale layers. The top part is dolomitized. Rohtas Limestone can be divided into three units- Lower, Middle and Upper which are well correlatable (Figure-1). The middle unit is more shaly and fractured than Lower and Upper units. The sedimentological analysis of cuttings of Rohtas section in Well Damoh-C has indicated the kaolinite and illite (34-39% each) and chlorite (25-29%) as the clay minerals. The Rohtas Limestone came into limelight after it flowed gas from Upper unit on barefoot testing in Well Nohta-A in 2011. Since then it has been the prime target of exploration in Son Valley. Subsequently drilled exploratory wells in Nohta, Damoh and Jabera areas have established presence of gas in multiple horizons in Rohtas Limestone from depths varying from 1300 to 2000m. Three wells, two from Nohta area and one from Damoh area have flowed gas with non-commercial rates ranging from 400-4000 m^3/day from Rohtas Limestone during initial testing.

Mohana Fawn Limestone, stratigraphically, lies underneath Rohtas Limestone separated by Basuhari Shale. Mohana Fawn Limestone has been penetrated in only few wells. In Well Nohta-A it had given gas indication during drilling. The same, however, could not be tested as the well was drilled for deeper prospects. Of late, Mohana Fawn Limestone flowed gas in Well Damoh-D on testing. Following the lead, Mohana Fawn Limestone is planned to be targeted in the upcoming wells.

Identification of gas bearing zones -methodology and approach:

Different log parameters show wide variation in their values against Rohtas and Mohana Fawn Limestones (Table-1). The clean sections are hard and compact having very low porosity (~ 1-5 %) and permeability (~0.001md) and high resistivity (~10,000Ωm). The shaly sections, however, have resistivity as low as 20 Ωm. Due to very low porosity and medium to high shaliness, the conventional logs including density and neutron porosity are not diagnostic of presence of gas and, thus, gas identification from logs is quite challenging.

For initial wells, identification of gas bearing zones were based on the gas indications provided by mud logging unit during drilling and then pin pointing the zones with the help of logs including electrical borehole imagery (FMI or XRMI) for fracture intensity. Thus, support from mud logging unit has been quite vital. However, the available conventional mud logging unit is not compatible with air hammer drilling technology which proved to be very effective in drilling the hard formations. When three wells namely Jabera-C, Nohta-E and Damoh-D were planned to be drilled entirely by air hammer technology, it was imperative to delineate gas bearing zones from logs somehow.

As mentioned earlier, in the tight Rohtas Limestone and Mohana Fawn Limestone resevoirs, the primary porosity is very low and, as such, fractures are presumed to play a significant role. For fracture detection, the electrical borehole imaging tools such as FMI and XRMI are in use. It has been observed, however, that many a times highly fractured zones have not given any gas indications during drilling or testing. On the other hand, zone having minimal or no fractures has flowed gas on testing. Thus, even though fractures are important but they do not necessarily represent the gas bearing zones.

In order to identify gas bearing zones from logs in a definitive manner, log characteristics of all the drilled wells alongwith other data like testing results and gas shows during drilling were studied and it was observed that the acoustic log parameters V_P/V_S and σ are helpful in delineating the gas bearing zones. The underlying principle is well known. The gas reduces the compressional wave velocity (V_P) by lowering the rock incompressibility but not the shear wave velocity (V_S) which is dependent on the rigidity of the rock framework. In fact gas leads to small increase in shear wave velocity due to reduction in the bulk density (Darwin V. Ellis et al., 2008). As a result, presence of gas reduces the ratio V_P/V_S and hence the Poisson's ratio (σ). In addition to gas presence, V_P/V_S and σ also depend on lithology, porosity and shaliness but these can be inferred from the logs.

To begin with, both compressional and shear measurements by dipole sonic (DSI, WSTT) tool were available in only two wells- Nohta-A and Damoh-C. In both these wells, V_P/V_S and σ were found to tally with gas indications observed during drilling through MLU and well testing results. In well Nohta-A, the 3'-5'conventional sonic (BSAT) waveform data was also available in addition to dipole sonic data against some interval in Rohtas Limestone section. A trial attempt was made to derive V_S through processing of BSAT waveforms. The V_S obtained from conventional BSAT data matched well with that from dipole sonic data (Figure-2). It paved way to get V_S in wells having only conventional sonic viz. Wells Nohta-B & C, Damoh-B and Jabera-C. In these wells again V_P/V_S and σ were found to tally with the gas observations during drilling and testing. In wells Jabera-C, Nohta-E and Damoh-D which were drilled entirely by air hammer technology in the absence of compatible mud logging unit, zones for testing were selected on the basis of logs, gas shows during drilling and results of the nearby wells. The testing results of these wells are also in agreement with the log characteristics. In well Damoh-D, even though no gas show was observed during drilling but gas bearing zones were detected from logs particularly V_P/V_S and σ ratio. Interval 1544-1550.4m in Mohana Fawn Limestone interpreted to be gas bearing from logs produced gas during initial testing.

Results and discussion

Due to space constraint, composite logs having V_P/V_S, Poisson's ratio σ and parts of XRMI along with gas shows and testing results are shown only against three objects one each from Nohta-C, Damoh-B and Damoh-D in Figures 3 to 5 respectively. However, zone wise log values, gas shows and testing results of all the objects tested in Rohtas and Mohana Fawn Limestone for all the nine wells are tabulated in the Annexure. Tables A & B give details of the objects with gas flow/gas indication on testing and with no gas on testing respectively. Against gas bearing zones in Upper Rohtas, V_P/V_S varies from 1.65 to 1.79 and Poisson's ratio σ from 0.21 to 0.27while for highly argillaceous Middle Rohtas the corresponding ranges are 1.6 to 1.67 and 0.18 to 0.22 respectively. In Lower Rohtas, the only object tested flowed gas with V_P/V_S and σ values 1.8 and 0.28 respectively. Against hard compact and clean limestone with no gas indication, the V_P/V_S and σ values are observed to be 1.92 and 0.32 respectively. In Mohana Fawn Limestone, the only interval tested flowed gas with V_P/V_S and σ values as low as 1.56 and 0.15 respectively.

Conclusions

The gas bearing zones in Rohtas and Mohana Fawn Limestones can be delineated more precisely with V_P/V_S and σ along with other logs and well data. A good agreement has been observed between V_P/V_S and σ values and the testing results. Estimation of gas saturation from acoustic data is the subject matter of further study.

Acknowledgements

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References

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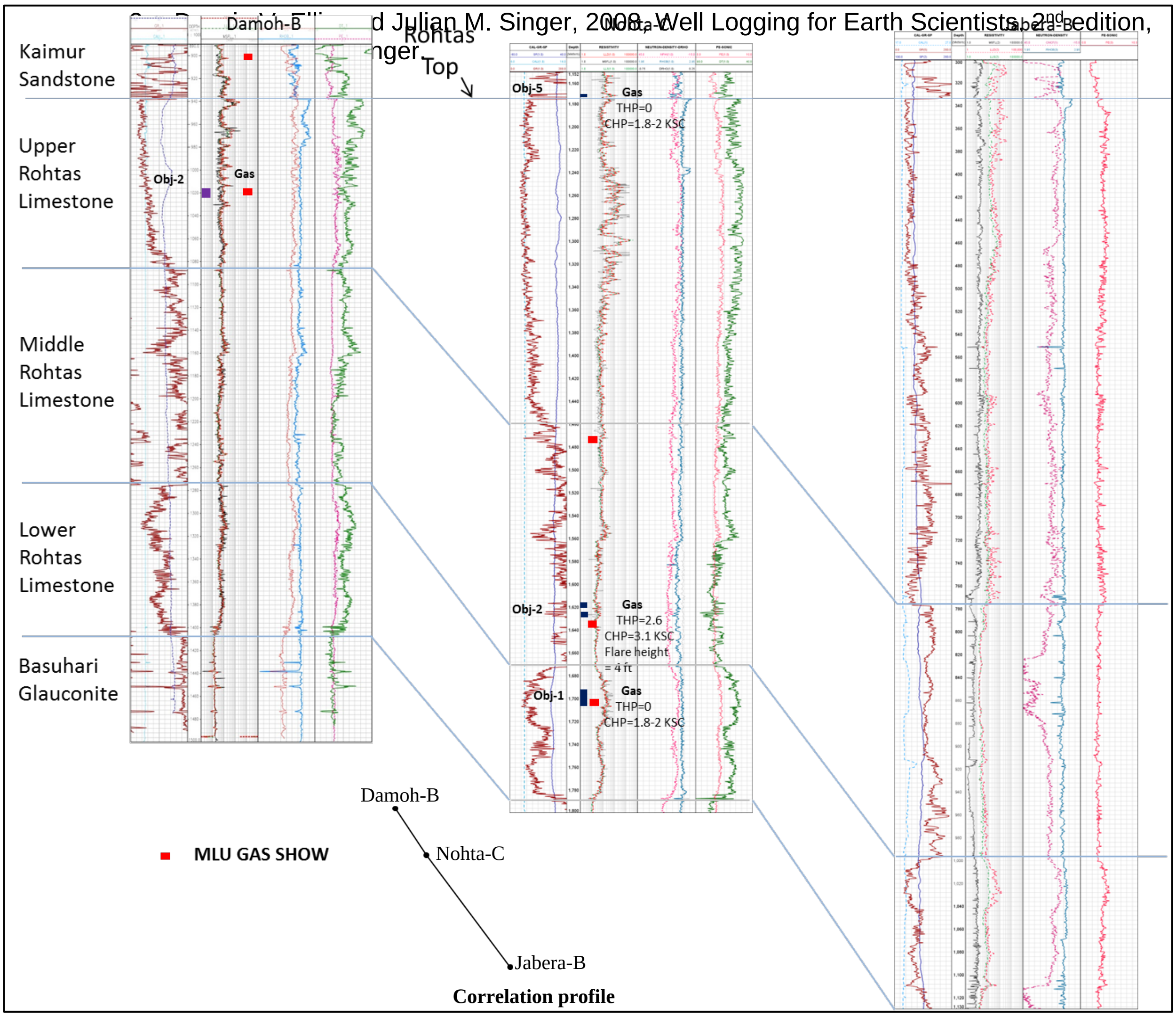

Figure-1: Log correlation of Wells Damoh-B, Nohta-C and Jabera-B showing Lower, Middle and Upper Rohtas Limestone units. The gas shows observed during drilling are also indicated.

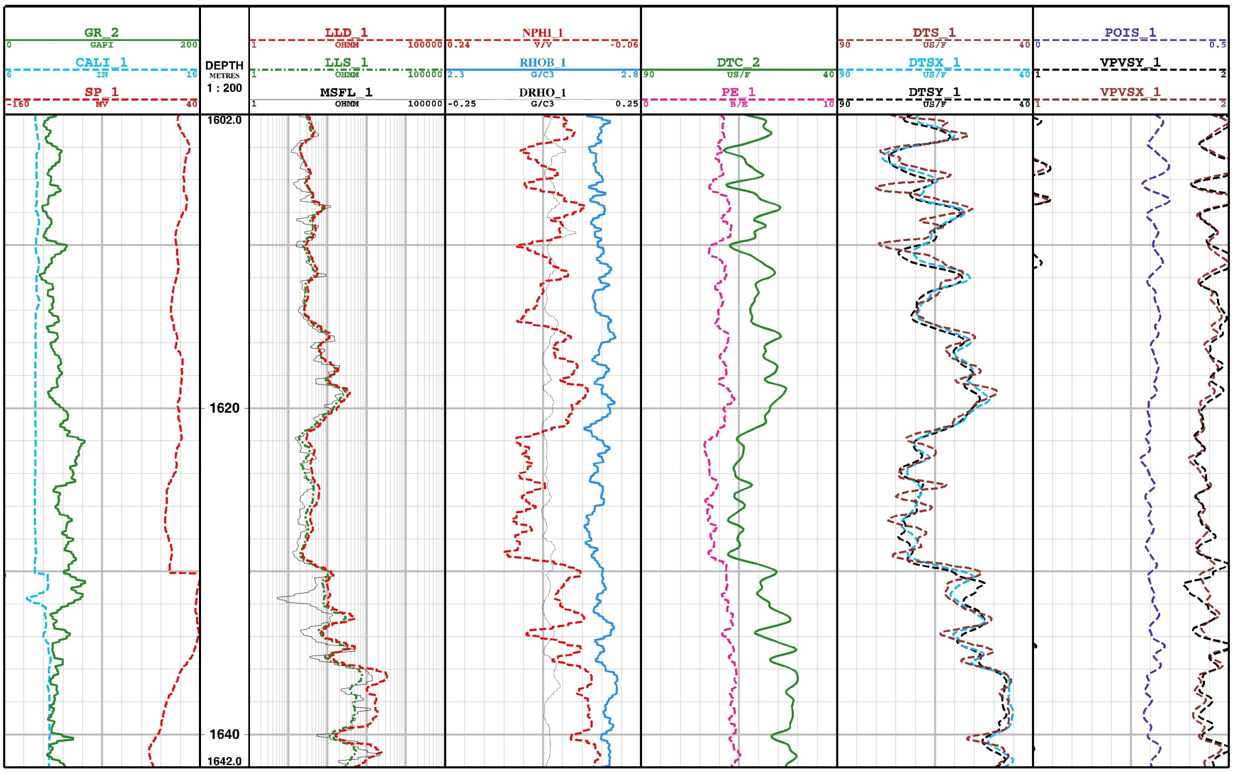

Figure-2: Composite log of Well Nohta-A showing conventional logs, P (DTC), S (DTS, DTSX, DTSY) transit times, and Poisson ratio σ (POIS) and V_P/V_S ratio (VPVSX, VPVSY). DTS derived from conventional sonic waveforms is matching with DTSX and DTSY measured by dipole sonic tool (6th track). The S transit times are appearing in back up scale (90-140μs/ft).

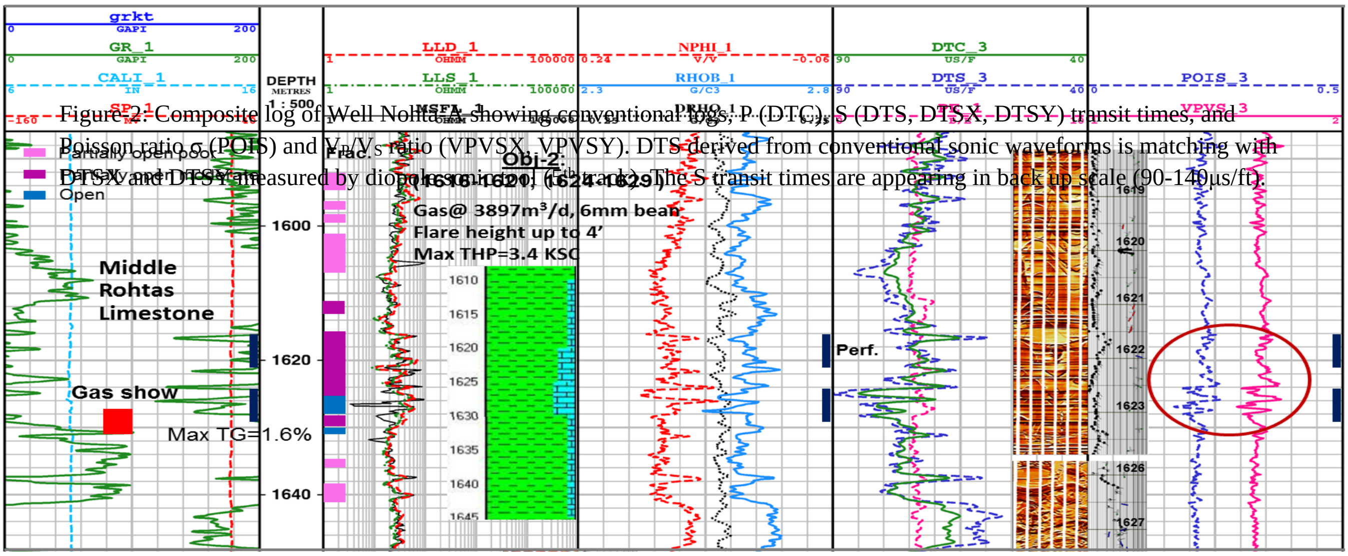

Figure-3: Integrated composite log showing part of Middle Rohtas unit in Well Nohta-C. The gas is clearly indicated by Poisson ratio (POIS) and V_P/V_S ratio (VPVS) in the last track (encircled part) against the tested zones which flowed gas @ 3897m³/d with 6mm bean.

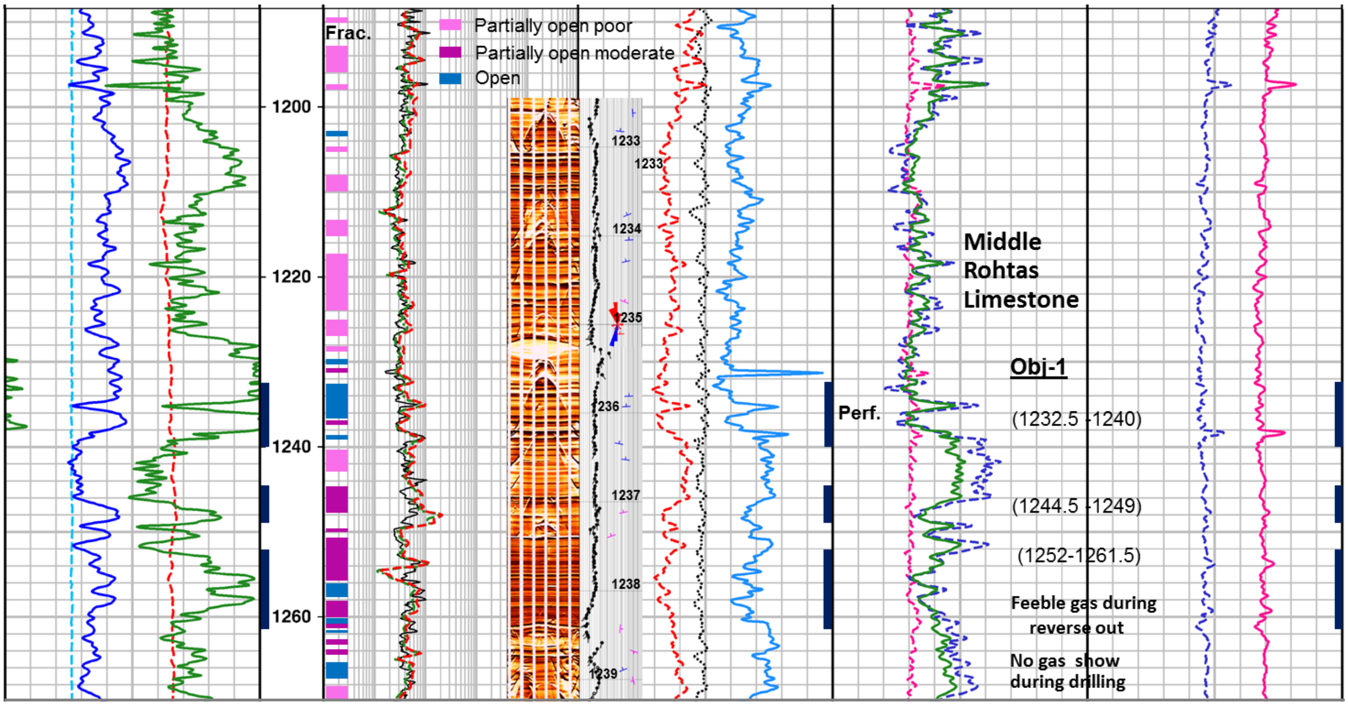

Figure-4: Integrated composite log showing part of Middle Rohtas unit in Well Damoh-B. The Poisson ratio (POIS) and V_P/V_S ratio (VPVS) in the last track do not show anomaly against the tested zones which gave very minor gas indication during reverse out.

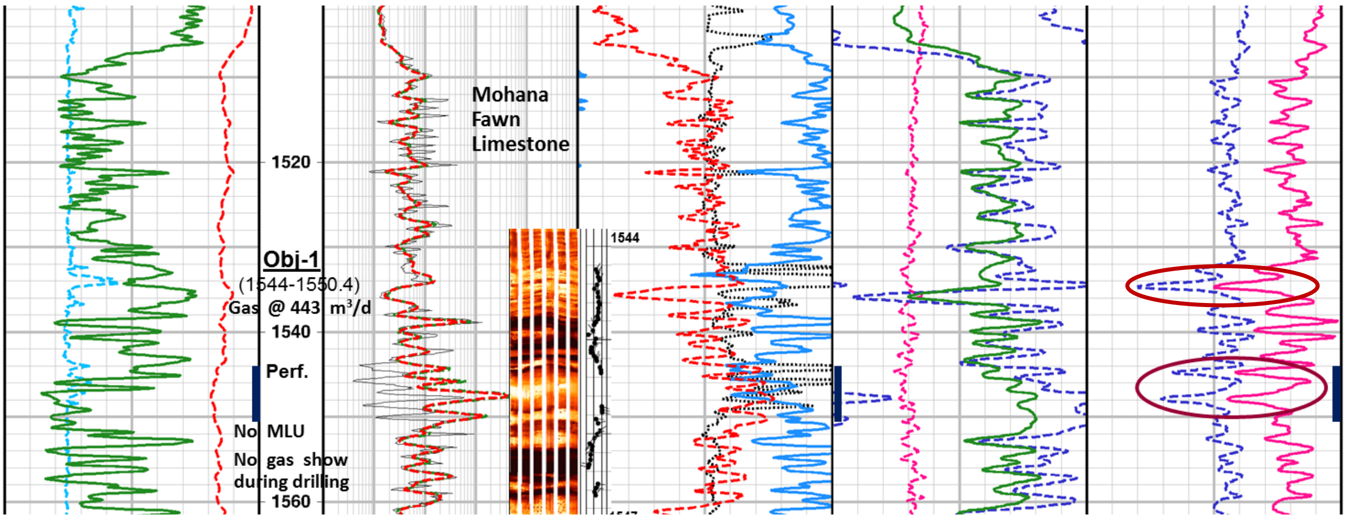

Figure-5: Integrated composite log showing part of Mohana Fawn Limestone in Well Damoh-D. The gas bearing zones (encircled) are detected by logs even though no gas show was observed during air hammer drilling in the absence of compatible MLU. Remarkably, the XRMI log is devoid of fractures.

Well wise tested intervals along with log parameters, gas shows and testing results

Table-A: Intervals which yielded gas flow/gas indication on testing

WELL	INTERVAL(S)	FORMATION	GR	RT	RHOB	NPHI	PE	DTC	DTS	VSH	PHIE	V_P/V_S	σ	GAS SHOWS	TESTING RESULTS
Nohta-A	1520-1667*	U Rohtas	50	100	2.69	0.03	4.2	57	94	0.2	0.03	1.65	0.21	TGmax 27.24%	Gas flow
Nohta-B	1664.5-1810.5#	U Rohtas	45	50	2.68	0.03	5	54.5	99	0.12	0.03	1.79	0.27	TGmax 33.43%	Gas flow
Nohta-C	1692-1707	L Rohtas	45	200	2.69	0.02	4.6	54	98	0.1	0.02	1.8	0.28	TG max-6%	Gas flare height 1ft.
	1616-1621	M Rohtas	135	60	2.63	0.1	3.2	73	122	0.6	0.04	1.66	0.22	TG max-11%	Gas flow
	1624-1629		120	60	2.58	0.14	3.4	84	135	0.5	0.06	1.6	0.18		
Nohta-D	1975-2008@	M Rohtas	150	50	2.59	0.15	3	82	130	0.6	0.05	1.6	0.17	TG max-17.73%	Feeble gas
	1585-1617.5$	U Rohtas	40	600	2.67	0.03	4.3	57	96	0.1	0.03	1.68	0.22	TG max-12.28%	Gas flow
Nohta-E	1797.5-1815	M Rohtas	100	60	2.63	0.08	3.1	70	116	0.4	0.04	1.67	0.22	No MLU	Feeble gas
Damoh-B	1015-1025	U Rohtas	53	100	2.67	0.07	4	68	115	0.1	0.03	1.7	0.23	TG max 9.52%	Gas flow
Damoh-C	1330-1347	U Rohtas	40	450	2.69	0.04	5	58	105	0.1	0.02	1.78	0.27	TG max 1.83%	Gas flow
Damoh-D	1544-1550.4	Mohana Fawn	36	4000	2.61	0.02	3.1	50	78	0.1	0.02	1.56	0.15	No MLU	Gas flow
	983-997	U Rohtas	40	600	2.68	0.03	4	61	111	0.1	0.015	1.8	0.28		Gas indication
Jabera-C	2131-2139	M Rohtas	40	1600	2.7	0.03	3.5	54	98	0.1	0.015	1.78	0.28	No MLU	Gas indication
	2144-2147.5		30	1000	2.71	0.03	3.5	54	94	0	0.015	1.75	0.25		
	2148.5-2151.5		42	400	2.71	0.03	3	53	90	0.1	0.015	1.65	0.21		
Jabera-D	1250-1350^	M Rohtas	175	16	2.6	0.21	3.7	90	146	0.8	0.1	1.61	0.18	No MLU	Gas flow

Table-B. Intervals which were dry on testing

WELL	INTERVALS	FORMATION	GR	RT	RHOB	NPHI	PE	DTC	DTS	VSH	PHIE	V_P/V_S	σ	GAS SHOWS	TESTING RESULTS
Nohta-E	1335-1338	U Rohtas	17	750	2.85	0.04	4.3	47.5	87	0	0.01	1.87	0.29	Nil	No gas
Damoh-B	1232.5-1240	M Rohtas	150	50	2.65	0.13	3.4	66	111	0.4	0.04	1.69	0.23	Nil	Very minor gas in reverse out
	1244.5-1249		160	60	2.64	0.14	3	71	123	0.6	0.06	1.73	0.25		
	1252-1261.5		200	70	2.6	0.14	3	71	122	0.7	0.04	1.72	0.24		
Damoh-C	1494-1519	U Rohtas	36	200	2.7	0.04	4	54	101	0.08	0.02	1.87	0.29	TG max 2.53% (?)	No gas
	1450-1468		40	200	2.7	0.04	4	55	106	0.1	0.02	1.9	0.3		
	1384-1400		60	750	2.71	0.06	4	53	100	0.15	0.03	1.89	0.29	TG max 2.53% (?)	No gas
	1374-1378		40	200	2.7	0.06	4.2	55	104	0.1	0.01	1.88	0.3	Nil	
Jabera-C	2088-2097	M Rohtas	60	360	2.7	0.02	4	53	96	0.15	0.02	1.81	0.28	No MLU	No gas
	2102-2105		55	300	2.69	0.03	4.3	53	98	0.15	0.02	1.85	0.28		
	2107.5-2110		30	1600	2.7	0.02	4	50	88	0	0.02	1.76	0.26		

* Barefoot testing during 9-5/8" drilling phase after the gas show was observed. Interval 1566-1574.5m appears to be the main contributor.

Barefoot testing. Interval 1702-1724m appears to be the main contributor.

@$ Barefoot testing of the two objects first combined together and then isolated by cement plug. Prominent zones: 1986-1988m and 1591-1593.5m.

(?) There might be depth discrepancy in MLU gas shows. Interval 1361-1374m appears to be a promising one with V_P/V_S and σ values 1.65 and 0.21 respectively but no gas show is reported against the same.

^Barefoot testing. Interval 1290-1330m seems interesting.