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Vp/Vs Analysis of Rohtas and Kaimur Formations, Son Valley, Vindhyan Basin

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Abstract

The presence of compressible fluid or gas in pore space of rock and fractures are known to have considerable influence on parameters like acoustic velocities. The ratio of compressional wave velocity to shear wave velocity (V_p/V_s) is a good tool in identifying fluid type, since the compressional wave velocity decreases and shear wave velocity increases with the increase of light hydrocarbon saturation. The analysis of V_p/V_s ratio, Poisson's ratio and density within different units of Rohtas and Kaimur formations were carried out in drilled wells Damoh#C, Nohta#A and Jabera#C in Son Valley, Vindhyan Basin. Various cross plots including V_p/V_s versus density, Poisson's ratio versus depth, density versus depth, Poisson's ratio versus density , V_p/V_s versus DTC were used to identify potential gas bearing zones as well as presence of fractures. Fractures identified based on the present analysis has more or less corroborated the results obtained from XRMI logs. The potential gas bearing reservoirs identified in these wells have been validated through this study and additional interesting zones have been identified.

Keywords: V_p/V_s ratio, Poisson's ratio, fractures

Introduction

The Son Valley, Vindhyan Basin has come to the forefront of hydrocarbon exploration after the recent significant discovery of gas within Proterozoic fractured reservoirs of Lower Vindhyan Rohtas Limestone and Upper Vindhyan Kaimur Sandstone spread over a large area in the exploration acreage (Fig.1). The reservoirs are unconventional with very low primary porosity and ultra-low permeability. Gas accumulation and flow potential is largely dependent on the presence of fractures. Since, the presence of compressible fluid or gas in pore space of rock and fractures are known to have considerable influence on parameters like acoustic velocities, the ratio of compressional wave velocity to shear wave velocity, V_p/V_s, is a good tool in identifying fluid type. The present paper brings out the results of the study carried out to calibrate the known fractured gas reservoirs based on analysis of cross plots using Vp/Vs ratio, Poisson's Ratio, density and sonic logs and an attempt to trace out the similar gas pools in other drilled wells.

Principle

In elastic and isotropic medium, the compressional and shear wave velocities are related to the dynamic elastic moduli with the relations:

$Vp=\sqrt{\{(K+4\mu/3)/\rho\}}$ 1 - equation 1

$Vs=\sqrt{(\mu/\rho)}$ 2 - equation 2

where;

Vp and Vs are compressional and shear wave velocities expressed in Km/sec, K and μ are bulk modulus and shear modulus expressed in GPa (Giga Pascals), ρ is the bulk density in g/cc (matrix, fluid and porosity combined)

- Presence of low density gas in the pore space of a reservoir rock decreases the rock density while there is no change in shear modulus (since fluids do not support shear). Gas, being very compressional and has large bulk modulus thereby, reduces the contribution of pore fluid to the overall bulk modulus of the formation, and therefore, Vp of the acoustic wave decreases (eq-1). In the case of shear wave, due to low-density gas, its velocity increases slightly (eq-2). Thus the net effect on V_p/V_s ratio, if gas is present in the pore space, it will decrease which, is around 1.58 to 1.6.It increases slightly beyond this value in unconsolidated sands and at low effective stress regimes.
- Compressional waves (Vp) are primarily affected by oblique fractures—those with dip angles between 15° and 85°—while (Vs) shear waves are primarily affected by horizontal or near-horizontal fractures. Thus, variations in the V_p/V_s ratio can be seen.

Poisson's ratio (n) is the ratio between strain in the direction of principal stress and strain in either transverse direction, and is defined in terms of P- and S-wave velocities by the following:

$$\nu = \frac{(a^2-2)}{2(a^2-1)},$$

where;

n = Poisson's ratio, a = V_p/V_s, V_p = P-wave velocity, V_s = S-wave velocity

For gas, Poisson's ratio lies between 0 and 0.25. However, some well log measurements, especially in slow gas formations produce a Poisson's ratio as large as 0.3.

Methodology

The analysis was carried out using the data from three exploratory wells, namely Damoh#C, Nohta#A and Jabera#C. Initially, the V_p/V_s, density and Poisson's ratio (obtained from wire line logs), for different formations / units were plotted against the depth, which led to the identification of interesting zones. To validate these interesting zones, Poisson's ratio versus density, V_p/V_s versus density and V_p/V_s versus DTC were plotted. The observed values indicated the presence of the gas as well as the fractures. The results were calibrated with the open and partial fractures seen in XRMI log for the particular intervals.

Results and Conclusions

The details of observations and analysis are placed as Fig. 1 to 10. The major findings are enumerated below

In well Nohta#A: The interval 1520-1667m flowed gas on barefoot testing. The present analysis suggests that the interval 1541-1574m seems to be principal gas contributing zone with the lowering of PR: 0.23-0.25, Vp/Vs: 1.61-1.62,density: 2.625-2.675g/cc.

The gas bearing layers of wells Nohta#A and Damoh#C may comprise Vp/Vs around 1.6 and PR: 0.2-0.3.

In well Damoh#C:

Higher values of Vp/Vs (1.79-1.95) and PR (0.27-0.32) were observed in the gas bearing interval of Upper Rohtas (1330-1347m).Relatively low values of Vp/Vs (1.65-1.9) and PR (0.225-0.32) were observed in the zone 1374-1400m. Although, the zone showed no activity during testing, the analysis suggests that thin layer within tested zones may be gas bearing, having lower Vp/Vs values.

Interval 1700-1725m (Middle Rohtas unit), seems to be interesting having Vp/Vs: 1.59.1.62, PR: 0.172-0.25 with appreciable partially open fractures

Interval 1205-1240m within Basal Kaimur Sandstone, having Vp/Vs: 1.5-1.62, PR: 0.03-0.25 and few partially open fractures appear as the most promising zone.

In well Jabera#C:
Interval 2088-2110m shows Vp/Vs: 1.61 -1.9 with scattered partially open fractures, appear to have thin gas bearing layers. This is corroborated by the continuous feeble flow of gas observed during initial testing. Intervals 1580-1610m (Basal Kaimur) seems to be most promising with Vp/Vs: 1.5-1.6 and PR: 0.03-0.23 with appreciable partially open fractures. Interval 1500-1530 m (Vp/Vs: 1.61-1.62, PR: 0.18-0.225 with appreciable partially open and open fractures) within lower Kaimur section also seems to be interesting. Both these zones yielded continuous feeble flow of gas during combined testing. Based on the above analysis, an additional untested zone has been identified in the interval 1540-1550m (Vp/Vs: 1.55-1.6, PR: 0.15-0.25 with appreciable partially open and open fractures.
The fractures identified on basis of Vp/Vs and density plots corroborate with the fractures seen on XRMI logs to a considerable extent.
These evaluated parameters can also be used for identification of interesting layers for testing, if shear wave is recorded along with other logs.

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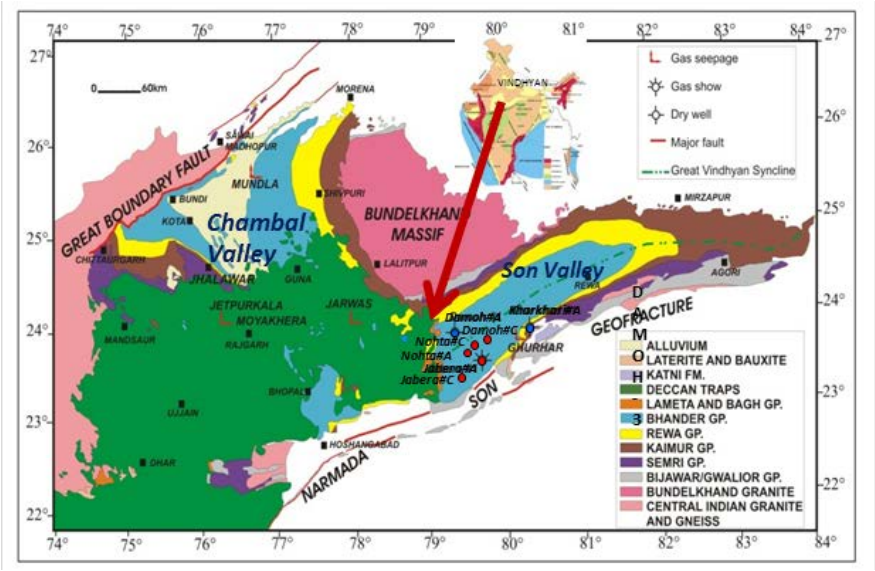

Fig.1 Geological map of Vindhyan Basin showing location of wells in Son Valley

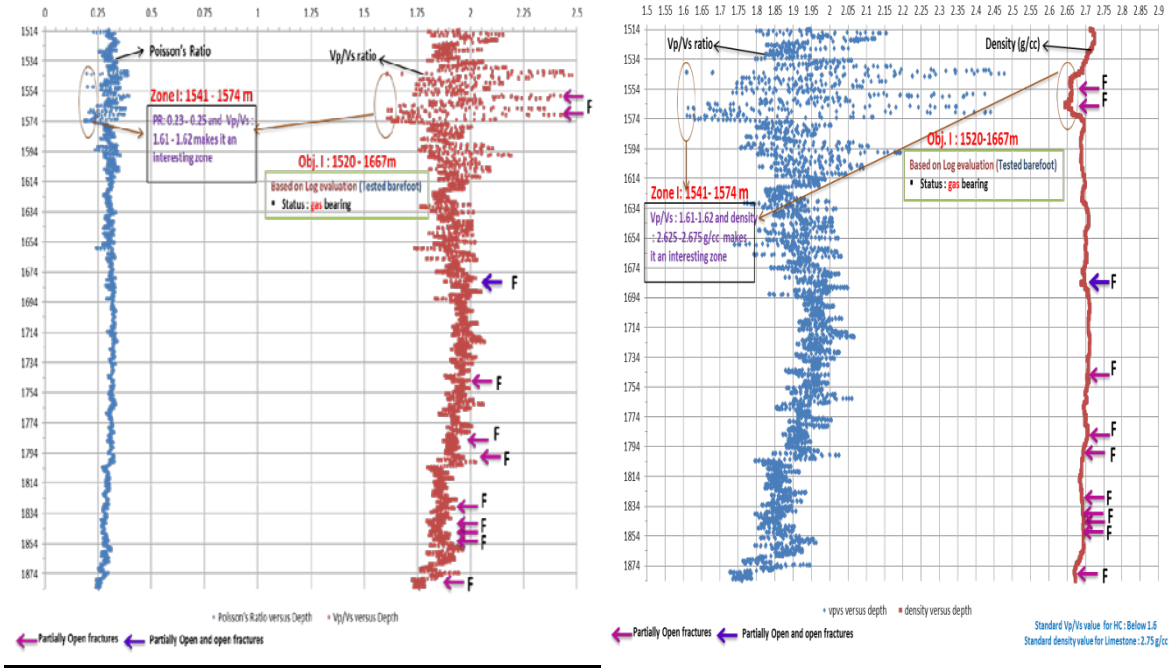

Fig 2: Crossplot of Vp/Vs ratio and density depth for Rohtas Formation-Upper Unit (1514-1885m), Nohta#A well

Fig 3: Crossplot of Poisson's Ratio and Vp/Vs ratio versus depth for Rohtas Formation-Upper Unit (1514-1885m), Nohta#A well

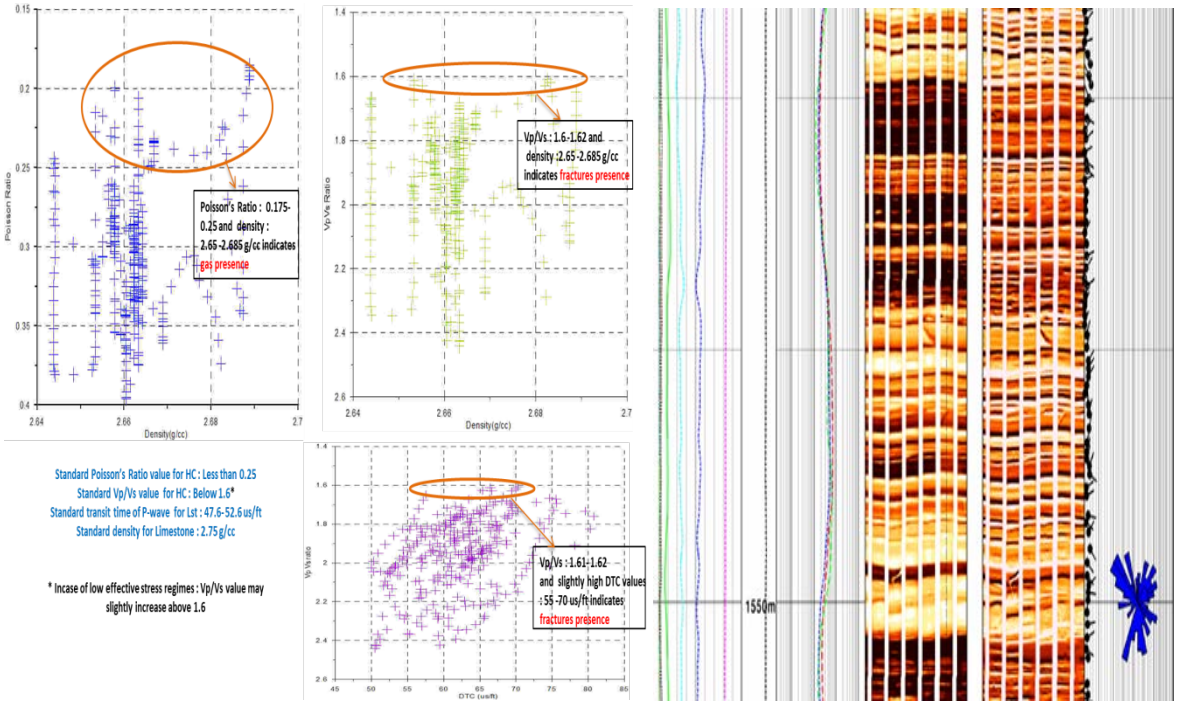

Fig 4: Crossplots for Zone (1541-1574m) of Rohtas Formation-Upper Unit, Nohta#A well

Fig 5: XRMI log for interval (1547-1551m) of Rohtas Formation-Upper Unit, Nohta#A well

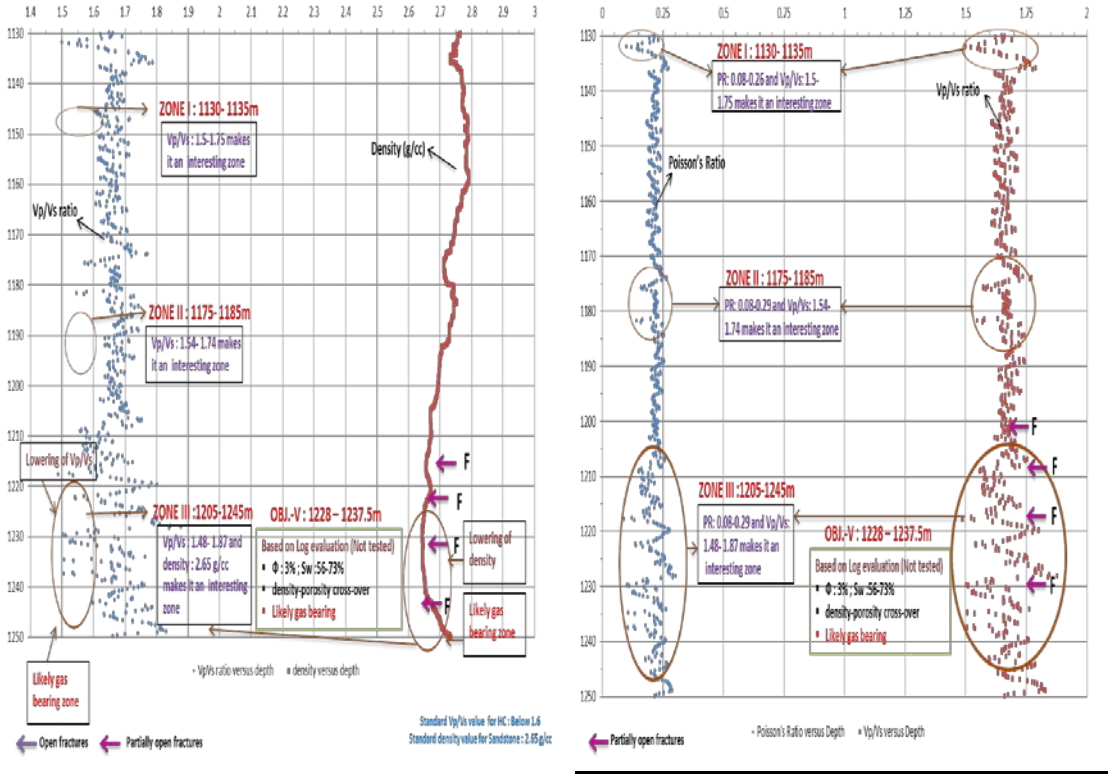

Fig 6: Crossplot of Vp/Vs ratio and density versus depth for Kaimur Formation (1130-1250m), Damoh#C well

Fig 7: Crossplot of Poisson's ratio and Vp/Vs ratio versus depth for Kaimur Formation (1130-1250m), Damoh#C well

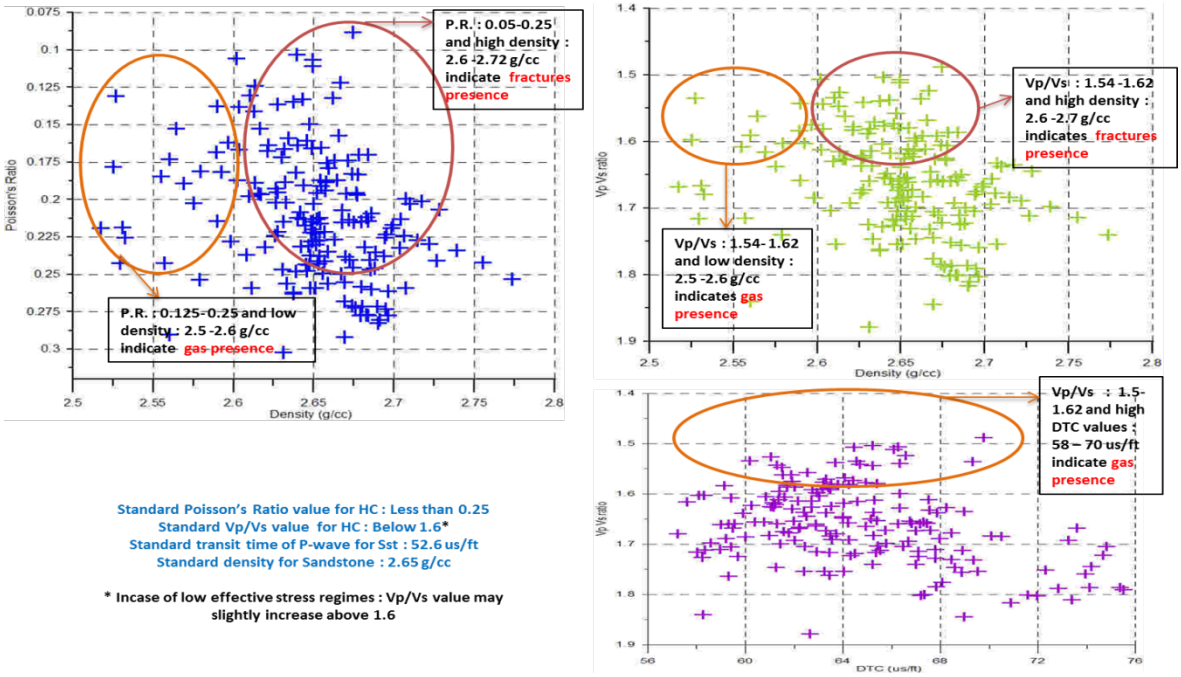

Fig 8: Crossplots for Zone (1205-1240m) of Kaimur Formation, Damoh#C well

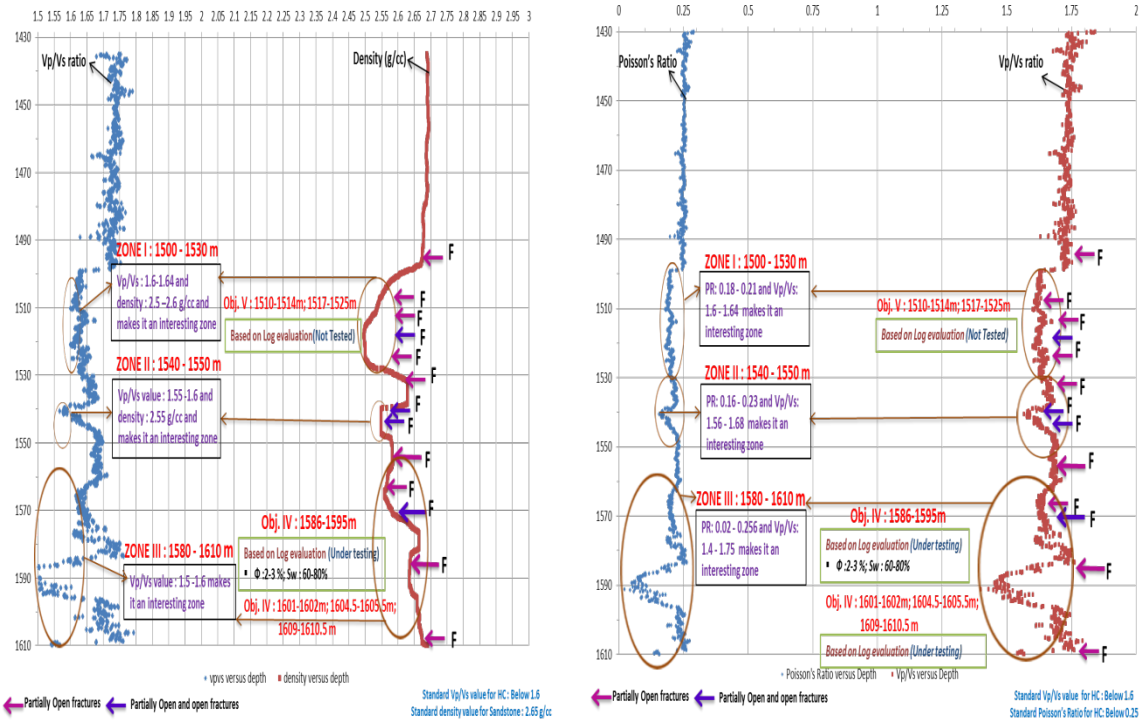

Fig 8: Crossplot of Vp/Vs ratio and density versus depth for Kaimur Formation (1435-1610m), Jabera#C well

Fig 9: Crossplot of Poisson's Ratio and Vp/Vs ratio versus depth for Kaimur Formation (1435-1610m), Jabera#C well

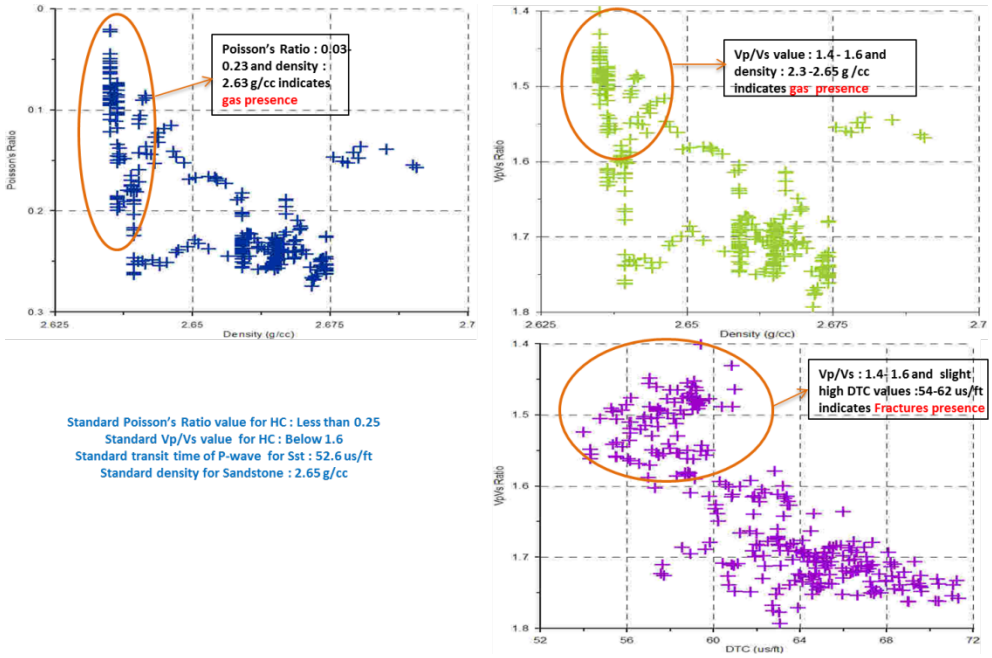

Fig10: Cross plots for Zone (1580-1610m) of Kaimur Formation, Jabera#C well