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Identification of gas using V_p/V_s vis-a-vis Poisson's ratio

***P. K. Jain*, C.V Jambhekar, P.B. Pandey**, ONGC*

Summary

The presence of compressible fluid, gas, in pore space of rock is known to have considerable influence on parameters like acoustic velocities and Poisson's ratio. Sonic travel time of compressional wave is generally used as porosity tool for given lithology. Introducing shear wave travel time is very helpful in determining mechanical rock properties. It is found that compressional wave is sensitive to the saturating fluid type. The use of the ratio of compressional wave velocity to shear wave velocity, V_p/V_s, is a good tool in identifying fluid type. The fact that compressional wave velocity decreases and shear wave velocity increases with the increase of light hydrocarbon saturation, makes the ratio of V_p/V_s more sensitive to change of fluid type than the use of V_p or V_s separately The V_p/V_s ratio obtained from wire line sonic logs versus DTc cross plot is widely used to differentiate gas from water. For gas the V_p/V_s value observed to be around 1.58-1.6 or less and for water and shales it varies with degree of compaction and effective stress besides other factors. Laboratory data supported by granular-medium and inclusion theories indicate that Poisson's ratio in gas saturated sands 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. These findings have been brought out in the present study by analyzing the data from two wells which is around 1.6 or more (V_p/V_s) and Poisson's ratio well with in 0.25. The findings have been corroborated with the available testing results Interestingly the sands developed in one well appear to be hydrocarbon bearing on LWD logs as well as interpreted to be gas bearing as per the ELAN processing, but on testing the sands did not yield expected production of hydrocarbons even after re-perforation and acidization job. V_p/V_s ratio versus DTc crosses plots as well as Poisson's ratio versus density cross plots clearly explained the production behavior of these sands, whereas quality LWD log data response did not match the testing results.

Keywords: *V_p = Compressional velocity in km/sec, V_s = Shear wave velocity in km/sec, ρ = Bulk density in g/cc, DTc = Slowness of compressional velocity in us/ft, DTs = Slowness of shear velocity in us/ft,*
V_p/V_s = Ratio of compressional & shear wave velocity, PR = Poisson's ratio

Introduction

As the drilling cost has been increasing day by day, it becomes imperative to make use of Direct Hydrocarbon Indicator (DHI) tools to minimize the failures. The present work is an attempt to highlight the use of one of DHI tool e.g. DSI (Dipole Sonic Image).

In sand bodies compressional and shear wave velocities are dependent on rock matrix, porosity, mineralogy, grain to grain contacts, type of fluid and degree of consolidation. In elastic and isotropic medium the compressional and shear wave velocities are related to the dynamic elastic moduli with the relations.

$$V_p=\sqrt{\{(K+4\mu/3)/\rho\}} \quad 1$$
$$V_s=\sqrt{(\mu/\rho)} \quad 2$$

V_p and V_s 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)

When water is replaced by low density gas in the pore space of a reservoir rock, the rock density decreases while there is no change in shear modulus (since fluids do not support shear). Replacement of liquid which has very large bulk modulus by gas, which is very compressional, reduces the contribution of pore fluid to the overall bulk modulus of the formation, and therefore, V_p of the acoustic

C-204, ShailRaj Complex, Opp. Baroda Dairy, Makarpura Road, Vadodara-390009;
pkjrj56@gmail.com

wave decreases (eq-1). In the case of shear wave, when water is replaced by low-density gas its velocity increases slightly (eq-2). Thus the net effect on V_p/V_s ratio if water in the pore space is replaced with gas is that it will decrease. The value is around 1.58 to 1.6 (Rao R.V., 2004). Laboratory data supported by granular-medium and inclusion theories indicate that Poisson's ratio in gas saturated sand lies within 0 to 0.25, with typical values about 0.15. It can also be calculated from the P and S wave elastic –wave velocity which are routinely measured in the laboratory/well. (Dworkin, J et al, 1998).

Data Analysis

The data used in the study pertains to two exploratory wells drilled in Cambay Basin of Western India. These wells are named as A and B. In case of well A, conventional logs e.g. Resistivity, Neutron and Density were recorded by Wire line; further DSI and CMR logs were also recorded. In case of well B due to operational reasons wire line logging could not be done and hence conventional logs were recorded using LWD, later cased hole DSI was recorded. Log motifs of well A and well B are shown in Fig 1 and Fig 2 respectively. In well A, a sand reservoir is developed in the interval 1890-98m, where as in case of well B three sand reservoirs are developed. Elan processing was carried out in the both the wells, processed results are shown in Fig 3 and Fig 4.

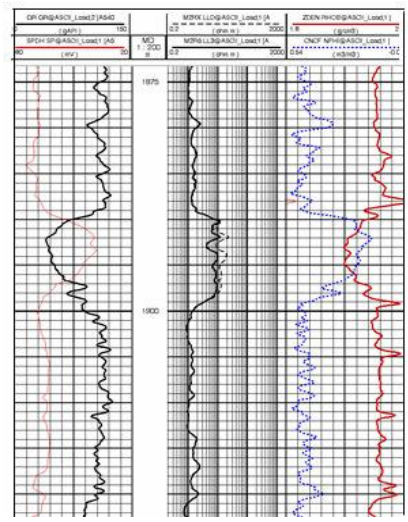

Fig 1 Log motiff of Well A

From the Elan results, the sand in the interval 1890- 1898.5m in well A is interpreted to be gas bearing and on testing, sand in the interval 1890-1896m(object-1) produced gas @ 77167m3/d and condensate @ 11m3/d through 6mm bean. In case of well B , sands in the interval 2184-2183m, 2181-2178.5m, 2178-2176m (object-I) and2170.5-2165m (object-II) and 2160-2156m, 2154-2152m.

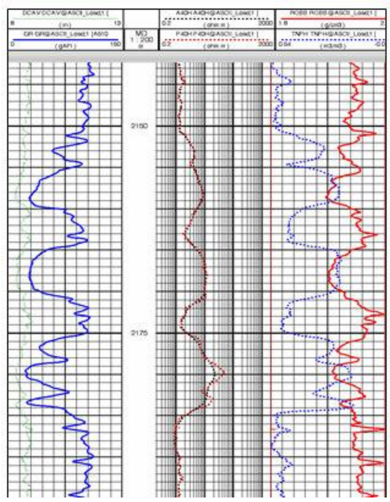

Fig 2 Log motiff of Well B

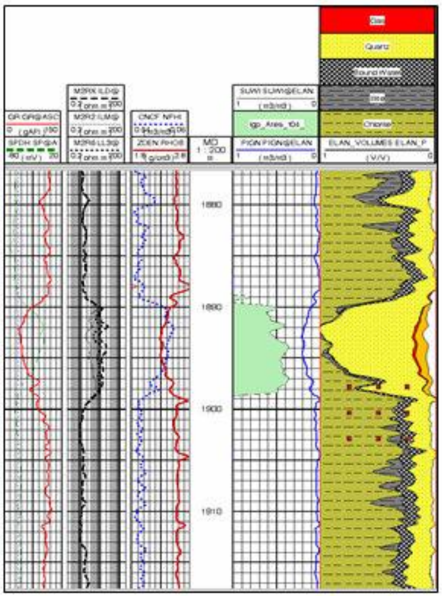

Fig 3 ELAN processing results for Object-I, Well A

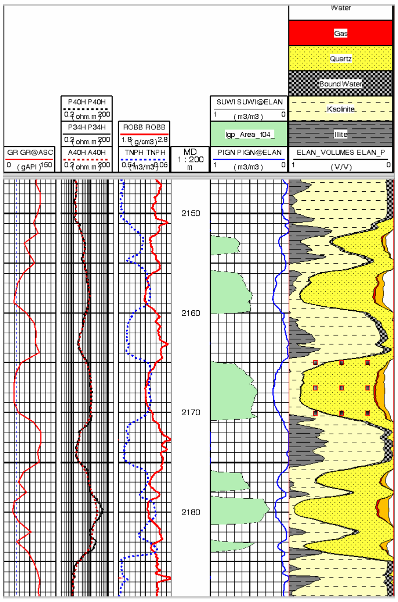

Fig. 4 ELAN processing results of Well B

(object-III) are also interpreted to be gas bearing, however, on testing bottommost sand in the object-I produced gas @ 39954m3/d and condensate @ 11m3/d with 6mm bean, middle sand object-II produced gas @ 6600m3/d only even after re-perforation and acid job similarly the top most sand (object-III) on testing produced gas @ 7634m3 only after repeated perforation and acid job.

From the log motifs as well as from Elan interpretation sands developed in the well B are characterized by almost similar porosity, water saturation ,clay volume and better resistivity compared to the sand developed in well A, but there is a marked difference in their production behavior compared to the sand of well A.

In order to fathom the production pattern of sands in these wells, it was thought fit to make use of DSI log; accordingly cross plots of Vp/Vs ratio versus DTc and Poisson's ratio (PR) versus Density (RHOB) were made for all the tested sands in both the wells.

Well A

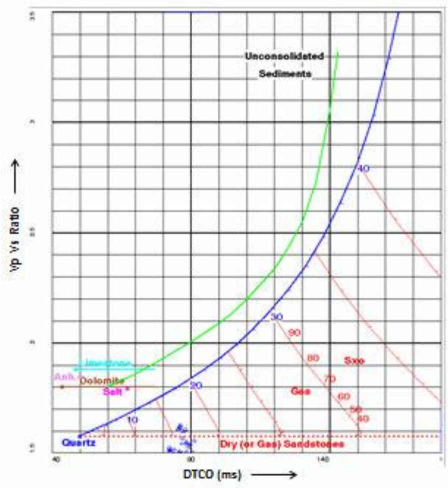

Fig 5 Crossplot for VpVs ratio & DTCO, Object-I, Well A

It has been established by various studies that V_p/V_s ratio tends to be around 1.58-1.6 for gas it reaches beyond this value in unconsolidated sands and low effective stress regimes. Similarly Poisson's ratio (PR) remains low less than 0.2 rarely cross this value but never goes beyond 0.3.In case of well A, the sand was perforated conventionally in the interval 1890.0-1896.0m as object-1, cross plot of V_p/V_s ratio versus DTc is shown in Fig 5 and cross plot of PR versus Rhob is shown in Fig 6. It is seen that in cross plot of V_p/V_s ratio versus DTc baring few points majority of points fall below the V_p/V_s value of 1.6 and in the cross plot of PR versus Rhob all the points fall below 0.2, the object produced gas @ 77167 m3/d and condensate @

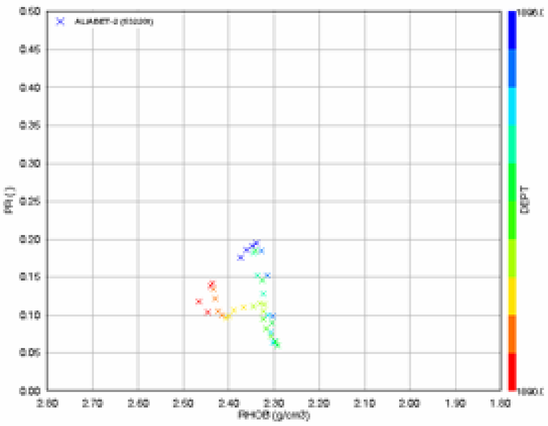

Fig 6 PR & Rhob crossplot, Well A

11m3/d through 6mm bean. Élan output of the well is shown in Fig 3. This is evident that the Vp/Vs ratio, PR Cross plots, log responses (Elan output) and production testing data are in agreement with each other.

Well B

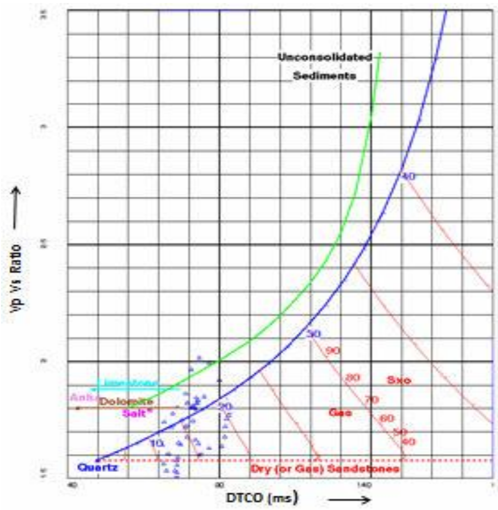

Fig 7 Crossplot for VpVs ratio & DTCO, Object-I, Well B

V_p/V_s versus DTC cross plots of object-I,II & III of well B are shown in Fig 7,8,9 respectively and cross plots of PR versus Rhob of these objects are shown in Fig 10, 11 &12 respectively. In case of object-1, V_p/V_s at some points fall below the range of 1.6 remaining fall above 1.6 and in case of PR about 40 percent points fall below 0.2 range remaining go beyond 0.2, the object produced gas @ 39954m3/d and condensate @ 11m3/d with 6mm bean. Against object-II the V_p/V_s value of all the points are

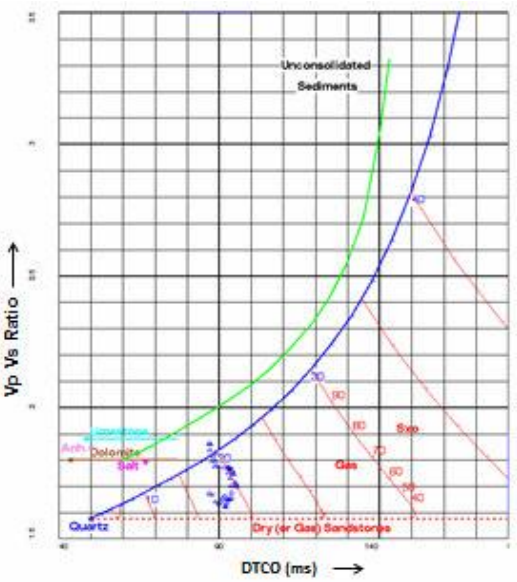

Fig 8 Crossplot for VpVs ratio & DTCO, Object-II, Well B

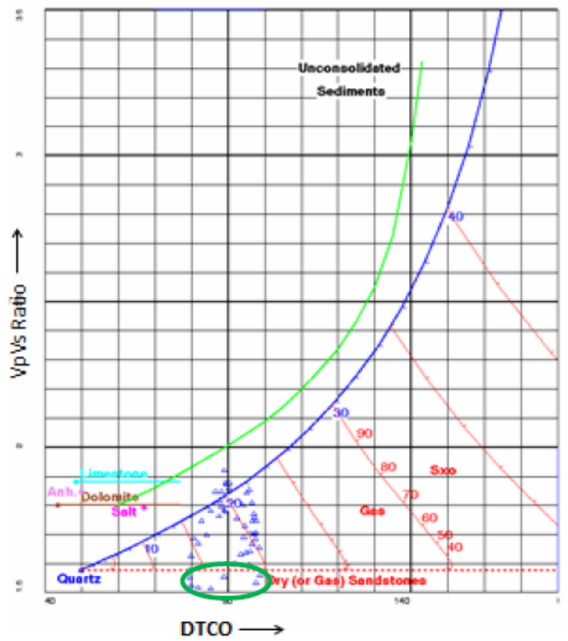

Fig 9 Crossplot for VpVs ratio & DTCO, Object-III, Well B

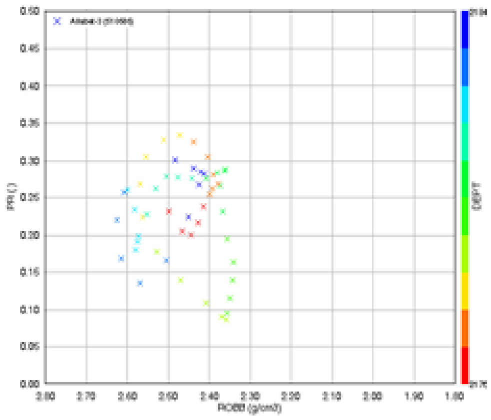

Fig 10 PR & Rhob crossplot, Object-I, Well B

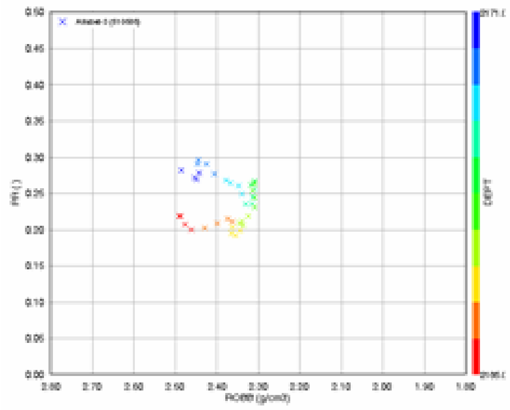

Fig 11 PR & Rhob crossplot, Object-II, Well B

above 0.6 and PR values are above 0.2 for majority of points, the object produced gas @ 6600m3/d only even after re-perforation and acid job.

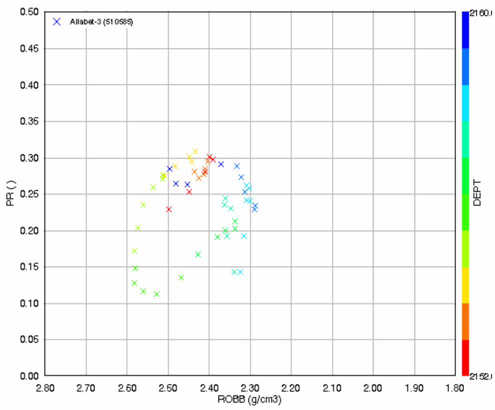

Fig 12 PR & Rhob crossplot, Object-III, Well B

As far as object-III, is concerned V_p/V_s ratio is by and large above 1.6 and PR remains above 0.2 baring few points, the object produced gas @ 7634m3 only after repeated perforation and acid job. Élan output of the well is shown in Fig4, this is evident that V_p/V_s and PR interpretation corroborates the production testing results, but the log responses (Elan output) are at variance with testing results.

Dependence of shear wave velocities and Poisson's ratio on rock properties has been clearly brought out in all the above discussed cross plots. These cross plots clearly explain the production pattern of all the sands in well A and well B, whereas the LWD logs do not corroborate the testing results in well B.

Conclusions

1. Gas or light hydrocarbon bearing zones can be easily identified by V_p/V_s and DTc cross plots as well as PR and Rhob cross plots.

2. V_p/V_s ratio for gas/light hydrocarbons is below 1.6; however, it may increase slightly beyond this value in unconsolidated sands and at low effective stress regimes.

3. Poisson's Ratio (PR) against gas/light hydrocarbons remains less than 0.25

4. In case of gas reservoir the above technique should be applied apart from conventional log interpretation.

5. Though the production behavior of the sand in both the wells have been successfully explained by V_p/V_s ratio and DTc as well as PR and Rhob cross plots the reason for LWD logs inability to corroborate testing results in well B warrants further study.

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