Pakistan Journal of Hydrocarbon Research
Vol. 16, (June 2006), p.45-50, 10 Figs, 3 Table

Imaging the Varied Lithology by Using Converted Shear Waves - a Case Study

Gulraiz Akhter[1], Zulfiqar Ahmad[1], Asam Farid[2] and Muhammad Imran[1]

ABSTRACT

Seismic velocities have long been used to determine the structural and stratigraphy traps suitable for the accumulation of hydrocarbon. In the present study an attempt has been made to differentiate between such subsurface rocks, bearing significant potential of hydrocarbon, using shear wave velocities. Six seismic lines and Gujwaro well, located in the Lower Indus Basin, have been used to investigate the Lower Goru Formation, which make its presence within time interval of 2000 to 2400 msec.

Seismic parameters such as poisson's ratio (б), primary and secondary wave velocity (Vp/Vs) ratio, and reflectivities are used to determine the reservoir characteristics. Rock model is prepared for the study area on the basis of these properties, which indicate the existence of soft, intermediate and hard rocks. As the Poisson's ratio being a function of Vp and Vs is relatively low in shales and high in calcareous sand where as its values varies from 0.23 to 0.25 for Gas sands. Similarly for gas sand the value of Vp/Vs falls in the range 1.68 to 1.74. From the findings of the study it is inferred that gas-producing zones lie in the intermediate rocks. The interpreted subsurface lithologies consist of pure sands, gas sands, shales and calcareous sands.

INTRODUCTION

Since the aim of many seismic surveys is to define the physical state of material deep in the earth, the more variables that can be defined the more tightly the physical state can be constrained. Compressional or P-wave velocity (Vp) has contributed greatly in defining the earth and is still the major source of subsurface information. This is due to reason that most artificial sources generate more compressional energy than shear energy. However, the values of Vp overlaps in a single rock suggest that for a detailed analysis of lithology further parameters are required.

Shear wave velocity can be very useful in determining the subsurface rock properties and is also little affected by change in fluid saturation. Thus they detect lithological changes and not attenuated at the water table (Goforth and Hayward, 1992) Shear wave velocity is more suitable for engineering purposes than compressional wave. It has been found that shear wave velocities in alluvium produce better results than compressional wave velocities (Imai & Torrouchik, 1982). Thus they detect lithological changes more precisely without being attenuated at the water table. According to Folke (2000) converted shear wave imaging becomes very useful when P-wave imaging fails, which means the acoustic-impedance contrast tends close to zero. Converted shear waves can, in some cases, image the reservoir too. In the present case study Lower Goru Formation encountered in Gujwaro well and six seismic lines namely TJ87-04, TJ87-06, TJ89-606, PSM96-115, PSM96-114 and PSM98-202 are used.

An approach is adopted to differentiate the subsurface rocks on the basis of varying hardness of the rocks. It is a difficult task to divide the rocks on the basis of poisson's ratio (б) and Vp/Vs ratio. The change in the value of poisson's ratio is due to physical properties of rocks that for soft rocks poisson's ratio value is higher than the harder rocks. For sea floor sediments value of Poisson's ratio is 0.5 (Folke, 2000), representing a place of recent deposition.

GEOLOGY OF THE AREA

The study area is located in the Lower Indus Basin of Pakistan as shown in Figure 1. Towards north lies Sulaiman-Fold belt, Kirthar Sub Basin in the south, Indian political boundary in the east and Kirthar-Fold belt in the west. The area lies in the rift zone with Jacobabad Khairpur High, Mari Khandkot High and Panno Aqil Graben as main structures. As it is a rift zone various normal faults traverse the area as a result horst-graben structures are commonly formed. A large horst-graben structure called Sukker Rift Zone is the most significant feature of the study area.

STARTIGRAPHY AND PETROLEUM SYSTEM

Oil production has been established in the Lower Goru sandstones, of Cretaceous age. Progressive rifting of the Indo-Madagascan plate commenced, as stretch troughs, early in the Cretaceous period. During the initial phase of the evolution of the rift system the Sembar formation with significant organic content was deposited under restricted circulation. The formation, along with the Basal Shales of the Lower Goru formation, represents the major source of hydrocarbon in the Lower Indus Basin.

The basal sands of Lower Goru formation act as a reservoir rock where as the thick sequence of shale and marl of upper Goru Formation serves as cap rock for underlying Lower Goru reservoir rock. The startigraphy of the area is shown in Figure 2.

METHODOLOGY

The data of the recorded S-wave velocity was not available so compressional wave velocity is converted to shear wave velocity by using the general Castagna equation: $Vp = 1.16Vs + 1.36$ (Vp & Vs = Km/sec) (Royle & Bezdan, 2001), while

[1] Department of Earth Sciences, Quaid-i-Azam University, Islamabad
[2] LMKR Pvt (Ltd), Islamabad

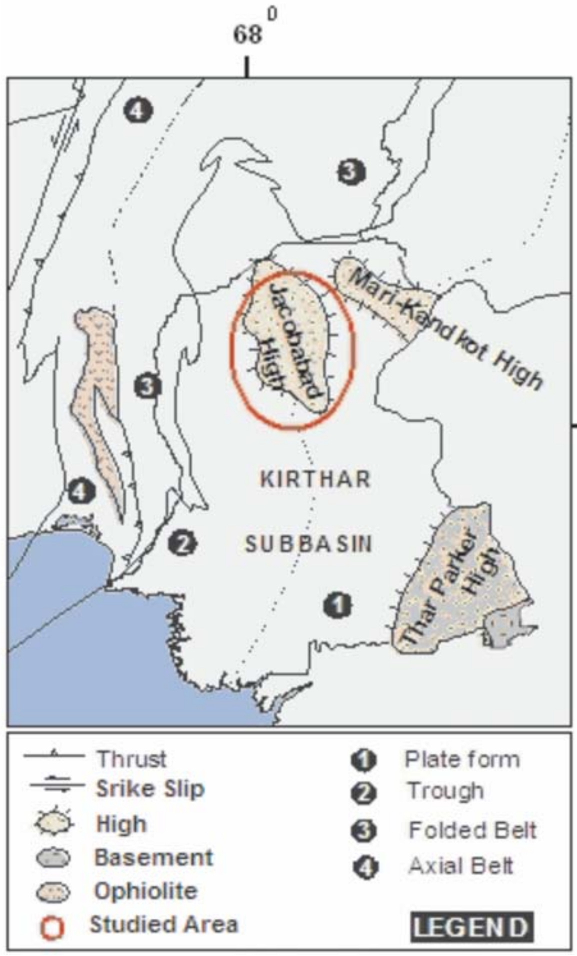

Figure 1- Geology and location of the area.

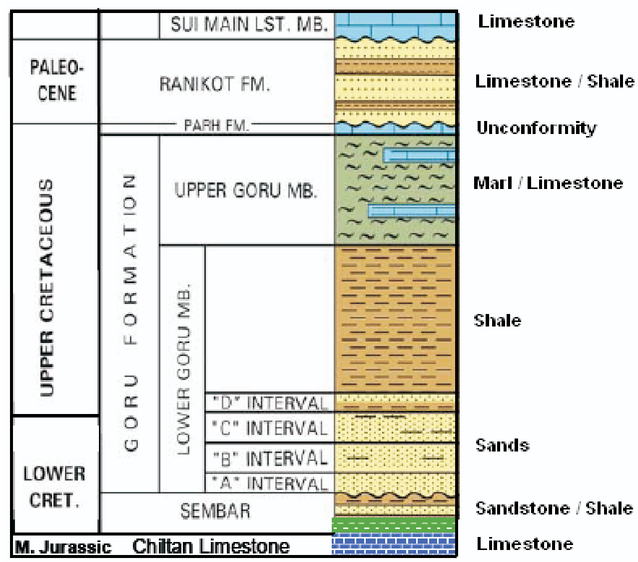

Figure 2- Stratigraphy of the study area (After Ahmad et al, 2004).

Poisson's ratio is calculated using the equation $\sigma = 0.5*(Vp^2-2Vs^2) / (Vp^2-Vs^2)$. It is the ratio of transverse strain to longitudinal strain or measure of amount of transverse distortion compared to longitudinal distortion. Vp / Vs ratio is calculated using the relation $Vp / Vs = SQRT (K/\mu + 4/3)$. It is the function of bulk modulus and shear modulus. Bulk Modulus (K) is calculated from the equation $K = \rho * (Vp^2\ 4/3\ Vs^2)$. It is the ratio of volume stress to volume strain or it is the measure of rigidity against changes in volume. Shear Modulus (μ) is calculated from the equation $\mu = \rho * Vs^2$, and defined as the ratio of shear stress to the angle of distortion or called the modulus of rigidity. Density (ρ) is calculated by $\rho = 0.31 * (Vp)^{0.25}$

The reflectivities for the S-wave are calculated by $Rps(\theta) = 4\sin(\theta)/r *[RCss\ \ ((r - 2)/8)*\text{delta } \rho/\rho)]$, where r = Vp/Vs and $RCss = -(1/2) * (\text{delta } \rho/\rho+\text{delta } Vs/Vs)$ (Folke, 2000). Results obtained from above equations are given in Table 1 and shown in Figure 3.

RESULTS AND DISCUSSION

On the basis of straight-line trend (Figure 3) the rocks are divided into soft, intermediate and hard type. The change in values of Poisson's ratio (Table 1) also indicated various types of rocks. The values of poisson ratio and Vp/Vs obtained from

Table 1- Values of Poisson's ratio and Vp / Vs ratio.

Time (msec)	Poisson's Ratio (б)	Vp/Vs Ratio
25	0.485	7.817
300	0.48	4.943
500	0.463	3.167
875	0.449	2.937
1175	0.41	2.397
1325	0.41	1.802
1550	0.373	2.136
1850	0.331	2.066
2200	0.35	1.745
2375	0.282	1.819
2725	0.252	1.733
3025	0.252	1.508
3250	0.199	1.634
3400	0.139	1.458
3625	0.179	1.652
3850	0.087	1.449
4100	0.071	1.445
4420	0.055	1.460
4750	0.03	1.441
5000	0.125	1.529

sonic log (Table 2) of the Gujwaro well are shown in Figure 4. Based on the poisson ratio values calculated earlier, trend matches again with the intermediate rock type and the lower portion of the formation due to compactness resembles with that of intermediate to hard rock types. Sharp changes observed in the segment of poisson ratio for various CDP data are projected on the seismic section and boundaries marked on the section to differentiate between the three rock types (Figure 5). Tops of the various formations are also marked on the siemic section on the basis of the information acquired from the wells, which are shown in Figure 6.

Table 2- Values of Poisson's ratio and Vp / Vs ratio based on sonic log.

Depth (m)	Poisson's Ratio	Vp/Vs ratio
2500	0.30	1.89
2525	0.31	1.89
2550	0.28	1.81
2575	0.23	1.70
2600	0.33	1.99
2625	0.28	1.81
2650	0.26	1.75
2675	0.29	1.84
2701	0.31	1.90
2725	0.31	1.90
2750	0.34	2.04
2775	0.26	1.75
2800	0.30	1.87
2825	0.28	1.81
2851	0.28	1.81
2875	0.29	1.85
2900	0.29	1.85
2925	0.31	1.89
2950	0.28	1.81
2975	0.27	1.77
3000	0.25	1.74
3025	0.25	1.74
3051	0.25	1.74
3075	0.23	1.68
3100	0.22	1.66
3125	0.24	1.71
3150	0.21	1.65
3175	0.25	1.73
3201	0.30	1.89
3225	0.27	1.77
3250	0.24	1.70
3275	0.25	1.74
3300	0.30	1.86
3325	0.23	1.69
3350	0.25	1.75
3375	0.30	1.87
3401	0.31	1.91
3425	0.27	1.78
3450	0.28	1.80
3475	0.26	1.75
3501	0.24	1.72
3525	0.19	1.67
3551	0.19	1.67
3575	0.17	1.64
3600	0.16	1.62

Reflectivities of rocks calculated at various angles of incidence are shown in Figure 7, which indicate that variation of reflectivity with angle is more prominent for soft rocks and least for hard rocks. The subsurface lithology is also interpreted for gas producing Lower Goru Formation (intermediate rock) based on the standard values of poission ratio (Table 3) as described by Robinson & Coruh, 1988. The relationship between Vp/Vs & lithology has been established and presented in Table 3. Contour maps of above-mentioned parameters are shown in Figure 8 and Figure 9. Using the standard values the interpreted lithology consists of pure sands, gas sands, shale and calcareous sands. Lower value of Poisson's ratio indicated that shale contents increase in sands and vice versa. The interpreted lithologies of Lower Goru Formation of the study area are shown in Figure 10.

Visual examination of Figure 8 and Figure 9 indicate that many gas production wells (SAWAN-02, SAWAN-07 and SAWAN-01) are represented by the closed contour (0.23 & 0.25) of Poisson's ratio and closed contour (1.68 to 1.74) of Vp/Vs. These closed contours values indicated the massive bodies of sands containing gas, which also resemble with the standard values. Based on these standardizations, it is concluded that other sites are also gas producing where such type of close contour values existed.

Table 3- Values of Poisson's ratio and Vp/Vs ratio for various lithologies.

Lithology	Poisson's Ratio	Vp/VsRatio
Pure sands	0.17 - 0.23	1.60 - 1.68
Gas sands	0.23 - 0.25	1.68 - 1.74
Calcareous sands	0.25 -0.27	1.70 - 1.74
Shale	Less than 0.17	< 1.60

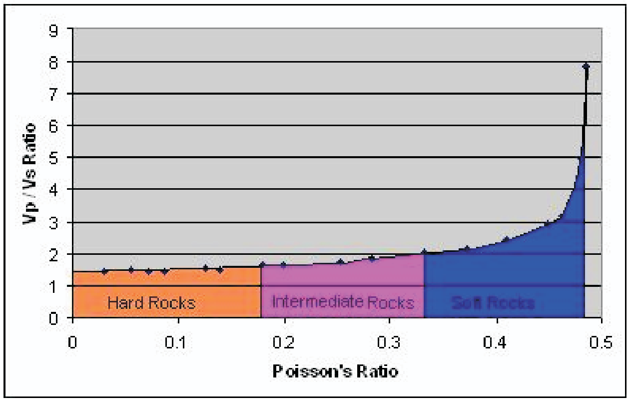

Figure 3- Rock types for CDP 1256.

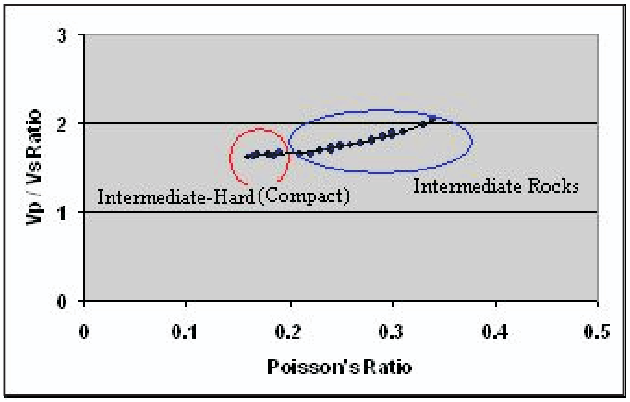

Figure 4- Rock types for the Lower Goru Formation at Gujwaro Well.

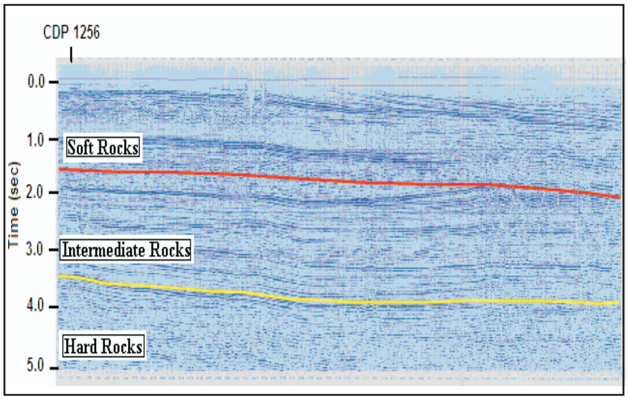

Figure 5- Differentiated Seismic Section (Line # PSM-96-115).

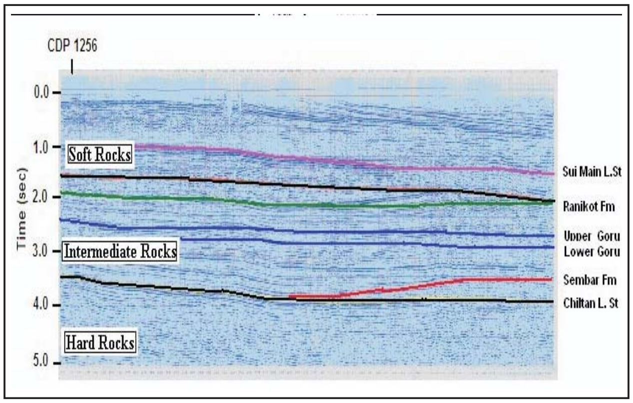

Figure 6- Tops of the various formations (Line # PSM-96-115).

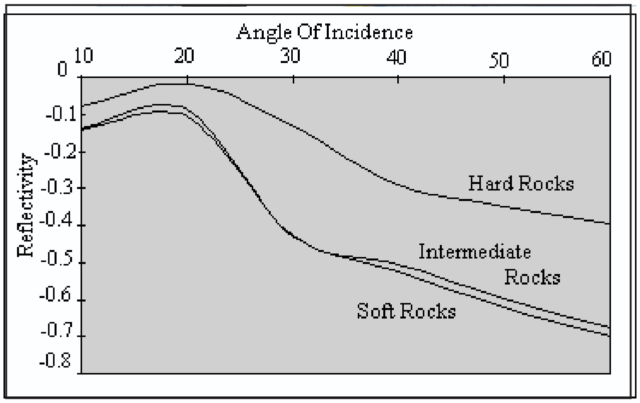

Figure 7- Reflectivities for various rock types for CDP 1576.

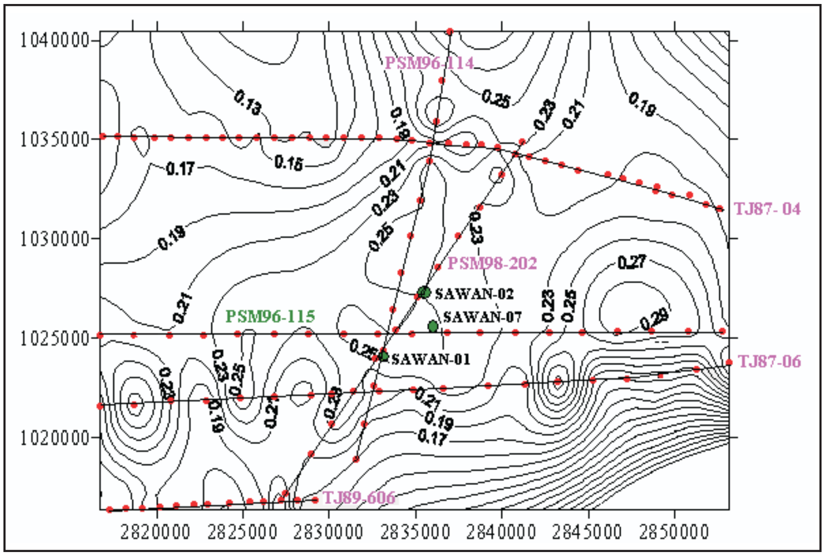

Figure 8- Contour map for Poisson's ratio for Lower Goru.

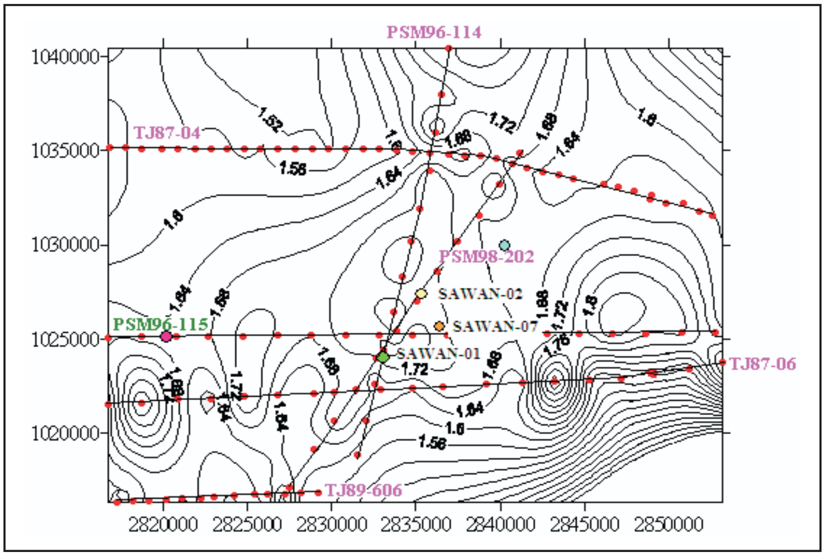

Figure 9- Contour map for Vp / Vs ratio for Lower Goru.

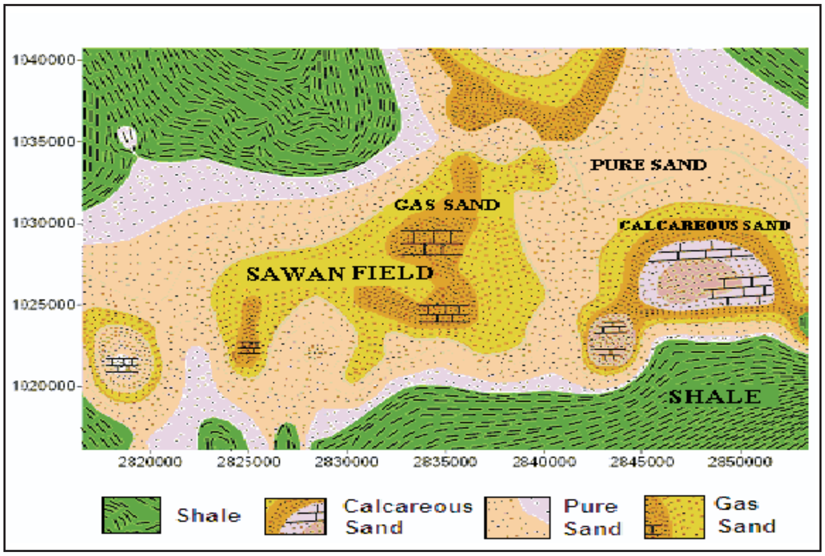

Figure 10- Lithologic map for Lower Goru based on Vp / Vs ratio.

CONCLUSIONS

1. Poisson ratio and Vp/Vs respond appreciably lithological variation and may be used as a third constraint on seismic interpretation.
2. Converted shear wave can be utilized for engineering purpose i.e. to mark the bedrocks for multiple building.
3. The subsurface lithologies interpreted within the Lower Goru formation are pure sands, gas sands, shales and calcareous sands.
4. The properties of the rocks i.e poisson's ratio and Vp/Vs ratio can be used as the predictive properties for the subsurface. By using this technique rock of the study area are divided into soft, intermediate and hard type. These rocks also interpreted with the help of reflectivities of the rock.
5. It is also concluded that Lower Goru Formation consists of intermediate rock, that is gas producing.
6. This property is very much important from the reservoir point of view as the best reservoirs are present in soft type rocks and soft- intermediate type**.**
7. Different locations are identified for gas producing well.
8. In addition to a trap, for a particular to act as a reservoir of gas it must exhibit three properties i.e. it must lie in either soft or intermediate rock type, Poisson's ratio values should be greater than 0.17 and Vp / Vs ratio values must be around 1.68 to 1.74.

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Recieved Feb. 24, 2007, revised March 12,2007, and accepted Sep. 20, 2007.