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Lithological interpretation of middle Miocene Gaj Formation, Indus Offshore, Pakistan

Sarfraz Khan [1], Muhammad Hanif [1], Saqlain Ali [1], Umair bin Nisar [2], Khalid Latif [1], Irfan U. Jan[1] and Abdul Rashid Pasha[1]
[1] NCE in Geology, University of Peshawar
[2] CIIT, Abbottabad

Abstract

Seismic reflection method along with well log serves as an important tool for characterization of reservoir. The present study focuses on blend of parameters derived from seismic data such as acoustic impedance, reflection coefficient, interval velocities, and then usage of density-velocity relation to graphically interpret the lithology by means of Gardener et al. (1974) density-velocity graphical relation. The above results were also justified by incorporating well log data of Indus Marine 1A well. The interval velocity in the Middle Miocene Gaj Formation ranges from 9944 ft/sec to 12532 ft/sec and represents soft lithologies towards south western and south eastern part of the study area. The Acoustic impedance and reflection coefficient values also exhibited a decreasing trend towards the southeastern and southwestern part of study area and indicate presence of soft lithology. However, central part of the study area added by high values of acoustic impedance, reflection coefficient, density and interval velocity are indicative of sand. The Gardner graph (generated on the basis of density-velocity relation) confirmed the lithology of the Middle Miocene Gaj Formation as shale (dip lines) and sandstone (strike lines). This lithological interpretation was later on confirmed by lithology interpretation of well log data of Indus marine 1A (Ali, 2013).

Based on the analysis the area is structurally less complex and comprises mostly of gentle sloping depositional layers of thick interbedded shale and sandstone (Ali, 2013). The sandstone dominates in the central part of study area while shale is mostly incorporated towards the south east and south west part of the area. The Offshore Indus Basin remains a frontier area as few wells drilled till now could not hit the commercial hydrocarbons. Considering the thick sedimentary fill and its deformational history, Offshore Indus Basin has a variety of potential plays which requires more studies.

Keywords: Interval velocity; Density; Gardner graph; Reflection coefficient; Middle Miocene; Lithology identification.

1. Introduction

The general theory of seismic reflection and transmission of waves that incident obliquely at an interface between two fluid-filled porous rocks is similar to that for two elastic non dissipative media. According to Biot's theory, an isotropic homogeneous porous rock and its pore-filling fluid are treated in the manner of two interpenetrating elastic continuation (Dutta and Ode, 1983).

The first use of amplitude information as hydrocarbon indicators was in the early 1970s when it was found that bright-spot amplitude anomalies could be associated with hydrocarbon traps (Hammond, 2011). Increasingly quantitative work after Ryseth et al. (1998) who used acoustic impedance inversions to guide the interpretation of sand channels and Zeng et al. (1996) used forward modeling to improve the understanding of shallow marine facies from seismic amplitudes. Neri (1997) used neural networks to map facies from seismic pulse shape.

The major constituents of a rock (cementation, mineral composition, granular nature, porosity, fluid content and environmental pressure), is directly related to the density and velocity of the rocks. It also depends on age and burial depth of rock (Gardner et al., 1974). The study area geographically lies between latitudes 23°15'00" to 24°30'00" N and longitudes 66°30'00" to 67°30'00" E.

2. Geology of the area

According to Kazmi (1979) Pakistan is

located along the Tertiary convergence zone, and this zone marks the interaction of three lithospheric plates (Indo-Pakistan, Arabian, and Eurasian plates). The triple junction of these three plates is located to the north west of Karachi (Kazmi and Jan, 1997). The Offshore Indus Basin represents the western part of the trailing edge of the Indian Plate, east of Murray Ridge. This basin is a typical Atlantic type Passive Margin developed as a result of the breakup of Gondwana during the Mesozoic (Jaswal and Maqsood, 2002).

The offshore Indus Basin is about 150 km in width, most of its eastern and south- eastern part is covered by the Indus fan deposits, and these deposits are developed over a large area of continental crust (Gaedicke et al., 2002). The seismic data across the western region of the basin shows complex structural geometry with some evidence of extensional tectonics (Jaswal and Maqsood, 2002).

Stratigraphy of the study area ranges from Cretaceous to Holocene (Quadri, 1995). The rocks are mainly detrital and non-detrital of different ages. These formations categorized in different ages on the basis of fossils (Hunting Survey Corporation, 1960). The stratigraphic set up of the area is shown in Figure 1; the oldest rocks of the area are Cretaceous in age. The Sembar and Goru formations are Early Cretaceous, whereas Pab, Parh, and Mughal Kot formations are late Cretaceous.

The Sembar Formation consists of shale, silty shale, or marl. Whereas, the Goru Formation comprises two units, Upper Goru and Lower Goru. The Upper Goru consist of Marl, and the Cretaceous Lower Goru Formation is a thick sequence of sands, interbedded with thick claystone /shale and minor limestone members (Malkani, 2010). The Late Cretaceous Mughal-Kot Formation is silty calcareous shale (Kazmi and Snee, 1989). The Paleocene Ranikot Group consists of clay/claystone and sandstone transparent to translucent, light brown (Shah, 1977). Whereas the Ghazij Formation contains shale, sandstone conglomerate and coal seams (Iqbal, 1973; Hunting Survey Corporation, 1960). The Early to Late Eocene Kirther Formation consist of limestone rich with fossil, interbedded with subsidiary marl and shale (Kazmi and Jan, 1997). The Oligocene Nari Formation, is mainly consist of fine to medium coarse grained sandstone having brown color and interbedded shale (Fatmi, 1977).

The Middle Miocene Gaj Formation is the focus of this study which is present in study area. This Formation was first introduced by Blanford (1876) and mainly composed of shale with subordinate sandstone and limestone. The shale is flecked, greenish grey. The sandstone is brown in color, greenish-grey, calcareous, ferruginous and cross bedded. The fossiliferous limestone is argillaceous having brown or yellowish white color. In some places minor pebbly conglomeratic beds are also present.

3. Methodology

Normally the horizons are named on the basis of Vertical Seismic Profile (VSP) or on the basis of check shot survey data. But sometime synthetic seismogram and well summery sheet can be used to name the horizons. In the present study only the horizon of interest (Middle Miocene Gaj Formation) was identified using VSP data and well correlation data on the selected seismic lines (Ali, 2013).

Parameters are required to identify the lithology and thickness of a formation i.e., a) Interval velocity (Vint) and b) Density (ρ). Both these parameters were used to interpret the lithology by simple correlation of the average of interval velocities and average of densities of the formation against shot points on a standard modified graph of Gardner et al. (1974).

3.1. Interval velocity calculation

On the seismic section the Root Mean Square (RMS) velocities (derived initially from stacking velocities) were given in velocity windows for different common depth points (CDP's). After putting the root-mean-square velocity (VRMS) function in velocity analysis software (K-tron-Vas), these velocities were converted to interval velocities.

3.2. Density determination

Density of rock is a major property which describes the amount of solid part of the rock body per unit volume. Seismic velocity is inversely proportional to density. Direct estimation of density from seismic velocities has been done by using the following equation 1 of Gardner et al. (1974):

$$\rho = 023 * (V_{int})^{0.25} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ (1)$$

Where ρ = Density in g/cc and interval velocity in ft/sec. The velocity is inversely proportional to the square root of density (Calves et al., 2010) but it is common observation that velocity appears to increase with density.

3.3. Velocity–density–lithology correlations

In the present study lithology was interpreted using standard velocity-density correlation graph of Gardner et al. (1974). This graph shows wide range of P-wave velocities and lesser range of bulk densities for the more prevalent sedimentary rock types through a wide range of depths. By using standard graph of Gardner et al. (1974), two cross lines are projected for each contact on the basis of average density (gm/cc) and interval velocity (ft/sec). The point of intersection of these two lines gives the appropriate type of lithology which is shown in Figures 4.2 to 4.3.

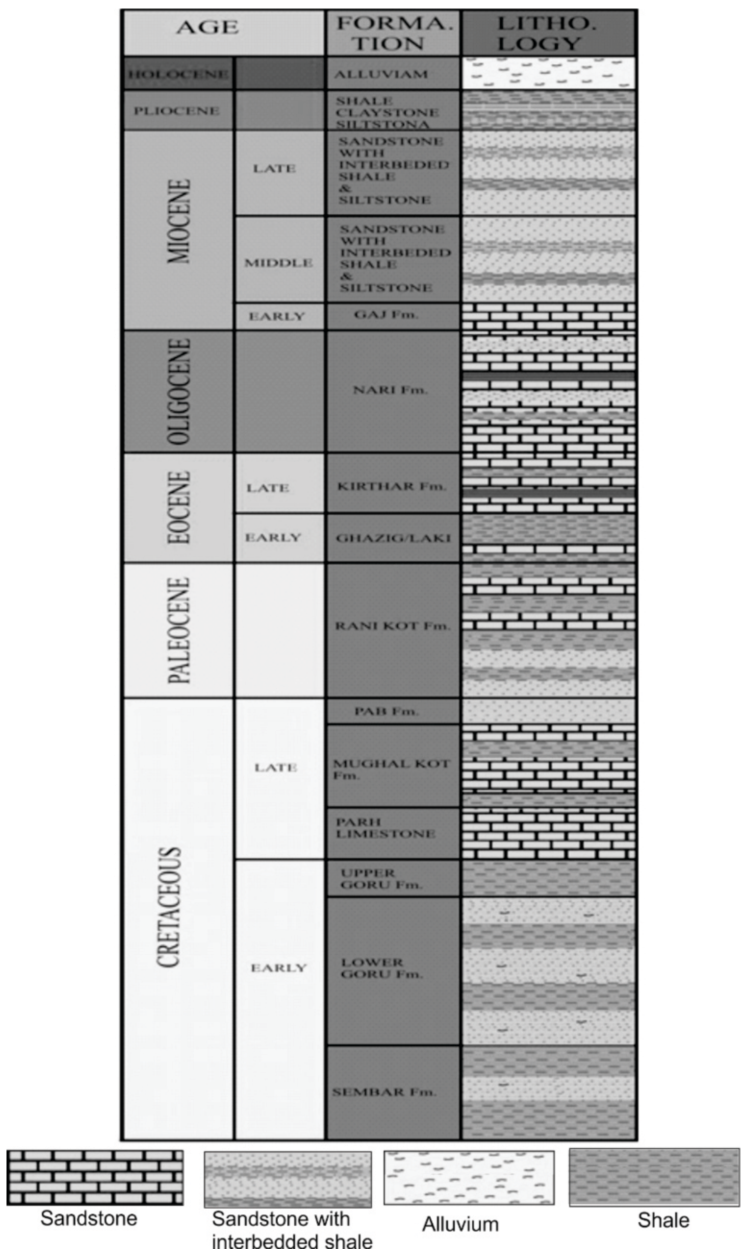

Fig. 1. Stratigraphic column of the study area.

3.4. Reflection coefficient

For a specific case of normal incidence there is a simple equation relating the incident amplitude to the reflected amplitude. The ratio of reflected amplitude to incident amplitude is called the reflection coefficient (Povey, 1997) and it is given as under;

$$R = \frac{\rho 2\, V2 - \rho 1\, V1}{\rho 2\, V2 + \rho 1\, V1} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where V1 is the interval velocity and ρ1 is the rock density of the first studied reflector (top of Middle Miocene Gaj Formation), and V2 is the interval velocity and ρ2 is the density of second studied reflector (bottom of Middle Miocene Gaj Formation), R is reflection coefficient between top and bottom of Middle Miocene Gaj Formation.

Generally, values of the reflection coefficient ranges from -1 to +1 (describing in words of positive and negative).

In order to interpret the reflection phenomenon in the study area, four seismic sections were interpreted for reflection coefficient and interval velocity in Middle Miocene Gaj Formation. The variation of reflection coefficient and interval velocity was interpreted by contouring the values in contouring program Surfer 12 (Fig. 4.4a and 4.4b).

To find the lithologies of Middle Miocene Gaj Formation in Offshore Indus Basin, we opt the results of Indus marine-1A well of Ali (2013). The well log data, included log curves of Gamma ray, Spontaneous potential, Sonic Log, and Density log. Lithological column for the selected well was prepared in Geographix 2007 software (Ali, 2013).

4. Results and discussions

The lithological interpretation on the basis of well logs, reflection coefficient and Gardener's relation between interval velocity and density are discussed below;

4.1. Well log interpretation

The well log data (Ali, 2013) was interpreted for lithology on the basis of Gamma ray (GR) values. Higher values of Gamma ray (greater than 60) indicate the presence of shale and low values (less than 60) indicates the presence of sandstone (Ali, 2013). Furthermore, lithologies were confirmed from the correlation of gamma ray and sonic log (Ali, 2013). From the interpretation of well log, dominant lithologies are sandstone, shales and their intercalation (Fig. 4.5).

4.2. Lithological identification using gardner relation

The results for lithological identification of the Middle Miocene Gaj Formation using Gardner relation are summarized in Table 1.

4.2.1. Lithology identification of line No 86-9033

For this line a perpendicular and horizontal line was drawn corresponding to 2.30 gm/cm^3 and 10052 ft/sec respectively on standard graph of Gardner et al. (1974). The points of intersection of these two lines also lie near to sandstone line shown in Fig. 4.2.

4.2.2. Lithology identification of line No 86-9007

The average interval velocity calculated from seismic section line number 86-9007 is 10199 feet/sec and average bulk density is 2.31 gm/cm^3. A perpendicular and horizontal line was drawn corresponding to 2.31 gm/cm^3 and 10199 ft/sec respectively on standard graph of Gardner et al. (1974). The point of intersection of these two lines gives the type of lithology of reflector, shown in Figure 4.2. The lithology identified for the reflector might be shale.

4.2.3. Lithology identification of line No 86-9013

The average interval velocity calculated from seismic section line number 86-9013 is 12532 ft/sec and average bulk density is 2.42 gm/cm^3. A perpendicular and horizontal line was drawn corresponding to 2.42 gm/cm^3 and 12532 ft/sec respectively on standard graph of Gardner et al. (1974). The points of intersection of these two lines lie near to shale line (Fig. 4.3).

4.2.4. Lithology identification of line No 86-9029

The average interval velocity calculated from seismic section line number 86-9029 is 9944 ft/sec and average bulk density is 2.30 gm/cm³. A perpendicular and horizontal line was drawn corresponding to density of 2.30 gm/cm³ and interval velocity of 9944 ft/sec respectively on standard graph of Gardner et al. (1974). The points of intersection of these two lines also lie near to shale line (Fig. 4.3).

4.2.5 Reflection coefficient and interval velocity

In order to interpret the behavior of Middle Miocene Gaj Formation in the subsurface of the study area 2D model of reflection coefficient and interval velocity were generated. The results indicated that in the south-west region of the study area there were low values of reflection coefficient (ranging from -0.05 to -0.35) corresponding to low values of acoustic impedance indicate less porous (Buenafama, 2004) shale or shale interbedded with sand; in north region moderate values of reflection coefficient (ranging from 0.1 to 0.45) corresponding to moderate acoustic impedance indicate the presence of sandstone; and in southeast region the values of reflection coefficient are ranging from -0.1 to -0.05 corresponding to low values of acoustic impedance indicate presence of shale and sand interbeds. Shale has low reflection coefficient as compare to sandstone (Chiadikobi et al., 2012).

Table 1. Average values of interpretation parameters (Interval velocity, Reflection coefficients, and density) for lithology determination.

S. No	Line No.	Types	Interval velocity (ft/sec)	Density (g/cc)	Reflection coefficient	Interpreted Lithology
1	PC/ 9033-86	Migrated Stack	10052	2.30	Negative	Shale
2	PC/9007-86	Migrated Stack	10199	2.31	Negative	Shale
2	PC/9013-86	Migrated Stack	12532	2.42	Negative	Shale
4	PC/9029-86	Migrated Stack	9944	2.30	Negative	Shale

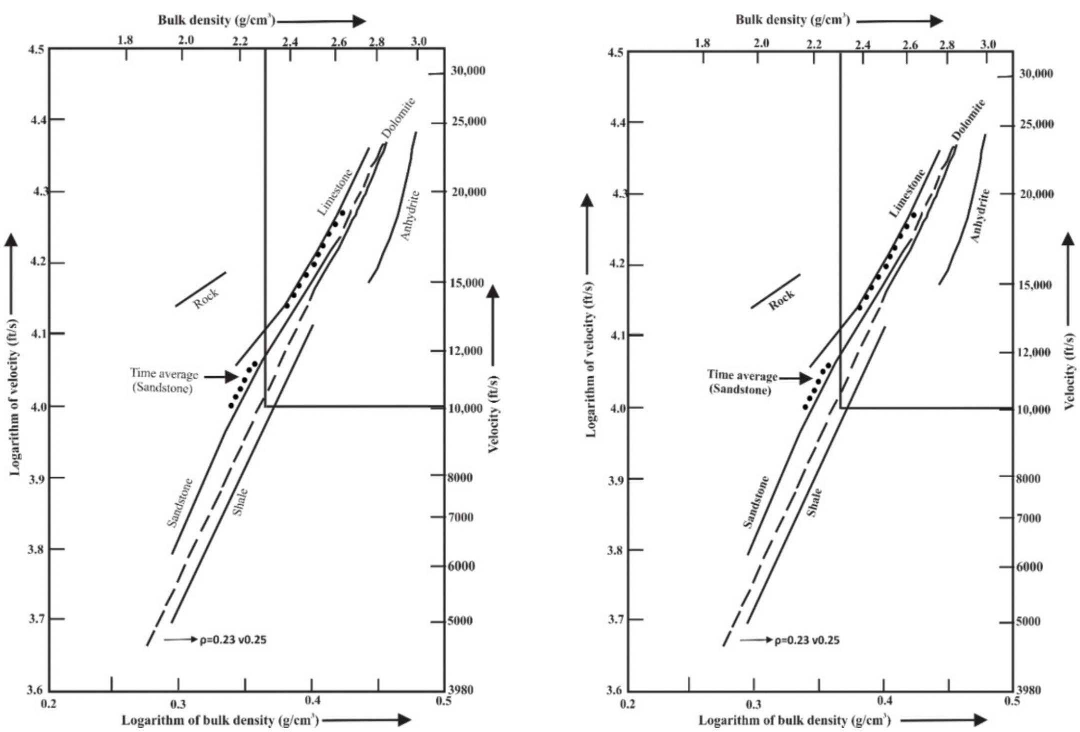

Fig. 4.2. Lithological interpretation of line # 86-9033 (left) and line # 86-9007 (right) showing the presence of shale in the studied area.

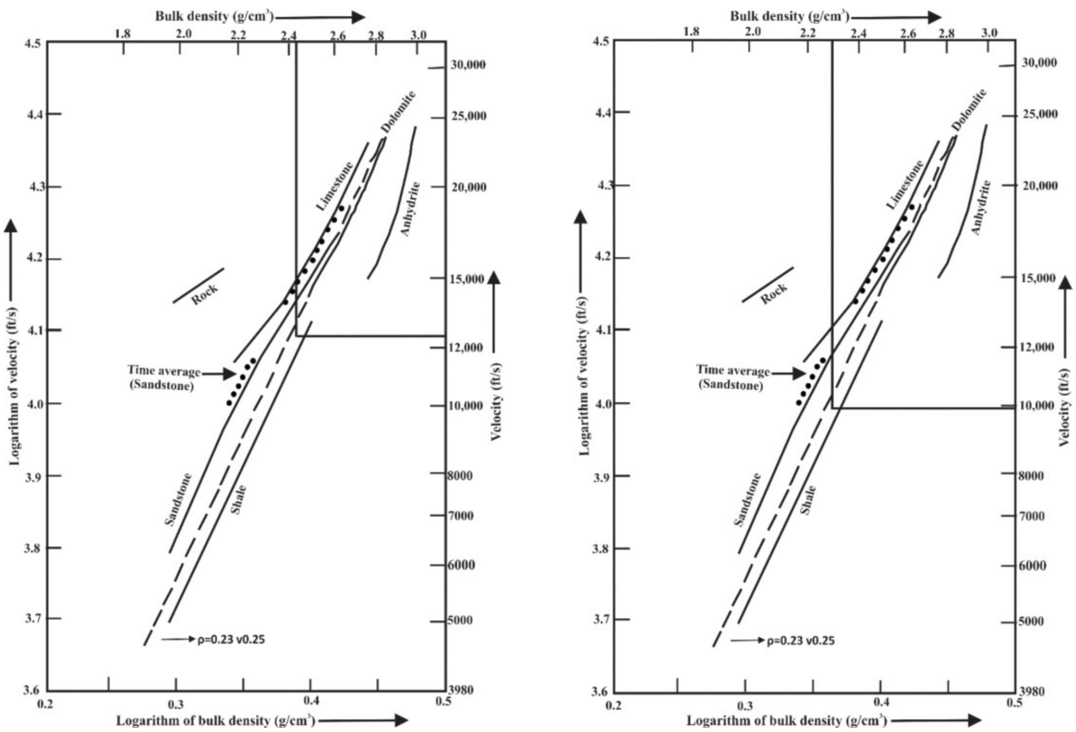

Fig. 4.3. Lithological interpretation of line # 86-9013 (left) and line # 86-9029 (right) showing the presence of shale in the studied area.

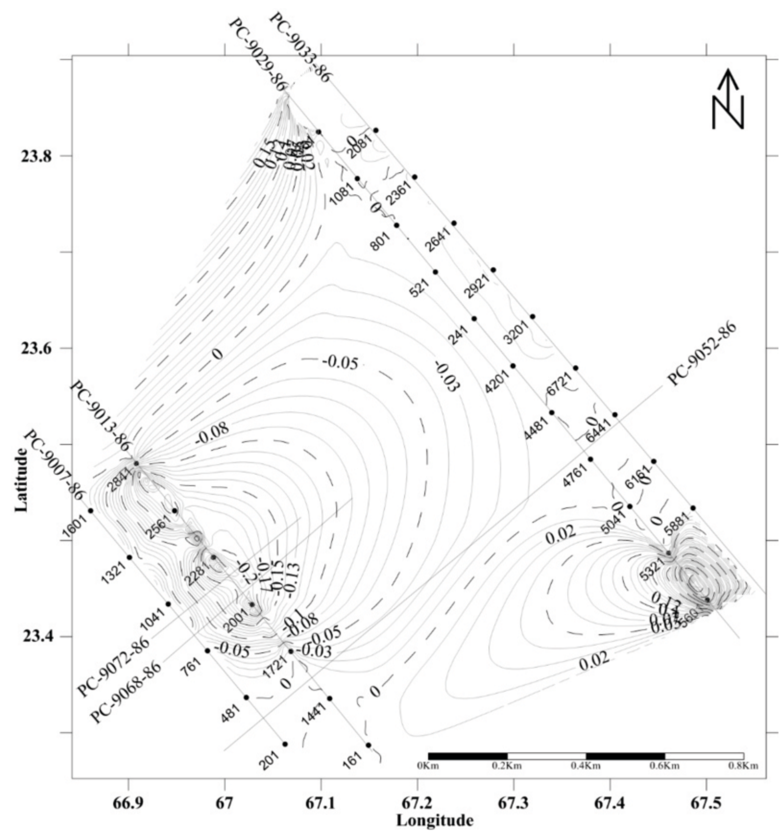

Fig. 4.4a. 2D reflection coefficient map of study area which shows low values of reflection coefficient in the southwest region (indicate the presence of dominated soft lithology) and high values in southeast region (indicate presence of stiff lithology), north region comprises moderate reflection coefficient values.

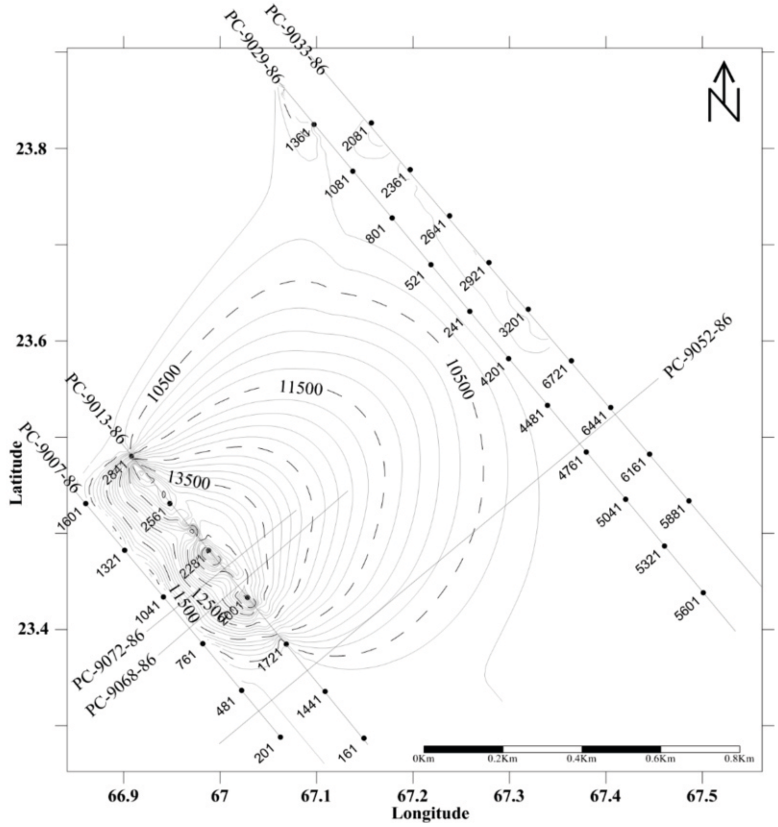

Fig. 4.4b. 2D map of interval velocity which shows a decrease in interval velocity values towards the north eastern part representing softer lithologies while the western part represent a mixture of high and low values (alternate harder and softer lithology beds).

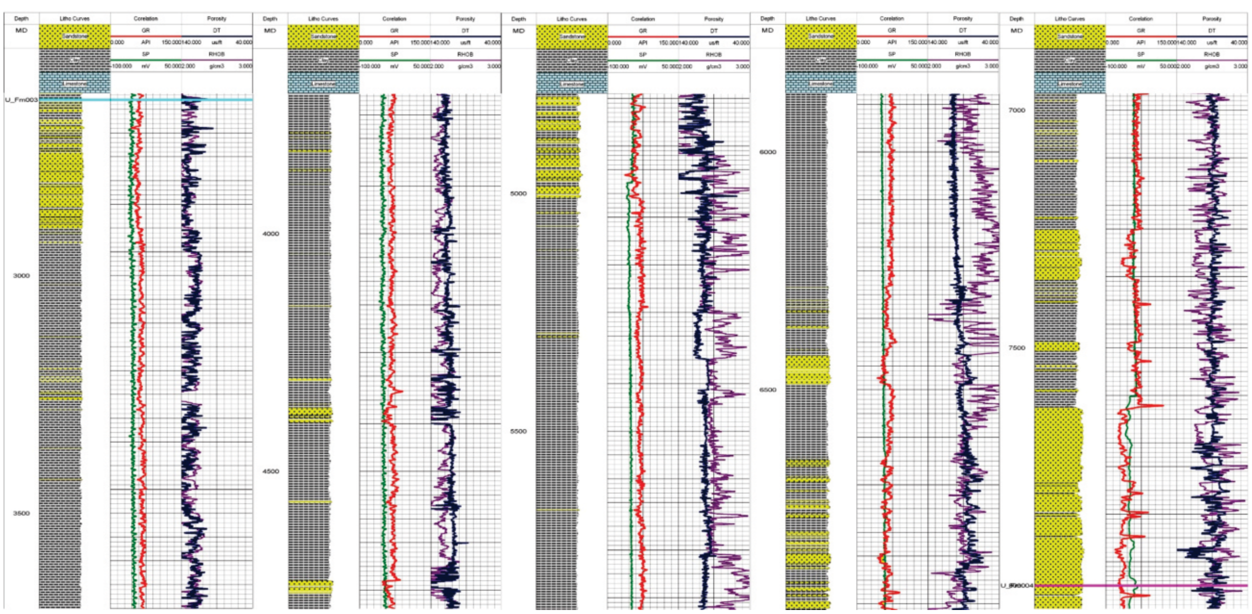

Fig. 4.5. Well curves of Indus marine-1A used to correlate the lithology of Middle Miocene Gaj Formation representing alternative shale sand pattern.

The lithology of Middle Miocene Gaj Formation is interpreted as shale and sand interbeds with a sand deposited central part and shale deposited western part. Few numbers of Faults in the study area represent less structural complexity and gentle slopes. The depositional pattern might be interpreted as shallow marine. The results of Acoustic impedance, interval velocity and density also confirm that the Middle Miocene Gaj Formation consist of thick and soft surfaces of shale beds with few thick beds of sand. The 2D contour models represent presence of shale and sand beds as the negative reflection coefficients (low acoustic impedance) and low interval velocities on southwest region of the study area indicate the presence of soft lithology and vice versa. The well log interpretation also confirms the alternate shale and sand interbeds at depth range of 801.6 meters to 2630 meters, thus proving the seismic parameters. The present study can be enhanced by incorporation of more well data and seismic lines so that extension of this depositional pattern can be deeply studied.

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