

Productive Lithology Discrimination in Structurally Complex Area by Means of AVO/AVA Synthetics and Petrophysical well log Analysis, A Case Study from Khipro Block, Southern Indus Basin, Pakistan

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Abstract—In this study, AVO/AVA Synthetics and petrophysical well log analysis was carried out to discriminate between the reservoir and non-productive lithology for two wells Naimat Basal 01 & Siraj South-01. Synthetic AVO/AVA traces of Naimat Basal 01 & Siraj South-01 were generated. The behavior of the theoretical and NMO corrected synthetics for Naimat Basal 01 has a weak response, while Siraj South-01 indicated a clear sharp anomaly. AVA synthetic created for well Naimat Basal-01 and Siraj South-01 using Zoeppritz equation clearly indicated amplitude variations. On the basis of AVO/AVA anomalies petrophysical well log analysis was carried out for Naimat Basal-01 from 2600-3550 m depth. The two zones interval 3395m- 3411m and 3480m-3497m were studied in detail which confirmed the results obtained from AVO/AVA synthetics and 3395-3411m and 3480-3497m may be good reservoir zone for the hydrocarbon accumulation.

Keywords— AVO/AVA Synthetics, Petrophysics, Reservoir Evaluation.

I. INTRODUCTION

Basic AVO theory is widely used as a tool in lithology identification, hydrocarbon detection, and fluid parameter analysis, by means of basis that seismic amplitudes across the interfaces are influenced by the difference in the physical characteristics immediately above and below the interface [1-2]. The dissimilarity in transmission and reflection coefficients with an increase in offset and angle of incidence (AVA) is often referred to as offset-dependent reflectivity property and primary root for amplitude-versus-offset (AVO) analysis. Conventional AVO (amplitude variation with offset) analysis is based on the well-known Knott-Zoeppritz equations [3-4]. Shear velocity measurements are essential since AVO seeks to employ the elastic nature of seismic wave propagation. Measurements of very slow shear waves using Dipole source shear logging increases the range of applicability and possibility for greater reliability in AVO interpretation [5]. The offset is a simple function of angle in relatively simple geologic settings, however, a more rational $V(z,m)$ will make a complex relation between offset and incidence angle. In such

cases, amplitude variation with an angle (AVA) is a preferable alternative to AVO analysis [6]. The modeling exercises provide valuable information on how to obtain a better fit with the measured data (iterative method with perturbation of the reservoir/seal properties). Data with different sample support should be integrated properly, with appropriate up- and down-scaling [7].

AVO analysis is commonly used in hydrocarbon exploration being considered as potent demarcation tool for lithologies and type of fluid present in within the reservoir achieved by investigating the Primary wave reflections output at the interface of the target zone and adjoining sediment [8]. We must also realize that AVO models are highly susceptible to small changes in the input parameters, in particular, Poisson's ratio. And unfortunately, Poisson's ratio is one of the parameters we know the least about.

The third cause for concern is the Domenico effect—a small amount of gas has almost the same effect on amplitude as does a large amount of gas. Therefore, when we see an increase or decrease in amplitude due to the presence of gas, we generally cannot predict the quantity of gas present.

Another limitation to the method is the homogeneity of the model, both laterally and vertically, versus the inhomogeneity of the subsurface. We naturally would like every relationship between an AVO response and a rock property to be linear and unique, but this is not often the case. Thus, using a single velocity versus density trend for the shale in the model did not reflect the true complexity of the area. Another reason for the failure of the "AVO response for a sand package depends not only on the degree of shaliness but also the shale distribution within the sand package" [9].

The fundamental objective of the evaluation of petrophysical parameters is to arrive at accurate estimates of in-situ permeability and porosity in which measurement of these parameters is impossible. In such cases, the values for these parameters can be determined through petrophysical correlations with those in similar oil reservoirs to be used in combination with information on their formation lithology in order to evaluate their average hydrocarbon saturation percentage and their approximate reserve volume. The adverse

effects of estimation errors cause higher venture risks and therefore the need for an estimation method that guarantees the minimum estimations errors possible [10-11].

Evaluation of oil reservoirs and their portrayal are crucial tools in the oil industry, especially for the appropriate discovery of reservoirs and their economic assessment. Parameters such as porosity, permeability, and formation structure are amid the most key features of reservoirs whose fortitude is difficult, more complications being introduced into the process by their heterogeneity. Functional management strategies can only be effective when the detailed spatial distribution of the reservoir petrophysical parameter is available [12].

In clastic reservoir during the evaluation, the occurrence of shale or clay within the sand is a factor to be judged precisely. The presence of shale influence formation properties and response of the logging tool. The limestone and dolomite are a typical example of, non-clastic carbonates reservoirs. Around carbonate rocks constitute 50 percent of the reservoir in the world. The response of well logging tool is principally dependent upon matrix chemical nature and fluid type in pores. The reservoir characterization aims to infer the petrophysical properties distribution at field scale spatially. Porosity and permeability of formation are linked through a broad relationship. The utilization of rock physics theory and data is actually observed in petrophysical interpretation for reservoir geophysics observations [13].

II. EASE OF USE

After the fragmentation of Gondwanaland in Carboniferous to Early Permian [14], India started to move rapidly northward relative to Australia and Antarctica [15] till establishment of its initial collision with Kohistan Island arc and Eurasian Plate in Late Cretaceous [16-19], marked by the exposures of ophiolites along the southern margin of Kohistan Island arc [19-21] The ongoing convergence after the initial collision caused deformation, crustal shortening and surface uplift which developed the Himalayas, Indus basin and Pakistani Fold and Thrust Belt [15 and 19].

Indus Basin which is tectonically divided into three Sub Basins, Sargodha High (Precambrian Indian Shield) which is considered to be the main controlling feature that divides the Indus basin into two Basins Upper Indus Basin from Lower Indus Basin. Another major Feature which rose through Jurassic and Cretaceous age is Jacobabad High, divides the Lower Indus Basin further two sub-basins Central Indus Basin and Southern Indus Basin [22].

Hydrocarbon Production Contribution of Southern Indus Basin includes:

- Sui Main Limestone (54%),
- Lower Goru (14%),
- Habib Rahi Limestone and Pab Formation (13%).

Study area Co-ordinates (Latitude: 25° 45' to 25° 57' North Longitude: 68° 36' to 68° 54' East) falls in Southern Indus Basin and geographically in Sanghar Distt., Sindh

province of Pakistan (Fig.1). Southern Indus Basin which is highly effected (tilted Faulted Blocks) because of extensional tectonic activities cause Indo-Pak divergence from Gondwanaland in early Paleozoic [23].

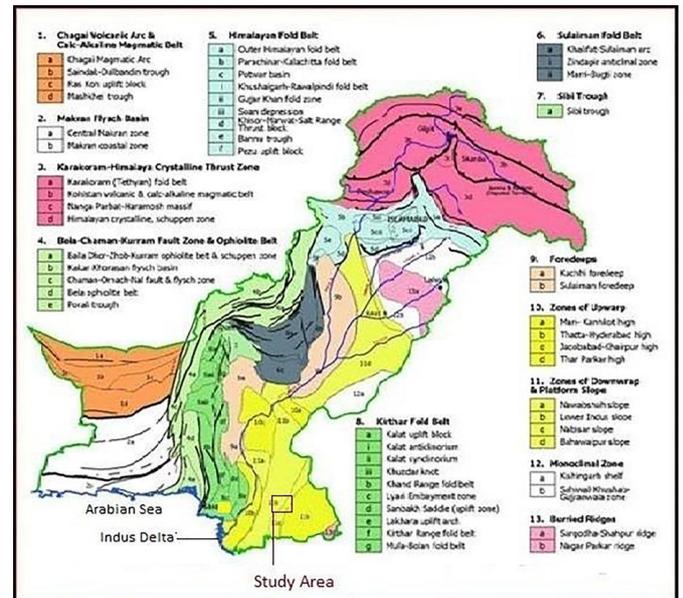


Figure 1. Study area location on tectonic map of Pakistan (modified after Faisal et al., 2013).

Cretaceous age Sembar is the main potential source rock of study area, deposits under restricted environment which is suitable for significant accumulation of Organic Matter [24]. Sands of Lower Goru formation overlying the sembar source rock is our main focus, where the Trapping mechanism is tilted fault blocks, faulted gentle role-overs and Stratigraphic traps. Sealing intervals are present for all potential reservoirs in the platform area, especially intra-formational shale for Lower Cretaceous reservoirs [25].

PERIOD		FORMATION	LITHOLOGY	NOMENCLATURE
TERTIARY	QUAT	ALLUVIUM	[Pattern]	KIRTHAR LIMESTONE
	EOCENE	KIRTHAR	[Pattern]	
		LAKI	[Pattern]	
	PALEOCENE	U.RANIKOT	[Pattern]	RANIKOT SHALE
L.RANIKOT		[Pattern]	RANIKOT SANDSTONE	
CRETACEOUS	UPPER	PARH	[Pattern]	CHALK & LIMESTONE
		UPPER GORU	[Pattern]	UPPER GORU MARL & SAND
	LOWER		[Pattern]	UPPER SAND
			[Pattern]	MIDDLE SAND
			[Pattern]	LOWER SHALE
			[Pattern]	BASAL SAND
SEMBAH		[Pattern]	SEMBAH SHALE AND SAND	
		[Pattern]		
JURASSIC	UPPER	CHILTAN	[Pattern]	CHILTAN LIMESTONE

Figure 2. Generalized stratigraphic column of the area (Khipro)

The rate of success compared with other basins of Pakistan is highest because small tilted faulted blocks of Lower Goru Reservoir in this region are targeted progressively [26]. The Figure 2 is a generalized stratigraphic chart for the study area.

III. PREPARE YOUR PAPER BEFORE STYLING

A. AVO/AVA Synthetics

Amplitude determination of reflected and transmitted plane waves at the planar boundary of two elastic media in welded

contact for all incidence angles is done using Zoeppritz's equations [27]. Two wells of the Khipro area were selected. Naimat Basal-01 (latitude 25°47'37.69" N and Longitude 68°41'47.34" E) and Siraj South-01 (Latitude 25.51°33.34" N and Longitude 68.43°01.51" E). For both wells AVO/AVA Synthetics were generated using Zoeppritz Equation (Fig.3, 4, 5, 6).

On the basis of anomaly indicated by AVO/AVA Synthetics Naimat Basal-01 was selected for further analysis.

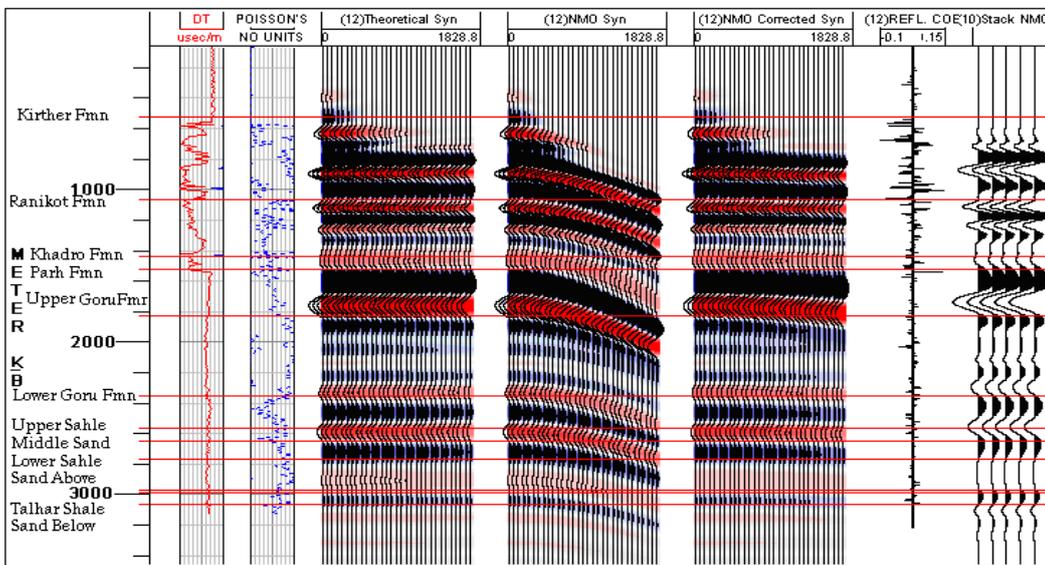


Figure 3. AVO synthetic has been created for well Siraj South 01 using Zoeppritz Equation

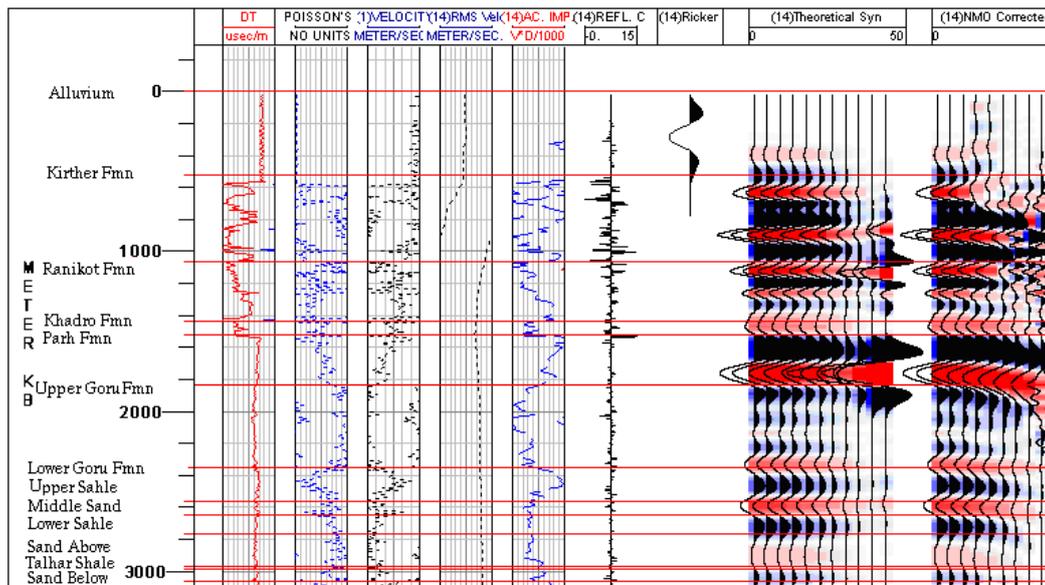


Figure 4. AVA synthetic has been created for well Siraj South 01 using Zoeppritz equation

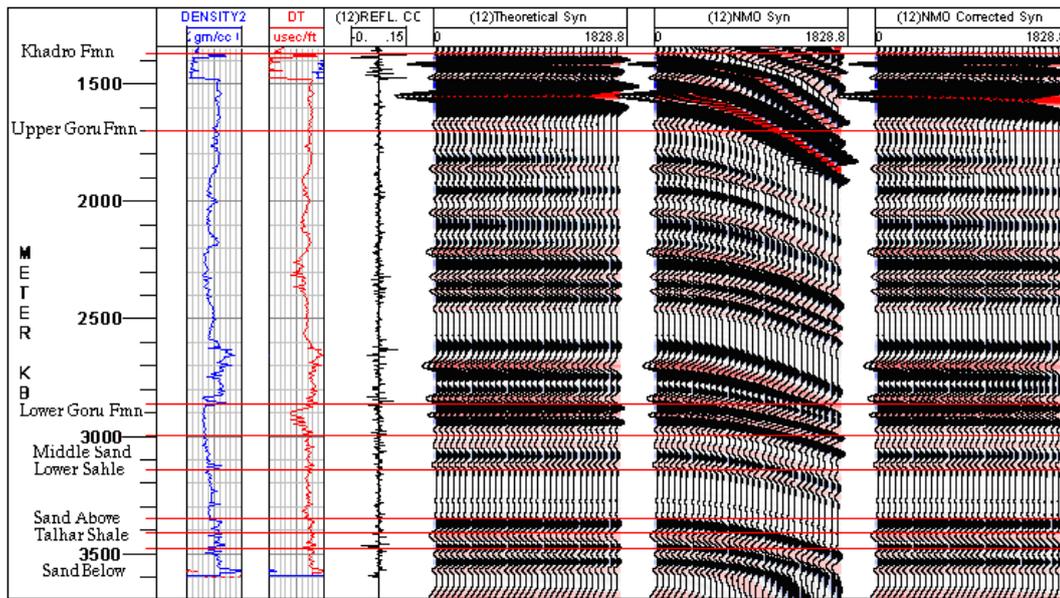


Figure 5. AVO synthetic created for well Naimat Basal 01 using Zoeppritz

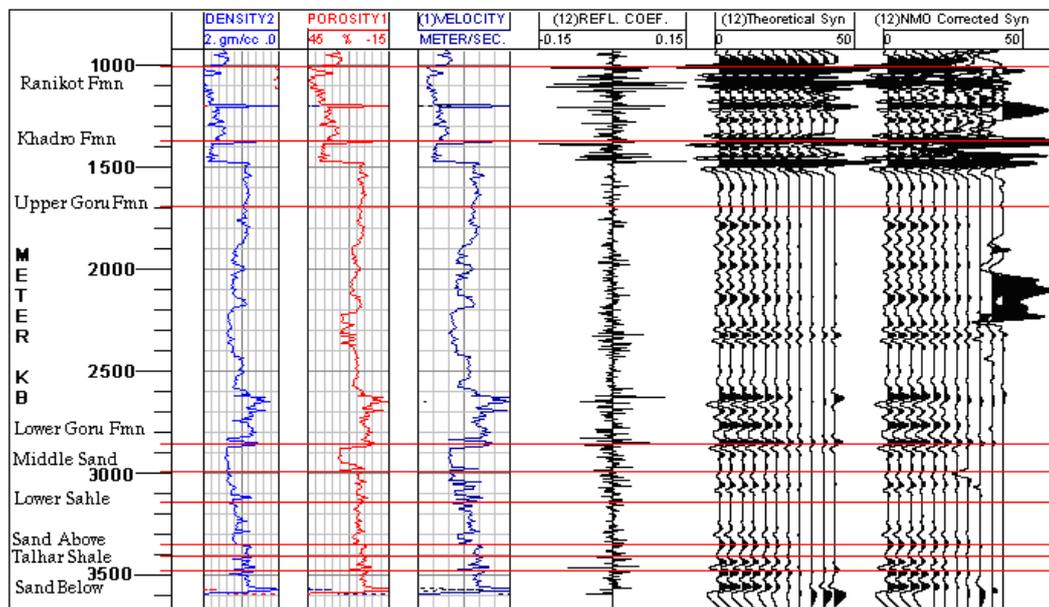


Figure 6. AVA synthetic has been created for well Naimat Basal using Zoeppritz equation

B. Petrophysical Parameters Evaluation

The well logging is the mainstream tasks for any well post drilling to resolve from log measurements the shale volume, porosity, permeability, and water saturation [28]. A detailed petrophysical analysis for Naimat Basal_01 was performed from depth 2800m to 3550 m.

The first step from where we start Petrophysical analysis, Shale volume curve have been generated on the basis GR log. This curve supposed to be helpful in separating the reservoir and non-reservoir zones. Other logs like NPHI, RHOB together use to target porous lithologies then PEF & DT use to confirm the lithology type. After that Resistivity log is used to target the porous and highly resistive zones within the interpreted lithologies. Lithology plot in last track represented by various standard colors (Fig.7). Yellow and Green illustrating

sandstone and shale intervals respectively because only two lithology exists in studied interval due which to delimit the intermediated zone between sand and shale has been represented as silt. After Separating the shale and sand intervals, named according to the General Stratigraphic Section. On the basis of the interpreted section, the well was divided into 6 major zones (Fig.7) representing intervals from

2805m to 3000m, 3000m to 3186m, 3186m to 3354m, 3354 m to 3412 m, 3412m to 3480m and 3480 to 3550m (Table.1). The overall impression of the interpreted section is alternating layers of sandstone and shale, the shale volume in sandstone ranges from 10 to 30 (above 30 Vsh was neglected for reason not to be selected for reservoir zone).

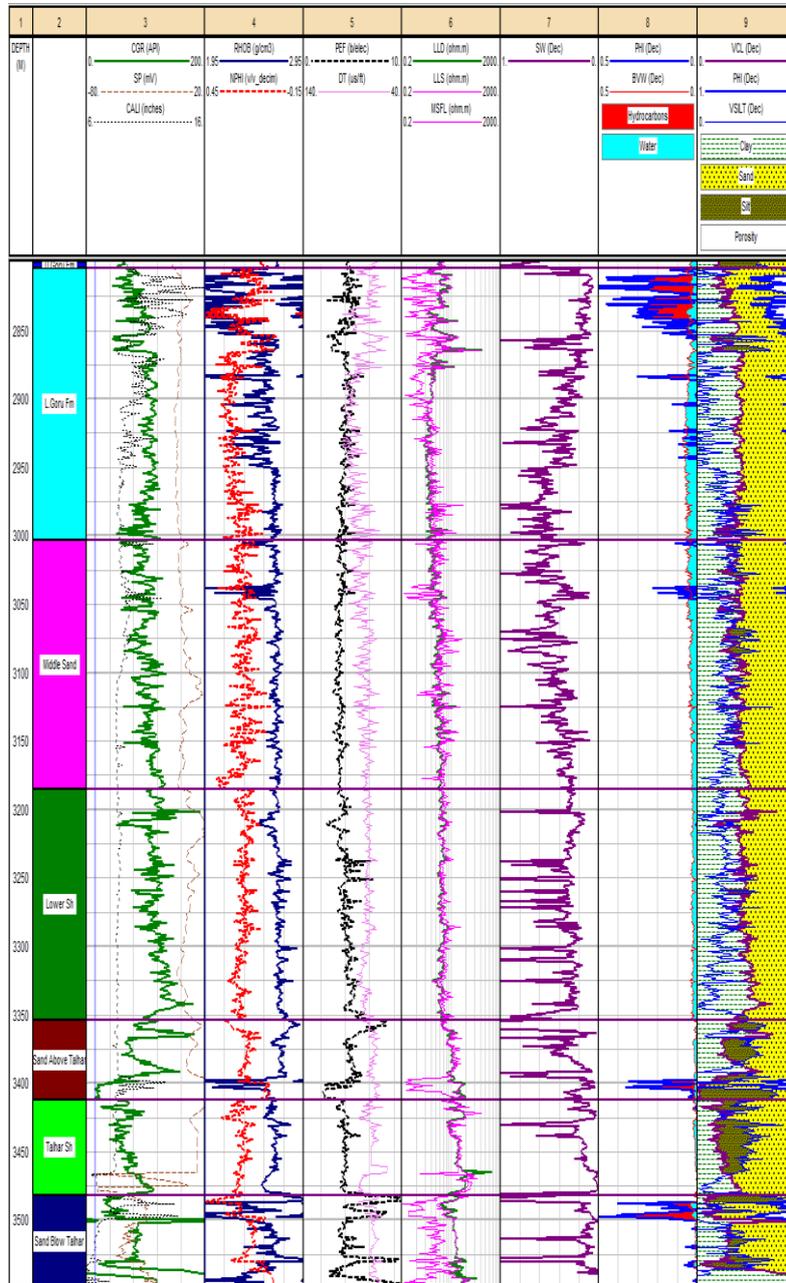


Figure 7. General Log plot for analyze the behavior of basic curves (3rd track Gamma-ray, Caliper and Spontaneous Potential, 4th track Neutron and Density, 5th track Photoelectric Factor and sonic, 6th track Saturation of water, 7th track resistivity logs, 8th track Porosity and Bulk volume of water and 9th track interpreted lithology track).

The porosity measurement and density contrast also indicate the fluid type but also the effect of Vsh on porosity (Fig. 7). On plotting the cross plot, it can clearly be seen that the output trend of the data points is linear and in increasing

order. Most of the data points are blue in color, showing the respective depth range between 2800m to 3500 meters. It can also be noted that for the rocks having high density and the low porosity values showing very compact rocks. Where ever the

higher denser rocks having high values of porosity can act as reservoir rocks (Fig. 8). This plot representing low GR Value with yellow color, we consider only those yellow clusters on this plot which falls in density rang of sandstone with high neutron porosity values. Similarly, the low denser and highly porous rocks may show the presence of shale contents. For the reservoir zone, one usually concerned with higher values of porosity and the respective higher values of the densities. Two zones Sand above Talhar thickness (3354m–3412m) and Sand below Talhar thickness (3480m – 3550m) has been picked for

detail investigation for possible hydrocarbon accumulation (Fig. 9 and 10). After that generating a cross plot of NPHI vs RHOB specifically for depth ranges from 3398m to 3406m & 3487m to 3499m. Which indicates the cluster lies in a rage of Sandstone. Then resistivity curves image of the same area also placed over cross plot to select the zone where hydrocarbon can possibly accumulate (Fig.11 and 12).

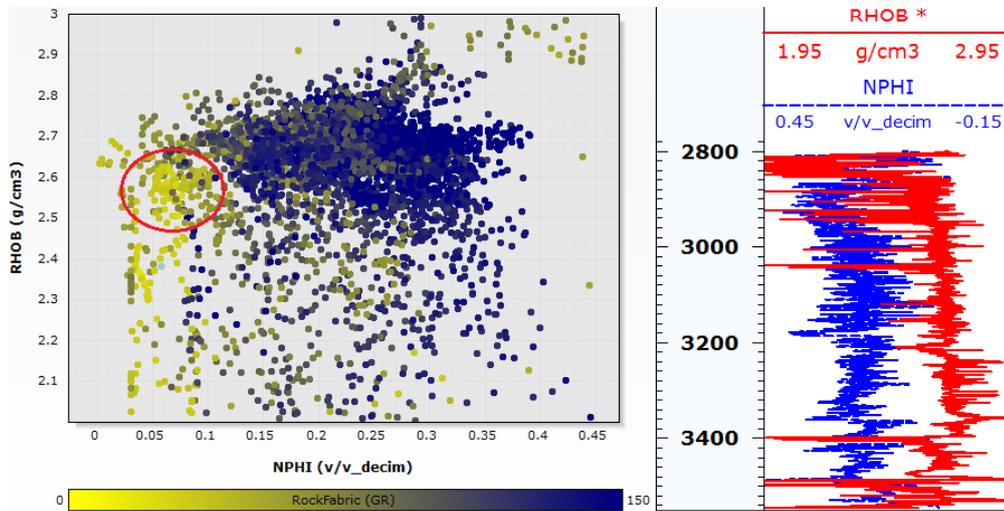


Figure 8. Cross Plot of Porosity Vs Density and GR color Scheme use to target the Low gamma ray value with high density and low porosity. Red circle indicating the best

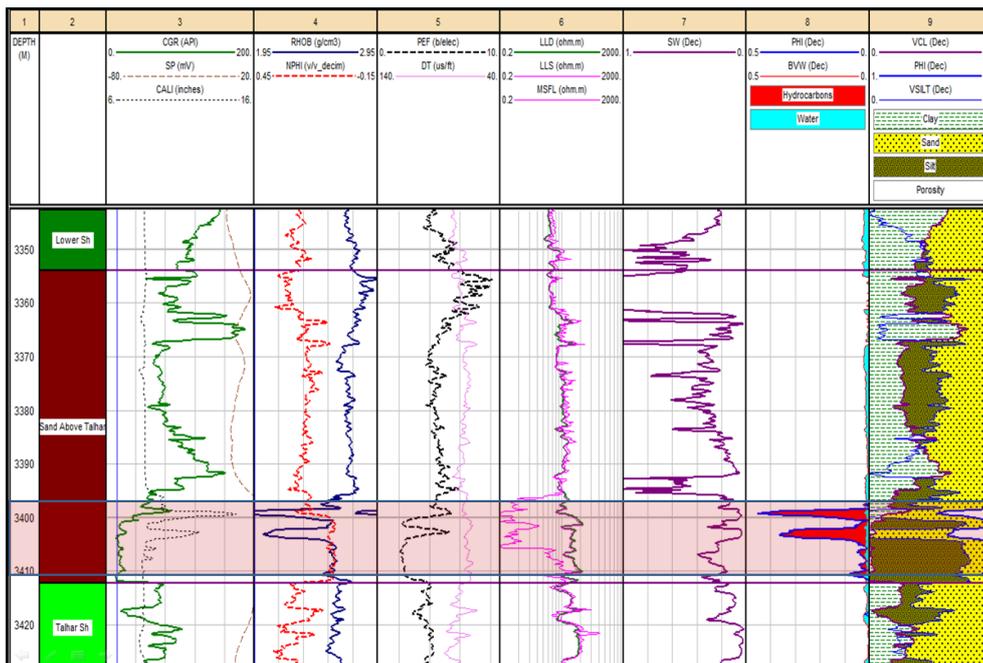


Figure 9. 1st Interpreted interval which fits on possible condition of reservoir. Resistivity curves separation provides the strong evidence about the existence of movable hydrocarbon accumulation. In 8th track aqua color representing pore spaces filled with water and red color representing the pore spaces filled with hydrocarbons

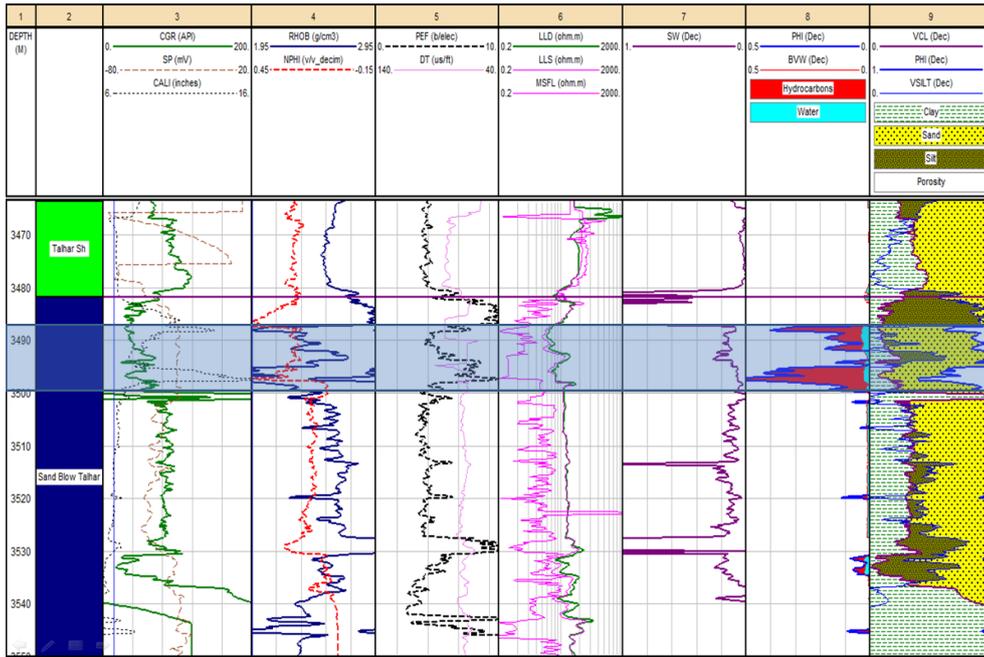


Figure 10. 2nd interpreted interval which also fits on possible condition of the reservoir. Resistivity curves separation provides strong evidence about the existence of movable hydrocarbon accumulation. In 8th track aqua color representing pore spaces filled with water and red color representing the pore spaces filled with hydrocarbons

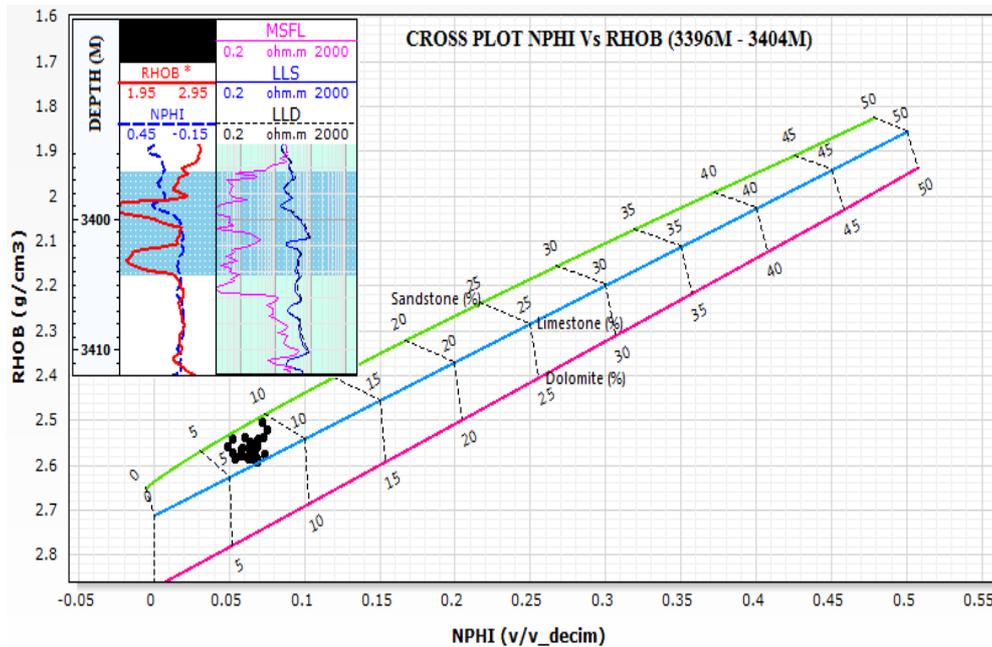


Figure 11. 1st interval (3396M – 3404M) cross plot between NPHI Vs RHOB which confirm the target zone exist in range of sandstone, and Resistivity separation clearly visible in left top resistivity curve plot

On the second step the picket plot was generated The picket plot It is a plot which is made on a logarithmic scale taking the values of true receptivity on the x-axis and the values of density porosity on the y-axis. A best-fit regression line of 100% value through the cluster of the points gives us the water saturation line represented by blue color (Fig.13). Sw curve is

also generated but the main purpose of Pickett plot is to find the water saturation of specific zone plotted against Porosity and Resistivity (LLD) with four lines of water saturation in the plot. These lines (Sw lines) have been represented as percentages of 25, 50, 75 and 100. Objective is to find the area where there is a possibility of hydrocarbon. Most of the porous

area of the well lies in the region having water saturation 100%, and rest of the area lies at 75% and between 50% to 60% water saturation as which is represented by colors, red and green representing most of the area less resistive because of high water saturation. Line that shows the value of water saturation as 50% to below is our focused zone where value of resistivity and porosity is high i.e. Initially interpreted two

zones highlighted in (Fig 9 and 10) also highlighted in picket plot to calculate saturation of water exist which falls within the range of 40 to 100 ohm.m resistivity, 15 to 20 % saturated with water and 10 to 60 ohm.m resistivity, 30 to 35 % saturated with water (Fig.14 and 15). In highlighted zones (Fig 9 and 10) red color filled between porosity and Bulk volume of water curves which indicating the presence of movable hydrocarbons.

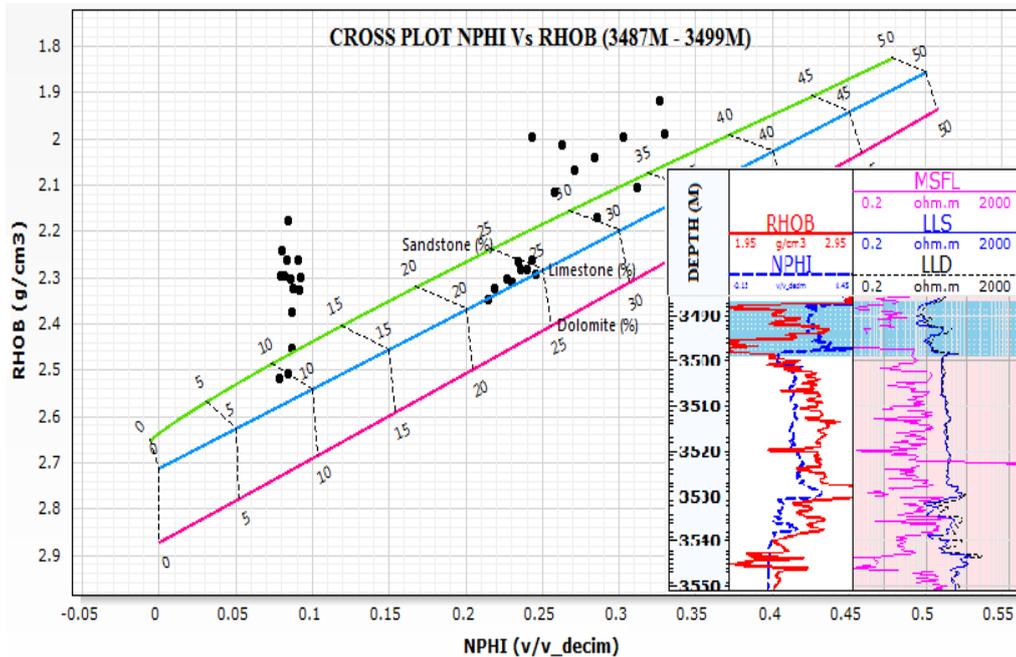


Figure 12. 2nd interval (3487M – 3499M) cross plot between NPHI Vs RHOB which shows the disperse values with in sandstone zone and below density value with high porosity ranges 10% to 30% and Resistivity separation clearly visible in right bottom resistivity curve plot.

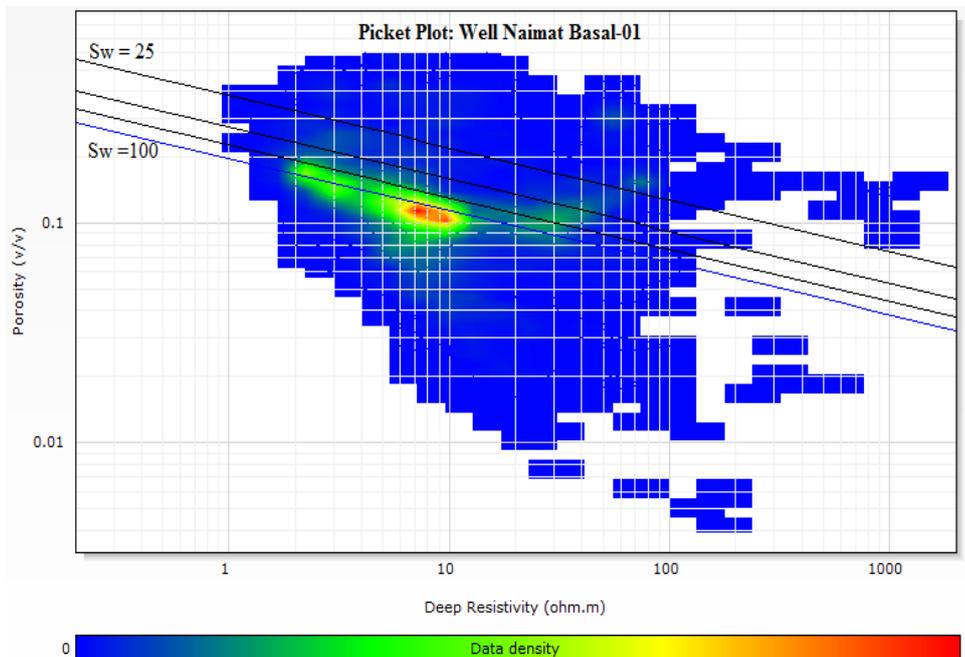


Figure 13. Picket plot between LLD and Porosity for water saturation. Color scheme use to find the general trend of data which lies above 75% water saturation.

Permeability calculated by using
Top Depth: 2805 meter
Bottom Depth: 3550 meter

The depth from 3395-3411 and 3480-3497 may be good reservoir zone for the hydrocarbon accumulation. To the oil and gas operator, reserves are volumes of crude oil, natural gas, and associated products that can be recovered profitably in the future from subsurface reservoirs.

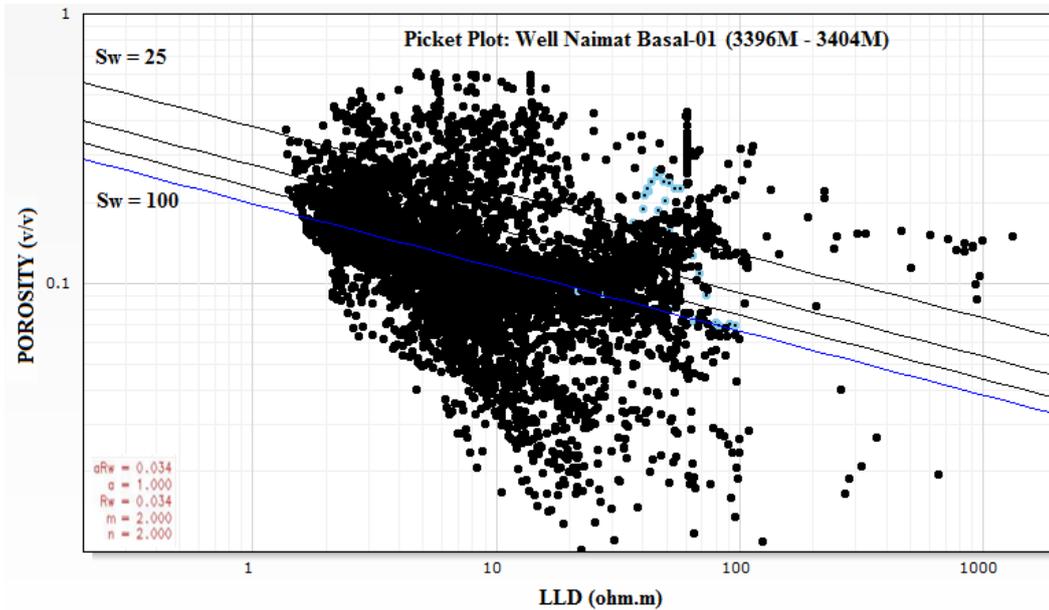


Figure 14. Interactively selected 1st interval in log plot is also highlighted in picket plot with sky blue color representing Sw ranges between 10% to 20%.

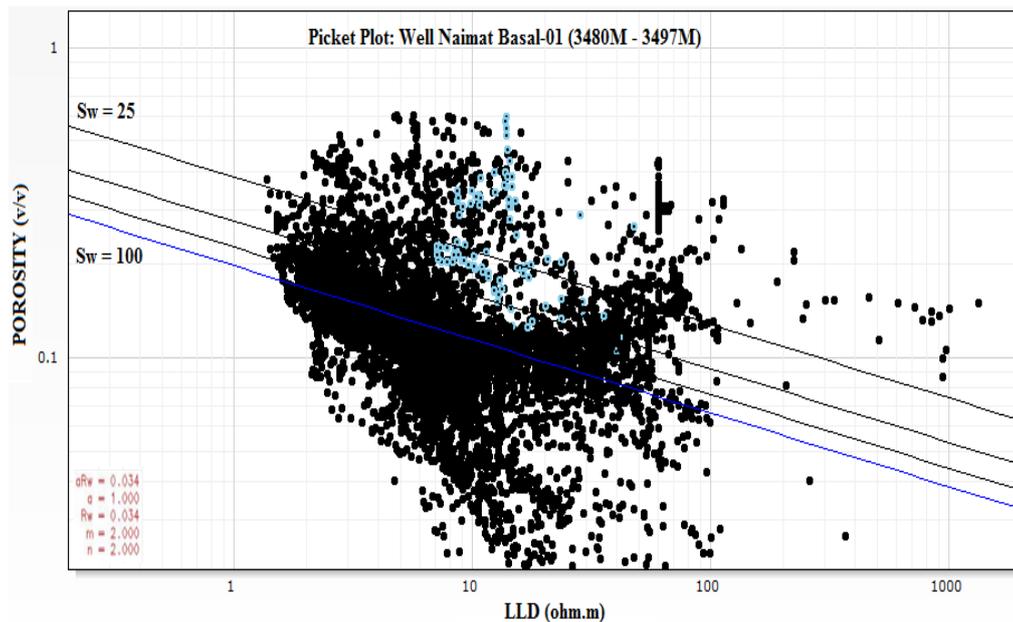


Figure 15. Interactively selected 2nd interval in the log plot is also highlighted in the picket plot with sky blue color representing Sw ranges between 10% to 30%.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

CONCLUSION

- This part must be written a refine and summary of your results and math with your experiments works. The behavior of the theoretical and NMO corrected synthetics created for well Naimat Basal 01 using Zoeppritz's Equation indicates very small variation along (Fig 1) the formation tops, marked. It is very difficult to analyze the amplitude variation because of strong reflectivity. The sharp reflection only observed along the Basal Sand but the amplitude variation is very difficult to analyze.
- There is a sharp fluctuation in amplitude with depth in AVO synthetic created for well Siraj South 01 based on Zoeppritz equation particularly the amplitude variation at the level of Basal Sand. This is directly giving a hint of the presence of hydrocarbon.
- AVA synthetic created for well Naimat Basal-01 and Siraj South-01 using Zoeppritz equation clearly indicate amplitude variations, both in the theoretically and NMO corrected synthetics. AVA has more implications to the structurally complex areas, rather than the AVO synthetics. Both of these have been created with different equations. The clear phase reversal can be seen at two different reflectors in AVA trace at 20° angle of incidence in the encircled zone. This usually acts as hydrocarbon indicator or gives a hint of the presence of some anomaly.
- Volume of clay and sand curve plot in trak 9th as well as trak 8th Porosity and Bulk volume of water curve interpretation assist to target movable hydrocarbon location is represented by red color in fig.A. These zones are also marked as an anomalous location in AVO & AVA section.
- Keeping in mind about anomaly synthetic of Naimat Basal-01 has been generated which perfectly ties with an interval having hydrocarbon indications.
- Two Intervals studied precisely, where in 1st interval 3395m- 3411m having very low density is underestimated because of bad hole condition. But resistivity shows a clear indication of hydrocarbon existence. On the other hand in 2nd interval 3480m-3497m low high-density value which is underestimated also because of repeated disturbance in hole size and hydrocarbons.

REFERENCES

- [1] Smith, G.C., and P.M. Gidlow. Weighted stacking for rock property estimation and detection of GAS. *Geophysical Prospecting*, 1987. 35(9): 993-1014.
- [2] Zhang, H., and R.J. Brown. A review of AVO analysis: CREWES Research Report. 2001. 358
- [3] Knott, C.G., III. Reflexion and refraction of elastic waves, with seismological applications." *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science*, 1899. 48(290): 64-97.
- [4] Zoeppritz, K. Erdbebenwellen VIII B. Uber Reflection and Durchgang seismischer Wellen durch Unstetigkeitsflachen. *Gottinger Nachrichten*.1919.1: 66-84.
- [5] Leaney, S.W., W.E. Borland. AVO and anisotropy from logs and walkaways. AAPG International Conference and Exhibition, Kuala Lumpur, Malaysia. 1994
- [6] Gratwick, D., Amplitude analysis in the angle domain: *SEP*, 2001. 108: 45-62.
- [7] Veeken, P.C.H., and Marianne Rauch-Davies. AVO attribute analysis and seismic reservoir characterization. *First Break*. 2006. 24(2): 41-52.
- [8] Tsa, C.C., C.S., Liu, P., Schnurle. Application of AVO method to analyze the seismic characteristics of gas hydrate offshore Southwestern Taiwan. 2007.
- [9] Hilterman, F., Is AVO the seismic signature of lithology? A case history of Ship Shoal - South Addition. *The Leading Edge* (1990). 9(6). 15-22.
- [10] Beucher-Darricau, H., B. Doligez, and J.M., Yarus. Modeling complex reservoirs with multiple conditional techniques: A practical approach to reservoir characterization, in T. C. Coburn, J. M. Yarus, and R. L. Chambers, eds., *Stochastic modeling and geostatistics: Principles, methods, and case studies*, volume II: AAPG Computer Applications in Geology 2006. 5: 289-299.
- [11] Valizadeh Alvan, H., Uncertainty of Estimated Petrophysical Parameters of Ahvaz Oil Reservoir. *J. Adv Sci Eng Res*. 2011. 1:165-176.
- [12] Ehinola, O. A., et al., Geology, geochemistry and biomarker evaluation of Lafia-Obi coal, Benue Trough, Nigeria. *Fuel*, (2002). 81(2) 219-233.
- [13] Aigbedion, I., and S.E.. Iyayi. Formation evaluation of Oshioka field using Geophysical well logs." *Middle-East J. Sci. Res*. 2007. 2(3-4): 107-110.
- [14] Searlc, M.P., *Geology and Tectonics of the Karakoram Mountains*. Chichester (John Wiley and Sons Ltd.), 1991. 358.
- [15] Powell, C.M., A speculative tectonic history of Pakistan and surroundings: Some constraints from the Indian Ocean." In: Farah, A. & DeJong, K. A. (eds.) *Geodynamics of Pakistan*. Geol. Surv. Quetta, Pak. 1979. 1-451.
- [16] Khan, S.D., et al., Did the Kohistan-Ladakh island arc collide first with India?." *Geological Society of America Bulletin*, 2009. 121(3-4): 366-384.
- [17] Valdiya, K.S., Emergence and evolution of Himalaya: reconstructing history in the light of recent studies. *Progress in physical geography*. 2002. 26(3): 360-399.
- [18] Chaudhry, M.N., M. Ghazanfar, J.G. Ramsay, D.A. Spencer and M. Qayyum. Northwest Himalaya – A Tectonic subdivision. 175-184, February 1994 In: (Eds: Ahmed, R and Shiekh, A.M) *Geology in South Asia-1: Proceeding of First South Asia Geological Congress*. Islamabad, Pakistan:
- [19] Burg, J.P., J.L., Bodinier, S.H., Chaudhry and H., Dawood. Infra-arc mantle-crust transition and intra-arc mantle diapirs in the Kohistan complex (Pakistani Himalaya): petro-structural evidence." *TERRA NOVA-OXFORD* 1998. 10: 74-80.
- [20] Khan, M.A., S., Rehman, M., Fahad ullah and N., Ahsan. Geochemistry and tectonic environments of Babusar amphibolites in southeast Kohistan, Pakistan. *Geol. Bull. Punjab Univ* 2009. 44: 105-116.
- [21] Khan, M.A., S., Rehman and N., Ahsan. Geology and geochemistry of Sumal amphibolites, Kamila amphibolite unit, southeast Kohistan, Pakistan. *Int. J. Agric. Appl. Sci*, 2012. 4(2): 99-111.
- [22] Qadri I.B., *Petroleum geology of Pakistan: Pakistan Petroleum Limited*. Karachi, Pakistan. 1995.
- [23] Zaigham, N.A., and K.A., Mallick. Prospect of hydrocarbon associated with fossil-rift structures of the southern Indus basin, Pakistan." *AAPG bulletin*. 2000. 84(11): 1833-1848.
- [24] Faisal, M., F., Rehman, S., Rehman and N., Ahsan. Better perceptive and enhanced visualization of seismic profiles for the exploration of hydrocarbon using a seismic and synthetic seismogram modeling of Khipro Block, Southern Indus Basin, Sindh Province, Pakistan." *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 2013. 35(22): 2101-2112.

- [25] Ahmad, Z., G. Akhter, F. Bashir, M.A., Khan, and M., Ahmad. Structural interpretation of seismic profiles integrated with reservoir characteristics of Bitrism block (Sind Province), Pakistan." *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*. 2009. 32(4): 303-314,
- [26] Jamil, A., A., Waheed, et al., Pakistan's Major Petroleum Plays - An overview of dwindling reserves. *AAPG*, 2012. 1-14.
- [27] Haase, A.B., Modelling of linearized Zoeppritz approximations. *AVO model*. *CREWES Research Report*. 2004. 16:1-4
- [28] Naji, H.S., et al., Sedimentology and quantitative well logs petrophysical parameters, Lower Qishn Clastic reservoir, Masila Oilfield, Yemen." *JKAU: Earth Sci*. 2010. 21(1): 53-77.