Petro-physical Investigation and Reservoir Characterization through Well Logging

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Abstract

This paper presents the results of a study conducted to estimate the petro physical and reservoir rock properties. Petro physics highlights those properties relating to the pore system; its fluid distributions and flow characteristics. These properties and relationships are used to evaluate hydrocarbon reservoirs, hydrocarbon sources, aquifers and seals. The reservoir and fluid characteristics to be determined are: Lithology of the area (rock type), fluid saturations, pressures, fractional flow (oil, gas and water), permeability (absolute), porosity, fluid identification characterization and thickness (bed boundaries). It is simple to distinguish these features and to value their part in the calculation of reserves. The difficult part comes in determining their real value at a level of assurance required to make economic decisions leading to development and production. The seven characteristics listed are interdependent (i.e., to properly determine porosity from a wire line log, one must know the lithology, fluid saturations, and fluid types). The knowledge of petro physics is then used to interpret the hidden world of rocks and fluid properties of reservoir from subsurface to a depth ranges up to four miles deep.

Key words: Semantic; Technology; Business rules management system; Business rules harvesting

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INTRODUCTION

Petro-physics is the study of chemical and physical rock properties and their interactions with fluids. The main application of petro-physics is to study hydrocarbon reservoirs. Petro-physicists are hired to help reservoir engineers and geoscientists to understand the rock properties of the reservoir, mostly how pores in the subsurface are interconnected, controlling the accumulation and hydrocarbons migration (Leonid et al., 2012).

Some of the significant properties studied in petro-physics are lithology, porosity, water saturation, permeability, water resistivity and density. A key feature of petro-physics is measuring and evaluating these rock properties by acquiring well log measurements in which a string of measurement tools is lowered in the borehole, core measurements in which rock samples are retrieved from subsurface and seismic measurements. These analyses are combined with geological, geophysics and reservoir engineering studies to give a complete picture of the reservoir (Oberto Serra, 1984).Well logging is the widely used techniques to achieve the objectives of assessing reservoir characterization. Well logs provide considerably uniform quality data from zone to zone, well to well and even reservoir to reservoir. They are continuous along the borehole and relatively extensive throughout the entire reservoir providing a practical, cost effective and fast source.

The current study is focused on the determination of petro physical properties of Goru Reservoir of Lower Indus Basin (Oberto Serra, 1984). Following petro-physical properties have been determined with the use of wireline logs.

- Porosity
- Permeability
- Shaliness
- Saturation

Petro physical properties play a vital role in every stage of reservoir studies; starting from exploration to abandonment stage. The objective of this study is to determine the petro physical properties of gas fields. The following petro physical properties have been determined using wireline logging techniques i.e. porosity, shaliness, permeability and saturation (Oberto Serra, 1984).

Reservoir description

Three different gas fields have been selected for the proposed work naming X, Y, Z. All these gas fields are located in Middle Indus Basin. So in order to investigate and evaluate petro physical properties of these gas fields by using wireline logging techniques, it's important to know about the location, stratigraphy, geology, and tectonics settings of the Middle Indus Basin.

Pakistan geographically located between 60°E to78°E & 24°N to 37°N. It has great density of active faults and is seismically one of the most active areas of the Asia. Tectonically it is sited in the region of intersection of three plates, Indian, Eurasian and Arabian Sea Plates. In the North there is convergent plate boundary between Eurasian and Indian Plate, resulting into great Himalaya (Zaigham et al., 2000). In the West the intersection between these two plates became transform in nature and in the South there is a subduction zone known as Makran Subduction Zone (MSZ) due to the subduction of Arabian Sea Plate under Eurasian Plate.

Middle Indus Basin rests on the continental margin of the Indo Pakistani Plate. Middle Indus Basin bounded in South by Jaisalmer-Mari kandkot High, while Suliman Range defines the Western boundary. The Sargodha Hills make the Northwestern boundary. Punjab platform dips West ward into the Suliman foredeep (Zaigham et al., 2000). The structural style of the Middle Indus Basin is obscured at surface by thick alluvial cover. Seismic and drilling study reveals subsurface structure features related mainly to phases of Precambrian to Cambrian and Mesozoic extension but also to the effect of the peripheral collisional orogeny and consequent foreland basin deposition (Kadri, 1995). Middle Indus Basin of Pakistan is well established gas prone area witnessed by many producing fields. Most of the discoveries are from three-way dip closure with one side bounded by strike-slip fault. The faults with spatial continuity are proven to be sealing at Lower Goru E-Sand level of Cretaceous. Consequently, the lateral continuity of the fault gains key importance in establishing trap integrity.

The Basin is separated from Upper Indus Basin by Sargodha High and Pizu uplift in the North. It is bounded by Indian Shield in the East, marginal zone of Indian Plate in the West Sukkur Rift in the South. The depth of basement is about 15,000 km in trough areas (Kadri et al., 1995; Zaigham et al., 2000). The Basin comprised from East to West, has three main units which are;

- Punjab Platform
- Sulaiman Depression
- Sulaiman Fold Belt

Geological structure

The lower Indus basin contains sedimentary rock fill up to 10,000 m thick, comprising Mesozoic and Cenozoic sections. Precambrian basement is exposed in the South-Eastern corner (Nagar Parkar High). A Litho-stratigraphic unit of Lower Indus Basin ranges from Triassic to Recent. However recently the older sedimentary rock units from Precambrian to Cambrian and Permian have been encountered in an oil and gas exploratory well known as Marvi-1. Salt Range Formation is composed of red gypsums marl with seams of salts while the beds of gypsum, dolomite, greenish clay and low grade oil shale are the constituents of the upper part (Kadri, 1995). The Cambrian rocks of the Salt and Surghar Ranges consist of sandstone, shale, dolomite with glauconitic inter beds. Permian Basalt is named as Marvi Basalt after well. No volcanic rock of this age is reported in whole of the Indus Basin. This basalt is related to the fossil rift which represents the early stages of Gondwana breakdown (Wandrey et-al., 2004).

The geologic evolution of the area covered by Lower Indus Basin in context with regional geology is such that with the exception of a few Triassic outcrops. The Mesozoic rock succession of the Lower Indus Basin is represented several thousand-meter-thick Jurassic sequences. These are shallow water marine rocks consisting of limestone and shale with subordinate sandstone inter-beds in the lower part. The intra Jurassic unconformity at the close of Callovian time occurs throughout the Indus Basin (Zaigham et al., 2000).

Stratigraphy

Siwalik Group

The surface geology of Siwalik Formation indicates thick and multi-channels sands of reservoir quality and expected to continue into the subsurface. There is sufficient shale especially in the lower section (Lower and Middle Siwalik Formations) to provide good quality seals (Bachrach et al., 2004; Gommesen et al., 2004).

Chinji Formation

Chinji Formation consists of red clay with subordinate brown grey sandstone and scattered pebbles of quartz and thin lenses of interformational conglomerate (Bachrach et al., 2004).

Nagri Formation

Nagri Formation consists of greenish sandstone with subordinate clay which is brown, reddish grey and pale orange, sandy and silty (Gommesen et al., 2004).

Dhok Pathan Formation

Dhok Pathan Formation is composed of cyclic alterations of grey, light grey, white, reddish brown, occasionally brownish grey, greenish grey, brown of buff sandstones and clays which are orange brown, dull red or reddish brown, calcareous and other formations like:

Darzinda Formation

- Pirkoh Limestone
- Sirki Formation
- Habib Rahi Limestone

Ghazij Formation

- Sui Main Limestone
- Ranikot Group
- Parh Formation
- Goru Formation

MATERIALS AND METHODS

Data Acquisition & Processing

The logs used in the current study for the project were of Y-2, X-1, and Z-3 of the gas fields in the Lower Indus Basin. The log suite contained of Gamma Ray, Resistivity, Sonic, Caliper, Density, Neutron and Spontaneous Potential.

It has been observed the logs with log plot7 and measured Gamma Ray, Sonic, Density, Neutron and Spontaneous Potential values. For the purpose of petro-physical evaluation the study of different parameters, visualize the trends from the depth of 2000ft to 2370ft in case of Y-2,2955ft to 3480ft in case X-1 and Z-3.we noted the readings at every 5ft depth. All these readings were saved in an excel sheet.

Petrophysical Properties Estimation

Porosity

After data processing, porosity was estimated by using different logs including Sonic, Neutron and Density. Porosity can be calculated by using sonic log data

$$\Phi_s = (\Delta t_{log} - \Delta t_{ma}) / (\Delta t_f - \Delta t_{ma})$$

The other values of The other values of porosity were established directly from the las files of Y-2, X-2 and Z-11 as shown in appendices

Irreducible water saturation

Irreducible water saturation was found with the help of following formula

S_{wirr} = KBUCKL / PHIe / (1 – V_{sh})

S_{wirr} = Irreducible Water Saturation

KBUCKL= Constant associated with lithology from core analysis

V_{sh}= Volume of Shale

Permeability

Permeability was determined after the estimation of porosity and irreducible water saturation using this formula (Oberto Serra, 1984):

$$K = (100 * PHIE^{2.25}/SwIrr)^2$$

Shale Volume

Shale volume was estimated with the help of the following relationship,

$$I_{GR} = (GR_{log} - GR_{min}) / (GR_{max} - Grmin)$$

Log Interpretation

Log interpretation is the process by which measurable parameters are translated into the desired petro physical parameters of porosity, hydrocarbon saturation, permeability, producibility and lithology. Since well logs do not measure any of the important rock and fluid properties directly. The accurate interpretation of log derived values requires a good understanding of borehole conditions, lithology, and the physical limitations of the tools and their proper calibration.

Porosity Log Interpretation

Sonic Log Interpretation

A log that measure interval transit time (Δt) of a compressional sound wave travelling through the formation along the axis of the borehole. The acoustic pulse from a transmitter detected at two or more receivers. The time of the first detection of the transmitted pulse at each receiver is treated to produce Δt. The Δt is transit time of the wave front above one foot of formation and is the reciprocal of the velocity Interval transit time where both dependent on lithology and porosity. Sonic Log is generally displayed in track 2 or 3 (Toby Darling, 2005).

Interpretation Goals

- Porosity
- Lithology Identification (Density or Neutron)
- Synthetic Seismograms (Density)
- Formation Mechanical Properties (Density)
- Detection of Abnormal Formation Pressure
- Permeability Identification

Density Log Interpretation

Gamma rays produced from a chemical source (Ce60, Co137) interact with electrons of the elements in that formation. The numbers of returned gamma rays are counted by two detectors which are related to formation electron density. For maximum earth materials, electron density is related to formation density through a constant. Returning gamma rays are measured at two different energy levels.

High energy gamma rays (Compton scattering) determine bulk density and therefore porosity.

Low energy gamma rays (due to photoelectric effect) are used to determine formation lithology.

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Low energy gamma rays (due to photoelectric effect) are used to determine formation lithology (Felder et al., 1979).

Interpretation

Porosity.

Lithology Identification (PEF, Sonic or Neutron).

Gas Indication (Neutron).

Synthetic seismograms (Sonic).

Formation Mechanical Properties (Sonic). Clay Content (shaliness) (Neutron).

Interpretation effects

- Lithology: porosity calculated from density depends on the choice of matrix density, which varies with lithology (DPHI might be negative).
- Fluid content: porosity calculated from density depends on the choice of fluid density, which varies with fluid type and salinity. In routine calculations, zone of investigations is assumed to be 100% filled with mud filtrate.
- Hydrocarbons: Presence of gas (light HC) in the pore space causes DPHI to be more than the actual porosity. In Density-Neutron combinations, this causes “cross-over”, where the NPHI values are less than the DPHI values.
- In all three cases above, the RHOB value from the tool is correct, but the calculated DPHI is erroneous.

Neutron Log Interpretation

Neutron Logs quantify the hydrogen content in the formation. In clean, shale free formations, where the porosity is filled with water or oil, the Neutron Logs measures liquid filled porosity (fN, PHIN, NPHI). Neutrons are produced from a chemical source (americium beryllium mixture). At smash with nuclei in the formation, the neutron drops energy (Felder et al.,1979). With sufficient collisions, the neutron is absorbed and a gamma ray is produced. Since a neutron is somewhat heavier than a proton, the element that closely approaches the mass of a neutron is hydrogen. In neutron-hydrogen collisions the average energy transfers to the hydrogen nucleus is about ½ that of the energy initially contained in the neutron, whereas, if the scattering nucleus was oxygen (mass 16 amu) the neutron would retain 77% of its energy (Toby Darling, 2005). Materials with huge hydrogen content like water or hydrocarbons become very important for slowing down neutrons. Meanwhile hydrogen in a porous formation is focused in the fluid-filled pores; energy loss can be related to the formation’s porosity.

Interpretation goals

- Porosity (displayed directly on the log).
- Lithology identification (Sonic and Density).
- Gas indication (Density).
- Clay content, shaliness (Density).
- Correlation, especially in cased holes.

Interpretation Effects

- Shaliness: NPHI > PHI in shaly zones.
- Gas: NPHI < PHI in gassy zone.

Lithology: In general, for logs recorded in limestone porosity units, if the actual lithology is sandstone, the log porosity is less than the actual porosity. If the actual lithology is dolomite, the log porosity is greater than the actual porosity.

Gamma Ray Log Interpretation

The Gamma Ray Log measures the total natural gamma radiation originating from a formation. This gamma radiation originates from potassium-40 and the isotopes of the Uranium-Radium and Thorium series. This log is commonly assumed the symbol GR. Once the gamma rays are released from an isotope in the formation, they progressively lessen in energy as the result of collisions with other atoms in the rock (Compton scattering). Compton scattering happens until the gamma ray is of such a low energy which is totally absorbed by the formation (Westaway et al.,1982). Hence, these rays intensity that the log measures is a function of:

- The initial intensity of gamma ray emission, which is a property of the elemental composition of the rock.
- The amount of Compton scattering that the gamma rays encounter, which is related to the distance between the gamma emission and the detector and the density of the intervening material.

The total Gamma Ray Log is typically recorded in track 1 with the Caliper Log, bit size and SP Log. In this instance, the other tracks utmost often contains Resistivity, Density, Neutron or Sonic Logs. Although the API scale goes from 0 to 200 API, it is more common to see 0 to 100 API and 0 to 150. API used in log presentations, as data greater than 150 API is not common, and can always be handled by the use of wrap-around. When gamma ray logging is carried out through the cement casing, a scale of 0 to 50 API is most often used, as a result of the lower values measured due to the attenuation of the gamma count rate by the casing.

Lithology Determination from Gamma Ray Log

The Gamma Ray Log is a very simple and useful log that is used in all petro physical interpretations, and is normally run as part of nearly every tool combination. The log is a very useful tool for discrimination of different lithology while it cannot exclusively explain any lithology; the information provided is invaluable when combined with information from other logs (Jurgen Schon, 2001).

Determination of Shale Volume

In greatest reservoirs the lithology are quite simple, being cycles of sandstones and shales or carbonates and shales. Once the main lithology have been identified, the Gamma Ray Log values can be used to calculate the shaliness or shale volume of the rock. This is important as a threshold value of shale volume is often used to help discriminate between reservoir and non-reservoir rock (Jurgen Schon, 2001).

$$I_{GR} = (GR_{log} - GR_{min}) / (GR_{max} – Grmin)$$

Interpreting Each Log

Sonic Log

Sonic Log shows a great variation when gas is encountered in the formation, its trend deviates from high to low value (Toby Darling, 2005).

Density Log

Density Log show the same trend as that of zone log, it decreases from high to low value in the presence of gas zone and the gas zone is best identified by their over-logging shows a high value of neutron porosity while in case of gas presence; it shows less value which requires another Porosity Log to be run for confirmation (Lawson et al., 1978).

Neutron Log

When oil is present in the formation, neutron log shows a high value of neutron porosity while in case of gas presence; it shows less value which requires another Porosity Log to be run for confirmation (Lawson et al., 1978).

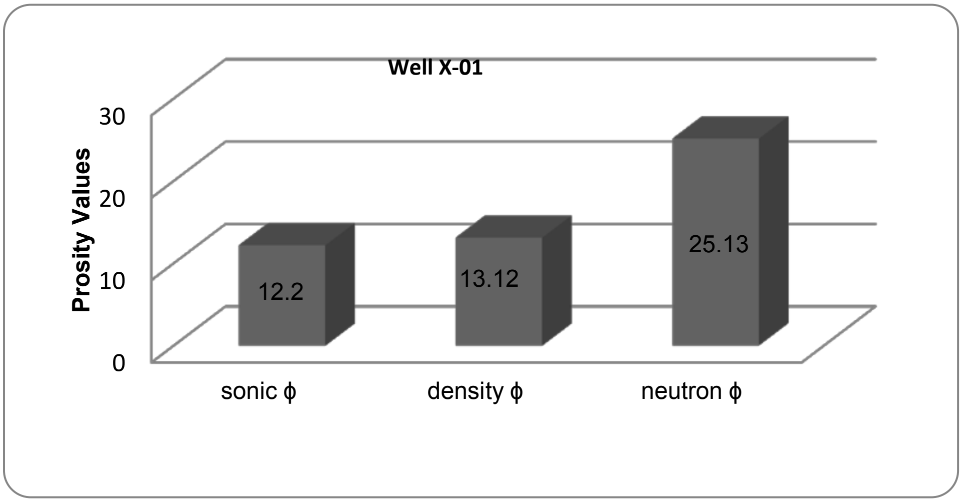
RESULTS

X-01 Well Logs Interpretation

The trend on the log of X-1 well

WELL NAME X-01	
Depth From	**Depth To**
9698	11420

Porosity	**Percentage**
Sonic ϕ	12.2
Density ϕ	13.12
Neutron ϕ	25.13
Permeability (md)	0.071
Shaliness %	26.98



According to the well tops provided by the DGPC, the zones of interest lie in the lower zone so we conclude that the reservoir rock is Lower Guru Sandstone.

It indicates that Lower Guru Formation at X-1 Well has good porosity as well as permeability. The reservoir may prove as a good reservoir but due to the high shaliness content, the reservoir may not categorize as a good reservoir.

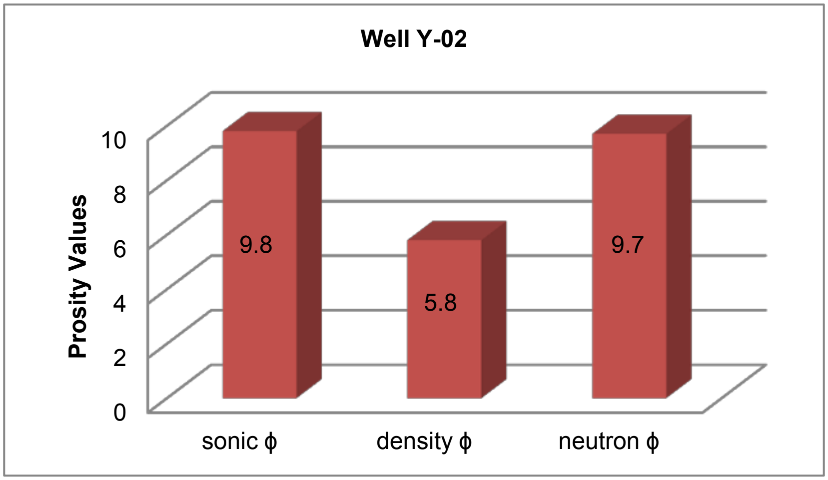
Y-02 Well Logs Interpretation

When visualize the trend on the log of Y-2 well, there is a zone of interest. In these zones, gas is present, because the sonic and density are decreasing and gamma ray curve is increasing because of increasing shale content in these zones.

WELL NAME Y-02	
Depth From	**Depth To**
2010	**2380**

Porosity	**Percentage**
Sonic ϕ	9.8
Density ϕ	5.8
Neutron ϕ	9.7
Permeability (md)	0.001
Shaliness %	22.25

In these zones, there are some porosity values that are negative, they are indicating the presence of heavy minerals like iron chloride and feldspar etc. that play the major role in depressing the porosity and making the formation tight.



According to the well tops provided by the DGPC, the zones of interest lies in the lower section so we conclude that the reservoir rock is Lower Guru Sandstone.

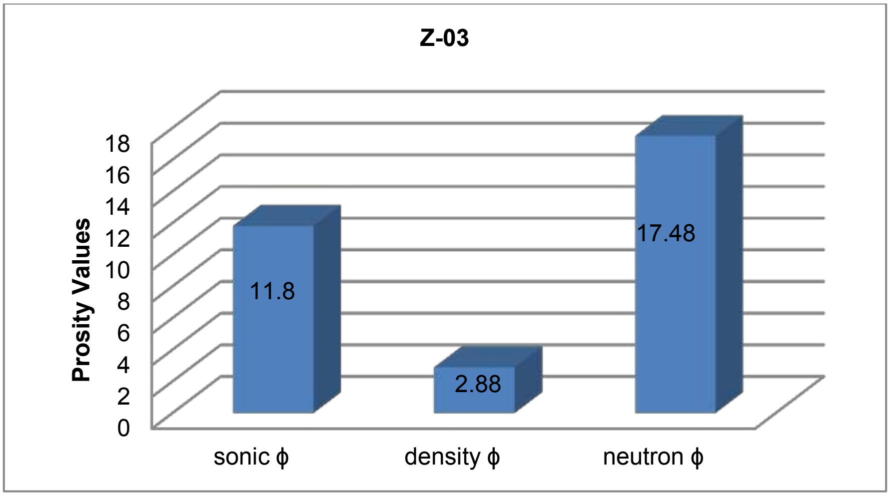
Z 03-Well Logging Interpretation

When visualize the trend on the log of Z-11 well, there is a zone of interest. In these zones, there are some porosity values that are negative, they are indicating the presence of heavy minerals like iron chloride and feldspar etc that play the major role in depressing the porosity and making the formation tight.

WELL NAME Z-03	
Depth From	**Depth To**
9698	11420

Porosity	**Percentage (%)**
Sonic ϕ	11.8
Density ϕ	2.88
Neutron ϕ	17.48
Permeability (Md)	0.001
Shaliness %	24.52

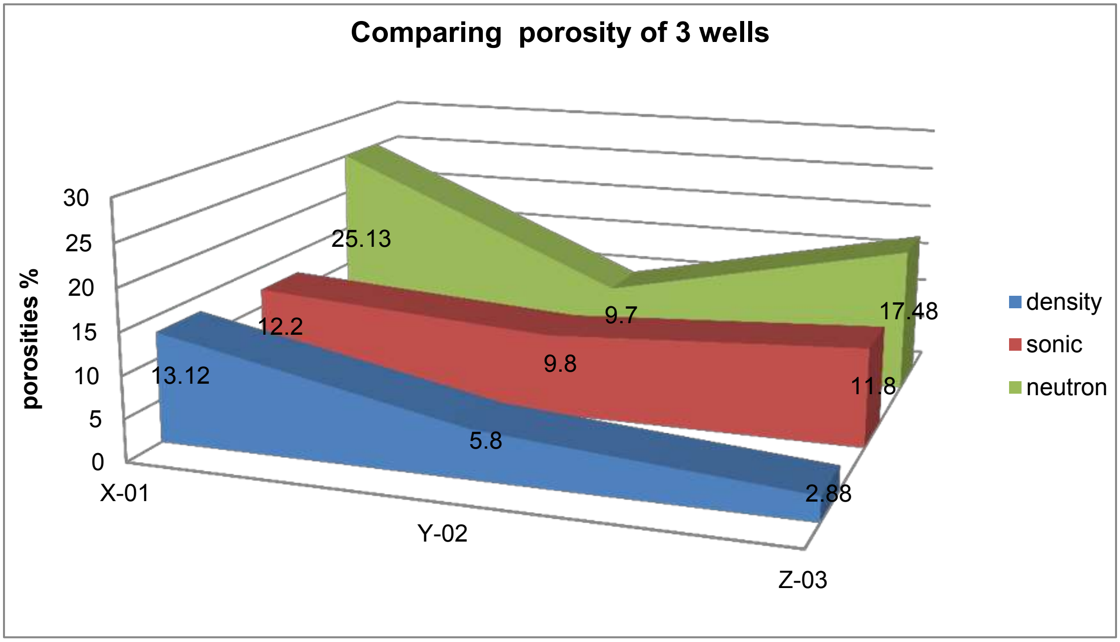
The trend of permeability's, average permeability value 0.010mD is very low.



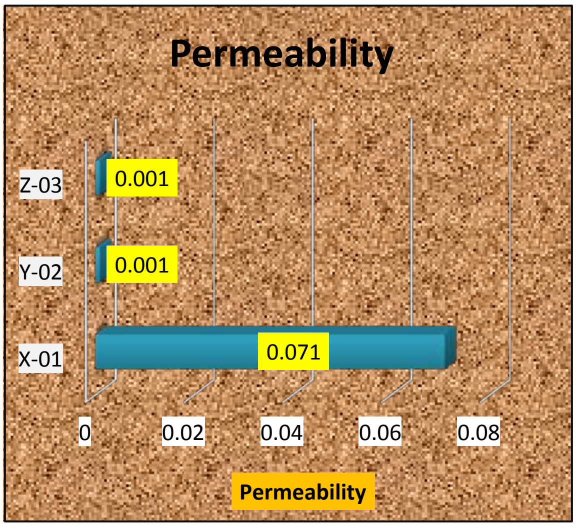
According to the well tops provided by the DGPC, the zones of interest lie in the lower part so we conclude that the reservoir rock is Lower Guru Sandstone. It indicates that Lower Guru Formation at Z-3. Well has good porosity but low permeability. The reservoir may prove as a good reservoir but due to the high shaliness content, the reservoir may not categorize as a good reservoir.

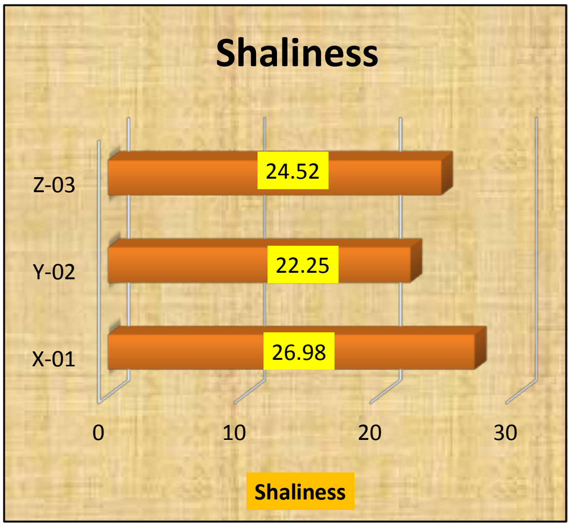
Comparative Analysis of Three Wells

At different depths it was found a single formation (Lower Guru Sandstone) with different values of shaliness, porosity, saturation and permeability. The variations in the values are because of overburden, due to clay mineral digenesis porosity also decreases. We have assumed our lithology to be sandstone. Although sandstone has good porosity and permeability but Y-2 well is composed of unconventional hydrocarbons. Other two wells are conventional which have good porosity values but pores may not be interconnected that's why permeability is low. Shaliness values are good at three wells but it is useless because of high shale content the reservoir may not be categorized as a good reservoir.



Based on comparison of three wells of Lower Guru Formation, X-2 well is located towards the north side and other two wells Y-2 and Z-11 are located on the South and Southeast side. The trend of porosity is increasing when we move towards North side and also the permeability value is also high.





Keeping in view the above trend if a well is drilled in between Y and X well this would be a good reservoir because of increasing trend of porosity and permeability values and same is the case for the shale volume and water saturation values. These comparisons allow us to better identify the possible productive zones of Lower Guru Formation in near future.

CONCLUSION

According to results and the facts determined, the formation in which the zones of interest are present has very low porosity and is tight. In order to exploit that and to obtain high recovery, it is strongly recommended that modern recovery techniques must be employed like hydraulic fracturing, multilateral wells. As tight gas isn't concentrated at the single portion of the reservoirs but present in small portion called as sweet spots, so in order to exploit it we can use the technique of horizontal drilling and multilateral wells. Acidizing the well is also a good choice because due to the phenomena of digenesis, the different mineral may incorporate in the pores of the rock and diminish the pore connectivity. Acidizing the well result into dissolve these heavy minerals like iron chlorite, calcite and Illite etc that will enhance the porosity and pore increase in the pore connectivity. Base on comparison of three wells of Lower Guru Formation. The trend of porosity and permeability is increasing when we move towards north side.

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