THREE DIMENSIONAL SEISMIC INTERPRETATION AND GEOSTATISTICAL RESERVOIR CHARACTERIZATION OF SAWAN GAS FIELD, LOWER INDUS BASIN, PAKISTAN

By

Sahrish Khan

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Institute of Geographical Information Systems
School of Civil and Environmental Engineering
National University of Sciences & Technology
Islamabad, Pakistan

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Dedicated to My mother Alia Naeem

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I am highly grateful to Almighty Allah, Most Kind, Merciful, and Beneficent who enabled me to complete this research work.

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LIST OF ABBREVIATIONS

Abbreviation	Explanation
e.g.	For example
LIB	Lowe Indus Basin
SIB	Southern Indus Basin
L.Goru	Lower Goru
LLS	Shallow Laterolog
LLD	Deep Laterolog
MSFL	Micro-Spherical Focused Log
RHOB	Density Log
NPHI	Neutron Porosity Log
DT	Sonic Log
Vsh	Volume of Shale
Rw	Resistivity of water
RT	Total Formation Resistivity
Rmf	Resistivity of Mud Filtrate
Rxo	Resistivity of Flushed zone

Sw	Saturation of water
NTG	Net to Gross ratio
DHI	Direct Hydrocarbon Indicator
PHIE	Effective porosity
φ	Porosity

ABSTRACT

The reservoir modeling gives detail information about stratigraphy, petrophysical properties distribution, and hydrocarbon prospects distribution in the field. Sawan Gas Field lies on the Khairpur High which is a north to south-dipping regional high and provides for important trapping mechanism for the reservoir hydrocarbons at the field. The purpose of this study is to do geostatistical reservoir modeling and to give a probable well location for exploration. The data for this project include 3D seismic data over Sawan field in SEGY and well logs of the block. OpendTect was used for 3D Seismic Interpretation and Seismic Attribute Analysis, Petrophysical Analysis and for Static Reservoir Modeling. The stratigraphic model was constructed through fine-scale stratigraphic well correlation. The structural model was constructed using interpreted horizons. The petrophysical analysis is used for derivation of porosity, water, and hydrocarbon saturation. Reservoir characterization studies were carried out using different seismic attributes. Sweetness attribute provides very high values as hydrocarbon indicator. It is used for static reservoir modeling. High porosity values even greater than 21 percent are observed in producing wells. Net to gross value range between 70 to 80 percent with high sweetness values indicating prospective gas zones.

Chapter 1

INTRODUCTION

1.1. Background Information

With the start of the industrial revolution, petroleum assets gain much more importance than ever. With the advancement of science and technology, all easy to access and explore petroleum assets have been developed. Most developed fields are depleting with time. So now more complex recovery techniques are required or there is need to move towards exploration of challenging petroleum reservoirs in harsh environments. With harsh environment, there is much more investment in exploration and development. So, the easy approach is to attain maximum petroleum reserves from already developed fields. For this purpose, a methodology known as reservoir characterization is adopted which integrates all available seismic, well logs, well-core, and geologic data to provide the most accurate description of subsurface for reservoir simulation and modeling.

Reservoir characterization studies can be carried out using different seismic attributes. These attributes can be analyzed during seismic interpretation processes (Partyka, Gridley, & Lopez, 1999). Seismic attributes can accurately predict various reservoir properties and geometries by revealing information which is not vivid in the original seismic data. The major aim of reservoir characterization is reservoir identification, pay zone delineation and determination of the distribution of physical properties such as thickness, porosity, and lithology (Anees, 2013).

The main challenge is to identify which attributes to use. The selected attributes then can be integrated with properties measured at the wells using one of the three most common methods i.e. regression, geostatistics, and neural networks. The selected method requires formation of an inference using seismic attribute(s) depending on its relationship to information attained from good data. Each method assumes that good data is representative of the reservoir (Chambers & Yarus, 2002).

Pakistan has a huge sedimentary basinal area, i.e. 827,000 km^2 and only 10-20 percent of it has been explored. The existing petroleum reserves in Pakistan has been depleting very rapidly. Major reservoirs which have contributed significantly toward the discovered oil/gas reserves include Sui Main Limestone (54%), L.Goru Formation (14%), Habib Rahi Limestone (13%) and Pab Formation (13%) (Jamil, Waheed, & Sheikh, 2012).

1.1.1 Petroleum Crisis in Pakistan

Upper members of L.Goru Formation acted as the major reservoir in most of the early discoveries. However, later reserves were discovered from the Central and Bottom sands of this formation. These discoveries were not very large but were cost-effective and led to an auspicious success rate in Pakistan (Wandrey, Law, & Shah, 2004). Most of these reserves are now depleting so there is a need for enhanced recovery by utilizing more complex technologies (Jamil et al., 2012).

1.1.2 Reservoir Modeling

A study conducted in the Morrison NE Field, Clark County, Manhattan for seismic reservoir characterization and prospect evaluation based 3D seismic attributes analysis provides successful static and dynamic hydrocarbon reserves estimation and can be used for reservoir characterization. Seismic attribute analysis gives insight into the presence of hydrocarbons, their movement, reservoir porosity, which can be used for reservoir potential evaluation. The Viola Limestone was the subjected horizon, which produces in four out of eight wells. Spectral decomposition was conducted considering amplitude anomalies to understand reservoir heterogeneities and it concluded that the production in the Viola paleotopographic traps is seen at low amplitudes (Vohs, 2016).

1.1.3 Reservoir Modeling in Pakistan

OMV (Pakistan) Exploration discovered Sawan gas field in 1998. Sawan-1 was the first exploration well in the block and it was drilled based on an amplitude anomaly and a small four-way dip closure. As expected it encountered a prosperous i.e. 103m thick gas column in the L.Goru “C” sands. Later in 1998, 3D seismic data (274 sq.km) was acquired over the whole prospect. More appraisal wells have been drilled, which indicates very heterogeneous nature of the Upper Cretaceous “L.Goru – C” sands. Reservoir quality “C” sands are characterized by low AI. In 2010, Sawan had 14 producing wells.

A seismic inversion is a tool for reservoir characterization. It results in only one parameter known as Acoustic impedance. It is related to reservoir properties and not to fluid type. Seismic Inversion of the Sawan and Gambat blocks 3D data, done by Mohammad Ibrahim in 2004 has proved the effectiveness of this process for better reservoir characterization, field size delineation, and identification of sweet spots with better porosity and permeability characteristics. These parameters enhance field development plans and result in improved volumetric estimation. A direct relationship was found between porosity and acoustic impedance of Sawan C sands which was utilized in stochastic porosity modeling (Abbas, Mirza, & Arif, 2015).

A reservoir model is required for the optimum exploitation of developed petroleum fields. But the model either static or dynamic has uncertainty. These uncertainties result in biased estimation of GIIP. Recently a study done was by Rahman & Ibrahim in 2009 on uncertainty analysis in the Sawan static model in which sensitivity analysis was performed and it was concluded that the reservoir properties namely rock facies, porosity, and permeability are the major source of uncertainty. 6 reservoir classes were formulated for the cored sediments of L.Goru C sands which require distinct porosity-permeability relationships. Unsupervised neural network method was then used to develop reservoir classes that hold distinct porosity-permeability relationships and can behave as flow units (ur Rahman & Ibrahim).

1.2. Objectives

The objectives of the research were:

1. Using 3-D seismic volume & Post Stack Seismic Attributes to highlight stratigraphic features for hydrocarbon reserves.

2. Identification of the potential hydrocarbon zones using the available 3-D seismic volume and well log data

3. Understanding reservoir compartmentalization and its properties distribution in the field using geostatistical reservoir modeling.

Chapter 2

MATERIALS AND METHODS

2.1 Study Area

Sawan gas field lies on the Khairpur High, in the Khairpur district, 80 km to the South East of Sukkur, in the Sindh Province. It was discovered by Österreichische Mineralölverwaltung (OMV) Pakistan, in 1998.

The first exploration well in the block was drilled based on an amplitude anomaly and a small four-way dip closure. It was named as Sawan-01. As expected it encountered a prosperous i.e. 103m thick gas column in the L.Goru “C” sands. Following the discovery, a 3D seismic data (274 sq.km) was acquired over the whole prospect and it was concluded that Sawan has approximately 2 tcf gas reserves. Till date, the field has 14 producing wells.

2.1.1 Tectonics & Petroleum geology of Study area

About 200 million years ago, Indus Basin was one unit but then rifting started and resulted in its dismemberment into Lower and Upper Indus Basins. In the Cretaceous and Palaeocene ages, LIB was further divided into MIB and SIB as a result of three major tectonic events which includes the uplift and erosion in the Late Cretaceous, followed by right-lateral wrenching and faulting in the Late Palaeocene and lastly the uplift of Khairpur High during the Late Tertiary (Nadeem Ahmad, Fink, Sturrock, Mahmood, & Ibrahim, 2004).

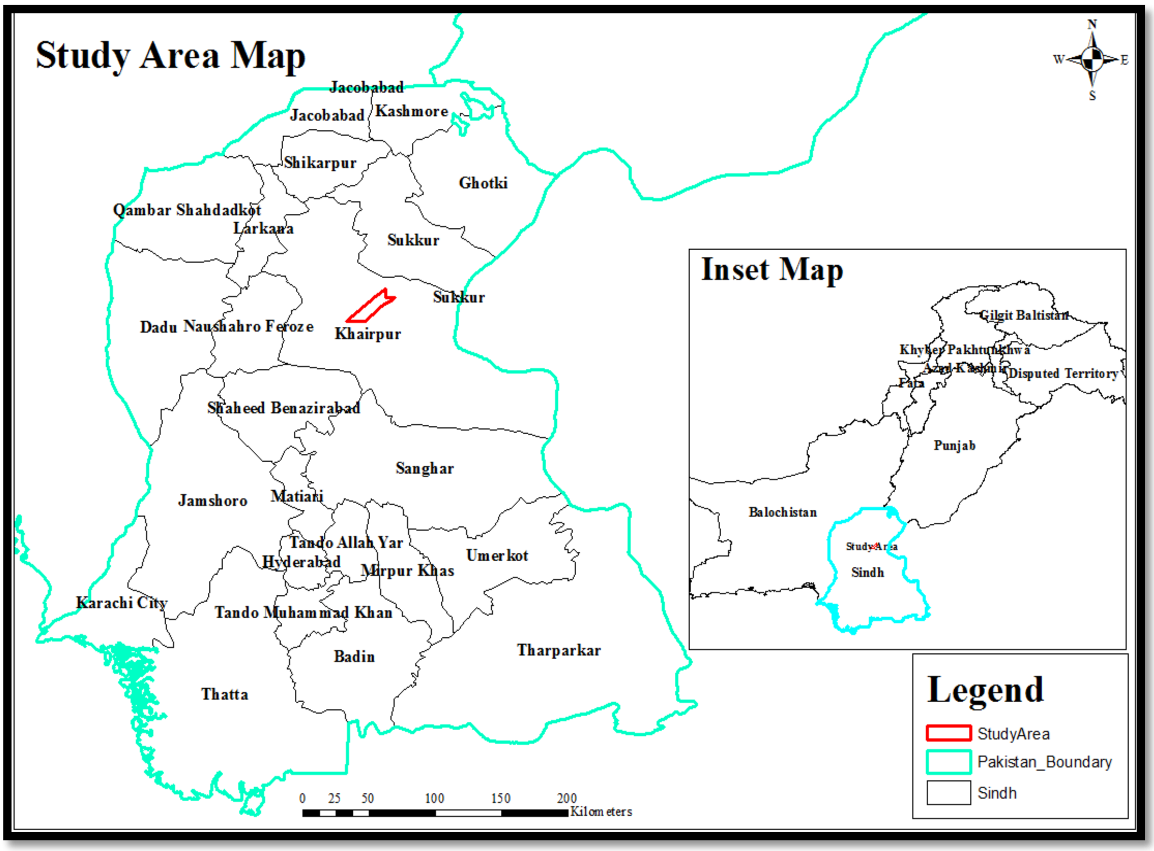

Figure 2.1. Geographic Location of Sawan Block.

Sawan block lies on the eastern arm Khairpur High which is a regional north to south-dipping high with influential trapping mechanisms at Kadanwari (Nasir Ahmad & Chaudhry, 2002), Miano (Krois, Mahmood, & Milan, 1998) and Sawan gas fields. This high is recognized by unusual high geothermal gradient, of up to 4.8° C / l00 m (A. Berger, S. Gier, & P. Krois, 2009)

In addition to this, the trapping mechanism at Sawan field includes loss of diagenetic character and structural dip of reservoir quality. This high disturbs the regional westward dip of the Thar Platform but at its west, the platform recommences its original dip, forming a monocline which dips towards Kirthar foredeep. This foredeep has its deepest part close to the Kirthar Fold Belt.

An unconformity of variable duration is present between the Jurassic age Chiltan limestone and the Sembar and L.Goru Formations, which are the clastic and lowermost sediments of the Cretaceous (Krois et al., 1998). Sembar organic-rich shales act as the major hydrocarbon source rock for the SIB.

L.Goru Member is composed of interbedded sandstones of one of the most productive reservoir quality and shales. The L.Goru sandstone has been informally divided (from bottom to top) into the “A”, “B” and “C” intervals (Krois et al., 1998). The L.Goru and Upper Goru shales act as a cap for the reservoirs of L.Goru sands.

2.1.2 Stratigraphic Setting

The oldest rocks in the SIB are of Precambrian age which forms the basement rocks. The paleozoic sequence is absent in the basin which marks the major unconformity. The Precambrian rocks are overlain by Triassic sediments of Wulgai formation (Kadri, 1995). The general stratigraphic section of SIB consists of rocks ranging from Jurassic to Quaternary age (Khan, Nawaz, Shah, & Hasan, 2016).

The Triassic rocks are overlain by Shirinab and Chiltan formations of Jurassic age. Chiltan formation has reservoir quality limestone but lies at a great depth. It is overlain by Sembar formation of Early Cretaceous which acts as excellent and restricted source rocks at the Thar platform where the formation has 75meters of gas and condensate bearing source rocks. L.Goru is the producing reservoir in the study area. The Upper Goru has shale and acts as cap rocks (Kadri, 1995). In the study are, upper Goru is overlain by relatively thick Paleocene's Ranikot and Ghazij formations. They are overlain by very thin Eocene's Kirthar formation followed by recent deposits. The study area has been evolved through rifting, wrenching, faulting and uplifting over the geological period and therefore has undergone deformations in more than one episodes (Nadeem Ahmad et al., 2004).

2.1.3 Structural styles of SIB

The SIB is separated from Middle Indus Basin by Jacobabad-Khairpur and Mari Kandhkot Highs together termed as Sukkur rift (Kadri, 1995). Towards its east is Indian shield and towards its west is Indian marginal zone. Its southward extension is confined by off-shore Murray Ridge- plate boundary. The SIB comprises of five units among which Thar platform is more important as study area lie in this topographic unit.

2.1.4.1 Thar Platform

It is a monocline which slopes gently according to basement topography. The sedimentary deposits become thin towards Nagar Parkar High, which is the surface expression of the Indian shield (Kadri, 1995).

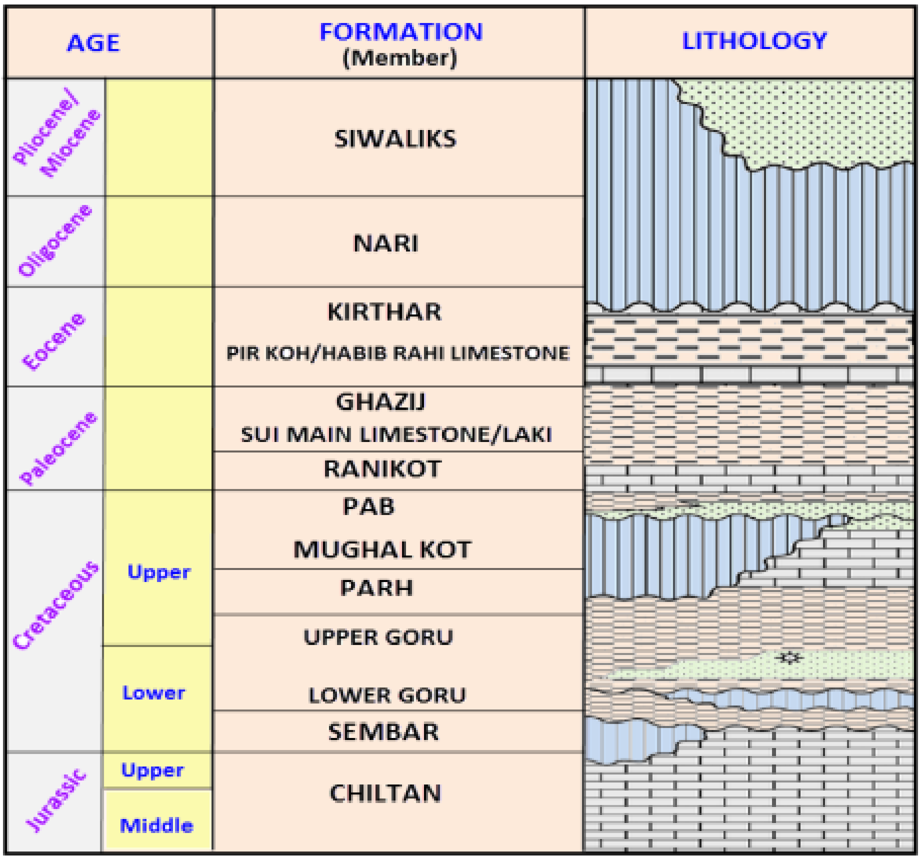

Figure 2.2. Generalized stratigraphy of Southern Indus Basin, Pakistan (Khan et al., 2016).

2.2 Data sources, quality and limitations

2.2.1 Data requirements

Following public domain data was acquired from DGPC, on behalf of the recommendation letter from the IGIS Department of NUST University, to achieve the desired research objectives.

2.2.1.2 Seismic data

3D seismic data of Sawan Block is selected to carry out the study. Migrated seismic sections and SEG-Y's of seismic cube with seismic velocities along with navigation files were acquired for the intended research work.

2.2.1.2 Well data

Complete suite of wireline logs (including Gamma-ray, Caliper, Resistivity LLD, Resistivity LLS, Sonic, Spontaneous Potential, PEF, Neutron, and Density logs; of at least five wells among the following that are falling inside the 3D seismic volume), well formation tops and VSP surveys were acquired for the intended research work for Sawan-01, Sawan-07 and Sawan-08.

Table 2.1. List of datasets used in geostatistical reservoir modeling along with description and sources.

Data	Description	Sources
Seismic data	3-D Seismic cube of Sawan Block (12 sq.km sub volume).	DGPC, LMKR
Well data	Wireline logs (including Gamma ray, Caliper, Resistivity, Sonic, Spontaneous Potential, Neutron and Density logs) & Formation Tops.	DGPC, LMKR
Geological data	Geological & tectonic maps	Geological Survey of Pakistan

2.2 Analytical Framework

All the above-described datasets were input to the Geostatistical Model. Modeling of Geostatistical model starts from the input of seismic cube, which includes all seismic data which forms the basis of Seismic interpretation and attribute analysis. The schematic view links all spatial features (supply and demand sites) by using nodes and seismic lines. Then the computation of scenarios was done. Figure 2.1 shows the schematic diagram of Sindh, which is part of LIB. Red polygon indicates study area.

Geostatistical model provides with a set of model objects and procedures that can resolve problems faced by petroleum management using scenario generated approach, which works on the likewise tectonic regime for reservoir evaluation and proposing new well location. It has built-in statistical and mathematical algorithms that use seismic and petrophysical data. Interpolation and extrapolation are done and 3D grid is generated.

Geostatistical model provides methods for data calibration using data analysis which incorporates trend and variogram analysis of petrophysical properties, which are then upscaled and populated on the wells. After that, multiple Gridding algorithms can be used to generate a 3D Grid, which involves deterministic as well as stochastic models (Kadri, 1998).

2.3 Seismic Interpretation

Seismic interpretation is a way of transforming the whole seismic information into a structural or stratigraphic model of the earth. As the seismic section represents the geological model of the earth, by seismic interpretation, demarcation of the zone of final

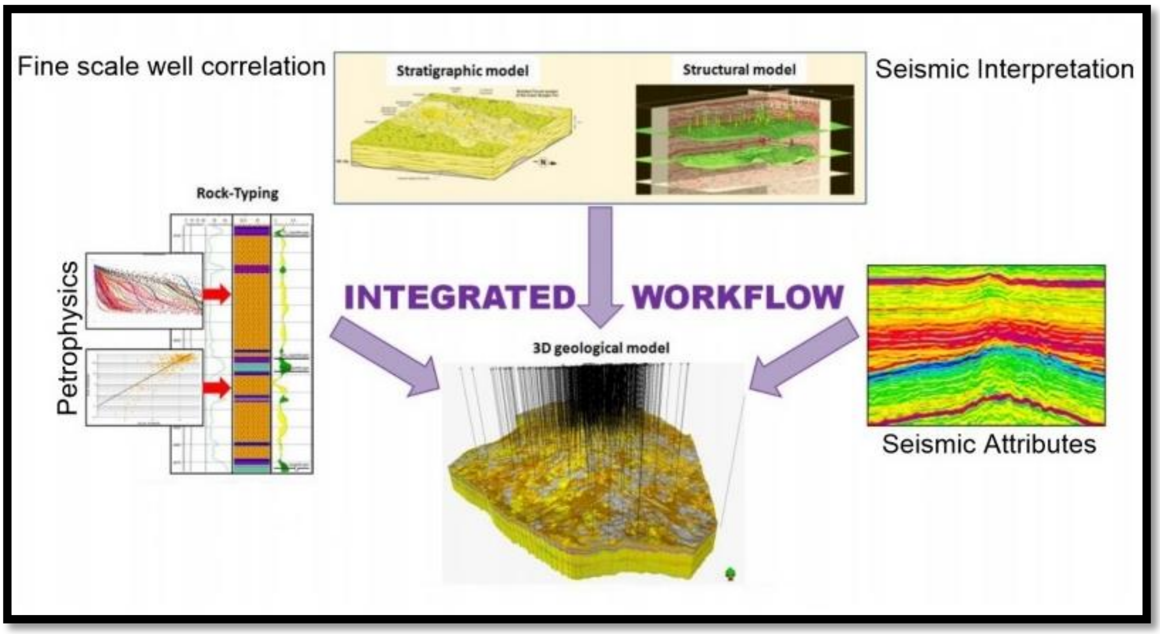

Figure 2.3. Integrated workflow of geostatistical modeling (Khan et al., 2016).

anomaly is done. Uncertainty or certainty of seismic interpretation is ascertained because the actual geology is rarely known. An excellent interpretation has consistency instead of correctness. Not only a good interpretation be consistent with all the seismic data, it is also important to know all about the area, including gravity and magnetic data, well information, surface geology as well as geologic and physical concept (Gao, 2004).

The 3-D seismic interpretation was made using OpendTect software. The interpretation was done in accordance with older information derived from literature review and well tops information. The seismic interpretation was started with picking horizons. Synthetic seismogram was made using sonic and density logs and then well tops were marked as horizons on seismic sections. Horizons picked are D-sand, C-sand, and B-sand.

2.3.1 Time Sections

In areas where velocity variation is mild, time migrated seismic sections can be used. If, however, there are large velocity variation, then time migrated sections can result in erroneous interpretation of structural features and leave them unsuitable for interpretation. To avoid erroneous interpretation, time migrated seismic sections should be converted to depth migrated seismic sections.

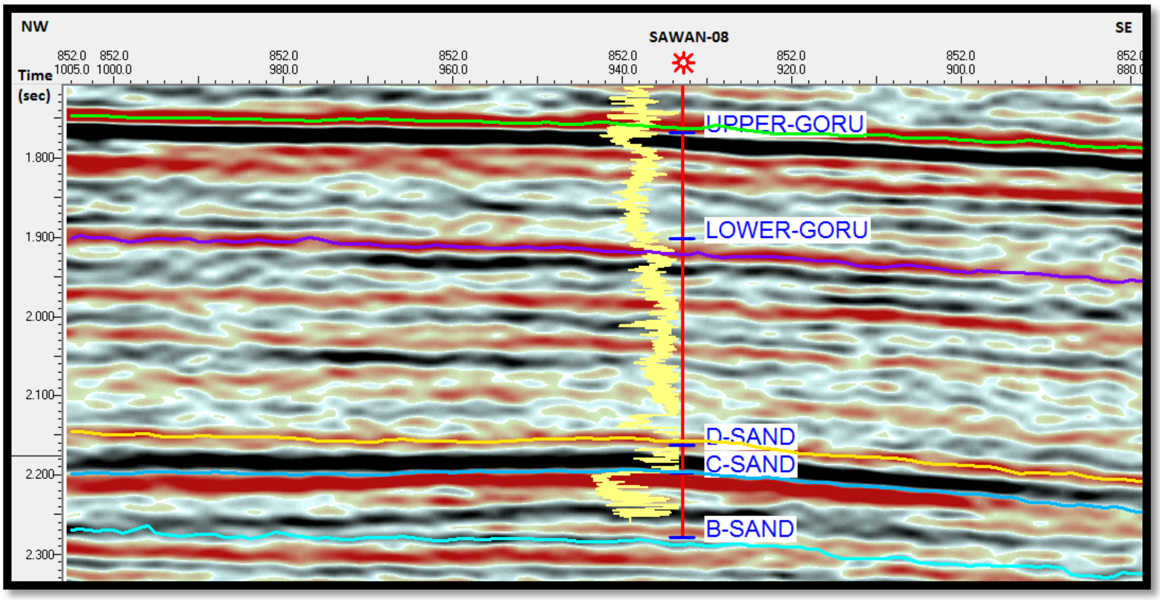

Figure 2.4. Integrated 3D seismic section on Sawan-08.

2.3.2 Depth Sections

Time migrated seismic section can be converted into depth migrated seismic section either by migrating using prestack depth migration algorithm on the raw seismic section, by depth migrating poststack data after time demigration (Cameron, Fomel, & Sethian, 2006), or by direct time to depth mapping. Each of these methods involves the conversion of the time migrated seismic section to a velocity model in depth. In the case of a laterally homogeneous medium, the conversion from time to depth is provided by the classic Dix method (Sattlegger, 1965). By using the appropriate values of velocity and time, the depth of each interface can be easily calculated.

2.3.3 Time and Depth Contour Maps

The results of seismic interpretation are either in the form time contour maps or depth contour maps. Mapping is part of the interpretation of the data. Reference datum is selected before mapping which can either be sea level or any other depth. So, to mark any shallow seismic event, another datum shallower than original datum should be used. This can have a great impact on the seismic interpretation of the zone of interest (Gadallah & Fisher, 2009). The seismic structural map is mostly the end product of seismic exploration. On this, usefulness of whole operation depends. The contours are the lines of equal time or depth wandering around the map as dictated by the data (Coffeen, 1986).

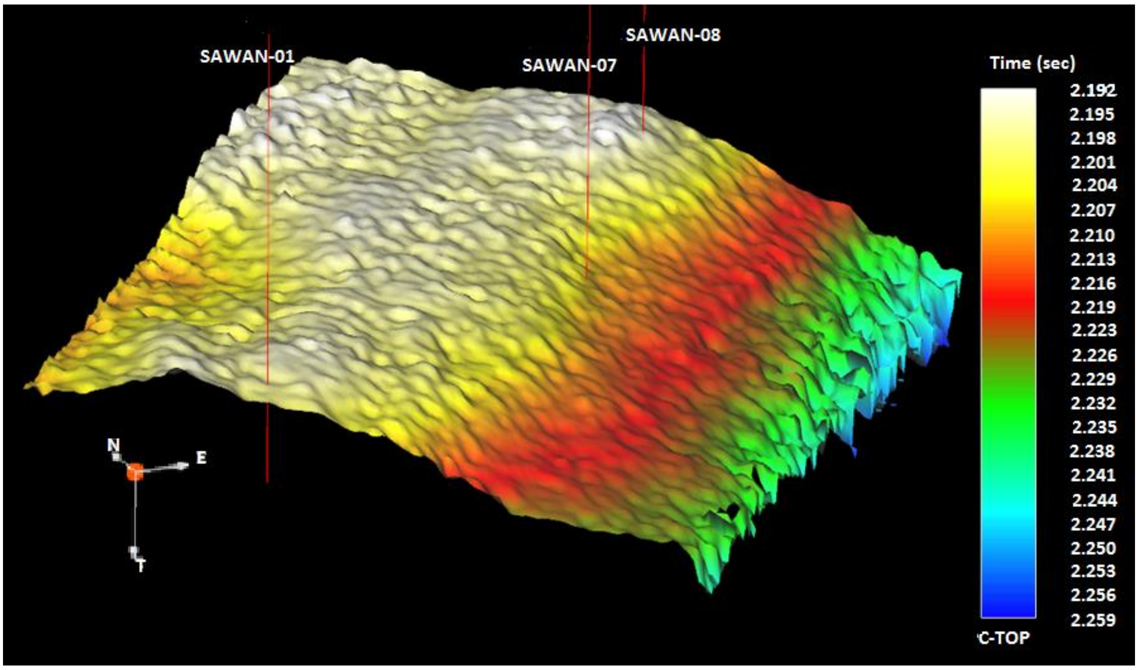

Figure 2.5. Time section of C-sand top.

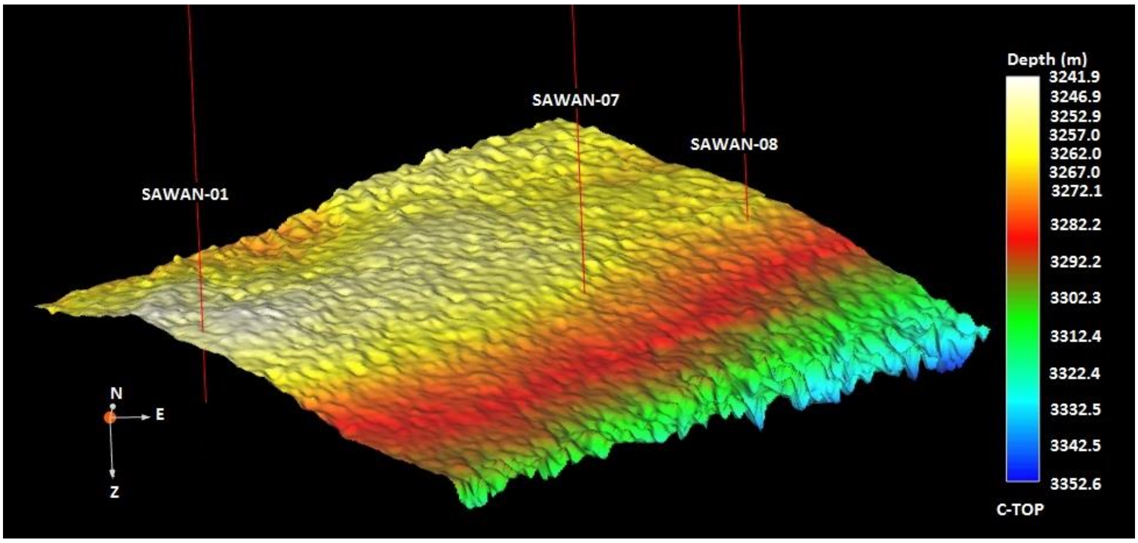

Figure 2.6. Depth section of C-sand top.

Contouring represents the 3D Earth on a 2D surface. The spacing between the contour lines indicates the steepness of the slope; the smaller spacing means steeper slope. The OpendTect software is used to generate all the contour maps.

2.4 Petrophysical Analysis

Petrophysics covers the physical and chemical properties of the rock and the probable fluid if there is some in the rock. Petrophysical data can be acquired from both well logs and from laboratory and can be used both qualitatively and quantitatively. The core responsibility of a petrophysicist is to devise a perfect static and dynamic model of the reservoir and its characterization by making valid decisions during the period of drilling and testing for the success of the well. Hydrocarbon reserve estimation, identification of petroleum system covering source rocks, cap rocks and aquifers, etc. can be done by the correlation between these properties.

Application of seismic studies sometimes does not provide the answers to geophysical queries (Lucy MacGregar, 2012). However, Petrophysics uses the integration of core, logs and production data to unveil the physical properties of the rock. Generally, the reservoir description can be done more effectively by using wellbore measurements rather than seismic. Important information like porosity, permeability, volume of shale. and zonation can be attained by using Petrophysics. Nowadays, accurate well log analysis is used to predict the important values of reservoir like Sh, Sw, lithology identification, porosity, and permeability. The procedure implemented is given in Fig 2.7 and discussed below.

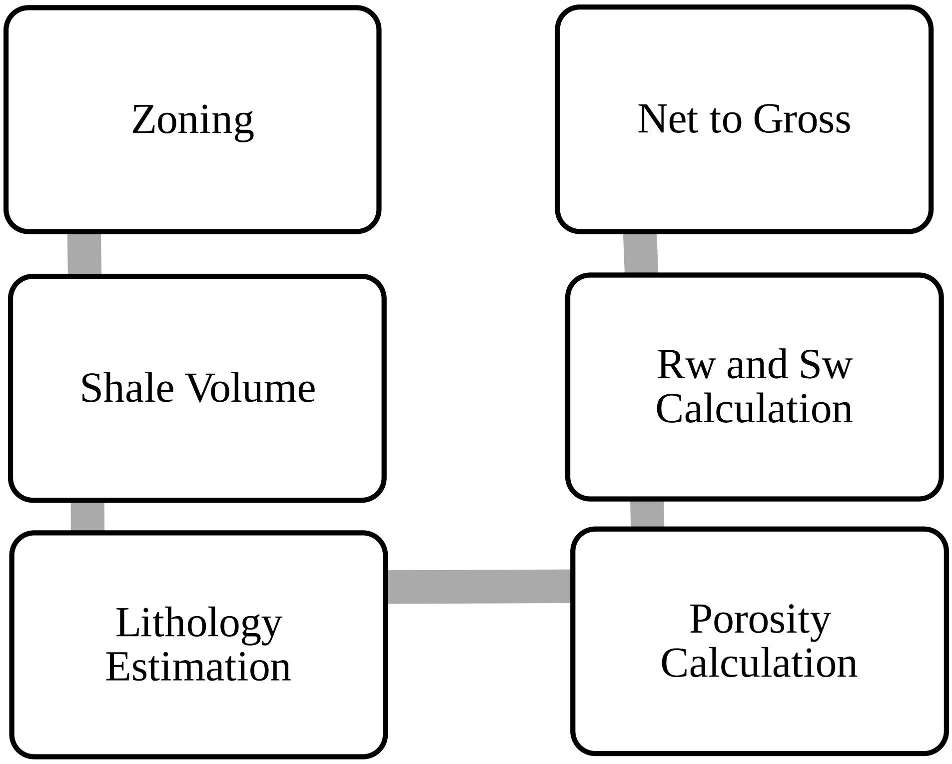

Figure 2.7. Workflow of petrophysical modeling.

2.4.1 Zoning

The zones of interest are defined using log curves and formation tops of Sawan wells. Zoning is the first step in any interpretation procedure. During zoning, the logs are split into intervals of Porous and non-porous rock, Permeable and non-permeable rock, Shaly, and clean rock, Good hole conditions and bad hole conditions, Good logs and bad logs Zoning Tools, SP, GR, Neutron Density, Resistivity.

2.4.2 Volume of shale

Volume of shale can be calculated with the application of GR log in porous reservoirs as shale is more radioactive than sand and carbonates. It can be expressed as volume of shale in decimal fraction or percentage and can be calculated from GR log by the following formula

$$Vsh = \frac{(GRlog - GRmin)}{(GRmax - GRmin)} \text{----------------Eq 1}$$

The Gamma Ray log along with GR value in clean sandstone and shale is used to determine volume of shale at particular depths. Figure 2.8, 2.9 and 2.10 shows volume of shale derived from GR log for Sawan-01, Sawan-07, and Sawan-08.

2.4.3 Lithology Estimation

Various techniques are in use for lithology determination. Combination of different well logs along with lithology cross-plots are used for this purpose. Some lithology plots are Neutron-Density plot, Neutron-Sonic plot, M-N plot, etc. In this study, Neutron-Density plot was used as shown in Figure 2.11.

2.4.4 Porosity Calculation

Porosity is formed because of voids formed by dissolution of grains along with fracturing due to overburden and tectonic activity. It is denoted by symbol "ϕ" and can be calculated either in percentage or in decimals. Two types of porosity are Primary and Secondary depending upon their mechanism of formation. The primary ϕ is formed during deposition of the rock and Secondary ϕ is formed mainly due to dissolution or fracturing. Secondary ϕ is mainly observed in limestone.

Density Porosity is derived from density log while NPHI is directly obtained from Neutron log. Hence, the Average Porosity is obtained by taking the mean of these two. Finally Effective Porosity is calculated by multiplying Average Porosity by Matrix volume.

$$\text{Density Porosity} = \frac{\text{Density Matrix} - \text{Density Log}}{(\text{Density Matrix} - \text{Density Fluid})} \text{----------------Eq 2}$$

$$\text{PHIA} = \frac{\text{DPHI} + \text{NPHI}}{2} \text{---Eq 3}$$

$$\text{Effective Porosity} = \text{PHIA} * \text{Vmatrix} \text{--------------------------Eq 4}$$

Here, Vmatrix is Vo1ume of Matrix given by subtracting volume of shale from 1.

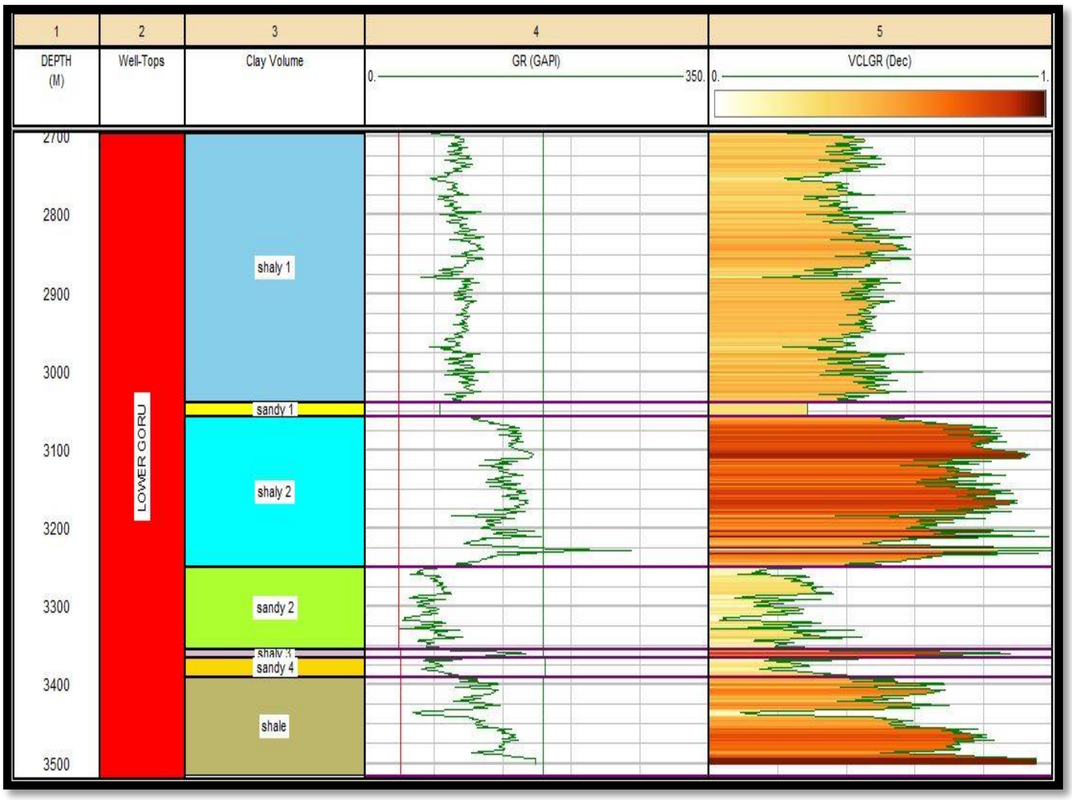

Figure 2.8. Calculation of Volume of Shale for Sawan-01.

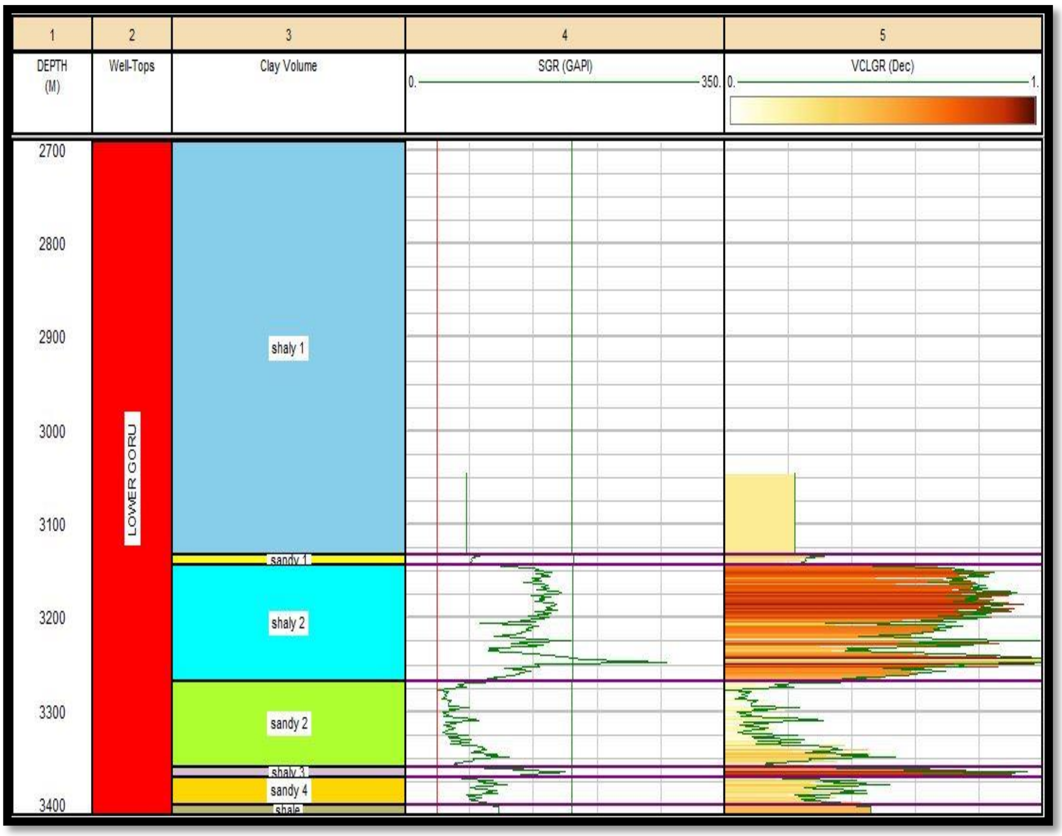

Figure 2.9. Calculation of Volume of Shale for Sawan-07.

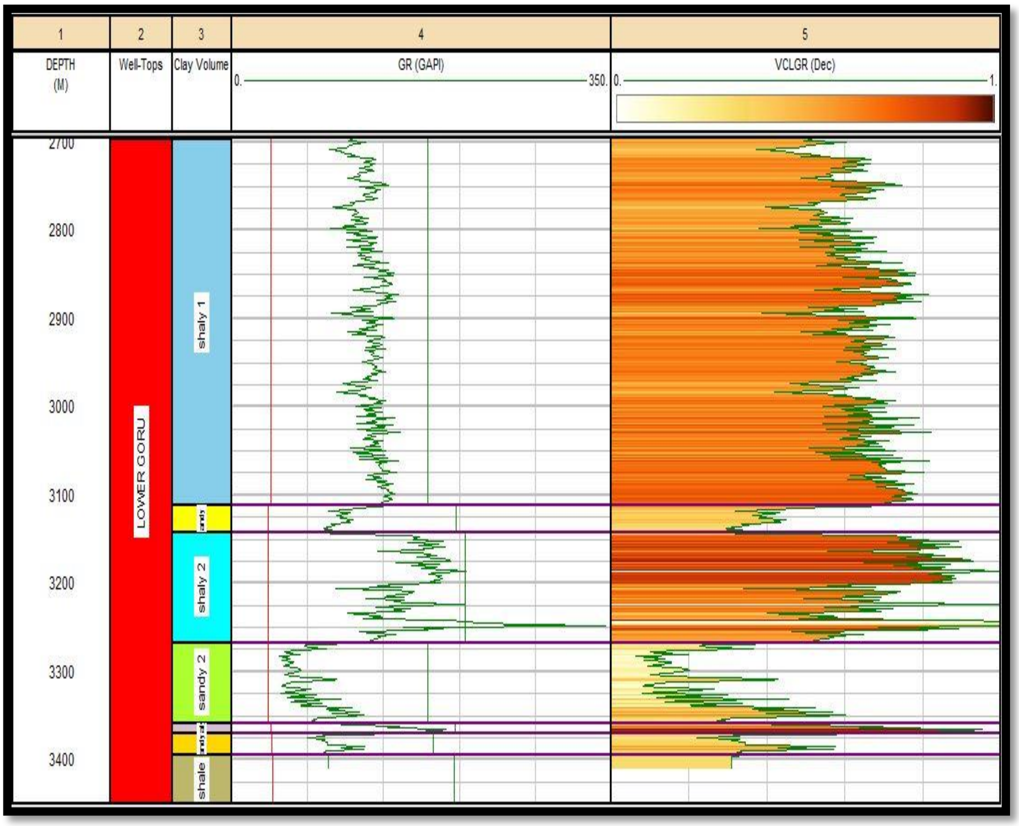

Figure 2.10. Calculation of Volume of Shale for Sawan-08.

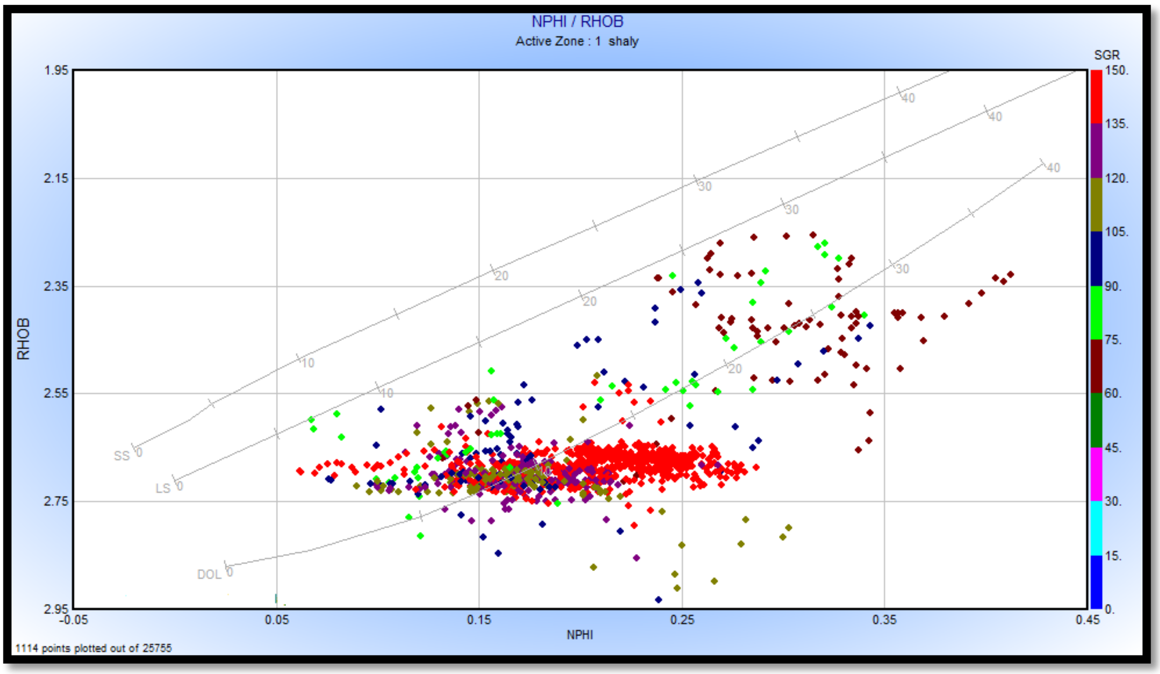

Figure 2.11. Neutron Density plot for shaly zone.

2.4.5 Calculation of Resistivity of water and Saturation of water

Rw can be calculated using the following equation where RT is obtained from LLD log, Rmf and Rxo values are provided by log header.

$$Rw = \frac{(RT*Rmf)}{Rxo}\text{---------------Eq 5}$$

Sw is the ratio of water volume to the pore volume of the rock and can be calculated with the help of the Archie's equation given as;

$$Sw = \left\{Rw\frac{1}{(RT*\phi m)}\right\} * 1/n\text{---------------Eq 6}$$

Where Φ is Porosity, m is Cementation factor (with a constant value 01) and n is Wettability factor (with a constant value 02).

2.4.6 Net to Gross

This va1ue can be obtained by dividing Net reservoir thickness by Gross reservoir thickness.

2.5 Static Reservoir Model

For mathematically describing the subsurface in 3D space, Geocellular reservoir modeling is used, which has structural and stratigraphic constraints. It is a way for creating a prototype of subsurface geology. The results of static reservoir modeling resemble too much extent as of real world. Static reservoir modeling is a crucial step in field development studies. The grid developed during static reservoir modeling is further used in reservoir simulation studies. Static reservoir modeling integrates structural, stratigraphic, petrophysical and lithological characteristics into one integrated model.

Building an accurate static model for a subset of Sawan gas field was the main objective. The goal was to develop a model with sufficient detail to represent vertical and lateral heterogeneity at the well, multi-well, and field scale, which could be used as a tool for reservoir management. The precise workflow for developing the Geostatistical Sawan Model has two major steps.

2.5.1 Stratigraphic Modeling

Stratigraphic modeling is comprised of two main processes namely zoning and layering. Zoning done during formation evaluation form the basis of make zone process. Utilizing top and bottom of depth contour maps of each zone, isochore mapping is done.

Isochore contour maps show vertical thickness of each zone. These maps are input for zoning.

After zoning, vertical layering is performed. In layering process, zones are further subdivided into layers for finer resolution of Geostatistical Model. The input for vertical layering requires number of layers in a zone and cell thickness. These parameters are defined during layering process. After vsertical layering, upscalling is done. In this process, petrophysical property values are associated with each cell in the 3D grid at each well location. 3D grid constructed for Geost modeling is shown in Figure 2.12.

2.5.2 Property Modeling

After upscaling, property modeling is performed. In this step, petrophysical values are interpolated for the whole 3D grid using data from upscaling at each well location. Various Geost techniques are used during this process. Property modeling is divided into two main steps namely data analysis and petrophysical modeling.

2.5.2.1 Data analysis

Data analysis acts as the quality control step for the Geost reservoir modeling. The quality control is basically of both types of petrophysical properties either discrete like facies or continuous like permeability values.

The major step in data analysis of Geostatistical model is variogram analysis or trend analysis. For this study, variogram analysis is performed. These analyses are performed on basis of zones and upscaled petrophysical properties.

Variogram gives results in accordance with autocorrelation i.e. things near to each other on earth surface has more similarity than things farther apart. So to control instant independence and spatial continuity during stochastic techniques, variogram analysis is performed. The variogram is calculated from data values and the variogram model fitted to this data. There are different types of variograms such as spherical, exponential, gaussian and power, etc.

2.5.2.2 Petrophysical Modeling

Petrophysical properties or seismic attribute values are used as input for petrophysical modeling. The major data required for this process are petrophysical values of various parameters like porosity, effective porosity, hydrocarbon saturation, etc. this model provides us with their physical distribution in the field.

Petrophysical modeling can be deterministic or stochastic but as variogram analysis is performed so it will be stochastic in nature. Various algorithms can be used for this process including Gaussian simulation, Gaussian random function, Ordinary Kriging, Universal Kriging, Neural Networks, and user-defined algorithms.

The Gaussian random function simulation was selected because of its faster co-simulation sequential algorithm for easy validation of results. Variogram analysis is performed for the simulation of petrophysical properties.

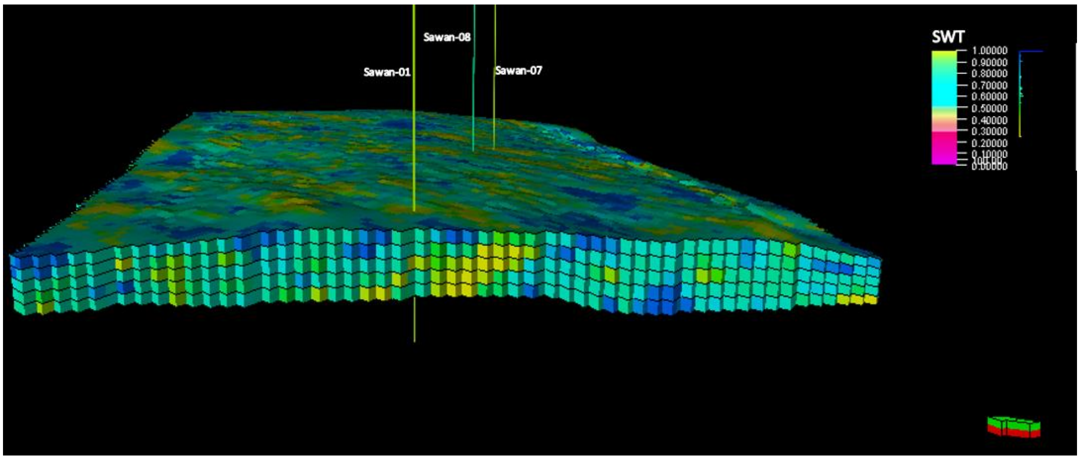

Figure 2.12. Cross sectional view of vertical layering of Total Water Saturation (SWT) for Lower Goru C-sands.

Chapter 3

RESULTS AND DISCUSSIONS

3.1 Seismic Attribute Analysis

According to Subrahmanyam, seismic attributes like instantaneous frequency and instantaneous amplitude are important attributes to help to interpret the seismic data (Subrahmanyam & Rao, 2008). Instantaneous Amplitude also called Reflection strength or trace envelope, denotes the total energy at any specific instance of the seismic trace and it is self-determining. Depending on seismic bandwidth, instantaneous amplitude delineates contrast between different interfaces or even combined interfaces. Its uses are to calculate bright spots and gas accumulation.

Instantaneous frequency basically illustrates the change of phase with time. Its low value indicates gas-bearing zones. Absorption of high frequencies is observed both below and above the interpreted gas sand in Porcupine Basin (Games, 2001) it can be used for hydrocarbon Indicator by low-frequency anomaly.

Using only one seismic attribute is not helpful in providing a decisive information (Subrahmanyam & Rao, 2008). So, Sweetness is determined by dividing the instantaneous amplitude by the square root of the instantaneous frequency. High values of sweetness indicate hydrocarbon saturated zones because the presence of hydrocarbons enhances the amplitude envelope and lowers the frequency (Hart, 2008).

High amplitude values are mostly related to the gas-bearing zones. Strongest amplitudes are directly related to the areas having high porosity and thickness i.e., best reservoir zones (Fatti, Smith, Vail, Strauss, & Levitt, 1994).

High sweetness values are observed in the areas of producing wells at respective depths suggesting gas-bearing formation. Three progrades were marked on the seismic section of Sawan field which are formed when the relative sea level drops. These progrades are highly prone to gas-bearing formations.

High sweetness values indicate the potential for hydrocarbon accumulation. Figure 3.1 shows the sweetness time slice for C-sand. High sweetness values are encountered at producing gas wells. So other areas having high sweetness values are demarcating probable well locations.

When the seismic fine resolution is used, stratigraphic features acting as trap for C-sands were delineated as three prograding features on seismic section in Figure 3.2. These progrades are sealed at top and bottom by L.Goru shales. They indicate sandstone deposition during global sea-level fall. Progrades mostly have high association with hydrocarbon accumulation unless disturbed by tectonic activity.

The trapping mechanism at Sawan field includes loss of diagemetic character and structural dip of reservoir quality. Sembar organic rich shales act as the major hydrocarbon source rock for the SIB.

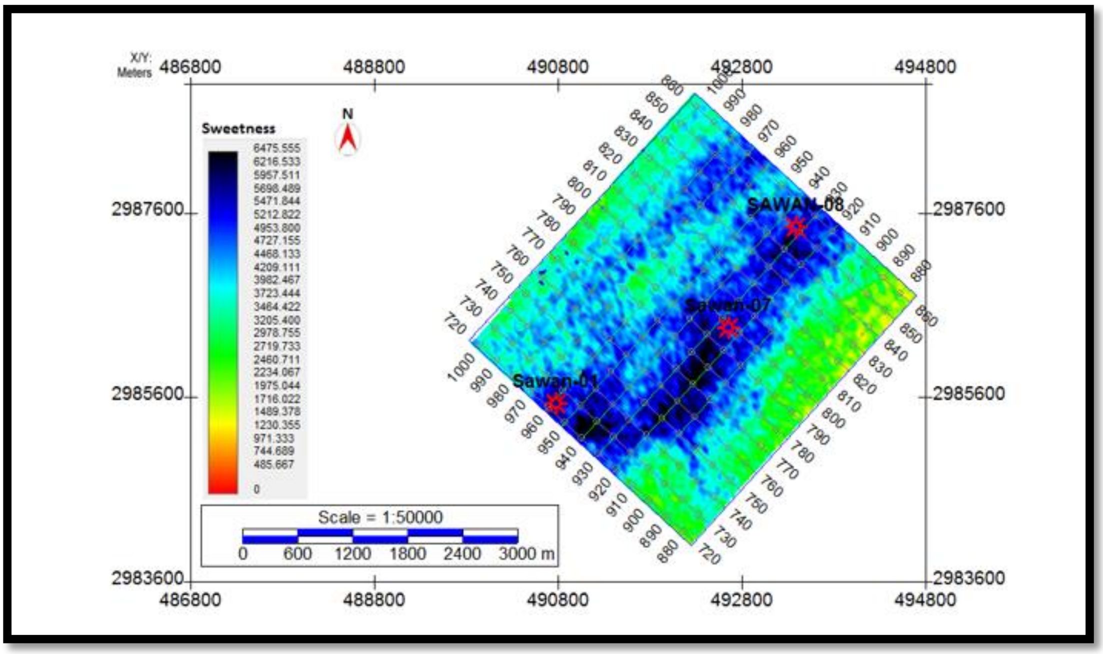

Figure 3.1. Sweetness Time Slice at 2.202 sec.

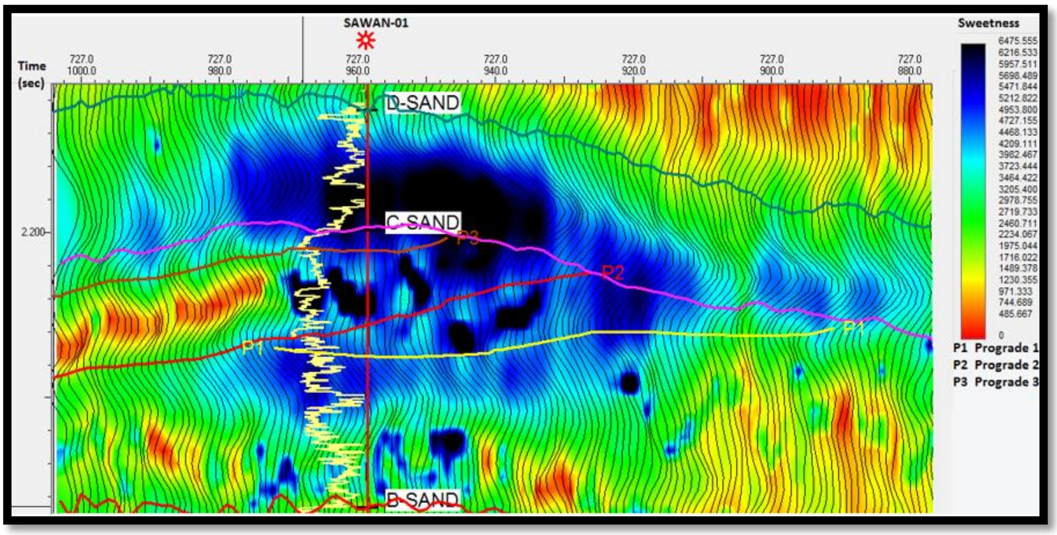

Figure 3.2. Sweetness revealing Stratigraphic Features.

3.2 Hydrocarbon zonation:

Prospective hydrocarbon prone zones in the reservoir formation are mostly identified by neutron-density log cross- over i.e., low value of both neutron log and density log (Ross & Kinman, 1995). Different flow units in the reservoir zonation are identified by using LLS and MSFL (Asgari, Sobhi, & Engineering, 2006). Basically the difference between LLS and MSFL indicates presence of hydrocarbons.

Figure 3.3, 3.4 and 3.5 illustrates various resistivity (LLS, LLD, MSFL) and porosity (RHOB, NPHI, DT) logs. In these figures, different zones are marked which have neutron-density log cross- over (shaded yellow) and the difference between LLS and MSFL (shaded aqua). These zones are basically gas prone zones. Their overall thickness is around 100 meters. There are three basic zones defines as Sandy-1, Sandy-2 and Sandy-4 in the C-sand of L.Goru Formation. Sandy-4 is the thickest zone in all three wells namely Sawan-01, Sawan-07, Sawan-08.

L.Goru Member is composed of interbedded sandstones of one of the most productive reservoir quality and shales. The L.Goru sandstone has been informally divided (from bottom to top) into the “A”, “B” and “C” intervals (Krois et al., 1998). The L.Goru and Upper Goru shales act as a cap for the reservoirs of L.Goru sands.

Sandy-1, Sandy-2 and Sandy-4 in the C-sand of L.Goru Formation showed low volume of shale i.e., low GR value which indicates the presence of low shale and high sandstone deposition. Sandstone has high porosity than shale and acts as reservoir formation. Low porosity shale acts as source and seal for reservoir zones.

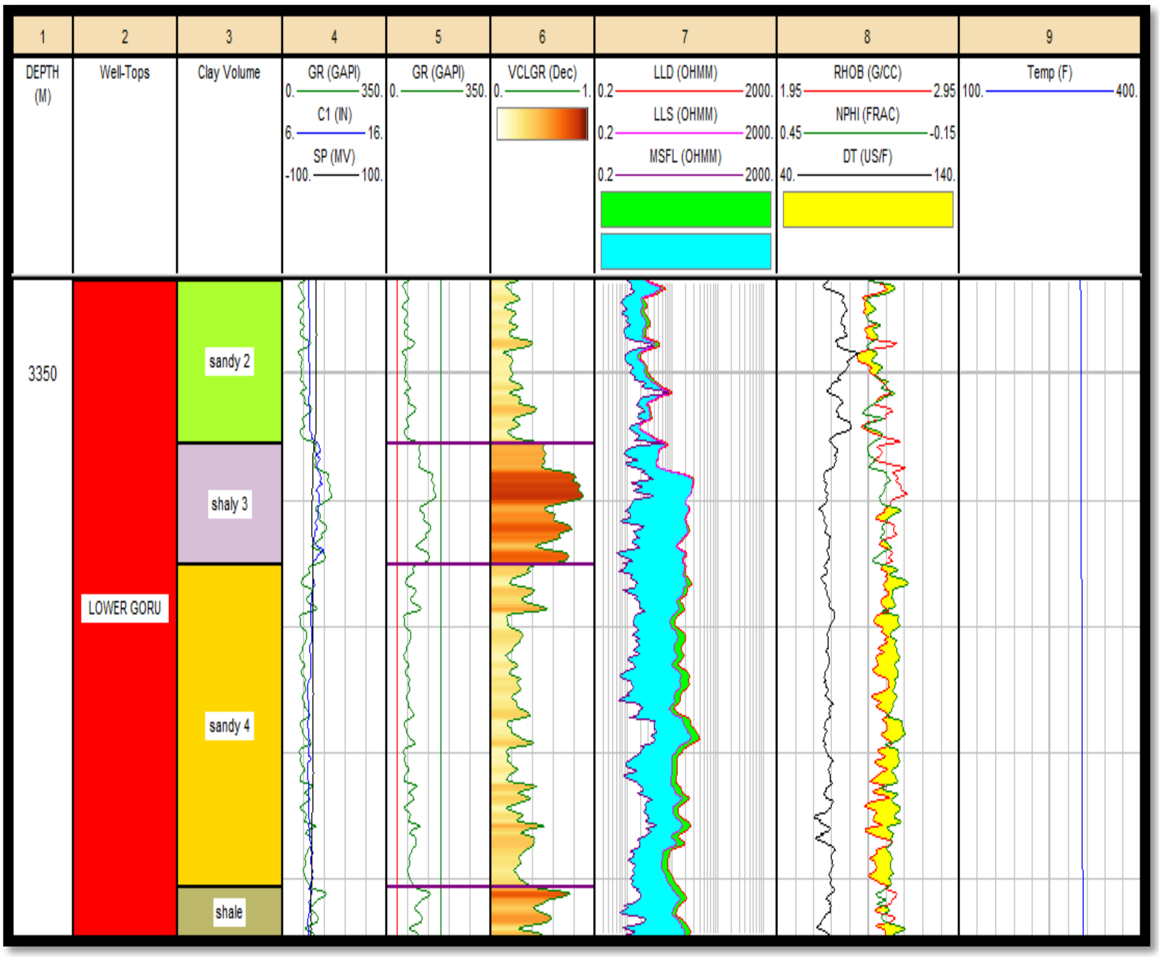

Figure 3.3. Resistivity & Porosity Logs for Hydrocarbon Indicators for Sawan-01.

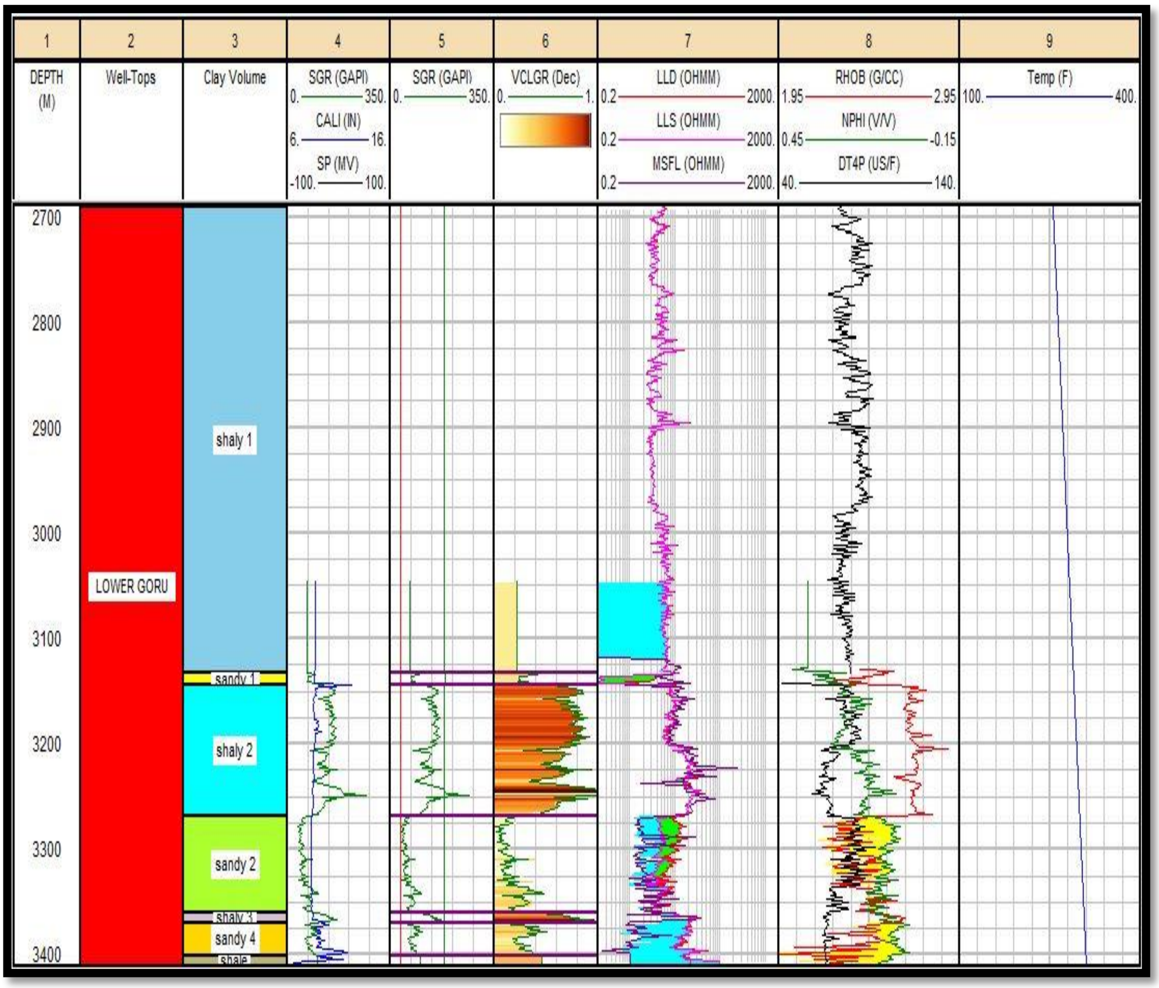

Figure 3.4. Resistivity & Porosity Logs for Hydrocarbon Indicators for Sawan-07.

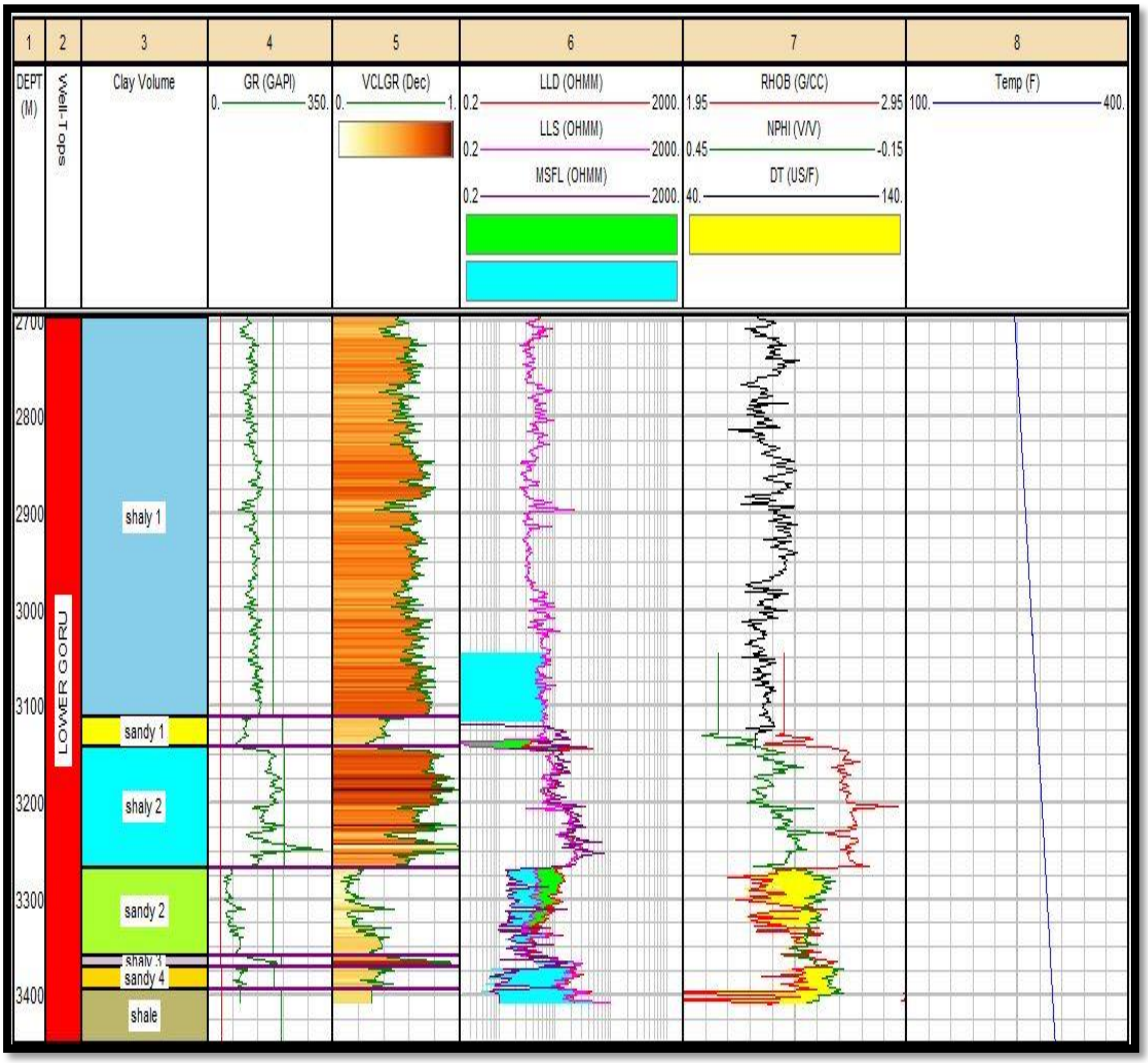

Figure 3.5. Resistivity & Porosity Logs for Hydrocarbon Indicators for Sawan-

08.

C-sand is divided into three potential hydrocarbon-bearing zones (sandy-1, sandy-2, and sandy-4) based on GR, resistivity and porosity logs.

Zone sandy-1 consist of sandstone with shale beds. Total porosity in this zone varies from 12 to 17 percent while effective porosity is around 6 percent. Saturation of water in this zone is 30 percent and shale volume ranges between 30 to 40 percent. Net to Gross ratio in this zone is 0.7. Zone sandy-2 consist of thick sandstone beds. Total porosity values are around 21 and even higher than 21 percent while effective porosity is around 17 to 20 percent. Shale volume and saturation of water is 6-7 percent and 27 percent, respectively. Net to Gross ratio is 0.9 in this zone.

Zone sandy-4 consist of sandstone with marl and shale beds dolomite. Total porosity values are around 16 to 21 percent, while effective porosity is around 11 percent. Shale volume in this zone is 34 to 36 percent and saturation of water is 27 percent. Net to Gross ratio in this zone is around 0.75.

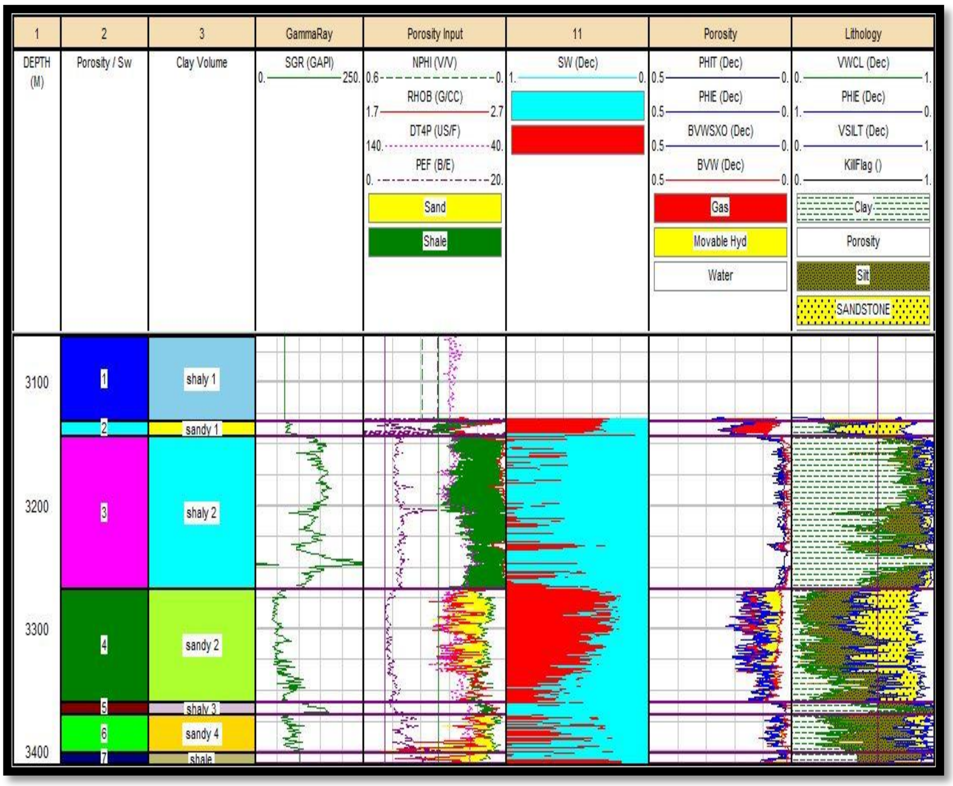

Figure 3.6. Petrophysical Analysis & Hydrocarbon Saturation for Sawan-07.

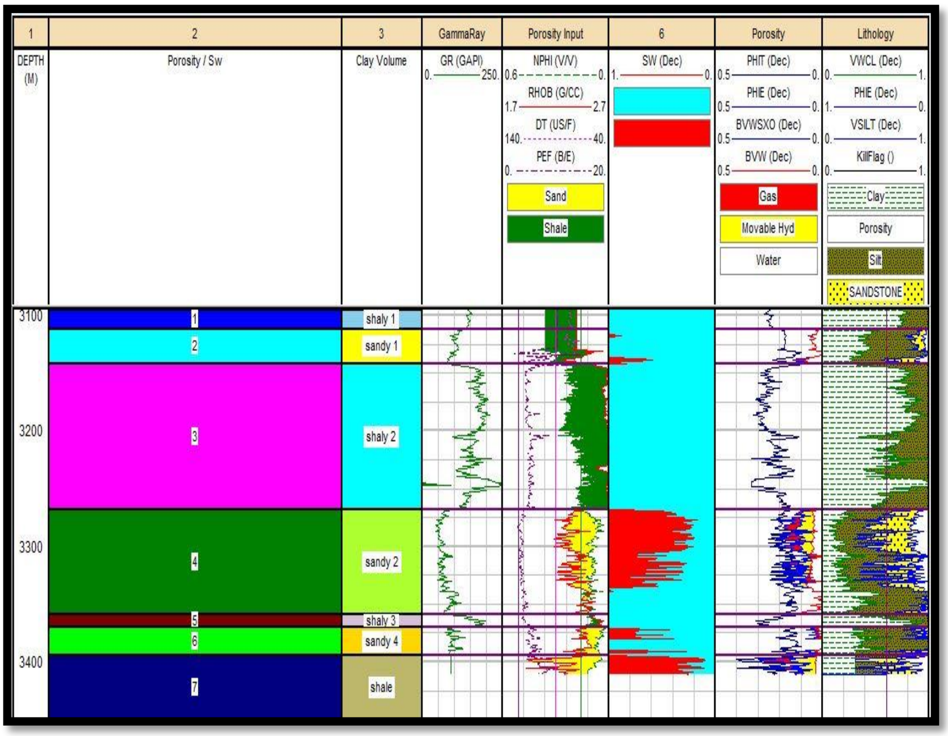

Figure 3.7. Petrophysical Analysis & Hydrocarbon Saturation for Sawan-08.

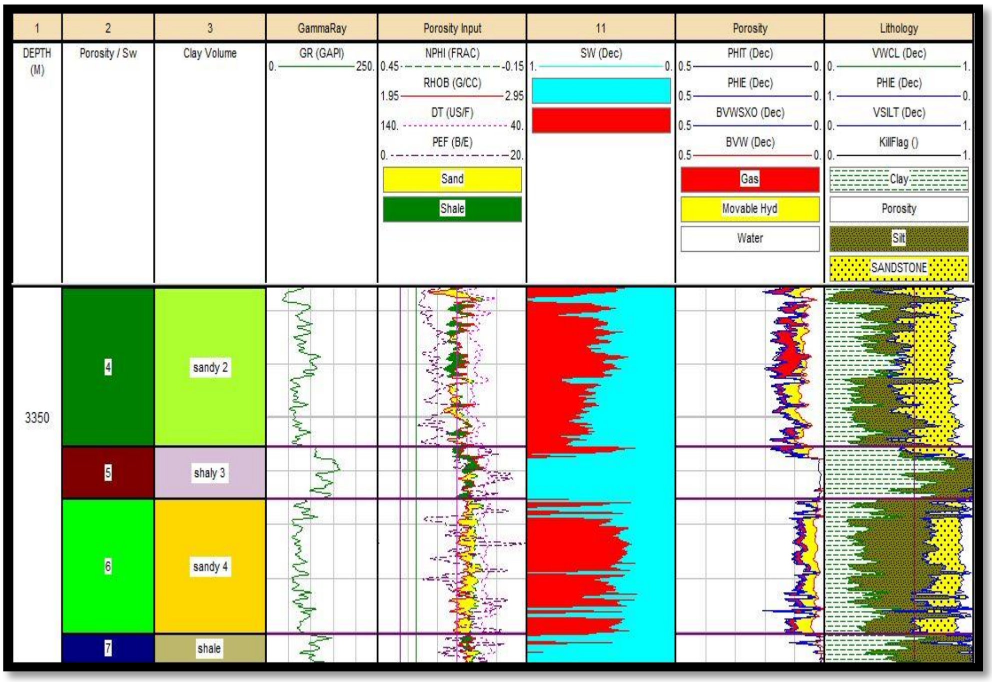

Figure 3.8. Petrophysical Analysis & Hydrocarbon Saturation for Sawan-01.

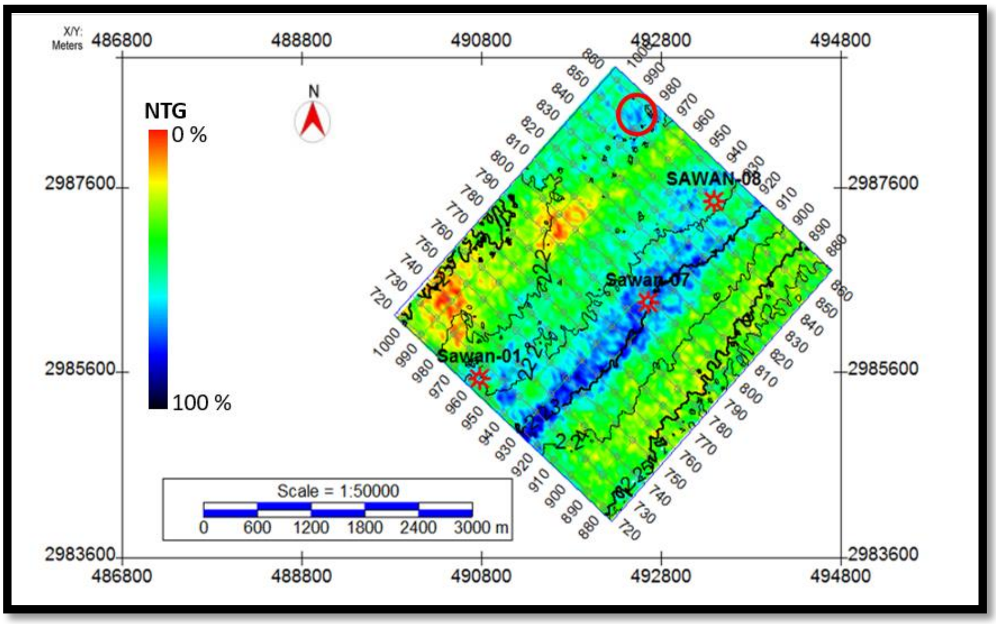

Figure 3.9. Time contours of C-sand overlaid over Net to Gross ratio Map.

3.3 Geostatistical reservoir modeling

To achieve sufficient detail to represent vertical and lateral heterogeneity at the well, multi-well, and field scale, which could be used as a tool for reservoir management, the model is vertically layered (5 layers).This required that the model be properly zoned (7 zones), finely layered (113 layers, 3-ft (1 m) average thickness), and have grid dimensions of 153x147x101. These criteria resulted in the development of a 2.3716-million cell model.

All the petrophysical properties like volume of shale, Sw, porosity, and NTG were populated in this 3D grid on the time contours of C-sand. The resultant map is shown in Figure 3.9 where dark blue color indicates very high NTG. A new well location is proposed using this value of NTG in reservoir zone indicated by red circle in Figure 3.9. The high NTG value means that this reservoir zone has maximum potential of production over time.

L.Goru's cretaceous sandstone (informally called C interval) is the reservoir horizon in Sawan block. Sandstones of the Lower Cretaceous to lowermost Upper Cretaceous L.Goru Member form the most productive reservoir in this basin. Ibrahim et al., (2004) concluded that L.Goru Member is divisible into 4 distinct intervals, namely A, B, C, and D sands.

3.4 Discussion

Azeem et al., found a good correlation with regression coefficient (R2) > 0.78 between seismic attributes namely average instantaneous frequency, peak spectral frequency, sweetness and gas layer thickness which lays the foundation for predicting the thickness of gas reservoir in the Sawan gas field, Pakistan (Azeem et al., 2016).

The highest amplitudes were found to be located roughly in the areas of best reservoir quality (i.e., highest porosity) in areas where the reservoir is relatively thick.(Fatti et al., 1994).

Neutron-density log cross- over (shaded) indicate hydrocarbon reservoirs (Ross & Kinman, 1995). Identify the different flow units in the reservoir zonation using LLS and MSFL (Asgari et al., 2006).

According to Subrahmanyam, seismic attributes like instantaneous frequency and instantaneous amplitude are useful tools for drawing a conclusion from the interpretation of seismic data. It may be noted that these attributes are very useful tools analysis of a single attribute may not provide a conclusive definitive information. Instead, useful conclusions can be drawn by using a combination of attributes together (Subrahmanyam & Rao, 2008).

Lower Goru Formation, show anomalously high porosities (20 %) at depths of 3,000 to 4,000 m (A. Berger, S. Gier, & P. J. A. b. Krois, 2009).

Seismic, as well as core study, indicate exposure of the Sawan basin during falling of sea-level. Six seismic events are identified, picked and mapped. These events tied with logs and core data defied as geological units (progrades) which are of variable size, shape, and areal distribution. The six progardes are not consistently present over the whole Sawan Field(Afzal, Kuffner, Rahman, & Ibrahim, 2009)

Chapter 4

CONCLUSTION AND RECOMMENDATIONS

4.1 Conclusion

Increase in unmet gas demand in LIB is not only due to human-induced factors but also due to the changes in petroleum consumption policies during last decade in Pakistan. Depleting petroleum reservoirs is due to the unsustainable consumption of petroleum products for domestic and industrial purposes for 200 million people. The presented analysis of management strategies for future prediction should be considered for planning, developing and designing sustainable exploration of hydrocarbon reserves.

Upper sands of L.Goru Formation acted as the main reservoir in most of the early discoveries however, later reserves were discovered from the Middle and Basal sands of this formation. These discoveries were not very large but were cost-effective and led to an auspicious success rate in Pakistan. Most of these reserves are now depleting so there is a need for enhanced recovery by utilizing more complex technologies.

With the start of the industrial revolution, petroleum assets gain much more important than ever. With the advancement, all easy to access and explore petroleum assets have been developed. Most developed fields are depleting with time. So now more complex recovery techniques are required or there is need to move towards exploration of challenging petroleum reservoirs in harsh environments. With harsh environment, there is much more investment in exploration and development. So, the easy approach is to attain maximum petroleum reserves from already developed fields.

Existing petroleum fields are on the only significant reservoirs in the Indus Basin which are under degradation due to high sediment loads. So, as this study suggests that with rapid population increase coupled with the increased gas requirement, and industrial revolution, it will make the further exploration of old and new major reservoirs the need of the hour, increasing petroleum productivity could buy some time against increasing gas demand and reducing gas supply until the new reservoirs are functional.

Geost Model of Sawan block indicates that the C-sand is the bright troughs (high negative value of amplitude) discovery. Also, a bright spot (DHI) was revealed at the location of the most productive well i.e. Sawan-07 in the block. From time and depth contour maps of C-sand it is revealed that all hydrocarbon producing wells in the study area are located at shallow depths. This means that at shallow depths where bright spots are located and amplitude values are very large, more hydrocarbon reserves can be discovered. Very high porosities greater than 21 percent are associated with Sawan wells which means a very high production. A new well location was proposed using variogram analysis during Geost reservoir modeling which have high NTG value and lies in Sawan C-sands. This well will enhance the petroleum productivity of Sawan field economically.

4.2 Recommendation for further research

In this study, the socio-economic, data availability and well logs data scarcity were the significant constraints. This issue has been highlighted by many in the literature (Abbas et al., 2015). Since we did not include the whole of the Sawan block therefore, we would like to recommend that future studies should include the whole Sawan block for giving a new well location from a managerial point of view.

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