Formation Evaluation of Hydrocarbon Reservoirs of Oil Fields in Geological Basin by the Help of Petrophysical Tools.

Joshua Gaima and Muhammad Ali*

School of Applied Physics, Papua New Guinea University of Technology, Lae 411, Morobe Province,

*Corresponding author email: mohammad.ali@pnguot.ac.pg,

Abstract: The purpose of formation evaluation is to identify the reservoir rock, evaluate the potential hydrocarbon and estimate the volume of those hydrocarbon reserves. Reservoir rock means it should be porous (void space) and permeable to get production of commercial volume of hydrocarbon. Petrophysical tools are to be lowered in the borehole to record continuous log data corresponding to depths within the borehole. Log data recorded from the tools are formation resistivity, resistivity of formation water of the reservoir, porosity, permeability, gamma ray log data for finding volume of shalyness etc. All these log data are used as inputs to the Special software of Electro Log Analysis (ELAN). Archie's equation for clean sand and Indonesian equation for shaly-sand are used in ELAN software for finding the water saturation in turn hydrocarbon saturation of the reservoir as an output. Also, effective porosity, volume of shalyness and matrix volume of the reservoir are displayed after ELAN processing.

Key words: Effective porosity, Volume of shalyness , Effective pay thickness, Secondary porosity, Water saturation

1. INTRODUCTION

Petrophysical tools lowered in the borehole for recording the continuous log data are resistivity tool along with spontaneous potential electrode, porosity tools and gamma ray tool. Resistivity of the formation can be found out from high resolution induction tool or Latero tools depending upon the type of fluids in the borehole. Induction tool is more favourable to the oil base mud and fresh water mud in the borehole whereas latero tools are more suitable in the borehole containing saline water bearing mud. For finding the porosity of the formation, we use at least two porosity tools such as litho density tool and neutron porosity tool. Litho density tool and neutron porosity tools are used to find the effective porosity and volume of shalyness of the reservoir rocks. Resistivity of formation water (R_w) can be found out from SP (spontaneous potential) log. Modular dynamic tester (MDT) is lowered against the reservoir rock in borehole and sample of formation water is collected and resistivity is measured on the surface. After giving temperature correction, the R_w can be determined exactly of the reservoir rock. The parameters *a* (Archie's constant), *m* (cementation factor) and *n* (saturation index) of particular field are found out from the core data in the core laboratory. After log data acquisition, it is processed by ELAN software to find water saturation in turn hydrocarbon saturation.

The effective pay thickness of the reservoir rocks and its area of cross-section can be found out from contour map of the particular reservoir of different wells of particular field. As we know the porosity (ϕ) and hydrocarbon saturation (S_{HC}), then the reserve of hydrocarbon can be estimated in a particular field. Here we will only concentrate about water saturation (S_w) in turn hydrocarbon saturation (S_{HC}), effective porosity (ϕ_e) and pay thickness of two different fields. One field is Sanand in Ahmedabad-Mehsana block of Cambay basin, India and another is the case history of one well log data interpretation of Indonesian field.

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Joshua Gaima and Muhammad Ali | 2 (2) : 165 - 175 | Received: 11/07/2025 | Reviewed: 06/08/2025 | Accepted: 03/09/2025 | **DOI: https://doi.org/10.63900/949f4274**

2. OPEN HOLE LOG DATA & IT'S CHARACTERISTICS

Figure 1 is the log motif of triple combo (Resistivity – Density-Neutron and Gamma Ray). Gamma ray log in the interval 1397 – 1410 meter reads the value in the order of 15 to 20 API indicating that it is sand reservoir. SP is negative in back-up scale supporting gamma ray. The interval 1397- 1401 meter is very interesting where resistivity is showing 17 ohms meter which is comparatively high. In this interval density - neutron porosity curves are showing cross-over characteristics which indicates that the interval 1397-1401 meter is gas bearing sand. The interval 1401-1404 meter is showing resistivity gradient where resistivity values are decreasing from 10 ohm- meter to 2 ohm- meter from 1401 meter to 1404 meter which interprets that oil saturation is decreasing. Density - neutron porosity in this interval is very close to each other. Therefore, the interval 1401-1404 meter is called oil bearing zone. The interval 1404 - 1410 meter is showing resistivity value only 2 ohm-meter only throughout this interval. Density - neutron porosity curves are overlapping each other within this interval 1404 – 1410 meter. From the resistivity and density - neutron porosity curves, it is interpreted that the interval 1404 -1410 meter is 100% water saturation.

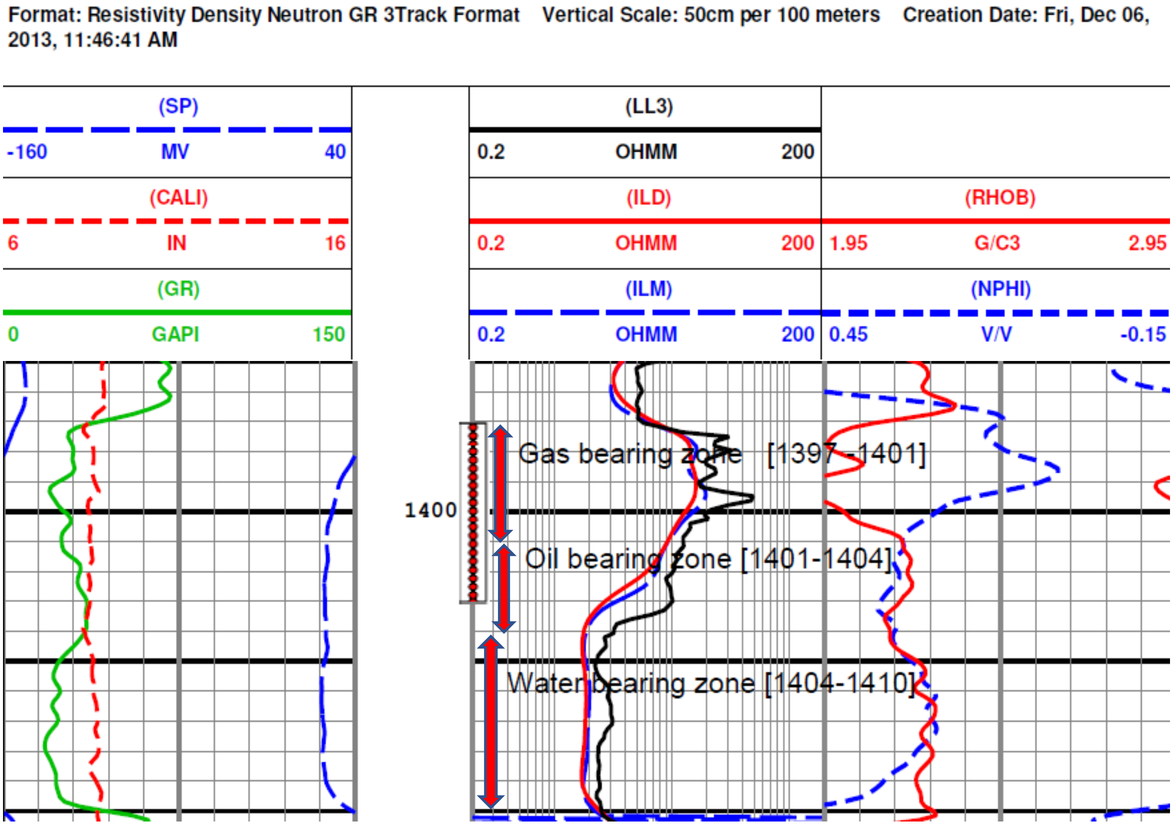

Figure 1: log motif of one well of ONGC-India showing cross-over between Density and neutron porosity in the interval 1397-1401 depicting gas reservoir characteristics. (Courtesy of ONGC, India 2013)

3. GEOLOGY OF CAMBAY BASIN, INDIA

The Cambay Basin in India is a proven hydrocarbon basin known for its thick tertiary sediments and significant shale gas potential. Cambay basin (figure 2) is located in North – West part of India, specifically within the West Indian state of Gujarat. It is an Intracratonic Rift Basin extending from Surat in the South to Sanchor in the North. Cambay Basin in the western part of India is divided into five tectonic blocks (figure 2). These blocks are separated by major cross faults. The five blocks are Narmada, Jambusar – Broach, Cambay – Tarapur, Ahmadabad – Mehsana and Patan – Sanchor.

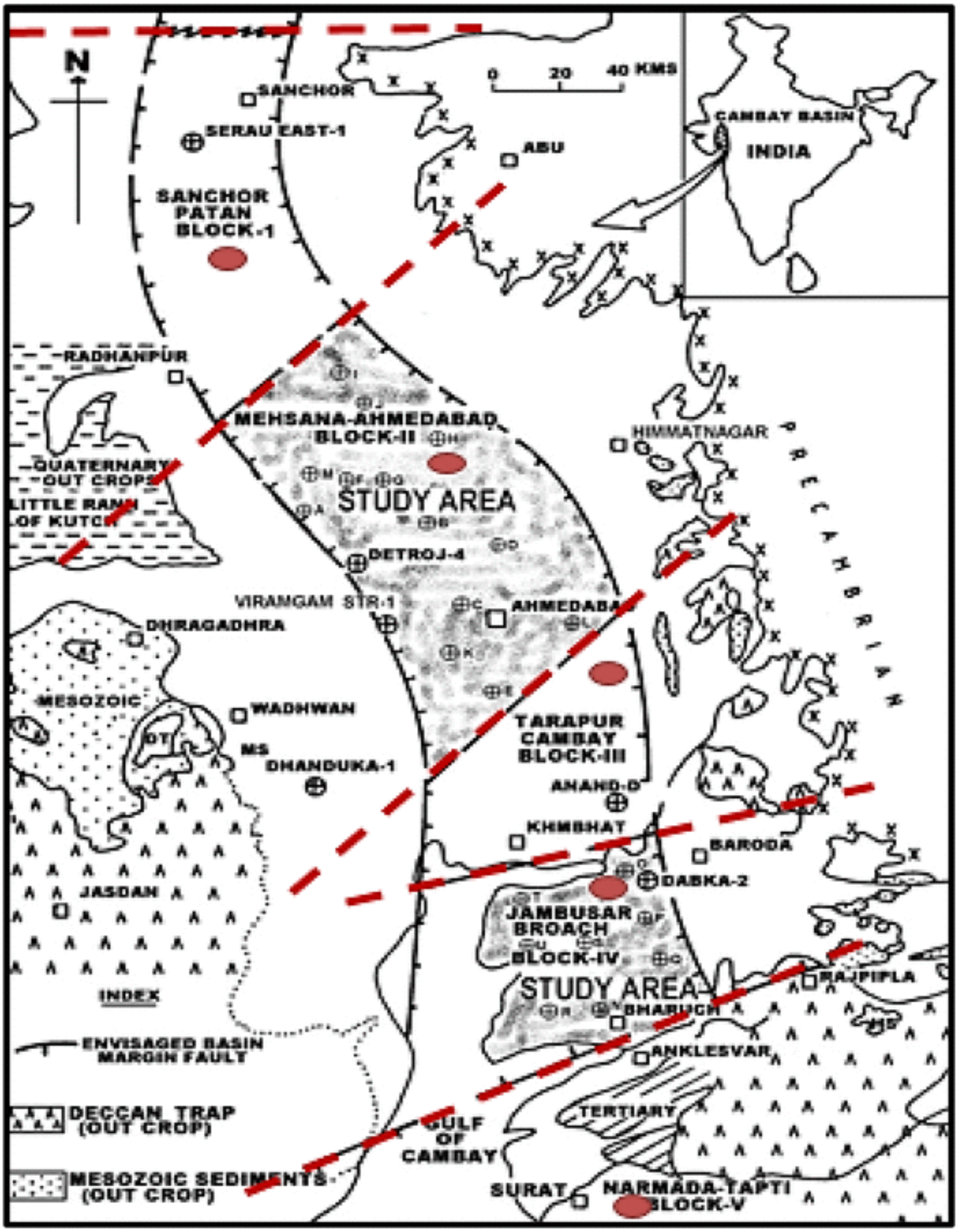

Figure 2 represents 5 tectonic blocks of Cambay basin, Western part, India. (Biswas, 1977)

4. STUDY AREA

Sanand field (Figure3) which is our study area is situated in Ahmedabad -Mehsana block

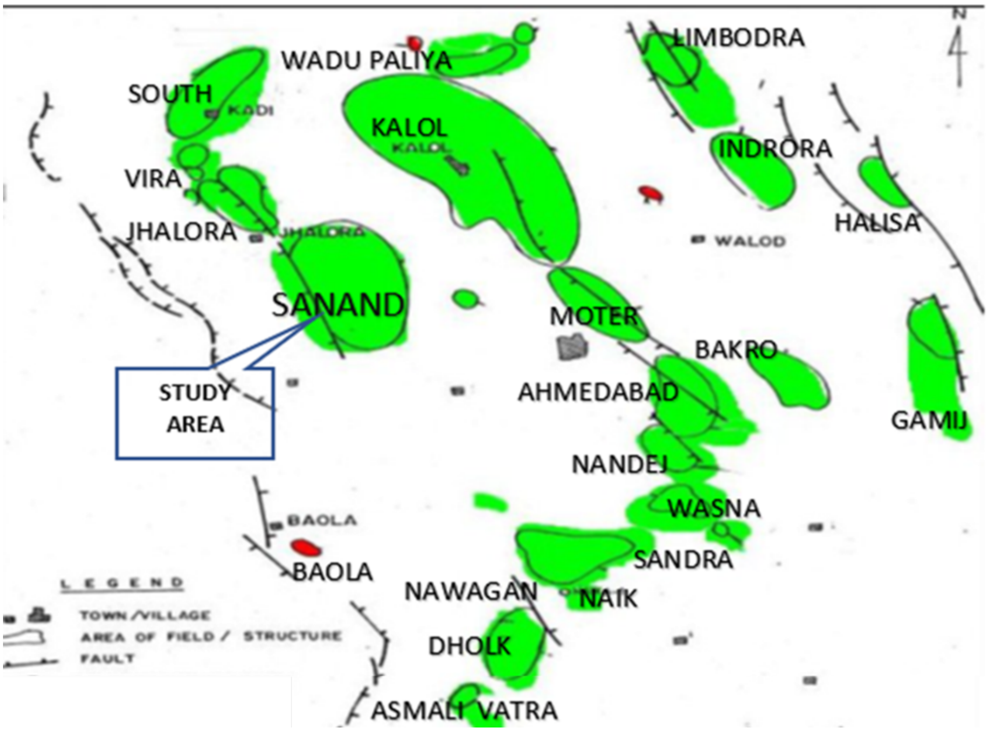

Figure 3 shows the Location map of different oil fields of Ahmedabad block and study area of Sanand field (Chandra, 1965)

Sanand field is located 25 Km of North – West of Ahmedabad (Figure 3). It is characterized by a geological structure of an elongated doubly plunging anticline trending NNW – SSE. It is famous for hydrocarbon reservoir in Kalol, Cambay shale and Olpad formations. Kalol formation is productive with K – III being the primary producer in the Northern part and K – IV in the South (Saraf, et al., 2008). Sanand field is situated on a prominent anticline which is fold in rock layers where the dips downward on both sides of the structure, creating a potential trap for hydrocarbon. Kalol formation is known for its sandstone, shale, carbonaceous shale and coal lithologies.

Tectonic – Setting

The Sanand field is part of the Mehsana – Ahmedabad tectonic block, specifically on the South Kadi – Jharora – Sanand high trend within the Cambay basin.

Source of Hydrocarbon

The older Cambay shale is considered the primary source rock for the hydrocarbon found in the Sanand field.

Trapping Mechanisms

Hydrocarbon are entrapped within the Kalol formation by structural features (like the anticline) and stratigraphic variations, such as the coal seems acting as seals for migrating hydrocarbons (Sharma et al., 2019).

We will discuss the log data acquisition of K-III pay zone of well X of Sanand field as well as ELAN processed data of K-III pay zone to find out water saturation, effective porosity, volume of shalyness etc. As the ELAN software is dealt with Archie's equation, Indonesian equation and effective porosity, therefore, those equations are to be discussed as follows.

5. EQUATIONS OF WATER SATURATION OF THE RESERVOIR & DISCUSSION ABOUT EFFECTIVE POROSITY.

$$S_W^n = \frac{aR_w}{\phi^m \times R_t} \qquad (1)$$

Where, S_w = Water saturation, n = Saturation index, a = Archie's constant, R_w = Resistivity of formation water ϕ = Porosity, m = Cementation factor, R_t = Resistivity of formation

The above equation is Archie's water saturation equation in clean formation. Clean formation means volume of shalyness in the reservoir should be less than 5%. In this case equation (1) holds good. But if the shalyness is greater than 5%, then Archie's equation is not applicable for finding water saturation of the reservoir. Due to presence of shalyness in the reservoir, the effective porosity of the reservoir is reduced. Effective porosity of the reservoir depends upon how the volume of shale is scattered in the reservoir. The presence of shale in the reservoir is as follows.

1. Laminated shale –it is taking certain volume of the reservoir as shown in figure 4 which reduces the total pore volume of the reservoir as a result effective porosity of the reservoir is reduced as shown in figure 4.
2. Dispersed shale – when the fine grain shale particles are dispersed within the reservoir, it occupies the space of the pore volume due to which pore volume of reservoir is reduced. Therefore, effective porosity of the reservoir is also reduced as shown in figure 4.
3. Structural shale – Here the shale particles are removing the sand grains and occupy the space of matrix grain of sand as shown in the figure 4. This shale particles are not occupying the pore space of the reservoir. Total matrix volume is same as before as a result the porosity of the reservoir is not disturbed and it is the same as before (figure 4).

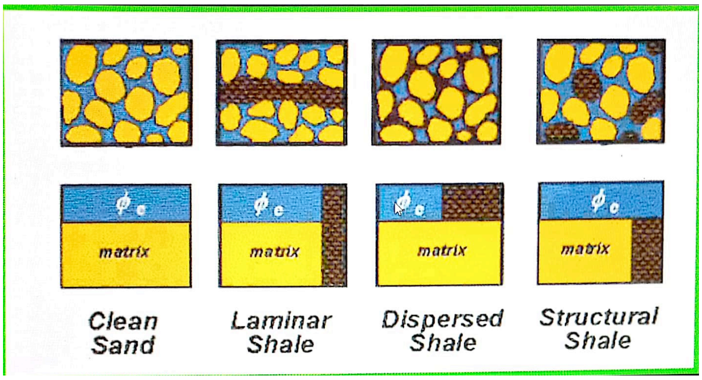

Figure 4 shows the effect of porosity due to presence of different type of shale in the reservoir. (Crain's Petrophysical handbook)

Due to presence of volume of shalyness in the reservoir as discussed above, the formation resistivity (R_t) can be written as follows.

$$\frac{1}{R_t} = \frac{V_{SH}}{R_{SH}} + \frac{1-V_{SH}}{R_{Sand}} \qquad (2)$$

Where, R_{SH} = Resistivity of the shale., R_{Sand} = Resistivity of sand, V_{SH} = Volume of shale

Poupon-Leveaux has given the equation for finding the water saturation in shaly-sand reservoir as follows.

$$S_W^n = \left\{ \left[\left(\frac{V_{SH}^{2-V_{SH}}}{R_{SH}} \right)^{\frac{1}{2}} + \left(\frac{\phi_e^m}{a \times R_w} \right)^{\frac{1}{2}} \right]^2 \times R_t \right\}^{-1} \quad (3)$$

Equation (3) is known as Indonesian Equation as this equation is applied first in shaly-sand reservoir of the oil field of Indonesia and its validity is justified. Later this equation is universally accepted for any oil field of shaly-sand reservoir.

6. DATA ACQUISITION AND ELAN PROCESSED DATA INTERPRETATION OF WELL X, SANAND FIELD, CAMBAY BASIN, INDIA

Triple combo logging tools stack (High Resolution Induction Tool- Compensated Density- Compensated Neutron and Gamma Ray) has been lowered in a **well X** of Sanand field in Ahmedabad, Cambay Basin, India. The log motif is shown in figure 5. The first three track from the left side is the data acquisition and the last three tracks represent the processed data of petrophysical interpretation by ELAN software (Electro Log Analysis).

6.1. Data acquisition of Well X

The first 3 tracks from left side of figure 5 are described as follows.

The first track consists of Gamma ray, Caliper and SP log. The second track is the resistivity curves of high resolution deep (HDRS) and medium (HMRS) induction, DFL (Digital Focus Log) and true Resistivity of formation obtained from 'High Resolution Induction tool'. Third track is showing bulk density (RHOB) and neutron- porosity (NPHI) curves. From the first three tracks, it indicates that the interval from 1390 and below is the shaly formation where GR curve reads an average of 75 API, RHOB and NPHI curves are having huge separation between themselves and resistivity curves HDRS & HMRS also read resistivity value in the order of 1 to 2-ohm meter. Therefore, the interval 1390 to 1405 meters is considered to be shale.

K-III (Kalol- III) reservoir of well X of Sanand field

The interval 1384.7 - 1389.5 meters is considered to be K-lll (Kalol III) reservoir. In this interval GR curve reads nearly 30 API, RHOB and NPHI curves in this interval are very close to each other. Resistivity curves HDRS & HMRS within the interval from 1384.7 - 1386.2m are showing very high resistivity of value 23-ohm meter. This interval 1384.7 – 1386.2 m = 1.5m is considered to be oil bearing. The interval from 1386.2 – 1389.5 meters is water bearing as resistivity curves reads the resistivity value of 2-ohm meter only which is of low value of resistivity.

Well X – Sanand Field (Ahmedabad – Mehsana block of Cambay Basin)

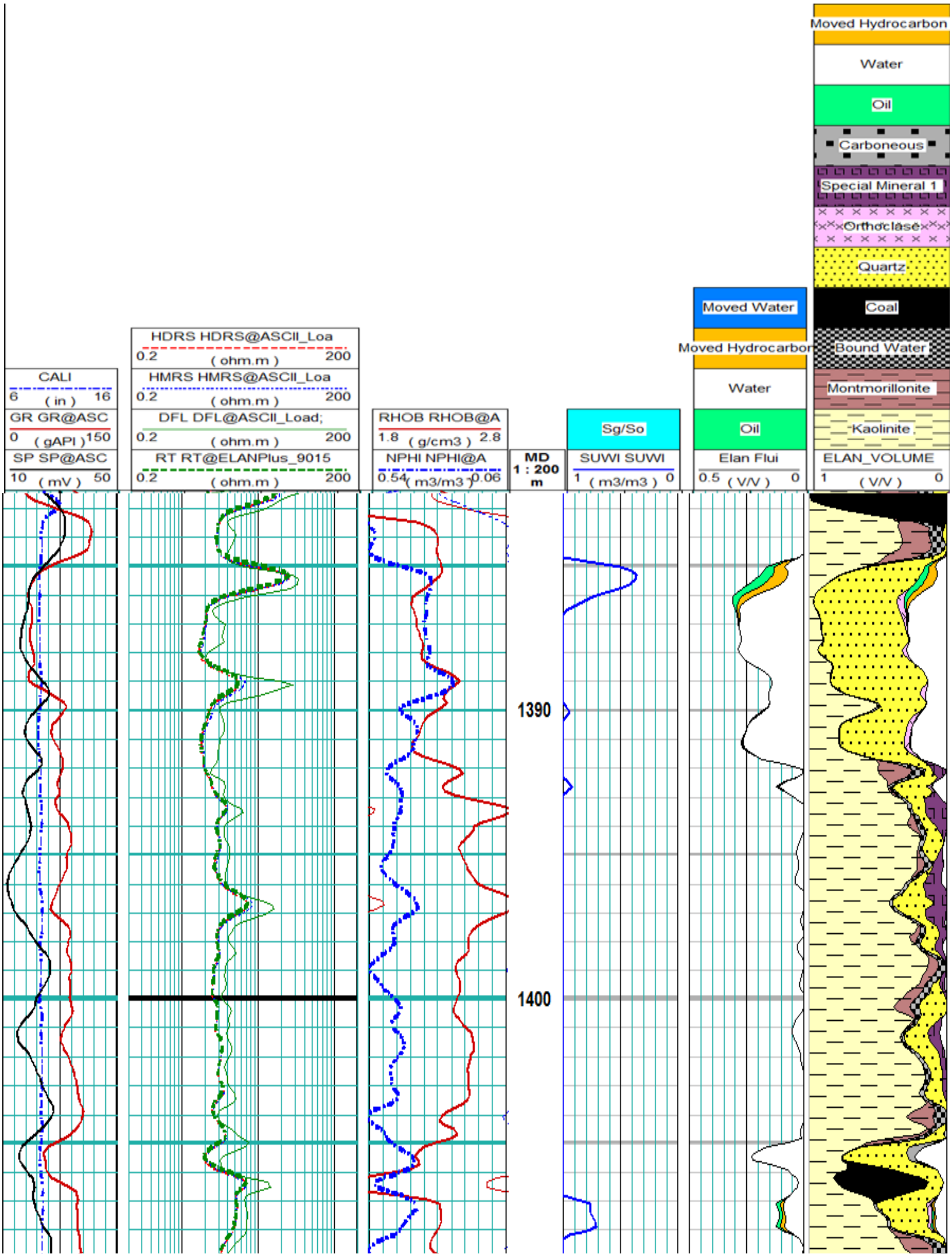

Figure 5 shows the data acquisition (first 3 tracks from the left) and ELAN processed data (last 3 tracks) of Well X, Sanand field. (Courtesy of Oil & Natural Gas Corporation Ltd., India 2013)

6.2. ELAN processed data of Well X

All the above data which are acquired from triple combo logging tools are stored as an input to the ELAN software for processing. The output of the ELAN is processed data as shown in figure 5 from fourth track to sixth track. Fourth to sixth track are ELAN processed data for finding water saturation, presence of minerals and rock types in the interval. Before processing the data, we monitored samples of cuttings data of drilling from which minerals choice is considered to put it as an input for processing. Here we have taken the mineral Kaolinite and Montmorillonite which are present in shale and Quartz minerals in sand obtained from cutting data. We also calculated moved hydrocarbon.

The fourth track is showing water saturation in the interval 1384.7 – 1386.2m is 37%. Therefore, oil saturation in this interval is showing 63% which is economically beneficial within this interval of 1.5m. The fifth track is showing 27% porosity in the interval 1384.7 – 1386.2m. Moved hydrocarbon is also shown in the fifth track.

The last track (6[th] track) is the summary of reservoir which is showing fluid and matrix part as a whole. The matrix part of the reservoir in the interval 1384.7 – 1392m is containing quartz (sand) and Kaolinite in shale. The pore volume contains fluids of water and oil.

As oil saturation is 63% in the interval 1384.7- 1386.2=1.5 m, the interval was considered to perforate for oil production. Production of oil of 50 Cubic meter per day was established from K-III formation, Sandstone reservoir of single porosity system.

7. CASE HISTORY OF FORMATION EVALUATION OF ONE WELL OF INDONESIA.

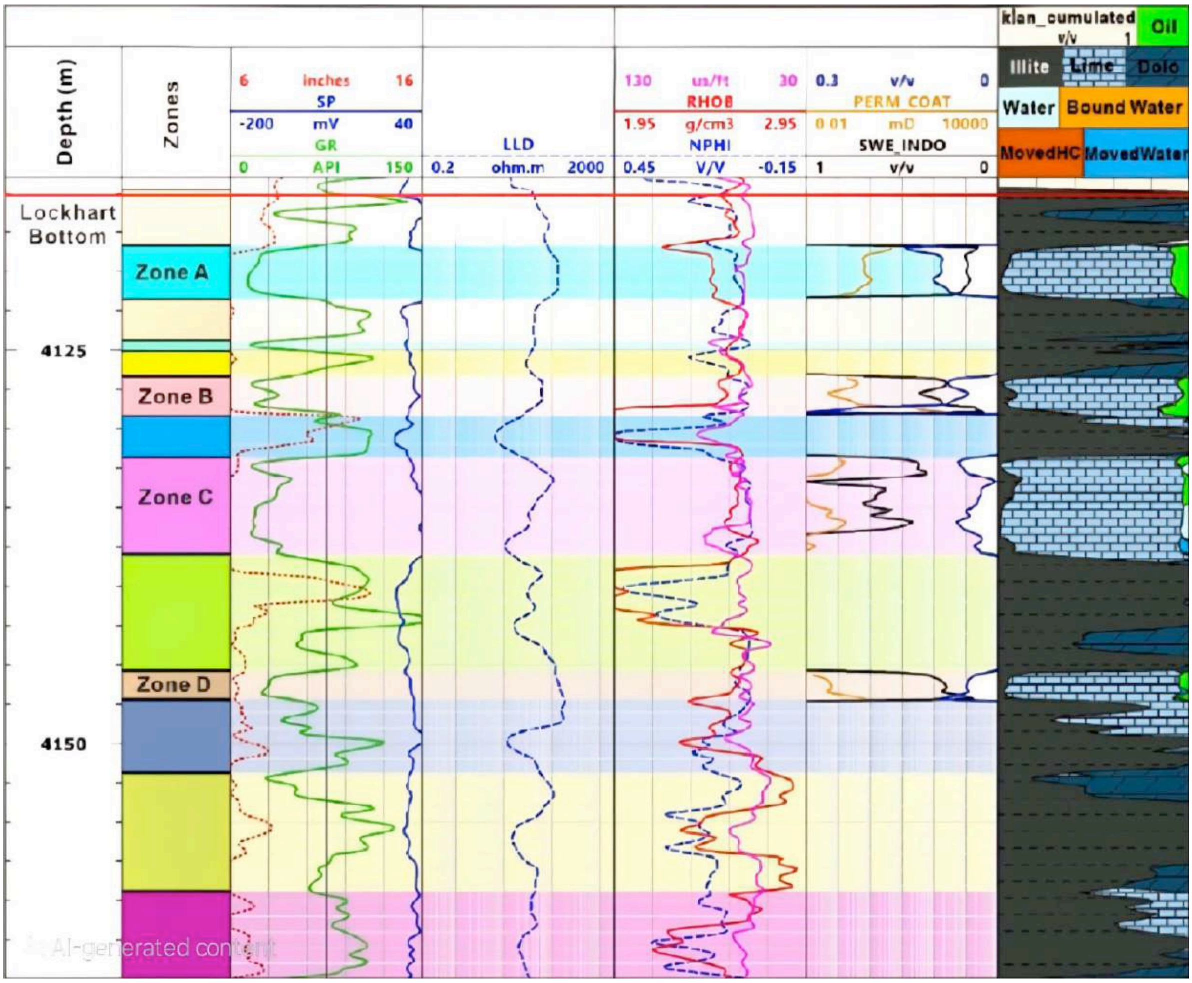

Figure 6 is the log data and ELAN processed data of one well of Indonesia. (by courtesy of Chevron Pacific Indonesia)

Figure 6 consists of 7 tracks out of which first 5 tracks from left are data acquisition tracks and last 2 tracks sixth and seventh are ELAN processed data. The first track is depth track, second track is zoning track, third track consist of Gamma ray, SP and calliper curves, fourth consists of LLD curve, fifth track consists of density and neutron porosity curves. Sixth track consists of effective porosity and water saturation curves and seventh track consists of matrix volume and fluid volume.

The figure 6 above is the log data and ELAN processed data within the depth interval 4120 – 4165m. There are four (4) zones, such as Zone A, Zone B, Zone C and Zone D. These four zones are limestone reservoir and is discussed about petrophysical analysis as follows.

Zone A

Zone A as shown in the figure 6 is a limestone reservoir.

Log data acquisition of Zone A:

$GR_{average}$ = average gamma ray = 15 API, SP = Spontaneous Potential is positive because of synthetic mud is used to avoid stuck up of logging tools.

LLD (Deep Latero Resistivity) > 100 Ω m, Φ_N = Neutron Porosity = 24%, Φ_D = Density Porosity = 30% , DT = Sonic Transit time = 62µs/ft

ELAN processed data of Zone A: (Indonesian equation for water saturation is used)

Φ_e = effective porosity = 10%, **S_w = water saturation = 16.66%, S_o = oil saturation = 83.33%**

K = coats permeability = 1md

Zone B

Zone B as shown in figure 6 is another limestone reservoir.

Log data acquisition of Zone B:

$GR_{average}$ = average gamma ray = 15 API, SP = Spontaneous Potential is Positive because of synthetic mud is used to avoid stuck up of logging tools.

LLD (Deep Latero Resistivity) = 80 Ω m, Φ_N = Neutron Porosity = 18%, Φ_D = Density Porosity = 24%, DT = Sonic Transit time = 62µs/ft

ELAN processed data of Zone B:

Φ_e = effective porosity = 7.5%, **S_w = water saturation = 33.3%, S_o = oil saturation = 66.7%**

K = coats permeability = 0.1md

Zone C

Zone C as shown in figure 6 is also a limestone reservoir.

Log data acquisition of Zone C:

$GR_{average}$ = average gamma ray = 20 API, SP = Spontaneous Potential is Positive because of synthetic mud is used to avoid stuck up of logging tools.

LLD (Deep Latero Resistivity) = 100 Ω m, Φ_N = Neutron Porosity = 18%, Φ_D = Density Porosity = 20%, DT = Sonic Transit time = 60µs/ft

ELAN processed data of Zone C:

Φ_e = effective porosity = 5%, Zone C top **S_w = water saturation = 41.66%,** Zone C bottom **S_w = water saturation = 66.66%**, Zone C top **S_o = oil saturation = 58.34%,** Zone C bottom **S_o = oil saturation = 33.34%,**

K = coats permeability = 0.1md

Zone D

Zone D as shown in figure 6 is also a limestone reservoir.

Log data acquisition of Zone D:

$GR_{average}$ = average gamma ray = 30 API, SP = Spontaneous Potential is Positive because of synthetic mud is used to avoid stuck up of logging tools.

LLD (Deep Latero Resistivity) > 100 Ω m, Φ_N = Neutron Porosity = 18%, Φ_D = Density Porosity = 20% , DT = Sonic Transit time = 60μs/ft

ELAN processed data of Zone D:

Φ_e = effective porosity = 5%, S_w = water saturation = 33.33%, S_o = oil saturation = 66.66%

K = coats permeability = 0.1md

From the above discussion of log data and ELAN processed data of one well of Indonesia, the effective porosity in four limestone reservoirs is of the order of 5 – 10 % only. Coats permeability is in the order of 0.1 – 1md considering very poor permeability. Density, neutron and sonic is giving the porosity which is primary porosity of limestone. The conventional tool in general cannot identify the secondary porosity of the reservoir. From the core data of the four zones it is observed in the core laboratory that the secondary porosity in limestone is of the order of 3% and total permeability is of the order of 450 md (core data not provided).

Primary porosities in these four-limestone zones are having less contribution of fluid flow from the reservoir. Most of the contribution of the oil flow is due to secondary porosity (3% porosity) which is having very high order of permeability of 450 md approximately. One zone data of zone C is contributing 2000 barrels/day. The above four limestone reservoir are having multi porosity system combination of primary and secondary porosity. The secondary porosity includes moldic, channel, fracture and vuggs as shown in figure 7.

These secondary porosities in limestone are responsible for increasing permeability to nearly 450 md in limestone reservoir as a result flow rate of crude oil of the limestone reservoir increased to many thousand barrels per day.

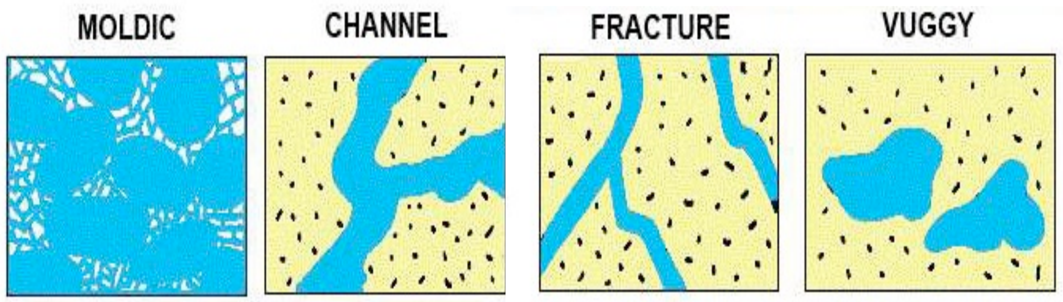

Figure 7 showing the secondary porosity in carbonate reservoir. (Crain's Petrophysical handbook)

8. DISCUSSION & CONCLUSION

1. K -III (Kalol formation) of Sanand field is sandstone reservoir which is single porosity system of primary porosity only. Primary porosity in the reservoir is also called the depositional porosity as it is formed at the time of deposition of the rocks. Grain sorting and packing of granules are responsible for primary porosity. Sandstone is the best example of single porosity system (primary porosity).

2. Multi porosity system is a combination of primary porosity and secondary porosity. Carbonate (limestone & dolomite) is the best example of multi porosity system. Secondary porosity is due to dissolution, dolomitization and fracturing.

3. Secondary porosity in carbonate is of the order of 2-5% only. But permeability in the carbonate reservoir is very high order due to the presence of secondary porosity. Most of the carbonate rock of different geological basins show many thousand barrels of production of hydrocarbon per day is due to secondary porosity and high permeability.

4. Well X of Sanand field is having sandstone reservoir which is single porosity system of primary porosity only. The effective porosity of this sandstone reservoir is 27%. No presence of secondary porosity in sandstone reservoir. Production rate per day from this reservoir is the order of 50 cubic meter or 315

barrels per day. Porosity is higher order but still now the production per day is less than 1000 BOPD. The production rate is less due to less permeability of the reservoir of the order of 20md (20md data of this reservoir of well X is obtained from build up pressure after shut in the well X by the reservoir engineer).

5. Reservoir zone C in the case history of one Indonesian well is a limestone reservoir having effective primary porosity of 5% only and Coat permeability is 0.1md. This reservoir of zone C is producing crude oil only of the order of 2000 BOPD. How this huge production from this reservoir is possible though the permeability is 0.1md? The answer is given from core data.

6. Core of zone C is collected and tested in core laboratory in details. Core data gives the value of secondary porosity is of the order of 3% only and permeability is of the order of 450md. This high permeability of the limestone of zone C is due to presence of 3% secondary porosity. Due to presence of secondary porosity and high permeability, the production rate of zone C has been reached up to 2000 BOPD.

7. From the above discussion, it may be concluded that multi porosity system of limestone reservoir is responsible to increase the high permeability of the carbonate reservoir although the secondary porosity is very less. This high permeability increases the productivity of the reservoir.

ACKNOWLEDGEMENT

We express our sincere gratitude to 'Oil & Natural Gas Corporation Limited, India' to permit both the authors to use the log data as a result an attempt is being taken to publish the paper.

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