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# RESEARCH ARTICLE

# HYDROCARBON RESERVOIR CHARACTERIZATION USING WELL LOG IN HALEWAH OILFIELD, MARIB-SHABWA BASIN, YEMEN

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## ABSTRACT

The purpose of this study was to decipher some petro physical properties of studied wells in Halewah Oilfield, block-5, Marib-Shabwa basin, Yemen. Reservoir characterization of hydrocarbon reservoirs using well logs have been carried out in order to evaluate the field's hydrocarbon prospectivity, delineate hydrocarbon and water bearing zones and petro physical properties of the Alif reservoir. Alif reservoir is mainly made up of sandstone sediments with bands of shale that contain a substantial amount of proven oil in the Halewah Oilfield. Data from four wells comprising of gamma ray, resistivity, neutron, density logs were used for the study. Gamma ray log was used for lithology differentiation, Resistivity log was used to identify form the response of resistivities of various zones. High resistivity denotes hydrocarbon bearing zone while low resistivity value indicates water bearing zone or shaley zones. The combined density and neutron logwas used for the identification and differentiation of the various fluids (Oli and Water) in the reservoir. Computer-assisted log analyses were used to evaluate the petro physical parameters such as shale volume, total porosity, effective porosity, water saturation, hydrocarbon saturation, flushed zone saturation and reservoir and pay flags. Cross-plots of the petro physical parameters versus depth were illustrated. The results from the study showed that the Alif reservoir is capable of yielding appreciable hydrocarbon. The Upper Jurassic Alif reservoir reflects that the matrix components are mainly quartz and shales. Moreover, the lithological-geologic model reflected that these shales are strongly affecting the porosity and, consequently, the fluid saturation in the Alif reservoir, especially in the lower part of reservoir. The results from the study showed that the maximum Net-Pay is 64.79 m recorded around Halewah-02 well whereas minimum is 3.78 m recorded around Halewah-09 well. The evaluated petrophysical parameter indicated that effective porosity (PHE) ranges between (13-34%), water saturation (SWE)range between (13-31%), hydrocarbon saturation SH range between (69-88%), and permeability (220-12250).The Alif reservoir reveals promising reservoir characteristics especially the upper reservoir unit. The northwestern area should be taken into consideration during future development of the oilfield area.



## INTRODUCTION

The Halewah field (Fig. 1) ispart of Block-5 which is located in Marib-Shabwa Basin, Yemen. This paper is deal with some petrophysical properties which is synergistic process of integrating multiple disciplines to characterize rock, pore and fluid systems through examining the physical and chemical properties that describe the occurrence and behavior of rocks and fluids. In exploration and development of hydrocarbon resources, a good understanding of basic reservoir parameters are essential for the analysis of any well log datasets for reservoir modeling and characterization. The properties of interest are the porosity, saturation, chemistry and mobility.

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These are in pursuit of the questions:

Is there any place in the rocks for fluids to exist? (Porosity).
How much of the fraction of pore volume is occupied by fluid? (Saturation).
What kind of fluids are there? (Chemistry).
Can the fluids be moved? (Mobility).

Porosity, the ultimate storage capacity of any reservoir, is defined as the percent of the space not occupied by the rock matrix. Porosity that built into the rock matrix during original deposition and includes its reduction by subsequent cementation and compaction is denoted primary porosity. Primary porosity is the main porosity types in classic reservoir sequence that composed mainly of sand/shale sequence. Permeability, the second reservoir parameter, defined as the degree to which pore system can conduct fluids. Reservoir permeability is a directional rock property. Cross bedding, ripple marks, cut and fill structures as well as variation in cementation, grain size, sorting and packing contribute to the variation in permeability with a certain depositional unit. Permeability in the direction of elongation of the component grains is considerably greater than in any other direction. In logging hydrocarbon bearing reservoir, many tools are used to make a wide variety of measurements. One uses the injection of an electrical current and the measurement of the voltage response to calculate the electrical resistance, which is multiplied by a geometric factor (determined by the electrode positions in space) to become the material property called electrical resistivity. Electrical resistivity is the property that describes the ability of a material to support the process of charge transport. Archie's Law (Archie, 1942) describes the relationship between electrical resistivity and porosity, fluid saturation, and fluid type in a rock. However, the results obtained from Archie's Law have built in assumptions. These include considerations of the rugosity of the borehole wall, properties of the drilling mud, invasion of the mud into the formation, morphology of the porosity, connectivity of the pores, wettability of the rock, presence or absence of clay minerals, and more. Depending upon the choices made about these assumptions, different interpretations result for porosity, saturation and fluid type. The location of petroleum reserves requires an understanding of the nature of the rocks in which these reserves may occur. Borehole geophysical measurements opposite the investigated unit is a fundamental method of the formation analysis since they measure the physical properties of the rock matrix and pore fluids. Utilizing log-derived measurements of such petrophysical properties makes it practical to determine, lithology, porosity, shale content, water saturation and hydrocarbon saturation and types, when oil and/or gas are present and to estimate permeability, to predict water cut, calculate residual oil saturation and detect over-pressured zones.

**Geological Setting**

The geological evolution of Yemen was mainly effected two major events, the plate motions that broke up Pangea apart in the Mesozoic and formation the Gulf of Aden and Red Sea, in the Cenozoic. The regional geology and stratigraphy of Yemen was established by several authors (Beydoun, 1964), (Powers *et al.,* 1966), (Beydoun and Greenwood (1968), (Hughes-Clarke 1988), (Beydoun, 1989), (Haitham and Nani, 1990), (Paul, 1990), (Hughes and Beydoun, 1992), (Bott *et al.,* 1992), (Schlumberger 1992), and (Beydoun *et al.,* 1993). The stratigraphic section in the Marib-Shabwa Basin is dominated by a thick Mesozoic succession and ranges in age from Jurassic to Cretaceous and can be elaborated in (Fig. 2). Hydrocarbon exploration activity became extensive after 1990 and provided considerable amount of subsurface data, which allowed revised synthesis of basin evolution in Yemen, such as the work done by (Redfern and Jones, 1995), (Ellis *et al.,* 1996) and (Beydoun *et al.,* 1996). The petroleum geology was summarized in (Csato *et al.,* 2001). Two major tectonic periods occurred that formed the tectonic evolution of Yemen. The first events took place in the Late Jurassic – Early Cretaceous, when three basins developed within Gondwana land: the Marib-Shabwa, the Sir-Sayun, and the Jeza-Qamar basin. The second major tectonic activity in the Cenozoic was related to the opening of the Gulf of Aden and the Red Sea and the collision of the Arabian Peninsula with Eurasia, respectively. The Mesozoic rifting and sedimentary basin evolution is well constrained e.g., (Redfern and Jones, 1995); (Beydoun *et al.,* 1996), while the complex, polyphase tectonics in the Tertiary (Ellis *et al.,* 1996) is much less understood. At the end of the syn-rift phase, the Marib-Shabwa basin became isolated from the sea maintaining a periodically opened marine passage, which supplied saline water into the basin. The geographic separation and the warm climate gave rise to massive evaporation which serve as seal rocks.

## MATERIALS AND METHODS

Four suits of composite wells logs Halewah-02, Halewah-04, Halewah-06 and Halewah-09 respectively, obtained from Petroleum Exploration and Production Authority of Yemen (PEPA) was used for this study. The well logsconsist of Gamma ray, resistivity, and neutron and density logs. These logs are used to evaluate and analyze the petrophysical properties such as hydrocarbon saturation(Sh), porosity(Φ), permeability(K), water saturation(Sw), waterresistivity(RW), etc. The evaluation of these properties will be directed to the Alif member which consider the main reservoir rocks in the study area.

**Lithology Identification**

The evaluation of the petrophysical properties commence with identifying the economic zones (i.e clean sand with sizable quantity of hydrocarbons and/ or gas). The lithologies (sandstone and shale) were identified using the gamma ray log with reference to sand/shale baseline. The percentage sand/shale is computed from the gamma ray log using the equation below. The % (shale/sand) is computed from the gamma ray log as:

$$I_{Sh} = \frac{Gr - Gr_{Clean}}{Gr_{Clay} - Gr_{Clean}} \quad \text{..................................} (1)$$

Where,

%shale = Percentage volume of shale in the formation
Gr =Gamma Ray Log Reading
$Gr_{Clean}$ = Gamma Ray Log Reading in clean Sand Zone.
$Gr_{clay}$ =Gamma Ray Log Reading in Shale Zone.

From the above equation,

%sand =100% - %shale

**Shale volume determination methods**

The volume of shale can be calculated using single clay volume indicators, e.g. gamma ray, Spontaneous Potential, Neutron or resistivity logs:

**Gamma-ray method**

Gamma-ray log is one of the best tools used for identifying and determining the shale volume (Schlumberger, 1972). This is principally due to its sensitive response for the radioactive materials normally concentrated in the shaly rocks. The following equation is used to determine the Gamma-ray index (Schlumberger, 1972):

$$I_{Sh} = \frac{Gr - Gr_{Clean}}{Gr_{Clay} - Gr_{Clean}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

(2)

Where,

%shale = Percentage volume of shale in the formation
Gr = Gamma Ray Log Reading
$Gr_{Clean}$ = Gamma Ray Log Reading in clean Sand Zone.
$Gr_{clay}$ =Gamma Ray Log Reading in Shale Zone.

From the above equation,

%sand =100% - %shale

Then, the shale volume can be calculated from the Gamma-ray index, by the followingformulae (Dresser Atlas, 1979):

**a -** Older rocks (Paleozoic and Mesozoic), consolidated:

$$Vsh = 0.33\ [2(2 \times IGR) - 1.0] \quad \ldots\ldots\ldots\ldots\ldots (3)$$

**b -** Younger rocks (Tertiary), unconsolidated:

$$Vsh = 0.083\ [2(3.7 \times IGR) - 1.0 \quad \ldots\ldots\ldots\ldots\ldots (4)$$

Accordingly, the first formula was applied in the present work.The log permits clay volume estimation in the zone of interest. Shale index, ISh, is firstcalculated from eq. (1). The clay volume is related to shale index, $I_{Sh}$. It is customary toassume that, Vcl= ISh. This assumption, however, tends to exaggerate the shale volume.

## Hydrocarbon and Non-hydrocarbon Bearing Zones

The combined density and neutron log was used for the identification and characterization of the various fluids inthe formation, i.e. hydrocarbon from non-hydrocarbon bearing zones, Gas zones are identified from the balloon effect (cross over) of the neutron and density logs. The resistivity log was also used to identify the fluids. In this regards, zones of possible oil accumulation is indicated by the high resistivity values whereas water zones have low resistivity.

## Porosity (Φ%) Determination

Density log is one of the best tools for determining the formation porosity due to the minor influence of argillaceous mailer, if present, in its response. In clean formations or zones, the porosities derived from density log (ΦD) are calculated from the relation (Wyllie, 1958):

$$\phi_D = \left[\frac{\sigma_{ma} - \sigma_b}{\sigma_{ma} - \sigma_{f\rightarrow}}\right] \quad \ldots\ldots\ldots\ldots\ldots (5)$$

Where:

σb is the formation bulk density,
σf is the fluid density (equals 1.1 for salt mud)
σma is the matrix density.

## Permeability Determination (K)

Various models have been proposed over the years relating the permeability of a rock to its porosity, Φ, and irreducible water saturation, %&' (as obtainable from wire line logs. According to (Tixier , 1949).

$$K = \left[\frac{250 \times \emptyset^2}{Swr}\right] \quad \ldots\ldots\ldots\ldots\ldots (6)$$

Where,

Swr =Irreducible water saturation
Φ = Total porosity

The irreducible water saturation Swr (may be derived using the Schlumberger approach. In the zone of Swr thehydrocarbon produced is water free. Swr ( is defined mathematically as

$$Swr = (F/200)^{1/2} \quad \ldots\ldots\ldots\ldots\ldots (7)$$

Where,

F = Formation factor

## Hydrocarbon Saturation (Sh)

Hydrocarbon saturation is calculated depending on the uninvaded zone and flushed zone. In the uninvaded zone, it is referred to as (SWE), whereas in the flushed zone it is referred to as (Sxo). Hydrocarbon saturation can be calculated using the following equation:

$$S_h = 1 - S_w \quad \ldots\ldots\ldots\ldots\ldots (8)$$

The hydrocarbons are normally differentiated into residual (Shr) andmovable (Shm) habits. They are calculated by the following formulae:

$$S_{hr} = 1 - S_{xo} \quad \ldots\ldots\ldots\ldots\ldots (9)$$

$$S_{hm} = S_h - S_{hr} \quad \ldots\ldots\ldots\ldots\ldots (10)$$

## Net/Gross Reservoir Thickness

The gross reservoir thickness (gross), was determined by looking at tops and bases of the reservoir sands across the well. The net thickness which is the thickness of the reservoir was determined by defining basis for non-reservoir and reservoir sands using the gamma ray log. This was carried out by drawing a shale baseline and sand baseline on the gamma ray log. The thicknesses of the shale, within the reservoir sands were obtained and thereafter subtracted from the gross reservoir thickness. Hence, net reservoir thickness was obtained for all the reservoirs in the wells.

## Cross-Plots

In this paper, three types of well log cross-plots between two variables were done and the resulting series of points were used to define the relationships between the variables. The cross-plots include:

increase and dominate the overall interval up to end of reservoir.

**Table 1. Summary of Computed Petrophysical Parameters for the Studied Wells**

| *Well Name* | *Rser. Name* | *Top (m)* | *Bottom (m)* | *Gross (m)* | *Net (m)* | *Perm (mD)* | *PHE (%)* | *VSH (%)* | *SWE (%)* | *SH (%)* |
|---|---|---|---|---|---|---|---|---|---|---|
| *Halewah-02* | *Alif Member* | *1252.15* | *1384.46* | *132.31* | *64.79* | *1553.0* | *34* | *21* | *12* | *88* |
| *Halewah-04* | *Alif Member* | *1274.43* | *1382.35* | *107.92* | *18.58* | *90.650* | *16* | *18* | *12* | *88* |
| *Halewah-06* | *Alif Member* | *1286.13* | *1395.29* | *109.16* | *7.16* | *154.54* | *13* | *25* | *18* | *82* |
| *Halewah-09* | *Alif Member* | *1278.80* | *1401.75* | *122.95* | *3.78* | *875.30* | *13* | *18* | *31* | *69* |

Net: Net pay reservoir, Perm: Permeability, PHE: Effective porosity, VSH: Volume of shale

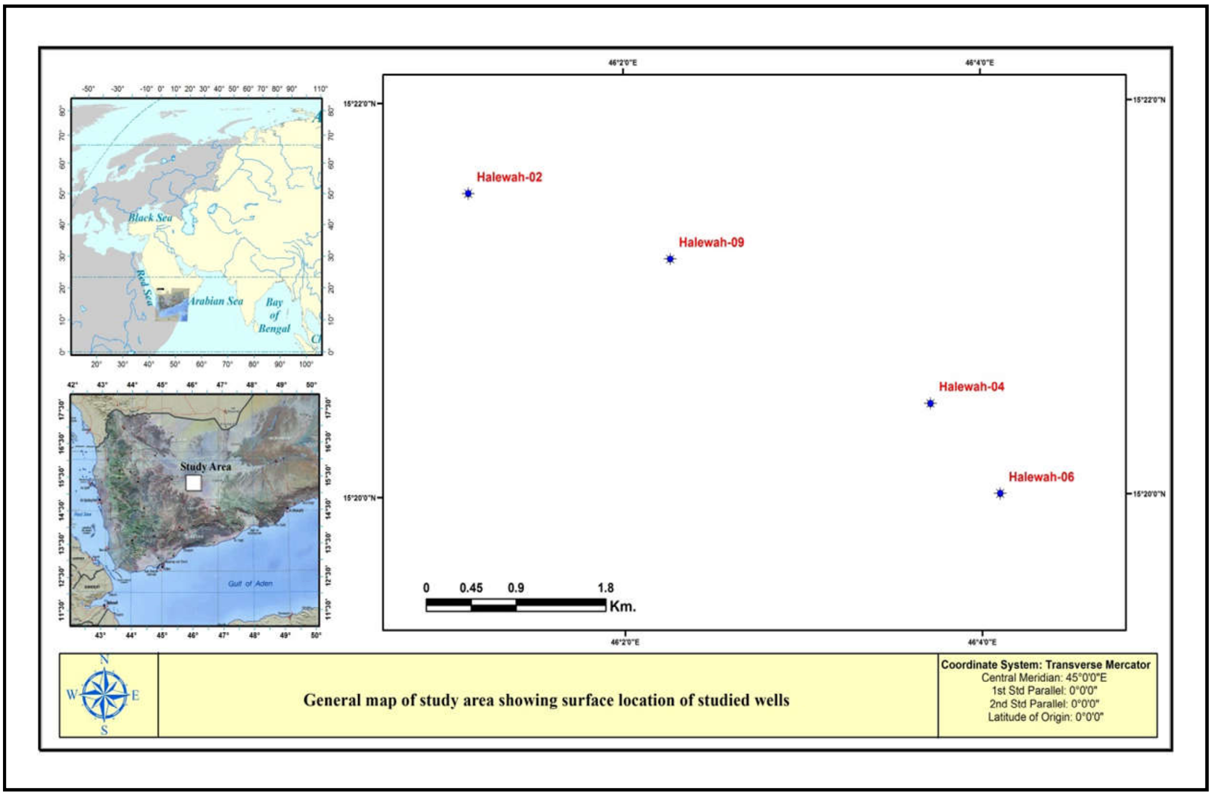


**Figure 1. General Map of Study surface area showing key wills location in Halewah field, Marib-Shabwa Basin**

A- Minerals identification using M-N cross-plot
B- Matrix identification using apparent matrix volumetric vs. apparent matrix grain density cross-plot

## RESULTS AND DISCUSSIONS

### Graphical Representation

### Lihtosaturation Crossplot of Halewah-02 well

The Halewah-02 well is located in the northwestern part of the study area (Fig. 1). In this well, Litho-saturation cross plots (Fig. 3) and data logs display for the studied interval extends from 1252.15m to 1384.46 m. The gross thickness is 132.31 m and net thickness is 64.79 m. Alif member is encountered through the depth range from 1252.12 m to 1384.46 m in the litho-saturation cross plots as shown in (fig. 3). It shows that, the member consist of Sandstone intercalated with shales. The parameters used in this study include volume of shale equals to 21 %, effective porosity equals to 34 % and fluid saturation (water saturation equal to 12 % and hydrocarbon saturation equals to 88 %). Their average values are tabulated in Table (1). Hydrocarbon bearing zones are not in continue interval as observed from lithosaturation log due to fluctuation of shale volume in this reservoir. Below 1349 m shale volume is

### Lihtosaturation Crossplot of Halewah-04 well

The Halewah-04 well is located relatively in the middle part of the study area (Fig. 1). In this well, Litho-saturation crossplots (Fig. 4)and data logs display for the studied interval extends from 1274.43 m to 1382.35 m. The gross thickness is 107.92 m and net thickness is 18.58 m. Alif member is encountered through the depth range from 1274.43 m to 1382.35 m in the litho-saturation crossplots as shown in (fig. 4). It shows that, the member consist of Sandstone intercalated with shales. The parameters used in this study include volume of shale equals to 18 %, effective porosity equals to 16 % and fluid saturation (water saturation equal to 12 % and hydrocarbon saturation equals to 88 %). Their average values are tabulated in Table (1). Oil water contact is encountered in several interval as evident from lith-saturation but below 1338 m water saturation dominated the reservoir until the base of reservoir.

### Lihtosaturation Crossplot of Halewah-06 well

The Halewah-06well is located in the southeastern part of the study area (Fig. 1). In this well, Litho-saturation crossplots (Fig. 5) and data logs display for the studied interval extends from 1286.13 m to 1395.29m. The gross thickness is 109.16 m and net thickness is 7.16 m. Alif member is encountered through the depth range from 1286.13 m to 1395.29 m in the litho-saturation crossplots as shown in (fig. 5).

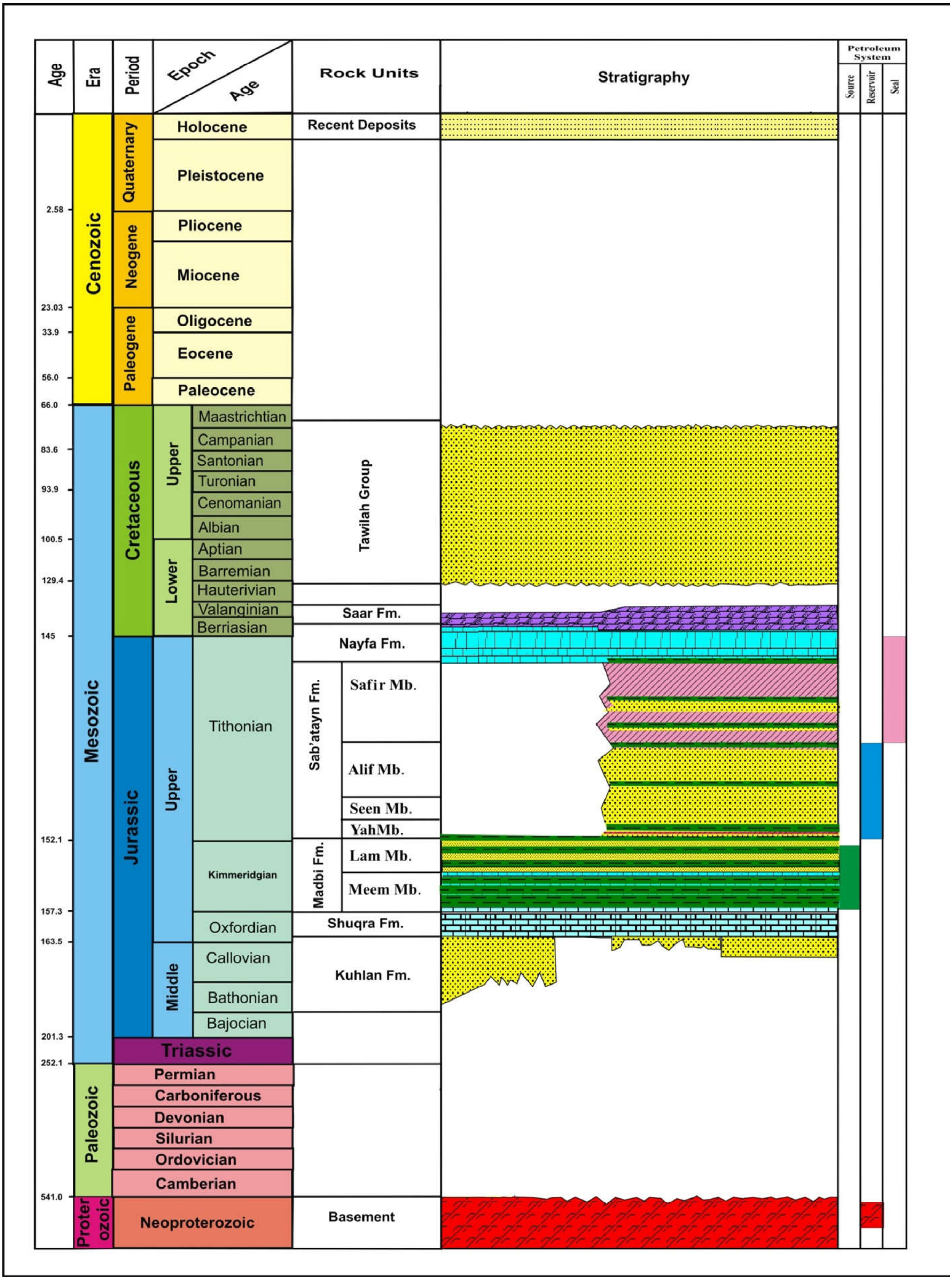


**Figure 2. Simplified Lithostratigraphic and chronostratigraphic chart of the Marib-Shabwa Basin (Including study area) with a summary of the petroleum system elements**

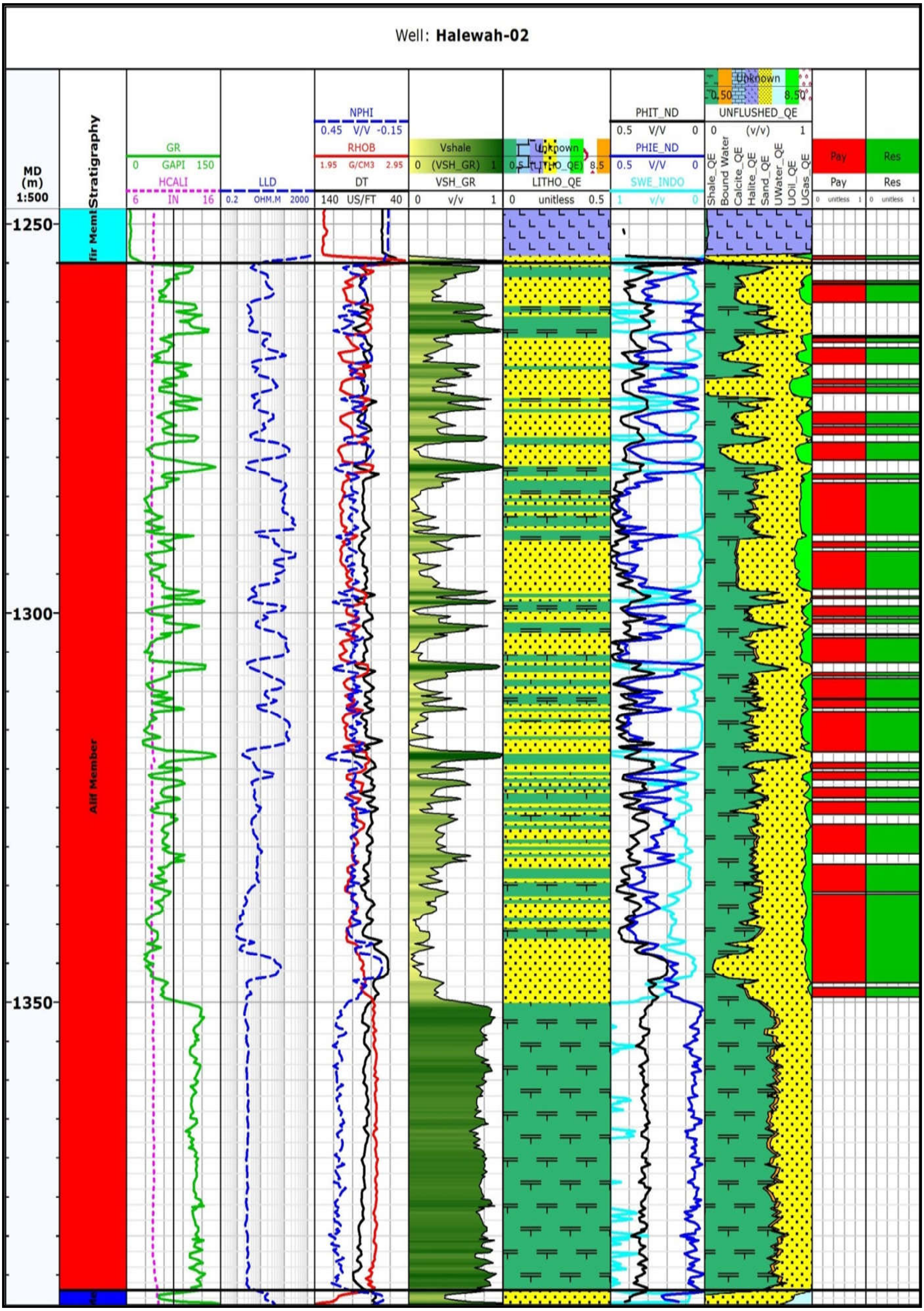


Figure 3. Litho-saturation cross-plot of the Halewah-02 well

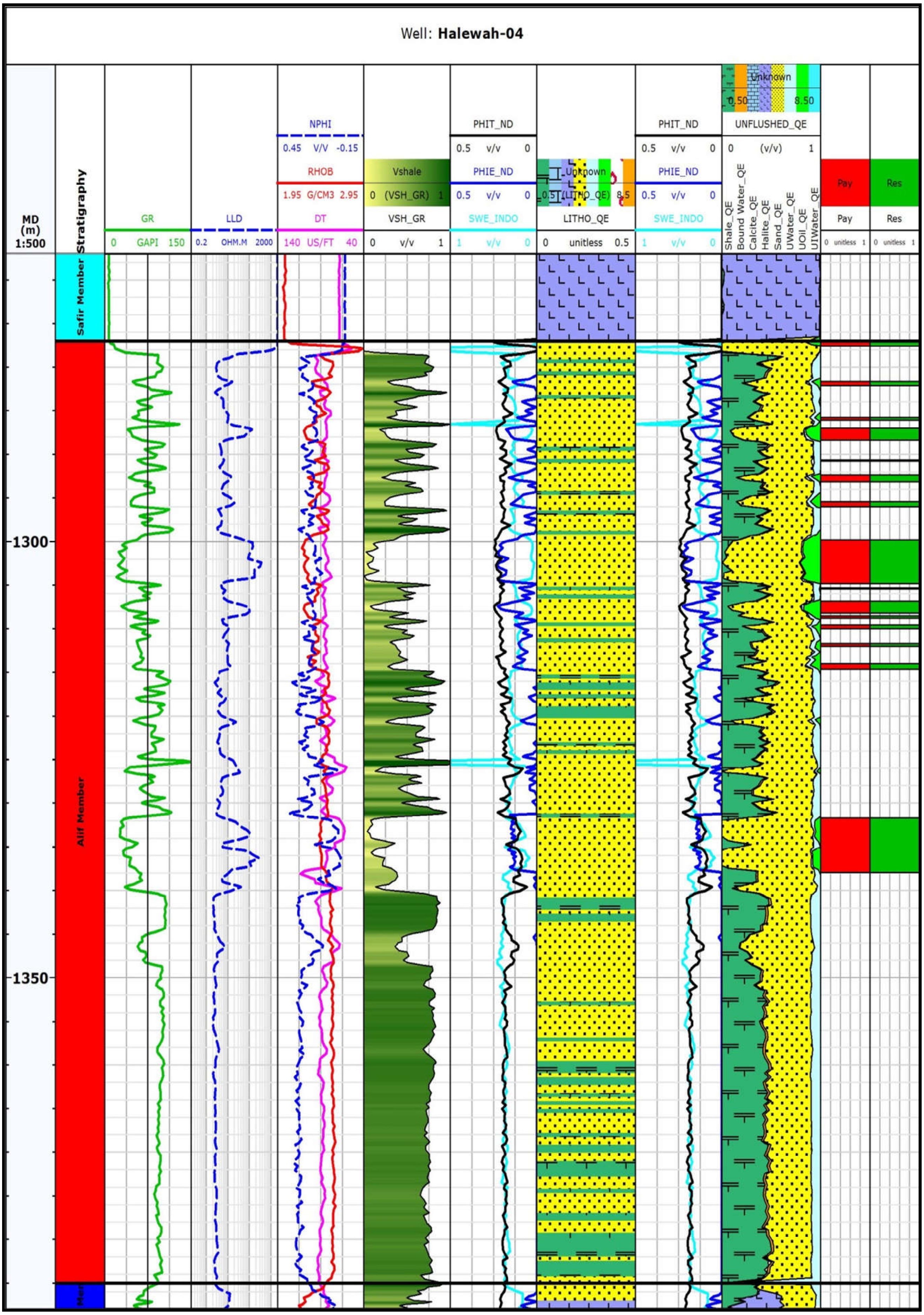


**Figure 4. Lith-satureation cross –plot of the Halewah-04 well**

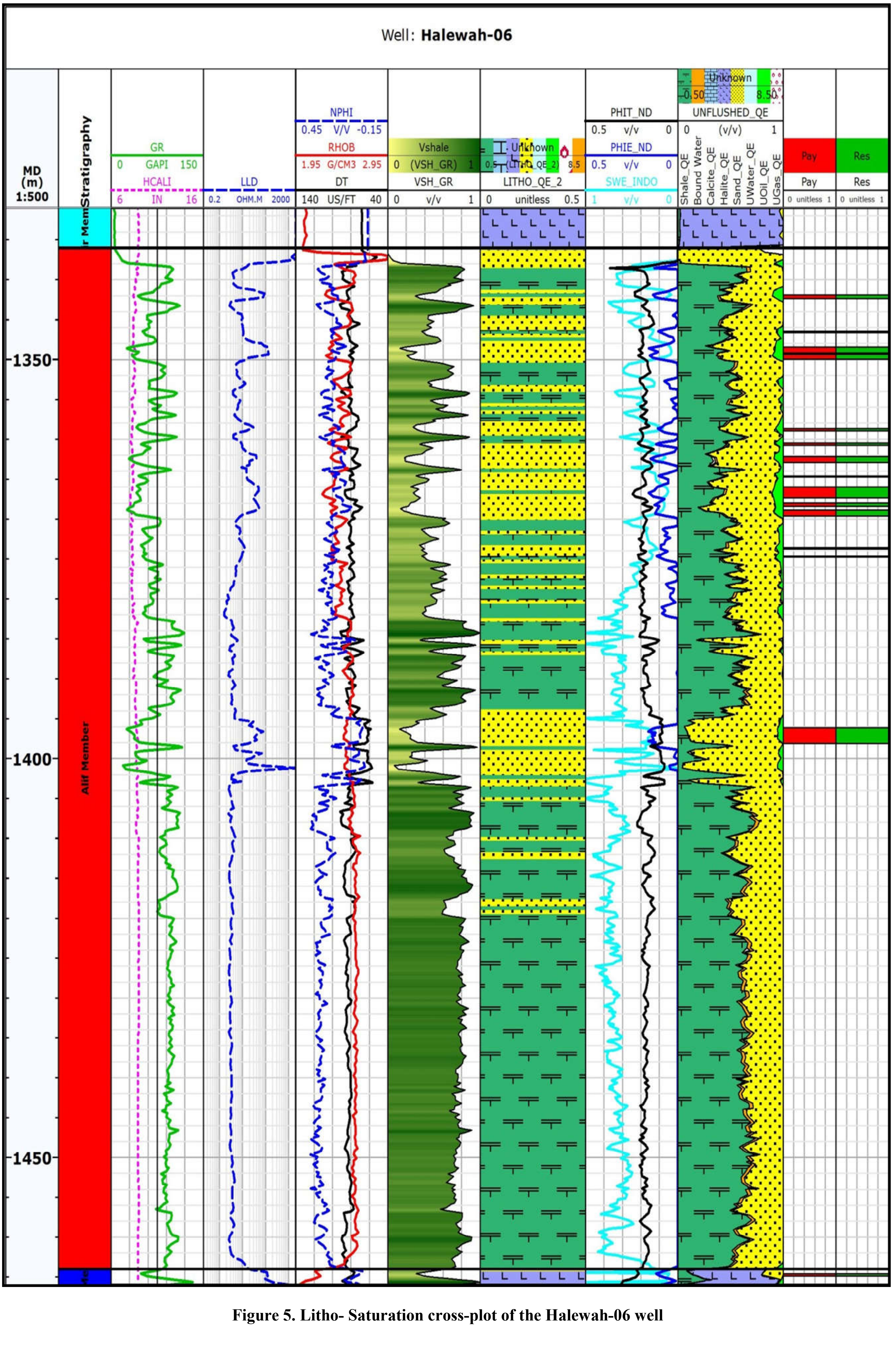


Figure 5. Litho- Saturation cross-plot of the Halewah-06 well

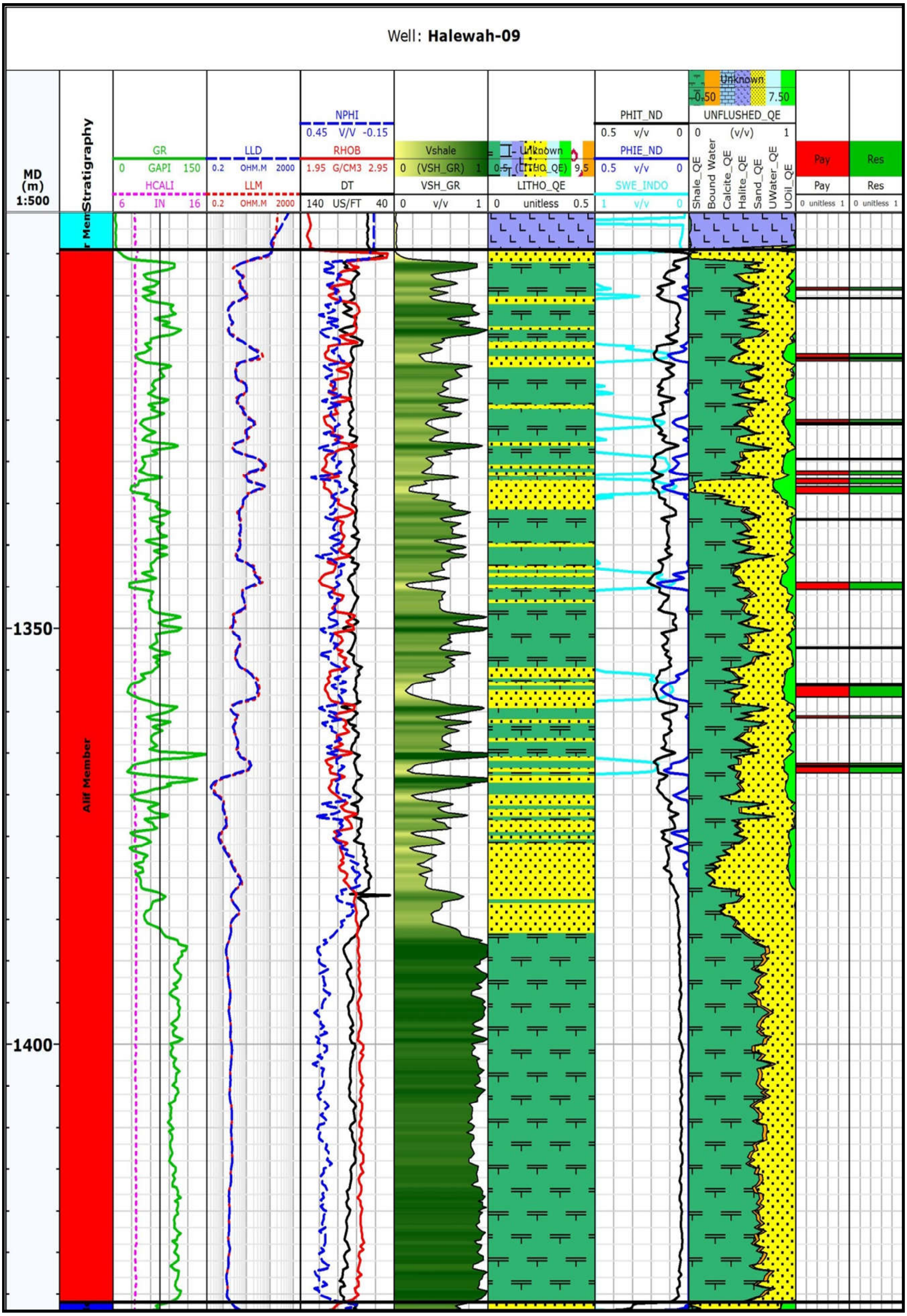


Figure 6. Litho- saturation cross-plot of the Halewah-09 well

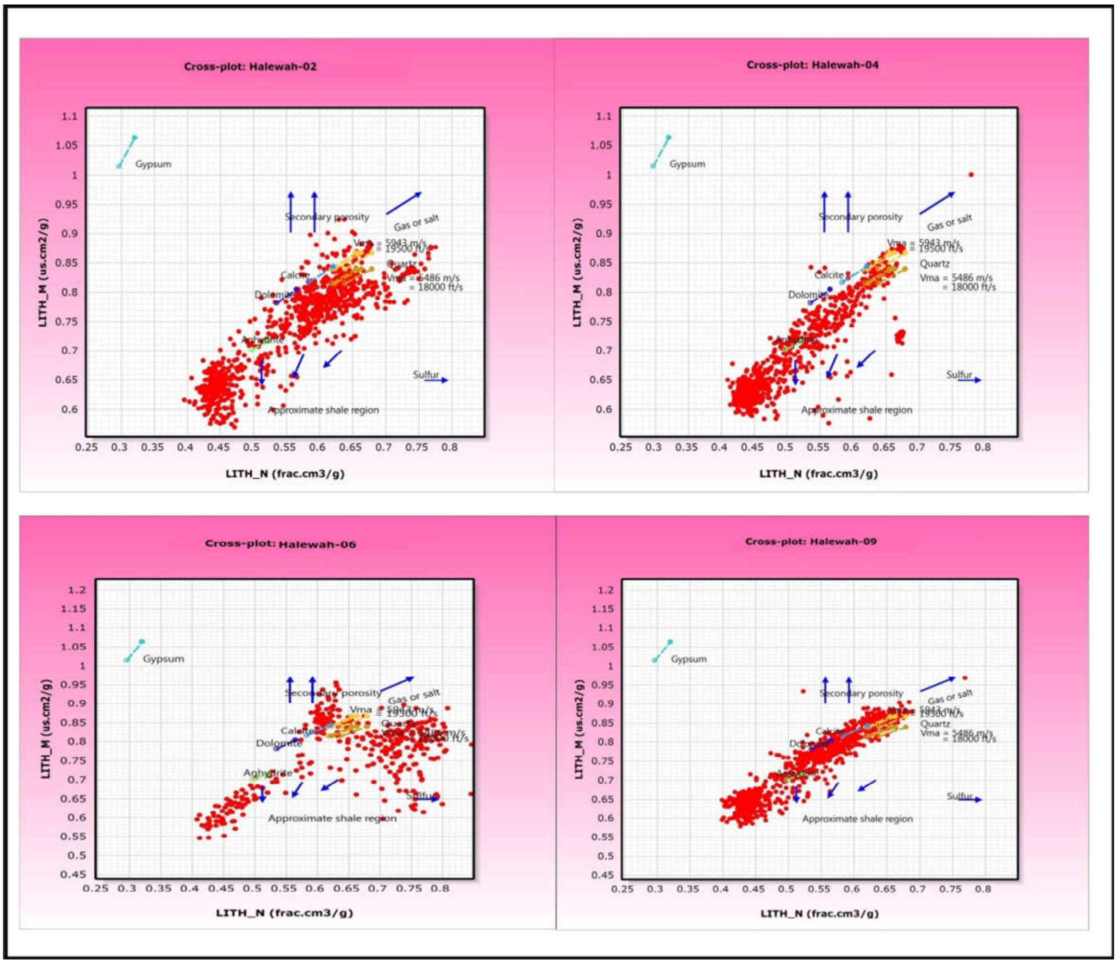


**Figure 7. Cross-plot of M-N for minerals identification for Alif reservoir in Halewah field**

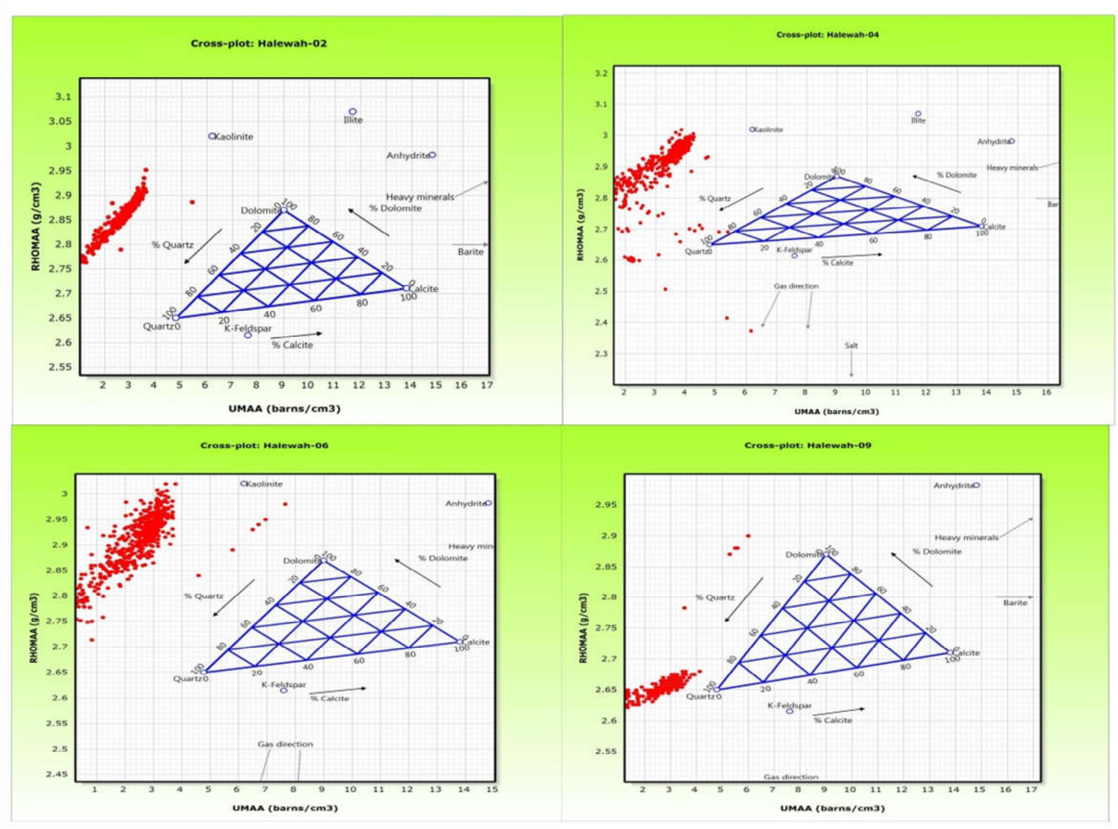


**Figure 8. Cross-plot of Umaa-Rhomaa of matrix identification for Alif reservoir in Halewah Field**

It shows that, the member consist of Sandstone intercalated with shales. The parameters used in this study include volume of shale equals to 25 %, effective porosity equals to 13 % and fluid saturation (water saturation equal to 18 % and hydrocarbon saturation equals to 82 %). Their average values are tabulated in Table (1).

**Lihtosaturation Crossplot of Halewah-09 well**

The Halewah-09 well is located relatively in the middle part of the study area (Fig. 1). In this well, Litho-saturation crossplots(Fig. 6) and data logs display for the studied interval extends from 1278.80 m to 1401.75 m. The gross thickness is 122.95 m and net thickness is 3.78 m. Alif member is encountered through the depth range from 1278.80 m to 1401.75 m in the litho-saturation crossplots as shown in (fig. 6). It shows that, the member consist of Sandstone intercalated with shales. The parameters used in this study include volume of shale equals to 18 %, effective porosity equals to 13 % and fluid saturation (water saturation equal to 31 % and hydrocarbon saturation equals to 69 %). Their average values are tabulated in Table (1). A detailed characterization of the hydrocarbon reservoirs in the Alif member (of interest) for analyzing thepetrophysical properties using the various methods is presented in theTable (1).

**M-N Cross-plots**

The M-N cross-plots of studied wells are constructed to elucidate the minerals type of Alif reservoir in Halewah field. (Fig. 7) shows that the sandstone and shaly sand with lesser carbonate minerals are the dominate constituent in Alif reservoir of Halewah field.

**Matrix identification**

The RHOmatrix-Umatrixcross-plot (fig. 8) shows that the majority of matrix is quartz. Appreciable amount of calcite matrix is presentin Alif reservoir of Halewah field.

**Conclusion**

The characterization of reservoirs by a detailed petrophysical parameter estimation revealed that the dominated of sand bodies as a result of the presence of high values of porosity and permeability as well as high fraction value of Sandstone. Findings from this study show that the Northwestern part is promising area for more prospecting activity because the maximum Pay-Net 64.79 m is recorded around Halewah-02 well. Hydrocarbon saturation falls around (69-88) percent, by comparing between results in Table (1), it is evident the highest values are recorded around Halewah-02 and Halewah-04 wells. We can conclude that the base of this reservoir is barren from hydrocarbon bearing zones.

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