Well Log Analysis for Hydrocarbon Exploration in Istanbul-Silivri Gas Field, Turkey

Aynur Büyükutku[1*], Aylin Geçer[2], Temel Karaarslan[3], Arzu Aktosun[4], Berk Can Büyükutku[5], Deniz Atasoy[6]

[1,3]Department of Geological Engineering, Engineering Faculty, Ankara University, Gölbaşı, Ankara, Turkey
[2]Department of Chemical Engineering, Engineering Faculty, Ankara University, Tandoğan, Ankara, Turkey
[4]Turkish Petroleum Corporation, Research and Development Center Department, Ankara, Turkey
[5]Department of Electrical Electronics Engineering, School of Engineering, Atılım University, Ankara, Turkey
[6]Turkish Petroleum Corporation, Exploration Department, Ankara, Turkey

Abstract:*Well logs are graphs that provide information about the physical and petrophysical properties of rocks present in the underground, especially used by oil companies in hydrocarbon exploration. Petrophysical parameters such as effective porosity and permeability, water saturation and hydrocarbon saturation, and real resistivity of these rocks, which cannot be seen with the eye, can be calculated with well log interpretations. In addition, comments can be made about the type of fluid (oil or gas). In this article, petrophysical properties of Hamitabat Formation sandstones were determined in a well opened in Silivri district of Istanbul province, in the south of the Thrace Basin, using Gamma Ray, Sonic, Resistivity, Neutron, Density logs.The quantitative porosity and permeability values obtained from well log interpretations and water saturation values are good enough for hydrocarbon production.*

Keywords: *Hamitabat Formation, well log, sandstone reservoir, porosity, permeability, water-hydrocarbon saturation*

1. Introduction

Geology and oil potential of the Thrace basin have been examined by various oil companies (Shell Oil Company, Mobil Oil, Esso, American Overseas Oil, and Tennessee Oil, Turkish Petroleum) since the 1930s. The Turkish national oil company (TPAO) made its first gas discovery from the Hamitabat sandstones in the Hamitabat field (7600 billion m^3) in 1970. The Thrace basin forms one of the largest Cenozoic sedimentary basins in Turkey. As such, It is one of the most important hydrocarbon provinces in the country, favourable particularly for natural gas exploration [2-7, 9-10].The Thrace Basin includes Greece, Bulgaria, and the Rhodope massif in the west, the Strandja massif, Bulgaria, and the Black Sea in the north, a part of the Marmara Sea and the Istanbul Paleozoic region in the east, the Marmara Sea, the Dardanelles in the south, and many areas of stratigraphy, tectonics and petroleum geology in the Saros Basin. It is bordered by the Gulf of Inlet and the northern part of the Aegean Sea in the south (Figure 1).

There is an Eocene-Oligocene aged sedimentary sequence reaching 8000-9000 m thick in the Thrace Basin. Hamitabat formation is Middle-Upper Eocene sediments. The Hamitabat Formation, which overlies the unconformity, consists of conglomerate, sandy conglomerate, sandstone and sandstone-shale alternation. It contains little conglomerate with organic matter black shale. Hamitabat sandstones

*Corresponding Author

contain rich channel fillings and present a submarine fan feature. Hydrocarbons are produced from sandstones of channel fillings [6].

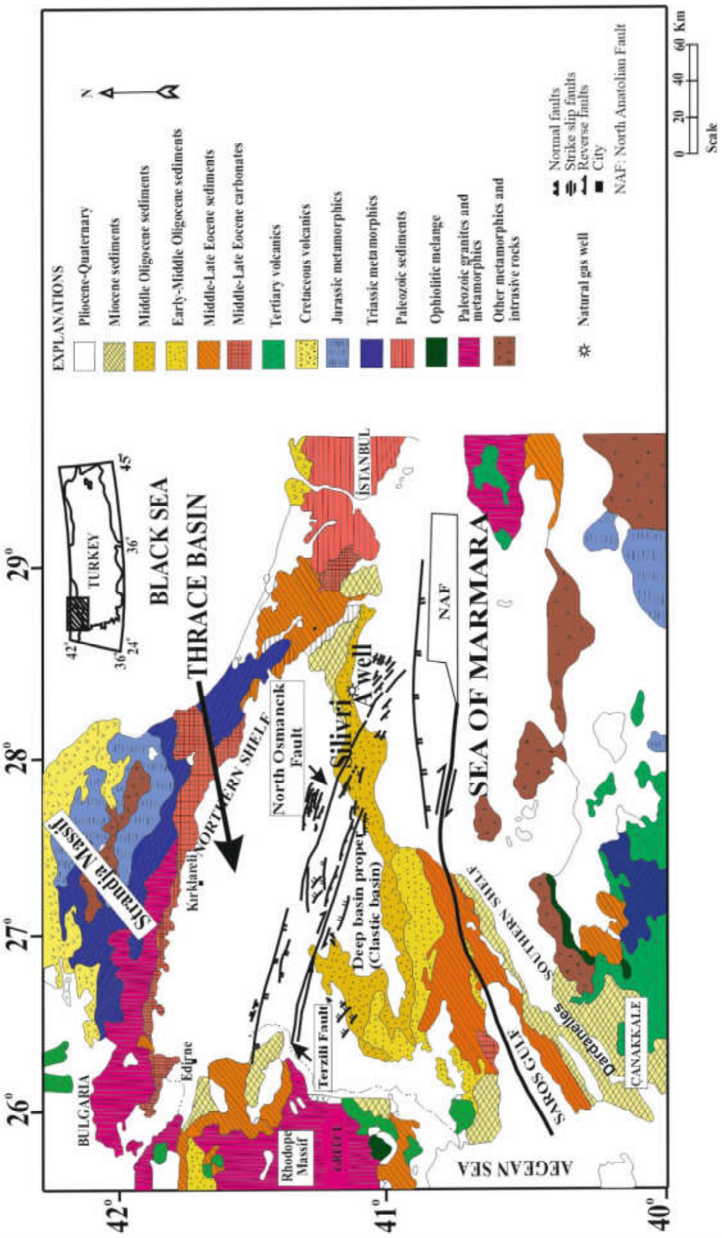

Figure 1. Distribution of Cenozoic units in the Thrace Basin and well A opened around Silivri. The study was carried out in 1 well. Hamitabat formation is Middle-Upper Eocene sediments (Modified from [6])

The best information about the underground can be obtained from well logs taken from drilled wells. Detailed information about the lithological, physical and petrophysical properties (effective porosity, permeability, water saturation and hydrocarbon saturation) of the rocks around the well can be obtained with well log interpretations [13]. Drilling is a very expensive process and well logs must be interpreted meticulously for economical hydrocarbon production.

Gamma Ray, Sonic, Density, Neutron and Resistivity logs were interpreted at depths of 1330-1363 meters in the Hamitabat Formation. The objectives of the proposed study are: 1. To calculate the Effective Porosity and Permeability, Water Saturation, and Hydrocarbon Saturation values. 2. To determine the reservoir quality of the sandstones passed in the drilling well opened around Silivri, Istanbul. 3. To determine the hydrocarbon production potential of the Hamitabat sandstone reservoir.

2. Material and Methods

Well logs were used in this study. Well logs consist of Resistivity, Sonic, Gamma Ray, Neutron and Density logs which are used to determine the petrophysical parameters such as Effective Porosity (PHI/Φ), Permeability (K), Hydrocarbon (S_h) and Water Saturation (S_w) and Reservoir Rock Resistivity (R_t) and Formation Water Resistivity (R_w) and to determine the hydrocarbon content of the basin.

3. Log analyses

3.1. Determination of Clay Amount with Gamma Ray and Effective Porosity Calculation from Sonic Log

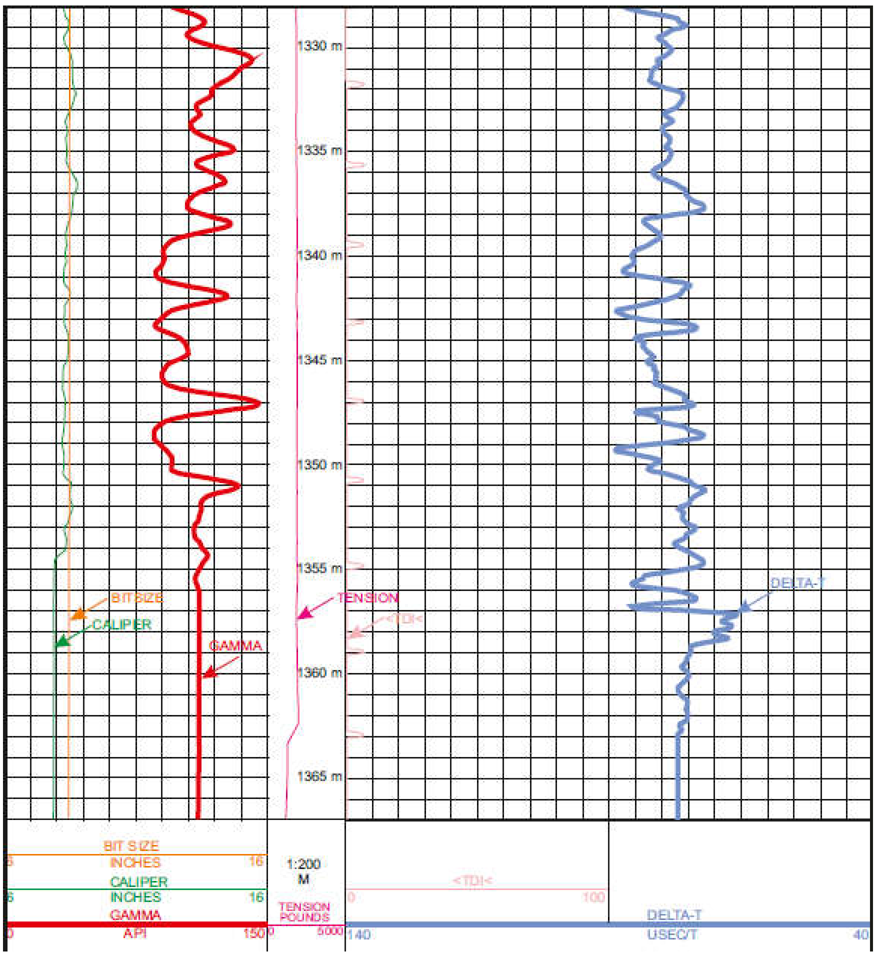

Figure 2. Gamma Ray and Sonic logs (Depth: 1330-1355 m.)

Interval transit time (Delta T) values were read between 1330-1355 meters in the Sonic Log. The average of these values is 89.0 µsec/ft (Figure 2).

The sonic porosity value is found using the appropriate velocity curve for sandstones from the Schlumberger Por-3 graph was calculated as 25.1% on average (Figure 3).

3.1.1. Determination of Clay Amount with Gamma Ray

The average of the GR readings made for the same depths in the Gamma Ray log is 112.5 API. The minimum Gamma Ray value is 88 API and the maximum Gamma Ray value is 148.0 API.

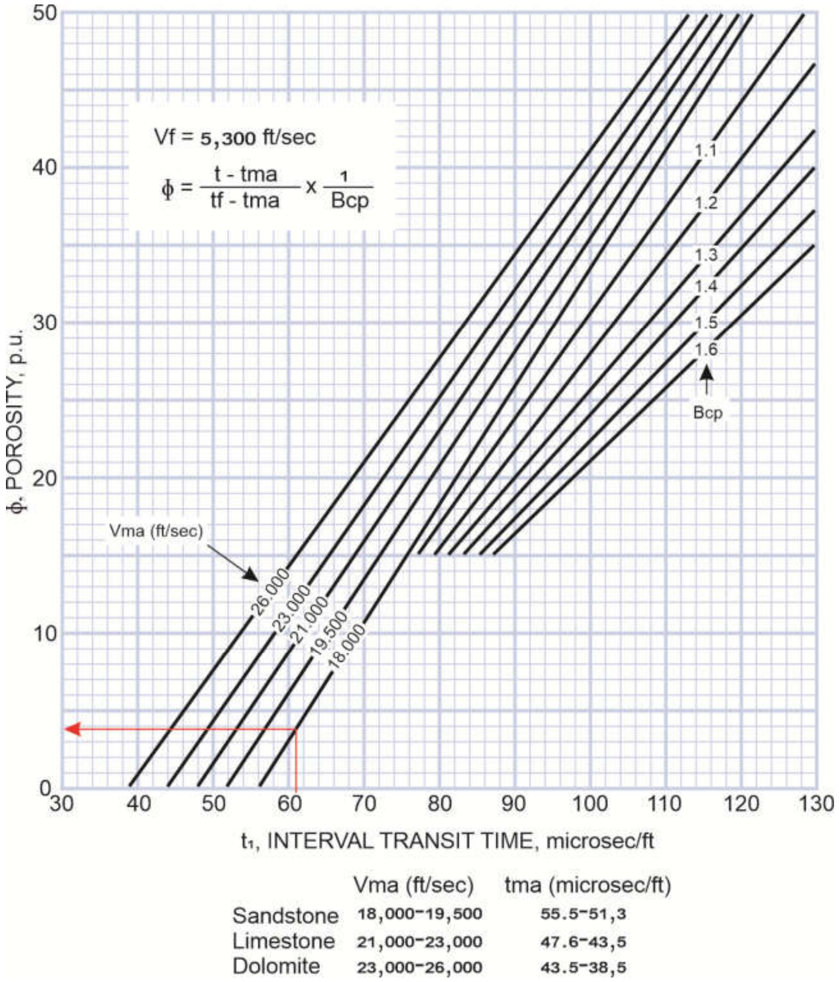

Figure 3. Schlumberger Por-3 graph

The clay percentage of Hamitabat Formation sandstones was calculated with the Gamma Ray Log. The shale volume V_{sh} in the Hamitabat Formation sandstones was estimated using the following equation [13]:

$$V_{sh} = \frac{GR - GR_{min}}{GR_{max} - GR_{min}} \qquad (1)$$

V_{sh}: Clay volume (%)
GR: Gamma Ray values in the range calculated on the log

GR_{max}: Gamma Ray value in clay layers (maximum clay value)
GR_{min}: Gamma Ray value in clean layer (minimum clay value)

The clay amount for Hamitabat Formation sandstones was calculated as 40% using Gamma Ray Log.

3.1.2. Porosity calculation from Sonic log

Porosity logs are affected by the clay minerals in the rock and give higher porosity values. In order to calculate water saturation accurately, these porosities must be corrected according to the clay effect. Using the clay amount calculated from the Gamma Ray log, effective porosity is determined with the following formula;

$$Dt_{cor} = \frac{(DT - V_{sh} * DT_{sh})}{(1 - V_{sh})} \quad (2)$$

Dt_{cor} : Sonic velocity value with clayey correction (corrected porosity)
DT : Sonic velocity value read in the log
V_{sh} : Clay volume (Clay amount)
DT_{sh} : DT value corresponding to the clayey zone (GR_{max})

With these sonic speed values, the corrected porosity values corresponding to the sandstone curve are read from the Schlumberger Por-3 graph and the clayey-corrected porosity value is found (Figure 3). The clayey-corrected porosity value (effective porosity) in the well opened in the study area is 19.1% on average. According to the reservoir rock classification of Rider [8], porosity of Hamitabat Sandstones are in the good class (Table 1).

Table 1. According to the Reservoir Rock Classification of Rider [8]

Percentage Porosity (%)	Qualitative Description
0-5	Negligible
5-10	Poor
11-15	Fair
15-20	Good
20–30	Very good
>30	Excellent
Average Permeability Value (md)	**Qualitative Description**
<10.5	Poor
11-15	Fair
15-50	Moderate
50-250	Good
250-1000	Very good
>1000	Excellent

In the depth-effective porosity graph, it is observed that the highest effective porosity values develop at 1250 meters. As the depth increases, porosity decreases due to subsidence (compaction) and the formation of clay minerals (Figure 4).

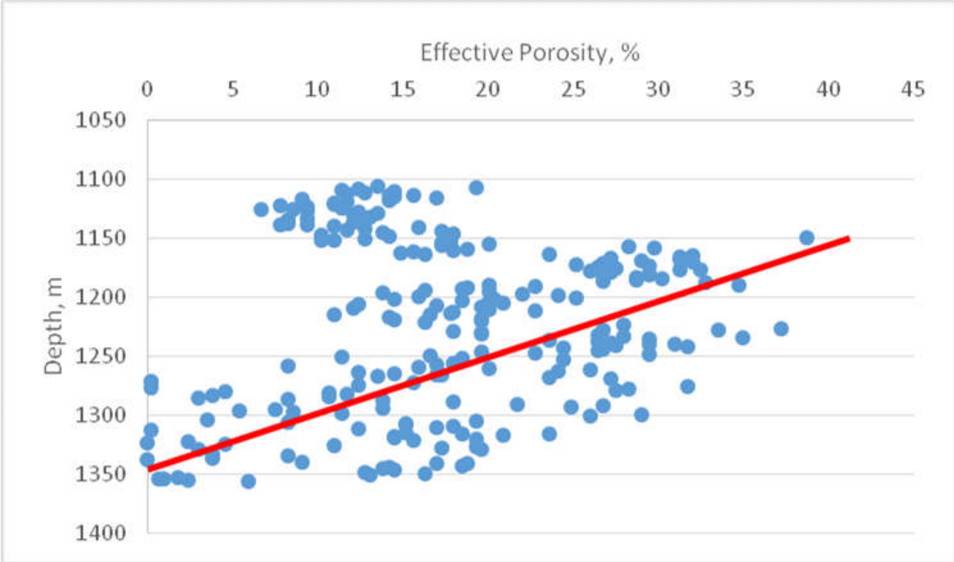

Figure 4. Depth-Effective Porosity Graph

3.2. Determination of Porosity with Neutron-Density Logs

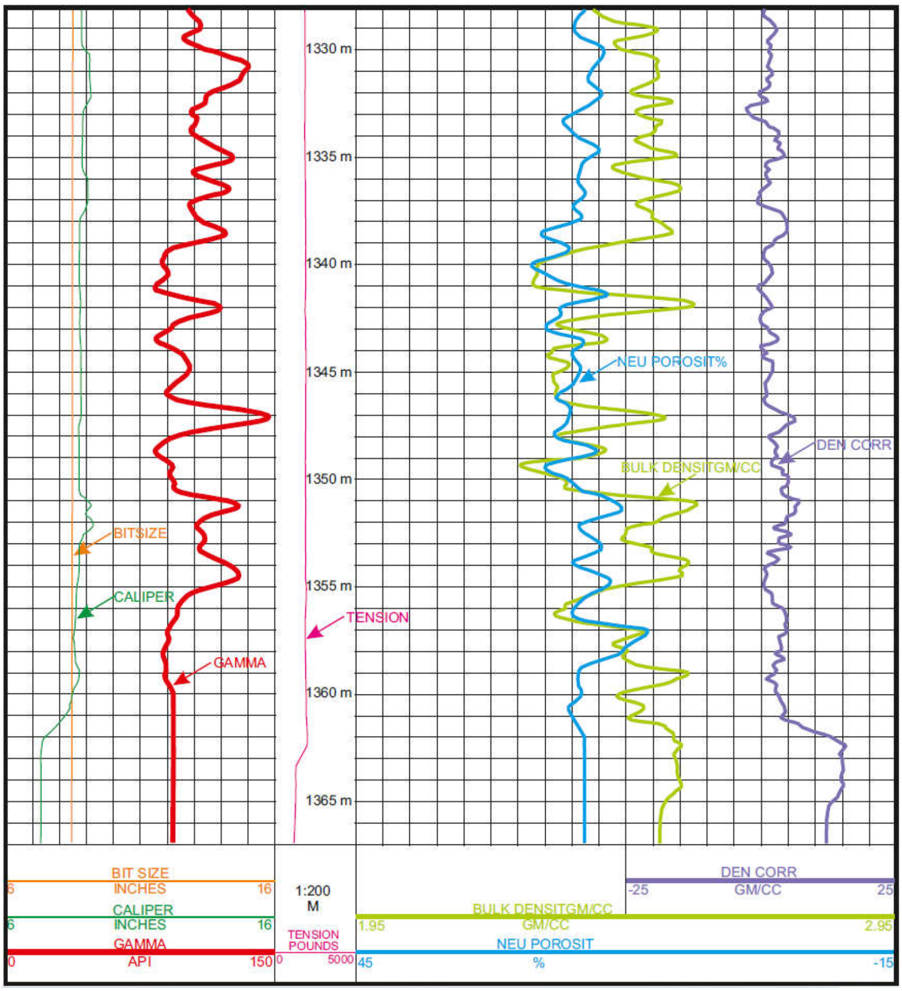

Figure 5. Neutron-density and Gamma Ray logs (Depth: 1330-1355 m)

Sonic Log alone is not sufficient for accurate effective porosity calculation in hydrocarbon fields close to the fault. Neutron and Density logs must also be evaluated together. Due to the fractured structure of the Hamitabat Sandstones in the studied well, neutron and density logs were evaluated together. Because there is a fault in the south of the region in the Marmara Sea that is thought to be the continuation of the North Anatolian Fault Line. This fault is a large-scale and active fault. The cracks and fractures in the sandstones may be due to this fault and North Osmancık Fault in the region (Figure 1). Sonic logs ignore secondary porosity (dissolution and fractures) and respond primarily to intergranular porosity; density and neutron logs respond to the total porosity. The density–neutron crossplots yield the total porosity [12].

The Neutron Porosity values (%) and Bulk Density values (GM/CC)/(g/cm^3) of the studied well (Figure 5) are read and these values are dotted on the Schlumberger CP-1c graph (Neutron-Density graph) [12]. (Figure 6). A large density–neutron crossover is an indication of hydrocarbons (i.e., gas) [12]. Therefore, the Hamitabat Formation sandstones have good reservoir rock properties on the basis of the density–neutron log responses (Figure 5).

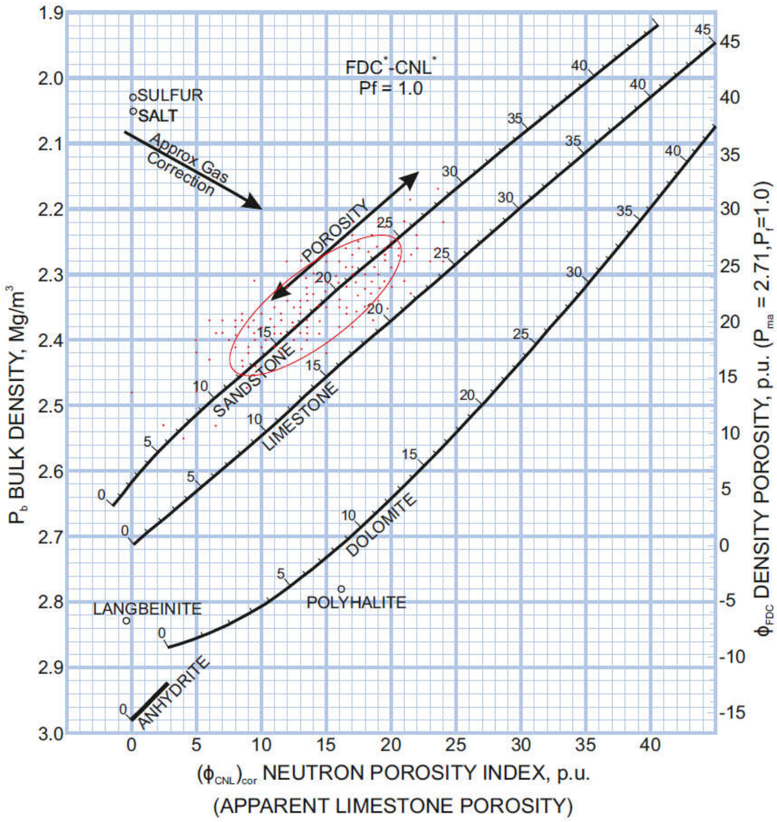

Figure 6. Neutron-density (CP-1c) graph (Schlumberger, 1986)

It is observed that the porosity value is clustered between 15%-25% in the dots in the Schlumberger (1986) CP-1c neutron-density graph (Figure 6). According to the reservoir rock classification of Rider [8], Hamitabat Sandstones are in the good- very good (Total porosity:15%-25%) class according to density–neutron crossplots (Table 1).

3.3. Determination of Water and Hydrocarbon Saturations Using Resistivity Log

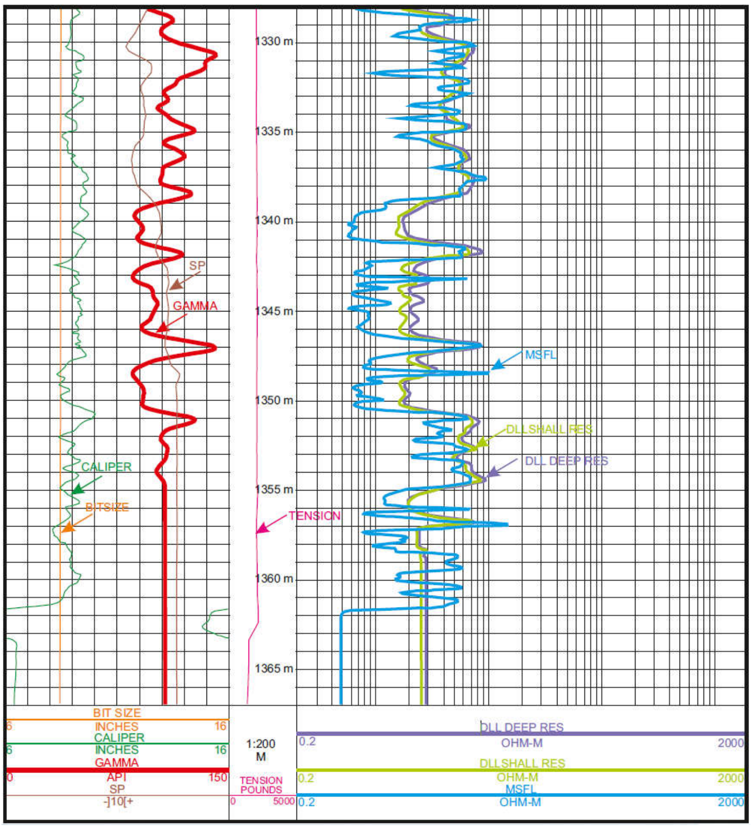

Figure 7. Resistivity log (MSFL: Resistivity of invasion zone, DLL Shallow Resistivity and DLL Deep Resistivity) (Depth: 1330-1355 m)

Laterallog Deep Resistivity (DLL Deep Resistivity) values and Microspherical Resistivity values corresponding to meters are read in ohms from the Resistivity log of the studied well (Figure 7) [12]. The effective porosity values obtained from the Neutron- Density graph were plotted against the Resistivity values. The total/effective Porosity-Resistivity graph was prepared (Figure 8).

It is observed in the graph that effective porosity values increase in direct proportion to resistivity values (Figure 8). High resistivity values in sandstones indicate high porosity, which indicates a hydrocarbon zone.

To calculate water saturation in %, the formula

$$S_w = \frac{R_w}{PHI * R_t} \tag{3}$$

is used.

S_w: Formation Water Saturation of clean zone
R_w: Formation Water Resistivity
PHI: Porosity
R_t: Resistivity of Clean Formation

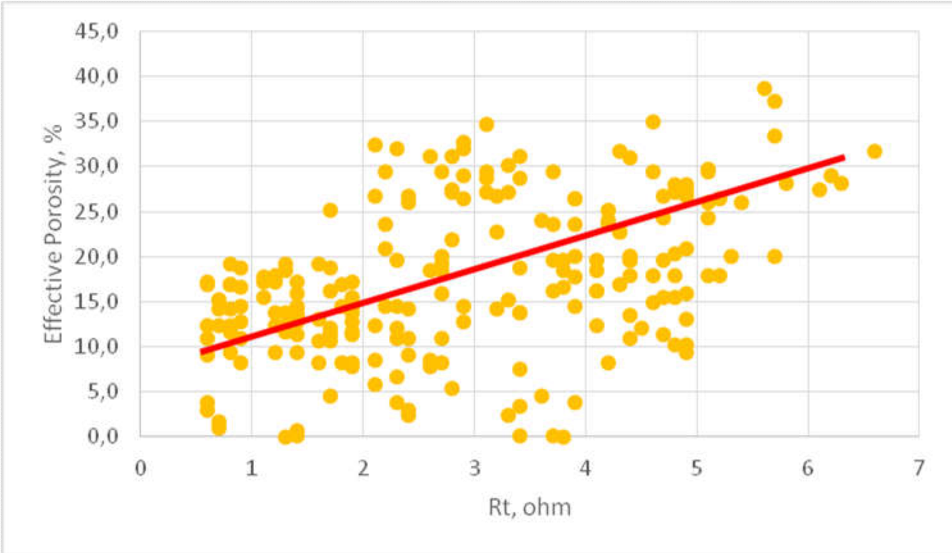

Figure 8. Effective Porosity-Resistivity Graph

Formation water saturation (S_w) in the study well was calculated as an average of 68% by reading the values in all meters. An inverse proportion is observed in the effective porosity water saturation graph. It is seen that as the water saturation (S_w) values increase in sandstones, the effective porosity values decrease (Figure 9).

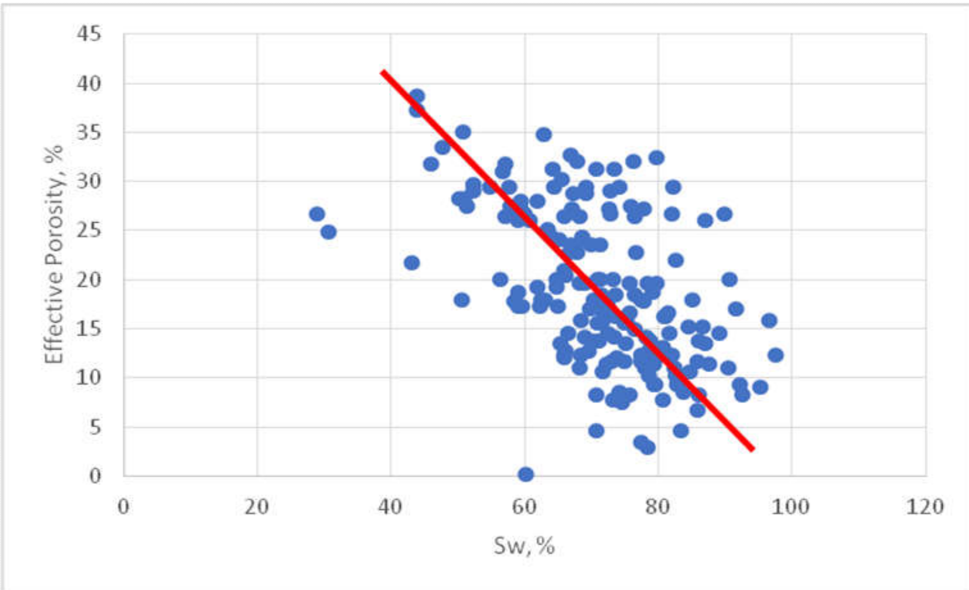

Figure 9. Effective porosity-water saturation graph

$$S_w + S_h = 1 \tag{4}$$

Equation 4 is a relation between hydrocarbon saturation and water saturation. When the calculated formation water saturation of clean zone (Sw) values are substituted into this equation, the hydrocarbon saturation (Sh) is found to be 32% on average for Hamitabat Formation sandstones. In the Effective Porosity-Hydrocarbon Saturation Graph, it is observed that the effective porosity and hydrocarbon saturation values are directly proportional (Figure 10).

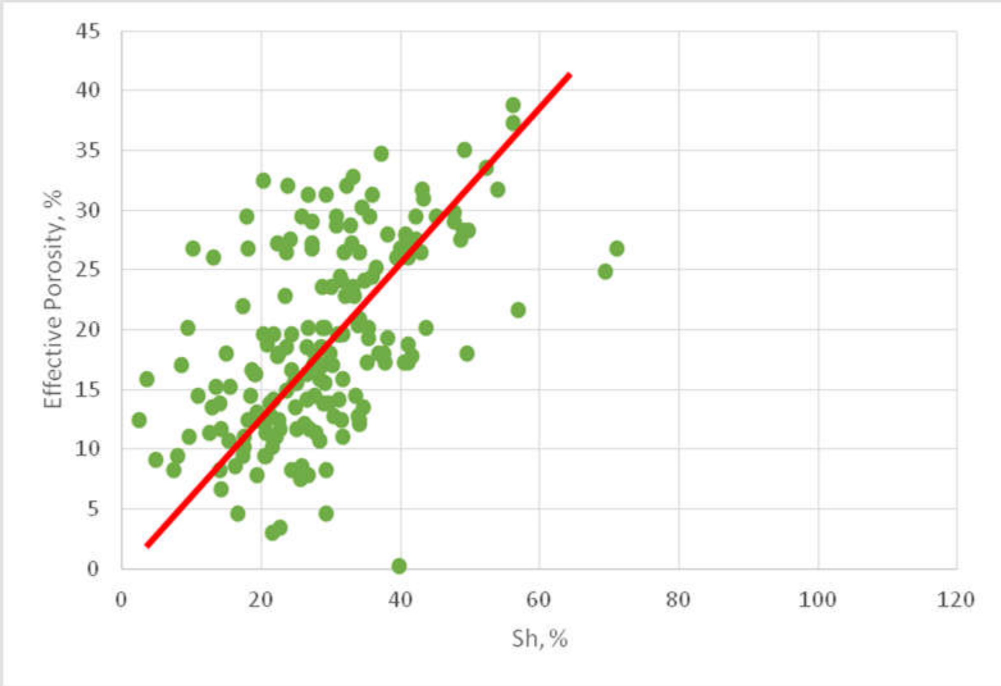

Figure 10. Effective porosity-hydrocarbon saturation graph

The formula for calculating mobile hydrocarbon saturation in percent is given below:

$$MOS = S_{xo} - S_w \tag{5}$$

is used

MOS: Mobile hydrocarbon saturation
S_{xo}: Water saturation of the invasion zone
S_w: Formation Water saturation of clean zone

Mobile hydrocarbon saturation in the study well was calculated as an average of 3% by reading the values in all meters.

The formula for calculating residual hydrocarbon saturation in percent is given below:

$$ROS = 1 - S_{xo} \tag{6}$$

is used.

ROS: Residual hydrocarbon saturation
S_{xo}: Water saturation of the invasion zone

Residual hydrocarbon saturation in the study well was calculated as an average of 13%.

4. Calculation of Permeability

Permeability is a property that expresses the capacity of a rock to allow fluids (liquid or gas) to pass through it. Permeability is related to the size of the pores, their interconnectedness and the physical properties of the fluid.

An F factor was calculated using the Archie equation to calculate permeability in sandstones. The Archie equation is given below [1]:

$$F = \frac{a}{PHI * m} \tag{7}$$

F: Archie formation factor
a: constant for sandstones, 0.81
PHI: Porosity
m: cementation factor is taken as 2.15 for sandstones.

In the study well, the Archie formation factor of the Hamitabat formation sandstones was calculated as an average of 0.34 by reading the values in all meters.

In order to calculate the permeability values in sandstones correctly, firstly the irreducible water saturation (S_{wirr}) values were calculated (According to [1])

$$S_{wirr} = \left(\frac{F}{2000}\right) * 0.5 \tag{8}$$

S_{wirr}: irreducible water saturation
F: Archie formation factor

The irreducible water saturation (S_{wirr}) value of the sandstone formation passed in the study well was calculated as 0.0027 on average by reading the values in all meters.

At irreducible water saturation, Timur's equation [11] is applied to determine the permeability (K) of the Hamitabat Formation as follows:

$$K(mD) = \frac{0.136 * \varphi_{ef}^{4}}{S_{wirr}^{2}} \tag{9}$$

K : Permeability (mD)
ϕ_{ef} : clay corrected porosity (effective porosity)
S_{wirr} : irreducible water saturation

When the irreducible water saturation value in the Hamitabat formation sandstones was calculated in the study well, the permeability of the sandstones was calculated as an average of 0.70 mD by reading the values in all meters. It is observed that permeability values increase up to 4 mD (Figure 11). According to the reservoir rock classification of Rider [8], Permeability of Hamitabat Sandstones are in the poor class (Table 1). Despite this, it was observed that the permeability value reached 17 mD at some depths. For example, according to the numerical calculations, the permeability were determined as 13 mD at 1223 m depth; 11.68 mD at 1228 m depth, 15 mD at 1235 m depth and 17 mD at 1239 m depth. According to the reservoir rock classification of Rider [8], Although the permeability of Hamitabat Sandstones is generally poor, it is observed to be in the moderate class at some depths (Table 1).

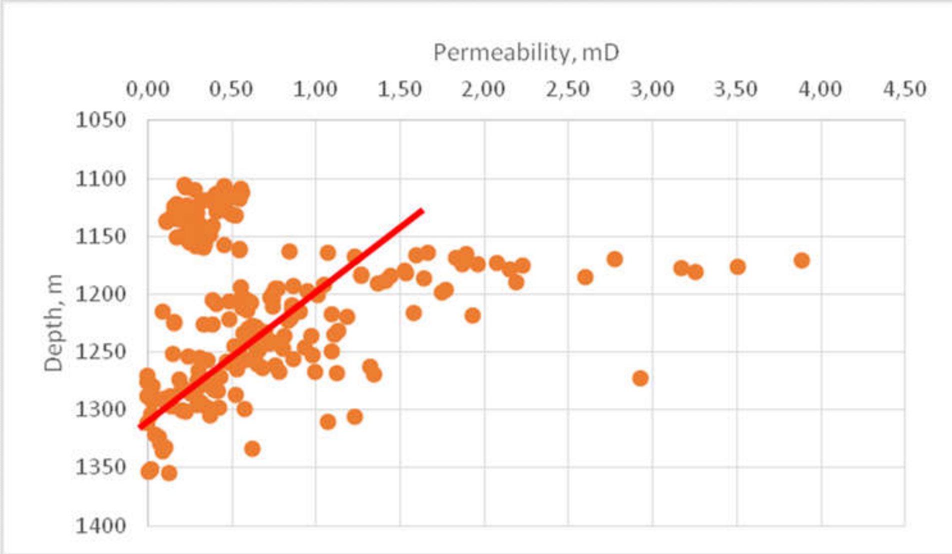

Figure 11. Depth-permeability graph

In the permeability-effective porosity graph, it is observed that as permeability values increase with direct proportion, effective porosity values increase (Figure 12). This permeability value is calculated with irreducible water saturation (S_{wirr}). It is observed that porosity and permeability are related to each other in the reservoir rock.

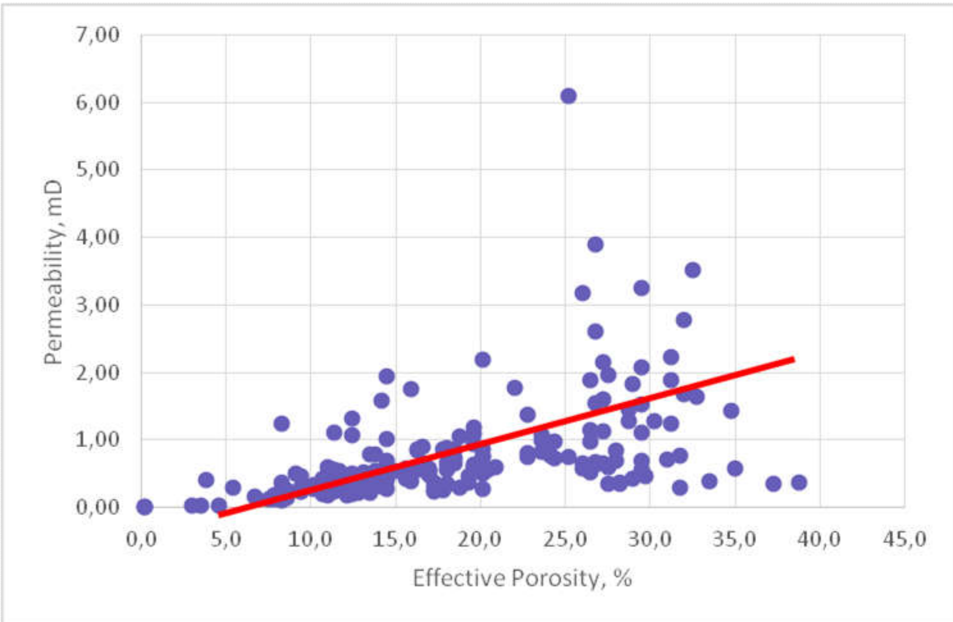

Figure 12. Permeability-effective porosity graph

5. Conclusions:

1. In this study, well log analyses from the well drilled near Istanbul-Silivri have been successfully completed. The study was carried out on the Hamitabat Formation sandstones, which are currently undergoing hydrocarbon production.

2. The clay ratio determined by Gamma Ray Log is 40%.

3. According to resistivity log evaluations, water saturation was calculated as 68% on average and hydrocarbon saturation as 32%. According to the reservoir rock classification of Rider [8], Although the permeability of Hamitabat Sandstones is generally poor, it is observed to be in the moderate class at some depths.

4. According to the reservoir rock classification of Rider [8], the porosity of Hamitabat Sandstones are in the good–very good class.

5. A large density–neutron crossover is an indication of hydrocarbons (i.e., gas) [12]. Therefore, In this study the Hamitabat Formation sandstones have good reservoir rock properties on the basis of the density–neutron log responses

6. The quantitative porosity and permeability values obtained from well log interpretations and water saturation values are good enough for hydrocarbon production.

Acknowledgments

The authors would like to thank the Turkish Petroleum Corporation (TPAO) and the General Directorate of Mining and Petroleum Affairs (MAPEG) for providing the necessary support for this study. This study forms part of the master thesis of Temel Karaarslan, which is conducted in Ankara University by the supervision of Dr. Aynur BÜYÜKUTKU.

REFERENCES

[1] *G. Archie,"The Electrical Resistivity Log as an Aid in Determining Some Reservoir Characteristics", Transactions of the AIME, vol 146, no. 1,* ***(1942)****, pp.54-62.*

[2] W. F. *Burke and G. Ugurtas (1974), "Seismic interpretation of Thrace Basin". Proceedings of the 2nd Petroleum. Congress of Turkey, Ankara, Turkey,* ***(1974)****.*

[3] *A. G. Buyukutku,"The Diagenesis of Middle Eocene Sandstones from the Western Thrace Basin, Turkey", Geological Society of India, vol. 62,* ***(2003)****, pp. 83-90.*

[4] *A. G. Buyukutku,"Sandstone Petrology and Tectonostratigraphic Terranes of the Northwestern Thrace Basin, Turkey", Journal Geological Society of India, vol 65, no.2,***(2005),** *pp.231-238.*

[5] *A. G. Buyukutku, "Diagenesis of Upper Eocene volcaniclastic rocks and its relavance to hydrocarbon exploration in the Thrace Basin, Turkey". Energy Sources, Part A, vol 28,* ***(2006)****, pp.1039-1049.*

[6] A. *Buyukutku. and A. Gecer, "Reservoir Potential of the Hamitabat Formation Submarine Fan Sandstones, Northwest of Thrace Basin". Journal of Gumushane University Institute of Science and Technology, vol. 10, no. 1,* ***(2020),*** *pp.174-189. In Turkish.*

[7] *C. Keskin, "Stratigraphy of the North of the Ergene Basin". Proceedings of 2nd Petroleum Congress of Turkey,Ankara, Turkey,* ***(1974)****, pp. 37-163. In Turkish.*

[8] *M. Rider, M."The geological interpretation of well logs", 2nd edn. Rider French Consulting Ltd., Aberdeen, Sutherland, 178 p.,* ***(1996).***

[9] *N. Sonel, "Stratigraphie von nordteil des Thrakische beckens", Communicatons de la Faculte des sciences de 'Universite d'Ankara, serie, c1, Geologie,* ***(1983a)****, 90-124, Turguie.*

[10] *N. Sonel, "Aufstellung eines sedimantologischen modells im nordteil des Thrakische beckens und seine erdölmöglichkeiten", Communicatons de la Faculte des Sciences de 'Universite d'Ankara, serie, c1, Geologie, 44-72,* ***(1983b)****, Turguie.*

[11] A. *Timur, "An investigation of permeability, porosity, and residual water saturation relationships for sandstones reservoirs". The Log Analyst, vol. 9,* ***(1968)****,3–5.*

[12] *Schlumberger (1986) "Log interpretation charts". Schlumberger Educational Services, Houston, pp 1–131,* ***(1986)***

[13] *Schlumberger (1996) "Log interpretation charts". Schlumberger Well Services, Houston, pp 2–34,* ***(1996)***