Journal of Geoscience and Environment Protection, 2022, 10, 55-65
https://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

3D Slicing of Weighted Index for Reservoir Quality of Lower Miocene Rocks, Belayim Marine Oil Field, Gulf of Suez, Egypt

Ibrahim Mohammad Al-Alfy[1*], Ali Mohammad El-Hawary[1], Hassan Badr El-Dein Mohammad[1], Mohammad Ahmed Shaheen[1], Muhammad Nabih[2]

[1]Exploration Division, Nuclear Materials Authority, Cairo, Egypt
[2]Geology Department, Faculty of Science, Zagazig University, Ash Sharqiyah, Egypt
Email: *ibelalfy@yahoo.com, *alalfy78@nma.org.eg

How to cite this paper: Al-Alfy, I. M., El-Hawary, A. M., Mohammad, H. B. E.-D., Shaheen, M. A., & Nabih, M. (2022). 3D Slicing of Weighted Index for Reservoir Quality of Lower Miocene Rocks, Belayim Marine Oil Field, Gulf of Suez, Egypt. *Journal of Geoscience and Environment Protection, 10,* 55-65.
https://doi.org/10.4236/gep.2022.108005

Received: July 1, 2022
Accepted: August 19, 2022
Published: August 22, 2022

Abstract

This study aims to have a single coefficient resulting from the integration of all the reservoir parameters through which a decision can be taken to determine the best quality places in the reservoir. The conventional well logging data in nine wells were used to determine the reservoir parameters in the study area. Seven different parameters were calculated, five of them were directly proportional to the quality of the reservoir, while the remaining two parameters which represent shale volume and water saturation were inversely proportional to the reservoir quality. The index of each parameter was calculated. A new value was created from the integration of the seven different parameter indexes called the weighted index for the reservoir quality. The reservoir quality values were sliced in the three dimensions depending on the effect of all reservoir parameters and not on any single parameter. It is clear from the results of this study that horizontal and vertical slicing, as well as cut-off values, illustrates that the middle and upper parts are the best places for the reservoir to explore hydrocarbons, where the values of the weighted index of the reservoir quality range from 0.65 to 0.9. Meanwhile, the quality of the reservoir decreases in its lower parts.

Keywords

3D Slicing, Weighted Index, Reservoir Parameters, Belayim Marine Oil Field

1. Introduction

Determining the quality of a reservoir depends on many petrophysical properties. Some of these properties may be directly proportional to the quality of the reservoir, and others may be inversely proportional. Therefore, the idea of this work was based on deriving one parameter by which the quality of the reservoir is determined, and this parameter is calculated by calculating the actual weight of each of the different tank parameters.

The study area is located between Latitudes 28˚34'45"N - 28˚38'32"N and Longitudes 33˚05'17"E - 33˚10'38"E inshore the Gulf of Suez, 25 km southeast of Suez City. The study wells distribution in Belayim marine oil field is illustrated in **Figure 1**. Because the rocks of Rudeis and Karim Formations contain adequate amounts of hydrocarbons; these rocks, which were formed in Lower Miocene age, are classified as a source and also reservoir rocks (Al-Alfy, 2009).

Locations that do not contain data are covered based on real data through an interpolation process (Ghoneimi, 2002).

Plotting of the reservoir characteristics in the form of 3D gives a clear view of what's inside the reservoir and helps to understand and image the distribution of reservoir parameters in all parts of the study area (Gadallah et al., 2010).

Al-Alfy and Nabih (2013) and Mohamed et al. (2017) used Tecplot computer program to build a 3D-slicing show the distribution and variation of the reservoir parameters.

2. Geological Setting

Belayim marine oil field is anticline has NW–SE trend, the main faults were trending in E-W direction with 2400 m displacement. Rudeis Formation is mainly consisting of sand, shales and marls denoted as Globigerina marls, as well as sandstones (Abu Al-Atta et al., 2014).

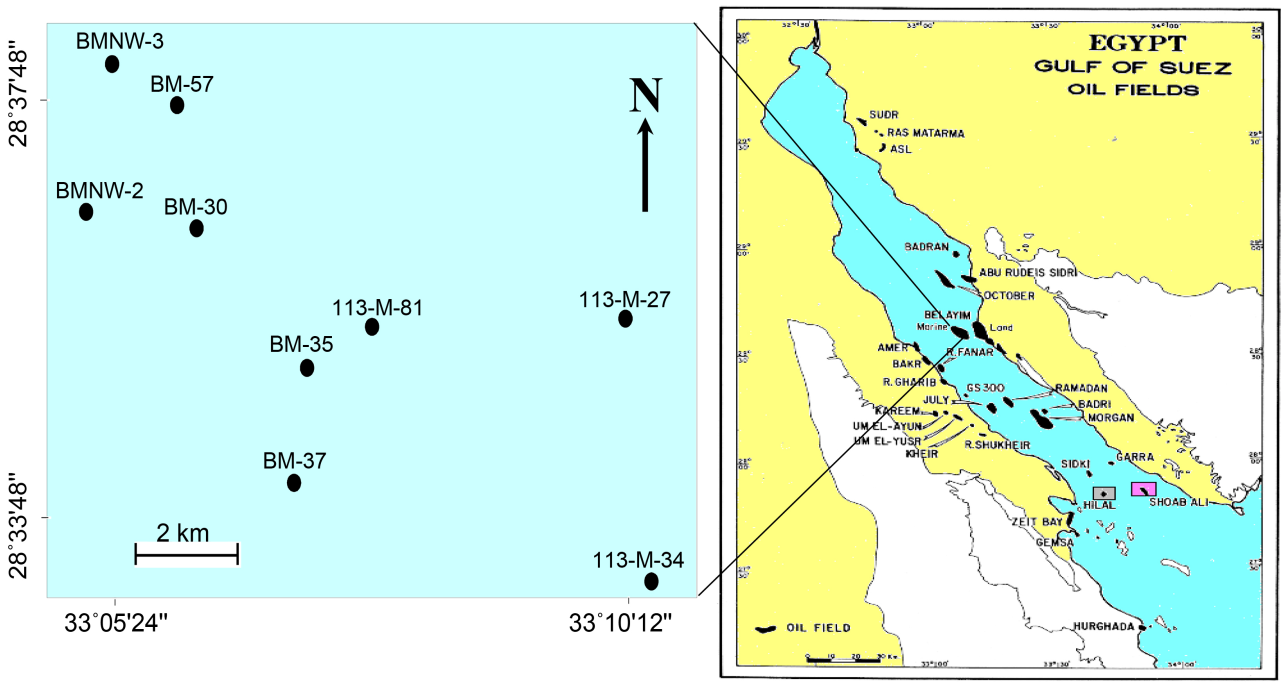


Figure 1. Location map of the study wells, Belayim marine oil field, Gulf of Suez, Egypt.

Rudeis Formation is a rift feature probably formed from Late Oligocene to Late Miocene (Patton et al., 1994; Omar & Steckler, 1995; Khalil & McClay, 2001; Afifi et al., 2017). Structurally, according to the dip directions, there are three provinces that can be classified as southern, central, and northern provinces. The rocks in the southern province have a southwest regional dip (Sallam et al., 2019).

Rudeis formation can be classified as a source rock according to its deposition under favorable conditions, according to having huge hydrocarbon amounts (Schlumberger, 1984). Lithologically (**Figure 2**), the bottommost part of Rudeis

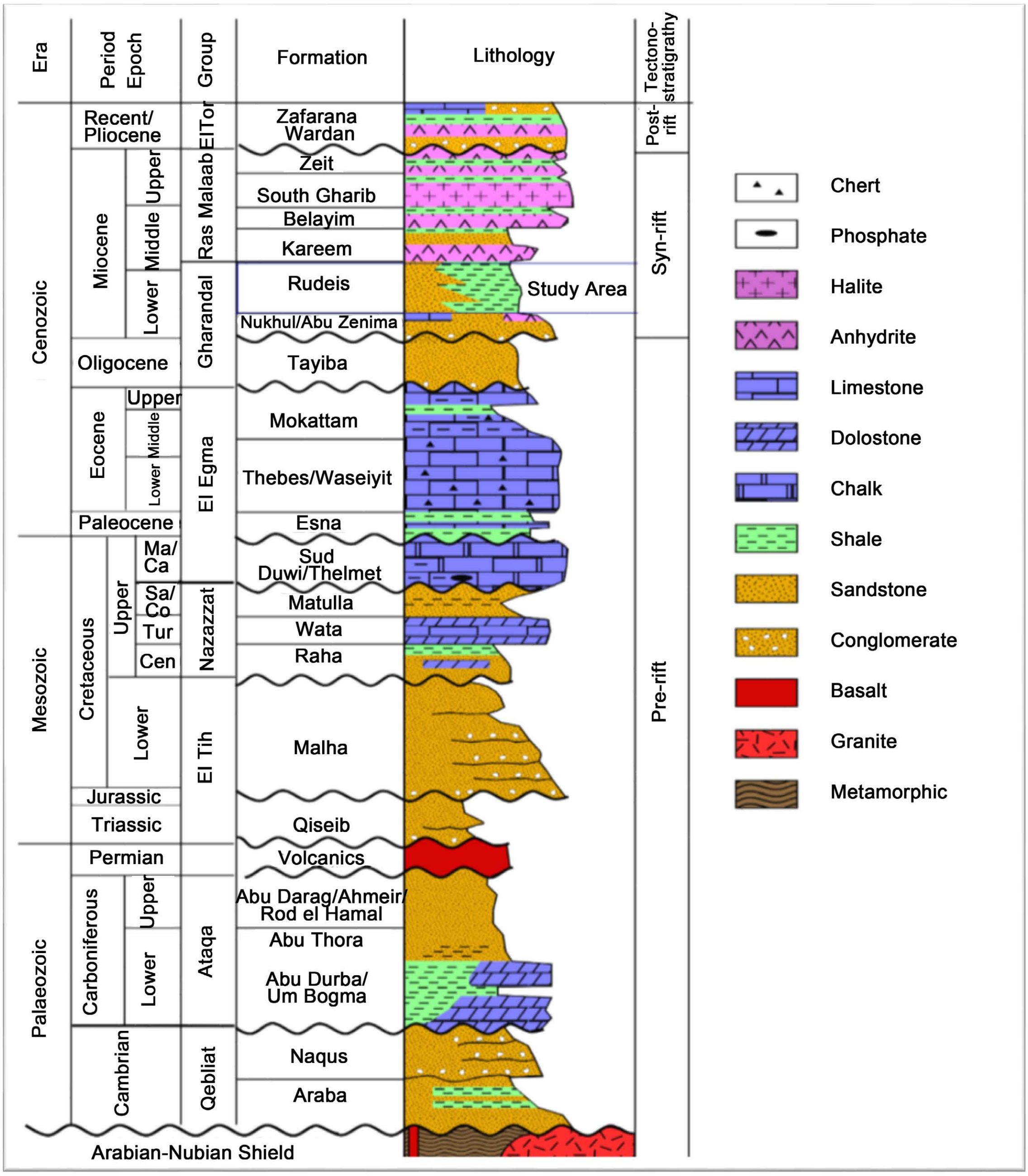


Figure 2. Litho-stratigraphic column of the Belayim marine oil field.

Formation, which was deposited on the Nukhul Formation is formed from sandstones. There are some beds of sand and shaly-sand that are intruded in calcareous shale rocks which are considered the main component of the middle part of Rudeis Formation. Meanwhile, shale and sandstone intercalations are the composition of the upper Rudeis (Takasu et al., 1984). Rudeis Formation was deposited in shallow to deep marine environment (Alsharhan & Salah, 1994). In the study area, Rudeis Formation is recorded in all of the nine wells.

3. Methodology

The available borehole data includes total gamma ray, neutron, density, shallow & deep resistivity logs were used to evaluate the different reservoir parameters as volume of shale, total & effective porosity, water & hydrocarbon saturations and oil in place percentage.

Dresser Atlas (1979) derived an equation for calculating the gamma-ray index in the rocks, in preparation for its use in calculating the volume of shale content inside the rocks, whose increase has a direct impact on the permeability and fluids movement inside the rocks, and therefore the values of the clay quantities decrease the quality of the hydrocarbon reservoir. This equation is as follows:

$$I_{GR} = \frac{GR_{\log} - GR_{\min}}{GR_{\max} - GR_{\min}} \tag{1}$$

where: I_{GR} is Gamma-ray index, $GR_{\log}$ is Gamma-ray reading, $GR_{\max}$ is maximum Gamma-ray, $GR_{\min}$ is minimum Gamma-ray.

Using this equation, the gamma ray index for any value measured in the wells will range from zero to one.

Seven parameters were calculated in the nine wells of Lower Miocene rocks in the study area. These parameters were represented in the volume of shale (Vsh), total porosity (ϕt), effective porosity (ϕe), water saturation (Sw), hydrocarbon saturation (Sh), hydrocarbon in place (Oip), and reservoir thickness.

Equation No. (1) was applied after modification to calculate the index for five parameters only (ϕt, ϕe, Sh, Oip and thickness) which is directly proportional to the reservoir quality. On the other hand (Vsh and Sw) are inversely proportional to the reservoir quality, so the result of Equation (1) will be subtracted from one.

A new value was created, called the weighted index, which is a sum of the seven different indexes. Dividing the new result by their number, the output is, therefore, an expression of the quality of the reservoir. This new value does not depend on any individual parameter but is based on the weighted index of all the seven reservoir parameters.

The modified equation is:

$$I_p = \frac{R_n - R_{\min}}{R_{\max} - R_{\min}}$$

where: I_p is parameter index, R_n is parameter value, $R_{\max}$ is maximum parameter value, $R_{\min}$ is minimum parameter value.

Depending on the preliminary data, Lower Miocene rocks in the study area can be divided into seven sub-layers according to the lithological content of the rocks. Therefore, the reservoir parameters will be calculated for each sub-layer separately.

Contouring was made to elicit the interpolated values between the different wells horizontally for each sub-layer. Then a vertical contour was made to elicit the values between the sub-layers. Finally, the model can be obtained for the entire reservoir in the study area. These calculations were conducted based on Equation No. (2) (Davis, 1986):

$$F(x) = \left((x_2 - x) f(x_1) + (x - x_1) f(x_2) \right) / (x_2 - x_1) \quad (2)$$

When only the values at the interpolation nodes $x_1, x_2, \cdots, x_n$, a piecewise linear function can be defined by interpolation.

3D slicing in the three directions (Easting, Northing and Depth) or (X, Y and Z) respectively, and the cutoff values for the weighted index of reservoir quality in the study area were constructed by TECPLOT software.

4. Results

The seven reservoir parameters (shale volume, total porosity, effective porosity, water saturation, hydrocarbon saturation, oil in place and thickness), as estimated from well-log data were used to estimate the weighted index for these seven derived reservoir parameters in three dimensions; X, Y and Z.

The weighted index is visualized within Rudeis Formation in Belayim marine oil field. The exterior view of the reservoir, (**Figure 3(a)**) represents the outer three faces. On the top face, the lower weighted index values extending below 0.35, appear in the northwestern part. Meanwhile, the higher values, reaching over 0.85, arise in the northeastern part. In the front face, higher weighted index values, attaining over 0.8, appear in the central and upper parts. Meanwhile, the lower values, falling under 0.25, appear in the southeastern corner of the front face. In the side face, the weighted index values are present ranging from 0.2 to 0.7.

The change in weighted index in the X-direction, shows a high value of 0.8. This value is common in all five planes, especially in the middle parts of all planes (**Figure 3(b)**). The weighted index values in the five planes reach 0.9 in the western portions of planes Nos. 3, 4 and 5. The variation of weighted index in the Y-direction is illustrated in **Figure 3(c)**. The lower value (under 0.20) appears in the northern portions of planes Nos. 4 and 5, while the higher values (over 0.7) appear in the north and northwestern parts of planes Nos. 1, 2, 3.

Figure 3(d) shows the vertical variation of the weighted index in the Z-direction. The maximum value (0.9) is recorded in the northeastern part of the plane No. (1), the western part of plane No. 2 and the western part of plane No. 3. Meanwhile, the values ranging from (0.40 to 0.70) were recorded at the central part of planes Nos. 4, 5, 6 and 7. The weighted index attains less than 0.20 in the top-eastern portion of the reservoir as illustrated from the interior view

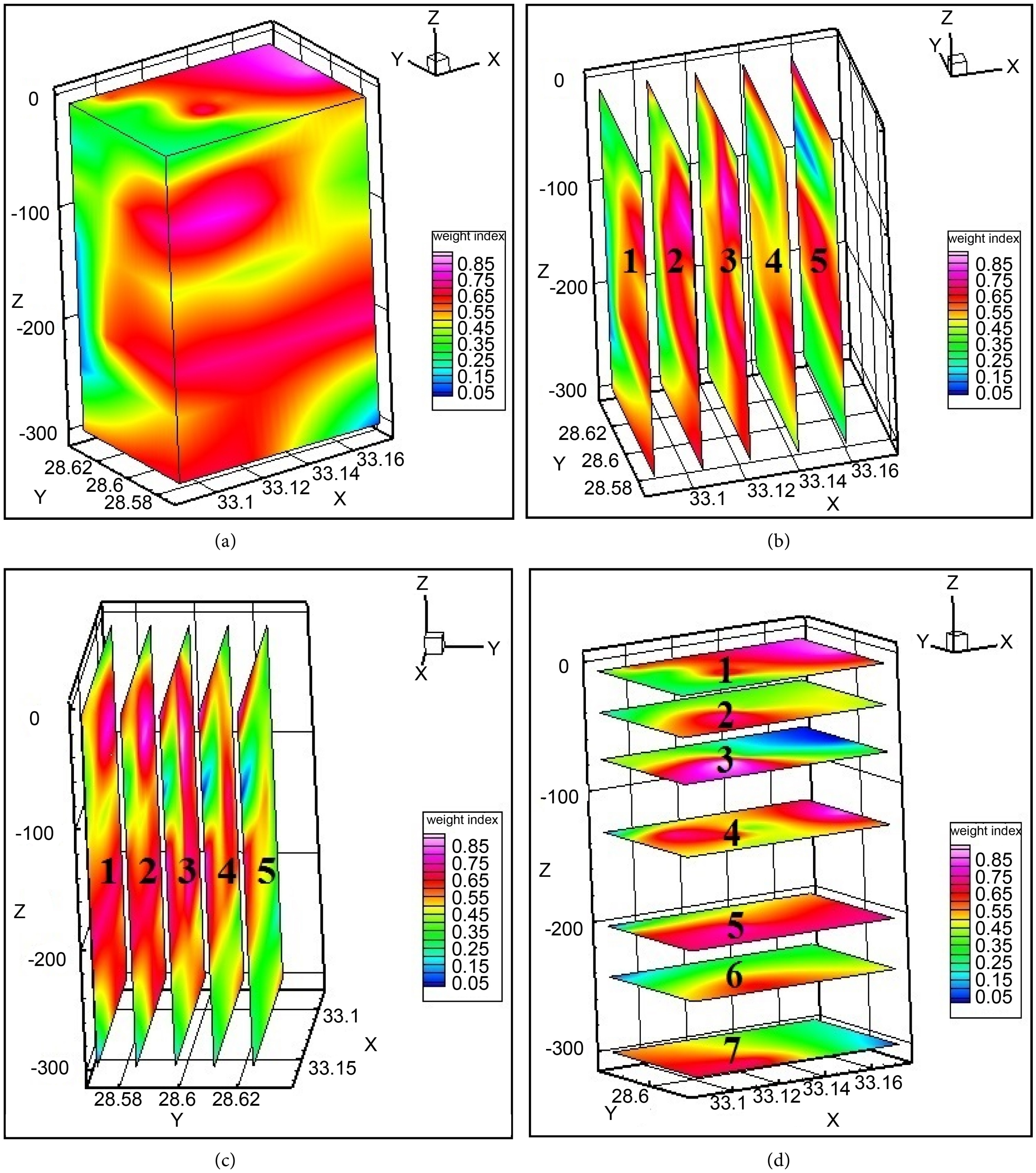


Figure 3. Exterior view and slicing in different directions for the weighted index, Rudeis Formation, Belayim marine oil field, Gulf of Suez, Egypt.

(**Figure 4**). On the other hand, the weighted index reaches more than 0.70 at the upper and central portions of the reservoir.

The weighted index cut-off (**Figure 5**) was carried out at two different values: 0.40 and 0.50. The weighted index reaches more than 0.40 in the central and top

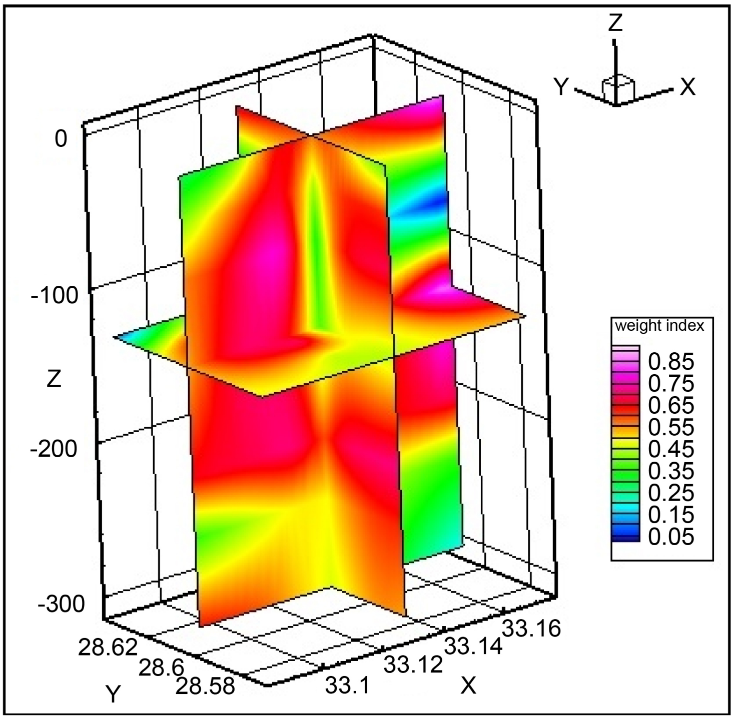


Figure 4. Interior view for the weighted index, Rudeis Formation, Belayim marine oil field, Gulf of Suez, Egypt.

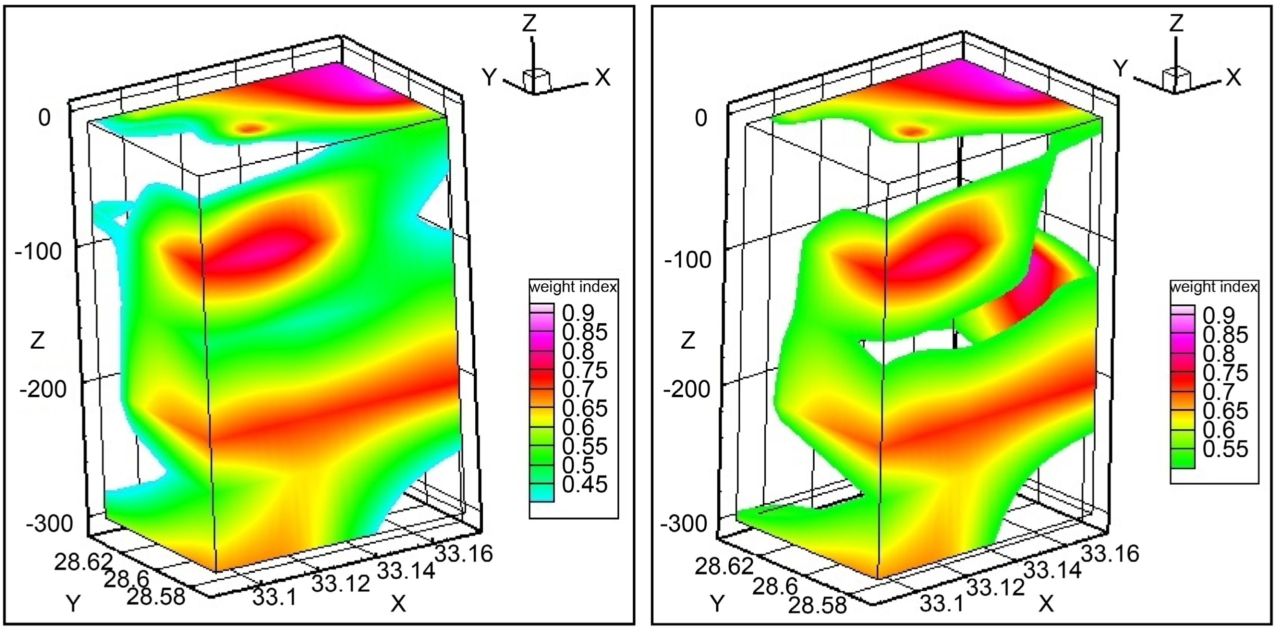
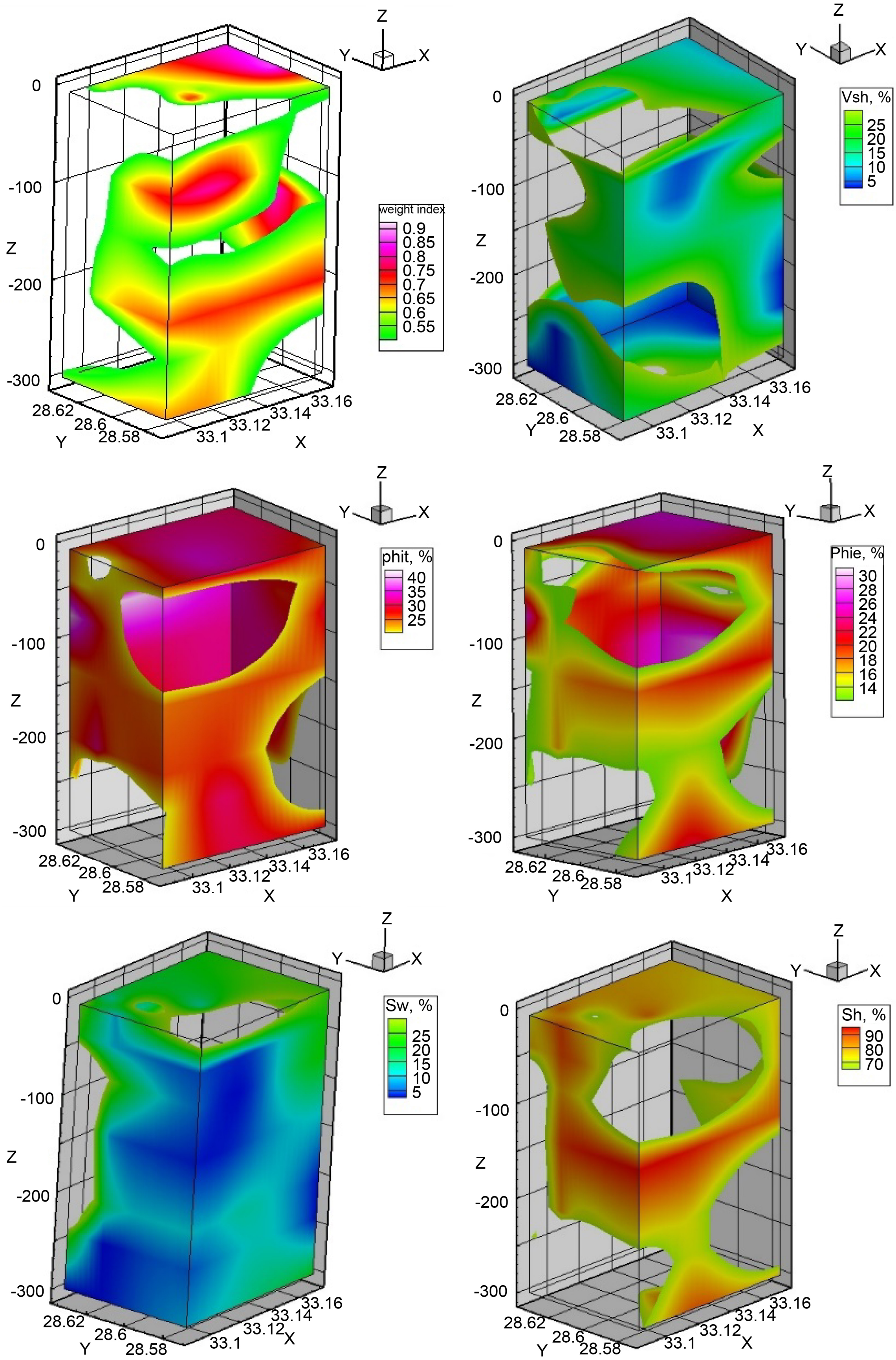


Figure 5. Cutoff for the weighted index, Rudeis Formation, Belayim marine oil field, Gulf of Suez, Egypt.

eastern portions of the reservoir. Meanwhile, it attains less than 0.40 in few portions of the reservoir. Similarly, the weighted index acquires more than 0.50 at the central and northeastern portions of the reservoir. The 3D distribution for the combined seven parameters shows a major presence for the weighted index in the central and northeastern portions of the reservoir.


weight index
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
Vsh, %
25
20
15
10
5
phit, %
40
35
30
25
Phie, %
30
28
26
24
22
20
18
16
14
Sw, %
25
20
15
10
5
Sh, %
90
80
70
Z
X
Y
0
-100
-200
-300
28.62
28.6
28.58
33.1
33.12
33.14
33.16

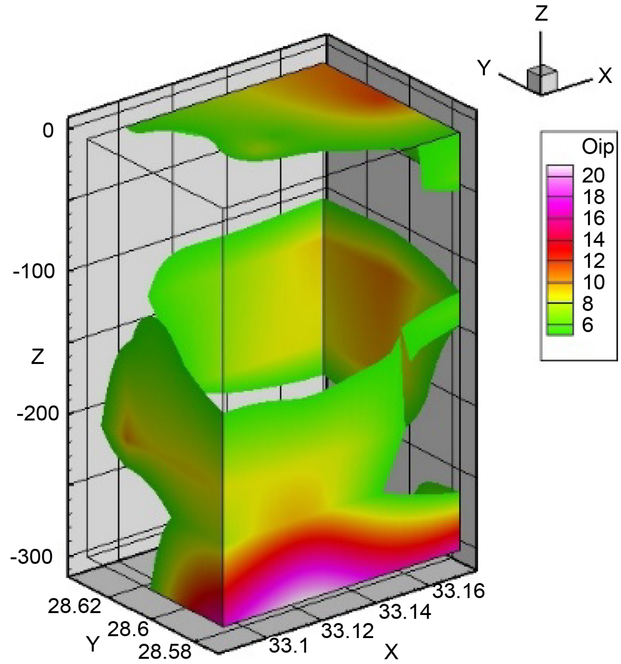


Figure 6. Cut-offs of individual reservoir parameters and weighted index for reservoir quality, Rudeis Formation, Belayim marine oil field, Gulf of Suez, Egypt.

5. Method Verification

To verify the accuracy of the results of this method, it is necessary to compare the results of the weighted index of reservoir quality with the results obtained from the conventional methods for determining the quality of the reservoir, which depend mainly on the individual reservoir parameters.

To clarify the comparison between the different results, cut-offs were made to avoid low values that express poor places for the properties of the reservoir so that the good places are available to us in the figures expressing the results of the individual properties of the reservoir such as (Vsh, ɸt, ɸe, Sw, Sh and OIP) and those resulting from the integration of all properties (weighted index).

Figure 6 shows that there is a large agreement between the results of the weighted index method and the results of the traditional methods for determining the reservoir quality depending on the individual parameters. While we find that there are differences between the individual parameters in determining the best reservoir portions.

The best quality parts of the reservoir that were extracted from the weighted index method correspond to the best parts specified from the individual reservoir parameters such as (Sh, ɸe and ɸt). While there are slight differences between these places and those that are determined from the parameters such as (Vsh, Sw and OIP).

Therefore, it is necessary to rely on the results of the weighted index method, because it is a compilation of the best quality reservoir portions based on all reservoir parameters not based on single ones.

6. Summary and Conclusions

1) Lower Miocene Rudeis Formation has a high hydrocarbon potentiality in their rocks and is considered a very good reservoir.

2) The weighted index of the reservoir quality was calculated from the different indexes of the reservoir parameters.

3) 3D slicing of the reservoir quality property cleared that the upper and central parts of the reservoir showed good quality, while the quality decreased towards the bottom.

4) The zones having cutoff values more than 0.65 of the reservoir quality index indicate excellent areas for hydrocarbon exploration.

5) The cut-off values of the weighted index parameter were compared with the cut-offs values of the individual reservoir parameters to verify the results of the weighted index method.

Acknowledgements

The authors thank and appreciate Prof. Dr. Ahmed A. M. Ammar, for revising the manuscript.

Conflicts of Interest

The authors declare that they have no competing interests.

References

Abu Al-Atta, M., Issa, G. I., Ahmed, M. A., & Afife, M. M. (2014). Source Rock Evaluation and Organic Geochemistry of Belayim Marine Oil Field, Gulf of Suez, Egypt. *Egyptian Journal of Petroleum, 23,* 285-302. https://doi.org/10.1016/j.ejpe.2014.08.005

Afifi, M. M., Sallam, E. S., & Faris, M. (2017). Integrated Petrophysical and Sedimentological Study of Middle Miocene Nullipore Formation Ras Fanar Field, Gulf of Suez, Egypt: An Approach to Volumetric Analysis of Reservoirs. *Journal of African Earth Sciences, 134,* 526-548. https://doi.org/10.1016/j.jafrearsci.2017.07.014

Al-Alfy, I. M. (2009). *Radioactivity and Reservoir Characteristics of Lower Miocene Rocks in Belayim Marine Oil Field, Gulf of Suez, Egypt* (174 p.). Ph.D. Thesis, Faculty of Science, Zagazig University.

Al-Alfy, I. M., & Nabih, M. A. (2013). 3D Slicing of Radiogenic Heat Production in Bahariya Formation, Tut Oil Field, North-Western Desert, Egypt. *Applied Radiation and Isotopes, 73,* 68-73. https://doi.org/10.1016/j.apradiso.2012.11.019

Alsharhan, A. S., & Salah, M. G. (1994). Geology and Hydrocarbon Habitat in a Rift Setting: Southern Gulf of Suez, Egypt. *Bulletin of Canadian Petroleum Geology, 42,* 312-331.

Davis, F. D. (1986). *A Technology Acceptance Model for Empirically Testing New End-User Information System: Theory and Results* (291 p.). Ph.D. Thesis, Massachusetts Institute of Technology.

Dresser Atlas (1979). *Log Interpretation Charts* (107 p.). Dresser Industries, Inc.

Gadallah, M. M., El-Terb, R. A., El-Kattan, E. M., & Al-Alfy, I. M. (2010). Spectrometry and Reservoir Characteristics of Rudeis Formation in Belayim Marine Oil Field, Gulf of Suez, Egypt. *Journal of King Abdulaziz University, 21,* 171-199. https://doi.org/10.4197/Ear.21-1.7

Ghoneimi, A. E. (2002). Reservoir 3-D Slicing of Log-Derived Parameters of Lower Bahariya Pay Zones in Hayat-Yasser Oil Fields, Western Desert, Egypt. *Journal of Applied Geophysics, 1,* 129-142.

Khalil, S. M., & McClay, K. R. (2001). Tectonic Evolution of the NW Red Sea-Gulf of Suez Rift System. In R. C. L. Wilson, R. B. Whitmarsh, B. Taylor, & N. Froitzheim (Eds.), *Non-Volcanic Rifting of Continental Margins: A Comparison of Evidence from Land and Sea* (Vol. 187, pp. 453-473). Special Publications, Geological Society, London. https://doi.org/10.1144/GSL.SP.2001.187.01.22

Mohamed, H., Mizunaga, H., Abou Ashour, N. M., Elterb, R. A., Alalfy, I. M., & Elsayed, A. S. (2017). Radiogenic Heat Production in Rudeis Formation, Lower Miocene, Belayim Marine Oil Field, Gulf of Suez, Egypt. *Exploration Geophysics, 48,* 512-522. https://doi.org/10.1071/EG15021

Omar, G. I., & Steckler, M. S. (1995). Fission-Track Evidence on the Initial Rifting of the Red Sea: Two Pulses, No Propagation. *Science, 270,* 1341-1344. https://doi.org/10.1126/science.270.5240.1341

Patton, T. L., Moustafa, A. R., Nelson, R. A., & Abdine, S. A. (1994). Tectonic Evolution and Structural Setting of the Suez Rift. In S. M. Landon (Ed.), *American Association of Petroleum Geologists* (Vol. 59, pp. 7-55). Interior Rift Basins. https://doi.org/10.1306/M59582C2

Sallam, E. S., Afifi, M. M., Fares, M., van Loon, A. J., & Ruban, D. A. (2019). Depositional Cycles of the Lower Miocene Rudeis Formation, Southwestern Offshore Margin of the Gulf of Suez, Egypt. Implications for Reservoir Evaluation. *Marine Geology, 415,* Article ID: 105964. https://doi.org/10.1016/j.margeo.2019.105964

Schlumberger (1984). Geology of Egypt. In *Well Evaluation Conference* (p. 201). Schlumberger.

Takasu, Y., Ganoub, A. F., & Hirano, M. (1984). Exploration History and Geology of West Bakr Fields, Eastern Desert, Egypt. In *Proceedings of the 6th Exploration Seminar* (pp. 350-379). Egyptian General Petroleum Corporation.