*Egyptian Geophysical Society*
*EGS Journal, vol. 3, No. 1, 181-194 (2005)*

# RESERVOIR 3D - SLICING OF ALAM EL-BUEIB PAY ZONES IN TUT OIL FIELD, NORTH WESTERN DESERT, EGYPT

GadAllah M.M. *, Basal, A.K. ** and Makharita, N.K.**

** Zagazig University, Faculty of science, Geology Dept.*
*** Mansoura University, Damietta Faculty of Science, Geology Dept.*

**تشريح ثلاثي الأبعاد للنطاقات الخازنة لمتكون علم البويب بحقل بترول توت، شمال الصحراء الغربية مصر**

**الخلاصة:** يمثل متكون علم البويب في حقل بترول توت بطبقات غير متجانسة ومتعددة وينقسم إلي ستة وحدات صخرية تبدأ بالوحدة AEB-1 من أعلي وتنتهي بالوحدة AEB-6 من أسفل. تم تحليل تسجيلات الآبار لمتكون علم البويب بحقل بترول توت باستخدام برنامج LOGANAL.وتم حساب سبعة معاملات بتروفيزيائية للنطاقات السية الخازنة لمتكون علم البويب في الآبار العشرة المدروسة بحقل بترول توت. وهذه المعاملات تشمل السمك الحامل للزيت والمسامية الكلية والمسامية المؤثرة وحجم الطفلة ونسبة التشبع بالماء والحجم الكلي للمسام وكمية الزيت الموجودة بالخزان. المسامية الكلية للمتكون تراوحت بين ١٠% إلي ٣٠% بينما تراوحت المسامية المؤثرة بين ٩% إلي ٢٩%. حجم الطفلة تراوح بين ٧% إلي ١٩% بينما تراوحت نسبة التشبع بالماء بين ٣٥% إلي ٧٠%. السمك الحامل للزيت للنطاقات المدروسة لمتكون علم البويب يتراوح بين ١٥٠ قدم إلي ٧٠٠ قدم بينما يتراوح الحجم الكلي للمسام ما بين ١٠ قدم و ٢٧٠ قدم في حين كان احتياطي الزيت يتراوح بين ٥ قدم و ١١٥ قدم. التشريح ثلاثي الأبعاد لمتكون علم البويب تم باستخدام طريقة Inverse distance to power.النموذج ثلاثي الأبعاد أعطي صورة واضحة لتوزيع المعاملات البتروفيزيائية لخزان علم البويب في الأبعاد الثلاثة وهذا العرض الواضح لخزان علم البويب في الأبعاد الثلاثة كان له بالغ الأثر في تحديد الأماكن القابلة للتطوير والتخطيط المستقبلي والأنتاج للزيت بمنطقة الدراسة.

**ABSTRACT:** *Alam El-Bueib Formation in Tut Oil Field is repesented by a high heterogeneous and multilayer reservoir. It is subdivided into six lithologic units starting by AEB-1 at the top and ending with AEB-6 at the bottom. Intensive well-log analysis of Alam El-Bueib in Tut Oil Field is analyzed, using Loganal program. Seven log–derived reservoir parameters are calculated for the six pay zones of Alam El-Bueib Formation in ten wells in this Tut Oil Field. The evaluated reservoir parameters are net pay thickness, total porosity, effective porosity, shale volume, water saturation, bulk pore volume and oil in place. The total porosity ranges from 10 % to 30 %, while the effective porosity ranges from 9 % to 29 %. The shale volume of Alam El-Bueib pay zones varies from 7 % to 19 % with depth, while the water saturation varies from 35 % to 70 %. The net pay thickness of the studied zones increases with depth from 150 to 700 ft. The bulk pore volume changes from 10 ft. to 270 ft., while the oil in place indicator changes from 5 ft. to 115 ft. with depth. The 3D-slicing of Alam El-Bueib reservoir model is constructed, using an inverse distance to power algorithm. It offers a clear insight and improves the visualization of the spatial distribution of the studied reservoir parameters in 3D. The visualization approach of Alam El-Bueib reservoir in 3D is improving the identification of promising areas for re-development and plan strategies for optimizing Alam El-Bueib reservoir production.*

## INTRODUCTION

Alam El-Bueib Formation is considered as one of the most producing formations in the Western Desert especially in the Khalda concession (Salam, Safir, Hayat and Tut fields). Tut Oil Field is located about 5 km North and northwest of Salam Field at the northern edge of the major Safir-Salam-Tut ridge at Khalda concession in the northwestern part of The Western Desert. It lies between Latitudes 30° 45' - 30° 48' to the North and Longitudes 26° 57' 45" – 26° 59' 50" to the East (Fig.1). Alam El-Bueib Formation has a huge thickness in general, while the lithology has been divided into six units from bottom to the top AEB-6 to AEB-1. The AEB-3 unit itself was subdivided into subunits: G, F, E, D, C, B, and A. The dominate lithology is represented by thick, massive sandstones with argillaceous and calcareous limestone intervals, interbedded with shales, however the high clean sands are represented in Salam-Safir ridge (Fig 2). At the Meleiha area, the sandstone becomes more clean, while the sands were lateraly changed by massive shale "match shale" towardss the Shushan basin. The Alam El-Bueib Formation ranges in age from Barremian to Aptian with at least one time gap identified within this unit. The depositional environment of Alam El-Bueib Formation was shallow marine with more continental influence towardss the South (Hanter, 1990). The available well-log data in this paper include caliper (CL), gamma ray (GR), formation density (FDC), compensated neutron (CNL), sonic (BHC) and resistivity logs (LLd, LLs and MSFL) in ten wells of Tut Oil Field. These wells are Tut-1x, Tut-3, Tut-6, Tut-8, Tut-9, Tut-11, Tut-12, Tut-14, Tut-22x & Tut-23x. The first objective of this paper is to analyze the collected well - log data of Alam El-Bueib Formation in this field. The second objective is to use the geostatistic techniques (inverse distance to power routine) to construct the 3D reservoir model for better representation of the reservoir behavior. The third objective is to clarify the variation of the reservoir parameters in three dimensions.

## METHODS OF INTERPRETATION AND INTERPOLATION

To perform computer analysis for well - logs of Alam El-Bueib Formation, the log reading must be in the digital format. The available well-logs have been digitized, quality controlled, data base editing, environmentally corrected, and multiwell normalized. The normalized well - log data are used to calculate some of the studied reservoir parameters of six pay zones (AEB-1 to AEB-6). The calculated reservoir parameters involve net pay thickness, total porosity, effective porosity, shale volume, water saturation, bulk pore volume and oil in place indicator. The estimation of porosity depends on the normalized logs of density, neutron and sonic using single log and cross-plots (Schlumberger, 1989). The calculated shale volume depends on gamma ray log. The water saturation value is calculated by using dual-water model. The bulk pore volume is carried out, using the equation:

PHIH = $\Phi$*h (Petcom, 1997) (1)

The oil in place is calculated, using the equation:

HPVH = PHIH * (1-Sw) (Petcom, 1997) (2)

The applied cut-off criteria which were used to compute net pay thicknesses are 10% for porosity, 35% for shale volume and 50% for water saturation. The computed reservoir parameters are averaged for each zone to reflect the general distribution.

Interpolation is a process of converting data to a real coverage, in which new values are estimated for locations where there are no tracks recorded on the basis of spatial patterns within the real data (Ghoneimi, 2002). The 3D slicing of Alam El-Bueib reservoir at the study area is required to detail petrophysical modeling and to determine the major reservoir characteristics of the Alam El-Bueib Formation which is divided into six zones. The values of log-derived parameters are grided. The inverse distance to power method is one of the most frequently used routines in modern interpolating algorithms. This method is used to extract data points in areas of unknown data. Through the use of this routine, one finally ends-up with a data matrix (for 2D-interpolation) or data volume (for 3D- interpolation) . Then, contours could be plotted at any selected planes. The inverse distance to power method is a weighted averaging interpolating technique. The equations used for the inverse distance to power are:

$$z_j = \sum_{i=1}^{n} \frac{z_i}{h_{ij}^{\beta}} \Big/ \sum_{i=1}^{n} \frac{1}{h_{ij}^{\beta}}$$

$$h_{ij} = \sqrt{d_{ij}^2 + \delta^2}$$ (Franke,1982) (4)

Where;

$Z_j$ is the interpolated value for destination data point;

$Z_i$ is the neighboring source data points;

$h_{ij}$ is the effective separation distance between the destination (output) data point (j) and the neighboring source (input) data point (I);

$\beta$ is the weighting power parameter;

$d_{ij}$ is the distance between the destination data point (j ) and the neighboring source point (I )

$\delta$ is the smoothing parameter.

Weighting is assigned to data through the use of the weighting power (ß) that controls how the weighting factors drop-off as distance (d) from a destination data point increases. The greater the weighting power, the less effect for points far from the grid node has during interpolation. As power increases, the destination data point value of the nearest source data point. For a smaller power, the weights are more evenly distributed among the neighboring source data point. The inverse distance to power weighting function is then scaled so that, it extends from one to zero over this distance. The process can be expressed in the following equation

$$\beta = \left(1 - \frac{d}{d_{max}}\right)^2 / \left(\frac{d}{d_{max}}\right)$$ (Daivs,1986) (5)

The inverse distance to power method can be either an exact or a smoothing interpolator. Normally, the inverse distance to power method behaves as an exact interpolator. When calculating a grid node, the weights assigned to the data points are fraction, and the sum of all the weights is equal to 1.0. In the inverse distance to power, the interpolated values are faithful to nearest data and the averaging effect between tracks assisted with weak distance weighting is reduced. The inverse distance to power algorithm is used in the present study to interpolate the log-derived reservoir parameters. The interpolation is carried out laterally in the X and Y- directions and vertically in the Z- direction. The result of interpolation is a volume of data in the three dimensions. This volume of data is used for the 3D-slicing of the Alam El-Bueib reservoir in any direction and at any location or depth.

## 3D- Slicing of Alam El-Bueib reservoir

The log-derived reservoir parameters are interpolated in three dimensions (X, Y and Z) to construct a 3D-model for each parameter (Gadallah 2001). The 3D-slicing of the generated models is used to show the variation and distribution of the studied reservoir parameters in varying sets of planes. The first set is the x-planes (five planes) showing the lateral variation of the petrophysical parameters with x-axis. The second set is the y-planes (six planes) showing the lateral variation of the petrophysical parameters with y-axis. The third set of planes with z-direction (six planes) showing the vertical variation of the petrophysical parameters with Z-axis. Figures (3 to 9) illustrate the layout of 3D-slicing of the pay-zones of Alam El- Bueib reservoir parameters. The a-sector and b-sectors of these figures show the outer faces of the model. The a-sector shows the three front faces (exterior view), while the b-sector shows the three back faces (interior view). The c, d and e-sectors show the internal slices dissecting the model in the X, Y and Z-planes, respectively. Finally, the f-sector shows selected samples of the internal slices in the three directions. It may be noted that, scale relations and orientation of the X, Y and Z-axes of the c, d and e-sectors are changed for a better prospective view of the variation.

## 3D-Slicing of total porosity of Alam El-Bueib pay zones:

Figure 3 illustrates the reservoir 3D-slicing of total porosity of Alam El-Bueib pay zones in Tut Oil Field. Figure (3a ) represents the exterior view of the reservoir which shows the changes of the total porosity in three faces. In the top face, the total porosity increases from 22 % to 28 % towardss the northeast. In the front and left side faces, there is a random distribution of the total porosity data that the minimum value (10 %) is encountered in the northwest of the front face and it increases slightly reaching (22%) at the centeral and the southeast sides. On the other hand, in the left side face, the total porosity increases slightly to the center, while it increases gradually from the center of the southern half towardss the southwest corner of the face reaching a maximum value of 30%. The interior view of the reservoir (Fig.3b) shows that the maximum value (30 %) is recorded in the bottom face, in the Southof the back and right side faces, while the minimum value of 10 % is encountered at the top boundaries between the back and right side faces. The variation of the total porosity with x – direction (Fig. 3c) reflects that the total porosity increases to reach the maximum value (30%) at the centeral part of the reservoir (plane III). It increases towardss the Southfor each plane with X-direction. On the other hand, the minimum value (10 %) is recorded in the east of planes IV, and V. Figure (3d) reflects the change of the total porosity in y – direction where the total porosity decreases from the left (plane V) to the right (plane I). The maximum value (30 %) is recorded in the three left planes V, IV and III, while the minimum value (10 %) is encountered in plane I. Figure (3e) shows the total porosity variation in Z-direction. The total porosity increases towardss the center of plane V and to the bottom ( plane I) reaching maximum value of 30 %, while the minimum value (10%) is present in the northeast and southwest corners of plane V. Figure (3f) illustrates the anatomy of the reservoir which represents the three tomographic zones together (X, Y and Z directions). The maximum total porosity value is recoded in the middle and Southof the reservoir, where the minimum value (14%) is encountered to the front of the reservoir.

## 3D-Slicing of effective porosity of Alam El-Bueib pay zones:

Figure 4 illustrates the reservoir 3D-slicing of effective porosity of Alam El-Bueib pay zones in Tut Oil Field. The exterior view (Fig. 4a) shows that in the top face, the effective porosity increases from the Southtowardss the northeast side. On the other hand, in the front and left side faces, there is an undulation increase of the data that the effective porosity values decrease from the Southto the center of the southern half (11%) then it increases again to the center of the reservoir (23%) after that it decreases and finally increases to the North edge. Figure (4b) shows the interior view of the reservoir which represents the change in the effective porosity in the opposite three faces. In the bottom face, the effective porosity increases gradually from the Southtowardss the North reaching the maximum value of 29%, while in the back and right side faces, the maximum value is encountered in the Southand in the center of boundaries between the two faces. The mimimum value of effective porosity is recorded in the North at the boundaries and the outer edges of the back and right side faces. The effective porosity increases from the outer edges to the inside boundaries of the back and right side faces reaching the maximum value of 29%. The variation of the effective porosity with X-direction (Fig. 4c) reflects the increasing of the values towards the center of the reservoir (plane III) and to the southwest of all the five planes. Figure (4d) represents the change of the effective porosity with Y-direction. The maximum value (29%) is recorded in the center of the middle plane (plane III) and to the Southof planes IV and V, while the minimum value of 11% is widespreaded in the southern half of all planes but common in the right planes (II and I). The vertical distribution of the effective porosity with Z-direction is illustrated in Figure (4e) where the largest value (29%) is present in the Southof plane I and in the center of plane IV. The lowest value of 11% is common in planes II and III and scattered in planes V and VI. The maximum value in these two planes is 25% to the northeast side. The internal view of the reservoir in the three directions X, Y and Z, is shown in Figure (4f) where the maximum value 29% is recorded in the center and back of the reservoir, while the minimum value is 11% is dominant in the middle of the southern half and in the front of the reservoir.

## 3D-Slicing of shale volume of Alam El-Bueib pay zones:

Figure 5 illustrates the reservoir 3D-slicing of shale volume of Alam El-Bueib pay zones in Tut Oil Field. The exterior view of the reservoir (Fig. 5a) represents the outer three faces; in the top face, the shale volume decreases from the Southto the north, where the maximum and minimum values are 19% and 7%, respectively. In the front face, the maximum value (19%) is recorded in the North at the boundary with the top face, while the minimum value (7%) spreads in the middle of the southern half of the face to the left side face. In the left side face, the maximum value is 13% at the northwest portion of the face. It decreases gradually to 7% at the centeral part of the face, while the minimum value 7% spreads in the southern part. The interior view (Fig. 5b) shows the opposite three faces. The bottom face is widespreaded with the shale volume of 13%, while in the back and right side faces, the common value is 7% at the Southand the North portions. The maximum value recorded in the back face is 17%, while it was 13% in the right side face. Figure (5c) represents the change of shale volume with X-direction. From Figure (5c), the minimum value (7%) is common in all the five planes specially to the right in planes III, IV and V. It spreads in the center and Southof planes I and II. The maximum value recorded in these five planes is 13%. The variation of shale volume in Y-direction (Fig. 5d) shows that the maximum value (19%) is recorded only the right top of plane I, while the minimum value (7%) increases towards the left till plane V. It is common in the South and in the right centeral sides of planes II, III, IV, V, VI. Figure 5e shows the vertical variation of the shale volume with Z-direction. From this figure, the shale volumes of 15% and 13% are common at the bottom of planes I and III, while plane II has a univolume of 7%. Planes IV and V show an increasing of shale volume from the northeast to the South of the reservoir. The maximum value (19%) is encountered only at the South of plane VI and gradual decreasing towards the North reaching a minimum value of 9%. The anatomy of the reservoir in three directions is illustrated in Fig.(5f), where the minimum values (7% & 9%) are spread in the middle of the South and center of the reservoir. The shale volume increases towards the top front of the reservoir reaching a maximum value of 17%.

## 3D-Slicing of water saturation of Alam El-Bueib pay zones:

Figure 6 illustrates the reservoir 3D-slicing of water saturation of Alam El-Bueib pay zones in Tut Oil Field. The exterior view of the reservoir (Fig 6a) is represented by three faces; the first is the top face, where the water saturation decreases from 65% in the South to 35% at the northern half of the planes. The second is the front face, where the lowest value (45%) is recorded in the northeast and southeast sides, while the maximum value (70%) spreads in the center of the face, and the third face is the left side face, where there is a gradual decrease from the left center towards the North and the southwest of the face. The maximum and the minimum values are recorded at the western half of the face. The interior view of the reservoir (Fig. 6b) represents the other outer three faces; the first is the bottom face, where the minimum value (35%) is common. In the South part of this face a slight increase of the water saturation data is encountered from the North to the South. The other two faces are the back and right side faces where the maximum values (70%) of the water saturation are present in the outer sides of the two faces, while the minimum value (35%) is scattered in the south, center and the middle North of the two faces. The variation of the water saturation with X–direction (Fig. 6c) shows that the minimum value (35%) is distributed in the left side of all the five planes but it is concentrated in the North of the right planes, where it increases from plane V to plane II. The maximum value (70%) is presented in the center of the right side of the planes and at the center of the left side of planes II and I. Figure (6d) reflects the change of the water saturation with Y–direction. The minimum value (35%) is common in the left three planes V, IV and III specially at the northern center, the middle and the South of these planes. The maximum value (70%) is spread in the middle of right planes (I, II) and is recorded in the west center of the other planes. Figure 6e shows the variation of the water saturation with Z–direction. The minimum value (35%) is common in four planes I, III, V and VI, while in plane II the main value is 55%, and in plane IV the water saturation decreases gradually to the northeast portion. The anatomy of the reservoir in the three directions X, Y and Z is shown in Figure (6f). From this figure, the maximum value is 70% encountered to the front of the reservoir, while the minimum value (35%) is recorded in the top of the X and Y planes and in the northeast of the centeral plane of the reservoir.

## 3D-Slicing of net pay thickness of Alam El-Bueib pay zones:

Figure 7 represents the reservoir 3D-slicing of net pay thickness of Alam El-Bueib zones in Tut Oil Field. The exterior view of the reservoir (Fig. 7a) shows that the minimum net pay thickness is 150 ft. that present at the top and bottom of all the three faces, while the maximum thickness of net pay is 450 ft. at the center edges between the front and left side faces that the net pay thickness increases towards the center of left side face and the centeral left of the front face. On the other hand, the net pay thickness increases to the northeast side of the top face, where the maximum value is 250 ft. The interior view of the reservoir Fig (7b) reflects that the net pay thickness is minimum (150 ft.) at the North and South of the left and back faces and increases gradually to reach a maximum value (450 ft.) at the centeral part of the back and right faces. Figure (7c) shows the variation of net pay thickness with X – direction. The net pay thickness increases in all planes towards the center of the reservoir, where the maximum thickness of net pay is recorded at the centeral part of plane III with a value of 700 ft. Also the net pay thickness increases towards the center of the reservoir for planes with Y – direction (Fig. 7d), where the maximum value is 700 ft. at the center of plane III and the minimum value (150 ft.) is encountered at the top

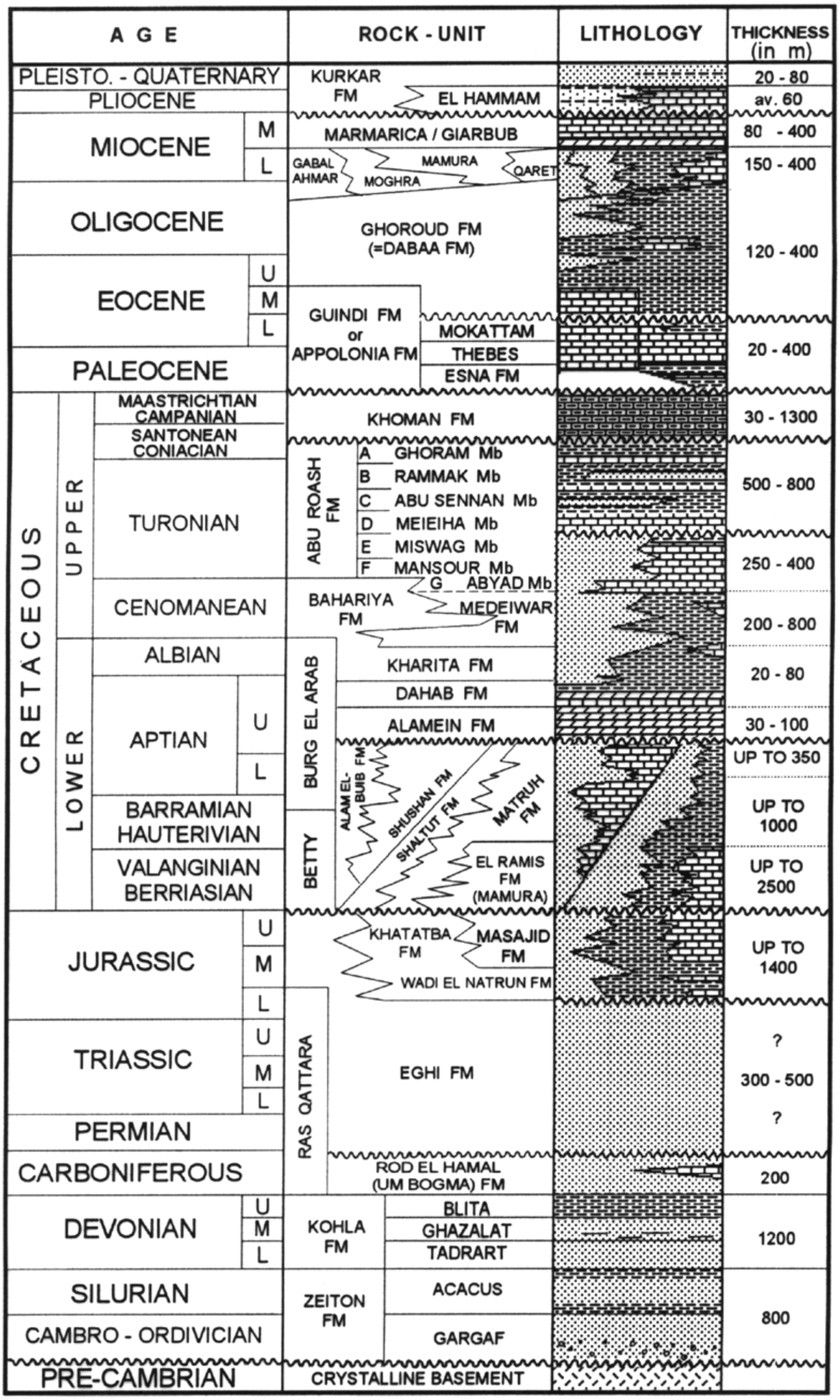


**Fig (2) Generalized litho-stratigraphic column of the northern Western Desert (Schlumberger, 1984 and 1995)**

and bottom of all planes. Figure (7e) represents the vertical distribution of the net pay thickness with Z-direction, where the maximum value is 700 ft. at the west centeral part of plane IV, while the minimum value (150 ft.) is encountered in the bottom of planes I, II and top of planes V and VI. The anatomy of the reservoir in X, Y and Z directions (Fig 7f) confirms the increasing of the net pay thickness towards the center of the reservoir with a value of 700 ft., while the minimum value (150 ft) is recorded at the top and bottom sides of the planes.

## 3D-Slicing of bulk pore volume and oil in place of Alam El-Bueib pay zones:

Figures 8 and 9 represent the reservoir 3D-slicing of Bulk pore volume and oil in place indicator of Alam El-Bueib pay zones in Tut Oil Field. The maximum values of bulk pore volume and oil in place indicator are shown in the central part of Alam El-Bueib Formation at the third zone little bit to the west. It is highly recommended to focuss the oil exploration in the identified areas of increasing oil in place indicator in Alam El-Bueib Formation, Tut Oil Field.

## CONCLUSIONS

The evaluated reservoir parameters of the six pay zones of Alam El-Buieb Formation in Tut Oil Field applying the inverse distance to power method on well-logging data of ten wells revealed the following:

1- The inverse distance to power algorithm gives acceptable results and allows greater choice of parameter setting, that can suit particular situation and requirements. It makes the reservoir identification possible in the inaccessible and /or lack of information areas.

2- Studying the reservoir 3D-slicing of gross thickness, net pay thickness, porosity, water saturation, bulk pore volume and hydrocarbon indicator of Alam El-Bueib pay zones give clear insight about the distribution of these reservoir parameters.

3- Evaluating the variation of petrophysical parameters with x, y and z directions and anatomy of Alam El-Bueib reservoir clarify the imaging reconstruction of reservoir characterization.

4- The visualization approach of Alam El-Bueib reservoir in 3D improves the identification of promising areas for redevelopment and plan strategies for optimizing Alam El-Bueib reservoir production.

5- It is highly recommended to integrate the present results with stratigraphy, structure and seismic data for better clarification of Alam El-Bueib reserevoir and for solvig the problems of oil production.

## REFERENCES

**Davis, J.C.; 1986:** Statistics and data analysis in geology. John Wiley and Sons, New York, 120 p.

**Franke, R.; 1982:** Scattered data interpolation: test of some method, Mathematics of Computations vol. 33, no. 157, pp. 181-200.

**GadAllah, M.M.; 2001:** Well-log analysis and reservoir 3D-slicing of Upper Cretaceous pay zones in October Oil Field, Gulf of Suez, Egypt. Journal of environmental research, vol. 3, pp 222-238.

**Ghoneimi, A. E.; 2002:** Reservoir 3D slicing of Lower Bahariya pay zones in Hayat and Yasser

Oil Fields, Western Desert, Egypt. J. Appl. Geophys., Vol. 1, September, pp 129-142.

**Hanter, G.; 1990:** North Western Desert, In the Geology of Egypt. R.Said (Ed.) Rotterdam, Netherlands, A.A. Balkema Publishers, pp. 293-319.

**Petcom; 1997:** PETCOM log analysis, software manual. Petcom Software and Services, Petcom, Inc. Dallas, Texas, USA, 455 P.

**Schlumberger; 1984:** Well evaluation conference of Egypt. Schlumberger Middle East, 305 P.

**Schlumberger; 1989:** Schlumberger log interpretation principles/applications, Schlumberger Educational Services, Houston, Texas, 250 P.

**Schlumberger; 1995:** Well evaluation conference of Egypt. Schlumberger Technical Editing Services, Chester, 365 P.