

EMPIRICAL INVESTIGATION OF WAVE VELOCITIES IN BAHARIYA FORMATION, WESTERN DESERT, EGYPT

BY

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بحث إستقرائي للسرعات الموجية في متكون البحرية بالصحراء الغربية ، مصر

عادل علي علي عثمان

تم اختيار ١١ بئراً محفورة في حقل بترول مليحة بالصحراء الغربية في مصر لبحث
السرعات السيزمية في متكون البحرية .

وقد درست علاقات السرعة بالعمق وكتبت معادلتها كما تم عرض توزيع متوسط
السرعة في المنطقة على هيئة خرائط كنتورية لمتكون البحرية ولبعض الصخور
السائدة فيه .

وقد حسبت قيم G كمعامل للتنوع ومثلت كخرائط كنتورية ، وكذلك
لعلاقات G مع العمق .

Key Words: Wave velocity, Velocity gradient, Heterogeneity factor.

ABSTRACT

In the Meleiha Oil Field, Western Desert of Egypt, eleven selected drilled wells were chosen to investigate the seismic velocities in the Bahariya Formation. The velocity-depth relations were studied and equated.

The average velocity distribution in the area was displayed in form of contour maps for the Bahariya Formation and some dominant rocks in it. G -values as an heterogeneity factor were calculated and presented as contour maps and also as G -depth relations.

INTRODUCTION

Empirical and theoretical investigations of the behavior of elastic waves in clastic sediments appeared in different publications. Among a great number of authors, [1-6], Wyllie [7], Jankowsky [8], and Cordier [9] are studied this phenomenon.

The velocity of propagation of seismic waves is affected by a number of factors as well as lithology, porosity, state of fractures, and the depth below the earth's surface. The physical characteristics of the rock are must affected by the depth below the earth's surface. The density and porosity of rocks vary essentially with depth. The effect of this variation is to increase the Velocity of propagation of seismic waves increases with depth.

Velocity plotted versus depth show wide scattering of values. Thus, clear relationships between velocity and depth cannot be established for different rock types in different localities. This lead to study the behavior of the elastic wave

velocities with depth in Bahariya Formation sediments which is not as well known. It is useful that, in the absence of well data, to apply a relation or formula connecting velocity and depth, which is more accurate for the geophysicists in both the interpretation or modeling.

A detailed analysis for the velocity behavior with depth for every rock type in the Bahariya Formation is the main goal of the present study. The used data come from wells in the Meleiha oil field, Western Desert of Egypt. The practical purpose arose from the fact that this Formation represents a problem for the depth prediction of seismic horizons in new exploratory wells, because the velocities vary considerably and in an unexpected manner over relatively short distances.

VELOCITY HETEROGENEITY FACTOR

Determination of velocity in simple geologic structures from surface seismic measurements depends largely on a simple mathematical model [10 & 11].

$$t^2 = t_o^2 + X^2 / V_{st}^2 \quad (1)$$

where t is the reflection travel time at source-receiver offset distance x , and t_o , and v_{st} are the zero-offset time and stacking velocity, respectively.

Table 1
Definition of the used symbols in the present work

SYMBOL	DEFINITION
V_p	longitudinal velocity
SH	shale
SHLS	shaly limestone
SS	sandstone
CALSH	calcareous shale
SSH	sandy shale
SHSS	shaly sandstone
LS	Limestone
V_{p7}	p-wave velocity in Well no. 7
V_{ave}	average wave velocity
V_{rms}	root mean square velocity
G	heterogeneity factor
FM	formation

For small values of x over a horizontally layered subsurface eq. (1) provides a satisfactory fit to the data; and the stacking velocity obtained by this way provides a good estimate of the root-mean squared (rms) velocity V_{rms} down to the reflecting horizon:

$$V_{rms} = \sqrt{\sum \Delta t_i v_i^2 / \sum \Delta t_i} \quad (2)$$

where Δt_i and v_i are the interval travel time and interval velocity within layer i , respectively. Al-Chalabi [12] studied relationships among rms, average, and stacking velocities of a source-receiver offset spread over a one-dimensional subsurface. Thus, the average velocity defined as:

$$V_{ave} = \sum \Delta t_i v_i / \sum \Delta t_i \quad (3)$$

Al-Chalabi shows that the differences between those velocities vary as functions of the velocity heterogeneity and the degree of stratification as:

$$G = (V_{rms}^2 - V_{ave}^2) / V_{ave}^2 \quad (4)$$

which G is the velocity heterogeneity factor. In case of rms velocity equals the average velocity, the ground will be homogeneous.

GEOLOGIC SETTING

The area falls in the unstable shelf of the Western Desert as shown in Fig. (1), which is characterized by a northward thickening of the sedimentary section. Another characteristic of the area is the basement high relief, resulting mainly from block faulting, but also affected by minor compressional folding. The central southern part of the area is characterized by a trough trending E-W bounded by major faults [13]. The sedimentary section ranges in age from Paleozoic to upper Tertiary. There are penetrated oldest rocks and are Permo-Triassic in age. The outcropping rocks in the area are the eroded Middle Miocene carbonates of the Marmarica Formation. A generalized stratigraphic column is presented in Fig. (2).

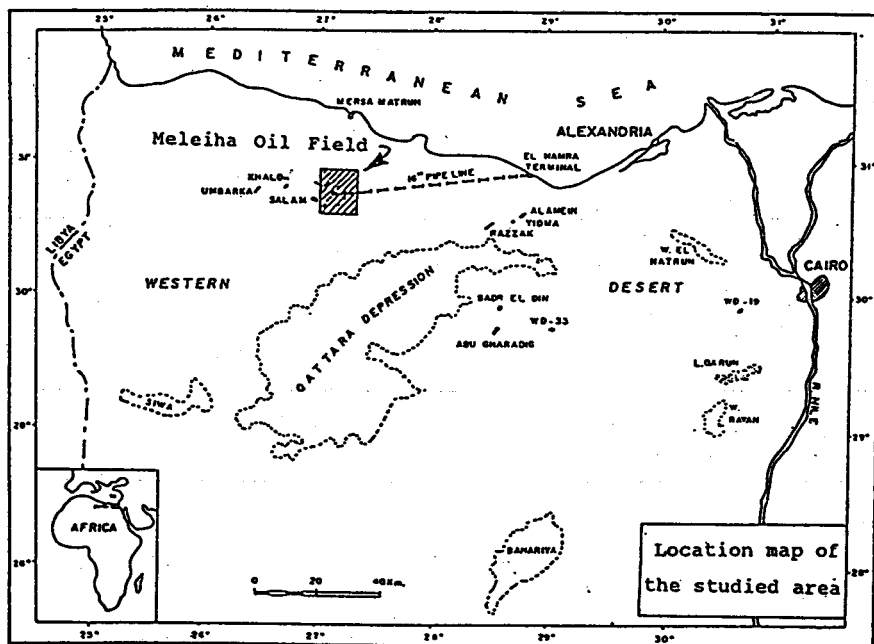


Fig. 1: Location map of the studied area.

The Meleiha area lies on the southern flank of the Matruh basin which has developed from a pre-Middle Jurassic graben by Late Jurassic time [14]. The top of the Jurassic was differentially eroded according the uplifting and faulting operations in most of the Western Desert.

Hydrocarbon production from the Western Desert is exclusively from the Cretaceous. The Bahariya Formation is of Cenomanian age and rests unconformably over the Burg el Arab Formation and conformably underlies the Abu Roash. Bahariya sandstones are part of the main gas pay zones at the Abu Gharadiq Field and constitute one of the main oil pays in the Razzaq Field.

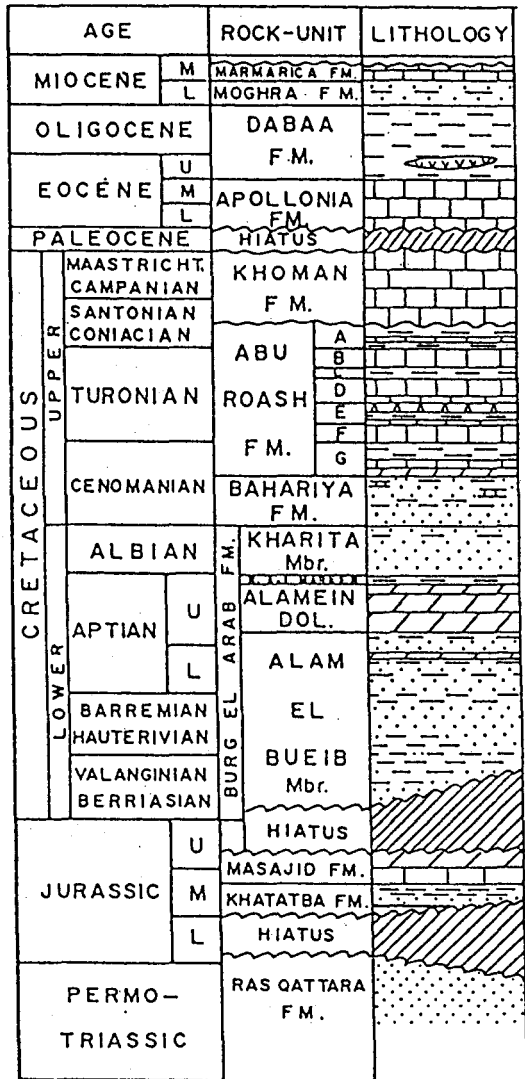


Fig. 2: Generalized stratigraphic column in Meleiha area.

BAHARIYA FORMATION

The Upper Cretaceous transgression started in the Cenomanian from the north of the Western Desert and spread as far south as the Bahariya Oasis, depositing the Bahariya Formation at this time. Gross interval thicknesses are typically 900 to 1200 feet thick, Schlumberger [15].

Lithologically, the Bahariya Formation consists mainly of sandstones with shale interbeds and carbonate inclusions. The Formation is characterized by numerous thin shale streaks, and shaly sandstones.

VELOCITY - DEPTH RELATIONS

As a result of the analysis for 11 wells drilled in Meleiha Oil Field, in the Western Desert of Egypt, the sonic logs were used to calculate the interval velocities of the p-waves. The relation between the velocities and the depth for all the available rock types in the Bahariya Formation, was plotted and displayed. The least linear fitting technique was applied to relate the velocity with the depth through the drilled wells in which the Bahariya Formation was presented.

As mentioned above, the normal relation between the velocity and the depth is increased by increasing depth. But the results, after analyzing the logs and some calculations, lead to some different relations between the velocity and depth in Bahariya Formation. The analysis procedure is executed for every rock type within the well and then for all rock types have been presented together, as shown in Fig. (3). For well M#7 in Meleiha Oil Field, as an example, the velocity values were calculated and plotted against depth. In shaly limestones decreased the velocity versus depth, Fig. (3d). It relates depth due to the following relations:

$$V_{SHLS7} = -3.07679 Z + 9738.91 \quad (5)$$

Shaly limestones in M#7 presented through the depth interval from 1845 m to 1905 m. It should be mentioned that V is the wave velocity in m/sec, and Z is the depth in meters. Subscript letters are defined in Table (1). The relation between velocity and depth for shale rocks in Bahariya Formation, which appeared at depth 1730 m down to 1830 m, as shown in Fig. (3c), increased steadily according to:

$$V_{SH7} = 0.97735 Z + 1414.27 \quad (6)$$

Equation (6) implies that the velocity increased as well as depth increased. A similar case was found when velocity-depth relation was computed for sandy shales rocks in well M#7, as displayed in Fig. (3b), which may be expressed as:

$$V_{SSH7} = 2.2194 Z - 834.145 \quad (7)$$

These rocks founded between 1850 m and 1910 m in M#7. This relation shows that the velocity increased by increasing the depth, in this well. The general relation between the wave velocity and the depth in the whole formation in well M#7 is displayed in Fig. (3a) and may be written as:

$$V_{P7} = 2.5623 Z - 777.161 \quad (8)$$

which describes the increase of the wave velocity with increasing the depth.

A general analysis was carried out for the rest of the 10 wells in the area. A similar technique was applied to the available data in these wells. That means studying the relation between velocity and depth for every rock type in every well throughout the Bahariya Formation which is analyzed and calculated. Results show that there are two groups of Bahariya Formation rock types in which the velocity-depth relations are changed. The first group which is composed of shale rocks, the main constituent rocks of the Bahariya Formation, shaly limestone, sandstone, and the calcareous shales. In this group, the velocity decreased by increasing the depth. In shale rocks, the velocity relates with depth by this relation:

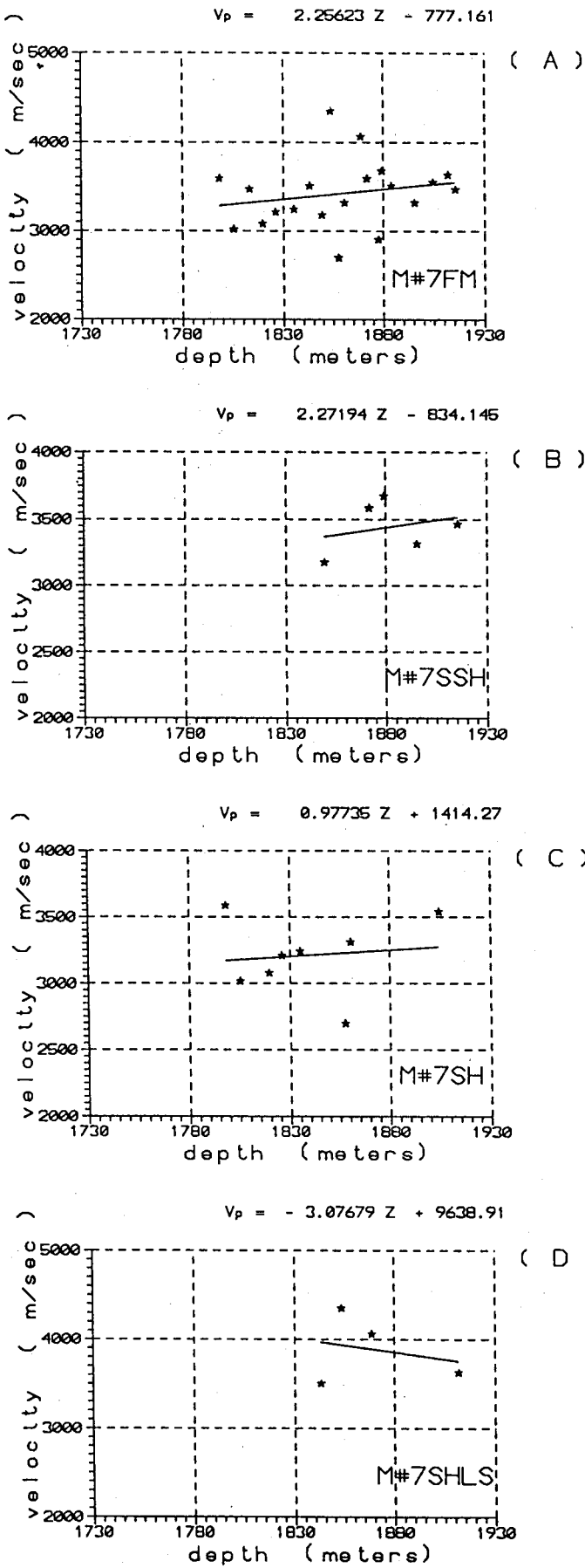


Fig. 3: Velocity-depth relations for rocks presented in well M#7.

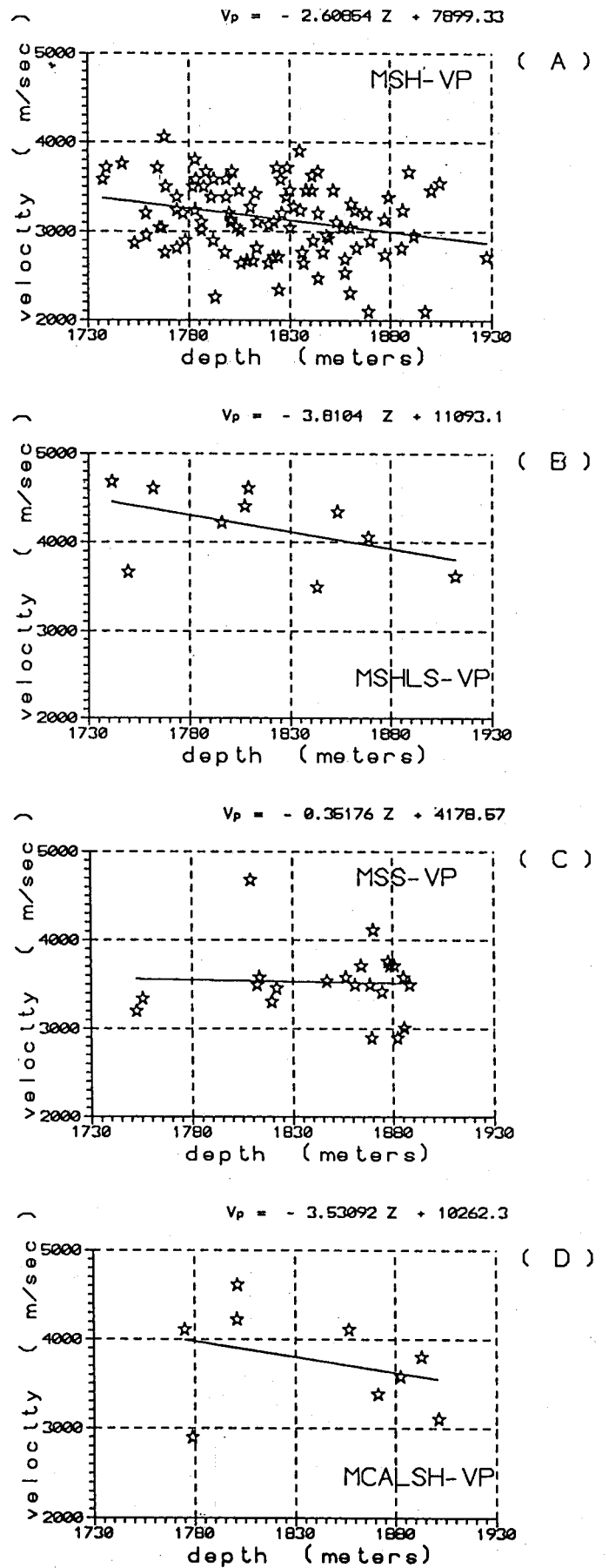


Fig. 4: Generalized velocity-depth relations displaying rocks of decreasing velocity with increasing depth in Bahariya Formation.

$$V_{SH} = -2.60854 Z + 7899.33 \quad (9)$$

The occurrences of shale rocks in Bahariya Formation, as shown in Fig. (4a), are of dense nature and ranged from depths equal to 1730 m from sea level to 1930 m. The wave velocity in these rocks decreases by increasing the depth as expressed in equation (9). But shaly limestones, which appear between depths equal to 1740 m and 1910 m, as displayed in Fig. (4b), are scattered and of small representation compared to shales for example. It constructs the following relation between velocity and depth:

$$V_{SHLS} = -3.8104 Z + 11093.1 \quad (10)$$

The existence of sandstone rocks in Bahariya Formation is represented, specially in the lower part of the Formation. The upper part shows a minor distribution of sandstones as shown in Fig. (4c). Wave velocities decrease downwards with depth in these rocks. Its relation is:

$$V_{SS} = -0.35176 Z + 4178.57 \quad (11)$$

Calcareous shale rocks, as shown in Fig. (4d) are dispersed throughout the Bahariya Formation and the velocity relates the depth according to the following equation:

$$V_{CALSH} = -3.53092 Z + 10262.3 \quad (12)$$

The second group of Bahariya Formation rocks are sandy shale, shaly sandstone, and limestone. In these rocks, the wave velocity increased by increasing the depth, and is considered as a normal relation which is expected one for velocity variations with depth when waves traveled through the earth's interior. Sandy shale rocks had a wide distribution within the Formation rocks which presented in Fig. (5a). It exists at depths equal to 1755 m and continues downwards to 1930 m. The velocity in these rocks increased y increasing depth, due to the relation:

$$V_{SSH} = 2.6487 Z - 1464.88 \quad (13)$$

Shaly sandstone rocks are represented only in the middle area of Bahariya Formation starting its depth at 1765 m and ending at 1830 m and plotted in Fig. (5b). The velocity relates the depth according to the following expression:

$$V_{SHSS} = 3.9229 Z - 3707.62 \quad (14)$$

From depth equals to 1775 m until 1920 m the limestone is occurring and dispersed in this range within Bahariya Formation rocks as shown in Fig. (5c). Its velocity increased by increasing depth as:

$$V_{LS} = 1.3467 Z + 1538.04 \quad (15)$$

Fig. (6) describes the general relation between the wave velocity and the depth in Bahariya Formation, which occupied the depths from 1730 m to 1930 m in Meleiha Oil Field, Western Desert of Egypt. In general, these results explain that the velocity of the wave propagated throughout the rocks and layers of Bahariya Formation decreases by increasing depth. This could be expressed by the following relation:

$$V_P = -0.00299 Z + 3491.01 \quad (16)$$

This resulted general decrease of the velocity with increasing the depth may be interpreted as well as the rich occurrence of the shales in Bahariya Formation.

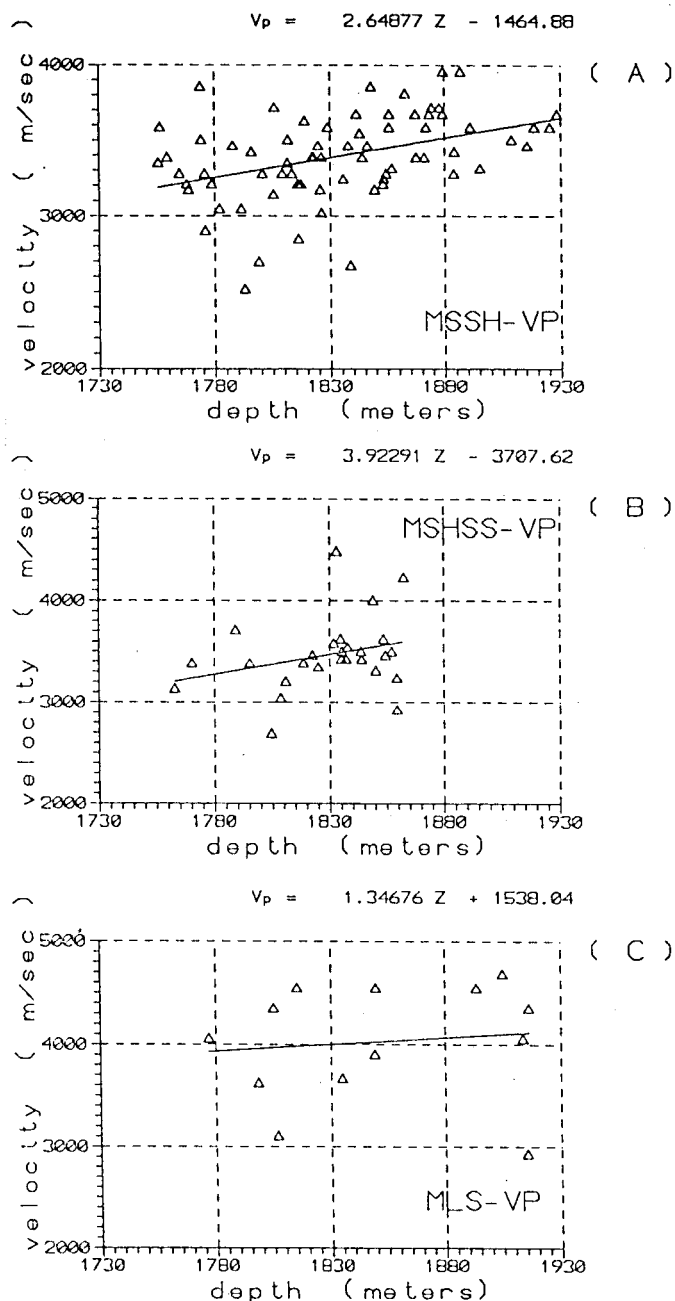


Fig. 5: Generalized velocity-depth relations showing rocks of increasing velocity with increasing depth in the Bahariya formation.

AERIAL DISTRIBUTION OF THE VELOCITY GRADIENT

The interval and the average velocities were calculated by applying equations two and three, respectively. The average and RMS velocities are used to compute the homogeneity factor G by means of equation four. Fig. (7) shows the relations of the interval velocities as function of depth in the studied wells in Bahariya Formation in Meleiha oil Field. It is easy to observe that, in general, the interval velocities increase by increasing the depth. But in M#6, the case is different. The velocity decreases with increasing depth, and the reason may

be due to the high occurrence of the sandstones in Bahariya Formation in this well.

$$V_p = - 0.0299 Z + 3491.01$$

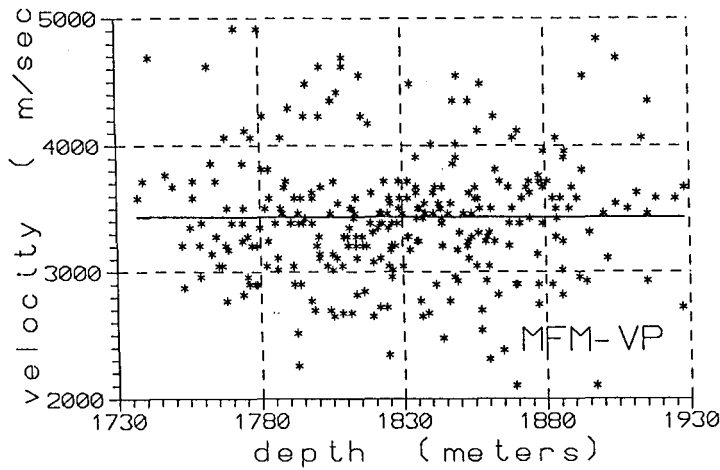


Fig. 6: Resultant general velocity-depth relation in Bahariya Formation, applying all the studied wells.

Average velocities which are depend mainly on the interval velocities, is displayed in Fig. (8). In this figure, increase the average velocities mostly by increasing depth in the studied wells. Exception cases appeared in this presentation as well as in wells M#4, M#6, and M#9. In M#4, shales occupied more area than the other rocks in Bahariya Formation. In well M#6 sandstones, sandy shales, and shales repeated it in a cyclic nature. In the last three rocks, the measured interval velocity decreases with increasing depth. In M#9, the shale dominates over a wide range in the Bahariya Formation presented in the well. After applying a linear fitting technique, as such as least square one, on the relation average velocity-depth, the slope of the fitted line (may be expressed as velocity gradient) was determined. Fig. (9), which is a map of the studied area, shows the well locations and the velocity gradient distribution. It is clear from the contour lines drowned in the map that the gradient values decrease in the eastern part of the area more than in the western one. The change of the velocity slope or gradient may be due to either the change of the depositional environment or a tectonic movement causes a shift for the Formation layers up or down from its original situations.

Structurally, Abdel Hady [16] studied the subsurface geology of the area and constructs a structural map, as shown in Fig. (10). By correlating this map with the map of velocity gradients, (Fig. (9)), some related features may be correlated. It may be used to study the structural setting and concluding the tectonic frame in the studied area. This actually depends mainly on the possibility of large number of wells to raise the resolution of the expected structural elements of an area. Although, in Fig. (9), two major trends may be defined from the condensation contour lines, the first directed NW-SE, and the second is NWW-SEE, as outlined from the map by line A-A and B-B, respectively. These two trends may be coinciding with the faults shown in Fig. (10) in the eastern part of the area. This coincidence may be lost in the western part of the area according to the shortage of drilled enough wells there.

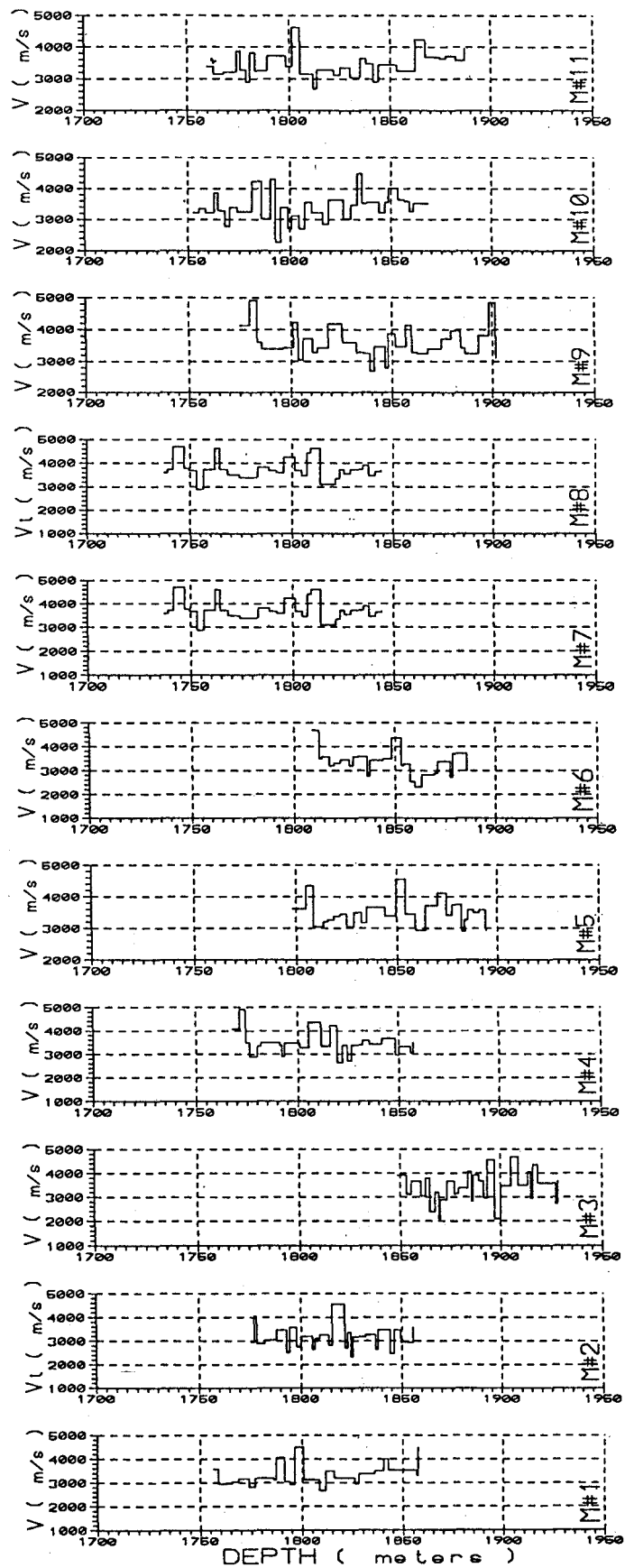


Fig. 7: Interval velocities as a close up view for the studied wells in the Bahariya Formation.

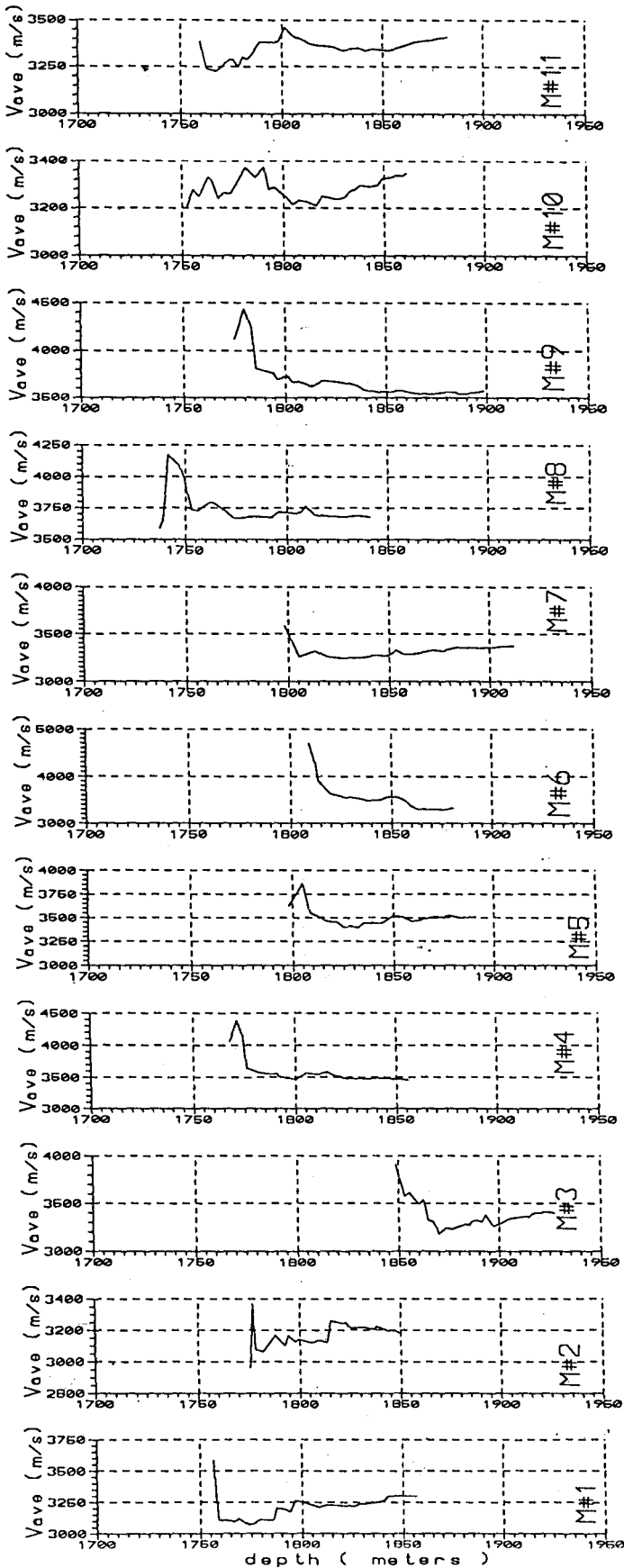


Fig. 8: Average velocities in the studied wells in Bahariya Formation as function of depth.

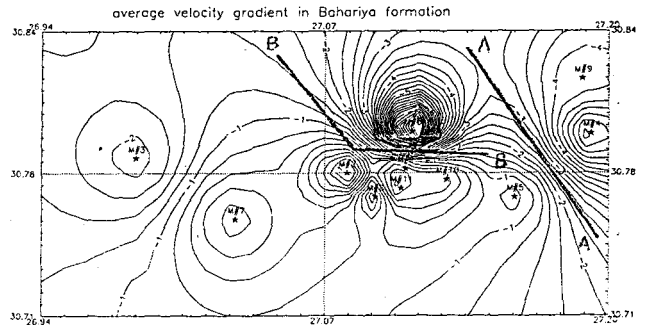


Fig. 9: Contour map for the average velocity gradient in the Bahariya Formation.

Two examples of the dominant rocks in Bahariya Formation will be studied. First example, is the velocity gradient distribution for sandy shale rocks. In Fig. (11), the contour lines confirm the presence of the two previous mentioned trends which explain that these velocity gradient trends may be due to existed structural faults. The second example, as shown in Fig. (12), is to display the velocity gradient contour lines for shale rocks in Bahariya Formation. It is obvious that shales are concentrated in the eastern part of the mapped area. These contour lines featuring the dominance of trend NW-SW which are in harmony with a fault has a similar direction in Fig. (10).

Fig. (13) shows the general variation of G-values with depth for all studied wells. The G-value is computed according to eq. 4. This factor, as stated before, describes the homogeneity state of the medium. That is means if G equals zero, then the medium is completely homogenous. As shown in Fig. (13), all the G-curves explain the inhomogeneity or the heterogeneity for the constituent rocks in Bahariya Formation by increasing the depth. The distribution of the G-values, as displayed in Fig. (14), expresses the inhomogeneity of the horizontal facies changes distribution. This inhomogeneity or heterogeneity is high in the western part of the map. The eastern part may show a nearly homogeneous case by comparing it with the western one.

CONCLUSIONS

The present study dealt with the velocity-depth relations and velocity gradient distribution in Bahariya Formation presented in 11 wells drilled in Meleiha Oil Field, Western Desert of Egypt. The following conclusions can be drawn from the results:

1. In Bahariya Formation there are two groups of rocks. The first group are shale, shaly limestone, sandstone, and calcareous shale. In which, the velocity-depth relation decreased by increasing the depth. In the second group which is composed from sandy shale, shaly sandstone, and limestone, the velocity increased with depth.
2. The velocity gradient in Bahariya Formation gives a good coherency with some structural elements in the studied area, and that may encourage more research to apply that technique as an indicator to inferring the subsurface structural framework.
3. G-values shows the heterogeneity vertically and horizontally in the Bahariya Formation. This is may be useful in the seismic modeling.

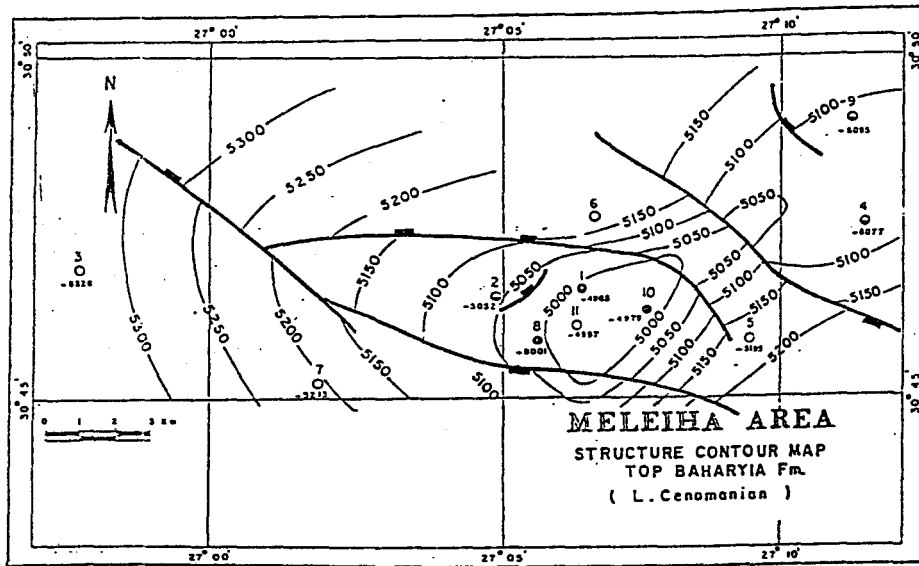


Fig. 10: Structure contour map for the top of the Bahariya Formation. (After Abdel Hady, 1985).

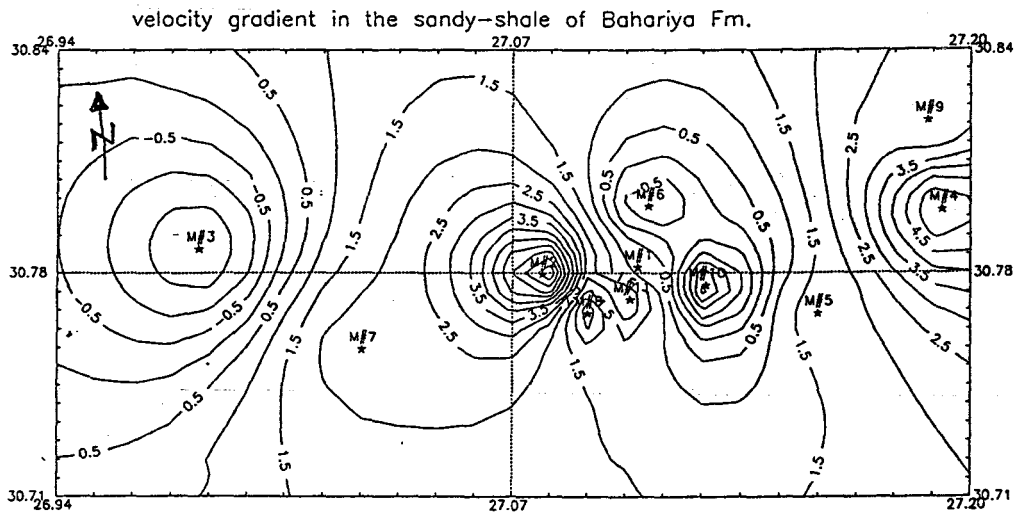


Fig. 11: Velocity gradient contour map for the sandy shales in the Bahariya Formation.

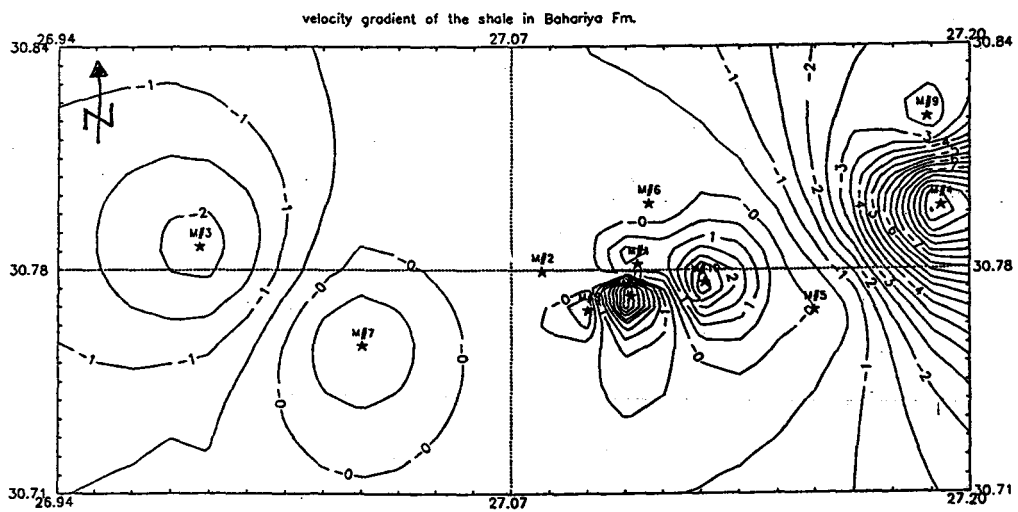


Fig. 12: Velocity gradient contour map for shale rocks in the Bahariya Formation.

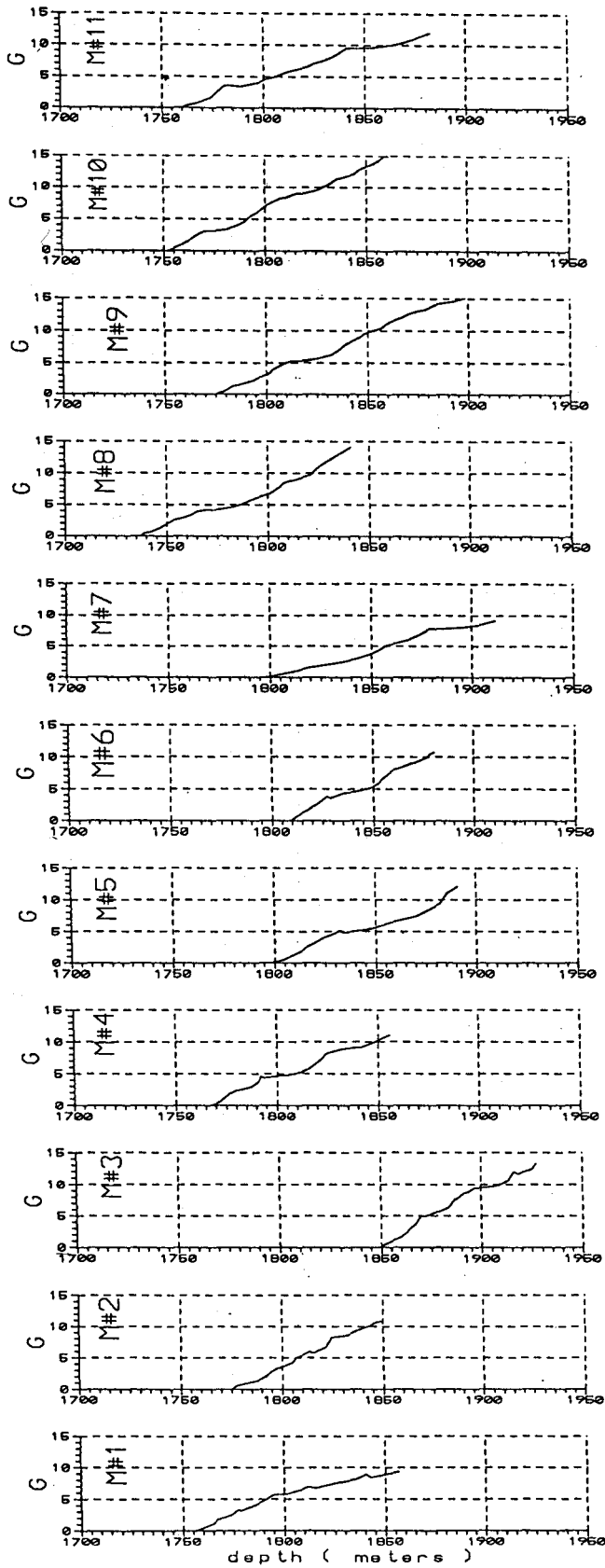


Fig. 13: Homogeneity factor (G) as function of depth in the studied wells in the Bahariya Formation.

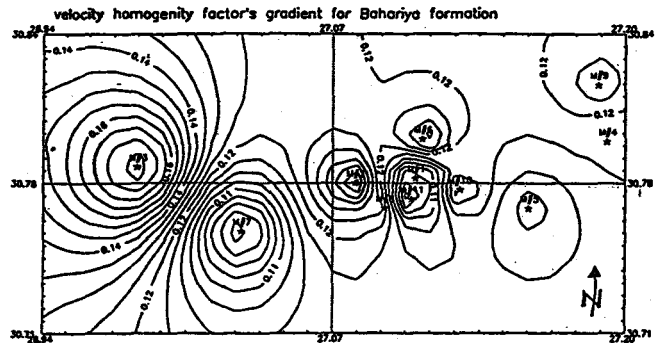


Fig. 14: G gradient contour map for the Bahariya Formation.

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