

A GEOPHYSICAL STUDY OF SOME GEOLOGICAL STRUCTURES IN THE LOW FOLDED ZONE, NORTH IRAQ

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ABSTRACT

The study area, which is characterized by numerous surface and subsurface structures of NW – SE dominating trend, is located in the Low Folded Zone of Iraq. The gravity responses of these structures are studied. The study is further extended to include the vertical and horizontal variations in density derived from seismic reflection data of two seismic profiles across Jambur structure. Such variations may be helpful in clarifying the sources of some gravity anomalies and also in theoretical modeling.

There are three aims of the present study; the first is to consider these responses, which reflect the effect on the gravity field due to the continuous compression of the Alpine stresses, taking into account that these stresses also have regional effects on the gravity field. Then, the total effects may be removed to obtain a new “corrected field”. The second is to estimate the maximum thickness of the sedimentary cover affected by the Alpine stresses, which might probably be observed in the gravity field “affected depth”, and the third aim is to calculate the gravity response of Jambur anticline from the available seismic data.

The results show that the gravity field responses are observed on the Bouguer map as gravity highs, lows and high gradients. The gravity highs coincide perfectly with the surface anticlines; however, some gravity highs show subsurface extensions. The gravity highs are elongate and narrow ellipsoidal or nose-shaped, whereas their magnitudes range from 1.2 to 8.0 mGal. The gravity lows can be divided into two groups according to their “origin”; the first has good matching with the synclines, while the second may be related to depressions. The shapes of these lows are either elongated and ellipsoidal running parallel to the gravity highs or broad circular shaped. The gravity value of those lows is close to – 2.0 mGal. Some gravity highs and lows are not reflected in the geologic map.

The results also show that the maximum thickness of the sedimentary cover where the Alpine stresses may be observed in the gravity field is about seven kilometers. In addition, two dimensional models of Jambur anticline show that the structure has a residual positive gravity value ranging between 8.0 and 9.0 mGal.

دراسة جيوفيزيائية لبعض التراكيب الجيولوجية في نطاق الطيات الواطئة، شمال العراق

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المستخلص

تقع منطقة الدراسة ضمن نطاق الطيات الواطئة وتتميز بوجود العديد من التراكيب السطحية وتحت السطحية ذات الاتجاه شمال غرب - جنوب شرق والناشئة عن الاجهادات الألبية المستمرة. تم دراسة تأثير تواجد هذه التراكيب على المجال الجذبي ودراسة أشكال ومقادير التغيرات الجهدية (الشواذ) المتسببة عنها.

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ان دراسة مثل هذه التأثيرات قد تكون مفيدة جدا خصوصا إذا ما تمت إزالتها وإعطاء خارطة مصححة من هذه التأثيرات. كما وتم دراسة علاقة الكثافة مع العمق، والمستنبطة من معلومات السرعة الزلزالية عبر تركيب جمبور، ومدى الاستفادة منها في فهم التغيرات العمودية والأفقية في الكثافة وعلاقة هذه التغيرات بالشواذ الجاذبية الملاحظة إضافة إلى إمكانية الاستفادة منها في تقديم نموذج ثنائي الأبعاد للمجال الجاذبي المحسوب لهذا التركيب.

لقد تبين من خلال نتائج الدراسة الحالية ان تأثير الاجهادات الألبية يكون واضحا على المجال الجاذبي ومعبر عنه بالمرتفعات والمنخفضات الجاذبية والانحدارات الأفقية العالية في قيم هذا المجال. تتخذ المرتفعات الجاذبية أشكال بيضوية أو بيضوية مفتوحة ضيقة ومتطاولة. كما وجد ان قيمة المرتفعات الجاذبية والعائدة إلى التراكيب الجيولوجية السطحية المتمثلة بالطيات المحدبة تتراوح بين 1,2 إلى 8,0 مليكال، أما المنخفضات الجاذبية المتطابقة مع الطيات المقعرة فتكون مقاديرها بحدود - 2,0 مليكال. إضافة إلى ذلك فقد كانت مقادير الانحدارات الأفقية في المجال الجاذبي والعائدة إلى تأثير الفوالق العكسية ما بين 5,25 إلى 7,5 مليكال\كم. لقد بينت الدراسة أيضا ان بعض المرتفعات الجاذبية لها امتدادات تحت السطح وأخرى غير مؤشرة على الخريطة الجيولوجية. كما ان هناك عدد من المنخفضات الجاذبية التي من الممكن ان لا تعود مصادرها إلى الطيات المقعرة، بل قد تشير إلى وجود منخفضات تحت سطحية قد تحتاج إلى دراسة تفصيلية لاحقة. أما الانحدارات الأفقية في الجهد الجاذبي فإنها ترتبط بالفوالق العكسية التي كان لها الدور الكبير في زيادة قيم المرتفعات الجاذبية.

لقد بينت تفسيرات نتائج دراسة العلاقة كثافة - عمق ان النطاق العلوي من العمود الرسوبي، والبالغ سمكه 13 كم في منطقة الدراسة، وبالتحديد السبعة كيلومترات الأولى تكون مسؤولة عن الشواذ الجاذبية ذات المصادر العائدة للغطاء الرسوبي والملاحظة في خارطة بوجير. أما الشواذ الجاذبية ذات المصادر الأعمق من هذا النطاق فهي تعود إلى الانبثاقات القاعدية أو فوق القاعدية نتيجة لوجود فرق كثافي قابل للقياس من على السطح، وقد سمي هذا النطاق "بالعمق الفعال". كما تم حساب التأثير الجاذبي لتركيب جمبور باستخدام المعلومات الزلزالية من خلال إنشاء موديل كثافي ثنائي الأبعاد. لقد وجد ان مقدار التأثير الجاذبي لهذا التركيب يتراوح بين 8 إلى 9 مليكال.

INTRODUCTION

The Low Folded Zone (LFZ) (or Foothill Zone) is located between the Mesopotamia Foredeep from SW and the High Folded Zone from the NE. The southern boundary of the zone runs parallel to the first topographic break of slope (step) made by first front of the Zagros mountain range, whereas the northeastern boundary is taken along the second topographic step made by series of relatively high shortening anticlines (Fouad, 2012) (Fig.1). It has a complete sedimentary pile due to strongly subsiding since the opening of the southern Neo-Tethys in the late Jurassic.

Consequently, the area contains three major oil bearing structures; Kirkuk, Bai Hassan and Jambur anticlines, which awarded the area an economic importance. Gravity survey has covered many parts of the study area since the earlier half of the last century. The gravity survey was followed by aeromagnetic survey during the 1970s. Unfortunately, the northern and northeastern parts of the study area were not covered neither by aeromagnetic nor gravity surveys. However, the present study is an attempt to understand the influence of such structures, which are built up through the of Alpine Orogeny, on the gravitational field. Moreover, the information gained from seismic reflection data on Jambur area in 1976 by the Compagnie General De Geophysique (CGG), which was not previously covered by a gravity survey, may be useful in studying the gravity response of this structure and also contribute to the enrichment of the geological knowledge of the area. The area of study is located between 43° 30' to 45° easting and 35° to 35° 45' northing (Figs.1 and 2).

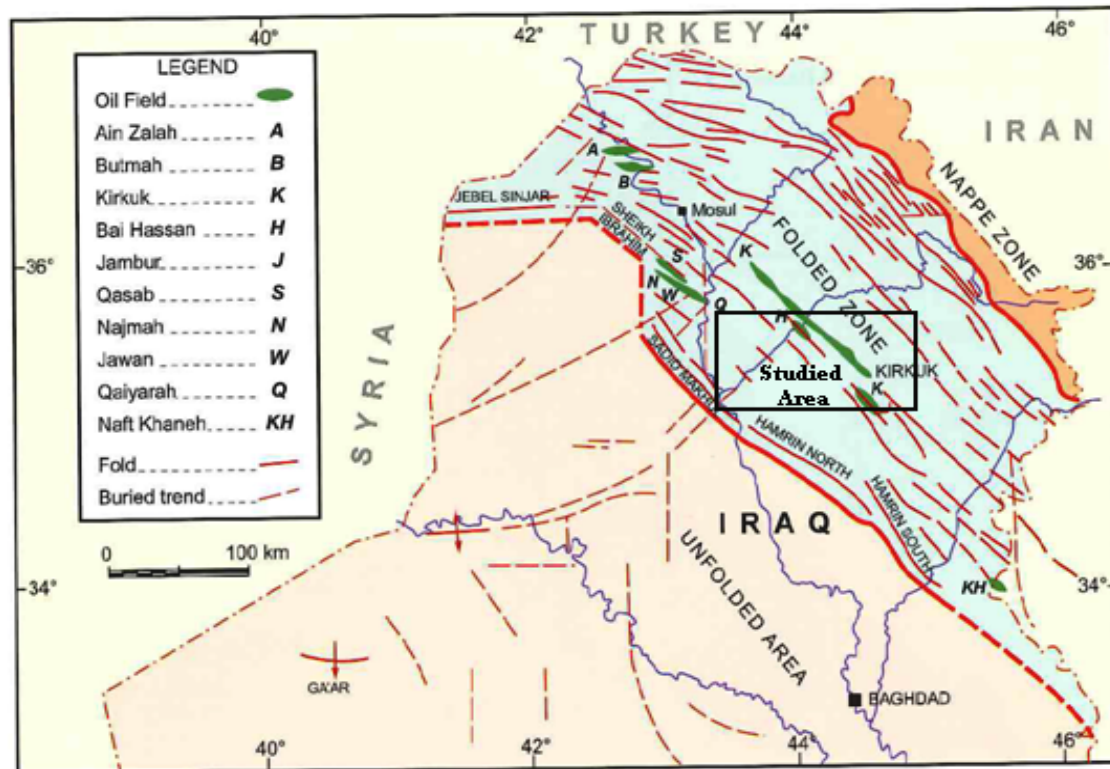


Fig.1: Map of northern Iraq, including the study area, where Nappe, Folded and Unfolded Zones are recognized. The southern boundary of the LFZ is marked by series of Folds (after Dunnigton, 1958 in Aqrabi *et al.*, 2010)

▪ Geological Setting

Tectonically, the study area lies in the northeastern part of the Arabian Platform. Fouad (2010) divided the Platform into Inner and Outer Platforms, and accordingly, the LFZ is located in the Outer Platform. He mentioned that the LFZ is an integral part of the Western Zagros Fold – Thrust belt. The Zone is bounded from the NE by the prominent mountain front of the High Folded Zone, and from the SW by relatively flat terrains of Mesopotamian Foredeep.

Structurally, the LFZ is characterized by structural trends and facies changes that are parallel to the Zagros – Taurus belts (dominantly NW – SE or E – W) (Jassim and Goff, 2006). The folds generally flatten towards the Mesopotamian Basin where relatively narrow anticlines are separated by wide synclines (Aqrabi *et al.*, 2010) filled by thick Pliocene and different types of Quaternary sediments (Sissakian, 1993 and Jassim and Goff, 2006). Moreover, the Zone has very thick Miocene – Pliocene molasse sediments (~ 3000 m thick), and the Hemrin Makhul block contains relatively narrow long anticlines (100 to 200 Km long) often associated with reverse and normal faults (Jassim and Goff, 2006). The anticlines present within the study area include Taq Taq, Cham Chamal N, Cham Chamal S, Bai Hassan, Jambur, Hemrin N and Makhmur and the synclines are Khal-Khalan and Qara Hanjir. Kirkuk structure is the longest and the largest structure within the study area extending from the SE to the NW for a distance of about 114 Km (Fig.2), and consists of three domes; Baba, Avanah and Khurmala. It is thrust along its axis. Hemrin, Jambur and Kirkuk anticlines have extensions outside the study area. Generally, the anticlines are long and trend with decollement thrust faults originated at detachments surfaces at the base of the saliferous beds

of Fatha Formation often producing “gamma-structures” and they are also segmented into doubly plunging domes; the segmentation usually occurs at intersections with transversal faults where the axis of the anticline are bent (Jassim and Goff, 2006). Different types of faults exist within the study area (CGG, 1976); all are associated with anticlines. The thrust faults are believed to be developed during the late stages of fold development to accommodate shortening as the folds tightened (Fouad, 2012).

▪ Previous Studies

The following geophysical works were made on the study area:

- The gravity survey that covered most of the Iraqi territory except the northern and northeastern parts. Many parts of the study area are covered by this survey. The results are compiled and unified as Bouguer Gravity maps scale 1: 250 000 by Al-Kadhimi *et al.* (1984).
- The seismic reflection survey was executed by the CGG in (1976) in Jambur area. Seismic time sections showed four reflectors (H1 to H4) represented by:
 - H1 represents the top of Fatha Fn.
 - H2 could be the base of Jeribe Fn.
 - H3 is Kometan Fn.; it represents the base of this formation (very close to the top of Qamchuqa Fn.).
 - H4 could be the top of the Jurassic.

Time sections 10.2 Km long which indicate more than 2.5 Km of depth show the actual size of Jambur anticline (Figs.3a and 3b). Again, no gravity measurements cover this area. Such measurements would be useful in quantitative evaluation when compared with seismic and boreholes information. Nevertheless, the gravitational effect of this structure could be calculated using the available seismic velocities (Gardner *et al.*, 1974 and Sharma, 1976).

- Al-Bahadily (1997) studied different types of empirical relationships derived from velocity analysis of seismic reflection data and sonic logs. The relationships relate the travel time, average and interval velocities with depth. He interpreted the parameters of these relations in terms of variations in porosity and compaction throughout the study area. The average velocity and the travel time may be used to study the relationship between density and depth as it will be explained subsequently in a paragraph of density-depth relationship derived from seismic reflection data.

The aim of the present study is to interpret the gravity responses of some Alpine structures of the LFZ by isolating their effects from the background with special reference to the Jambur structure. It also aimed to estimate the maximum thickness of the sedimentary cover affected by the Alpine stresses “effective depth” by studying the density-depth relationship.

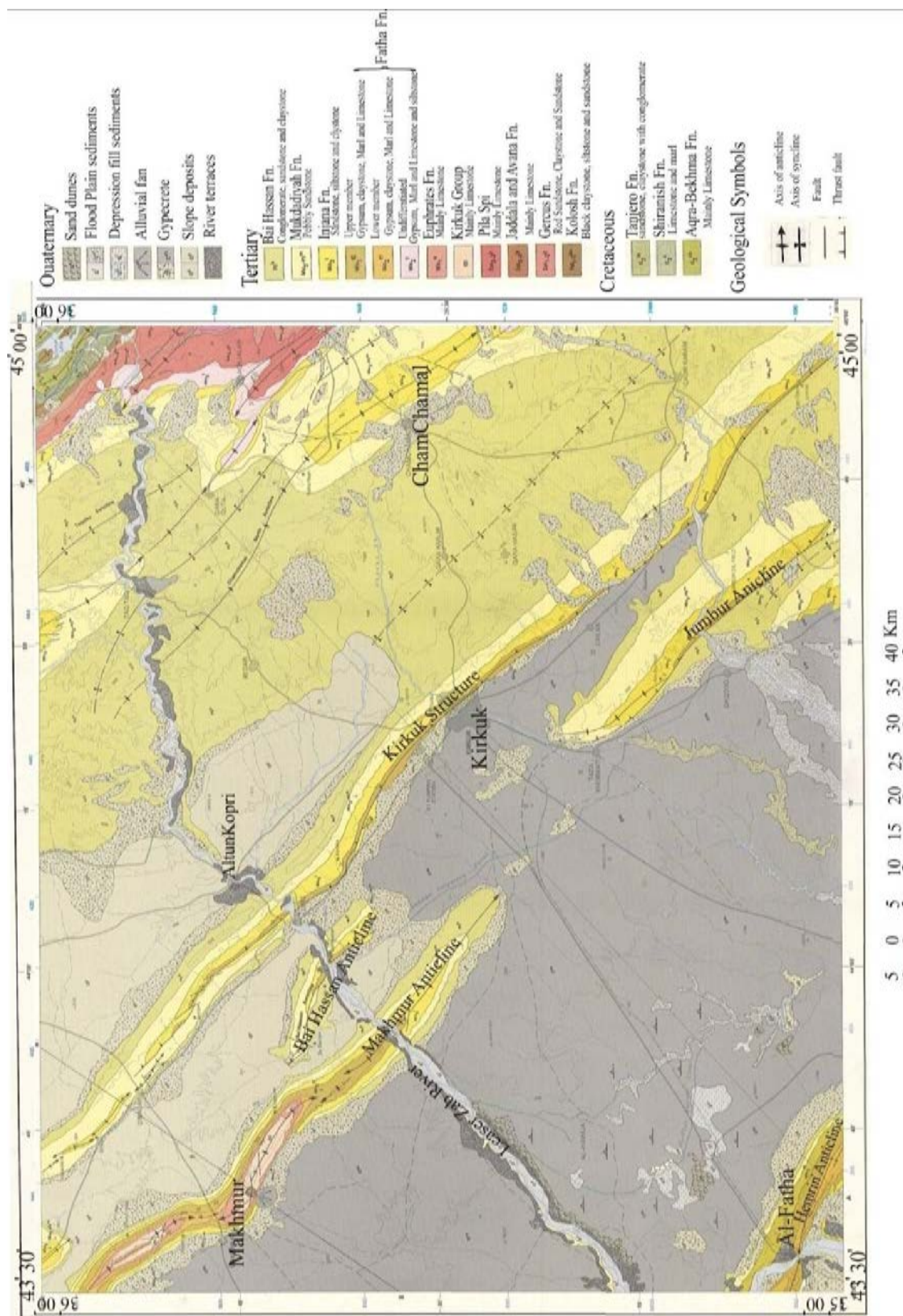


Fig.2: Geologic map of the study area (after Sissakian, 1993)

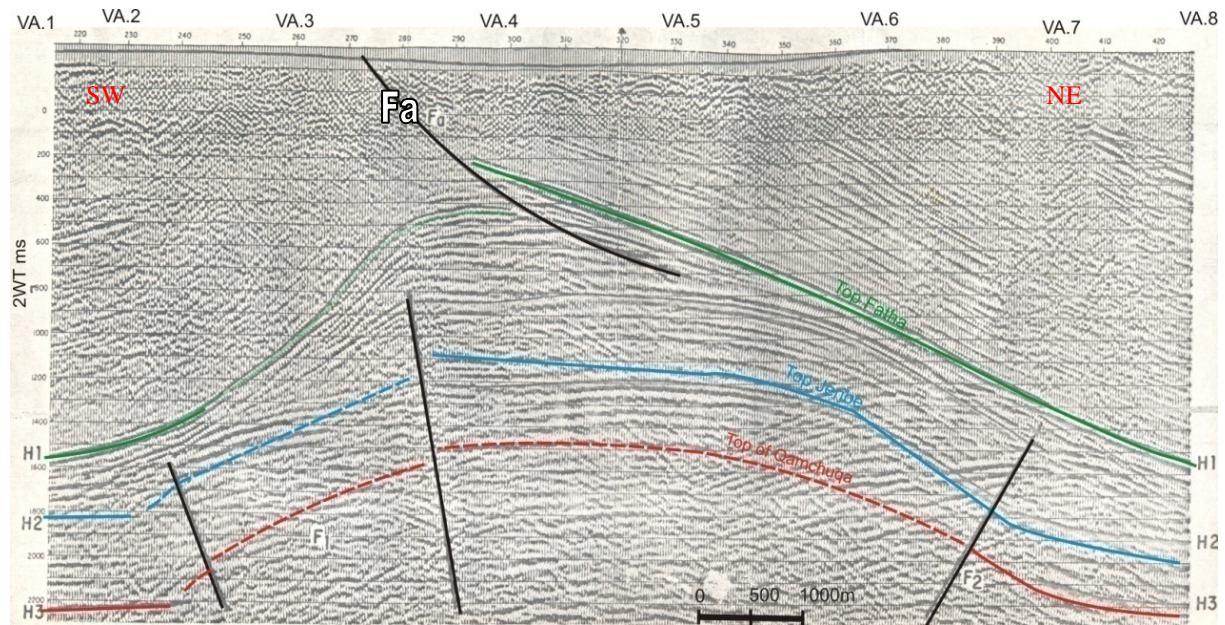


Fig.3a: Time section across Jambur anticline (seismic line J1) shows the decollement thrust fault (Fa) originated in a detachment surface at the base of the saliferous beds of Fatha Fn.; VA.1 represents the location and the number of the velocity analysis. H1, H2 and H3 represent the tops of Fatha, Jeribe and Kometan Formations, respectively, (CGG, 1976). For location refer to Fig.4

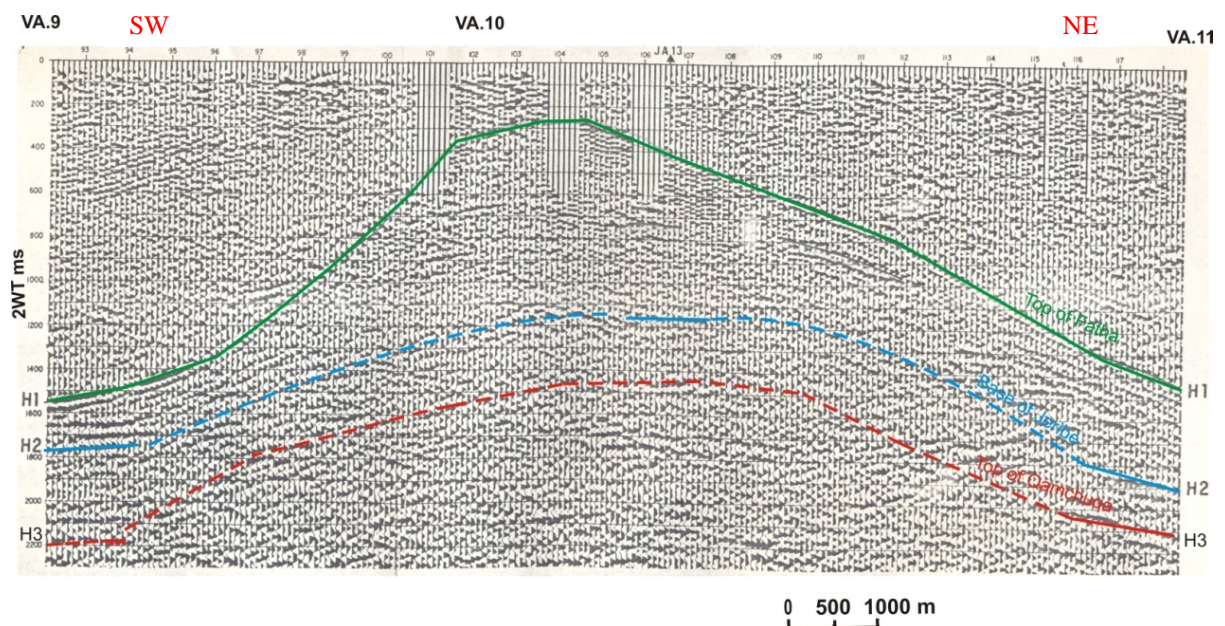


Fig.3b: Time section across Jambur anticline (seismic line J2) (CGG, 1976). For the location refer to Fig.4

GEOPHYSICAL DATA

▪ Description and Some Possible Interpretations of the Gravity Anomalies

Bouguer gravity and residual maps of Al-Kadhimi *et al.*, (1984) scale 1: 250 000 are used to delineate the gravity anomalies especially that of regional nature; the studied anomalies are more than 10 Km long (Fig.4). They mentioned that the regional field is calculated by using Griffin's ring (eight points method) in which the circle radius (R) = $2\sqrt{5}$ Km. The rings of this radius may cover the studied anomalies.

The most prominent features in Fig. (4) are the elongated gravity highs (often ellipsoidal and nose-shaped anomalies), which geologically reflect the narrow anticlines of NW – SE trends. These highs are numbered with the letter G from the SW to the NE. Table (1) gives the gravity value of each high and its corresponding anticline. The gravity values are extracted from the residual map.

Table 1: The magnitudes (Δg) of the gravity highs

Gravity high	Structure	Δg (mGal)
G1	Hemrin anticline	7.0
G2	Southwestern part of Makhmur anticline	2.8
G3	Southeastern part of Bai Hassan anticline	1.2
G5	Southeastern part of Jambur anticline	7.0
G6	Kirkuk anticline	8.0
G9	Chamchamal N anticline	4.0
G10	Southern part of Taq Taq anticline	1.0

The geological map (Fig.2) shows that G3 (the gravity effect of Bai-Hassan anticline) disappears gradually towards the SE while the Bouguer map (Fig.4) shows a distinctive subsurface continuation of this high. Also, some gravity highs are not reflected in the geological map. These are G4, G12, G13 and G14. G4 has an extension towards the southeast outside the study area with maximum amplitude of 3.0 mGal. G12, G13 and G14 trend NE – SW, and are relatively short (11, 8 and 17 Km, respectively) with ellipsoidal shapes and Δg of about 2.2, 1.6 and 1.4 mGal, respectively. They may be attributed to subsurface antiforms or facies changes. In addition, the gravity lows are shown in Table (2) as follows.

Table 2: The magnitudes (Δg) of the gravity lows

Gravity Lows	Structure or other possible source	Δg (mGal)
G17	A structural low trending NW – SE	– 2.2
G18	A narrow and elongated depression runs along the southwestern flank of Kirkuk anticline	– 6.0
G20	Syncline	– 2.4
G21	E – W ellipsoidal depression	– 2.0
G22	Qara Hanjir syncline	– 2.0
G24	E – W ellipsoidal depression	– 2.0

The gravity lows G17, G18 and G21 have almost the same direction as that of the above mentioned gravity highs. Furthermore, two high gradients are seen on the Bouguer map; the first is accompanied with Hemrin gravity high (G1), with an average of 5.25 mGal/Km. This

high gradient may be related to subsurface thrust faults which is not reflected on geological map. The second one is accompanied with Kirkuk gravity high (G6), with an average of 7.5 mGal/Km. This high gradient represents the gravity response of the thrust fault. The magnitudes of these high gradients depend mainly on the intensity of folding and the depth of the structure. The Himreen – north gravity field over the S of Makhmur to Himreen – north anticlines exhibits a uniform gradient (0.5 mGal/Km) in nearly E – W direction and it shows different gravity response to that in the area north of Makhmur anticline.

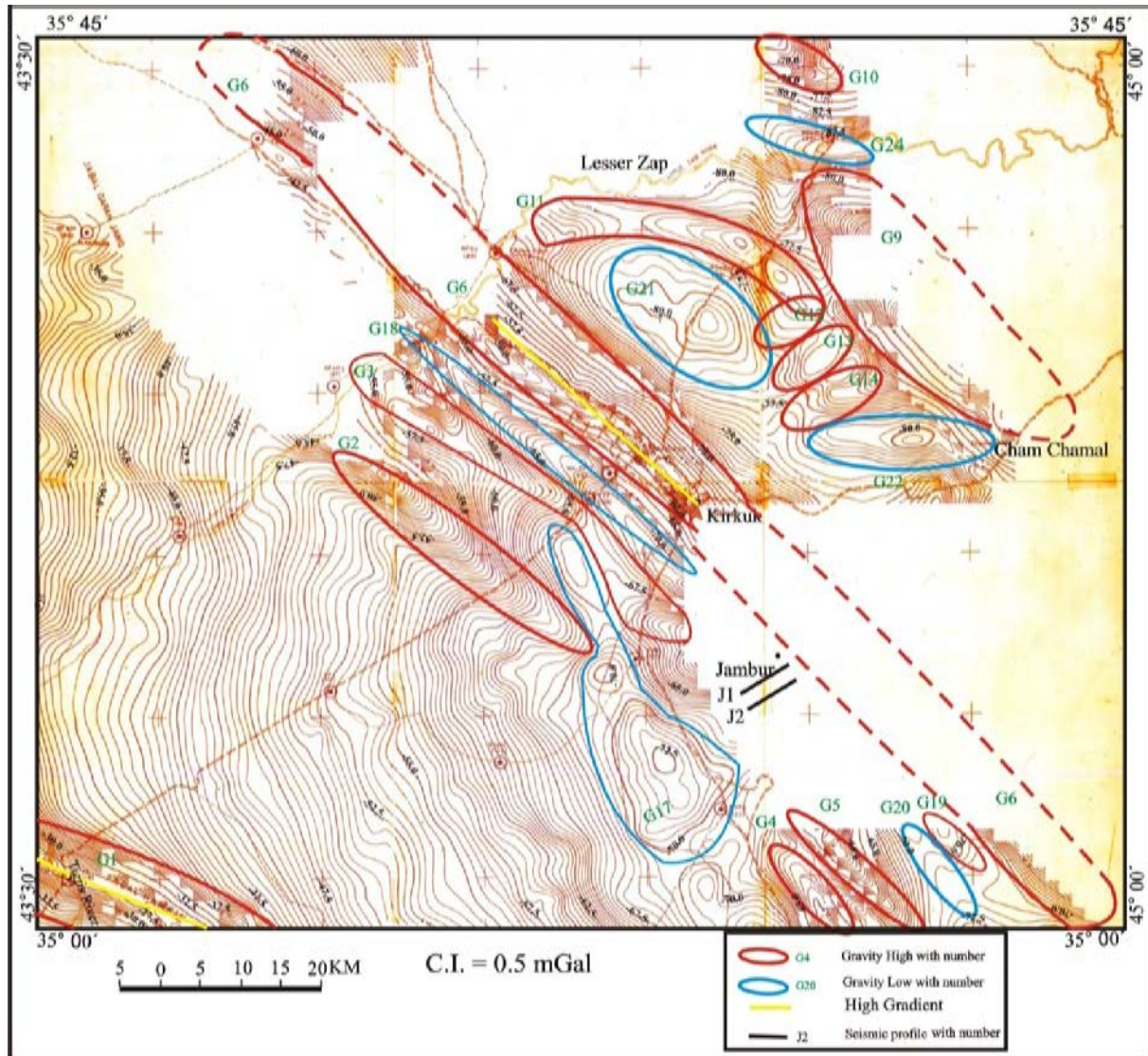


Fig.4: Bouguer gravity map of the study area (after Al-Kadhimi *et al.*, 1984)

▪ Seismic Data

The available seismic reflection data of Jambur structure are two migrated time sections (seismic lines J1 and J2) and the velocity analyses of eleven locations distributed on these lines. Velocity analyses from VA.1 to VA.8 lie on line J1 and the others (from VA.9 to VA.11) lie on line J2 (CGG, 1976).

– **Density – Depth Relations Derived from Seismic Reflection Data:** There is no gravity measurement covering Jambur area (Fig.4). However, any information related to distributions of density with depth may be useful for gravity interpretations. Therefore, the velocity analyses are used to calculate the density using Nafe and Drake's relationship (Nafe and Drake, 1957), which is commonly used to estimate density from V_p :

$$\rho = 0.23 V_p^{0.25}$$

Where: ρ = bulk density in g/cm^3 ; V_p ($V_{\text{ave.}}$) = P-wave velocity in ft/sec

Figure (5) shows the distribution of densities along the entire sedimentary column. Wide range of densities (ρ from 2.04 to 2.38) gm/cm^3 is observed near the surface of the earth while a relatively narrow range at the deeper part (ρ from 2.53 to 2.62) gm/cm^3 . Based on these results, the following conclusions are revealed:

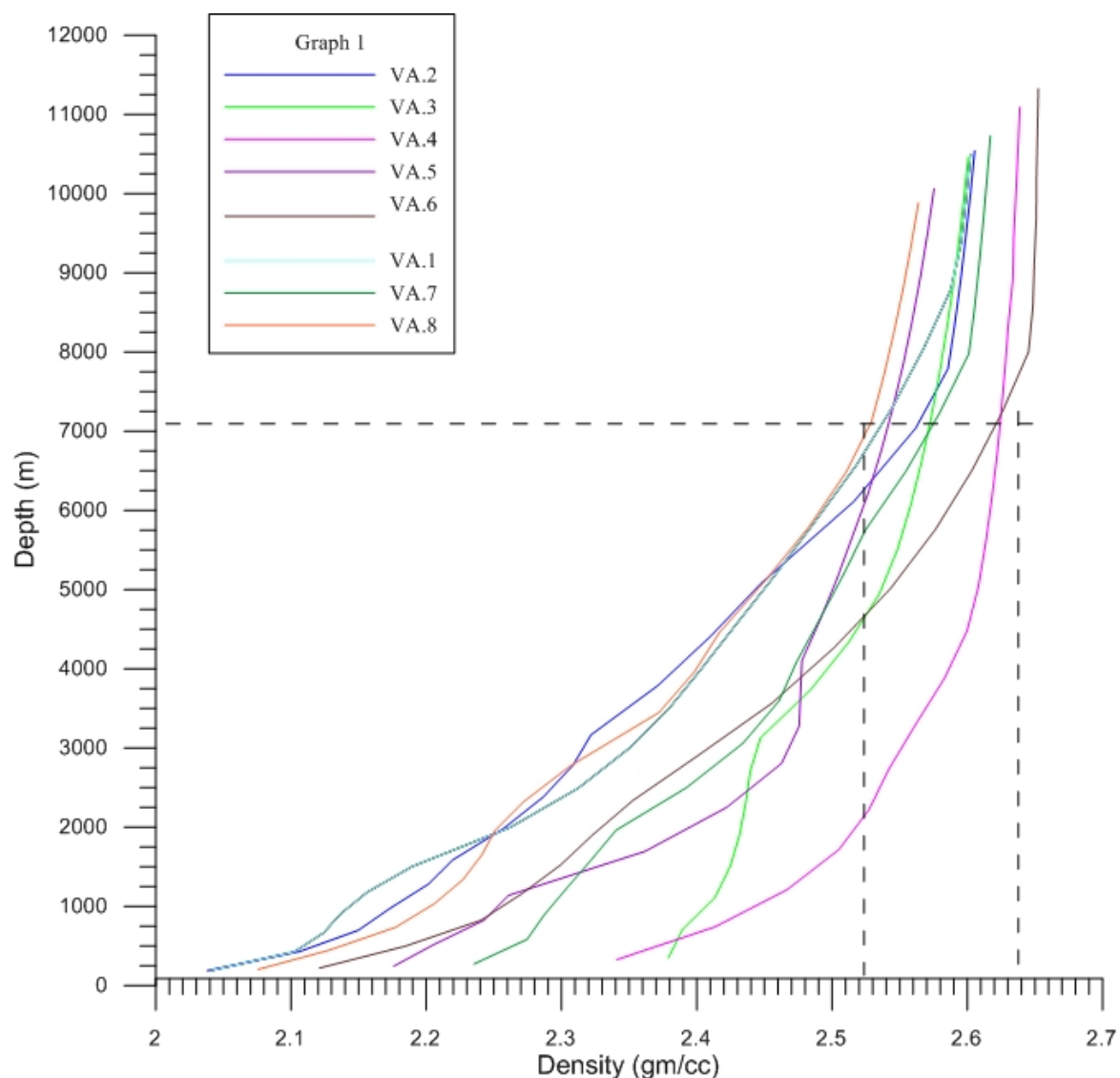


Fig.5: Density – depth curves derived from seismic reflection velocities of eight locations

- 1- The density changes remarkably within the first 7 Km of the sedimentary cover; beyond that it tends to be constant. Therefore, it is expected that most of the gravity anomalies are related to the upper seven kilometers of the sedimentary cover.
- 2- The density is relatively higher at the core of the anticline (2.4 gm/cm^3), which corresponds to the massive anhydrite of Fatha Fn., and it gradually decreases reaching the lower limit at the flanks (2.04 gm/cm^3) corresponding to a relatively light clastic content of Mukdadiyah Fm formation.
- 3- Any intrasedimentary granitic intrusion ($\rho \sim 2.64 \text{ gm/cm}^3$) or structural uplift, occurring at deep levels ($\geq 7 \text{ Km}$) within sedimentary cover, is not easy to be detected by gravity measurements, because of the low density contrasts with the surroundings. However, basic or ultrabasic intrusions ($\rho \geq 3.0 \text{ gm/cm}^3$) may have a measurable density contrast.

– **Gravitational Model of Jambur Anticline:** The sedimentary column can be divided into five intervals; H0 – H1, H1 – H2, H2 – H3, H3 – H4 and H4 – H5. H0, H1, H2, H3, H4 and H5 are the ground surface, top of Fatha Fn., base of Jeribe Fn., top of Qamchuqa Fn., top of Jurassic and top of the basement, respectively. The average velocities under each location of velocity analysis are given in the Table (3). However, the corresponding average density (arithmetic mean) for each interval is given in Table (4).

Table 3: The average velocities at each reflector

Depth(Z) in (m)	VA.1	VA.2	VA.3	VA.4	VA.5	VA.6	VA.7	VA.8	VA.9	VA.10	VA.11
H1	2319	2149	1887	2149	700	1304	2357	2249	2607	499	2632
H2	3022	2857	2749	2857	1920	2351	3579	3081	3074	2135	2995
H3	4157	3895	3813	3895	2933	3177	4338	3863	3872	3003	4228
H4	6500	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000
H5	12500	12500	12500	12500	12500	12500	12500	12500	12500	12500	12500

Table 4: The average density for each interval

Ave. Density in (gm/cm^3)	VA.1	VA.2	VA.3	VA.4	VA.5	VA.6	VA.7	VA.8	VA.9	VA.10	VA.11
H0 – H1	2.165	2.177	2.408	2.368	2.230	2.208	2.306	2.196	2.252	2.295	2.230
H1 – H2	2.334	2.298	2.436	2.478	2.314	2.325	2.429	2.306	2.375	2.389	2.378
H2 – H3	2.404	2.356	2.465	2.559	2.451	2.393	2.472	2.382	2.405	2.453	2.418
H3 – H4	2.493	2.510	2.555	2.618	2.522	2.585	2.535	2.491	2.460	2.510	2.464
H4 – H5	2.650	2.650	2.650	2.650	2.650	2.650	2.650	2.650	2.650	2.650	2.650
H5	2.935	2.935	2.935	2.935	2.935	2.935	2.935	2.935	2.935	2.935	2.935

The gravitational effect of Jambur anticline can be calculated according to the data given in Tables (3 and 4) (Sharma, 1986 and El-Kelani, 2005). For this purpose, 2-D modeling along seismic lines J1 and J2 using Geosoft version 7.3 are shown in Figs. (6a and 6b, respectively).

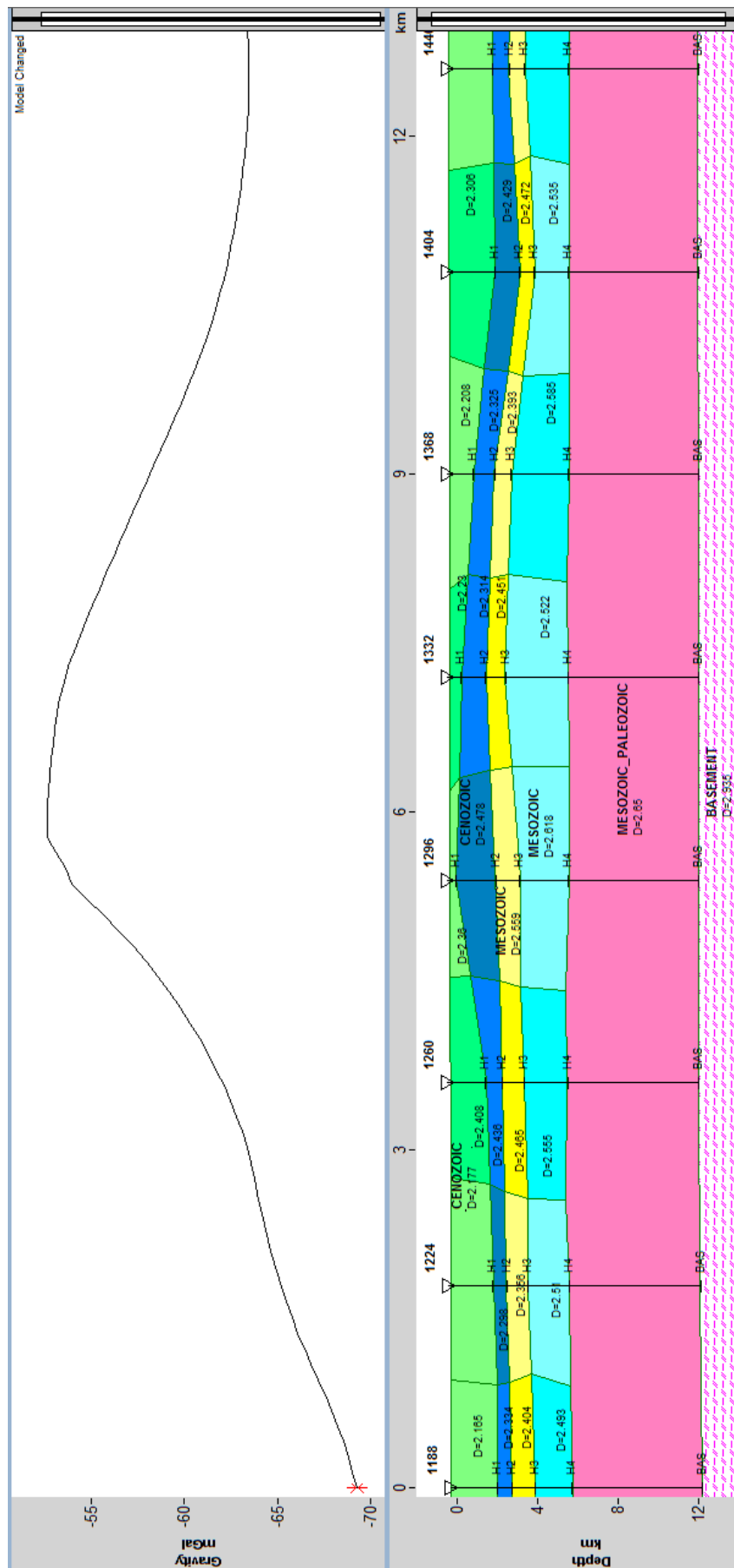


Fig.6a: Gravitational model of Jambur anticline along seismic line J1. The model is built up according to information gained from eight velocity analyses (from VA.1 to VA.9)

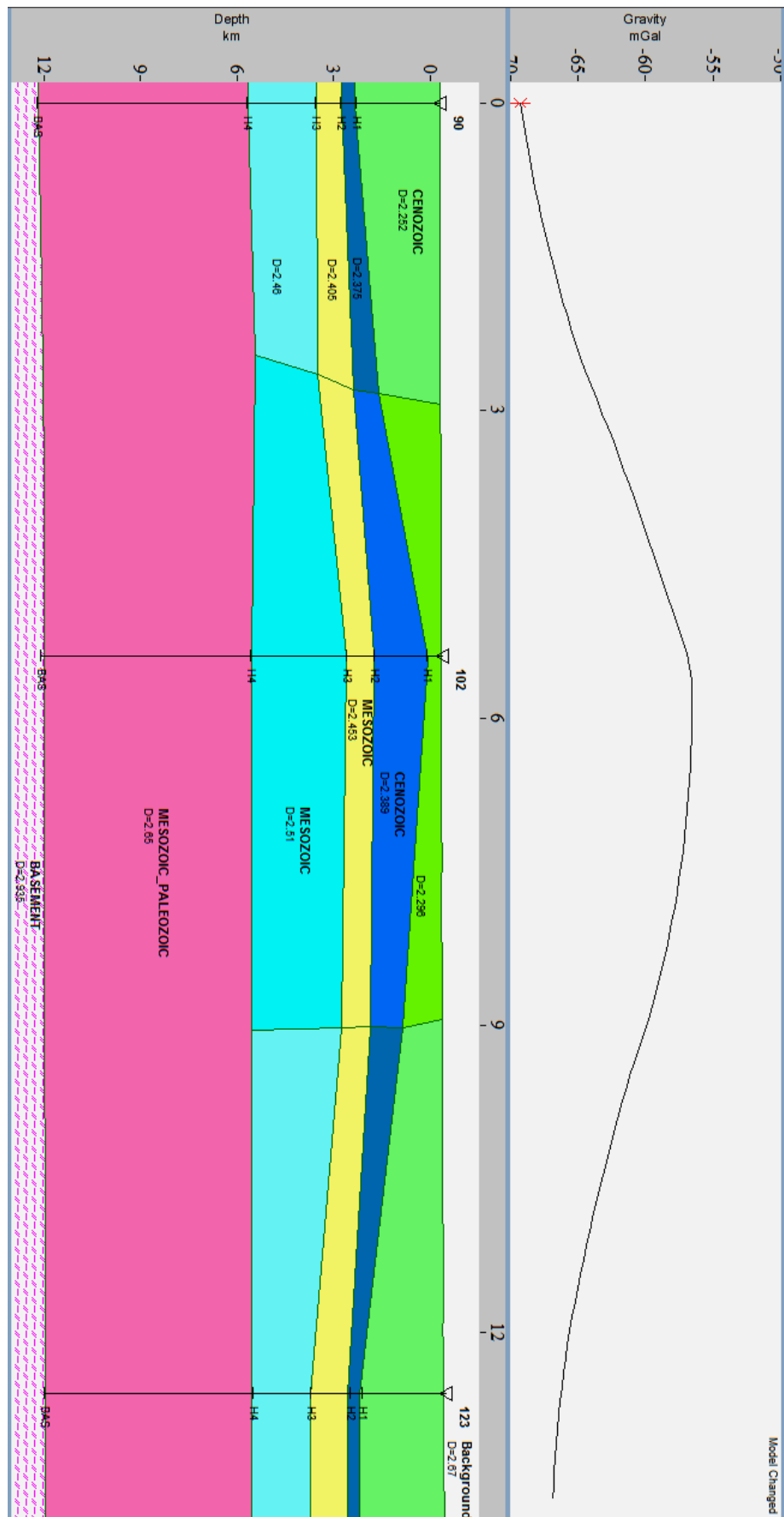


Fig.6b: Gravitational model of Jambur anticline along seismic line J2

The gravity anomaly is about 9 mGal in Fig. (6a) whereas it is about 8 mGal in Fig. (6b). However, Fig. (6a) reflects a more detailed picture of the gravity field across the anticline due to using eight velocity analyses in the model compared with three velocity analyses used in the model shown in Fig. (6b).

It is important to mention that the values of depth and average density used in the models are 12.5 Km and $\sim 2.935 \text{ gm/cm}^3$ for the Precambrian basement as extracted from the basement depth map of CGG (1974) and the postulated basement composition given by Jassim and Goff (2006). However, the average density of the rocks below depth of 6500 m is supposed to be constant at its average value of 2.65 gm/cm^3 according to density – depth curves discussed in the Section of Density – Depth Relations.

▪ Gravity Field

Gravity field is much affected by the upper part of the sedimentary cover than the deepest part or basement. The Alpine stresses have generated numerous surface and subsurface geological structures that modified this field. The responses are generally represented as gravity highs, lows and sharp gradients. Gravity highs are narrow and elongated in shapes and closely coincide with the surface anticlines on the geological map. The amplitudes of the gravity highs, however, depend upon the depth and amplitudes of these structures. Some gravity lows are matched with the synclines. However, thrust faults along anticlines are reflected as sharp gradients, and these faults play the main role in increasing the gravity response of these anticlines.

DISCUSSION AND CONCLUSIONS

Bouguer map (Fig.4) shows that the area between the southwestern part of Taq Taq anticline and the southwestern part of Makhmur anticline appears much more affected by Alpine stresses than that occupying the area to the S of Makhmur to Hemrin north anticline, which, in turn, exhibits uniform gradient, of about 0.5 mGal/Km in nearly E – W direction. This area has gently steepening gravity field that indicates a different response to the Alpine stresses.

The gravity responses of these structures display the effects on the local field only. However, the regional component is also affected by the Alpine stresses that should be considered for any attempt of removing the total effects of these stresses from the observed gravity field to obtain a new “corrected field”.

Some anticlines have subsurface plunging extensions that are easily detected by the gravity measurements and others are not reflected on the geological map and only can be seen on the gravity map. However, some gravity lows may not be synclines according to their orientations and shapes. They may be depressions caused by solution.

Density – depth relationship shows that the upper 7 Km of the sedimentary cover is the "effective depth" for any source of gravity anomaly within the sedimentary cover. However, the deep-source anomalies ($\geq 7 \text{ Km}$) should be related to dense intrusions due to an unexpected high density contrast. Therefore, the effects of the Alpine stresses on the sedimentary cover that may be reflected on gravity field are restricted to the upper seven kilometers only. However, the sedimentary cover of the study area reaches 13 Km, thus, there is an ambiguity associated with the gravity field about the sedimentary structures deeper than 7 Km.

Two dimensional modeling of Jambur anticline using the information deduced from seismic reflection data shows that the structure has a residual gravity value ranging from 8 to 9 mGal.

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