ISSN: 0067-2904

Enhance the delineation of masked structures in southern Iraq by applying the Biharmonic operator to their gravity field.

Ali M. Al-Rahim
Department of Geology, College of Science, University of Baghdad, Baghdad, Iraq.

Abstract

The gravity field of southern Iraq shows steep gradient of regional trend. The gravity contours over the anticline structures in this area do not show the closure characteristic of these structures. The effect of lateral density variation for Hormuz Salt complicates the case in the area. Higher derivatives are one of the means that have been used to remove the effect of such regional gravity variations, which can easily mask significant structures. Biharmonic Operator is used to delineate these distort structures, follow their extent and at the same time distinguish new features. The Biharmonic operator manipulation has ability to suppress the effect of regional and enhance the local anomalies. The problem with higher derivatives operation is that, it enhance dramatically high frequency components of gravity field, but with smoothing the result is remarkable. A synthetic model is used to support the idea, and then the operation is applied to the gravity field of southern Iraq. Many new features are deduced and new extents of the old known ones are determined.

Keywords: Biharmonic Operator, Enhance masked structures, Gravity field of Iraq.

تحسين تصوير التراكيب المتخفية في جنوب العراق بتطبيق معامل التوافقية المزدوجة على مجالها الجذبي

علي مكي حسين الرحيم
قسم علوم الارض، كلية العلوم ، جامعة بغداد

الخلاصة

يظهر المجال الجذبي لمنطقة جنوب العراق مجال اقليميا ذا انحدار شديد. خطوط الكنتور الجذبية فوق تراكيب الطيات لا تظهر صفات انغلاق فوق التراكيب وتأثير التباين الكثافي الجانبي لملح الهرمز يزيد الحالة تعقيدا. استخدام المشتقات العليا يمكن ان تكون احد الوسائل لازالة تأثير التغيرات الجذبية الاقليمية التي تخفي التراكيب المهمة بسهولة. استخدم معالج التوافقية المزدوجة لتحديد التراكيب المشوهة وايجاد امتدادتها وفي نفس الوقت تحديد تراكيب جديدة. لمعالج التوافقية المزدوجة القدرة على قمع تأثير المجال الاقليمي وفي نفس الوقت ابراز التراكيب الضحلة. المشكلة في معالجات المشتقات العليا في انها تحسن بشكل كبير مركبات الترددات العالية في المجال الجذبي، ولكن مع عملية تنعيم تكون النتائج ملفتة للانتباه. استخدمت موديلات مصنعة لدعم الفكرة، بعدها تم تطبيق المعالج على المجال الجذبي لجنوب العراق. تم الاستدلال على العديد من التراكيب الجديدة وتم تحديد امتداد جديد للتراكيب السابقة.

Introduction

The gravity and magnetic methods have played a key role in exploration geophysics [1]. The gravity field of Iraq shows steep gradient regional trend in many locations. The gravity contour map of

Email: alial_rahim@yahoo.com

southern Iraq, particularly over an anticline in this area does not show the closure characteristic of the structures (as will be shown latter). Using higher derivatives could be one of the means for removing the effect of such regional gravity variations, which can easily mask significant structures. The derivatives methods are used in qualitative, quantitative interpretations for gravity and magnetic data and finding the characteristics of bodies that are include their dimensions (shape), depth to center of mass and/or the top of the body causing the anomaly. Their density or susceptibility contrasts are of major and essential importance. Many techniques have been proposed and developed for this aim besides the great developments in computerized presentations including forward and inverse modeling techniques and due to long period of development of the qualitative and quantitative interpretation methods; it is possible to list tens of these works. But very little are published regarding the Biharmonic operator in spite of its well-known in mathematics for a long period. The Biharmonic $\nabla^4 Z$ is simply Bilaplacian operator where the Laplacian $\nabla^2 Z$ is a second derivative function. That's mean it will greatly amplify short wavelength anomalies; but with simple smoothing, the users can get remarkable information from using the Biharmonic operator. Fortunately, the well known contouring program (SURFER) is included the Biharmonic operator in its Grid-Calculus menu for a gridded data and this will simplifying dealing with synthesized models such us; spherical, prismatic, vertical or horizontal cylinder and vertical contact bodies which are the approximation to many geological bodies of interest such as salt dome, anticline and fault structures due to their association with the oil field and ore mass structures.

Al-Rahim [2, 3] used the Biharmonic operator to derive body characteristic for spherical and prismatic bodies from their gravity field. He used several states for each body with a complicate test and successfully examines the method on a field example.

The present paper is aimed to highlight the main results of Al-Rahim [3] method and going beyond what is new that can be getting from Biharmonic ∇^4 to solve the limitation in locating bodies when they are at great depth and/or short distance between them. The method will examine very low density contrast body that is obscured by the effect of strong regional field. The method will be applied with differential operators (Gradient ∇ and Laplacian ∇^2) in order to determine its comparison usefulness. Then, the method is tested on a field example for the gravity field of southern Iraq which contains giant oil fields that are highly influenced in their structural tectonics with the effect of Hormuz Salt diapirism. The result can be greatly guiding the seismic exploration for more future promising ambitious works.

Theoretical background

The Differential Operator of a scalar field – gravitational field (g) is including Gradient operator, Laplacian operator, and Biharmonic operator. Their formulas are shown as follow with their dependent location of interest by the interpreter:

Gradient operator ∇g

$\nabla g = \sqrt{\left(\frac{\partial g}{\partial x}\right)^2 + \left(\frac{\partial g}{\partial y}\right)^2}$. The maxima are the locations of interest for this operator [3].

Laplacian operator $\nabla^2 g$ **:** is equivalent to the divergence of a gradient, that is,

div grad g = $\Delta g = (\nabla.\nabla)g = \nabla^2 g = \frac{\partial^2 g}{\partial x^2} + \frac{\partial^2 g}{\partial y^2}$. The zeros and maxima for vertical contact bodies are of primer interest [3].

Biharmonic operator $\nabla^4 g$ **(**which is the equation of interest)**:** is equivalent to the divergence of Laplacian (the Laplacian of the Laplacian), may be written and defined in multivariable calculus as:

$\nabla^4 g = (\nabla.\nabla)(\nabla.\nabla)g = (\nabla^2.\nabla^2)g = \frac{\partial^4 g}{\partial x^4} + 2\frac{\partial^4 g}{\partial x^2 \partial y^2} + \frac{\partial^4 g}{\partial y^4}$. The location, diameter and dimension of the zero crossing contours are of major interest for gravity data and the maxima for magnetic data [3].

All of these operators could be applied for 2D data simply by using SURFER program [4].

Insure the singularities principle by using Biharmonic operator

Singularities are the location of points where the potential field is maximum (or minimum). The singularities of the field are confined to the region filled with sources. It turns out that the position of singularity is closely related to some of the importance features of the shape of the anomaly causing body; for example, at each corner of the body there is a singularity. The importance of the singularities lies in the fact that these can be uniquely determined from the observed field [5]. Each singularity is described by three sets of parameters namely: location, amplitude and order of singularity. A group of singularities associated with a source may be enclosed by a convex surface. Often, it is the top most singular point on the convex surface which is of great interest, and it is also the one which can be determined relatively easily. The exact location of maximum value (singular point) of the field could be determined using derivative (Gradient) method. The Biharmonic operator is of great importance due to its ability to insure the concept of singularity for the potential field signals.

Highlight Al-Rahim [3] method to determine the boundary of prismatic bodies:

Al-Rahim [3] applies the Differential Operators (∇, ∇^2, and ∇^4) for prismatic bodies using 27 cases for different depths to the top of prisms, various dimensions and density contrasts. Figure-1 shows one of his results where the Biharmonic operator is applied for the gravity filed of three modeled prismatic bodies. Two have large dimensions and one with small dimension extruded between them. This example simulate the case for a potential field survey where, the observed data comprises the combined effects produced by all underground sources with a small-scale structure buried at shallow or deep depths. The response of this small target is vanishing by the influence of regional field or other targets arise from neighboring sources that are usually larger in size and/or buried at deeper depth. From the gravity map Figure-1a, it is very difficult to recognize the small prism in the middle part due to the effect of surrounding two prisms that have larger sizes and density contrast. He proves imperially that the Biharmonic operator map has two zero closed contours (see Figure-1d). The internal one circumscribes four protrusions (one for each corner of the prismatic model and insure the singularity aspect that has been mentioned above) and has dimension exactly the same dimension of the modeled prisms. Also, the Biharmonic operator could resolve the anomaly for the middle prism and determine its boundary accurately (Figure- 1d, see the zero small contour). With no doubt, its depth calculation will be less accurate due to the effect with the surrounding prisms. Many more details could be found in [3] paper. The following more synthetic examples is prepared in this paper to improve the validity of the method.

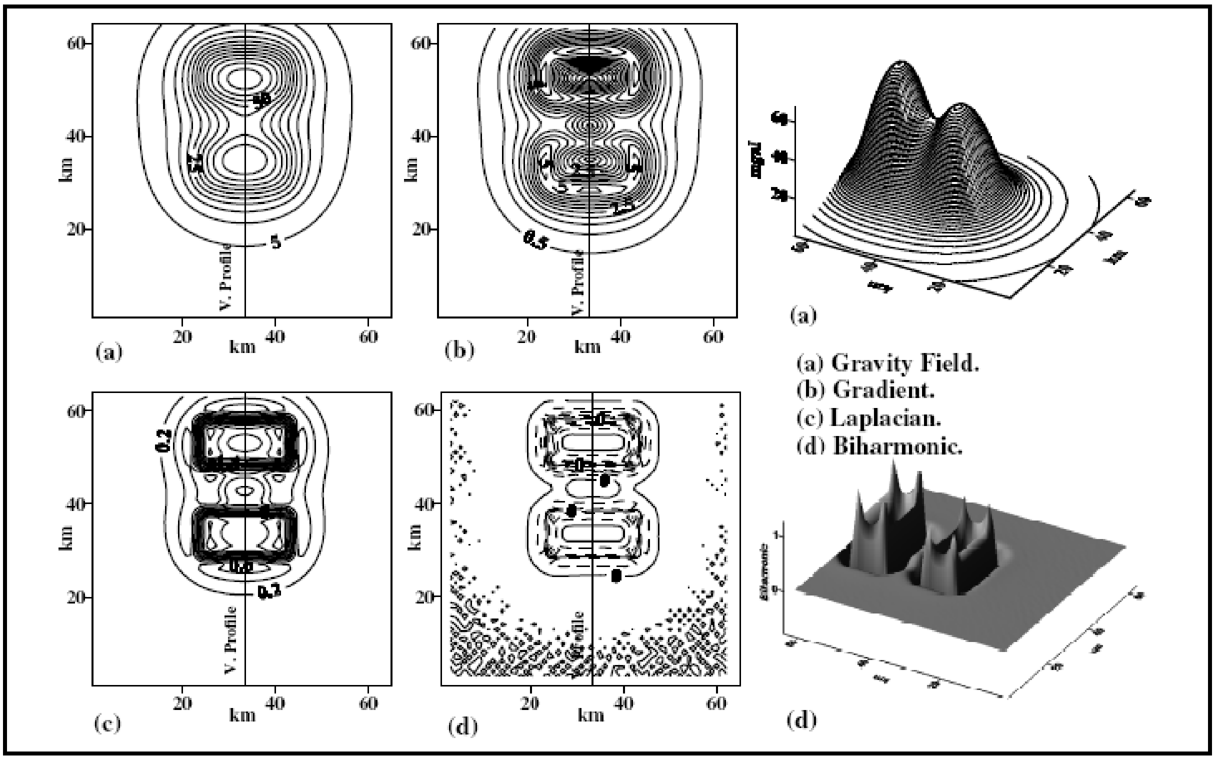

Figure 1- 2D and 3D representation of the small target case [3].

Could the Biharmonic operator avoid the effect of regional?

The Laplacian operator works as a second vertical derivative enhance filter. The latter is used to enhance local anomalies obscured by broader regional trends and to assist in the definition of the edges of the source bodies. Vertical second derivative can be regarded as a type of high-pass filter that enhance anomalies caused by small features while suppressing longer-wavelength regional trends [6]. The Biharmonic operator will tend to duplicate such suppressing of longer-wavelength and lead to more enhancements for the local small features. For the vertical contact bodies, normally the zero contour line in the second derivative map is used as a guide to determine the boundary of the bodies. But when the data has regional effect, this zero line will be shifted. In the Biharmonic operator map the zero contour line will be coincide exactly with the boundary of the causative source as shown in following test example.

Five bodies of different shapes, depths and density contrasts have been designed as a synthetic test example Figure- 2. They included two spherical bodies (subroutine sphere by [1]), one prismatic body (subroutine sphere by [7]) and two triangular prismatic bodies (subroutine NEWTON by [8]). The data of such type named as stationary data [9]. A second order regional trend field is added to the test example to make an actual field (Non-stationary data). A remarkable effect of the regional field on anomaly shapes made the recognition of the locations and types of each anomaly is very difficult. Herein, the important of the manipulation of the three differential operators on these data appears. These operators are applied to the synthetic test example and the actual field to examine the effect of regional field on the differential operator Figure- 2 . The Gradient operator gives different result due to the affects of the regional field, so as the Laplacian operator where the zero contour line is added to the figure, but it has better recognitions for the shapes of the bodies. It is very clear that the Biharmonic operator is suppressing the regional trend and does not affected by it and gives the exact shape of the prepared synthetic map. This is very important result because it may solve the inherent problems of separations the actual field to regional and residual, and gives the exact shapes of the used bodies. Also, the Biharmonic operator works with stationary and non stationary data where it produced the same results and could give clear morphological shapes of the causative bodies.

Dealing with very low density contrast and high depth structure

Another test is made for prismatic body (30x10 km dimension) with very low density contrast (0.01 g/cm3) and depth of 6 km Figure-3a. The gravity value of such prism does not exceeding 1 mGal. Regional field with high gradient Figure-3b is added to the field of the prism and the result is shown on Figure-3c. Very small bend in the regional contour is hardly recognized even with careful inspection. This very small bend could be amplified using the Biharmonic Operator, but the result is a very noisy map Figure-3d that must be smoothed to get better resolution. Moving average smooth is done for Figure-3d and the result is shown in Figure-3e. The perfect shape and dimension of the prism is defined as shown in the figure. This test emphasis the previous results even for very low density contrast model.

Application of the method to field example from southern Iraq

The gravity field for the area of southern Iraq shows steep gradient regional trend. The gravity contours over an anticline in this area do not show the closure characteristic of the structures. The effect of lateral density variation for Hormuz Salt complicates the case. This area is highly prolific for oil production and containing many giant oil fields (Figure-4). The basement in this region is too deep and the depth is reaching to more than 10 km. Neoproterozoic Horrmuz Series (1.5 to 2.5 km thick) cover this basement. Major intersecting basement faults cut the buoyant salt beds, mainly the extensional N-S Arabian trend and control salt tectonism in the basin. Diapiric movement of salt has been initiated by repeated extensional and strike-slip (wrench) movements in the crystalline Precambrian basement complex [10].

This diapirism usually occurs where intersecting basement fault trends cut part of the overlying sedimentary sequence, providing localized area of pressure relief for the upward movement of buoyant salt. These diapirs either reach to the surface as piercements and salt fissures in area of active tectonism, or dome up the overlying strata. This is the main factors to be considered in halokinesis the mechanism of salt movement and the regularity of spacing of salt structures [11, 12].

Deep seismic survey in the area over the oil field anticlines shows the increasing presence with depth of reactivated and reverse faults in deep subsurface [13]. This is considered a pathway for the upward movement of Neoproterozoic salt

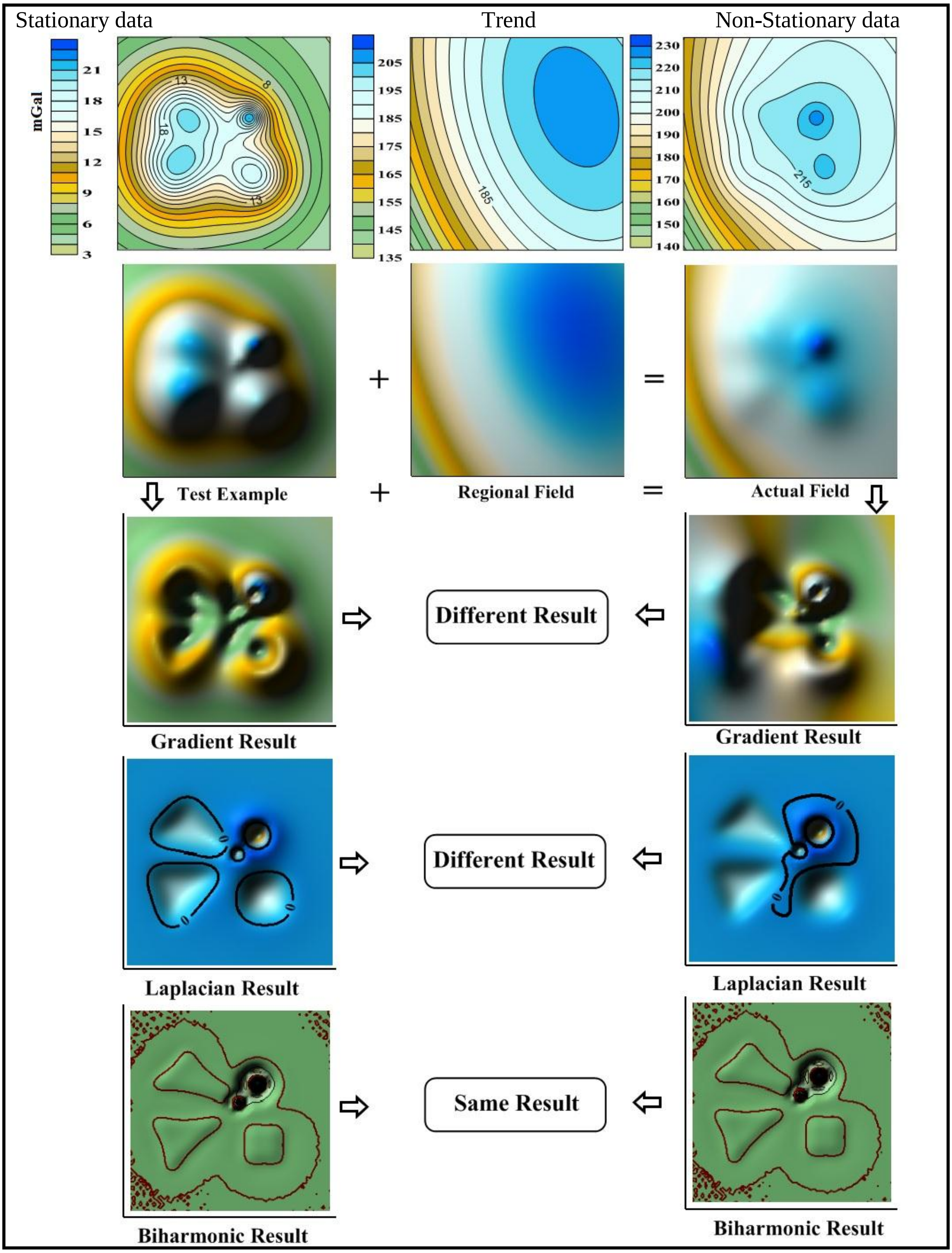

Figure 2- Illustrate the resolving power of Biharmonic operator in defining the parameters of source body and removing the effect of regional trend.

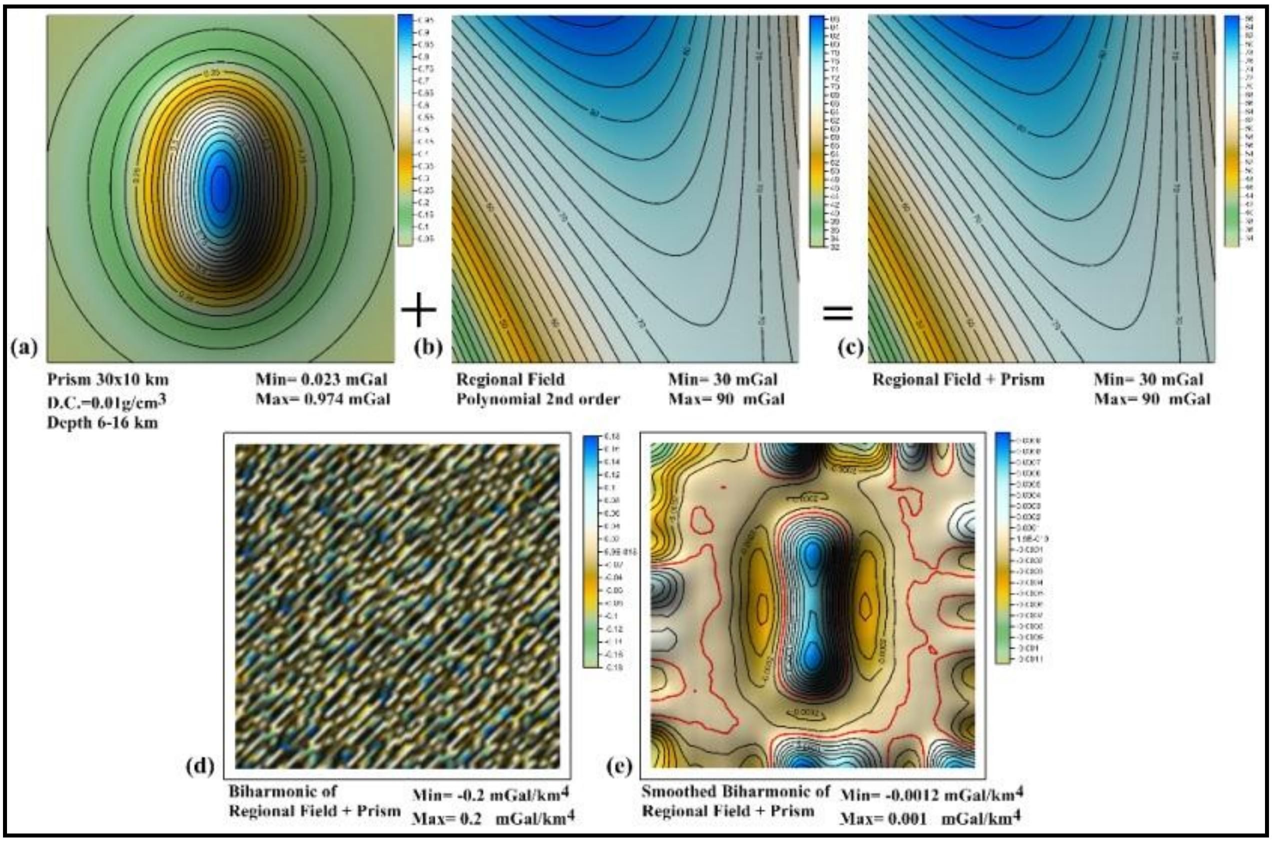

Figure 3- Illustrate the successes of Biharmonic operator in suppressing the effect of regional trend and enhance the field due to prism. The internal zero contour bound the prismatic body with exact dimension 30x10 km.

a) Gravity field for prismatic body. 30x10 km, D.C. = 0.01 g/cm^3.
b) Regional field 2nd order.
c) Regional + Prism gravity field, note the very small effect of the prism to the regional.
d) Biharmonic map for (c), note the amplification of high frequency effect.
e) Smooth Biharmonic map (d) using moving average method, note the shape of the prism with exact dimension.

Rate of growth of salt structures is clearly not uniform as can be seen by some dormant salt piercements, such as Jebel Sanam Figure- 4g). Edgell [11] has mentioned that the spacing of Neoproterozoic salt diapirs in the area is between 10 and 50 km, largely dependent on the spacing of basement fault structures, on the salt layer thickness, on roof subsidence and on lateral variations in loading and/or facies. The principle types of geological structures due to salt tectonism in the area are salt wall structures and piercements salt structure. Salt wall structure are very elongated anticlines cored at depth by salt walls along single basement fault trends with forced folding of overlying strata, together with their diapirism [10].

In gravity exploration for oil, the main problem with salt structures is that the salt has constant density (2.15 g/cm^3 for rock salt and reach to 2.8 g/cm^3 for anhydrite); while there is a regular density increase with depth in the sedimentary section due to compaction (Hedberg 1936 after [6]. So that, in shallow depth the residual gravity will give positive anomaly and in deep depth more than 2500 ft the residual will give negative anomaly and in-between there will be no anomaly at all [14, 15].

The field example area has cyclic sequence of clastic and carbonate sediments along all period of geological time. A large-scale intrashelf basin termed the Gotnia Basin formed at the end of the Early Jurassic where thick halite and anhydrite units were deposited in SE Iraq [16, 17]. This causes another problem for reflection survey because this formation (Gotnia) beside all thick carbonate layers are a perfect reflector making velocity pitfalls (pull-up) reflector bed and give an anticlinal feature [6]. Gotnia thick evaporate bed has high density and attenuate the seismic single beyond this layer, for that many difficulties face the seismic deep investigation survey and any modern process to amplify the amplitude of the reflectors beyond Gotnia formation will give a factious and non truth pictures about the structural situation of the area. For that, all calculated velocity to interpret the seismic survey depends on velocity measured through wells that penetrate the sequence [13].

So, many difficulties face the interpreter for such complicated area. For that, the interpreter makes his effort to enhance the signal for specific target (formation) in the area and this lead to distort the signal of other formations that are located deeper or shallower from that target.

In such states, the Biharmonic could give certain advice about the locations and extend of the oil field structures. Figure-4 shows the location map of the field example and the following are the details of the figure:

a) Bouguer gravity map of the area [18].

b) Regional field has been determined using average smooth method. This regional field still has some effect from the deeper structure but this hardly recognized. Here is the importance of the process, where the Biharmonic could exaggerate these remains effects. This state is similar to the case that is shown in Figure- 3.

c) The residual anomaly is the result of subtracting map Figure- 4b from map Figure- 4a. The residual map is showing that most of the giant oil fields in the area are located within negative values (Al-Sayyab and Valek [19] are the first who mentioned for this characteristics), while Jebel Sanam is located in positive values where the salt reach near the surface holding many of Dolerite (Daibase) rocks, Green/ Red Marl Unit, Gypsum Unit, Limestone Unit and Dibdibba Formation Clastics Unit rock from the basement and Hormuz Series making dome structure [20-22].

d) The Biharmonic process for the regional gravity field Figure-4b.

e) Average smoothing map of Figure-4d, which gives complete coincidence between the negative anomalies and the giant oil fields in the area. This map Figure- 4e bring attention to many locations have the same phenomena of Rumaila and Zubair oil field but it seems nothing known about it (specially the western part of the map) other location shows extension of negative anomaly to the north of Ratawi oil field. This area is located in a marsh area, which needs to special program and crew for seismic exploration. Seismic section for Zubair structure and Jebel Sanam salt dome are shown in the same figure (Figure-4f and Figure-4g), the sections declare the presence of the salt plug and dome in the area which is coincide with negative line in the Biharmonic map.

These results encourage and guide the seismic exploration for more future promising and ambitious works.

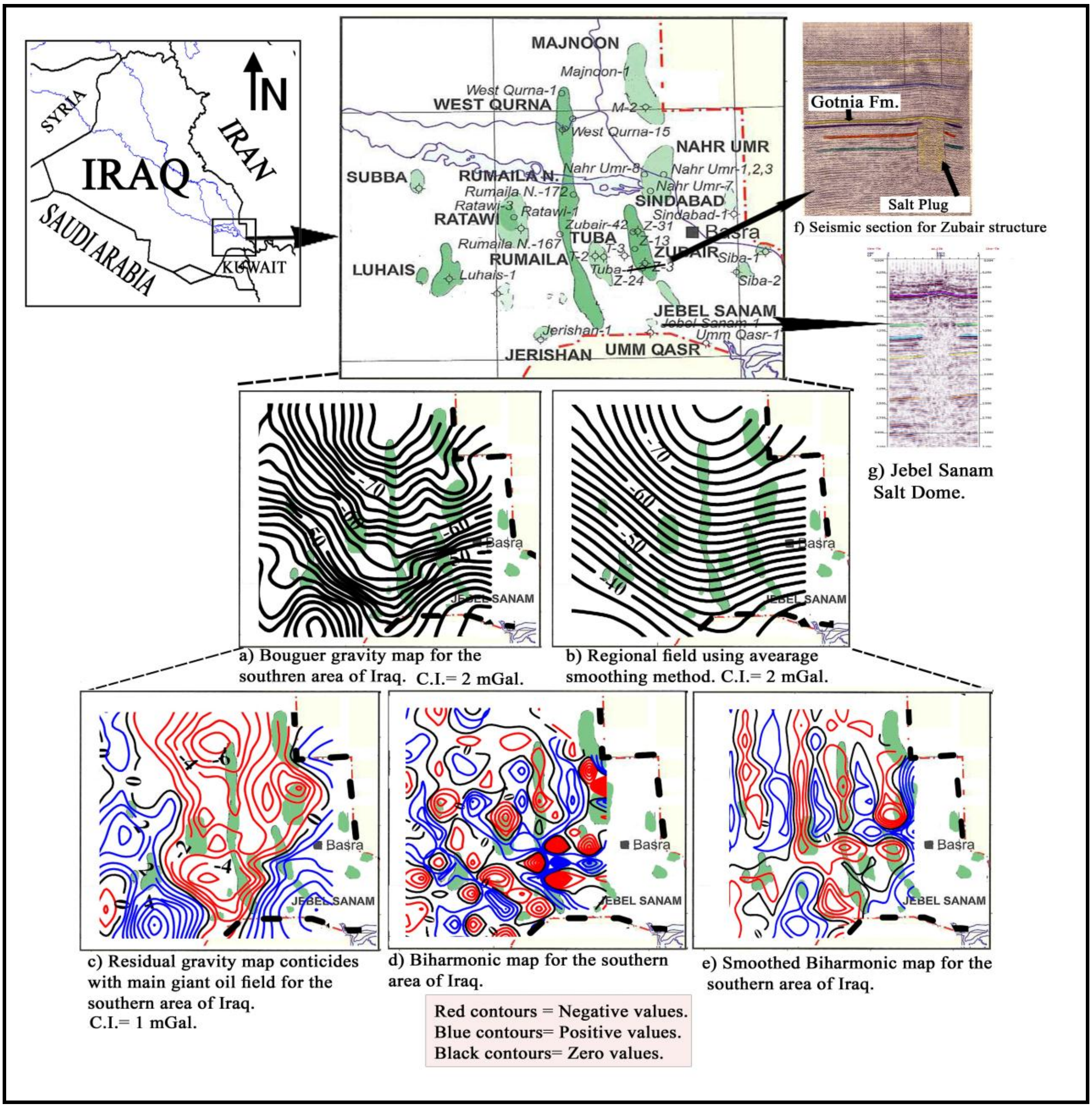

Figure 4- High prolific area for oil production that containing many giant oil fields is chosen as a field example from southern Iraq. (Modified from [16]). Description of each map is clarified in the text. The smoothed Biharmonic map (e) shows its exact coincidence with oil fields and some have more lateral extend which encourages and guide the seismic exploration to more future works. Some other location (the left part of the map) may regard as a new extended structure.

Conclusion

The Biharmonic operator map shows several important advantages over derivatives method and can solve many difficulties in determining body boundary, dimension, depth and other characteristics where the zero closed contour is the key factor for that. From the current study; the Biharmonic operator has the ability to find concealed structures at any depth with no limitations and avoid the effect of regional field. This is due to the Biharmonic operator has insures the concept of singularity for the potential field signals. This facilitates the direct knowing of the causative body shape without any prior information. The application is completely empirical, for that a lot of synthetic examples are demonstrated and presented in 2D and 3D to prove its validity. The operator is applied to test field example and it gives reliable results when they compared with the known geology of the area. Smoothing should be applied to both the real field data and Biharmonic operator maps to enhance the signal-to-noise ratio and get better result. The outcomes of such type of interpretation can be utilized together with other sets of geological and geophysical information and greatly guiding the seismic exploration for more future promising ambitious works.

References

1. Blakey, R.J. **1996**. *Potential Theory in Gravity and Magnetic Applications*. Cambridge University Press.

2. Al-Rahim, A.M. **2009**. Depth estimation of spherical bodies using Differential Operators (Gradient , Laplacian and Biharmonic) to its gravity fields. *J. of University of Anbar for Pure Science – Anbar – Iraq.* 3, pp: 74-85.

3. Al-Rahim, A.M. **2011**. New novel method to estimate body characteristics (Dimensions, Depths and Density Contrasts) of three dimensional prismatic bodies by applying differential operator (Gradient $\Pi \vec{g} \Pi$, Laplacian $\nabla^2 Z$ and Biharmonic $\nabla^4 Z$) to their gravity fields. *J. of University of Anbar for Pure Science – Anbar – Iraq.* 5, pp: 65-82.

4. Surfer Version 11. *Surface Mapping System*. Copyright © **1993-2015**, Golden Software, Inc.

5. Naidu, P.S., and Mathew, M.P. **1998**. *Analysis of geophysical potential fields. A digital signal processing approach.* ELSEVIER.

6. Dobrin, M.B., and Savit. C.H. **1988**. *Introduction to Geophysical Prospecting*. McGRAW-HILL, 4th Edition, 883 pp.

7. Mendonca, C.A. Ahmed M., Meguid, A. **2008**. Programs to compute magnetization to density ratio and the magnetization inclination from 3-D gravity and magnetic anomalie. *Computers & Geosciences*, 34, pp: 603-610.

8. Götze, H.L. and B. Lahmeyer. **1988**. Application of three-dimensional interactive modeling in gravity and magnetics. *Geophysics*, 53, pp: 1096-1108.

9. Davis, J.C. **2002**. *Statistics and Data Analysis in Geology*. John Wiley & Sons, Inc., New York, 3rd Edition, 634 pp.

10. Al-Rahim, A. M. **1997**. A Study of Geological Structure of Southern Iraq from Gravity and magnetic data and their Tectonic Implications. Ph.D thesis, University of Baghdad - College of Science – Department of Geology. (Unpublished).

11. Edgell, H.S. *Salt tectonism in the Persian Gulf Basin*. From Alsop, G.I., Blundell, D.J. and Davison, I. **1996**. *Salt Tectonics*. Geological Society. Special Publication No. 100. London.

12. Alsop, G.I., Blundell, D.J. and Davison, I. **1996**. *Salt Tectonics*. Geological Society. Special Publication No. 100. London.

13. Stefan, J.O., Carlof, F., Al-Jouhar, R.H., Hacob, A., Mussen, N., and Khalil, N.M. **1984**. Study for the results of interpretation deep seismic survey for south Rumaliah and Zubair areas. Second Scientific Exploration Conference. *Oil Exploration Company. Ministry of Oil. Baghdad-IRAQ. (In Arabic).*

14. Nettelton, L.L. **1934**. Fluid Mechanics of Salt Domes. *Bull. Am. Assoc. Petrol. Geol*., 18, pp: 1175-1204.

15. Nettelton, L.L. **1962**. Gravity and Magnetic for geologists and seismologist. *AAPG,* 46, pp: 1815-1838.

16. Aqrawi, A.A.M., Goff, J.C. Horbury, A.D. and Sadooni, F.N. **2010**. *The petroleum geology of Iraq*. Scientific Press Ltd. UK.

17. Jassim, S.Z, and Goff, J.C. **2006**. *Geology of Iraq*. Published by Dolin, Prague and Moravian Museum, Brno.

18. Al-Kadhimi, J.A.M., Abbas, M.J. and Fattah, A.S. **1984**. Gravity map of Iraq.: SOM Library, Now GEOSURV, Baghdad-Iraq.

19. Al-Sayyab, A. and Valek, R. **1968**. Patterns and general properties of gravity field of Iraq. 23rd Intern. Geol. Cong., Czechoslovakia, sec. 5, pp: 129-142.

20. Al- Naqib, K. M. **1970**. Geology of Jabal Sanam, South Iraq , *Jour.Geol*., *Soc. Iraq*, 3, pp: 9-36.

21. Al-Muttory, W.G. **2002**. Structure *and* Tectonism of Jabal Sanam Southern Iraq. M.Sc. thesis, University of Basrh - College of Science – Department of Geology. (Unpublished). In Arabic.

22. Soltan, B.H. **2002**. Petrology & origin Of Jabal Sanam Structure Southern Iraq. M.Sc. thesis, University of Baghdad - College of Science – Department of Geology. (Unpublished). In Arabic.