

تفسیر داده‌های گرانی از طریق گرادیانهای گرانی و سیگنال تحلیلی

نوشته: دکتر وحید ابراهیم زاده اردستانی*

Gravity Interpretation via Gravity Gradients and Analytic Signal

By: Dr. V. E. Ardestani*

چکیده

گرادیانهای گرانی و استفاده از آنها در تفسیر گرانی هنوز یک مسئله مطرح می باشد. محاسبه گرادیانهای گرانی برای داده های نوفه دار کاری مشکل می باشد. یکی از جدید ترین روشها برای تعیین محل آنومالی با استفاده از گرادیانهای گرانی متد سیگنال تحلیلی می باشد. این روش در ابتدا برای داده های دقیق گرانی و مغناطیسی استفاده می شده است و در مورد داده های با نوفه بالا کمتر به کار برده شده است. در این مقاله از این روش برای تعیین محل بی هنجاری در دو ناحیه مختلف در ایران استفاده شده است.

کلید واژه‌ها: آنومالی بوگه، آنومالی باقیمانده، گرادیانهای گرانی، سیگنال تحلیلی، تهران، زاهدان.

Abstract

Gravity and its usage in gravity interpretation is still a challenging field. It is not easy to compute these gradients especially in the case of noisy data. Analytical signal is one of the new methods that uses gravity gradients to locate the perturbing body. This method had already been used for high-resolution magnetic and gravity data and rarely used for low-quality gravity data. The gravity gradients and analytical signal have been applied in two different areas, Zahedan where we are looking for Choromite anomalies and Tehran (Mard Abad) where we are investigating for low density anomaly, Probably hydrocarbon.

Key words: Bouguer anomaly, residual anomaly, gravity gradients, analytic signal, Tehran, Zahedan.

Introduction

Over the last few years increasing interest has been expressed for using the gravity gradient for gravity interpretation due to more sensitivity of gravity gradient to geologic structure than gravity itself. The gravity measurements can directly be transformed to vertical gravity gradients. Different methods in quantitative interpretation of the gravity are based on gravity gradients such as analytical signal. The basic concepts of this

method in two dimensions for magnetic data were extensively discussed by Nabighian (1972, 1974) and Green & Stanley (1975). Their counterparts in the case of gravity gradiometric data have been introduced by Klingele et al. (1991). Cordell and Grauch (1985) presented a method to locate abrupt changes in density of subsurface rocks by using the position of maxima of horizontal gradient or gravity anomalies. Their method can

also be used for determining the location of the maxima of the analytical signal.

Analytic Signal

According to Nabighian (1982), the analytical signal of the vertical gradient of gravity produced by a 3-D source is defined as follows:

$$A(x, y) = \frac{\partial^2 g}{\partial x \partial z} + \frac{\partial^2 g}{\partial y \partial z} - i \frac{\partial^2 g}{\partial z^2} \quad (1)$$

The corresponding amplitude of the last expression is:

$$|A(x, y)| = \sqrt{\left(\frac{\partial^2 g}{\partial x \partial z}\right)^2 + \left(\frac{\partial^2 g}{\partial y \partial z}\right)^2 + \left(\frac{\partial^2 g}{\partial z^2}\right)^2} \quad (2)$$

Green (1976) discussed the properties of the analytical signal for 2-D gravity data analysis.

Hansen et al. (1987) demonstrated the usefulness of this technique for the gravity field.

The location of the amplitude maxima of the analytical signal is determined by the method of Blakely and Simpson (1986).

According to Marson and Klingele (1993), the horizontal co-ordinates of the corners are related to position of the maxima of the analytical signal.

Solution strategy

The first step to use the equation (3) is computing the gravity gradients. In computing the vertical gradient, the surface ground data continued to 10 cm, where the gradient between the two levels is believed to be constant. Then the gradient was computed by subtracting the 10 cm height data from the ground surface data and dividing it by height difference. The same strategy is used for computing the second vertical derivative. Relation used for upwards continuation is based on Fourier transform method (Grant & West, 1965),

$$g_z(x, y) = \frac{1}{4\pi^2} \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} F_0(p, q) \exp[\sqrt{p^2 + q^2} z - i(px + qy)] dp dq \quad (3)$$

where $F_0(p, q)$ is the Fourier transform of data $g_0(x, y)$ which is bouguer or residual anomaly at the ground surface, p and q are discrete frequencies and $g_z(x, y)$ is gravity data at height z , where z is positive downwards. The next step is providing horizontal derivative from vertical gradient. To compute the horizontal derivatives, a five point Lagrangian differentiation operator is used (Abromowitz & Stegun, 1970).

$$\left. \frac{d^k f(x)}{dx^k} \right|_{x=x_j} = \frac{k!}{m! h^k} \sum_{i=0}^m A_i f(x_i), \quad (4)$$

Where for first order derivative k is 1, and for five points operator, m is 5. The coefficients A_i are presented by Abromowitz et al. (1970) in the related tables. Then the equation (2) was used and the method presented by Blakely and Simpson (1986) was used to determine the location of the maxima of the analytical signal.

Numerical results

To determine the location of perturbing body based on the analytical signal method, a computer code in Fortran 77 has been prepared.

The program input is residual anomalies provided by Sarma and Selvaraj (1990) method.

Then the vertical gradients are computed through implementing equation (3).

Horizontal derivatives from vertical derivatives are provided by using equation. (4).

The analytical signal method is then used to locate the anomaly.

The first set of data which has been used are low-quality gravity data from Nosrat abad where we are looking for Choromite. Figure (1) shows the bouguer anomalies of the area.

The bouguer anomalies are transferred to residual anomalies (Fig. (2)).

The two first figures clearly show the existence of perturbing body. The first vertical derivatives are computed using the residual anomalies (Fig. (3)).

There is no a significant difference in the place of the main anomaly between the residual anomaly and the first vertical derivative plan. The first vertical derivatives have been used to compute the second vertical derivatives, Fig. (4).

Finally, after computing the horizontal derivatives and consequently analytical signal (Fig. (5)) the existence of the anomaly in the nearly vast area is approved.

Therefore, at this case the clustering of results, coordinates of main anomaly is nearly acceptable and appropriate.

The second set of data belongs to Mard Abad area and Figures (6), (7), (8), (9) and (10) indicates the bouguer, residual, first vertical derivative and the second vertical derivative values.

In Fig. (6), the area with the black color is the most probable area for hydrocarbon. In the residual anomaly map (Fig. (7)) confirms it again.

The first vertical derivative map (Fig. (8)) shows the coordinates of the main anomaly.

The second vertical derivative map Fig. (9) approves the same coordinates.

The amplitude signal map (Fig. (10)) determines the coordinates sharply with a good clustering.

Conclusion

It is evident from numeric results that the code works well. In case of hydrocarbon exploration by low-quality data,

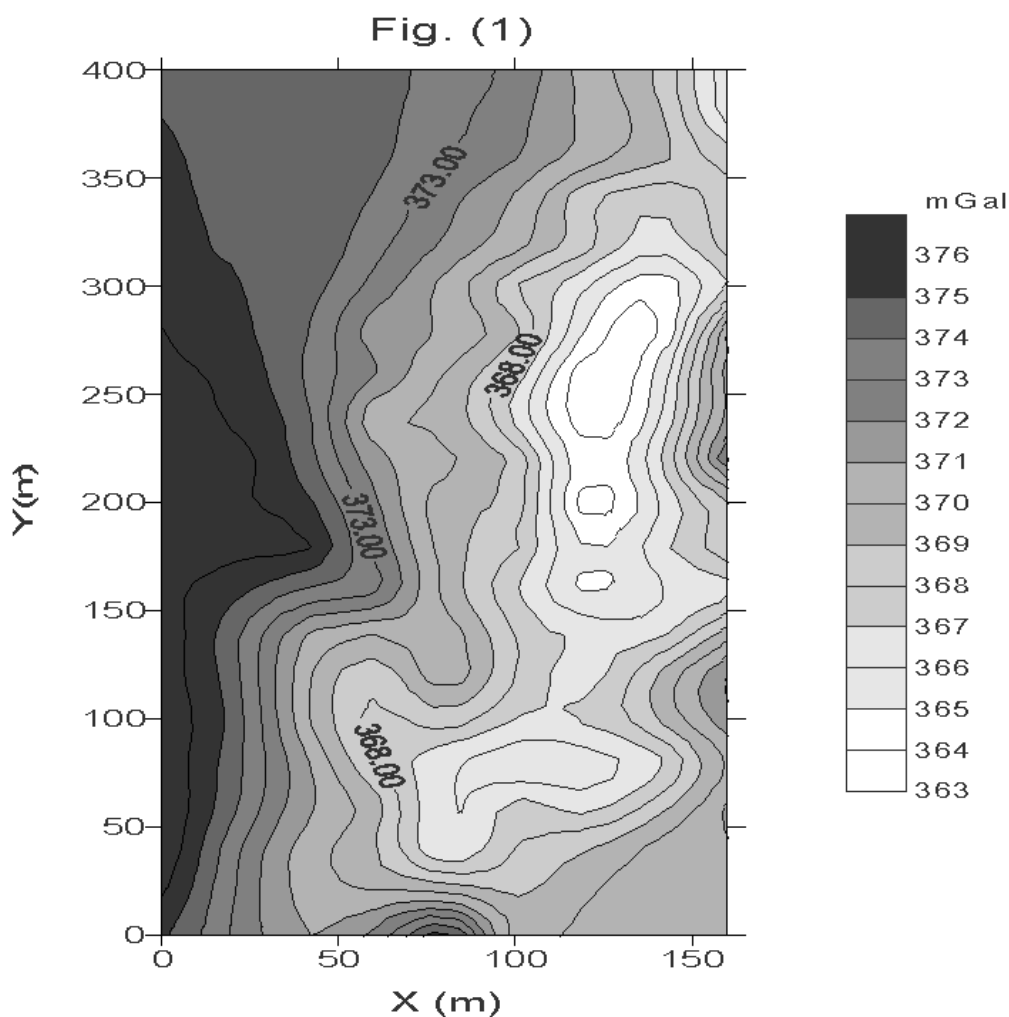
an accurate solution was obtained. However, in this case analytical signal method can play a vital role while investigating in a vast area.

Considering the estimation of the location of anomaly, some other method such as EULDPH (Thompson 1982), can help the process of interpretation, especially in case of

Chromite investigation in which clustering of the solution is not so good.

Acknowledgement

The author is thankful to institute of Geophysics, Tehran university for all supports.



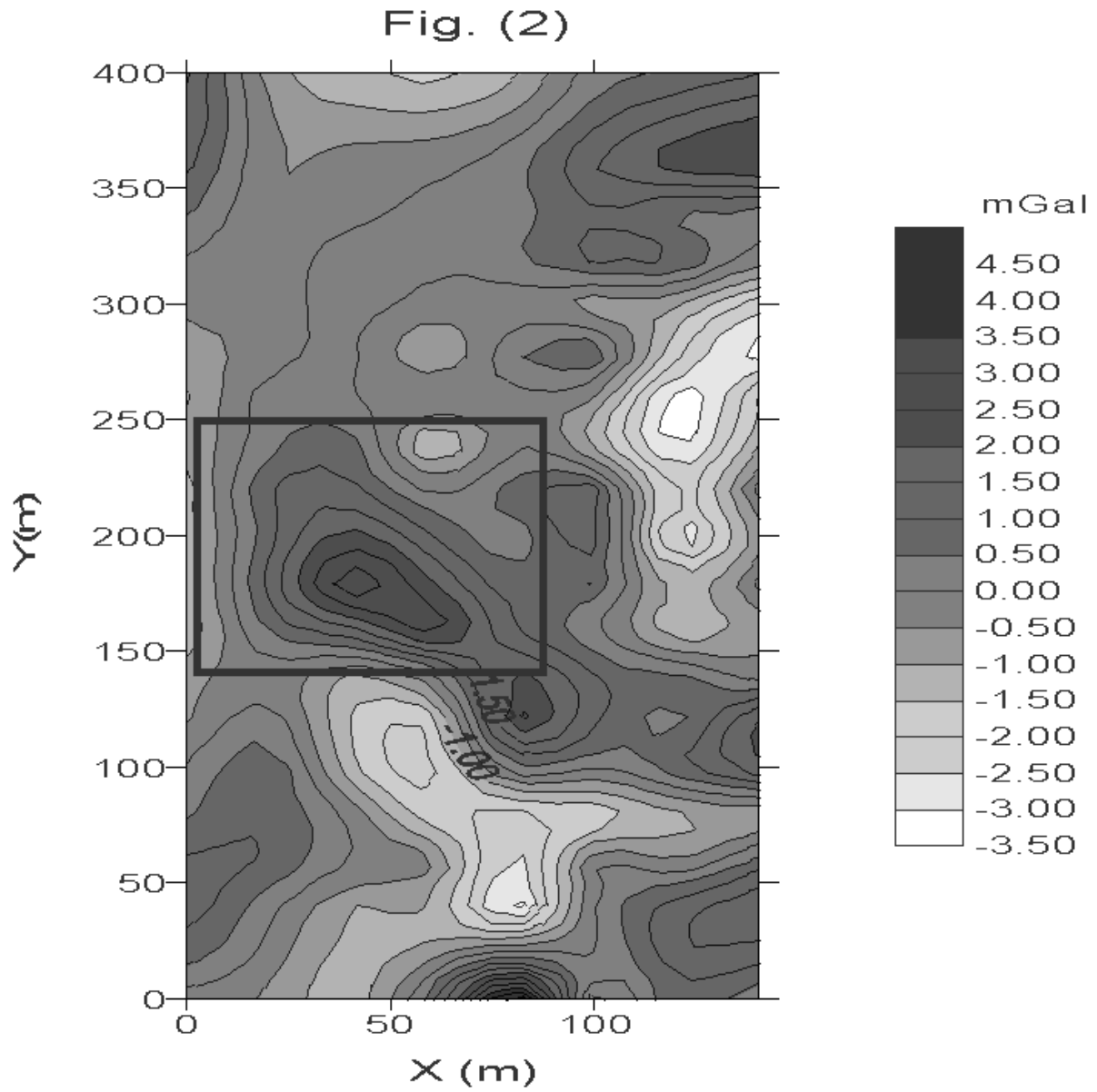


Figure 2: Residual anomalies (Nosrat Abad, mGal).

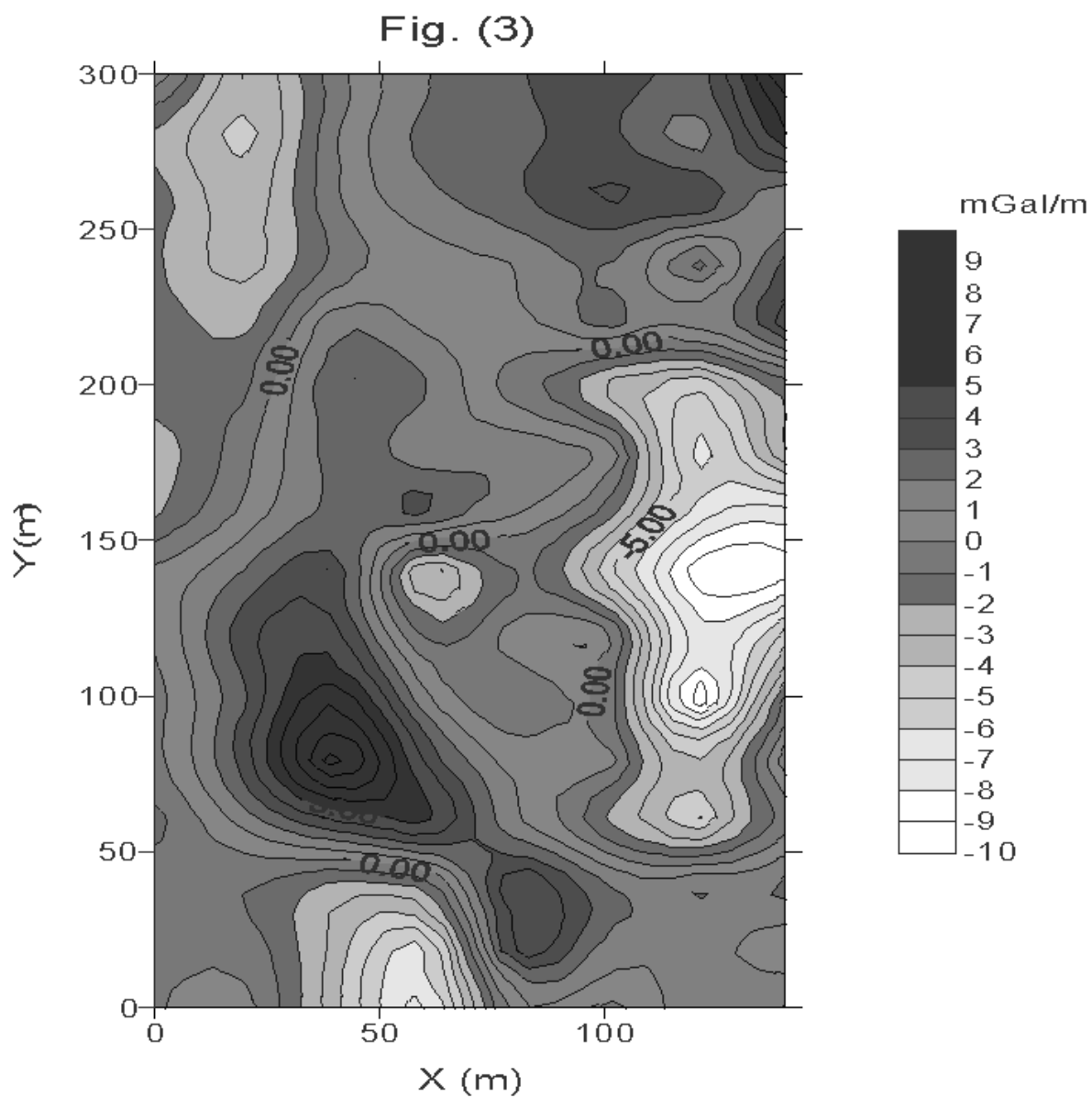


Figure 3: First vertical derivatives (Nosrat Abad mGal/m).

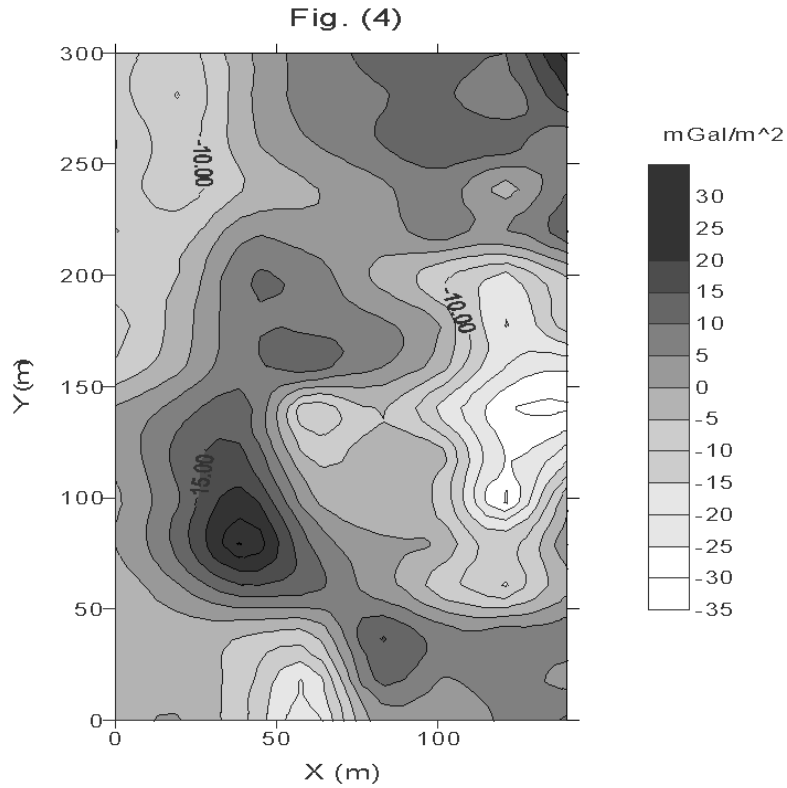


Figure 4: Second vertical derivatives (Nosrat Abad, mGal/m²).

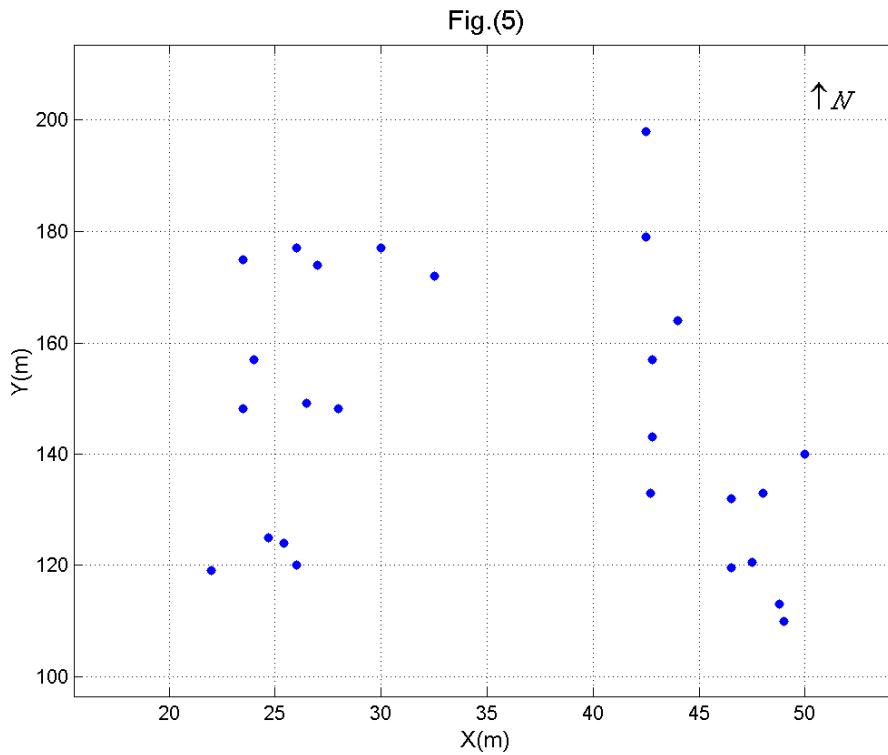


Figure 5: Amplitude of analytic signal (Nosrat Abad, mGal/m²).

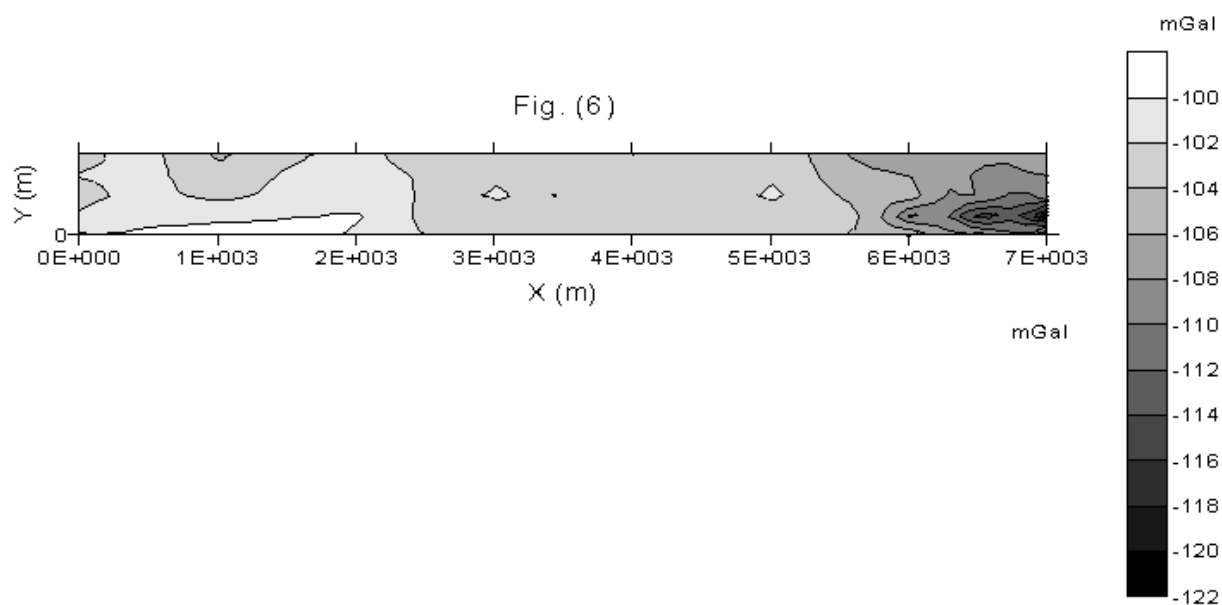


Figure 6: Bouguer anomalies (Mard Abad, mGal).

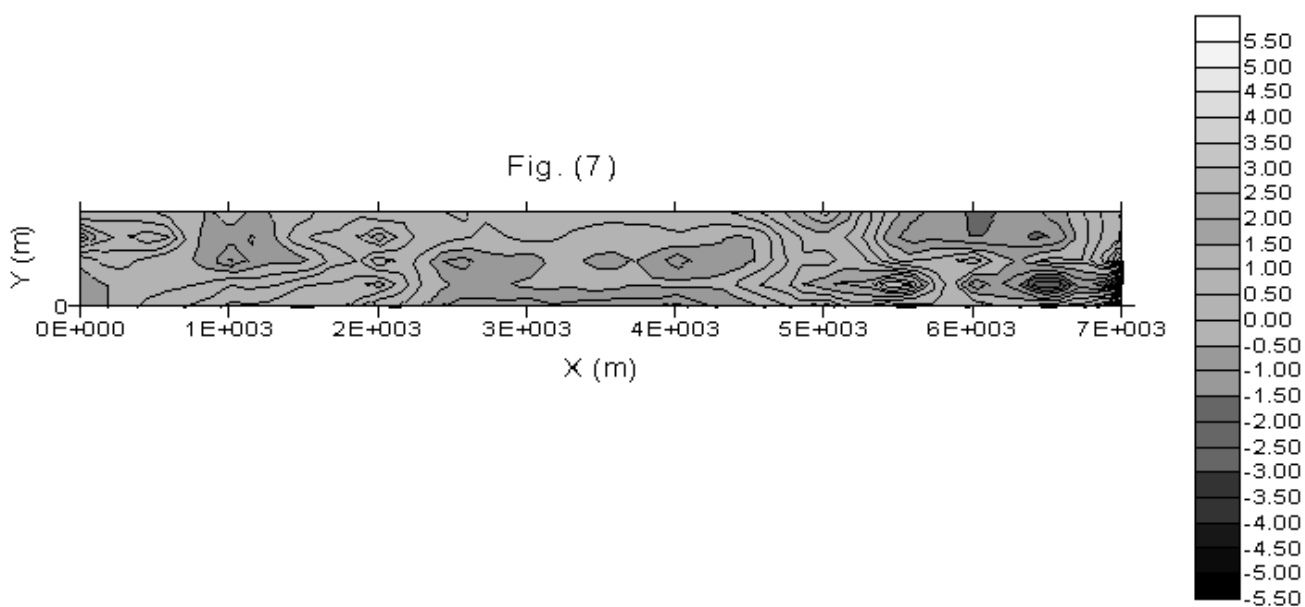


Figure 7: Residual anomalies (Mard Abad, mGal).

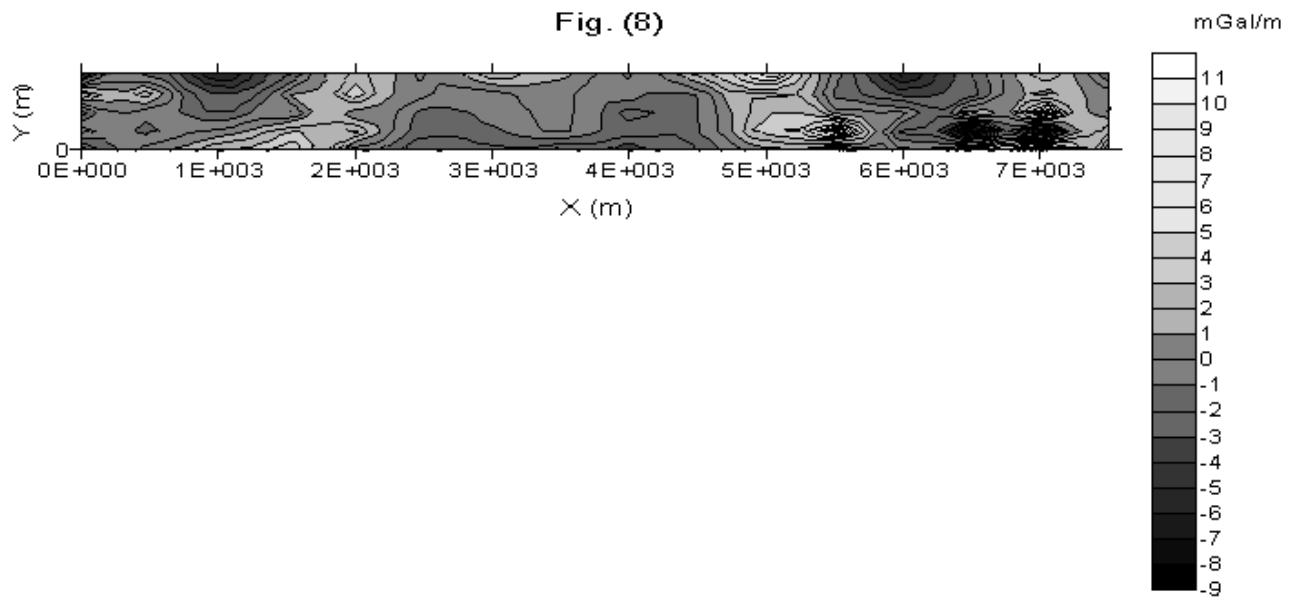


Figure 8: First vertical derivatives (Mard Abad mGal/m).

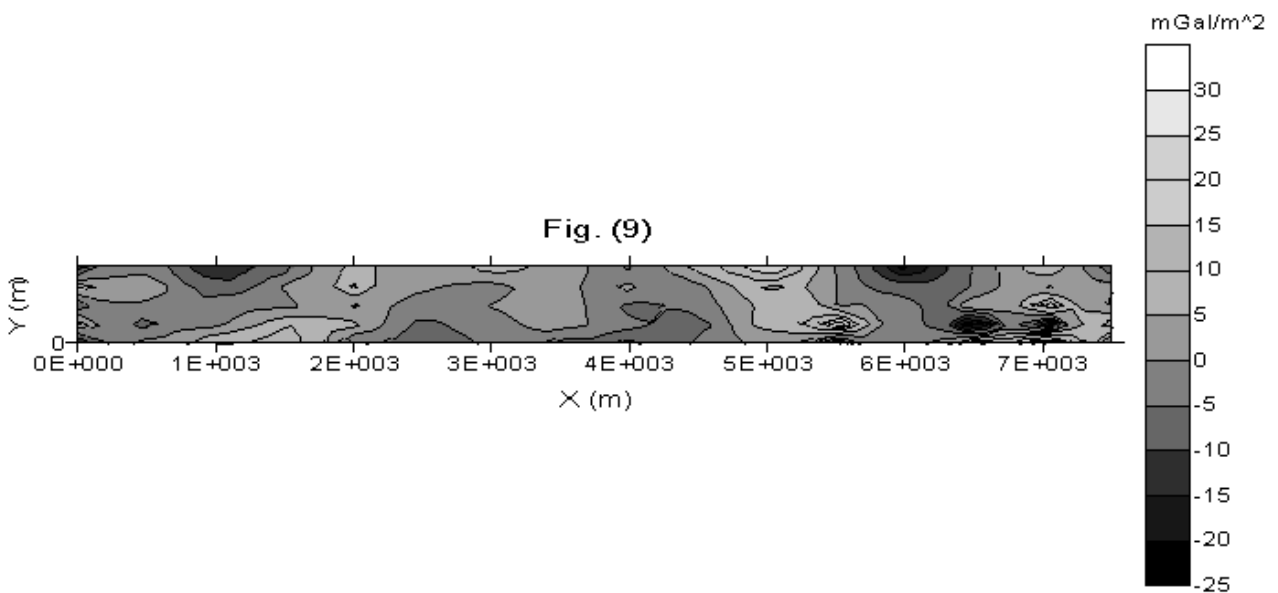


Figure 9: Second vertical derivatives (Mard Abad, mGal/m²).

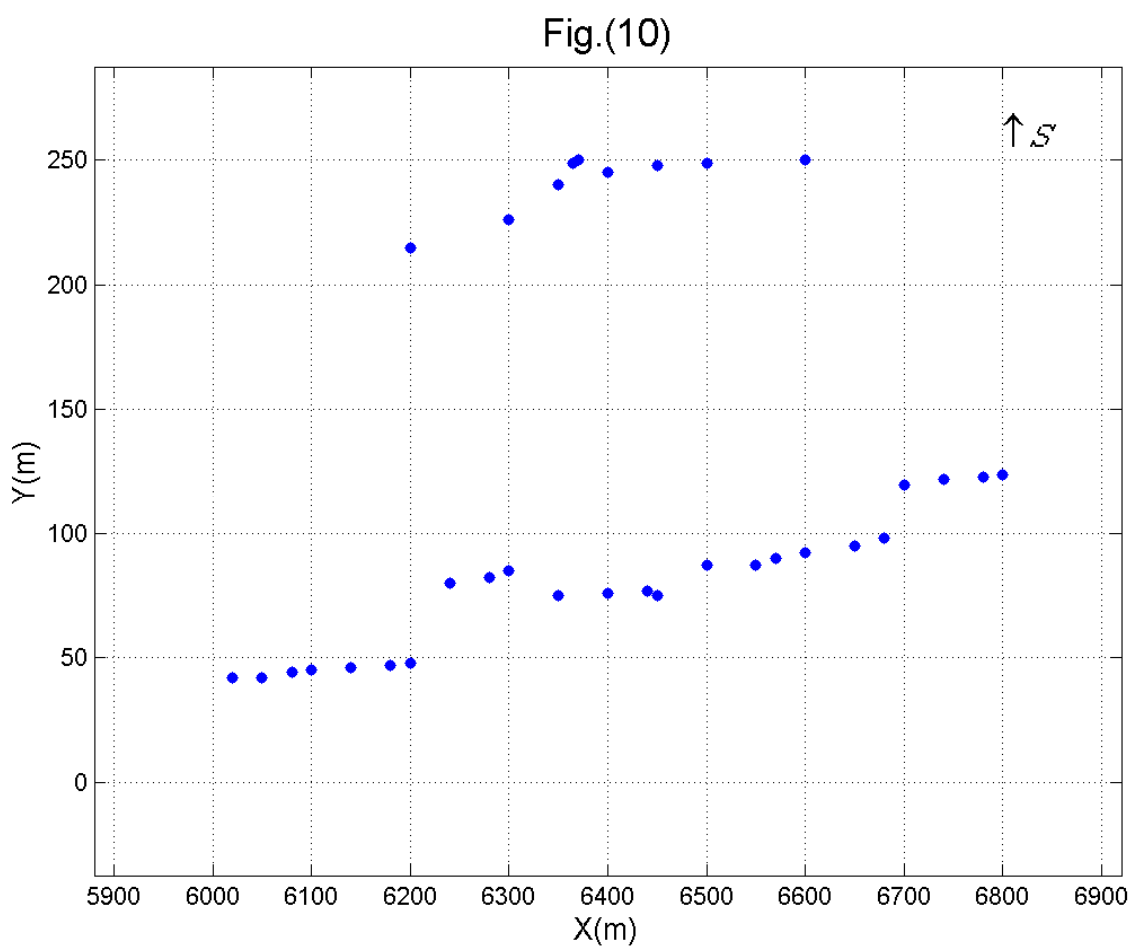


Figure 10: Amplitude of analytic signal (Mard Abad, $mGal/m^2$).

References

- Abromowitz, M. & Stegun, I.A., 1970- Handbook of mathematical functions. Dover Publ., New York.
- Blakely, J. & Simpson, R. W., 1986- Approximating age of source bodies from magnetic or Gravity anomalies. Geophysics, Vol. 51, No. 7, pp. 1494-1498.
- Cordell, L. & Grauch, V.J.S., 1985- Mapping basement magnetization zones from aeromagnetic data in the San Juan basin, New Mexico, in Hinze, W.J., Ed., The utility of regional gravity and magnetic anomaly maps: Soc. Expl. Geophys., 181-197.
- Grant, F.S. & West, G.F., 1965- Interpretation theory in applied geophysics. McGraw-Hill Book Company, New York, U.S.A.
- Green, R. & Stanley, J.M., 1975- Application of a Hilbert transform method to the interpretation of surface – vehicle magnetic data. Geophysical Prosp. 23, pp. 18-27.
- Green, R., 1976- Accurate determination of the dip angle of a geological contact using the Gravity method. Geophys. Prosp., 24, 265-272.
- Hansen, R.O., Pawlowski, R.S. & Wang, X., 1987- Joint use of analytic signal and amplitude of horizontal gradient maxima for three-dimensional gravity data interpretation. 57th Ann. Internat. Mtg. Soc. Expl. Geophys., Expanded abstract, 100-102.
- Klinge, E.E. & Mars, I., 1991- Automatic interpretation of gravity gradient data in two dimension : Vertical gradient. Geophysical Prosp. Vol. 39, pp. 407-439.
- Marson I., & Klinge, E.E., 1993- Advantages of using the vertical gradient of gravity for 3-D interpretation. Geophys. Vol. 58, No. 11, pp. 1588-1595.
- Nabighian, M.N., 1984- Toward a three dimensional automatic interpretation of potential field via generalized Hilbert transform- fundamental relations. Geophysics, vol. 49, pp. 780-786.
- Sarma, D.D. & Sevaraj, J.B., 1990- Two dimensional orthonormal trend surface for prospecting. Computer Geosciences, 16, 897-909.
- Thompson, D.T., 1982- EULDPH, A new method for making computer-assisted depth estimates from magnetic data. Geophysics, Vol. 47.

*موسسه ژئوفیزیک دانشگاه تهران

*Institute of Geophysics, Tehran university, Tehran, Iran.