MODELING THE ANOMALOUS GRAVITATIONAL FIELD OF FAULT-BLOCK STRUCTURES

Kerimov I.A.

Schmidt Institute of Physics of the Earth of the Russian Academy of Sciences
kerimov@ifz.ru

Abstract. *Algorithms and computer programs have been developed for calculating the elements of the anomalous gravitational field for a system of fault-block structures. The anomalous gravitational field was calculated for various types of models. Criteria for identifying faults and fracture zones on maps of higher derivatives of the gravitational field have been determined. Standard geological-density models have been created for characteristic fault-block structures. Based on calculations using the F-approximation method, a Wzzz map was constructed and the fault systems of the Terek-Sunzha anticlinal zone were identified.*
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In connection with the reduction of oil and gas reserves in the Mesozoic deposits of the North Caucasus in recent years, the search and exploration of hydrocarbon deposits associated with non-structural traps in the Cenozoic deposits is very relevant. Non-structural hydrocarbon traps are in most cases confined to deep fault zones. One of the promising directions in the North Caucasus is in zones of increased fracturing in the upper horizons of the sedimentary cover. One of the effective ways to predict fracture zones is detailed gravimetric survey. In this regard, there is a need to improve existing and develop new methods for interpreting gravimetric data.

The F-approximation method for anomalous gravitational and magnetic fields, developed within the framework of the method of linear integral representations by V.N. Strakhov, is completely adequate to real geophysical practice and allows us to get rid of various idealizations (idealization of a flat field; idealization of the ground-air interface as an infinite horizontal plane; idealization of the continuous assignment of one or another field element on an infinite horizontal plane or a piece of this plane; idealization of the assignment of one or another another field element at the nodes of a regular geometric network, etc.).

The F-approximation method developed by the author within the framework of the theory of integral representations allows us to solve in a fundamentally new way a number of issues of transformation of potential fields given on an irregular and different-height network:

$$W_a(x), \qquad x = (x_1, x_2, x_3) \tag{1}$$

The results of testing the method on model and actual geophysical data specified on an irregular network allowed us to conclude that the field reconstruction is highly accurate by F-approximation [1-8]. As shown by modeling the anomalous gravitational field of a system of differently oriented faults, the most effective way to trace them is to use the third vertical derivative Wzzz of the gravity potential. Previously [4, 5] an expression was obtained for Wzzz for a given arbitrary network of design points:

$$W_z(\xi_{1,l}, \xi_{2,l}, \xi_{3,l}) = \frac{3}{2\pi} \sum_{k=1}^{N} \lambda_k \frac{(2z_{k,l}^2 - 3p_{k,l}^2) \cdot z}{(z_{k,l}^2 + p_{k,l}^2)^{\frac{7}{2}}}, \tag{2}$$

where

λ_i - Lagrangemultipliers;

$$p_{k,l} = \sqrt{(x_{1,k} - \xi_{1,l})^2 + (x_{2,k} - \xi_{2,l})^2} \;;$$

$$z_{k,l} = x_{3,k} + \xi_{3,l} + 2H \;.$$

The expression for Wzzz based on the F-approximation is as follows:

$$W_{zzz}(\xi_{1,l}, \xi_{2,l}, \xi_{3,l}) = \frac{75}{\pi} \sum_{k=1}^{N} \lambda_k \frac{z_{k,l}(8z_{k,l}^4 - 40\rho_{k,l}^2 z_{k,l}^2 + 15\rho_{k,l}^4)}{(z_{k,l}^2 + \rho_{k,l}^2)^{5.5}} \qquad (3)$$

This expression allows to find the spatial distribution of Wzzz based on the F-approximation in a given network of design points.

Model and practical examples demonstrate the effectiveness of solutions based on F-approximation for a wide range of important practical problems:

• Restoring the values of potential fields at the nodes of a regular network, taking into account the difference in height of the source and result points (3D interpolation).

• Elimination of the distorting influence of an anomalous vertical gradient when recalculating the observed field to a horizontal plane or any given surface.

• Filtering of interference that disrupts the harmonic nature of the observed field.

Within the framework of the theory of the F-approximation method, algorithms and computer technologies for 3D transformation have been developed (calculation of higher derivatives of potential fields, analytical continuation into the upper and lower half-spaces of elements of potential fields, separation of anomalous fields). Algorithms and computer technologies for F-approximation of the relief of the earth's surface have also been developed, used to solve various problems of gravimetry, magnetometry, applied cartography, geomorphology, etc. Using a number of real geological and geophysical materials, the effectiveness of using gravimagnetic data for studying fault tectonics and predicting oil and gas promising traps in deep-seated horizons.

To assess the effectiveness of gravimetric methods in studying fault systems and fracture zones, a series of models were developed and the anomalous gravitational field and its derivatives were calculated. To solve the direct problem of gravity survey for vertical linear prisms of various orientations, a program was developed based on the ideas of solving direct problems of gravimetry for field elements from standard approximating bodies.

In Fig. 1 we see the diagram of the arrangement of blocks, representing in plan two rows of 3 prismatic bodies of sub-latitudinal orientation, offset relative to each other by 1 km. Prisms 1, 3, 4 and 5 have the same dimensions 5x15 km, the depth of the upper face is 2 km, the bottom – 5 km. Prisms 2 and 5 have dimensions of 5x20 km, the depth of the upper face is 1.5 km, the bottom – 5 km.

The map of the anomalous gravity field Δg for this model is shown in Fig. 2. This map shows that the anomalous field appears in the form of a complex anomaly, the shape of which does not allow us to unambiguously identify the boundaries of the blocks. On the map of vectors of the horizontal gravity gradient (Fig. 3), sublatitudinal boundaries are distinguished relatively well, while at the same time, meridional boundaries are clearly difficult to identify.

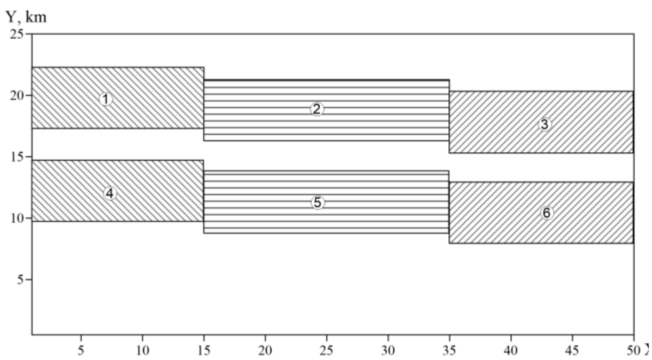

Fig. 1. Layout plan of vertical prisms

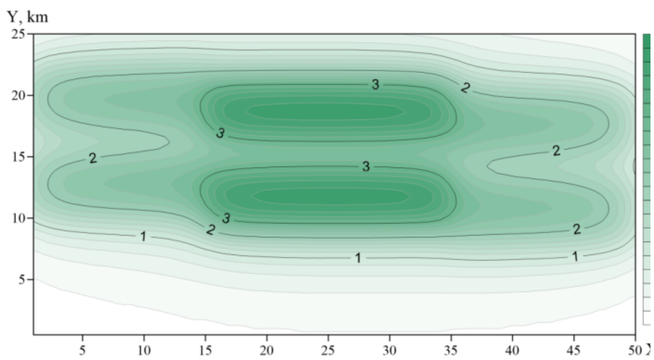

Fig. 2. Map of the anomalous gravity field Δg

On the Wzzz map (Fig. 4), built for this model, blocks in the form of quasi-rectangular anomalies are clearly visible, and the displacement of blocks is also clearly visible.

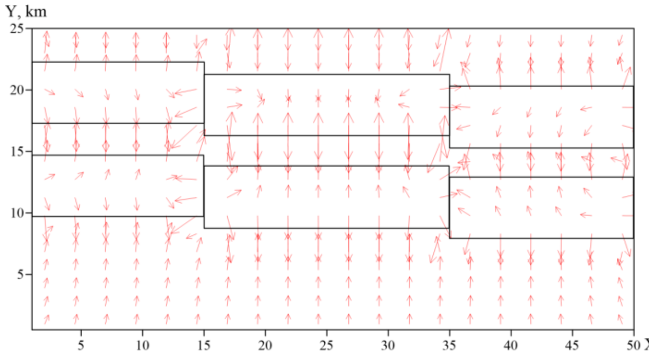

Fig. 3. Map of horizontal gravity gradient vector.s

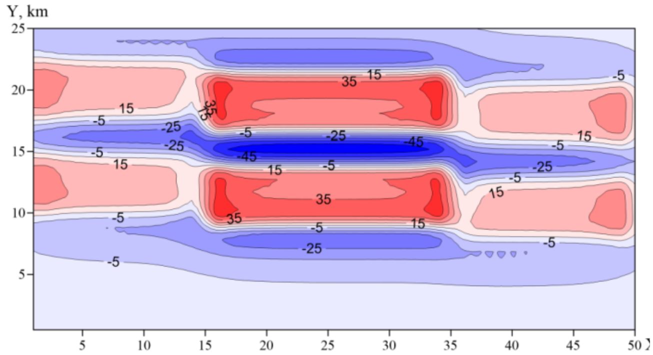

Fig. 4. Map of the third vertical derivative Wzzz.

There is a map of Wzzz and fault systems of the western part of the Terek-Sunzha anticlinal zone in Fig. 5. When identifying faults, the following features were used on maps of the anomalous gravitational field:

- large gradients of anomalous gravitational field;
- stripes of intense positive or chains of gravity maxima;
- a sharp change in the strike of gravity field anomalies;
- a sharp change in the signs of the anomalous gravitational field;
- change in the general nature of gravitational fields;
- change from the linear shape of weakly expressed anomalies to an isometric one.

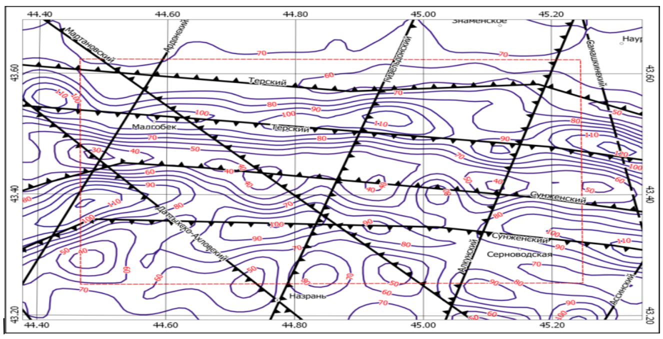

Fig. 5. Map of Wzzz and fault systems of the western part Terek-Sunzha anticline zone.

In Fig. 6 shows a comparison of the fault pattern, earthquake epicenters and topography of the described region of the Terek-Sunzha anticlinal zone.

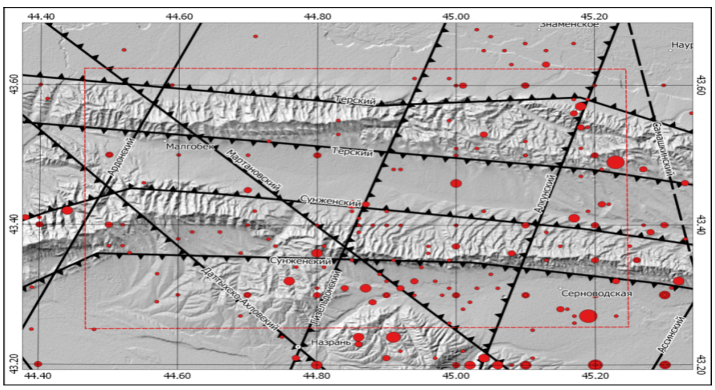

Fig. 6. Map of fault systems and relief of the western part Terek-Sunzha anticline zone.

Conclusions

1. An algorithm and computer program have been developed for calculating the elements of the anomalous gravitational field for a system of faults of various orientations, based on the formulas of V.N. Strakhov.

2. The program was tested on a series of model examples. It has been established that fault-block tectonics and zones of increased fracturing are most clearly reflected in the field of the third vertical derivative Wzzz.

3. The F-approximation method is a highly efficient method for calculating higher derivatives for initial data given on a gravity field that is irregular in plan and height.

4. Based on the interpretation of the field of the third vertical derivative Wzzz and morphometric analysis of the relief of the earth's surface, the location of faults for the western part of the Terek-Sunzha anticlinal zone was clarified.

5. The epicenters of strong earthquakes, as a rule, are noted at the intersections of faults, while the epicenters of weak earthquakes are noted inside blocks.

References

[1] Kerimov I.A. Use of F-approximation when interpreting gravity data. I. Methods and results of testing on model examples. // Physics of the Earth, No. 1, 2003, pp. 57-76.

[2] Kerimov I.A. Use of F-approximation when interpreting gravity data. II. The results of testing on the materials of gravimetric and magnetometric surveys". // Physics of the Earth, No. 5, 2009, pp. 77-93.

[3] Kerimov, I.A. F-approximations of the relief of the earth's surface. // Physics of the Earth, No.8, 2009, pp. 101-112.

[4] Kerimov I.A. F-approximation method for solving problems of gravimetry and magnetometry. // Moscow, Fizmatlit, 2011.

[5] Kerimov I.A. Calculation of the higher derivatives of the gravitational potential based on the F-approximation. // Geology and Geophysics of the South of Russia, No. 3, 2016, pp. 65-84.

[6] Kerimov I.A., Stepanova I.E., Raevsky, D.N. Combined Approximation Methods for Solving Gravity and Magnetic Problems. // Geology and Geophysics of the South of Russia, No. 3, 2018, pp. 37-50.

[7] Stepanova, I.E., Kerimov, I.A., Raevsky, D.N., Shchepetilov, A.V. On improving methods for processing large amounts of data in geophysics and geomorphology based on modified S- and F-approximations. // Physics of the Earth, No. 3, 2020, pp. 82-97.

[8] Stepanova I.E., Kerimov I.A., Yagola A.G. Approximation approach in various modifications of the method of linear integral representations. // Physics of the Earth, No 2, 2019, pp. 31-46.

[9] Strakhov, V.N., Kerimov, I.A. Approximation constructions of spectral analysis (F-approximation) of gravimetric data. // Physics of the Earth, No. 12, 2001, pp. 3-20.