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SYNTHESIS OF QUALITATIVE AND QUANTITATIVE METHODS OF EXTRACTION OF GEOLOGICAL INFORMATION OUT OF GRAVIMETRIC DATA

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The technology of joint usage of qualitative and quantitative methods of interpretation of gravimetric data id examined. Field separation by formal procedures for the series of components with different depths is suggested ti realize taking inverse task solution in account, while solving of inverse task themselves is proposed to conduct using the results of fields separation. Such technique allows to approach to required construction model of the examined object of geological medium with every step of interpretation process. At the initial stage of interpretation process, Vector system is used for building the image of geological medium, this system allows to get 3D distribution of quasi-density, reflecting some elements of physical geological model. The results of vector scanning are using for detalization of geological hypotheses and setting a priori restrictions in consequent solving of inverse task. Then miltiple solving of inverse task is executed via the mounting method. The obtained complex of partial solutions is transformed in net distribution of possibility of revealing the anomaly forming object that is an appropriate geo-density model. This model has real 3D coordinates and characterize distribution of anomaly forming masses in the examined volume of geological medium. Usage of geo-information systems for storage of starting and resulting gravimetric data, as well as for transferring the intermediate results of interpretation between other programs is seemed to be quite suitable. Practical examples testifying about the efficiency of presented technology are described.

Key words: *gravimetric exploration, geological information, interpretation of results, solving of reverse tasks.*

Geological efficiency of geophysical, in particular gravimetric, researches is stipulated mainly by the methods of interpretation of the data, i.e. by the whole complex of the methods for obtain of information on the base of the fields observation. Methods of interpretation may be divided to qualitative and quantitative [1]. Anomalies of gravity and their supposed geological nature are marked at the stage of qualitative interpretation. Quantitative interpretation permits to obtain parameters describing the shape, dimensions, depth of bedding and density of the objects with abnormal parameters. Thus, for interpretation of gravimetric data it is necessary, first of all, to divide the studied field to the components with marking of abnormal zones in the plan and by depth. Secondly, it is necessary to do qualitative estimation of parameters of the zones by means of solution of the reverse task of gravimetric exploration. It is advisably to use above mentioned methods in common: parceling of the field by the formal procedures to series of the components of "different depth" in accordance with solution of the reverse task. And solution of the reverse task has to be carried out with usage of results of parceling of the fields. Authors suppose that above mentioned method will permit to approach to the formed model of structure of studied volume of geological medium at the every step of interpretation process.

Quality of volume of information of geological methods, using potential fields (first of all — gravitational and magnetic) in course of studying of the earth's crust, is connected with attempts to obtain by the seam distribution of physical properties of the rock, i.e. to divide sources of the fields by vertical. It is known that the task can not be solved, in the main, by dismemberment of geological section by vertical in accordance with the data of gravimetric prospecting [1]. Nevertheless necessity to obtain three-dimensional distribution of density of the rock is dictated by experience of geophysical works, complication of geological tasks, high degree of development of mining of the mineral resources and so on. So, taking into account the known theoretical restrictions, using some properties of potential fields and geological information a priori it is created lately new, in the main, methods of the field interpretation, directed to constructing of the three-dimensional model of geological medium, adequate to studied field and available information a priori. Vector scanning is one of the new methods. It has been realized in computer technology Vector worked up in the Mining Institute of Ural Branch of Russian Academy of Sciences under the leadership of Novoselitsky V. M. [2].

Components of gravitational field are the result of fulfilled vector scanning. They are identified with abnormal effects of the some intervals of geological section. Above mentioned components are connected linearly with distribution of density within the studied layer. So, they may be used for marking and contouring of geological objects located within some interval of the depth.

Efficiency of technology Vector is confirmed by numerous results of its practical application for solution of wide range of geological tasks including study of Verkhnekamsky deposit of potassium salt [2]. But result of operation of the system Vector does not permit to determine parameters of geological objects. It is in fact gravimetrical image of geological medium and it may be used, for example, as the model of "zero approaching" for preliminary analysis and for comparison with the other geological information.

Parameters of the form, depth of bedding and density of abnormal objects permit to obtain solution of non-linear reverse gravimetrical task (NRG). Assembly method, realizing final-element approach to gravitational modeling, is highly effective. Method has been offered by Strakhov V.N. [3] and Ovcharenko A.V. [4] and has been developed in the works of Balk P.I. [5]. Method uses discrete (net) description of the geo-denseness medium. Abnormal objects (configurations) Ω are presented here as amalgamation of some number of elementary geometrical figures (for example, cubes) ω_α with constant density. Principal operations in the net classes are carried out with usage of the terms: kernel Я $[\Omega]$, cover О $[\Omega]$, inside kernel ЯО $[\Omega]$ and border Г $[\Omega]$ of configuration (Fig. 1).

For simplest OZG for isolated object S^T with known density $\sigma^T > 0$ assembling principle of solution consists in following: to dispatch from the set liaison configuration Ω^0, to draw up final sequence Ω^0 with the bound in the area $\Omega^0, \Omega^1 \ldots, \Omega^n$ with the bound in area Ω^*.Field of the area (for chosen density $\sigma^* \approx \sigma^T$) coordinates with measurements Δg_k ($k = 1, 2, \ldots, m$) of the gravitational field. Regular approaching Ω^n is formed by means of bringing of some single element ω_α from О $[\Omega^{n-1}]$ in the kernel Я$[\Omega^n]$ ensuring minimum average-square discrepancy of choosing.

Final-element approach to solution of NRG eliminates the problem of instability in its classical form since final scale of the model and its natural restrictions primarily leads to compact multitude of possible solutions and with due regard for some volume of information a priori, it ensures reliable solution of the set geological task. But for increase of trustworthiness of interpretation constructions it is advisably not to examine the separate solution of NRG G but to consider total volume of reliable information about disturbing objects. At the same time the separate solution gives us the point estimation of parameters of the model with accidental quality. Task of localization of the single disturbing object may be considered as the task of forming of two areas: D_1, contenting all permissible solutions of NRG, and D_2 — fragment of the all permissible solutions (and, as a result, fragment of the object forming anomaly).

Methodical base for above mentioned construction is the reliable method of approach offered by Kantorovich L. V. in 1962 [6] and developed for application in gravimetry in the works of Balk P. I. [7]. Method is directed to obtain of reliable information in uncertain conditions. It has shown itself to advantage in different spheres of science (first of all — in theory of management). For construction of the areas D_1 and D_2 it is enough to construct representative excerpt of permissible solutions of NRG, differing one from another even if the only element. After that it is necessary to obtain unification of D_1 and intersection of D_2.

Share of D_1/D_2-space is the area of uncertainty. Its measure μ gives quantitative estimation of degree of showing of ε-equivalency. Expansion of the matrix $\tau(D_1, D_2) = \mu(D_2)/\mu(D_1)$ serves as estimation of information valuables of combined data. But "clean" dependable approach is, to some extent, excessively categorical. Fulfillment on its base of dividing of the studied volume by probability of discovering of abnormal objects is the more effective method. Principle of dividing is following: permissible solutions of NRG are equal in rights a priori. So, every solution may be approximated, in the best measure, to unknown disturbing object Ω with equal probability. N is number of the all permissible solutions of the reverse task (it is the great but finite quantity), N_k, α, — is number of permissible solutions of Ω_k^*. Every solution contents the some element ω_α. Thus, ρ_k, $\alpha = N_k$, α/N — probability that the element ω_α is the small fragment of unknown disturbing object.

Algorithm of joint application of qualitative and quantitative methods in interpretation of gravimetrical data is following. System Vector is used at initial stage of interpretative process. It is used form construction of image of geological medium — spatial distribution of quasi-density, reflecting some elements of physical-geological model. Parameter of quasi-density does not have dimension value of physical parameter density. Scale of the depth of constructed sections and 3D-diagrams do not correspond to the real ones. But results of vector scanning are successfully used for specifying of geological hypotheses for setting of restrictions a priori in subsequent solution of the reverse task. Then it is carried out multiple (about 300–1500 cycles) solution of NRG by assembling method. Obtained whole complex of particular solutions

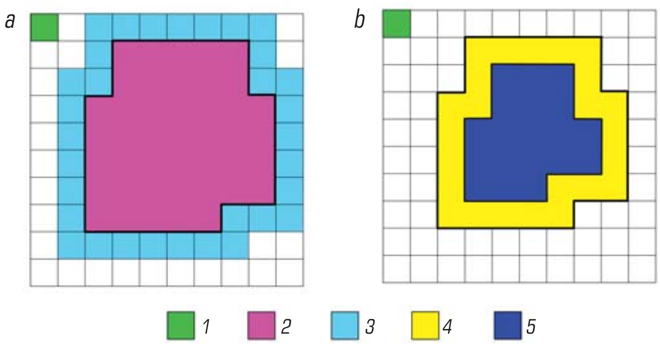

Fig. 1. Graphic illustration of the principal terms used in the assembling method:
a — cover О $[\Omega]$ Я $[\Omega]$ and kernel Я $[\Omega]$; *b* — border Г $[\Omega]$ and inner kernel of two-dimensional configuration Ω; *1* — single (separate) element of replacing ω_α; 2–5 — elements of replacing ω_α, belonging to: *2* — kernel Я $[\Omega]$, *3* — cover О $[\Omega]$, *4* — border Г $[\Omega]$, *5* — inner kernel $Я_0$ $[\Omega]$

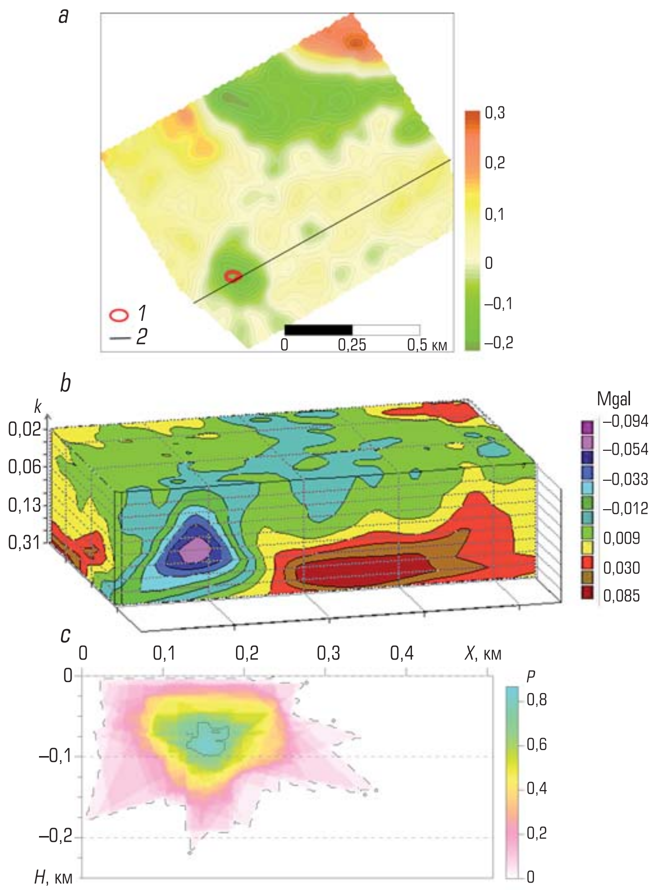

Fig. 2. Results of interpretation of gravimetrical data in the downfall zone in Beresniky-town

a — gravitation field (*1* — contour of the downfall zone, *2* — line of vertical section of the field); *b* — transformation of the field in the system Vector; *c* — result of quantitative interpretation of the local anomaly

is transformed to the net distribution of probabilistic parameters $\rho_{k,\alpha}$, that is substantial geo-density model. The model has the real spatial coordinates and characterizes distribution of abnormal masses in studied geological volume. Zones of high values $\rho_{k,\alpha}$ correspond to most trustworthy marked disturbing objects (or their fragments). Then it may be used for setting of the holes or mining workings.

Let us to consider the examples of solution of the practical tasks on the base of synthesis of described above methods of quantitative and qualitative interpretation of the gravitational field.

Example 1. In November of 2010 it has taken place downfall of the surface about 15 meters diameter at the flooded mine of Verkhnekamsky deposit of potassium salt to the south of the building of railway station Beresniky. To January of 2011 size of downfall of the surface has increased to 50×100 meters. In December of 2010 detailed highly precise gravimetrical survey has been carried out in the area of downfall of the surface. The goal of the survey was contouring and study of the zone of downfall, clearing up of its nature, depth of spreading of the rock with low density and revealing of the plots with low density on adjacent territory.

Source of above mentioned anomaly is distinctly observed at the three-dimensional model, obtained in the system Vector, as isolated body with decreased density. Qualitative calculation has been carried out proceeding from the assumption that negative local anomaly is conditioned by the only object that lies at the depth 50–300 meters with abnormal density from –0.02 to –2 g/cm³. Dimensions of abnormal objects by horizontal line are from 10 to 500 meters, by vertical line — from 20 to 150 meters.

Results of interpretation are given at the Fig. 2, *c*. Dotted line contours comparatively wide area, including all permissible solutions of NRG. Iso-line of probability $\rho_{k,\alpha} = 0.8$ localizes the most probable location of the source within the bounds of above-mentioned area. Center of the area with low density has been fixed at the depth 80 meters, i.e. above the bedding. Calculation has shown that the task has solution only in the case of value of the bounds of abnormal density from –0.02 to 0.9 g/cm³. It means that the real rock density within the bounds of the object may change from 1.4 to 2.28 g/cm³.

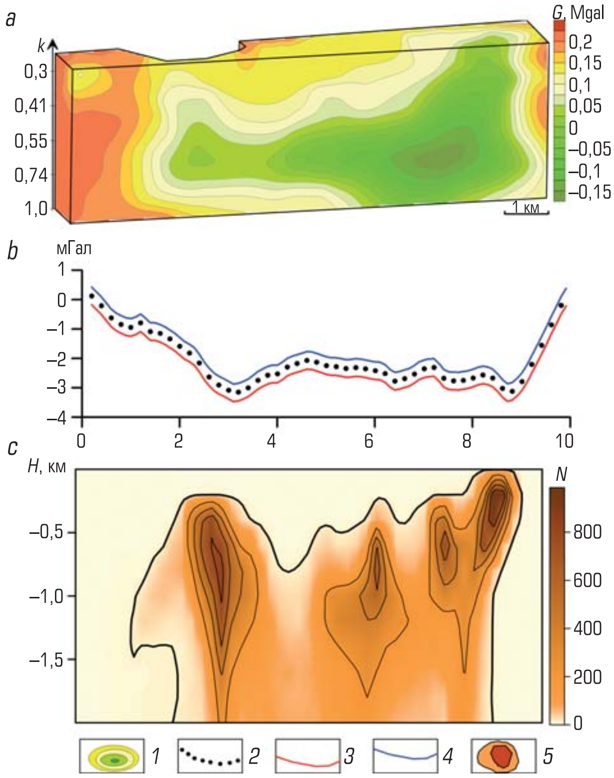

Fig. 3. Marking out and contouring of the granite massifs with possible copper-molybdenum ore-bearing

a — image of geological medium constructed in the system Vector; *b* — diagram of abnormal gravity; *c* — vertical map of probability of presence of abnormal object; *1* — three-dimensional diagram of quasi-density of the rock; *2* — local component of gravitational field; *3, 4* — borders of the intervals for discrepancy of the studied and model fields; *5* — iso-lines of probability $\rho_{k,\alpha}$

Example 2. Results of interpretation of large-scale gravimetric survey, carried out at the deposit of copper-molybdenum ore (Eastern Siberia), are given at the Fig. 3. Ore formations are connected, spatially and by genesis, with the massif of granite-porphyry. The last ones are characterized by decreased density (to –0.1 g/cm^3) in comparison with enclosing metamorphic rock. Contour of supposed magmatic system has been determined by means of technology "Vector" (Fig.3, *a*).

Probability of finding of the objects with low density, identified with granite massifs, has been obtained on the base of 985 permissible solutions of NRG by the assembling method. It has been assumed that density of disturbing object is –0.1 g/cm^3, dimensions of the element ω_α are 200×200 meters. Multitude of permissible solutions has been determined by value of discrepancy of the fields ±0.3 mGal. It means that in case of normal law of distribution of the interference about 68% of the values of the model field will be characterized by deflection from the studied field not more than above mentioned value. It means that they will lie in the "corridor" between the red and blue diagrams at the Fig.3, *b*.

Object with low density, located in the eastern part of the profile, is bound up with the known deposit of copper-molybdenum ore. The object is identified with the most hydro-thermally changed and quartz-contenting zone of intrusion. The object is thinned out at the depth about 700–800 meters from the surface. It permits to estimate approximately vertical scale of the zone of copper-molybdenum ore-bearing. Presence of unknown earlier steeply dipping ore-perspective object with low density is greatly probable in western part of the profile. Its upper edge lies at the depth about 400 meters from the surface.

In conclusion it has to be noted that geophysical data always are "tied" in the space. So, storing of initial and resulting gravimetrical information, transmission of intermediate results of interpretation between the separate programs may be simply carried out with application of geo-information systems. Information-analytical system "Gravis" has been created in the Mining institute of Ural Branch of Russian Academy of Sciences on the base of geo-information system ArcGIS. System permits to solve wide range of the tasks, connected with working, interpretation and storing of numerical, gravimetrical and other geological-geophysical information including the tasks of common usage of qualitative and quantitative methods of obtain of geological information on the base of gravimetrical data.

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