DEVELOPMENT OF POTENTIAL FIELDS INTERPRETATION DIRECTION WITHOUT OF ADDITIONAL INFORMATION – THE BEREZKIN'S METHOD AND THE QUASISINGULAR POINTS METHOD

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Abstract

The second half of the 20th century was marked by fast development of the computer facilities which has allowed to create the newest technologies of geophysical data processing. Such development resulted in creation of directions and doctrines of potential fields interpretation. Among them is the method of gravity fields interpretation offered by V.M. Berezkin. It does not require any additional data, for example – information on density or basic boundaries position (the errors, when defying density or basic boundaries position, could have resulted in relative errors in results). The method is based on the interpreted anomaly decomposition into Fourier's series and subsequent calculation of several variants of total normalized gravity gradient fields to the downward. The extremums fix of anomaly sources in cross section. The method of quasi-singular points is the development of the Berezkin's method.

INTRODUCTION

The method of total normalized gravity gradient (TNG) intended for direct searches of petroleum and gas deposits was elaborated in the middle sixties due to wide application of electronic computers. Subsequently it has become widely known as "Berezkin's method". This method opportunities are connected to a consecutive usage of a useful part of gravity fields by easing other anomalies considered as noises. The operator GH changes frequencies range used. It allows to reveal components of initial fields corresponding to of anomalous sources of different depths. Such information is delivered by the TNG extremums. The method basic advantage is its complete independence of additional geological-geophysical info (info of rocks density, position of a basic boundaries in a cross section etc.).
Such mode of gravity data interpretation has immediately caused wide interest and has resulted in the set of techniques and frameworks for the potential fields interpretation. The method offered and developed by V.M. Berezkin gave life to the method of total complete gradient TCG, techniques of an electrical and seismic data processing by the operator GH, method of magnetic fields interpretation for oil deposits etc. Many of his disciples contributed to this direction development. Some of them were engaged in studying of geological structures of various regions, others have developed and improved technology and mathematical software, creating the methods of potential fields interpretation. One of them is the of quasisingular points method - QSP [1].

THE BEREZKIN'S METHOD AND MEANS OF ITS MODERNIZATION

The mathematical basis of Berezkin's method means interpretive function Δg decomposition in a Fourier's series by the Simpthon's formula Bn and than continuation to the lower half-space the complete gravity gradient G(x,z) normalized on its average value G(z) at each calculation level. The function $G(x, z) = \sqrt{(V^2_{zz} + V^2_{xz})}$ is vector, which projections on coordinate axis are the derivatives $V_{zz}(x,z)$ and $V_{xz}(x, z)$ calculated as:

$$V_{zz}(x,z)=\pi n/N^* \sum_{1}^{N} B n n Q^2 n \exp(\pi n z/L)\sin(\pi n x/L \quad (1)$$

$$V_{xz}(x,z)=\pi n/N^* \sum_{1}^{N^*} B_n n Q_n \exp(\pi n z/L)\cos(\pi n x/L), \quad (2)$$

where $N^* \leq N$ - used number of a series expansion terms, n - serial number of Fourier's coefficient, and $Q_n = [\sin \pi n/N^* / \ \pi n/N^*] = \text{sinC}$ is a low-pass filter.
The first steps to the Berezkin's method modernization were targeted at its mathematical device improvement. It was noticed, that the assumed function decomposition in a Fourier's series on a Simpthon's mode contents systematic mistake, which is displayed with $N^*/N \rightarrow 2/3$ and increases in such a manner that $B_n = 0.3333B_1$ with $N^*/N \rightarrow 1$. This error can be avoided when using the Filon's mode expense. The influence of an assumed data errors m_f on a Fourier's coefficients appears to be almost twice less.
The passage from sine wave components B_n to cosine wave components A_n has become another object of improvement of the Berezkin's method mathematical device. It has allowed to refuse subtraction of a background component and has enabled to carry out the interpretation for gravity fields of strong gradient zones, such as areas of transition from the continental type of the crust to oceanic.
During use of the Berezkin's method for study of the geological structure of crust of various regions a number of defects of algorithm was revealed. These defects are:

1. Representation of fields of TNG as isolines, which is visual only if anomalous sources disposition is widely spaced.
2. Absence of criterion for a choice of optimum quantity of the used Fourier's coefficients N^*_{opt}.
3. Impossibility to establish probability to get in advance the info in the given range of depths.
4. Absence of criterion for passage from position of the TNG field maximums to anomalous sources coordinates. Criterion of "maximum" in the Berezkin's method, which principle is based on a position of the greatest maximum in TNG fields various variants (differing in parameter N* value), can be used only if the anomalous sources are located at the same depth.
5. Instability of inverse problem solution: the definition of horizontal cylinder depth can be carried out with a relative error more than 0.10.

Their elimination originated in development of the QSP method theoretical base.

THE QUASISINGULAR POINTS METHOD AS OUTCOME OF THE BEREZKIN'S METHOD MODERNIZATION

The first of the listed above defects was eliminated by passage from representation TNG-fields on lines to tracing an sinphasic axeses of extremums at sequential calculation levels. It has enabled to consider the dynamics of position changes and vertical extent of each of the axes, and also the position and the greatest extremum magnitude with parameter N* modification. It was noticed that the anomalous zones TNG gravity fields from various sources (2D isometric body, subvertical density contact, subhorizontal boundary microrelief) are differently displayed in sinphasic axeses dynamics, which has become the basis of qualitative QSP method interpretation.
An attempt to get rid of other defects caused the reflections: whether the usage can be limited by:

- function G, based on second derivatives V_{zz} and V_{xz}, and
- square of a function Q_n only.

The expressions for m-order derivatives for gradient $\Gamma^{(m)}(x,z)=\sqrt{[U_z^{(m)2}(x,z)+U_x^{(m)2}(x,z)]} / \bar{\Gamma}^{m}(z)$ can be represented as:

$$U_z^{(m)}=\sum^{N^*} A_n \Phi_n^{(m)} \cos \pi n x/L, \qquad (3)$$

$$U_x^{(m)}=\sum^{N^*} A_n \Phi_n^{(m)} \sin \pi n x/L, \qquad (4)$$

were frequency characteristic $\Phi_n = (\pi N^*/ N\Delta x)^{(m-1)}\, n^{(m-1)} (\sin c)^q \exp(\pi n/N^* R_n)$, and $R_n = (N^* / N)(z / dx)$.
The Φ_n depends on four parameters:

- m - the degree of derivatives (with m =1 we deal with potential derivatives and gradient $F(x,z) = \sqrt{V^2_z(x,z)+ V^2_x(x,z)}$, with m = 2 - with derivatives and gradient $G(x,z) = \sqrt{V^2_{zz}(x,z) + V^2_{xz}(x,z)}$ etc.,
- q - degree of sinC- function,
- N^* or N^*/N - length of used part of a Fourier's series, and
- z/dx - depth normalized on an initial function pitch.

Supposing that factors An do not contain any systematic bias and the casual error is determined by an error of interpreted anomaly $m_A = 0.8m_g/\sqrt{N}$, it is possible to use in the first approximation as criterion for Fourier's series optimum length N^*_{opt} a frequencies range N^*_{limit}/N by discarding a high-frequency components less than m_a.
There is a certain dependence between a steepness of the peak spectrum enveloping and anomalous source depth. The required depth is achieved if the spectrum envelop is parallel to the abscissa axis. Thus, it is necessary to choose out the parameters, at which the spectrum bending will be parallel to X-axis in an optimum frequency range. It is carried out by peak spectrum analysis, which aim is to determine the optimum parameters for field transform. In this case the gradient maxima $\Gamma^{(m)}_{max}$ will fix a position of sources of anomaly, if all of them are approximately at the same depth, and if they are placed at the different depths (features of a gravity boundaries microrelief), each of theme can be characterized by their own group of factors A_n having some common law of their change, and for each its own frequency characteristic Φ_n for the further transformations is selected. Thus it is possible to receive the information about an amount of levels and depth range of anomalous sources.

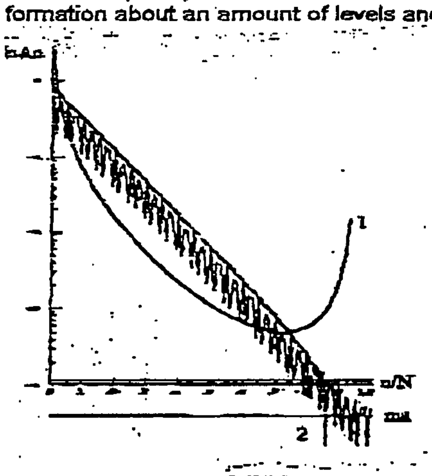

Table of the spectrum analysis

m	q	R	N*/N	Z/dx	C
2	2	-.26	95	2.74	29
1	-.18	2.6	86	3.02	0.0

Table of the result

N	x	xmax	z	zmax	S
1	40	40	3.0	2.95	017

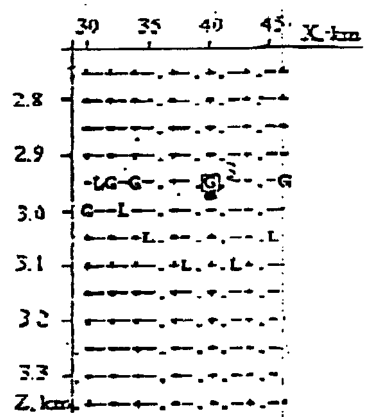

Fig.1. The peak spectrum of gravity anomaly for the horizontal cylinder with its analysis results (a) and fragment of TNG - field transformed with the optimum parameters (b) : 1 - enveloping on the Berezkin's method, 2- enveloping on the QSP method, 3 - extremum of TNG-field

The advantage of such method (QSP) can be illustrated with an example for the horizontal cylinder located on depth of 3 km. The peak spectrum of gravity anomaly (given in 101 discrete points with constants by the pitch 1km) is shown on fig.1 along with the diagram of frequency characteristic used in the Berezkin's method corresponding to function G (m = 2, q = 2), and the diagram of the selected frequency characteristic requiring the further transformation of TNG fields F (m =1) with q = -0.18. This transformation results in the second case (QSP method) the maximum at the depth adequate to the cylinder center with an error 0.01 (fig.1b), while usage of function G allows to find it with a relative error about 0.25 (fig.3). This example shows the necessity of the univalent correspondence between the interpreted function peak spectrum and parameters of its transformation.

In the following figure (fig.2) the selected enveloping for the peak spectrum of the gravity anomaly (the thin layer on the depth 3km) is shown. It testifies the necessity of usage of the function G ($m = 2$) with $q = 0.12$ for the consequent transformations. That allows to reduce an error of outcome to 0,017.

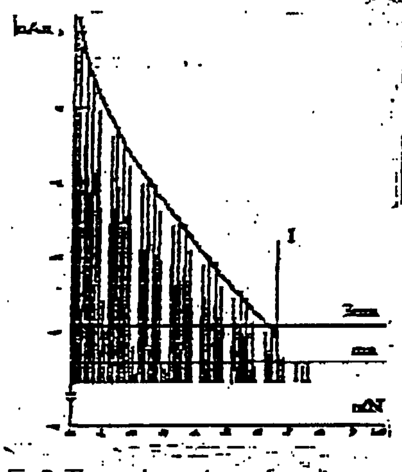

Table of the spectrum analysis

m	q	R	N*/N	Z/dx	C
2	.12	2.95	.86	3.11	3.9

Table of the result

N	x	xmax	z	zmax	б
1	40	40	3.0	2.95	.017
2	60	60	3.0	2.95	.017

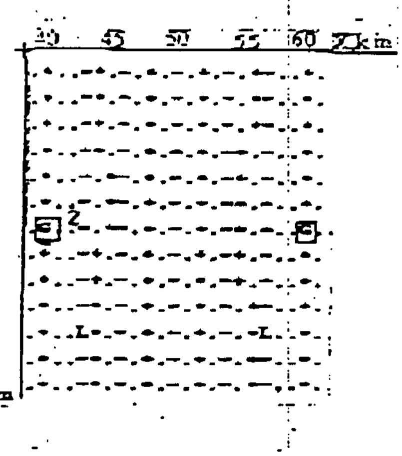

Fig.2. The peak spectrum of gravity anomaly for the thin layer with its analysis results (a) and fragment of TNG- field transformed with the optimum parameters (b) : 1- enveloping on the QSP method, 2 - extremum of TNG field.

CRITERION OF THE QSP METHOD QUANTITATIVE INTERPRETATION

It was noted above that position of function TNG extremums at each subsequent of transformation levels are fixed in the method of QSP. The value of the greatest of them at depth z for a single source of anomaly (and with several located on the same depth – sum of the maximal values of gradient) $\Gamma_{нmax} = zN^* / 2\,[\ln 2N^* + C_e\,]$, using condition $A_n\Phi_n$= Const. Thus the greatest value of the TNG maximum «$\Gamma_{нmax}$» of interpreted zone can be expected for N^*_{opt}, as it provides an opportunity of performance of equality $A_n\Phi_n$ = Const in the greatest frequency range.

Use of this expression as criterion for the anomalous source depth definition is equivalent to criterion "maximum" in a Berezkin's method for the only depth of anomalous sources (z) max. In general it will be transformed as:

$$\Gamma_{нmax} = p\pi\,[N^*_{опт} + \chi(x)]/\,2[\ln 2N^*_{опт} + C_e + \chi\,(x)], \quad (5)$$

where $p \le 1$ depends on number and intensity of the high values TNG zones, and $(\chi)_x$ – number of products $A_n\Phi_n$ not satisfying to condition of maximum appearance at depth $(Z)_{max}$ with use N*opt. The frequency range increase results in increase of last members in numerator and denominator.

The following variants are possible: $(\chi)_x > P(\chi)_x$, and it causes the reduction of the maximum of zone (as in case of single depth of sources of anomaly); $\chi = P(\chi)_x$ - the maximum decreases when $N^* > N^*_{opt}$ and ascending of values $(\chi)_x$ and χ; $\chi < P(\chi)_x$ - the maximum continues to grow, but law of increase varies according to the parity of values $(\chi)_x$ and χ.

Thus the former criterion - criterion «$\Gamma_н$» - of an anomalous sources depth is:

1. position of the zone maximum TNG calculated in the optimum frequency range N^*_{opt};
2. position of the zone TNG greatest maximum $\Gamma_{нmax}$ for the several variants of fields differing by frequency ranges – analogue of the Berezkin's "maximum" criterion;
3. position of angular points of the diagram $\Gamma_{нmax} = f\,(N^*/N)$, corresponding to an alteration of the values maximum growing law depending on a parity of values $(\chi)_x$ and χ.

It is convenient to normalize the maxima on value $N^*/\,2\,[\ln 2N^* + Ce]$, as $\Gamma_{нmax}$ is the function only of parameter N^*.

The second criterion in the QSP method is the criterion "α", based on the diagram of $G_{нmax}$ depth as function of parameter N^* nearby N^*_{opt}. The performance of the condition $A_n\Phi_n$= Const for both peak spectrum and its separate group is possible in the range $N^*<N^*_{opt}$ limited by such frequency $(n/N^*)_\Phi$ as frequency characteristic Φn reaches its maximum. In general the dependence between $(n/N^*)_\Phi$ and parameters m, q, N^*/N и z/dx can be represented as:

$$R_n = (N^*/N)(z/dx) = -1/\pi[(Q_n)' / Q_n + (m-1) / (n / N^*)_\Phi\,], \quad (6)$$

The function R_n describes the law of maximum frequency characteristic depth alteration as a function of frequencies used. It can be represented by hyperbolas family with asymptotes parallel to coordinate axes N^*/N and z/dx, each of them is geometrical locus with frequency $(n/N^*)_\Phi$ constant value, corresponding to maximum of Φ_{nmax}.

The procedure of fields recalculation $\Gamma^{(m)}_н$ is usually carried out within the limits of some ranges z/dx and N^*/N with the constant parameters m and q, so the character of depth changing $\Gamma_{нmax}$ as functions of used range N^*/N depends only on value of $(n/N^*)_\Phi$. If the new entered factors submit to former law with increasing of N^*/N, the value $(n/N^*)_\Phi$ remains to be a constant or can grow. In the first case $G_{нmax}$ moves in system of coordinates z/dx, N^*/N on a trajectory conterminous to the appropriate diagram of the function R_n, and in second case - (R_n + α), where α is some positive value. With use of $(N^*/N) > (N^*_{opt}/N)$ of addition of high-frequency series components (exceeding of earlier traced regularity), the value $(n/N^*)_\Phi$ decreases, so parameter α accepts negative values. Thus, analysis of diagram of the depth $\Gamma_{нmax}$ change as the function of frequency $(z)_{max}/dx = f(N^*/N)$ on the background of curves set R_n it's enough to choose a point described by the greatest possible value of R_n.

The practice shows an opportunity of successful application of both this criteria for extremums $\Gamma_{нmin}$ of lowered values fields zones. That can be used for determination of smooth sites of density or magnetic boundaries position.

It is convenient to use the special forms-passports (fig.3) where the information concerning each interpreted zone is collected for qualitative and quantitative interpretation. The appropriate choice of nonlinear scale of abscess axis (N^*/N) permits to achieve representation of the diagrams of function R_n by line segments, that simplifies a procedure of use the "α" criterion.

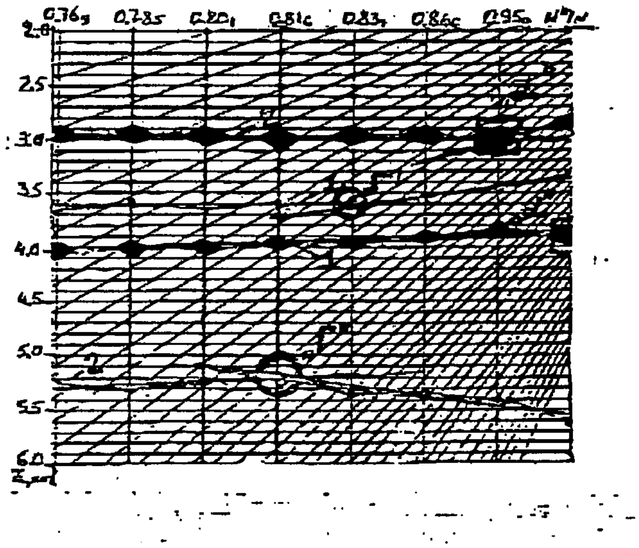

Fig.3 The fragment of passport for zone 1 (horizontal cylinder, x=40km, frequency range 0.435- 1.000) on Berezkin's method (1) and QSP method (2); "α" and "T" – criterion position

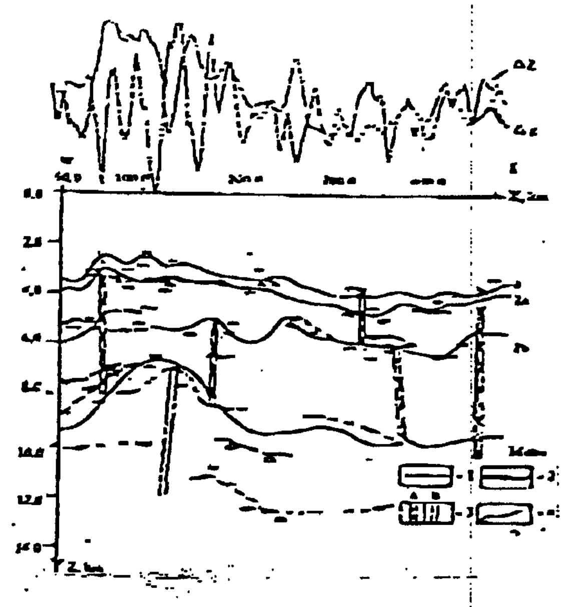

Fig.4. The scheme of density and magnetic inhomogeneity for geotraverse "Atlant-2" fragment. Subhorizontal boundary: 1-density, 2 – magnetic; subvertical contact: 3a - density, 3b – magnetic; 4 - seismic boundary

The last stage of gravity or magnetic data interpretation by the QSP method is drawing up of the catalogue of anomalous sources coordinates with the their character pointing (isolated masses centre, subhorizontal boundary microrelief feature, subvertical contact), or cross section scheme inhomogeneity. The correlation between the position of the next anomalous sources allows to trace segments of subhorizontal boundaries.

The QSP method is intended just for a tracing some sloping subhorizontal boundaries. The allocation of subvertical contacts is reached by this method special modification application. The example of the QSP opportunities is shown in figure 4 - the results of gravity and magnetic data interpretation for a fragment of a geotraverse "Atlant-2" located in the central part of the Atlantic ocean at breadth about 30° of northern latitude.

CONCLUSION

The scheme of density and/or magnetic inhomogeneities according to the QSP data gives the general perception of the character of inhomogeneity of the cut of unexplored regions or to serve as a skeleton for drawing up of density/magnetic model of environment, and with presence of other geological-geophysical data can be used when studying the entire set of all independent results. Depending on scale of interpreted materials the top part of a cross section as well as the entire crust can be an object of the method application. The method is tested when solving various types of geological tasks [2]:

- For studying peculiarities of distribution of minerals of such a unique, from the point of view of ecological environment, region as Kamchatka, where seismic exploration or drilling is absolutely forbidden,
- For studying deep structures of oil-bearing regions of the Near Kaspiy and Siberia,
- For studying seismically dangerous zones of the Far East and Armenia,
- For studying possible neotectonic activities in areas of constructing unique engineering structures, e.g. in areas of Smolensk atomic power station,
- For searching places suitable for burying nuclear waste products,
- For the express analysis of magnetic anomalies which sources can be the cimberlite pipes.

This list can be continued.

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