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Algorithms of correlation methods for comprehensive interpretation of gravimetric and seismic data

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The article considers correlation methods used in complex interpretation of geophysical data, which is very important during the geological interpretation. A special place belongs to the methods for correlating gravity, seismicity, and geology. The point of such methods is to establish statistical relationships between the depths of various sedimentary complexes according to seismic exploration (or drilling) data and Bouguer anomalies and their transformants from the gravity surveys. The findings are extrapolated to the areas less studied by seismic exploration and drilling such as fields and hard-to-reach sites for which gravity data is available. For example, in the eastern part of the Middle Kura Depression of Azerbaijan, it is impossible to obtain reliable reference seismic data on the structure of the lower Eocene-Mesozoic stage due to the complex seismic and geological environments. The Department of Geophysics of the Azerbaijan State Oil and Industry University has developed a method for applying multivariate regression analysisusing the individual sections of conditional seismic horizons and detailed gravity survey data. Forecasting seismic-geological boundaries using statistical methods based on available reference seismic and gravity data improves the quality of gravity studies. The capabilities of existing methods of correlation and multivariate regression analysis have been analyzed. A combined method of correlation analysis and forecasting has been developed with taking into account the advantages of existing methods, which allows increasing the accuracy of forecasting seismogeological boundaries. Based on this method, a corresponding algorithm and the MRA-COMS-COM program have been developed and successfully tested on the available factual material.

Key words: correlation, regression, forecast space, seismic-geological data, multivariate regression analysis, correlation methods of analysis, algorithm, program.

Introduction. In prospecting, exploration and study of the geological structure of complex promising oil, gas and ore-bearing areas, the gravimetric exploration method is of great importance. It is based on the distribution of gravity fields created by individual structural uplifts with excess rock density. At the stage of quantitative interpretation of gravimetric data, the inverse problem is solved; based on the observed gravity anomalies and *a priori* seismic-geological data, the structural scheme of the seismic-geological boundary is predicted, which gives us additional information on the structure, depth, and shape of the geological boundary. The importance of combining seismic and gravimetric data in solving direct and inverse gravity problems is shown in the works [Starostenko, 1981; Starostenko et al.,1984] and other. To predict the depths of seismic-geological boundaries, correlation methods of interpretation use elements of mathematical statistics [Nikitin, 1986; Serkerov, 1986]. To predict the depth of the surface of the Upper Mesozoic deposits in the Middle Kura Depression of Azerbaijan, software was developed for a multivariate re-

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gressive analysis (MRA) technique. This technique was substantiated as the most effective for these deposits which are weakly displayed in the gravity field in the form of local anomalies. Their excess density is approximately 0.2 g/cm^3. The analysis of geological-geophysical and seismic-gravimetric materials allowed Sharifova et al. [1983] to conclude that large gravity anomalies are associated with the uplift of the Mesozoic complex of deposits, and small local anomalies are associated with uplifts of the Eocene-Upper Cretaceous volcanogenic-sedimentary formations. The MRA method was used to predict the structure of the Upper Mesozoic sedimentary complex at the Talysh Mugan region, and, as a result, a structural scheme was constructed for the corresponding surface [Tsimelzon et al., 1985]. Then, the MRA method was used to predict the surface of the Upper Cretaceous sediments (seismic horizon SH-1) in the eastern part of the Middle Kura Depression [Tsimelzon et al., 1988]. At present, this problem is solved using all the possibilities of correlation methods for transforming fields and MRA using modern graphic programs in two-dimensional and three-dimensional versions on a computer [Iskandarov, 1990, 1994, 1998, 2007, 2015; Isgandarov, 2023; Isgandarov, Rzabayli, 2023; Isgandarov et al., 2024]. The purpose of such research is to develop effective methods, algorithms and programs for the comprehensive interpretation of gravimetric and seismic-geological data using correlation methods and modern computer technologies [Mikheeva, 2020].

Tools and methods. Currently, due to the increasing complexity of geological problems being solved, complex interpretation of geophysical data using elements of mathematical statistics is widely used. Statistical methods for constructing structural maps based on a set of geological and geophysical findings are used mainly in the modified MRA and correlation methods for transforming anomalies.

MRA is used to establish statistical relationships between the depths of various sedimentary complexes from the seismic exploration (or drilling) data and Bouguer anomalies (and their transformants) to extrapolate these relationships to the less studied areas. These may be areas agricultural fields and difficult-to-access regions for which gravity survey data are available. Such areas include, in particular, the eastern part of the Middle Kura Depression of Azerbaijan, where, due to complex seismic and geological environments, it is impossible to obtain unambiguous reference seismic structural data of the lower Eocene-Mesozoic stage. The Department of Geophysics of the Azerbaijan State Oil and Industry University has developed a methodology for applying MRA using individual sections of conditional seismic horizons and detailed gravity survey data. In this case, the depth of the studied sedimentary complex H is expressed by a polynomial that includes parameters that are products of $\Delta g_{\text{Bouguer}}$ and its transform:

$$H = a_0 + a_1\Delta g_{\text{Bouguer}} + a_2\Delta g_i + a_3\Delta g_{\text{Bouguer}}{}^2 + \\ + a_4\Delta g_{\text{Bouguer}}\Delta g_i + a_5\Delta g_i{}^2 + \ldots, \qquad (1)$$

where $a_0 \ldots a_n$, etc. are the coefficients of the regression equation; $\Delta g_{\text{Bouguer}}$ is the gravity anomaly in the Bouguer reduction; Δg_i are the values of various local anomalies obtained by different transformation methods with different transformation parameters.

The coefficients of the regression equation are found by the least-squares method from the condition of the minimum of the sum of the squares of the deviations of the predicted and actual values of the depths of the sought geological boundaries:

$$\sum_{i=1}^{n}\left(H_i - Hpr_i\right)^2 \to \min . \qquad (2)$$

Here, H_i and Hpr_i are actual and predicted depths, respectively; n — number of H_i, Hpr_i meanings.

The essence of the correlation methods of field separation and prediction (COMS-A, COMS-B), developed at the Gubkin Russian State University of Oil and Gas by V.I. Shraibman, M.S. Zhdanov, and O.V. Vitvitsky, is that a residual anomaly is extracted from the observed field, which best correlates with the depth of the desired geological boundary. To implement the MRA and COMS algorithms, the Geophysics Department developed the FORTRAN program MRA-COMS which operates in two modes: the MRA mode and the trend analysis mode (called COMS by the author [Amiraslanov, 1980]). The figure below shows the block diagram of this program (Fig. 1).

According to the MRA-COMS algorithm, the following parameters are first entered:

– NA is number of analyses;

– the initial data.

NP is the number of parameters involved in the regression equation; NN is the length of the parameter array. Then the statistical characteristics of the parameters are calculated [Chetvertakova et al., 2017]:

a) average value

$$\overline{xx_i} = \frac{\sum_{k=1}^{N} xx_{ik}}{N}, \tag{3}$$

where $xx_{i,}$ xx_{ik} are the geological and geophysical parameters and their meanings; N is the length of the data array;

b) standard deviation

$$xx_i = \sqrt{\frac{\sum_{k=1}^{N}\left(xx_{ik} - \overline{xx_i}\right)^2}{N-1}}, \tag{4}$$

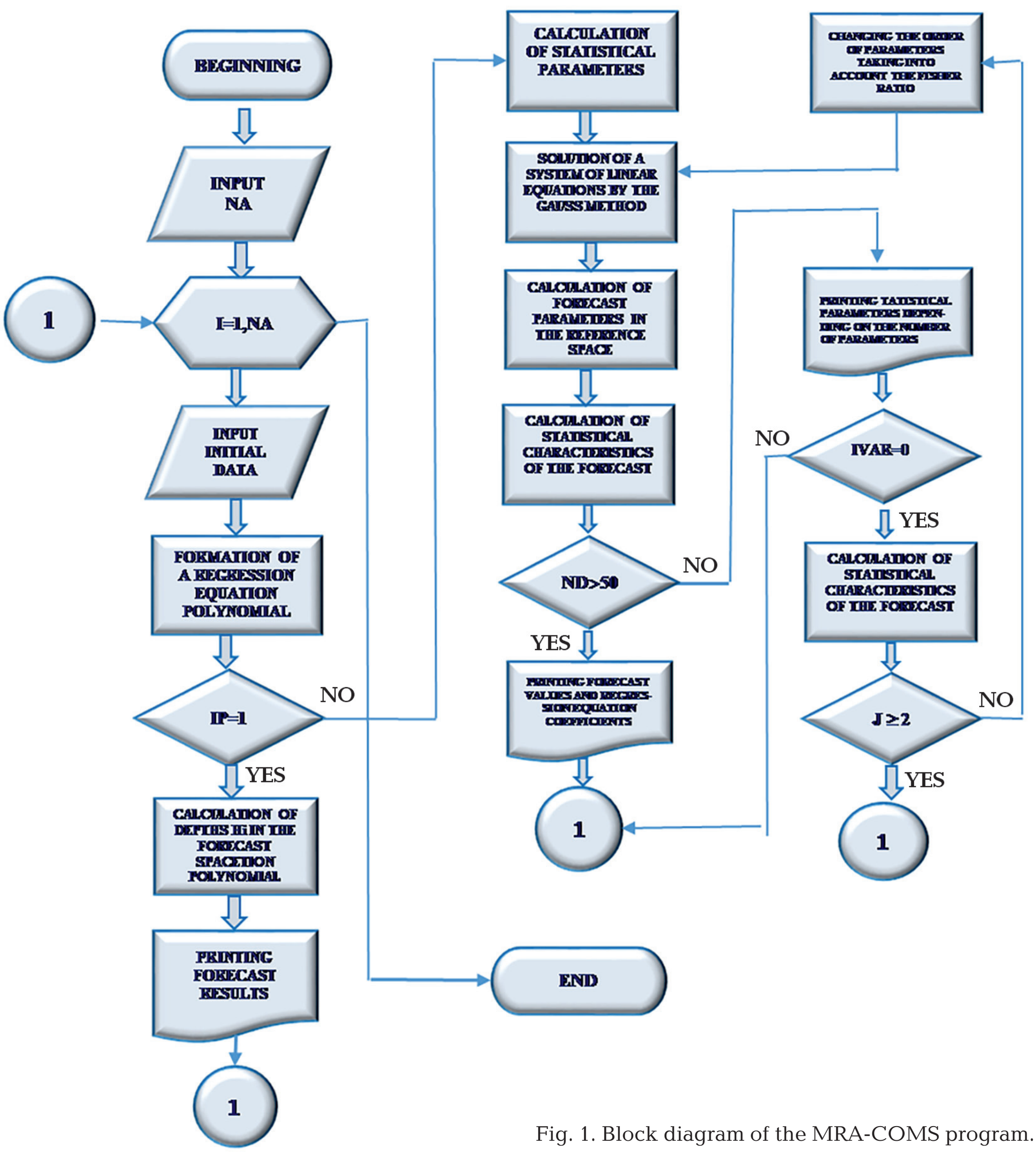

Fig. 1. Block diagram of the MRA-COMS program.

c) correlation coefficient between the geological and geophysical parameters:

$$R(H,g)=\frac{\sum_{k=1}^{N}\left(H_k-\bar{H}\right)\left(g_k-\bar{g}\right)}{\sqrt{\sum_{k=1}^{N}\left(H_k-\bar{H}\right)^2\sum_{k=1}^{N}\left(g_k-\bar{g}\right)^2}}. \quad (5)$$

Here H_k, g_k are the values of the boundary depths according to seismic exploration or drilling data and the values of the gravity anomaly according to gravity exploration data.

Then the system of linear equations is solved by the Gauss method and the coefficients of the regression equations are calculated, including the statistical characteristics of the predicted values in the reference space and the estimate of the approximation depth:

a) residual standard deviation of the reference depths from the approximation line

$$\hat{S}=\sqrt{\frac{\sum_{i=1}^{N}\left(H_i-\hat{H}_i\right)^2}{N-n-1}}. \quad (6)$$

Here H_i are the actual depth values; $\hat{H}_i$ are the predicted depth values; n is the number of parameters in the regression equation.

b) multiple regression coefficient

$$R_{\text{mreg}}=\sqrt{1-\frac{\hat{S}^2}{S^2}}. \quad (7)$$

Here

$$S=\sqrt{\frac{\sum_{i=1}^{N}\left(H_i-\bar{H}_i\right)^2}{N-1}}, \quad (8)$$

where S — standard deviation of the actual depth of the studied surface from the average value; H_i are values of actual depth; $\bar{H}_i$ is average value this depth.

c) Fisher coefficient

$$F=\frac{\hat{S}_k^2}{\hat{S}_{k-1}^2}, \quad (9)$$

where $\hat{S}_k^2$ is the square of the residual depth deviation at the k-th step: $\hat{S}_{k-1}^2$ is the square of the residual depth deviation at the (k–1) step.

If ND (step to increment the number of parameters)is greater than 50, i.e., one regression equation with a certain number of parameters for the subsequent forecast is compiled, then the predicted values of the reference profile depths, regression equation coefficients, and statistical characteristics are printed. When ND is less than 50 (step-by-step regression analysis with a successively increasing number of regression equation parameters is performed), the statistical characteristics (S, $\hat{S}$, F, and R_{mreg}) are printed. The following criteria are adopted for selecting the length of the transformation polynomial:

1) maximum of the correlation coefficient between the residual component of the field and the geological boundary on the reference;

2) minimums of the standard deviation of the approximation error of the geological boundary on the reference profiles;

3) maximum of the multiple regression coefficient.

The accuracy of the predicted depths depends on the reliability of the reference geological data on the studied horizon (the accuracy of identifying the geological boundary using seismic exploration or drilling data). The reliability of the depths is assessed based on the value of the statistical parameters R, S, F. The cross-section of the isolines when constructing a structural map is usually associated with the value of the root-mean-square deviation of the approximation error on the reference profiles. In this case, the error value is usually multiplied by a coefficient of 2.5—3. The cross-section of the isolines can also be assessed using histograms of the modulus of deviations of the predicted depths from the reference ones along the profiles. In this case, the cross-section is selected equal to the maximum modulus of deviations.

Methods and results. The COMS-A method allows one to extract from the observed field value the residual anomaly that best correlates with the depth of the surface under study. The idea of correlation methods for transforming anomaliesis that the observed gravitational field is represented in the following form:

$$G_{\text{obs}} = G_{\text{res}} + G_{\text{fon}}, \qquad (10)$$

where G_{obs} is the observed value of gravity; G_{res} is the residual component of gravity; G_{fon} is the background component of gravity.

The background component of gravity is represented as a polynomial that depends on the coordinates of the observation points and is called a transformation polynomial:

$$G_{\text{fon}} = \sum_{P=1}^{N} a_p f_p(x, y). \qquad (11)$$

Here a_p are the coefficients of the transformation polynomial; $f_p(x, y)$ are the basis functions depending on x, y, x^2, xy, y^2…($f_1(x, y)=x$; $f_2(x, y)=y$; $f_3(x, y)=x^2$; $f_3(x, y)=xy$; $f_4(x, y)=y^2$…); N is the length of the transformation polynomial; x, y are the coordinates of the observation points.

The residual component of gravity is represented as:

$$G_{\text{res}} = \sum_{i=1}^{k-1} b_i j_i + c, \qquad (12)$$

where b_i, c are the coefficients of the linear regression equation and free coefficient; k is the number of geological and geophysical parameters; j_i are the geological and geophysical parameters ($j_{k-1}=h$, depth of occurrence of the geological boundary).

The coefficients a_p, b_i, and c are determined from the condition of the minimum standard deviation of functional φ:

$$\varphi = \Big[G_{\text{obs}} - \sum_{p=1}^{N} a_p f_p(x,y) - \\ - \sum_{i=1}^{k-1} b_i j_i - c \Big]^2 \to \min, \qquad (13)$$

which is possible provided:

$$\begin{cases} \dfrac{\partial \varphi}{\partial c} = 0 \\ \dfrac{\partial \varphi}{\partial a_p} = 0 \\ \dfrac{\partial \varphi}{\partial b_i} = 0 \end{cases}, \ (\mathrm{P} \in N), \ (i=1, 2\ldots, k-1). \qquad (14)$$

By solving this system, we can determine the regression coefficients a_p, b_i, and c.

When the local structure of the studied sediment complex is weakly reflected in the gravitational field, it would be rational to choose the form of the polynomial as shown below. Let there be a surface of a sedimentary complex that has regional (H_{reg}) and local (H_{loc}) components of the depth of occurrence (Fig. 2). Then the depth of occurrence of the studied complex H will be equal to:

$$H = H_{\text{reg}} + H_{\text{loc}}, \qquad (15)$$

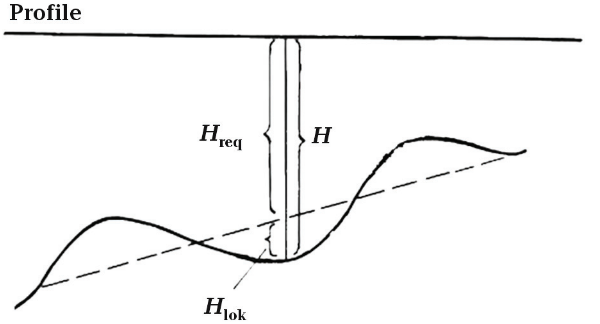

Fig. 2. Geological boundary model.

The local component of the parameter depth can be represented as a polynomial:

$$H_{\text{loc}} = \sum_{p=1}^{N} a_p f_p(\Delta g_{\text{loc1}}, \Delta g_{\text{loc2}}), \qquad (16)$$

where Δg_{loc1}, Δg_{loc2} are the local transformants of gravity field; $f_p(\Delta g_{\text{loc1}}, \Delta g_{\text{loc2}})$ are the basis functions depending on Δg_{loc1}, Δg_{loc2}, $\Delta g_{\text{loc1}}{}^2$, Δg_{loc1}, Δg_{loc2}, $\Delta g_{\text{loc2}}{}^2$…; N is the length of the transformation polynomial.

If the regional component of depth according to the seismic data is considered as a linear function of $\Delta g_{\text{Bouguer}}$ that is:

$$H_{\text{reg}} = b \Delta g_{\text{Bouguer}} + c. \qquad (17)$$

Then equality (15) can be represented as:

$$H = \sum_{p=1}^{N} a_p f_p(\Delta g_{\text{loc1}}, \Delta g_{\text{loc2}}) + \\ + \left(b \Delta g_{\text{Bouguer}} + c\right). \qquad (18)$$

Here f_p are basis functions depending on $\Delta g_{\Delta \text{loc1}}$ and $\Delta g_{\Delta \text{loc2}}$; N is length of the polynomial regression; Δg_{loc1}, Δg_{loc2} are the values of local gravity anomalies; a_p are the coefficients of the regression equation; b, c are coefficients showing the relationship of the regional component of the depth with the gravity anomaly.

These expressions resemble the expressions in the case of the COMS-A and COMS-B methods [Shraibman et al.,1977]. However, unlike them, here in the transformation polynomial instead of the coordinates of the observation points (x, y) the values of the different two transforms of the gravity field $\Delta g_{\Delta loc1}$ and $\Delta g_{\Delta loc2}$ are involved.

Coefficients of the regression equation a_p, b_i, and c can be determined from the functional φ:

$$\varphi = \Big[H - \sum_{p=1}^{N} a_p f_p\left(\Delta g_{\mathrm{loc1}}, \Delta g_{\mathrm{loc2}}\right) - \left(b\Delta g_{\mathrm{Bouguer}} - c\right)\Big]^2 \to \min . \qquad (19)$$

Based on these formulas and the MRA-COMS program, we have compiled an algorithm and the FORCE-FORTRAN program MRA-COMS-COM, which operates in the mode of MRA, trend analysis (COMS), correlation method of field separation (COMS-A), and in the mode of the combined method (COM) based on formulas 15—19. The block diagram of this program is shown below (Fig. 3). According to this algorithm, the program operates in four modes, i.e., for each mode, the program performs a correlation analysis, on the basis of which a forecast of the desired geological boundary is performed for the optimal options.

To test the MRA-COMS-COM program, the reference seismic-gravimetric profile 841408 was selected as a model. The prepared initial data, i.e. the values of gravity, its transforms, the depths of the SH-P and SH-1 surfaces according to seismic exploration data (Fig. 4), and the coordinates of the field discretization points (X, Y), were entered into the program for analyzing the statistical parameters using various methods and further forecasting in the reference space. The results of the correlation analysis between the parameters $SH\text{-}P$, $\Delta g_{\mathrm{Bouguer}}$, X, Y along the profile in the COMS mode are shown in Table 1. As can be seen from the table, the correlation coefficients R_{res} are very low (approximately 0.08) for any length of the transformation polynomial. The root-mean-square deviations of the approximation are practically independent of the length of the transformation polynomial and are approximately 576 m. The best approximation occurs when the length of the transformation polynomial is 3. In this case, the statistical characteristics are SS=576.26 m; FF=1.0; R_{res}=0.08. According

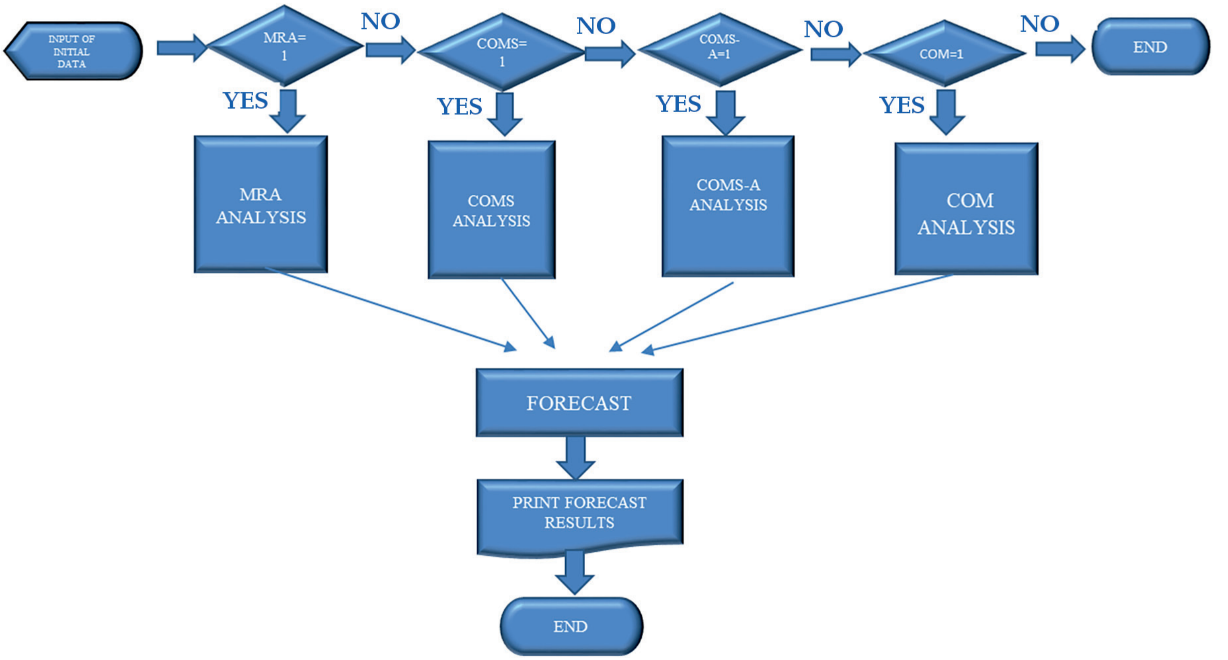

Fig. 3. Brief block diagram of the MRA-COMS-COM program.

to the COMS-A method, the best approximation is obtained in the case when the length of the transformation polynomial is 13 (Table 2), and the statistical characteristics are as follows: SS=99.06 m; FF=33.06; R_{res}=0.99. As can be seen, for profile 841408, the *SH-P* boundary predicted by the COMS-A method gives a better approximation to the *SH-P* surface than the forecast obtained when working in the COMS mode (Fig. 5). The advantage of the COMS-A apparatus compared to trend analysis is also obvious when predicting the boundary (SH-1), which is strongly dislocated and located below the SH-P boundary. The root-mean-square error of approximation of the geological boundary for all lengths of the transformation polynomial in the case of COMS is approximately the same (Table 3). In the case of COMS-A, the best forecast is observed with the optimal length of the transformation polynomial of 12 (Table 4). The results of the correlation analysis of seismic-gravimetric data for the same profile using the MRA method and the combined COM method based on formulas (15—19) are shown below (Tables 5, 6). The results of the comparison of the predicted depths are also shown below (Fig. 6). As can be seen, the best approximation is obtained when predicting the SH-1 boundary using the COM method, (the predicted boundary almost coincides with the actual one).

Conclusions. 1. The capabilities of correlation methods for complex interpretation of seismogeological and gravity data using the FORTRAN program MRA-COMS were analyzed. A block diagram of the MRA-COMS program was compiled.

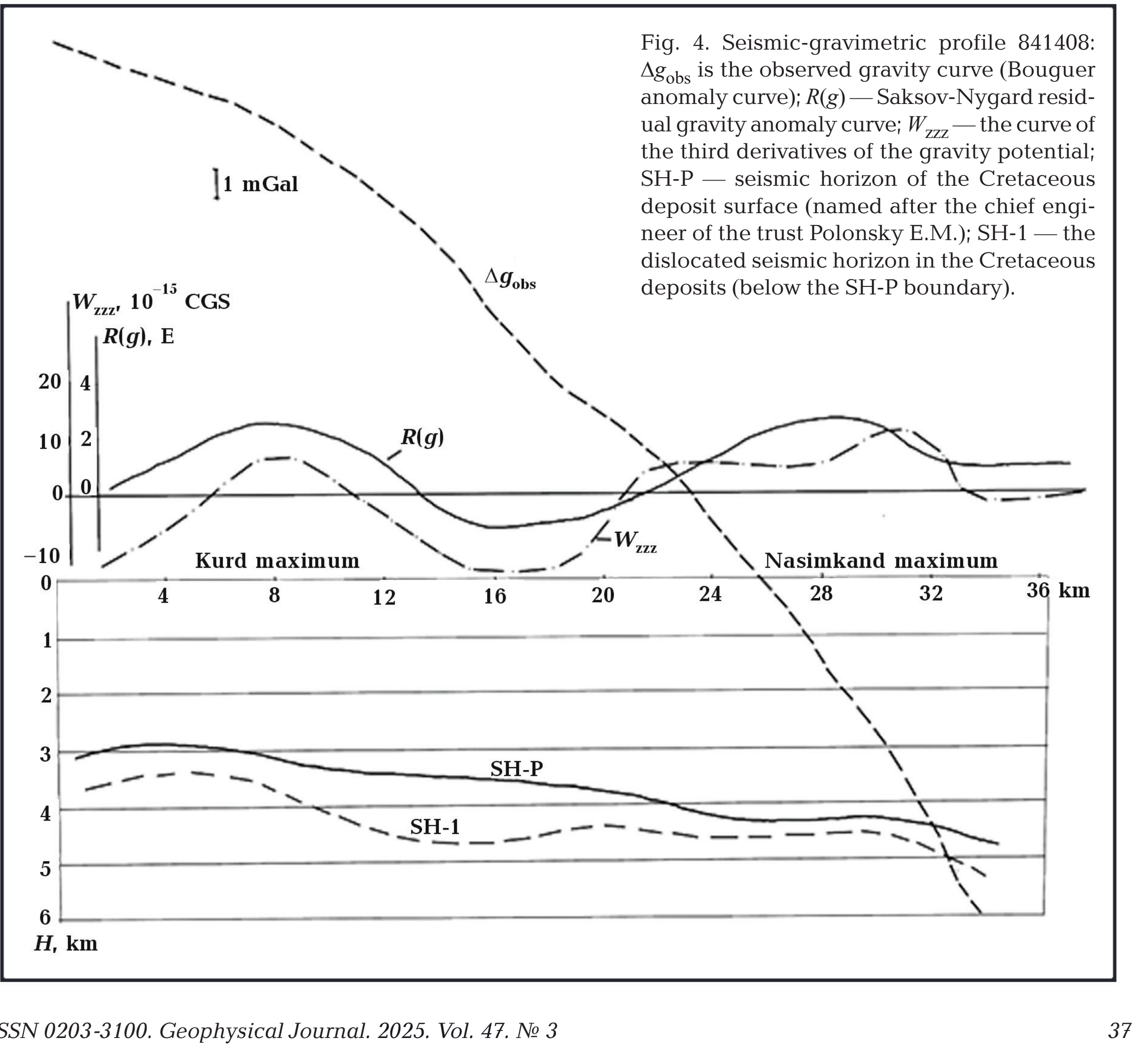

Fig. 4. Seismic-gravimetric profile 841408: Δg_{obs} is the observed gravity curve (Bouguer anomaly curve); $R(g)$ — Saksov-Nygard residual gravity anomaly curve; W_{zzz} — the curve of the third derivatives of the gravity potential; SH-P — seismic horizon of the Cretaceous deposit surface (named after the chief engineer of the trust Polonsky E.M.); SH-1 — the dislocated seismic horizon in the Cretaceous deposits (below the SH-P boundary).

2. Using a model seismic-gravimetric profile as an example, the advantage of the COMS-A method was shown compared to the COMS method in predicting a seismic boundary SH-P, which is well displayed in the gravity field.

3. A COM method was developed for the combined use of the capabilities of the MRA

Table 1. Results of correlation analysis between parameters $\Delta g_{Bouguer}$, X, Y, Hp, along profile 841408 in COMS mode

№	Parameter	R_B	NN	S_B	F	R_{mul}	C_2	C_1	SS	FF	R_{res}
2	X	–0.98	4	1.58	42.67	0.98	3747.42	5.48	576.93	1.0	0.01
3	Y	–0.78	8	0.70	5.15	0.99	3747.50	67.44	576.26	1.0	–0.08
4	X^2	–0.99	13	0.36	3.71	0.99	3747.51	62.58	576.60	1.0	–0.03
5	XY	–0.98	2	0.28	1.64	0.99	3747.46	20.91	576.97	1.0	–0.01
6	Y^2	–0.78	12	0.27	1.11	0.99	3747.38	112.26	576.34	1.0	0.04
7	X^3	–0.96	7	0.36	0.55	0.99	3747.43	1.03	576.99	1.0	0.00
8	X^2Y	–0.99	5	0.73	0.25	0.99	3747.42	3.55	576.99	1.0	0.00
9	XY^2	–0.96	9	0.25	8.19	0.99	3747.44	12.83	576.98	1.0	–0.01
10	Y^3	–0.78	14	0.22	1.31	0.99	3747.45	15.77	576.98	1.0	–0.01
11	X^4	–0.95	11	0.21	1.11	0.99	3747.50	52.26	576.92	1.0	–0.01
12	X^3Y	–0.98	3	0.26	0.65	0.99	3747.41	11.57	576.99	1.0	0.00
13	X^2Y^2	–0.99	6	0.40	0.43	0.99	3747.55	75.49	576.50	1.0	–0.04
14	XY^3	–0. 95	10	0.36	1.24	0.99	3747.55	66.05	576.70	1.0	–0.03
15	Y^4	–0.77	15	0.33	1.20	0.99	3747.51	73.90	576.71	1.0	–0.03

Notes: N is the serial number of parameters; R_B is the correlation coefficient of parameters with $\Delta g_{Bouguer}$; NN is the number of parameters in ascending order of correlation coefficients; S_B is the root-mean-square deviation of the approximation error of the $\Delta g_{Bouguer}$ curve; F is the Fisher ratio for S_B; R_{mul} is the multiple regression coefficient; SS is the residual root-mean-square deviation of reference depths from the approximation line; FF is the Fisher ratio for SS; R_{res} is the correlation coefficient between G_{res} and H; C_2, C_1 are the free term and the coefficient for G_{res} in the regression equation.

Table 2. Results of correlation analysis between parameters $\Delta g_{Bouguer}$, X, Y, Hp, along profile 841408 in COMS-A mode

№	Parameter	R_B	NN	S_B	F	R_{mul}	SS	FF	R_{res}
2	X	–0.98	4	5.30	3.80	0.85	1196.74	0.0	0.43
3	Y	–0.78	8	15.67	0.11	1.14	149.51	14.0	–0.96
4	X^2	–0.99	13	5.48	8.18	0.84	251.34	5.0	–0.91
5	XY	–0.98	2	2.11	6.74	0.97	534.45	1.0	–0.73
6	Y^2	–0.78	12	5.79	0.13	0.82	181.52	10.0	0.95
7	X^3	–0.96	7	0.64	83.10	0.99	2672.28	0.0	0.20
8	X^2Y	–0.99	5	2.78	0.05	0.96	1041.87	0.0	–0.47
9	XY^2	–0.96	9	2.49	1.25	0.97	400.88	2.0	–0.81
10	Y^3	–0.78	14	2.90	0.74	0.95	306.32	3.0	–0.88
11	X^4	–0.95	11	4.91	0.35	0.87	165.35	12.0	–0.96
12	X^3Y	–0.98	3	2.13	5.30	0.97	477.47	1.0	–0.76
13	X^2Y^2	–0.99	6	15.38	0.02	1.10	99.06	33.0	–0.98
14	XY^3	–0. 95	10	11.10	1.92	0.39	120.51	22.0	–0.97
15	Y^4	–0.77	15	8.33	1.78	0.59	141.15	16.0	–0.97

Notes see table 1.

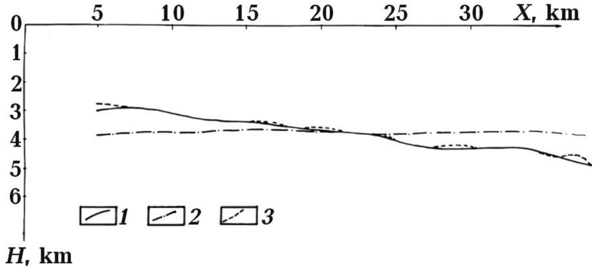

Fig. 5. SH-P boundary prediction along profile 841408: *1* — SH-P boundary according to seismic exploration data; *2* — SH-P boundary predicted by the COMS method (N=3); *3* — SH-P boundary predicted by the COMS-A method (N=13).

Table 3. Results of correlation analysis between parameters $\Delta g_{\text{Bouguer}}$, X, Y, H_1, by profile 841408 in COMS mode

№	Parameter	R_B	NN	S_B	F	R_{mul}	C_2	C_1	SS	FF	R_{res}
2	X	–0.98	4	1.58	42.67	0.98	4369.95	42.06	527.61	1.0	0.12
3	Y	–0.78	8	0.70	5.15	0.99	4369.88	105.82	526.86	1.0	0.13
4	X^2	–0.99	13	0.36	3.71	0.99	4370.48	–351.34	517.97	1.0	–0.22
5	XY	–0.98	2	0.28	1.64	0.99	4370.25	–174.34	529.59	1.0	–0.08
6	Y^2	–0.78	12	0.27	1.11	0.99	4369.93	175.27	529.83	1.0	0.08
7	X^3	–0.96	7	0.36	0.55	0.99	4369.98	196.60	527.74	1.0	0.11
8	X^2Y	–0.99	5	0.73	0.25	0.99	4369.9I	58.50	530.23	1.0	0.07
9	XY^2	–0.96	9	0.25	8.19	0.99	4369.73	236.91	529.01	1.0	0.09
10	Y^3	–0.78	14	0.22	1.31	0.99	4369.54	360.12	527.28	1.0	0.12
11	X^4	–0.95	11	0.21	1.11	0.99	4369.54	322.53	528.58	1.0	0.10
12	X^3Y	–0.98	3	0.26	0.65	0.99	4369.56	334.34	526.88	1.0	0.13
13	X^2Y^2	–0.99	6	0.40	0.43	0.99	4369.91	51.43	531.29	1.0	0.03
14	XY^3	–0.95	10	0.36	1.24	0.99	4369.79	110.02	530.67	1.0	0.05
15	Y^4	–0.77	15	0.33	1.20	0.99	4369.84	130.32	530.57	1.0	0.06

Notes see table 1.

Table 4. Results of correlation analysis between parameters $\Delta g_{\text{Bouguer}}$, X, Y, H_1, by profile 841408 in COMS-A mode

№	Parameter	R_B	NN	S_B	F	R_{mul}	SS	FF	R_{res}
2	X	–0.98	4	5.64	3.35	0.83	1266.93	0.00	0.38
3	Y	–0.78	8	2.66	4.68	0.96	1168.15	0.00	0.42
4	X^2	–0.99	13	3.80	0.49	0.92	355.94	2.00	–0.82
5	XY	–0.98	2	2.73	I.93	0.96	468.44	1.00	–0.74
6	Y^2	–0.78	12	1.90	2.06	0.98	655.49	0.00	0.63
7	X^3	–0.96	7	4.24	0.20	0.91	425.55	1.00	078
8	X^2Y	–0.99	5	4.91	0.75	0.87	618.68	0.00	0.65
9	XY^2	–0.96	9	2.37	4.71	0.97	467.97	1.00	0.75
10	Y^3	–0.78	14	2.8I	0.71	0.96	321.55	2.00	0.85
11	X^4	–0.95	11	3.53	0.63	0.93	275.20	3.00	0.88
12	X^3Y	–0.98	3	4.64	0.58	0.89	242.88	4.00	0.9I
13	X^2Y^2	–0.99	6	I.56	8.80	0.98	1209.77	0.00	0.40
14	XY^3	–0. 95	10	2.63	0.35	0.96	634.58	0.00	0.64
15	Y^4	–0.77	15	2.71	0.94	0.96	559.22	0.00	0.69

Notes see table 1.

Table 5. Results of correlation analysis between parameters H_1, $\Delta g_{Bouguer}$, X, Y by profile 841408 in MRA mode

№	Parameter	R_H	NN	SS	FF	R_{mul}
2	$\Delta g_{Bouguer}$	–0.23	10	532.48	1.00	0.05
3	$R(g)$	0.04	4	487.95	1.19	0.39
4	W_{zzz}	–0.81	7	255.55	3.65	0.87
5	$\Delta g^2_{Bouguer}$	–0.24	5	259.70	0.97	0.87
6	$\Delta g_{Bouguer}R(g)$	0.16	2	263.97	0.97	0.86
7	$\Delta g_{Bouguer}W_{zzz}$	–0.26	6	267.03	0.98	0.86
8	$R^2(g)$	0.03	9	174.43	2.34	0.94
9	$R(g)W_{zzz}$	0.04	3	169.90	1.05	0.94
10	W_{zzz}^2	–0.81	8	173.92	0.96	0.94

Notes: R_H is the correlation coefficient of parameters with H_1. For other designations see table 1.

Table 6. Results of correlation analysis between parameters H_1, $\Delta g_{Bouguer}$, X, Y by profile 841408 in COM mode

№	Parameter	R_H	NN	SS	FF	R_{mul}
2	$R(g)$	–0.23	7	251.41	4.47	0.88
3	W_{zzz}	0.04	14	255.55	0.97	0.87
4	$R^2(g)$	–0.24	4	259.70	0.97	0.87
5	$R(g)W_{zzz}$	0.16	11	263.97	0.97	0.86
6	W_{zzz}^2	0.03	2	181.68	2.11	0.93
7	$R^3(g)$	–0.25	9	183.80	0.98	0.93
8	$R^2(g)W_{zzz}$	–0.07	5	178.40	1.06	0.94
9	$R(g)W_{zzz}^2$	–0.18	15	177.84	1.01	0.94
10	W_{zzz}^3	–0.01	8	148.86	1.43	0.95
11	$R^4(g)$	–0.23	12	152.13	0.96	0.95
12	$R^3(g)W_{zzz}$	–0.06	3	155.51	0.96	0.95
13	$R^2(g)W_{zzz}^2$	–0.00	6	154.42	1.01	0.95
14	$R(g)W_{zzz}^3$	0.24	10	156.05	0.98	0.95
15	W_{zzz}^4	0.09	13	156.84	0.99	0.95

Notes see table 1, 2

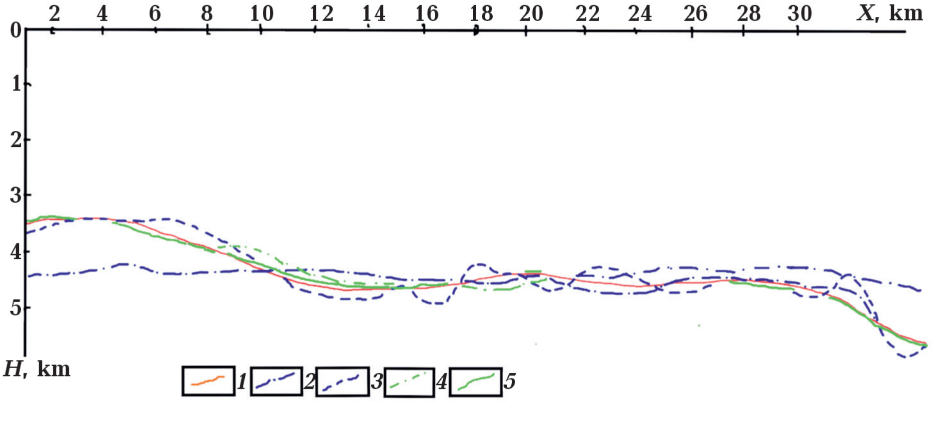

Fig. 6. SH-1 boundary prediction along profile 841408: *1* — SH-1 boundary according to seismic exploration data; *2* — SH-1 boundary predicted by the COMS method (N=4); *3* — SH-1 boundary predicted by the COMS-A method (N = 12); *4* — SH-1 boundary predicted by the MRA method (N=9); *5* — SH-1 bounda rypredicted by the COM method (N=10).

and COMS-A methods in analyzing and predicting boundaries in the case of their weak display in the gravity field.

4. An algorithm, a block diagram, and a FORCE-FORTRAN program MRA-COMS-COM have been developed. The software operates in four modes (COMS, COMS-A, MRA, and COM).Based on the computer calculations, the advantage of the COMS-A and COM methods in predicting seismic-geological boundaries based on gravity exploration data has been demonstrated.

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Алгоритми кореляційних методів комплексної інтерпретації гравіметричних і сейсмічних даних

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Статтю присвячено питанню кореляційних методів комплексної інтерпретації геофізичних даних, вирішення якого відіграє важливу роль при геологічній інтерпретації геофізичних даних. Особливе місце у цьому напрямі займають кореляційні методи інтерпретації гравіметричних, сейсмічних і геологічних даних. Суть кореляційних методів комплексної інтерпретації геофізичних даних полягає у встановленні статистичних зв'язків між глибинами залягання різних комплексів відкладень за даними сейсморозвідки (або буріння) та аномаліями Буге та їх трансформантами за даними гравірозвідки, а також в екстраполяції цих зв'язків на невивчені сейсморозвідкою та бурінням ділянки. Це можуть бути посівні та важкодоступні для сейсморозвідки площі, де можливо проводити гравіметричні роботи. До них належить, зокрема, східна частина Середньокуринської западини Азербайджану, де через складні сейсмогеологічні умови однозначні опорні сейсмічні дані про структуру нижнього еоцен-мезозойського поверху отримати не вдається. На кафедрі геофізики Азербайджанського державного університету нафти і промисловості розроблено методику застосування багатовимірного регресійного аналізу з використанням окремих ділянок умовних сейсмічних горизонтів і даних детальної гравірозвідки. Прогнозування сейсмогеологічних границь статистичними методами на основі наявних еталонних сейсмічних і гравіметричних даних у прогнозному просторі підвищує якість гравіметричних досліджень. У цьому напрямі проаналізовано можливості наявних методів кореляційного та багатовимірного регресійного аналізу, на основі чого було розроблено комбінований метод кореляційного аналізу та прогнозу, який враховує переваги цих методів, що дає змогу підвищити точність прогнозу сейсмогеологічних границь. Розроблено відповідний алгоритм та програму MRA-COMR-COM, яка успішно випробувана на фактичному матеріалі.

Ключові слова: кореляція, регресія, прогнозний простір, сейсмогеологічні дані, багатовимірний регресійний аналіз, кореляційні методи аналізу, алгоритм, програма.