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АНАЛИТИКО-ГЕОМЕТРИЧЕН МЕТОД ЗА ОЦЕНКА НА ГЕОЛОЖКАТА СЛОЖНОСТ НА НАХОДИЩАТА

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РЕЗЮМЕ
Разгледаният метод за оценяване на сложността на геоложки контур и ориентираността на изменчивостта може да се използва за определяне геометрията на подготвителните и добивни изработки, при създаването на методика за нормативи за загубите и обедняването, при изграждане на система за управление на качеството и др.

Находищата, които са обекти на дейност на минно-добивните фирми са пулсиращи системи. Природните дадености и конюнктурата на пазара на суровините определя пулсацията на геоложките (промишлените) запаси на фирмата (Topalov S., и др. 2000). Количествената оценка на природните условия, в частност запасите на фирмата и пазара е вероятностна. Независимо от строгостта на проектните и инженерните решения по разработване на находището, тяхната реализация е подчинена на определена вероятност. Тя е близка до единица за находища с несложен (химичен, минераложки, структурен и т.н.) състав и достатъчно добре проучени и близка до нула - при геоложки сложни и недостатъчно проучени находища.

Степента на проученост на находището и геоложката му сложност по понятни причини са тясно свързани. От геоложката сложност зависи методиката на проучването. За съжаление количествен норматив, регламентиращ геоложката сложност на нашите находища все още не е изграден. Създаването на такъв норматив би решило: съотношението между сондажните и минните проучвателни дейности; геометрията и плътността на проучвателната мрежа, методите и начините на опробване, достигане на еднозначни решения при прилагането на приетата у нас три-показателна класификация на запасите и ресурсите.

Методичният подход при оценката на геоложката сложност значително би облекчил: нормирането, планирането и контрола на загубите и обедняването (замърсяването) при добива на полезните изкопаеми, опазването на земните недра и т.н.

Трудността за количествена оценка на геоложката сложност на находището (или негови участъци) възниква от хипотетичния характер на изходните геоложки данни, методите на интерполация и екстраполация, ограничена от местоположението на точките на наблюдения (изборната статистическа съвкупност) са основни за геоложките решения.

Сложността на находището, в зависимост от етапите и задачите на геолого-проучвателния и добивния цикъл, в (Попов В.Н., и др. 1996) се предлага да бъде разграничена на геоложка и минно-геоложка и оценката да бъде чрез *<u>интегрален показател</u>*, който да включва: геоложки фактори по степен на тяхната изменчивост количествено оценяващи находището и влияещи на точността на оценката на прогнозните минерални ресурси, на рационалното извличане на богатствата от недрата и на технико-икономическите показатели на дейността на минно-добивната фирма. Моделът на минно-геоложката сложност се предлага да бъде графо-аналитичен и да се изрази чрез топофункция от вида - $V = f(x,y,z)$

Оценката на минно-геоложката сложност трябва според (Попов В.Н., и др. 1996) да се извършва чрез показател, към който да бъдат предявени следните изисквания:

- безразмерност - различните геоложки показатели да се изразяват с безразмерни величини без загуба на физическия смисъл, позволяващ сравняемост на участъците от находищата;
- пространствена обвързаност - отразяване характера на изменение при решаване на конкретни инженерни задачи;

- отчитане на дискретния и непрекъснатия характер на геоложките показатели;
- възможност за формализация на качествените и описателните фактори;
- универсалност, гъвкавост и надеждност при изградения обемен модел на находището, даващ възможност да се използва при планирането и управлението на минните работи.

Посочените изисквания за показателя, могат да бъдат реализирани на основата на метод, почиващ на минно-геометрични зависимости (Христов Ив. 1974). Същността на метода в аналитичната му част се основава на теорията на случайните функции - нормираната корелационна функция:

$$\rho_x(\tau) = \sigma_1^2 e^{\alpha_i(\tau)} + \sigma_2^2 e^{\alpha_j(\tau).\cos\beta_j(\tau)},$$

където:

σ_1^2 и σ_2^2 са съответно дисперсии на случайната и закономерната (периодичната) съставящи в разпределението на геоложкия показател;

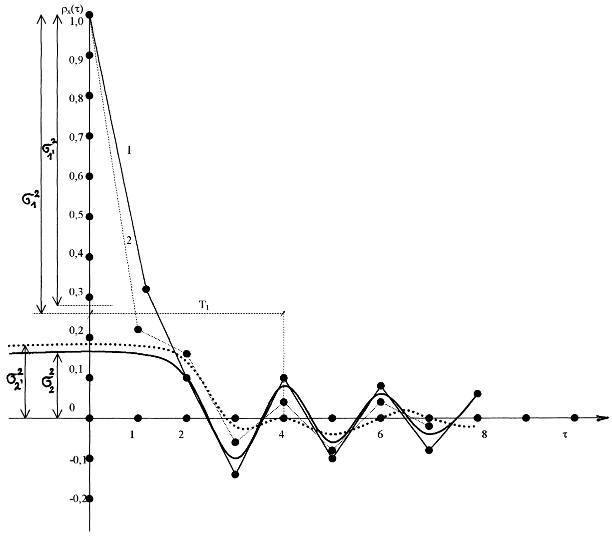
$\alpha_{i,\ j}$ - показател на степента на намаляване на корелацията между показателите в пространството;

β - кръгова честота на периодичната (закономерната) съставяща на изменчивостта на геоложкия показател.

На фиг. 1. са показани графиките на нормираната, приведена към дисперсия равна на единица, автокорелационна функция на изменението на съдържанието на мед по дадено направление в находище, което се разработва по открит начин - с 1 е означена графиката, построена на базата на сондажите от детайлното проучване, а с 2 - на базата на експлоатационното проучване. От фигурата се вижда, че наред със случайната съставяща, дисперсията на която е равна, за графика 1 на σ_1^2, средноквадратичното отклонение σ_1 = 0,87 (основна съставяща) има и закономерна съставяща с дисперсия σ_2^2 и средно квадратично отклонение σ_2 = 0,38, с период T_1, равен на четирикратния размер на мрежата на опробване.

Графичната част на предлагания метод се изразява, както в показаното в аналитичната му част, така и в следния ред графични построения:

- за всеки хоризонт хипотетично, на база геоложки контур се определя центъра на тежестта;
- през центъра на тежестта се прокарват прави, чието ориентиране се определя чрез стойността на посочен ъгъл;
- за всяка права се определят точките на наблюдение за изучаване на геоложкия показател, определящ сложността на находището и се определя стойността на σ_1 и σ_2;
- стойностите на σ_1 и σ_2 се нанасят на отделни лъчеви графики, чиито начала са стойностите на X и Y на центъра на тежестта на хоризонта на рудника;
- крайните точки се съединяват с начупена крива, която определя бездименсионната площ на случайната (закономерната) съставяща в изменчивостта на показателя; ориентираността на двата вида изменчивост в координатната система на минните работи;
- определя се периметъра на фигурата P (дължината на начупената крива), чиято големина се използва като решаващо правило при оценка на сложността на геоложкия показател.

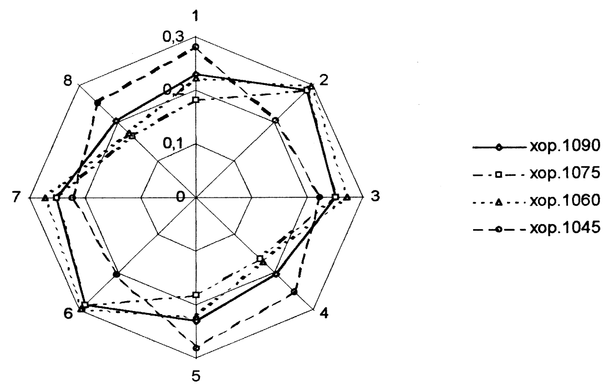


Фигура 1.

На фиг.2. са показани лъчевите графики за случайната съставяща на съдържанието на мед за хоризонтите 1090, 1075, 1060 и 1045 (по данни от детайлното проучване) - рудник "Елаците", която е съставена въз основа на характера на автокорелационната функция (стойностите на радиуса на автокорелация) за осемте формирани направления. Графичната основа за оценка на закономерната съставяща е производна на показаната на фиг.2.

Достигането на посочените резултати, на настоящия етап, е извършено чрез използване на някои стандартни приложни програмни продукти (напр. "*Statgraph - Plus*"), приложения на Microsoft Office (Excel), прилагане на серии логически операции и др.

От анализа на използваните графични модели на случайната съставяща за разглежданите хоризонти 1090, 1075, 1060 и 1045, по отношение на съдържанието на мед, могат да се направят следните по-значими изводи:



Фигура 2.

1. По отношение на нееднородност (на база информация от детайлно проучване) - за най-сложен може да се приеме хоризонт 1090, за хоризонт 1060 и 1045 може да се каже, че са със сходна сложност, а хоризонт 1075 е с най-малка сложност по отношение разпределението на съдържанието на мед.
2. Увеличаването на обема на информацията (данните от опробването при експлоатационното проучване) за съдържанието на мед намалява случайната съставяща за отделните хоризонти, както следва:

на хор.1090 - 61,5 %;
на хор.1075 - 62,0 %;
на хор.1060 - 63,5 % и
на хор.1045 - 55,9 %.

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ANALYTICAL-GEOMETRICAL METHOD FOR ASSESSING THE OREBODY GEOLOGICAL COMPLEXITY

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AbstracT
The method proposed for assessing the geological profile complexity and the orientation of changeability can be used for determining the geometry of the development and extraction workings, for devising a methodology for standardising ore loss and contamination, for building up a quality control system, etc.

The orebodies which are being mined by the mining companies are pulsating systems. The natural factors and the raw materials market situation determine the pulsation of the geological (industrial) reserves of the company (Topalov S. et. al. 2000). The quantitative evaluation of the natural conditions and, in particular, the company and market reserves, is probabilistic. Despite the strictness of the design and engineering solutions on working the orebody, their implementation depends on a certain probability. It is close to 1 for well-explored orebodies with simple chemical, mineralogical, structural, etc. composition and close to 0 for geologically complex and insufficiently explored orebodies.

The degree of exploration of the orebody and its geological complexity are closely interrelated for well-known reasons. The exploration methodology depends on the geological complexity. Unfortunately, no quantitative standard has been elaborated so far for regulating the geological complexity of the Bulgarian ore deposits. Such a standard would solve the problems related to: the ratio between drilling and mining exploration works; the geometry and density of the exploration grid; the methods and techniques of sampling; the obtaining of single solutions by applying the three-index classification of reserves and resources adopted in this country.

The methodological approach to assessing the geological complexity would significantly facilitate: the standardization, planning and control of losses and contamination in mineral extraction, subsoil protection, etc.

The difficulty in assessing quantitatively the geological complexity of the orebody (or its sections) arises out of the hypothetical character of the output geological data. The methods of interpolation and extrapolation, limited by the location of the sampling points (selected statistical sample) are essential for the geological solutions.

The complexity of the orebody, depending on the stages and tasks of the geological exploration and mining cycle, is proposed to be subdivided into geological and mining-geological (Попов В.Н. и др. 1996). The assessment is designed to be made by using an *integral index* which should involve: geological factors by degree of their changeability which assess the deposit quantitatively and have an influence on the accuracy of evaluation of the predicted mineral resources, on the rational extraction of valuable minerals from the Earth’s crust and on the technical and economic indices for the activity of the mining company. We suggest that the mining-geological complexity model be grapho-analytical and be expressed by the topofunction of the type V = f (x,y,z).

According to (Попов В.Н. и др. 1996), the assessment of the mining-geological complexity should be carried out by an index which has to meet the following requirements:

- zero dimension - the different geological indices are expressed by dimensionless variables without losing the physical sense thus enabling us to compare the orebody areas;
- spatial relationship - reflecting the character of change when solving particular engineering problems;

- taking into account the discrete and continuous character of the geological indices;
- possibility for formalisation of the qualitative and descriptive factors;
- versatility, flexibility and reliability of the constructed volumetric model capable of being used in the planning and management of mining operations.

The requirements to the index mentioned above can be implemented by a method based on the mining-geometrical relationships (Христов Ив. 1974). In its analytical part the method is based on the theory of random functions - the normalised correlation function:

$$\rho_x(\tau) = \sigma_1^2 e^{\alpha_i(\tau)} + \sigma_2^2 e^{\alpha_j(\tau) \cdot \cos\beta_j(\tau)}$$

where:

σ_1^2 and σ_2^2 are variances of the random and regular (periodic) components in the distribution of the geological index;

$\alpha_{i,j}$ - an index of the degree of reduction of the correlation between the spatial indices;

ß - angular velocity of the periodic (regular) component of the changeability in the geological index.

Fig. 1 shows the graphs of the normalised, reduced to a variance=1, auto-correlation function of the change in the copper content along a given direction in the orebody which is being extracted by open-pit mining methods. 1 designates the graph plotted on the basis of data from detailed exploration drill-holes and 2 designates data from the exploitation exploration. The figure shows clearly that along with the random component whose variance for graph 1 equals σ_1^2, with a standard deviation σ_1 = 0.87 (basic component), there is also a regular component with a variance of σ_2^2 and a standard deviation σ_2 = 0,38, with a period T_1 equal to four times the sampling grid size.

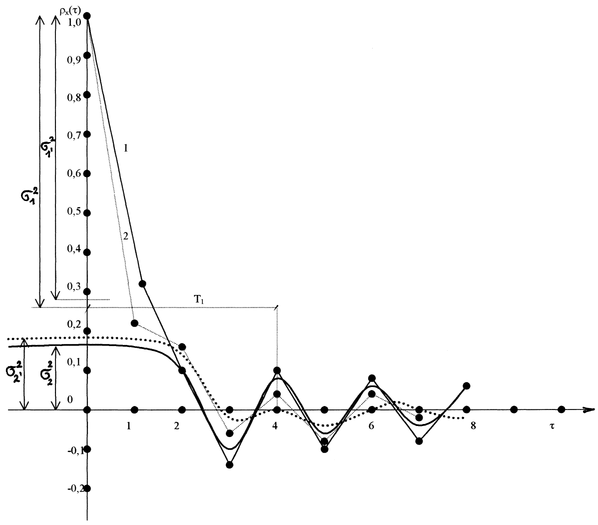

Figure 1

The graphical part of the proposed model is expressed both by what has already been shown in its analytical part and by the following sequence of graphic constructions:

- for each level the centre of gravity is defined hypothetically on the basis of a geological profile;
- straight lines are drawn through the centre of gravity whose orientation is defined by the value of a true bearing;
- the sampling points are defined for each straight line in order to study the geological index determining the orebody complexity and the values of s_1 and σ_2^2 are also defined;
- the values of σ_1 and σ_2 are plotted on separate radial diagrams whose origins coincide with the values of X and Y of the gravity centre of the mine level;
- the final points are connected with a closed polygon line which defines the dimensionless area of the random (regular) component in the changeability of the index; the orientation of the two types of changeability in the coordinate system of the mining operations;
- the circumference P in the figure is defined (the length of the closed polygon line) whose length is used as a decisive factor in assessing the complexity of the geological index.

Fig. 2 shows radial diagrams for the random component of the copper content for levels 1090, 1075, 1060 and 1045 (according to data from the detailed exploration at the Elatsite Mine), which are constructed on the basis of the character of the auto-correlation function (the values of the radius of auto-correlation) for the eight defined directions. The graphical basis for assessing the regular component is a derivative of the one shown in Fig. 2.

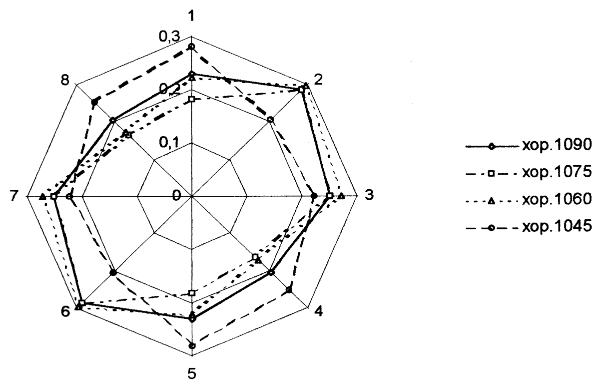

Figure 2

The results were obtained by using some standard application software packages (e.g. "*Statgraph - Plus*"), applications of Microsoft Office (Excel), application of a series of logical operations, etc.

From the analysis of the applied graphic models of the random component for the levels under study, viz. 1090, 1075, 1060 and 1045, with regard to copper content, it is possible to draw the following important conclusions:

2. In terms of non-homogeneity (based on data from detailed exploration) - level 1090 can be said be the most complex one, levels 1060 and 1045 can be said to be of similar complexity and level 1075 can be considered the least complex one with respect to the distribution of copper content.
3. With increasing the bulk of information (sampling data from the exploitation exploration) on the copper content, the random component for each level decreases as follows:
   on level 1090 by 61,5 %;
   on level 1075 by 62,0 %;
   on level 1060 by 63,5 % and
   on level 1045 by 55,9 %.

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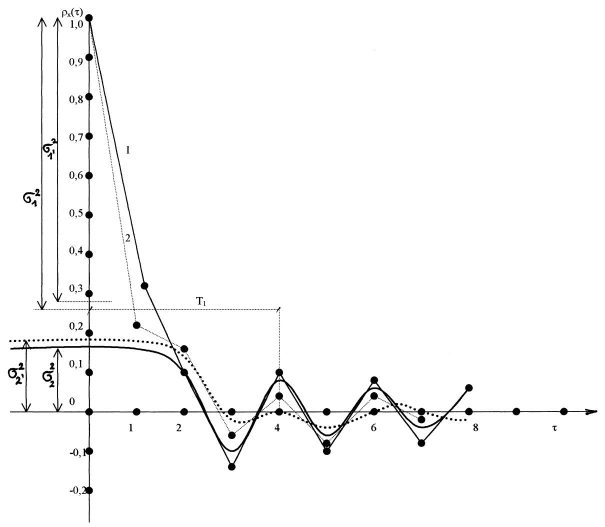

Figure 1

The graphical part of the proposed model is expressed both by what has already been shown in its analytical part and by the following sequence of graphic constructions:

- for each level the centre of gravity is defined hypothetically on the basis of a geological profile;
- straight lines are drawn through the centre of gravity whose orientation is defined by the value of a true bearing;
- the sampling points are defined for each straight line in order to study the geological index determining the orebody complexity and the values of s_1 and σ_2^2 are also defined;
- the values of σ_1 and σ_2 are plotted on separate radial diagrams whose origins coincide with the values of X and Y of the gravity centre of the mine level;
- the final points are connected with a closed polygon line which defines the dimensionless area of the random (regular) component in the changeability of the index; the orientation of the two types of changeability in the coordinate system of the mining operations;
- the circumference P in the figure is defined (the length of the closed polygon line) whose length is used as a decisive factor in assessing the complexity of the geological index.

Fig. 2 shows radial diagrams for the random component of the copper content for levels 1090, 1075, 1060 and 1045 (according to data from the detailed exploration at the Elatsite Mine), which are constructed on the basis of the character of the auto-correlation function (the values of the radius of auto-correlation) for the eight defined directions. The graphical basis for assessing the regular component is a derivative of the one shown in Fig. 2.

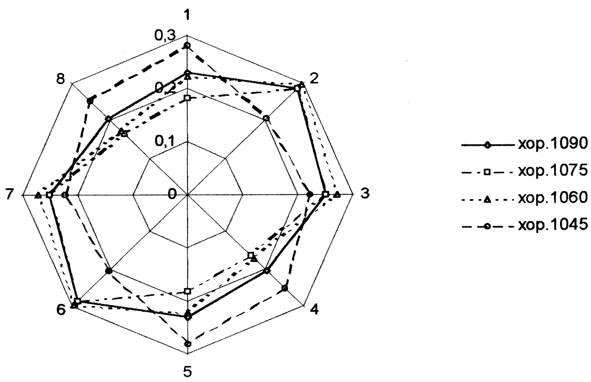

Figure 2

The results were obtained by using some standard application software packages (e.g. "*Statgraph - Plus*"), applications of Microsoft Office (Excel), application of a series of logical operations, etc.

From the analysis of the applied graphic models of the random component for the levels under study, viz. 1090, 1075, 1060 and 1045, with regard to copper content, it is possible to draw the following important conclusions:

4. In terms of non-homogeneity (based on data from detailed exploration) - level 1090 can be said be the most complex one, levels 1060 and 1045 can be said to be of similar complexity and level 1075 can be considered the least complex one with respect to the distribution of copper content.
5. With increasing the bulk of information (sampling data from the exploitation exploration) on the copper content, the random component for each level decreases as follows:
   on level 1090 by 61,5 %;
   on level 1075 by 62,0 %;
   on level 1060 by 63,5 % and
   on level 1045 by 55,9 %.

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Recommended for publication by Department of Mine Surveying and Geodesy, Faculty of Mining Technology

ANALYTICAL-GEOMETRICAL METHOD FOR ASSESSING THE OREBODY GEOLOGICAL COMPLEXITY

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AbstracT

The method proposed for assessing the geological profile complexity and the orientation of changeability can be used for determining the geometry of the development and extraction workings, for devising a methodology for standardising ore loss and contamination, for building up a quality control system, etc.

The orebodies which are being mined by the mining companies are pulsating systems. The natural factors and the raw materials market situation determine the pulsation of the geological (industrial) reserves of the company (Topalov S. et. al. 2000). The quantitative evaluation of the natural conditions and, in particular, the company and market reserves, is probabilistic. Despite the strictness of the design and engineering solutions on working the orebody, their implementation depends on a certain probability. It is close to 1 for well-explored orebodies with simple chemical, mineralogical, structural, etc. composition and close to 0 for geologically complex and insufficiently explored orebodies.

The degree of exploration of the orebody and its geological complexity are closely interrelated for well-known reasons. The exploration methodology depends on the geological complexity. Unfortunately, no quantitative standard has been elaborated so far for regulating the geological complexity of the Bulgarian ore deposits. Such a standard would solve the problems related to: the ratio between drilling and mining exploration works; the geometry and density of the exploration grid; the methods and techniques of sampling; the obtaining of single solutions by applying the three-index classification of reserves and resources adopted in this country.

The methodological approach to assessing the geological complexity would significantly facilitate: the standardization, planning and control of losses and contamination in mineral extraction, subsoil protection, etc.

The difficulty in assessing quantitatively the geological complexity of the orebody (or its sections) arises out of the hypothetical character of the output geological data. The methods of interpolation and extrapolation, limited by the location of the sampling points (selected statistical sample) are essential for the geological solutions.

The complexity of the orebody, depending on the stages and tasks of the geological exploration and mining cycle, is proposed to be subdivided into geological and mining-geological (Попов В.Н. и др. 1996). The assessment is designed to be made by using an *integral index* which should involve: geological factors by degree of their changeability which assess the deposit quantitatively and have an influence on the accuracy of evaluation of the predicted mineral resources, on the rational extraction of valuable minerals from the Earth’s crust and on the technical and economic indices for the activity of the mining company. We suggest that the mining-geological complexity model be grapho-analytical and be expressed by the topofunction of the type V = f (x,y,z).

According to (Попов В.Н. и др. 1996), the assessment of the mining-geological complexity should be carried out by an index which has to meet the following requirements:

- zero dimension - the different geological indices are expressed by dimensionless variables without losing the physical sense thus enabling us to compare the orebody areas;
- spatial relationship - reflecting the character of change when solving particular engineering problems;
- taking into account the discrete and continuous character of the geological indices;
- possibility for formalisation of the qualitative and descriptive factors;
- versatility, flexibility and reliability of the constructed volumetric model capable of being used in the planning and management of mining operations.

The requirements to the index mentioned above can be implemented by a method based on the mining-geometrical relationships (Христов Ив. 1974). In its analytical part the method is based on the theory of random functions - the normalised correlation function:

$$\rho_x(\tau) = \sigma_1^2 e^{\alpha_i(\tau)} + \sigma_2^2 e^{\alpha_j(\tau).\cos\beta_j(\tau)}$$

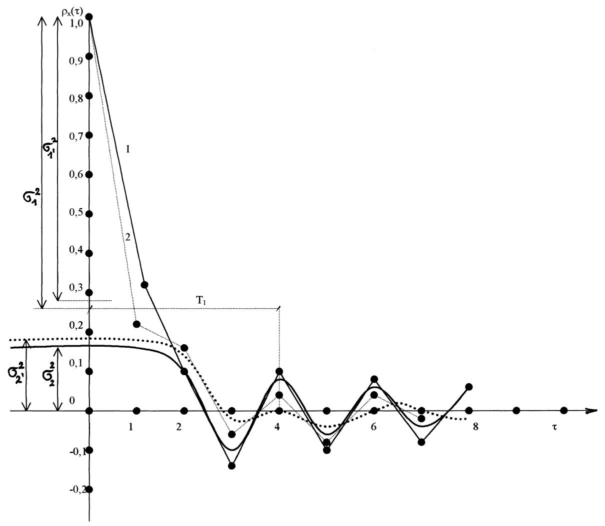
where:

σ_1^2 and σ_2^2 are variances of the random and regular (periodic) components in the distribution of the geological index;

$\alpha_{i,j}$ - an index of the degree of reduction of the correlation between the spatial indices;

ß - angular velocity of the periodic (regular) component of the changeability in the geological index.

Fig. 1 shows the graphs of the normalised, reduced to a variance=1, auto-correlation function of the change in the copper content along a given direction in the orebody which is being extracted by open-pit mining methods. 1 designates the graph plotted on the basis of data from detailed exploration drill-holes and 2 designates data from the exploitation exploration. The figure shows clearly that along with the random component whose variance for graph 1 equals σ_1^2, with a standard deviation σ_1 = 0.87 (basic component), there is also a regular component with a variance of σ_2^2 and a standard deviation σ_2 = 0,38, with a period T_1 equal to four times the sampling grid size.



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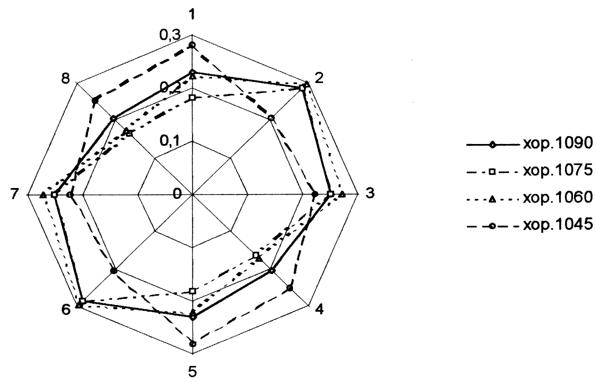

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