GEOLOGICA BALCANICA, 27. 3-4, Sofia, Augus. 1997, p. 105-111.

Metallogenic prognostication of the Luki ore field (scale 1:50000) by means of computer-prognosticating system

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(Received 12. 09. 1994; accepted 21. 09. 1994)

В. Иванова, Л. Гугов, С. Димовска – Металлогеническое прогнозирование Лыкинского рудного поля (М 1:50 000) с помощью компьютерно-прогнозирующей системы. Система содержит два блока: база данных и блок для обработки, анализа и прогнозирования.

База данных обеспечивает сохранение геологической, геофизической и других видов информации, которую можно извлекать селективно по выбранным показателям.

Блок для обработки, анализа и прогнозирования подготавливает данные к анализу, производит статистику и прогнозирование (распознавание) с классификатором Бейсик, путем линейного дискриминантного анализа и кластер-анализа. Распознавание можно провести с обучением или без обучения. Исследуется информативность данных и надежность результатов.

Прогнозирование проводится на площади 350 km^2, представляющей территорию Лыкинского рудного поля. Прогнозным объектом является единица площади с размерами 0,5×0,5 km. Использованы 30 признаков: литолого-стратиграфические, геохимические, геофизические. Сформированы альтернативные эталонные совокупности – известные рудные месторождения и рудопроявления и условно бесперспективные площади. Произведен сравнительный статистический анализ совокупностей, чтобы оценить их разделяемость по отдельным признакам. Обучением на основе классификационного алгоритма Бейсик получен классификационный критерий, позволяющий разделить прогнозные объекты на руднoперспективные и бесперспективные. Прогнозирование проведено в различных вариантах, для различных признаков, при указании надежности прогнозых результатов.

Abstract. The system consits of two blocks: block of database and block of processing, analysis and prognostication. The database provides the conservation of the geological, geophysical and other kind of information, which can selectively be extracted according to desired features.

The block of processing, analysis and prognostication prepares the data for analysis, produces the statistics, as well the prognostication (the recognition) with the classificator Basic, by means of a linear discriminant analysis and a cluster analysis. The recognition can be made with education or without education. The informatively of the data and the reliability of the results were studied.

The prognostication was carried out on the area of 350 km^2, which represented the territory of the Luki ore field. The prognostic object constituted an unit of surface with dimensions 0.5×0.5 km. On the whole 30 features were used: lithologo-stratigraphic, geochemical and geophysical ones. Alternative model sets were formed: for the well-known ore deposits and ore manifestations and for the conditionally subcommercial areas. A comparative statistical analysis of the sets was carried out in order to estimate their divisibility according to the separate features. By education via Basic classification algorithm a classification criterion was obtained, that allowed to subdivide the prognostic objects to commercial and subcommercial ones. The prognostication was produced in many variants, for different combinations of features, and the degree of reliability of the prognostic results was shown for each case.

Ivanova, V., Gougov, L., Dimovski, S. 1997. Metallogenic prognostication of the Luki ore field (scale 1:50000) by means of computer-prognosticating system. —*Geologica Balc.*, 27, 3-4; 105-111.

Key words: metallogeny, computer prognostics, Luki ore field, Rhodopes, Bulgaria

Introduction

The computer-oriented systems represent a modern technology for solution of prognosticating tasks. Their main advantage is the large informative capacity of computers, allowing the creation of multifunctional databases and the possibility to systematize the accumulated information, to extract it selectively, to process and analyse it. Such systems were used by the authors several times for the geological prognostication in different regions of Bulgaria (Иванова et al., 1984; Иванова et al., 1987). This paper describes an original author's computer system, which was already used for the metallogenic prognostication on the territory of the Rhodopes on different scales. The results of the metallogenic prognostication of the Luki ore field on scale 1:50 000 are presented as well.

Computer system for solving prognosticating tasks

As a structure, this system consists of two blocks: block of database by means of service, and block for processing, analysis and prognostic solutions.

The detabase is formed and governed by means of the program products of the system for database control ADABAS, made by the firm Software AG — Germany (Software AG, 1991). ADABAS is used by the authors for compiling database with a composition, a structure and an internal organisation, suitable for solving concrete problems. The system languages of the product served for compiling programmes for regrouping and purposeful extracting the information for its further use in the process of prognostication.

The block of processing and analysis is constructed on a modular principle. The separate stages, such as the preliminary processing of data, their preparing for analysis, the analysis itself and the adoption of the prognosticate solutions, may function independently from each other, and in case of need they may follow in a chosen succession, according to the requirement of the users.

In the context of the system the prognostication is a process of pattern recognition. The patterns in this case are the elementary surfaces (cells) from the studied territory, the dimensions of which depend on the scale of study. Each elementary cell possesses a complex of variables (vector), characterizing it in geological, geophysical, geochemical and other respect. The complex of features constitutes a feature space, in which the vector fixes the position of the pattern. The recognition puts the patterns to areas, preliminary defined in the space (conventionally or with education), that predetermines their metallogenic commercial or subcommercial significance.

The system takes into account the diversity of methods of pattern recognition. It foresees working by three algorithms:

— education probability-statistical algorithm — Basic classificator;

— heuristic algorithm with education — linear discriminant analysis;

— classification without models.

The system is open for recognising algorithm. The first two approaches form a classification cryterion on the basis of education by the use of model objects. The probability-statistical algorithm is suitable for the mixed patterns in the feature space, while the heuristic one is suitable for independent patterns. The recognition with education includes the following main operations of the data:

— statistical analysis of the features;

— testing for normal distribution of the data of each aspect;

— selection of standard objects with given description of features from the database;

—estimation of the invormativity of the features and choice of a space of features optimal for the recognition;

— education on models and making a classification rule;

— classification of the objects.

The classification without models subdivides the objects into a preliminary defined number of classes, proceeding from the assumed proximity of the patterns in the feature space and from the favourable configuration of this spece.

General characteristic of the initial data in the metallogenic prognostication of the Luki ore field

The Luki ore field is situated in the northern part of the Central Rhodopes. It embrasses the river systems of Manastirska, Djurkovska and Yugovska rivers.

The ore field is mapped on a scale 1:25 000, while the most interesting and the most promising sectors are mapped even on more detailed scales —1:5000 and 1:2000. Equally with the largescale mapping, the metallometric, hydrochemical and geophysical prospection defines the high extent of study of the region.

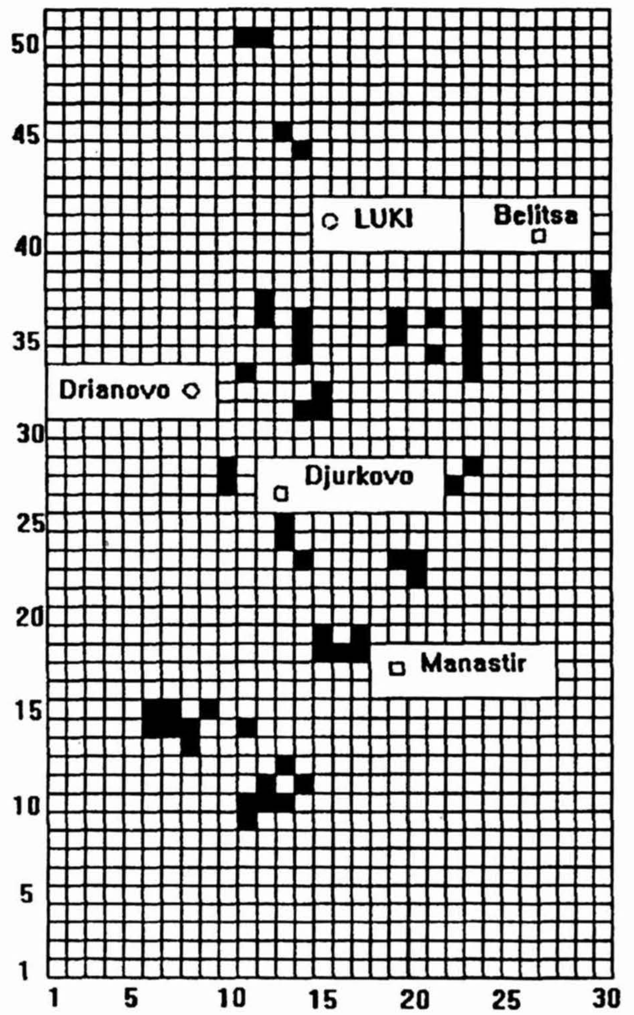

Fig. 1. Situation scheme of the studied territory (The Luki ore field) for the Probability-statistical metallogenic prognostication. The dark cells represent model objects of the ore class

The subject of this study is a territory of about 350 km². A cell with dimensions 0.5×0.5 km is accepted as elementary prognostic surface, that coresponds to the scale 1:50 000. On the studied territory there is in sum 1560 elementary cells, disposed on 52 lines and 30 columns of the initial surface matrix (Fig. 1).

Based to the analysis of the available geologic-geophysical information on the Luki ore field and to the requirement for uniform study of the whole territory (uniform conditional description of all elementary cells), 30 features were chosen. Unfortunately, very important ore control cryteria such as the zones of conductivity and of polarization, cannot be completely used, because of the insufficient study of the ore field in this respect. In spite of this, there are 6 features, characterizing 460 elementary cells, i. e. about 30% of the territory, which are included in the feature space. The full list of the features is systematized in the Table 1.

The geophysical features are represented by the variation of the total vector of the magnetic field and the gamma-spectrometric components — the intensity of the total gamma-radiation and the content, thorium, and potassium-40 (Nikolov et al., 1977 — unpublished fund materials). The results of the detailed electric prospection in some sectors — the density and the direction of the zones of conductivity and

Table 1
List of the features, used for the metallogenic prognostication

Code numbers of the features	Features
1.	Geophysical
1.1	Geomagnetic
1 1.1.1.	Variation of the vertical component
2 1.1.2.	Field of the vertical component on altitude 2.5 km
3 1.1.3.	Residual field of the vertical compnent of the analytical continuation on altitude 2.5 km
4 1.1.4.	Total vector of the magnetic field
1.2.	Aerogammaspectrometric
5 1.2.1.	Total gamma-radiation
6 1.2.2.	Content of uranium
7 1.2.3.	Contentof thorium
8 1.2.4.	Content of potassium-40
1.3	Zones of conductivity
9 1.3.1.	Density of the zones
10 1.3.2.	Direction of the zones
1.4.	Zones of polarization
11 1.4.1.	Density of the zones
12 1.4.2.	Direction of the zones
2.	Geochemical
13 2.1.	Content of lead, zinc and copper
14 2.2.	Content of molybdenum
15 2.3.	Content of tin
3.	Zones of sulphide mineralization
16 3.1.	Density of the zones
17 3.2.	Direction of the zones
18 4.	Remains of base level surfaces
5.	Recent rocky valley bottoms
19 5.1.	Present of valley bottoms
20 5.2.	Direction of the valley bottoms
6.	Lithologic-stratigraphic
21 6.1.	Trachiandesite (Oligocene)
22 6.2.	Rhyodacites and dacites (Oligocene)
23 6.3.	Rhyolite coatings and bodies
24 6.4.	Rhyolite tuffs
25 6.5.	Latite coatings and dykes
26 6.6.	Latite breccia
27 6.7.	Priabonian breccia-conglomerates
28 6.8.	Aplitoide granites (Upper Cretaceous)
29 6.9.	Silicate-carbonate formation
30 6.10.	Marbles (Proterozoic)
31 6.11.	Regional hydrothermal alteration of the marbles
32 6.12.	Upper variegated formation (Proterozoic)
33 6.13.	Formation of the biotite gneisses (Proterozoic)
34 6.14.	Amphibolites (Proterozoic)
35 6.15.	Lower variegated formation (Proterozoic)
36 6.16.	Upper granitogneiss formation (Proterozoic)

polarization — were processed, toc. The information on the direction is codified in 9 unform intervals of 20°, while the density of the faults is expressed numerically.

The geometrical characteristics are taken from the map of the anomalies by separate elements (Subev et al., 1973 — unpublished fund materials). The data on the total content of Pb, Zn and Cu are codified numerically, and the distribution of K, Mo in the space — binarily. The density of the zones of sulphide mineralization is codified numerically, and the direction — cyclically, in 9 uniform intervals of 20°. The geomorphological map was also treated for completing the features, characterizing the Luki ore fields (unpublished fund materials of Subev, 1973 were used too). The presence of remains of base level surfaces is codified binarily. The spatial distribution of the recent rocky valley bottoms is represented by two features — density and direction. The density is codified binarily, and the direction — cyclically, in 4 uniform intervals of 45°.

The lithologic-stratigraphic characteristic of the studied territory is totally described by the use of the geological map of the Luki region (Netsov et al., 1973 — unpublished fund materials). In this respect 16 features were chosen and codified binarily.

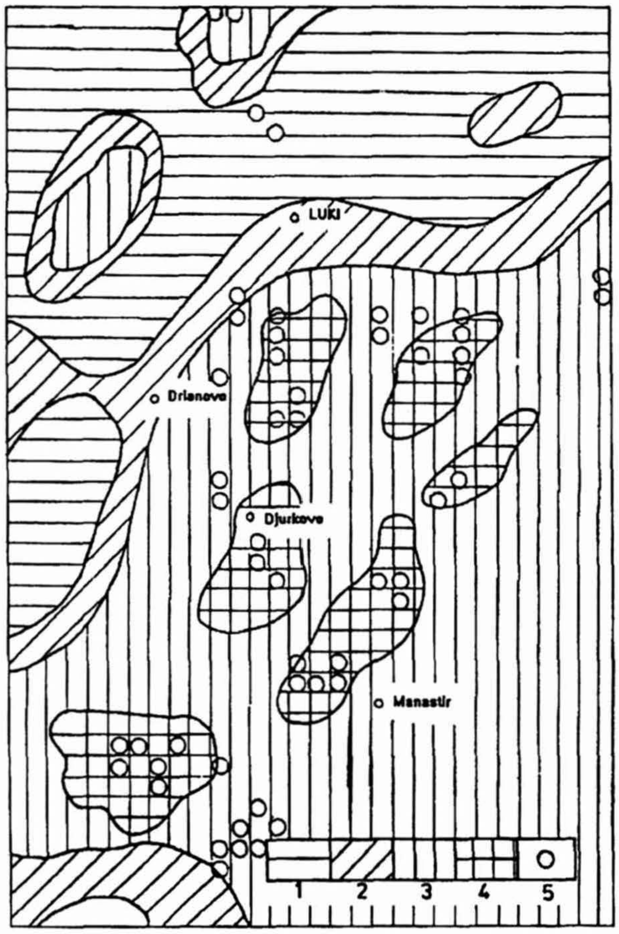

Fig. 2. Prognostic scheme of the Luki ore field by a complex of features with code numbers 3, 13, 14, 15, 18, 19, 20, 21-26.
Probability of belonging to the ore class: 1 — -P<0.45; 2 —0.45<P<0.5; 3 — 0.55<P<0.75; 4 —P>0.75; 5 — well-known ore deposuts and are manifestations

Formation of model sets

Based to the analysis of the available data on the metallogeny of the Luki ore field 53 model cells were separated, und the well-known ore deposits and ore manifestations were bound to them. They constitute the full model set of class "A". By the use of a generator for accidental numbers, model of class "A_2" were formed, each of them containing 20-30 elementary cells, from the set of class "A". It ought to be taken into consideration, that all samples equally contain ore deposits with different economic valuation, and for such a purpose an uniform distribution of the standard cells is provided on the whole studied territory. The model samples of class "B" are formed with a considerable conditionality. All the elementary cells with a vague economic significance are conditionaly assumed as subcommercial ones, and they fall on class "B". By the use of a generator for accidental numbers, model samples of class "B_2" were formed from this set, each of them consisting of 20-50 elementary cells.

For the evaluation of the informativity of the features and for making the classification rules, different combinations of model samples of class "A" and class "B" were used.

Statistical characteristic of the features

The statistical analysis of the distribution of the features is made on the total set of elementary cells and on two sets for the first class and two sets the second class. The main statistical characteristic — mean values, standard deviations, asymmetry, excess, as well as the correlation between the features — are studied. Rose-diagrams for those features, which express a direction, were constructed on the basis of the data on the total set.

The analysis of the statistical characteristics shows a comparatively feebly marked difference between the mean values for the sets of the two classes. For all geophysical and geochemical features the mean values for the sets, characterizing the class "A", are higher than those for the class "B". In the statistical distribution this tendency is manifested by a positive asymmetry and a positive excess.

The rose-diagrams of the directions of the

Table 2
Correlation matrix of the aerogeophysical features (code numbers 4, 5, 6, 7, 8), geochemical features (code numbers 13, 14, 15) and the features 18 and 19

Code numbers of the features	4	5	6	7	8	13	14	15	18	19
4	1	0.32	0.19	0.27	0.23	0.07	0.03	0.18	0.06	0.09
5	0.32	1	0.61	0.35	0.79	0.12	0.07	0.17	0.09	0.16
6	0.19	0.61	1	0.6	0.51	0.04	0.08	0.06	0.06	0.09
7	0.27	0.85	0.6	1	0.75	0.13	0.03	0.13	0.08	0.14
8	0.23	0.79	0.51	0.75	1	0.08	0.09	0.14	0.06	0.09
13	0.07	0.12	0.04	0.13	0.08	1	0.29	0.04	0.03	0.02
14	0.03	0.07	0.08	0.03	0.09	0.29	1	0.11	0.06	0.01
15	0.18	0.17	0.06	0.13	0.14	0.04	0.11	1	0.02	0.06
18	0.06	0.09	0.06	0.08	0.04	0.03	0.06	0.02	1	0.04
19	0.09	0.16	0.09	0.14	0.13	0.02	0.01	0.06	0.04	1

Table 3
Correlation matrix for the zones of conductivity (code numbers 9 and 10), polarization (code number 12), sulphide mineralization (code numbers 16 and 17) and the geochemical features (code numbers 13 and 14) for the territory of the Luki ore field

Code numbers of the features	9	10	12	13	14	16	17	20
9	1	0.54	0.32	0.12	0.07	0.14	0.18	0.01
10	0.54	1	0.26	0.16	0.09	0.19	0.14	0.03
12	0.32	0.26	1	0.1	0.05	0.003	0.001	0.5
13	0.12	0.16	0.1	1	0.28	0.10	0.13	0.11
14	0.07	0.09	0.05	0.28	1	0.05	0.02	0.05
16	0.14	0.19	0.003	0.1	0.05	1	0.69	0.003
17	0.18	0.14	0.001	0.13	0.02	0.60	1	0.05
20	0.01	0.003	0.05	0.11	0.05	0.003	0.05	1

conductivity, polarization and sulfide mineralization zones are characterised by a clearly expressed trend to the north-northeast. The dominating directrix is 10-30°. No such trend is observed for the distribution of the directions of the rocky valley bottoms.

The interdependence between the separate features is studied by a correlation analysis. The results are systematized in the Tables 2 and 3. The interest for such kind of research arises from the necessity of reducing the number of features, facilitating by this way the procedure of recognition. Comparatively close linear correlation is observed between the gammaspectrometric components. The interdependence between the conductivity, polarization and sulphide mineralization zones is considerably less expressed. For the features, characterized by a density and a direction, there is an impressionable connection between these two parameters. For example, the correlation between the density and the direction for the zones of conductivity is 0.54, and for the zones of sulphide mineralization — it is 0.69. This interdependence is caused by the increase of the fault density and by the density of the intersection points of different fault systems. The lithologic-stratigraphical features appear as completely independent ones.

Evaluation of the informativity of the features

The informativity of all the features chosen for metallogenic prognostication of the Luki ore field was calculated for five different combinations of samples of both classes. The data on the probility *a posteriori* for classification, as a range between the minimum and the maximum values, are presented in Fig. 3. The estimation of the representativity is based to the distribution of the absolute values of probability and to the range of variation as independent parameter, characterizing the stability of the feature.

The aerogeophysical features (code numbers 3, 5, 6, 7, 8) are manifested with equal stability, but they substancially differ in the informativi-

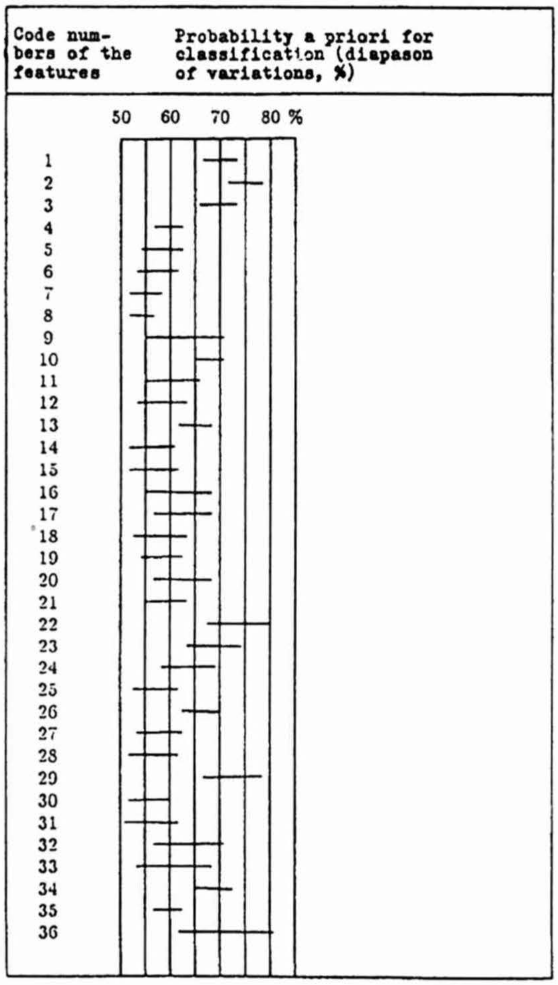

Fig. 3. Informativity of the features, used for the metallogenic prognostication of the Luki ore field

ty. The probability *a posteriori* for classification is higher for the total gamma-radiation (feature 5) and it progressively decreases for the contents of uranium (features 6), thorium (feature 7) and potassium-40 (feature 8).

The feature components, obtained from the electrometrical investigations, substancially differe in informativity. For the density (features 9 and 11), especially of the conductivity zones, the probability *a posteriori* for classification varies in large limits. Such a distribution is caused as well by the insufficient representativity of the model samples, characterizing only a small part of the studied territory (about 25%). The analogous situation is observed for the density of the sulphide minerazation zones too (feature 16). The highest and the most stable informativity is characteristic for the direction of the conductivity zones (feature 10).

The geochemical features (codes numbers 13, 14 and 15) have different individual represenativity. The probability *a posteriori* for classification is the highest for the contents of lead, zinc and copper. The contents of potassium and molybdenum show an equal low informativity.

The lithologic-stratigraphic features (21-36) substancially differ in informativity. However, the introduction of marginal effects with the precodification ought to be taken into account. Inspite of the expressed unstability of the distribution of the probability *a posteriori* values, the Oligocene rhyodacites and dacites, the silicate-carbonate formation and the upper granitogneise formation are distinguished with an increased informativity. The lowest informativity is characteristic for the latite sheets and dykes, the Priabonian breccia-conglomerates, the aplitoid granites (Upper Cretaceous) and marbles (Proterozoic). The remaining lithostratigraphic formations have an intermediate position.

The generalized analysis of the obtained probability-statistical characteristics of the features, applied to the Luki ore field, and the estimation of their informativity show a comparatively low individual representativity of these features, so that the definitive formation of a feature space is dificult. However, the relative independence of the features allows the combinations in different variants for establishing the classification rules.

Prognostic-metallogenic regional division of the Luki ore field by a complex of features

The metallogenic prognostication of the Luki ore field was carried out by a composition of different variant schemes mainly on the basis of the features, for which there was an information of comparatively uniform density for the whole territory. The electrometric features, obtained only a part of the territory, were used in separate constructions for precising the prognostic classification in some sectors.

The prognostic scheme of distribution of the probabilioties for belonging to the ore class, composed by three geochemical features (code numbers 10, 11 and 12) and three geomorphologic features (code numbers 15, 16 and 17), is characterized by strongly expressed diversitry. The sectors in the limits of the well-known deposits Djurkovo, Drujba and Chetroka are distinguished with the highest commercial significance. Another commercial zone is outlined in the southwestern part of the territory under investigation. It embraces a large area, in which three sectors with a probability of belonging to the ore class over 75% are localized. The well-known small deposit Studenets is situated in this zone. In the northwestern part of the studied territory a sector with increased commercial significance is outlined too (area of the ore showing Pashaliitsa). One more commercially significant sector is localized near the village Yugovo in the north part, wich is defined on a whole as a subcommercial area.

The scheme of distribution of the probilities for beloning to the ore class, composed by the aerogeophysical features (1, 2, 3, 4 and 5), is considerably less expressed. Accordingly to this scheme, the part of the Luki ore field south of the town of Luki is mainly outlined as area with indefined commercial significance. Commercial zones are outlined in the areas of the deposits Drujba and Djurkovo. The largest commercial zone is distinguished in the western part of the studied territory (in the areas of the ore deposits Chetroka and Urvata and the ore manifestation Kanar Dere). On the same scheme, in the northwest part of the territory, there is an outlined sector of higher commercial significance. Against a background of a large subcommercial zone north of the town Luki, a commercial sector is localized near the village Yugovo.

By different combinations of lithologic-stratigraphic features two prognostic schemes were obtained. On the first one, by the features with the code numbers 19, 20, 21, 23, 24, 26, 31 and 33, the territory is divided into two zones — commercial southeastern one and subcommercial northwestern one. On the second scheme (by the features 18, 22, 25, 27, 28, 29, 30, 32), only the zone between the villages Dryanovo and Manastir with a direction southwest — northeast is more or less differentiated. There, several sectors with a complex configuration are outlined with a high commercial significance. However, the general analysis shows an undefinite representativity of the schemes obtained by lithologic-stratigraphic features. That is connected with the specificity of the spatial distribution of these features, manifested in deforming marginal effects. By unfavourable combination of these features with numerical ones they may exert negative influence on the complex infofmativity of the prognostication.

The prognostic scheme, composed by geochemical (10, 11, 12), geomorphological (15, 16, 17) and lithologic-stratigraphic (19, 26, 31, 33) features, contains the same main elements as the scheme, composed only by the complex of geochemical and geomorphological features, but there is an additional background effect from the lithologic-stratigraphic features.

On the basis of a complex classification rule, composed by use of aerogammaspectrometric (code numbers 2, 3, 4, 5), geochemical (10, 11, 12) and geomorphological (15, 16, 17) features one more prognostic scheme is obtained. By this scheme, the central eastern areas of the territory are the most promising in ore-bearing respect. Well outlined commercial zones appear in the southwest and the northwewst parts as well.

The prognostic scheme by the full complex of features — aerogeofhysical (1, 2, 3, 4, 5), geochemical (10, 11, 12), geomorphological (15, 16, 17) and lithologic-stratigraphic (18-33)- is shown on Fig. 2. The reliability of the prognostic metallogenic regional division is estimate at 91-95%. The commercial area is outlined in this scheme as a regional zone with northeast direction, situated between the villages Dryanovo and Manastir. Six sectors are distinguished there as the most promising in ore-bearing respect. The spatial distribution of these sectors defines the mentioned zonal set. The main well-known ore deposits and ore manifestations fall on these sectors. The northeastern part of the studied territory is classified as subcommercial one. Only two sectors stand out, against this background — sectors near the villages Yugovo and Pashaliitsa.

In spite of the small number (33) of the used features and of their comparatively low informativity, the stable and geologically well-grounded space distribution of the sectors with large commercial significance, confirms the capacity of the complex of computer means and the algorithms for the analysis and the classification in the prognostic metallogenic regional division.

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