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TYPES OF GEOCHEMICAL ASSOCIATIONS IN THE BOROV DOL – SHOPUR AREA

INTERPRETATION OF THE DATA OF PRIMARY AND SECONDARY HALOES

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Abstract: The paper presents statistical calculations of the results of geochemical investigations of the primary and secondary dispersion haloes carried out on an area of some 40 km^2 in the Borov Dol – Shopur region (the Buchim ore district). Sampling was carried out on 500 x 200 m spacing by research workers from IMGRE – Moscow and the Buchim mine. The results obtained were first interpreted by the Geoscan method and the cluster analysis method (discussed in this paper), as well as the factor analysis or the Kaiser method.

Based on complex statistical calculations, correlation dependencies and classification of individual elements according to variograms, factor distributions and dendograms, the types and geochemical associations distinguished are grouped as follows:

I. Based on cluster analysis the following were distinguished:
  a) according to primary dispersion haloes
    (Pb, Zn, Sn), [(Ga, Ag) Yb], (Ni, Co, Cr), [(Ti, Zr, Y) Nb];
  b) according to secondary dispersion haloes
    [(Ni, Cr, Co) Mn]; [(Ti, V) Sc]; [(Yb, Nb) Ag]; (W, Ga); (Cu, Y) Mo; (Pb, Zn, Sn);

II. Based on data of factor analysis the following were distinguished:
  a) according to primary haloes
    [(Zr, Y, B, Ti) Nb]; (Sr); (Pb, Zn, Sn); (Ga, Ag, Yb); (B, Mn, Ni) Co, Cr;
  b) according to secondary haloes:
    [(Ni, Cr, Co) Mn]; [(Yb, W, Nb) Ag, Ga)]; [(Ti, V) Sc)]; (Pb, Zn, Sn); (Cu, Y, Mo).

Particular mention should be made of the (Pb, Zn, Sn) geochemical association which is clearly defined in both groups as well as (Cu, Y, Mo) as a characteristic association for the secondary dispersion haloes.

Key words: Borov Dol – Shopur area; geochemical associations; interpretation; statistical analysis; primary and secondary haloes

INTRODUCTION

The investigation of the primary and secondary geochemical haloes for different copper mineralization styles aims at determination of characteristics of spatial behaviour of elements. For that purpose data obtained from various types of hydrothermally altered rocks are used. Statistical analysis of distribution of each element is used when analyzing information obtained. Analysis of affiliation in behaviour of elements for the determination of geochemical association and graphic presentation of spatial distribution of individual elements and their associations are used.

The Borov Dol district was investigated using 273 samples for the primary geochemical haloes and 189 samples for the secondary haloes (beneath the humus material) studied by 20 cross–sections for each. The sample contents were determined more quantitatively by spectral analysis for 24 elements performed in IMGRE, Moscow. Due to lack of information about some elements whose contents are not measured by more than 20% of the samples, As, W and P of the primary and As and P of the secondary haloes were excluded. Data of both haloes were analyzed in detail since the different types and the specific information that they have could be lost if analyzed as a whole. It will be shown that the relations between elements determined based on secondary haloes are rather poor with possibility to obscure the effects of primary haloes associations.

Geological and metallogenetic features of the area under investigation are analysed in detail by Serafimovski (1993), Tudžarov and Serafimovski (1994), Čifliganec et al. (1994), Serafimovski and Chifliganec (1996), Stefanova (1997), and Pockov (1997). Some geochemical data and methods can be found in the papers of Jankovich et al. (1994) and Popov et al. (1996).

Monomeasure statistical analysis

Investigation of the character of distribution of individual elements is an essential part of the analysis of geochemical haloes. Parameters obtained makes it possible to determine the properties of linear functions, plausibility of values calculated and errors allowed. The parameters describing the distribution of chemical elements for primary and secondary haloes are shown in Tables 1 and 2.

Table 1

Monomeasure statistical analysis of element contents for primary geochemical haloes

	Sr	**Ba**	**Ti**	**Mn**	**Cr**	**V**	**Ni**
Mean	494.4139	789.4322	2622.418	634.4689	164.7711	212.2125	76.12637
Std. error	36.49226	54.68585	71.80678	44.5358	26.63452	6.651468	15.76932
Median	400	500	3000	400	20	200	10
Mode	1000	1500	3000	300	10	300	10
Std. dev.	602.9511	903.5586	1186.443	735.8522	440.0745	109.9003	260.5519
Variance	363550	816418.2	1407646	541478.5	193665.6	12078.07	67887.31
Kurtosis	26.54945	39.37668	– 0.11965	14.50684	16.95335	0.002001	72.43833
Skewness	4.310787	4.528251	– 0.58424	3.388516	3.964252	0.1719	7.752801
Range	4985	9985	4980	4970	2998.5	597	2999
Minimum	15	15	20	30	1.5	3	1
Maximum	5000	10000	5000	5000	3000	600	3000

	Co	**Cu**	**Ag**	**Zn**	**Pb**	**Sn**	**Mo**
Mean	13.99359	441.6907	0.640256	59.54212	118.6355	3.815018	5.659524
Std. error	1.083991	105.0474	0.382156	6.109157	37.1499	0.161964	1.260793
Median	10	30	0.05	40	40	4	3
Mode	8	30	0.025	30	10	4	3
Std. dev.	17.91048	1735.668	6.314246	100.9398	613.817	2.676084	20.83172
Variance	320.7851	3012542	39.8697	10188.85	376771.3	7.161428	433.9607
Kurtosis	46.75449	23.34388	229.1688	154.631	249.427	34.70523	151.5206
Skewness	5.62891	4.896743	14.80319	11.2469	15.48074	4.110448	11.48582
Range	199.75	9999.95	99.975	1495	9999.5	29.5	299.75
Minimum	0.25	0.05	0.025	5	0.5	0.5	0.25
Maximum	200	10000	100	1500	10000	30	300

	Ga	**Sc**	**Y**	**Yb**	**Zr**	**Nb**	**B**
Mean	30.60623	5.749084	7.529304	3.324176	57.95421	4.869963	16.31685
Std. error	6.225591	0.269558	0.35977	0.839054	2.433556	0.179165	1.190673
Median	20	4	6	1	50	4	10
Mode	30	4	10	1	100	3	10
Std. dev.	102.8636	4.453833	5.94437	13.86344	40.20895	2.960297	19.67314
Variance	10580.93	19.83663	35.33554	192.1951	1616.76	8.763359	387.0325
Kurtosis	85.90545	9.300508	26.11171	60.07398	1.112304	1.880849	10.57147
Skewness	9.294901	2.43737	3.836767	7.226712	0.866617	1.1826	3.281909
Range	999.5	29.5	59.5	149.5	199.5	18.5	97.5
Minimum	0.5	0.5	0.5	0.5	0.5	1.5	2.5
Maximum	1000	30	60	150	200	20	100

Table 2

Monomeasure statistical analysis of element contents for secondary geochemical haloes

	Sr	Ba	Ti	Mn	Cr	V	Ni
Mean	274.6032	662.6984	3139.153	786.5608	134.8677	294.2857	98.44444
Std. error	20.31099	42.98228	69.71466	27.11911	13.42311	8.239814	10.84216
Median	200	500	3000	800	80	300	50
Mode	300	300	3000	800	100	300	50
Std. dev.	279.23	590.9086	958.4181	372.8261	184.5372	113.2787	149.055
Variance	77969.39	349173	918565.2	138999.3	34053.98	12832.07	22217.4
Kurtosis	7.281724	9.451721	0.74029	6.298461	10.47188	− 0.26855	16.1933
Skewness	2.068228	2.371234	− 0.53128	1.483732	3.085148	− 0.02759	3.641793
Range	1985	3900	4800	2980	997	580	995
Minimum	15	100	200	20	3	20	5
Maximum	2000	4000	5000	3000	1000	600	1000

	Co	Cu	Ag	Zn	Pb	Sn	Mo	W
Mean	17.85714	50.61217	1.476852	168.3545	130.0979	5.339153	1.151587	4.214286
Std. error	0.698117	7.524182	0.679219	13.05817	1.387044	0.228804	0.175321	0.245846
Median	15	30	0.06	100	60	4	0.8	3
Mode	10	30	0.05	30	30	3	1	3
Std. dev.	9.597524	103.4404	9.337723	179.5202	190.687	3.145539	2.410261	3.37983
Variance	92.11246	10699.92	87.19307	32227.5	36361.52	9.894416	5.809359	11.42325
Kurtosis	1.012952	75.09289	73.97703	5.034111	18.64663	0.986939	111.738	3.391894
Skewness	1.129943	8.392682	8.126714	1.996731	3.738253	1.069263	9.801321	1.956166
Range	47	999.95	99.975	996	1499.5	14.5	29.75	13.5
Minimum	3	0.05	0.025	4	0.5	0.5	0.25	1.5
Maximum	50	1000	100	1000	1500	15	30	15

	Ga	Sc	Y	Yb	Zr	Nb	B
Mean	31.81217	8.298942	12.36772	16.6455	53.7619	7.460317	16.19048
Std. error	10.39871	0.415741	1.250241	2.484924	3.410605	0.677366	0.99858
Median	10	8	10	1	50	5	15
Mode	10	10	10	1	50	5	15
Std. dev.	142.9587	5.715488	17.18798	34.16206	46.88807	9.312241	13.7282
Variance	20437.18	32.66681	295.4266	1167.047	2198.491	86.71783	188.4635
Kurtosis	43.16495	15.85865	28.90113	5.075494	4.735012	55.62967	50.48466
Skewness	6.67672	2.945725	4.882018	2.352106	1.69942	6.416702	5.96316
Range	999.5	49.5	149	149.5	297	98.5	145
Minimum	0.5	0.5	1	0.5	3	1.5	5
Maximum	1000	50	150	150	300	100	150

A strong asymmetric distribution with prevalence of low contents is a characteristic of chemical analysis as a whole. An indicator for this is the differences between medium arithmetic, median and modal values along with high values of asymmetry. Neither element of both haloes shows distribution close to Gauss's, but logarithmic function normalizes to some extent the distribution of some of them. In conclusion, it can be said that due to high dispersion of data and their deviation from the normal distribution, the values calculated by median arithmetic manner as well as some standard geochemical element indicators and relationships can change largely. Lognormal distribution or geochemical indicators can be used when possible, independent of the distribution mode.

Analysis of geochemical associations

Element classification by analogy in spatial behaviour necessary for modelling of genetic processes results in development of deposits and the occurrence of zoning. For that purpose data for contents of elements are analyzed by cluster and factor analyses. Correlation coefficient is used as measure for analogy, which avoids lack of possible measure units and ratio of individual elements. Correlations between all couples of elements for both variations of primary and secondary haloes are shown by matrix in Tables 3 and 4. Analysis of individual correlations is often necessary for confirmation of classification results.

Cluster analysis based on averaging of correlations between elements and groups was used in elements classification.

In this manner correlation coefficient between given element and classification, shown to the right in Figs. 1 and 2, is the mean value of correlations between that element and elements of the group that it is related with. Grouping of elements is carried out beginning with couples, having the highest correlation and goes further on to complete relation into one group.

Reading the strength and direction of the relation is an important thing in analysis, but it does not imply any unified criterion that can show the value at the beginning of correlation, after which classification loses the idea. Bearing in mind the large changeability of data, the value of correlation of the order of 0.25 to 0.5 can also be interpreted as the presence of at least weak relationship.

Element groups of similar spatial changeability interpreted as geochemical associations that can be determined based on cluster analysis are as follows:

for primary geochemical haloes
[Pb, Zn, Sn]
([Ga, Ag] Yb)
[Ni, Co, Cr]
([Ti, Zr, Y] Nb)

for secondary geochemical haloes
([Ni, Cr, Co])
([Ti, V] Sc)
([Yb, Nb] Ag)
(W, Ga)
(Cu, Y) Mo
(Pb, Zn) Sn

Quadratic nets are used when representing th geochemical associations according to the strength o relationships between elements and influence on adequate factor showing the elements of greatest intensit participating in the association as well as ordinary net limiting the general tendencies towards classificatio Unification is graphically shown in Figs. 1 and 2. I fact, when dealing with large massifs these analyse use similarities of possible pairs of variables. This requires the use of factor analysis in analyzing data. I this manner the position of axes of ellipsoid of anisotropic elements investigated is determined. The newl formed axes are read with different level of changeability since only part of them represent 90% of tota dispersion. The axes are interpreted as factors illustrating the similarity in element distribution caused b pertinent genetic processes. Each element has differen (per cent) of influence on the new factors develope most in adequate basis.

Line functions are used in describing factor influences. Geometry of function can be presented a variable projection for each element at the top o each factor axis.

The survey for element classification and thei influence on factor axes can be seen from Figs. and 4. Projection of elements in coordinate syste formed by the first and second (Figs 3a and 4a) an the second and the third factor axes (Fig. 3b an 4b) is plotted. The graphs show factor dismembering by the method of major components (MMC using factors that are equal to the number of variables. Rotation of factor axes after the Kaise method – the Varimax procedure was used for further dismembering of individual associations providing complete reflection and general dispersion Here axes rotate in such a manner that extreme values of dispersion for each element are read. In thi manner each element of each factor present tend towards zero or one which leads to greater contras

Table 3

Correlation between elements of primary geochemical haloes

	Sr	Ba	Ti	Mn	Cr	V	Ni	Co	Cu	Ag	Zn	Pb	Sn	Mo	Ga	Sc	Y	Yb	Zr	Nb	B
Sr	1.0000																				
Ba	0.1473	1.0000																			
Ti	–0.1240	0.2357	1.0000																		
Mn	0.0161	–0.0932	–0.2471	1.0000																	
Cr	–0.2049	–0.2367	–0.3390	0.1198	1.0000																
V	–0.1162	0.3415	0.4992	–0.2031	–0.1917	1.0000															
Ni	–0.1604	–0.1848	–0.3020	0.1358	0.5743	–0.2488	1.0000														
Co	–0.2150	–0.1711	–0.2410	0.2432	0.6382	–0.1348	0.7033	1.0000													
Cu	–0.0493	0.2432	–0.0789	0.0364	–0.0785	–0.0799	–0.0533	0.1023	1.0000												
Ag	–0.0038	0.0755	0.0223	–0.0071	0.0170	–0.1431	–0.0209	0.0683	0.0220	1.0000											
Zn	–0.1273	0.0008	0.1041	–0.0025	–0.0134	0.0263	0.0085	0.0450	0.0587	0.0324	1.0000										
Pb	–0.0400	0.0630	–0.0237	–0.0434	–0.0461	–0.0067	–0.0329	–0.0506	0.0567	0.0182	0.8606	1.0000									
Sn	–0.1419	0.1121	0.3227	–0.2222	–0.2779	0.1424	–0.1995	–0.1960	0.1727	–0.0304	0.5500	0.6129	1.0000								
Mo	–0.0382	0.0694	0.0671	–0.1100	–0.0689	0.0047	–0.0566	–0.0766	0.0531	0.0025	–0.0206	0.0297	0.2011	1.0000							
Ga	0.0151	0.1317	0.0971	–0.0290	–0.0372	–0.0513	–0.0593	0.0239	–0.0156	0.7129	0.0255	0.0029	0.0068	0.0026	1.0000						
Sc	–0.2732	–0.0652	0.1397	0.0608	0.2921	0.3059	0.0491	0.2361	–0.0598	0.0349	0.0213	–0.0510	–0.1019	–0.0209	0.0223	1.0000					
Y	–0.1561	0.0631	0.3557	–0.0285	–0.1288	0.0236	–0.1227	–0.0950	0.0360	–0.0776	0.0345	–0.0176	0.2444	0.0098	–0.0860	0.1172	1.0000				
Yb	–0.0154	0.0402	0.0963	0.0425	–0.0388	–0.0326	–0.0402	0.0118	–0.0386	0.2527	0.0349	0.0004	0.0170	–0.0223	0.4723	–0.0374	–0.0911	1.0000			
Zr	–0.1516	0.1056	0.6322	–0.1688	–0.1315	0.2655	–0.1514	–0.1243	–0.1350	–0.0974	0.0562	–0.0414	0.2932	0.0076	–0.0800	0.1438	0.5460	–0.2030	1.0000		
Nb	–0.0098	0.2047	0.4236	–0.2162	–0.2111	0.1820	–0.1321	–0.1766	0.0246	0.0092	0.0522	0.0191	0.3659	0.1388	0.0494	–0.1167	0.1805	0.2106	0.3489	1.0000	
B	–0.1905	–0.1695	0.1770	0.2385	0.1441	–0.1752	0.3056	0.1956	–0.0540	–0.0273	0.1105	–0.0547	–.00419	–0.0411	–0.0471	0.2067	0.2315	–0.0472	0.2342	0.0044	1.0000

Table 4

Correlation between elements of secondary geochemical haloes

	Sr	Ba	Ti	Mn	Cr	V	Ni	Co	Cu	Ag	Zn	Pb	Sn	Mo	W	Ga	Sc	Y	Yb	Zr	Nb	B
Sr	1.0000																					
Ba	0.2405	1.0000																				
Ti	0.1898	–0.0571	1.0000																			
Mn	–0.0116	–0.1048	0.1692	1.0000																		
Cr	–0.2437	–0.1329	–0.2158	0.2007	1.0000																	
V	0.0705	0.0669	0.4524	0.0446	–0.4073	1.0000																
Ni	–0.2075	–0.2653	–0.2092	0.3308	0.8304	–0.3554	1.0000															
Co	–0.3969	–0.0777	–0.0414	0.3149	0.5933	–0.1725	0.5951	1.0000														
Cu	–0.0885	–0.0398	0.1772	0.0435	0.1995	0.0323	0.2808	0.1522	1.0000													
Ag	–0.1080	0.1726	–0.2583	–0.0498	0.0305	–0.0591	–0.0486	0.2462	–0.0131	1.0000												
Zn	–0.0694	–0.0631	0.1044	0.0817	0.0649	0.1409	0.0858	–0.0300	0.0147	–0.0976	1.0000											
Pb	0.0621	0.0523	0.0535	0.1102	–0.0850	0.1576	–0.0845	–0.1624	0.0125	–0.0925	0.3304	1.0000										
Sn	0.0254	–0.0494	0.0655	–0.1226	–0.1638	0.1289	0.0855	–0.2660	0.0937	–0.2184	0.2164	0.1452	1.0000									
Mo	–0.0062	–0.0013	0.0545	–0.0887	0.1145	0.0109	0.0956	0.0478	0.2682	0.0303	0.0974	0.0711	0.0198	1.0000								
W	0.0325	0.3810	–0.0412	–0.0418	–0.1104	0.0402	–0.1396	–0.0162	0.0347	0.2802	–0.0570	0.0921	0.0542	0.1885	1.0000							
Ga	0.1581	0.0121	–0.0934	0.0814	–0.0811	0.0782	–0.0532	–0.1121	–0.0264	–0.0323	–0.0013	0.2098	0.1555	0.0193	0.4139	1.0000						
Sc	–0.2549	0.0251	0.3693	0.2507	0.1408	0.2288	0.1109	- 0.3560	0.1075	0.0545	0.0528	–0.0373	–0.1730	0.2472	0.2253	0.0091	1.0000					
Y	–0.0402	0.0949	0.2162	0.0960	0.0742	0.1764	0.1701	0.1434	0.4263	–0.0932	0.0019	0.1356	0.1105	0.0599	0.0204	–0.0965	0.0752	1.0000				
Yb	0.0376	0.0142	0.0554	0.0541	–0.0182	0.1277	–0.0539	0.0536	0.1646	0.2024	0.1156	0.1064	0.1152	0.0819	0.3471	0.3195	0.1954	–0.1441	1.0000			
Zr	–0.0294	0.0748	0.3689	0.1514	–0.0891	–0.0015	–0.0867	–0.1527	–0.0898	–0.1447	0.0306	0.0329	0.1228	–0.0519	–0.1410	–0.1333	–0.0442	–0.0030	–0.4450	1.0000		
Nb	–0.1405	–0.0399	0.0447	0.0073	–0.0918	0.0728	–0.0845	0.0364	–0.0060	0.3459	0.0253	0.0207	0.1468	0.0131	0.2011	0.0766	0.0072	–0.0581	0.4478	–0.0881	1.0000	
B	0.2388	–0.2062	–0.3597	–0.0267	0.0217	–0.3460	0.0782	0.0818	–0.0302	–0.0140	–0.1119	–0.0681	–0.0886	–0.0548	–0.1038	–0.0191	–0.1019	–0.0535	–0.0417	–0.1733	–0.0854	1.0000

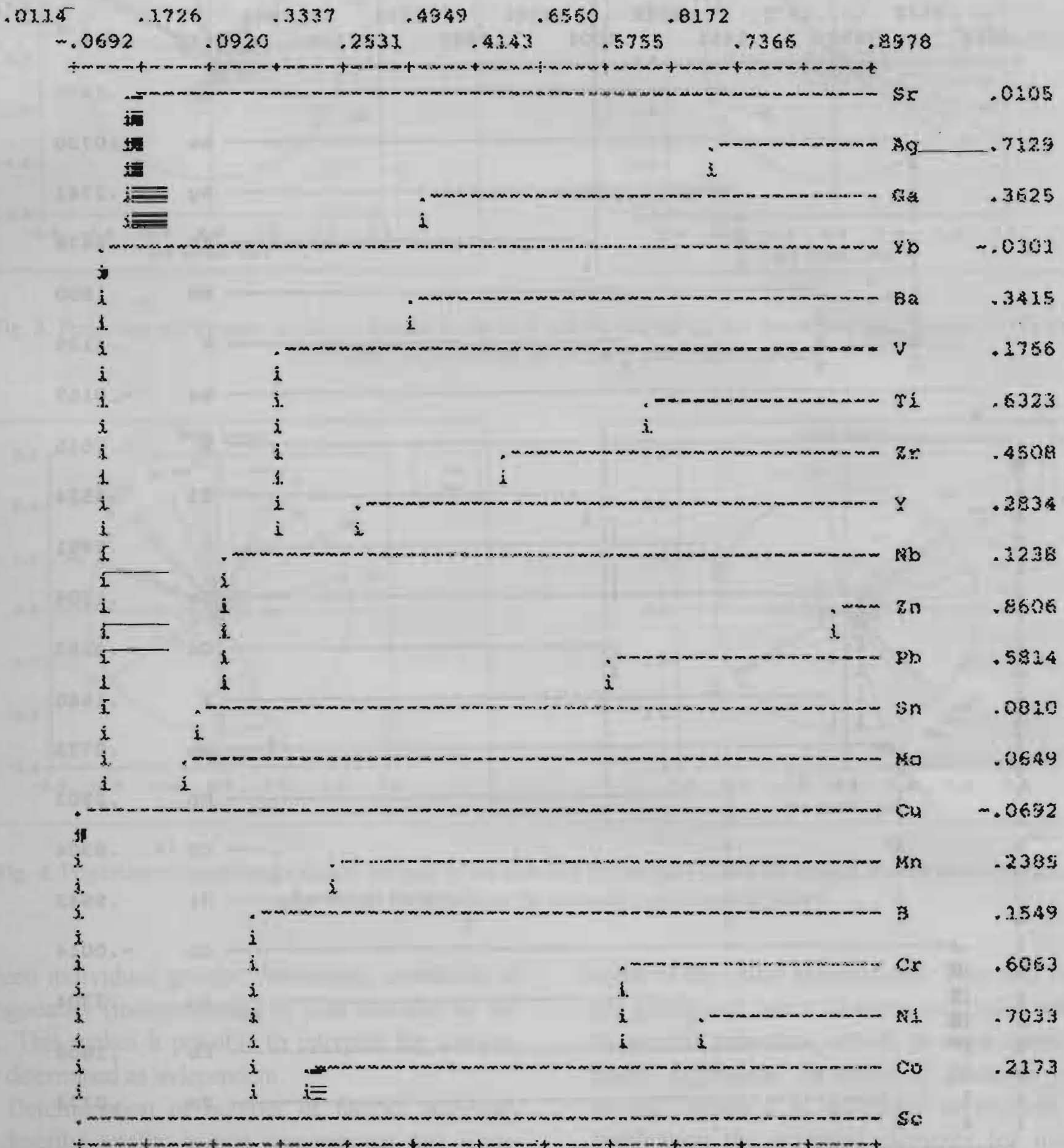


Fig. 1. Dendogram representing classification of elements for primary geochemical haloes based on cluster analysis. Values of correlation coefficient are written along abscissa

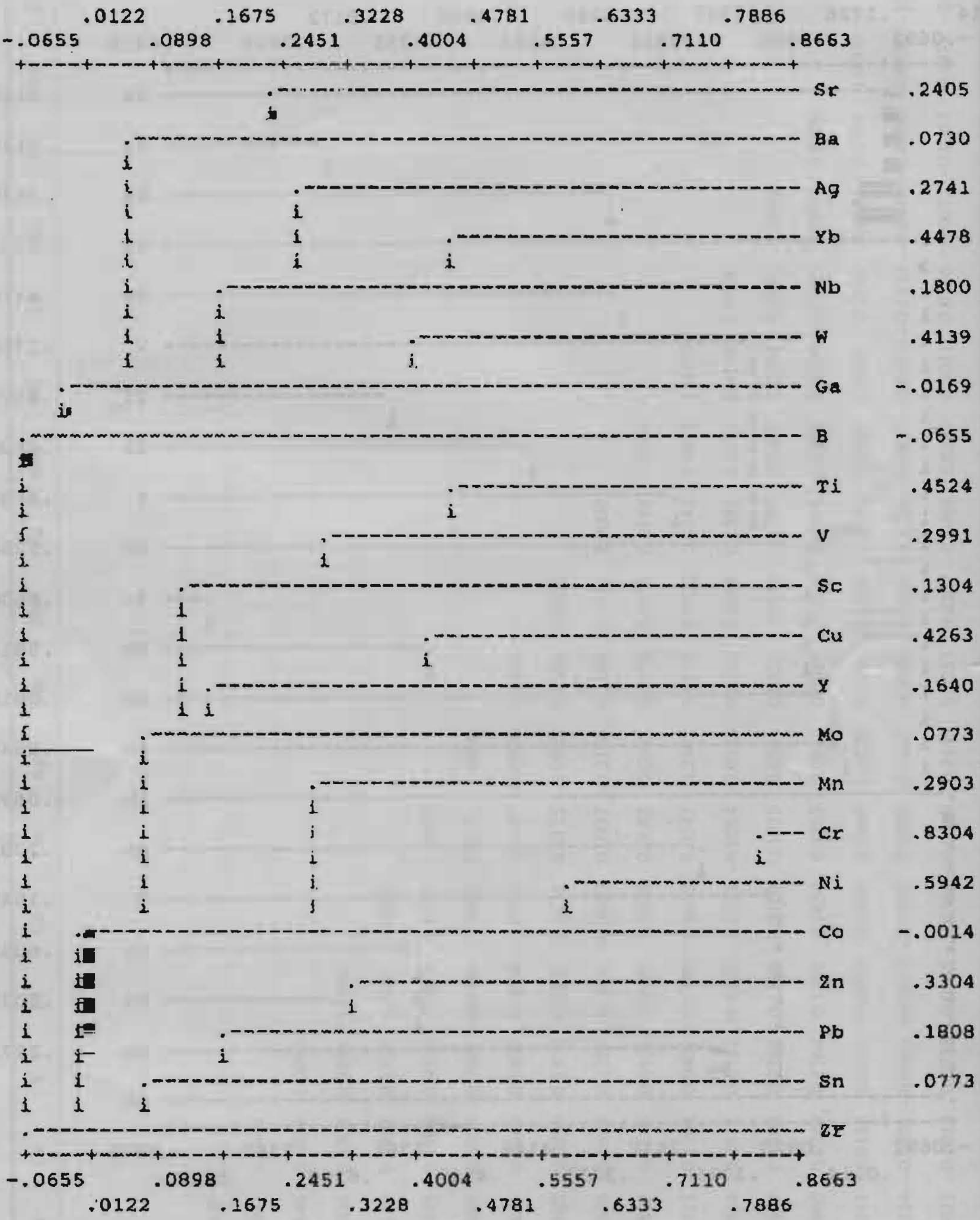
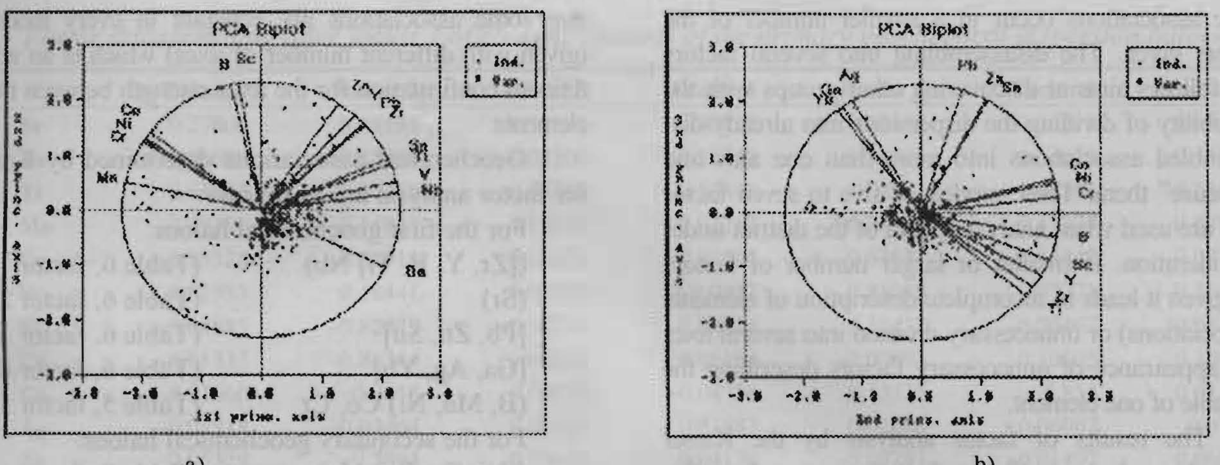
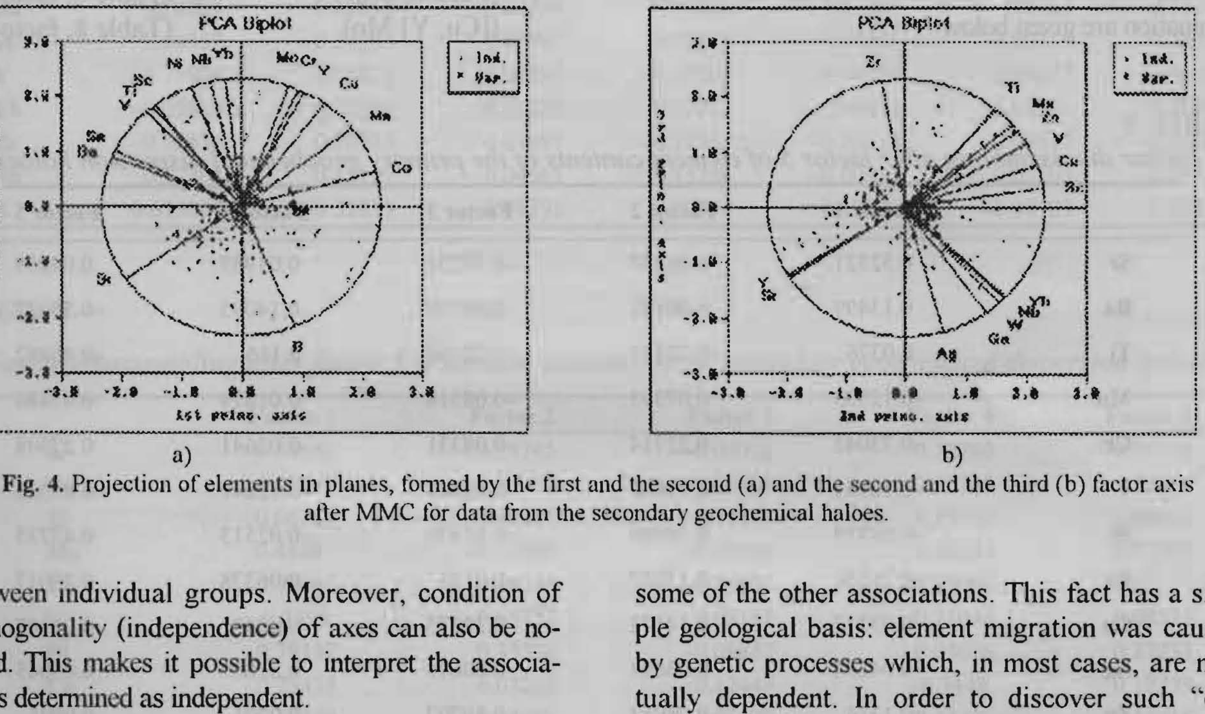


Fig. 2. Dendogram representing classification of elements for secondary geochemical haloes based on cluster anal
Values of correlation coefficient are written along abscissa.



a) b)

Fig. 3. Projection of elements in planes, formed by the first and the second (a) and the second and the third (b) factor axis after MMC for data from the primary geochemical haloes



a) b)

Fig. 4. Projection of elements in planes, formed by the first and the second (a) and the second and the third (b) factor axis after MMC for data from the secondary geochemical haloes.

between individual groups. Moreover, condition of orthogonality (independence) of axes can also be noticed. This makes it possible to interpret the associations determined as independent.

Determination of number of factors necessary that describe totality is non conventional and somewhat personal task. Generally the number is given first requiring a primary information such as the number of associations determined by cluster analysis. For this purpose two criteria were studied when analyzing the data. The major component method used factors of values greater than one, whereas Varimax rotation the number of factors close to geochemical associations determined based on cluster analysis. Both methods work well and the results obtained are very close.

In some cases the association given can remain obscured and stay unread by the factor basis due to right or opposite proportional dependence with some of the other associations. This fact has a simple geological basis: element migration was caused by genetic processes which, in most cases, are mutually dependent. In order to discover such "obscured" group it is necessary to exclude from investigation the essential elements (of most factor percentage) from some already distinguished association. Such is the case with factor analysis of data of secondary haloes where the Ti–V–Sc association appears after exclusion the Pb–Zn–Sn group. Sr (with the primary and the secondary haloes) exhibits strong influence than Ba (with the secondary haloes). Such behaviour is independent and is not associated with other elements.

When dealing with a large number of variable factor analysis, it is often imposed that factor analysis be carried out several times by different number of factor axes. Eventually, the model described in greatest contrast is chosen for pertinent association. Thus, some associations occur in a smaller number of the factors given. The disassembling into several factors that follows aims at discovering other groups with the possibility of dividing the dispersions into already disassembled associations into more than one axis and "obscure" them. Thus, models of five to seven factor axes are used when analyzing data of the district under consideration. If smaller or larger number of factors are given it leads to incomplete description of elements (associations) or unnecessary division into several axes and appearance of unnecessary factors describing the variable of one element.

The results of factor analysis by the Kaiser method are shown in Tables 5–9 illustrating the influence (per cent) of each factor element given for adequate model. Associations and models distinguished and selected for map compilation for the surface dissemination are given below.

The tables illustrating the factor models show that some associations are constant in every model (given with different number of axes) which is an additional confirmation for the axes strength between the elements.

Geochemical associations determined by Kaiser factor analysis are as follows:

For the first geochemical haloes:

([Zr, Y, B, Ti] Nb)	(Table 6, factor 1)
(Sr)	(Table 6, factor 2)
[Pb, Zn, Sn]	(Table 6, factor 3)
[Ga, Ag, Yb]	(Table 6, factor 4)
(B, Mn, Ni) Co, Cr	(Table 5, factor 5)

For the secondary geochemical haloes:

([Ni, Cr, Co] Mn)	(Table 8, factor 1)
([Yb, W, Nb,] Ag, Ga)	(Table 7, factor 3)
([Ti, V,] Sc)	(Table 9, factor 3)
[Pb, Zn, Sn]	(Table 8, factor 4)
([Cu, Y] Mo)	(Table 8, factor 5)

Table 5

Factor disassembling after factor 5 of element contents of the primary geochemical dispersion haloes

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Sr	0.52321	0.26537	–0.13233	0.01939	0.04059
Ba	0.13499	0.00182	0.06359	0.14095	–0.55027
Ti	0.0376	–0.72583	0.02163	0.116	–0.46882
Mn	–0.12903	0.07393	–0.08518	0.01879	0.45486
Cr	–0.73045	0.22714	–0.08331	–0.02641	0.27348
V	–0.18951	–0.15822	–0.02866	–0.12241	–0.83325
Ni	–0.61919	0.14584	–0.01976	–0.02513	0.43735
Co	–0.76556	0.17037	–0.0156	0.06378	0.29017
Cu	0.03317	0.14172	0.22275	0.0045	–0.06387
Ag	–0.04234	0.03694	0.00615	0.81867	0.03045
Zn	–0.1314	–0.08054	0.89707	0.0301	0.0405
Pb	–0.01367	0.06491	0.93557	–0.00936	–0.00214
Sn	0.15259	–0.34552	0.7671	–0.00376	–0.18651
Mo	0.08202	–0.04395	0.11686	0.00407	–0.12887
Ga	–0.01125	0.0104	–0.00543	0.90486	–0.06034
Sc	–0.64806	–0.16014	–0.12246	–0.01142	–0.27079
Y	0.04046	–0.72801	0.01446	–0.11034	0.08249
Yb	0.04617	0.02307	0.01664	0.68018	–0.0146
Zr	–0.03695	–0.82354	–0.01545	–0.14539	–0.18478
Nb	0.19019	–0.46794	0.12619	0.17751	–0.24362
B	–0.29783	–0.51992	–0.03882	–0.00819	0.47958

Table 6

Factor disassembling after factor 7 of element contents of the primary geochemical dispersion haloes

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7
Sr	–0.27806	0.43191	–0.15999	0.00793	0.27455	0.00718	0.01537
Ba	–0.01098	0.25568	–0.02106	0.11749	–0.31046	0.64029	–0.16149
Ti	0.61513	0.27238	0.05307	0.13849	–0.4574	–0.01994	–0.28453
Mn	0.09391	–0.14839	–0.04535	0.02213	0.23296	0.17277	0.64996
Cr	–0.15525	–0.80916	–0.06873	–0.02595	–0.03831	–0.14442	0.08202
V	0.02953	0.18441	0.01321	–0.0927	–0.85048	0.07771	–0.16639
Ni	–0.04885	–0.82077	–0.04743	–0.04224	0.20432	–0.06467	–0.02229
Co	–0.05333	–0.86344	–0.0335	0.05124	–0.00093	0.10605	0.10904
Cu	–0.01666	–0.0618	0.08718	–0.04734	0.13335	0.855	0.01143
Ag	–0.02918	–0.03464	0.01123	0.81887	0.02586	0.06087	0.0716
Zn	0.05329	–0.5894	0.93432	0.04176	–0.03291	–0.01492	0.06653
Pb	–0.1057	0.02715	0.95212	–0.00484	0.01618	0.01855	0.00633
Sn	0.26452	0.1648	0.72556	–0.01445	–0.01206	0.14372	–0.38185
Mo	–0.00501	–0.06665	0.01458	–0.02886	0.10195	0.14177	–0.54607
Ga	–0.0303	0.02555	0.00299	0.90816	–0.03945	0.0333	0.01142
Sc	0.16537	–0.34383	–0.02187	0.02895	–0.64559	–0.06213	0.28793
Y	0.75909	0.08879	0.02597	–0.10564	0.01054	0.09837	0.00698
Yb	–0.05919	0.02346	0.01255	0.67913	0.0453	–0.05526	–0.10599
Zr	0.76536	0.10985	0.01997	–0.12563	–0.26613	–0.09517	–0.20606
Nb	0.37204	0.13157	0.04961	0.15756	–0.00831	0.07703	–0.63327
B	0.623090	–0.32953	0.01391	0.00394	0.17429	–0.10709	0.27899

Table 7

Factor disassembling after factor 5 of element contents of the secondary geochemical dispersion haloes

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Sr	–0.56682	0.33745	–0.04012	0.12786	0.16948
Ba	–0.47247	–0.10092	0.12564	–0.36249	0.3893
Ti	0.06371	–0.82197	–0.18393	0.15305	0.09266
Mn	0.4444	–0.17537	–0.02059	0.10873	0.07503
Cr	0.75087	0.34243	–0.03826	–0.09966	0.24311
V	–0.2399	–0.65757	0.08112	0.21044	0.08323
Ni	0.79137	0.35376	–0.08837	0.03036	0.27233
Co	0.75433	0.03242	0.12449	–0.3448	0.17339
Cu	0.22888	–0.03928	0.01679	0.13422	0.63916
Ag	0.03959	0.01179	0.51726	–0.50428	–0.0794
Zn	0.19053	–0.1357	0.06237	0.56722	–0.01712
Pb	–0.10087	–0.06513	0.11862	0.54754	0.18007
Sn	–0.16098	–0.04716	0.04545	0.6203	0.02724
Mo	0.06286	–0.04296	0.15611	0.03767	0.46669
W	–0.25394	–0.08448	0.63319	–0.14973	0.35758
Ga	–0.17155	0.1209	0.48065	0.33029	0.12031
Sc	0.35476	–0.49085	0.22232	–0.20268	0.26252
Y	0.07526	–0.15588	–0.21729	0.08957	0.6552
Yb	0.06898	–0.07298	0.79908	0.21401	0.01105
Zr	–0.07109	–0.35898	–0.51837	0.02093	–0.08619
Nb	0.09198	–0.19922	0.59946	0.05648	–0.2759
B	0.00326	0.60221	–0.03991	–0.01774	–0.07137

Table 8

Factor disassembling after factor 7 of element contents of the secondary geochemical dispersion haloes

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7
Sr	–0.32085	0.18238	–0.65792	0.0264	–0.04489	0.13047	0.17277
Ba	–0.16197	0.03166	–0.07728	–0.05624	0.08421	–0.18778	0.80884
ti	–0.22034	–0.76953	0115525	0.10201	0.18583	–0.22332	–0.14572
Mn	0.49787	–0.49595	–0.23569	0.17196	–0.20648	0.01772	–0.01936
Cr	0.86119	0.17145	0.06772	0.0195	0.16023	–0.0439	–0.05151
V	–0.44557	–0.62061	0.02822	0.12671	0.12647	0.06961	0.00128
Ni	0.86587	0.12951	–0.0195	0.07796	0.21503	–0.01094	–0.18156
Co	0.77082	–0.1649	0.2053	–0.25009	0.0946	0.08562	0.00888
Cu	0.13727	–0.06097	0.02345	0.01778	0.79767	0.11359	–0.08455
Ag	0.10872	0.14602	0.47131	–0.29146	–0.11164	0.24457	0.44558
Zn	0.1049	–0.07567	0.13141	0.65579	0.00125	–0.01145	–0.10377
Pb	–0.02481	–0.08016	–0.16999	0.65568	0.02135	0.05464	0.15305
Sn	–0.29458	0.17199	0.1478	0.60018	0.22507	0.01983	–0.14421
Mo	0.06998	–0.02918	0.04691	0.04937	0.49228	0.12751	0.15472
W	–0.04807	–0.07152	0.05244	0.07935	0.09651	0.38512	0.71905
Ga	–0.01861	–0.05709	–0.28217	0.37237	–0.13205	0.49335	0.27011
Sc	0.27688	–0.68935	0.07461	–0.17475	0.12925	0.17972	0.13469
Y	0.06116	–0.15566	–0.11624	0.0491	0.69852	–0.1796	0.03538
Yb	–0.03761	–0.15615	0.21181	0.16369	0.03737	0.79925	0.09177
Zr	–0.05816	–0.18457	0.0427	0.21327	–0.16169	–0.71007	0.07519
Nb	–0.10495	–0.00783	0.61793	0.12531	–0.09084	0.42057	0.054
B	0.09937	0.3516	–0.41879	–0.25998	–0.06876	0.28562	–0.28489

Table 9

Factor disassembling after factor 5 of element contents of the secondary dispersion haloes with exclusion of Pb, Zn, Sn, P and As

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Sr	0.60098	0.12092	–0.35619	0.20525	0.06045
Ba	0.26692	–0.1295	0.02775	0.24372	–0.71677
Ti	0.06114	–0.1102	0.83368	0.15328	0.22741
Mn	–0.36229	0.09108	0.22661	0.07957	0.32547
Cr	–0.77969	–0.06736	–0.30538	0.23301	0.061
V	0.33513	0.15245	0.66056	0.11197	0.08064
Ni	–0.76664	–0.03186	–0.29788	0.29763	0.23006
Co	–0.83527	0.04047	–0.00859	0.11118	–0.06304
Cu	–0.18988	0.12351	0.08039	0.68075	0.06332
Ag	–0.27189	0.20586	–0.04172	–0.25372	–0.66319
Mo	–0.0768	0.14463	0.04758	0.46514	–0.16748
W	0.09192	0.47373	0.09026	0.20734	–0.5876
Ga	0.20846	0.60138	–0.05197	0.09355	0.05015
Sc	–0.3648	0.21244	0.50055	0.22542	–0.04942
Y	–0.6273	–0.1616	0.167	0.66483	0.00895
Yb	–0.05627	0.84003	0.14365	–0.03143	–0.07773
Zr	0.08579	–0.60818	0.32604	–0.07641	0.02296
Nb	–0.14906	0.46303	0.24614	–0.35583	–0.23661
B	0.01955	0.12922	–0.59751	–0.03002	0.25561

The right side shows factor models which according to the present author describe best the associations used when compiling the maps for surface dissemination.

The element associations obtained are close to those determined by cluster analysis. A significant advantage of the factor analysis is the possibility to calculate the percentages of each probe of given factor and compile maps presenting element group by isolines.

Determination of geochemical associations by cluster and factor analyses is in accord with the primary state of group of elements in different areas of dissemination most commonly due to the influence of various temporal and spatial genetic processes mutually dependent or not. In this regard, associations should not be interpreted as paragenetially related elements. Nevertheless, maps illustrating their distribution are more informative than monoelement maps since they offer possible presence of zoning. These maps are more interesting than those compiled based on additive and multiplicative haloes since elements of proven correlation relation and influence that is proportional to their participation in the general changeability and totality are included in individual associations. Correlation between geochemical associations systematized and calculated on data of primary and secondary dissemination haloes in Borov Dol and associations after the primary and secondary haloes of specific deposits in the Panagjurishte district (Bulgaria) are presented in Table 10.

Table 10

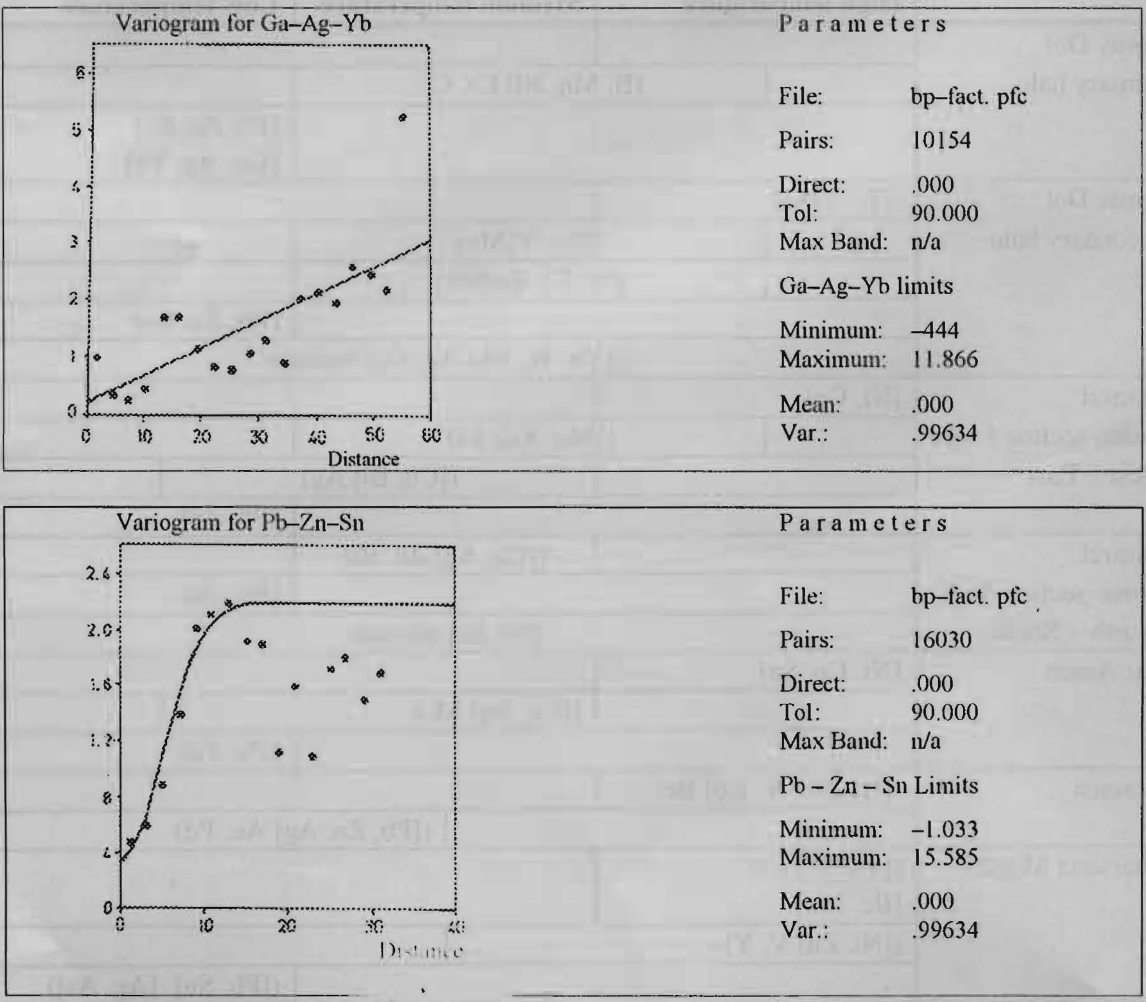
Comparison between geochemical associations characteristic for some deposits in the Buchim ore district (Macedonia) and the Panagjurishte ore district (Bulgaria)

<table>
<tr><th></th><th colspan="2">High temperature</th><th colspan="2">Medium temperature</th><th colspan="2">Low temperature</th></tr>
<tr><td rowspan="3">Borov Dol
Primary halo</td><td colspan="2"></td><td colspan="4"></td></tr>
<tr><td></td><td colspan="3">(B, Mn, Ni) Cr, Co</td><td colspan="2"></td></tr>
<tr><td colspan="4"></td><td colspan="2">[Pb, Zn, Sn]
[Ga, Ag, Yb]</td></tr>
<tr><td rowspan="5">Borov Dol
Secondary halo</td><td colspan="2">([Ti, V]Sc)</td><td colspan="4"></td></tr>
<tr><td></td><td colspan="3">([Cu, Y]Mo)</td><td colspan="2"></td></tr>
<tr><td></td><td colspan="3">(Ni, Cr, Co]Mn)</td><td colspan="2"></td></tr>
<tr><td colspan="4"></td><td colspan="2">[Pb, Zn, Sn]</td></tr>
<tr><td colspan="6">([Yb, W, Nb] Ag, Ga) mixture</td></tr>
<tr><td rowspan="4">Assarel
Cross–section I – I
West – East</td><td colspan="2">[Ni, Co]</td><td colspan="4"></td></tr>
<tr><td></td><td colspan="3">([Mo, Au] As)</td><td colspan="2"></td></tr>
<tr><td colspan="2"></td><td colspan="3">([Cu, Bi] Ag)</td><td></td></tr>
<tr><td colspan="4"></td><td colspan="2">[Pb, Zn]</td></tr>
<tr><td rowspan="3">Assarel
Cross–section X–X
(North – South)</td><td colspan="2"></td><td colspan="2">([Cu, Ag] As, Bi)</td><td colspan="2"></td></tr>
<tr><td colspan="4"></td><td colspan="2">[Pb, Zn]</td></tr>
<tr><td colspan="6">[Ni, Ba] mixture</td></tr>
<tr><td rowspan="3">Car Assen</td><td colspan="2">[Ni, Co, Sn]</td><td colspan="4"></td></tr>
<tr><td colspan="2"></td><td colspan="3">([Cu, Ag] Mo)</td><td></td></tr>
<tr><td colspan="4"></td><td colspan="2">[Pb, Zn]</td></tr>
<tr><td rowspan="2">Krassen</td><td colspan="2">([Ni, Mn, V, Co] Be)</td><td colspan="4"></td></tr>
<tr><td colspan="3"></td><td colspan="3">([Pb, Zn, Ag] Au, Pd)</td></tr>
<tr><td rowspan="3">Chervena Mogila</td><td colspan="2">([Yb, Ti] Cr)
[Be, Mn]</td><td colspan="4"></td></tr>
<tr><td colspan="3">([Ni, Zn] V, Y)</td><td colspan="3"></td></tr>
<tr><td colspan="4"></td><td colspan="2">([Pb, Sn], [Ag, As])</td></tr>
</table>

Spatial distribution of element associations

Variogram analysis was used for the character of changeability of geochemical associations based on investigations of similarities between associations studied depending on spatial position or direction and distances between them. The purpose is to define the essential indicators of variogram function e.g. the effects of nugget, sill and range of all four directions East – West (0°), North-east – South-west (45°), North – South (90°) and North-west – South-east (135°).

In this manner the anisotropy in horizontal changes in investigated associations is also described. These data were used when compiling the geochemical maps. The results of variogram analysis are shown in Figs 5 and 6. Since data possess highly pronounced changeability, the theoretical variogram model can be closely evaluated by the extreme variogram. A conclusive characteristic of the distribution of association is the large gap read from the effect of inclusion along with the presence of quasi periodicity. The latter is represented by a periodic uncertainty component of dependence between samples and is due to higher structural effects due to zone formation of increased and lower elements content of the association given. The geological assumption is the occurrence of various rocks and hydrothermal alterations. The effect is clearly seen from the Pb–Zn–Sn association in both primary and secondary dispersion haloes. Based on continuity in different directions, the Ga–Ag–Yb and Pb–Zn–Sn associations along the primary and Cu–Y–Mo, Yb–W–Nb along the secondary halo can be interpreted as isotropic along horizontal distribution. Other associations display anisotropy with northeast–southwest direction of minimum changeability. Part of the anisotropy can be due to anisotropic net of sampling. The B–Mn–Ni association of secondary haloes alone displays northwest–southeast direction of minimum changeability.



Parameters

File: bp–fact. pfc

Pairs: 10154

Direct: .000
Tol: 90.000
Max Band: n/a

Ga–Ag–Yb limits

Minimum: –444
Maximum: 11.866

Mean: .000
Var.: .99634

Parameters

File: bp–fact. pfc

Pairs: 16030

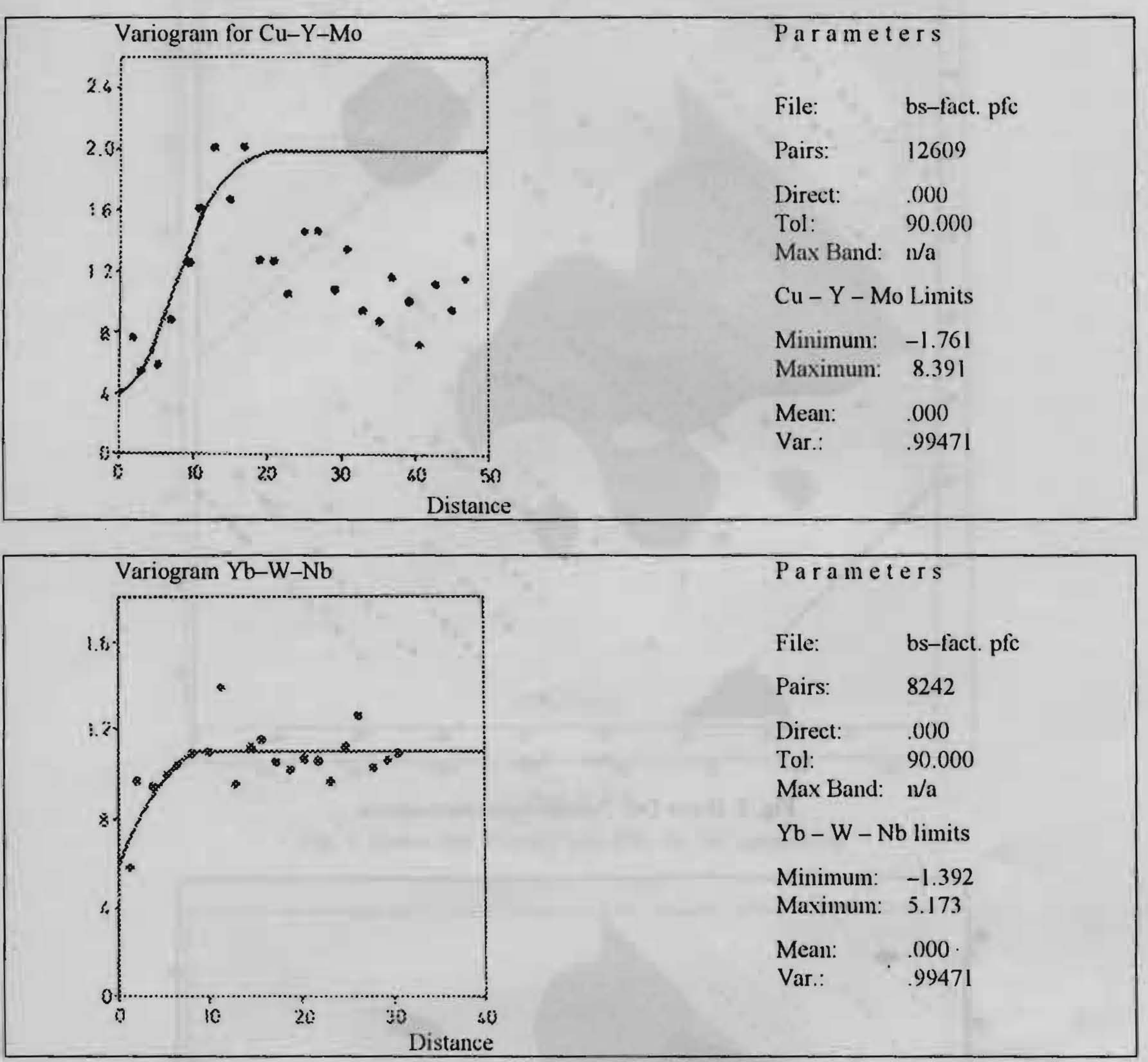
Direct: .000
Tol: 90.000
Max Band: n/a

Pb – Zn – Sn Limits

Minimum: –1.033
Maximum: 15.585

Mean: .000
Var.: .99634

Fig 5. Variograms of primary haloes from Borov Dol–Shopur deposit



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Parameters

File:          bs–fact. pfc
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Direct:        .000
Tol:           90.000
Max Band:      n/a
Cu – Y – Mo Limits
Minimum:       -1.761
Maximum:        8.391
Mean:          .000
Var.:          .99471
```

```
Parameters

File:          bs–fact. pfc
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Direct:        .000
Tol:           90.000
Max Band:      n/a
Yb – W – Nb limits
Minimum:       -1.392
Maximum:       5.173
Mean:          .000
Var.:          .99471
```

Fig. 6. Variograms of secondary haloes from Borov Dol–Shopur deposit

The results of the factor analysis are used in compiling the maps showing the horizontal distribution of separated associations showing the process of each sample as units of standard deviation. Craiging method was used based on the above mentioned variogram models. The method is considered to be the most correct because it reads the anisotropy, the spatial position of the points as well as the correlations between them. Outlining was carried out for planes with reliable values of factor percentage on samples for adequate association. Other planes involved are those that are out of outlined planes and samples of zones separated in which the association is absent. Quadratic net the size 20 x 20 was used, and evaluation was carried out on the first 10 closely observed reaching certain agreement. Maps are given in Figs. 7–17 and are shown in dark gray colour for greater visibility.

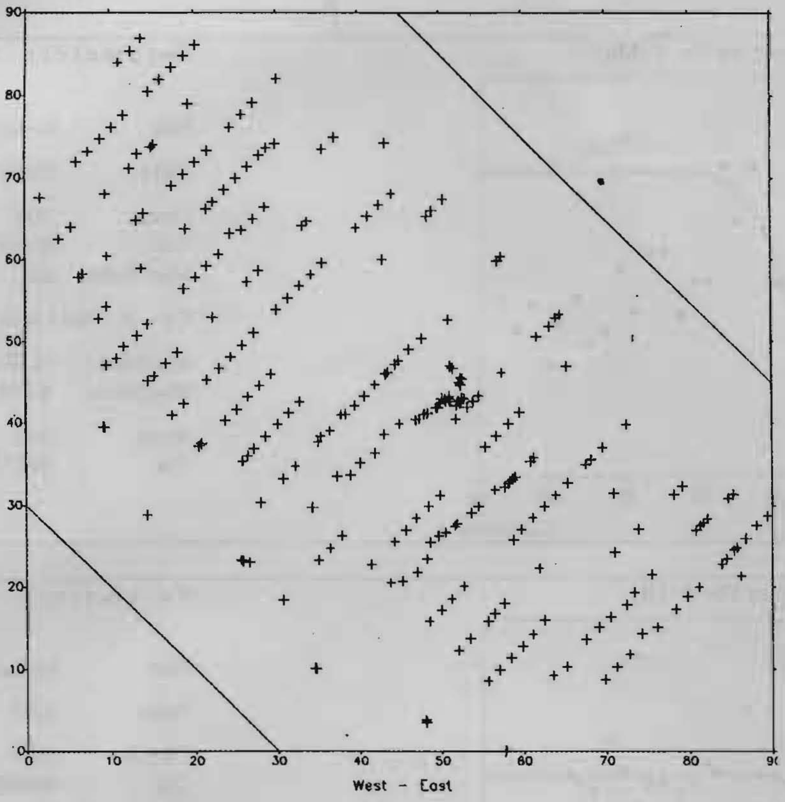

Fig. 7. Borov Dol. Primary halo observations

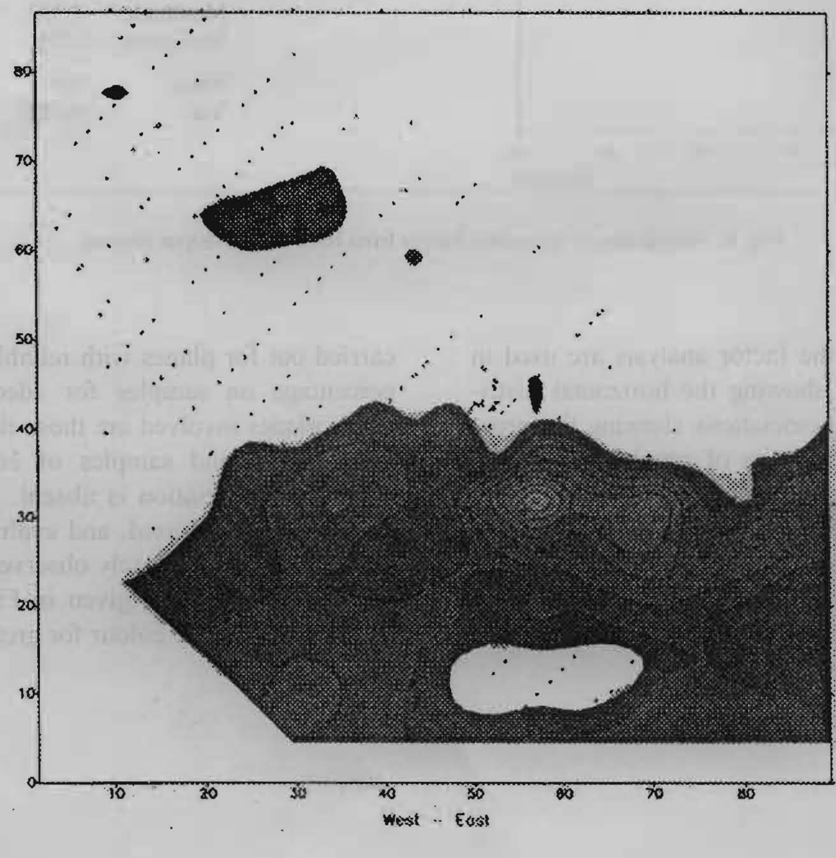

Fig. 8. Borov Dol. Primary halo ([Zr, Y, B, Ti] Nb) association

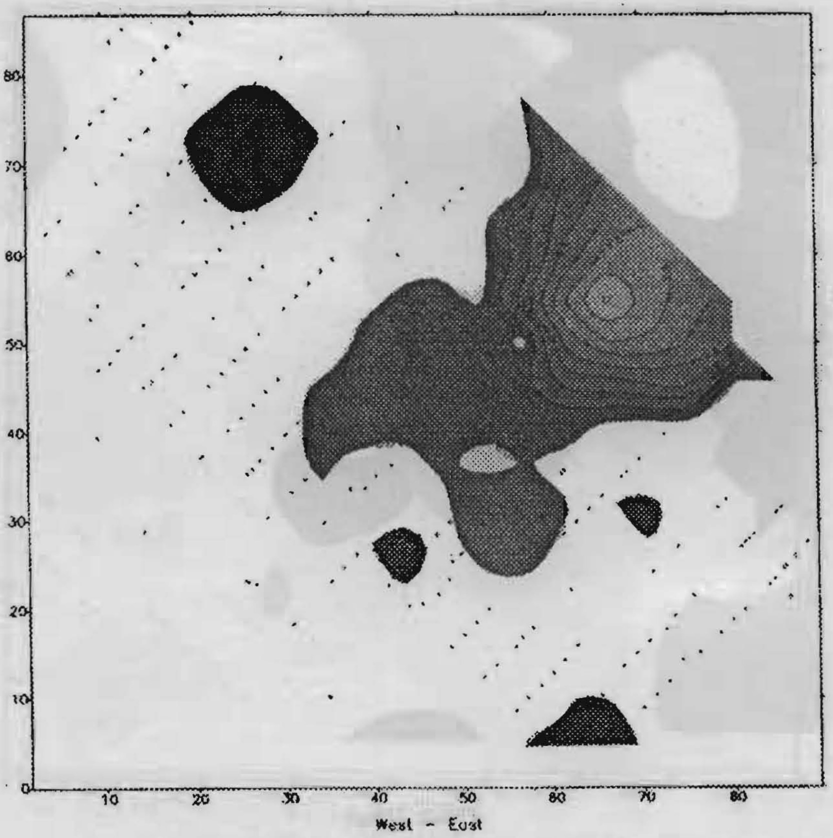

Fig. 9. Borov Dol. Primary halo [Pb, Zn, Sn] association

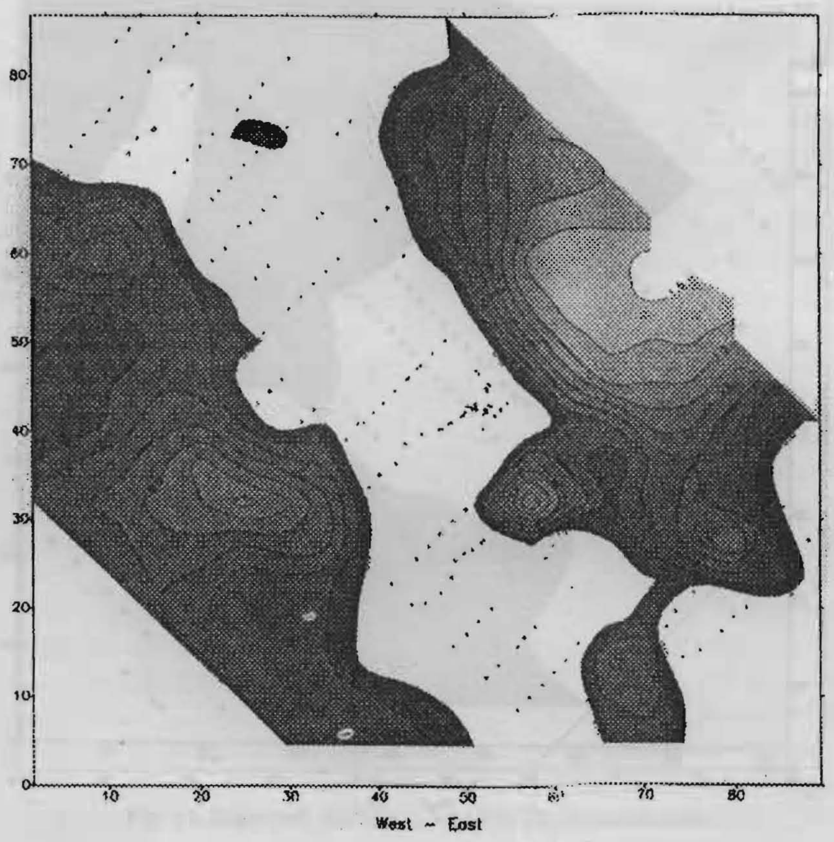

Fig. 10. Borov Dol. Primary halo (B, Mn, Ni) Co, Cr association

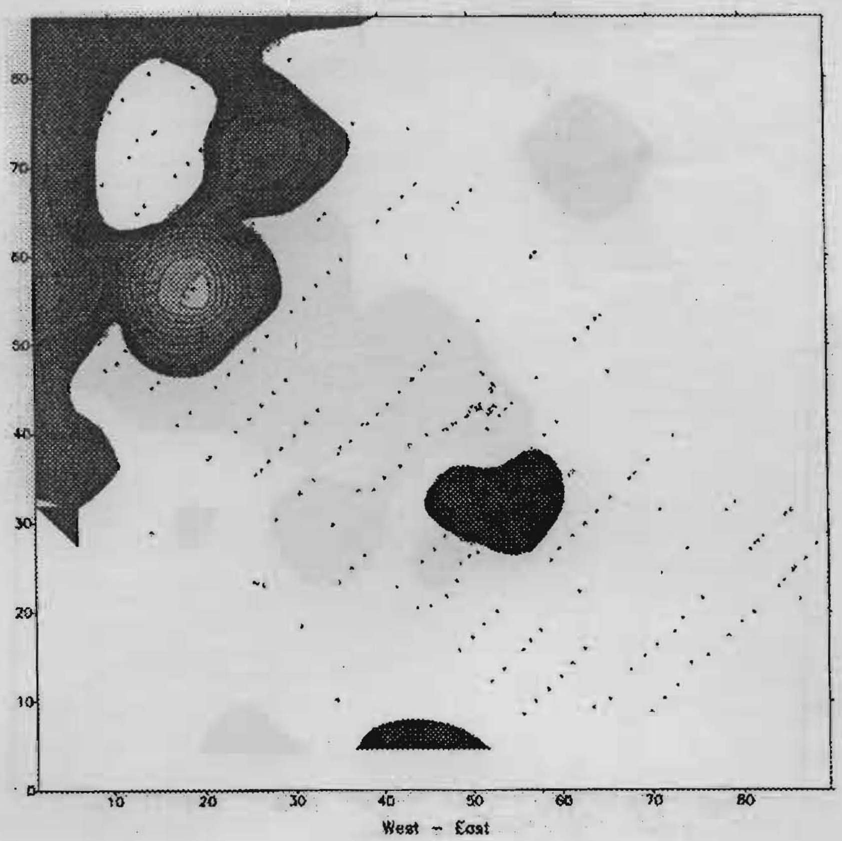

Fig. 11. Borov Dol. Primary halo [Ga, Ag, Yb] association

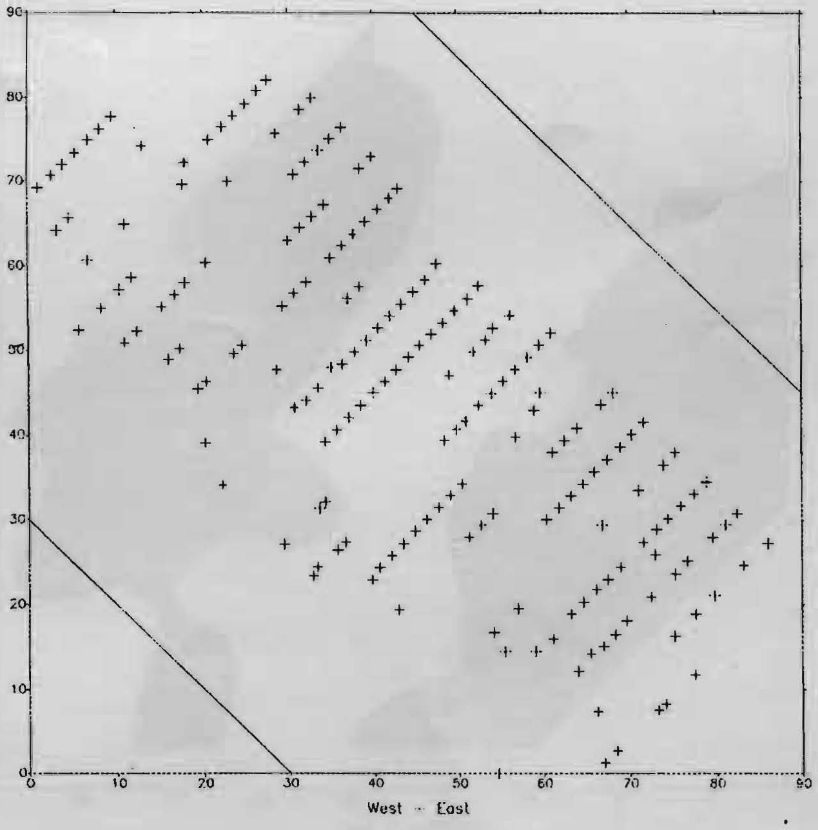

Fig. 12. Borov Dol. Secondary halo observations

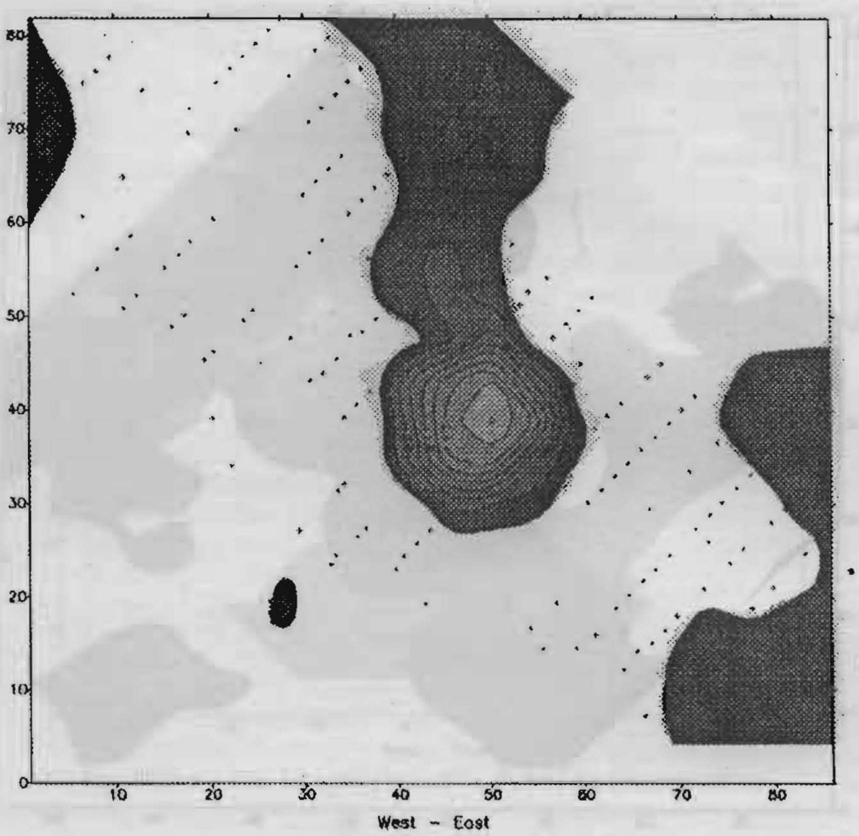

Fig. 13. Borov Dol. Secondary halo ([Cu, Y] Mo) associations

Fig. 14. Borov Dol. Secondary halo [Pb, Zn, Sn] association

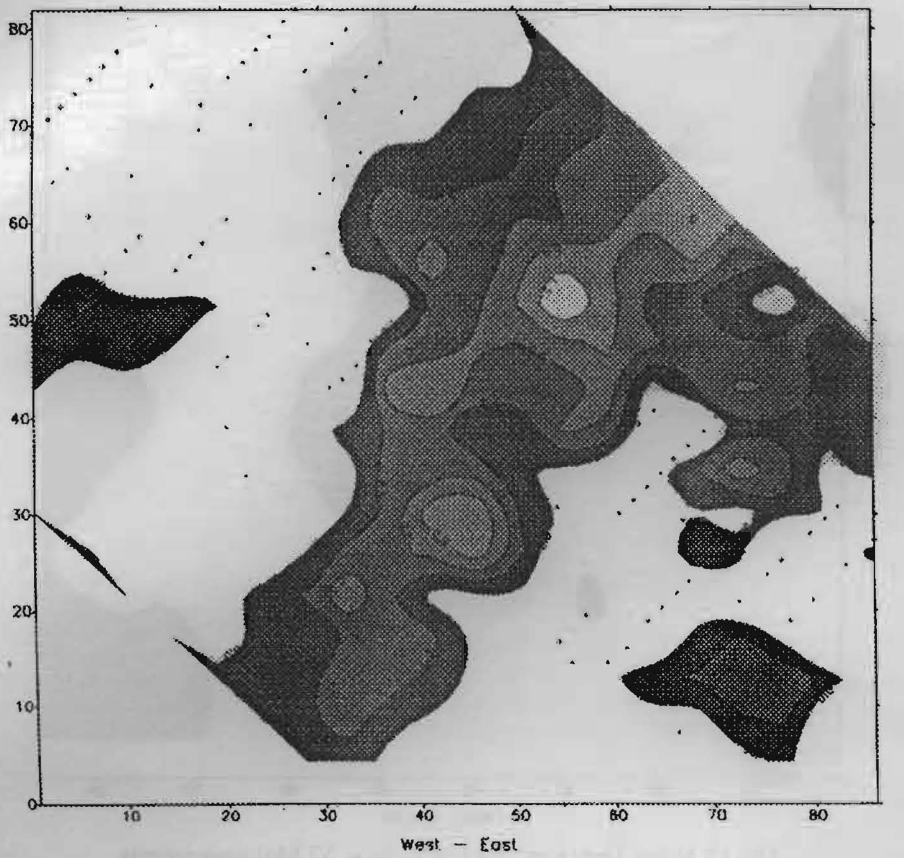

Fig. 15. Borov Dol. Secondary halo ([Ti, V] Sc) association

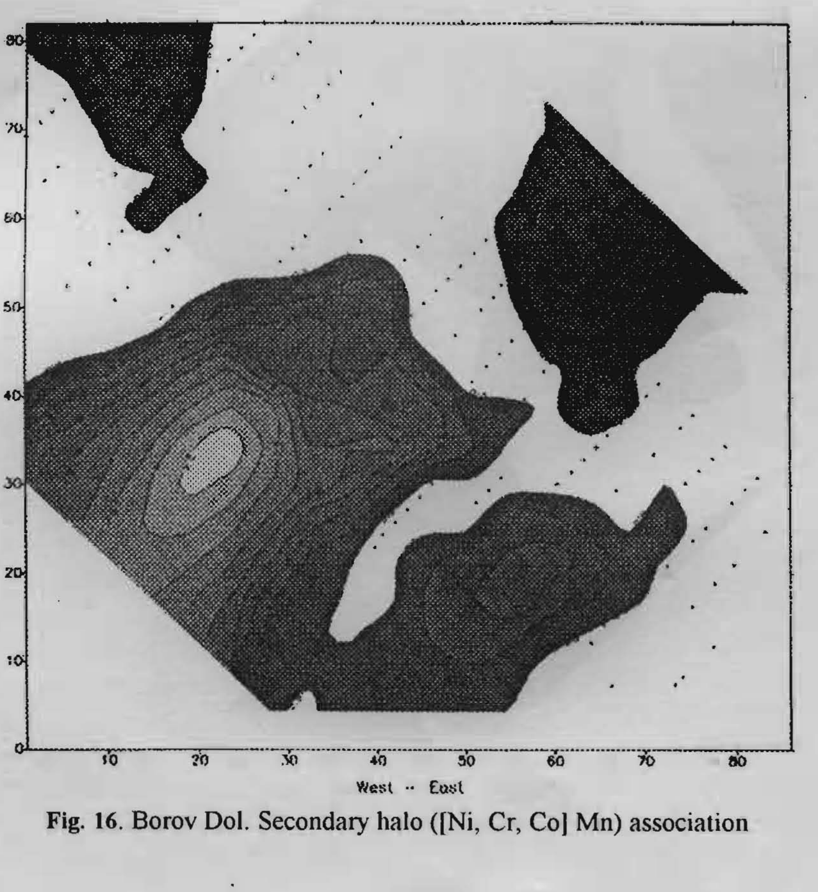

Fig. 16. Borov Dol. Secondary halo ([Ni, Cr, Co] Mn) association

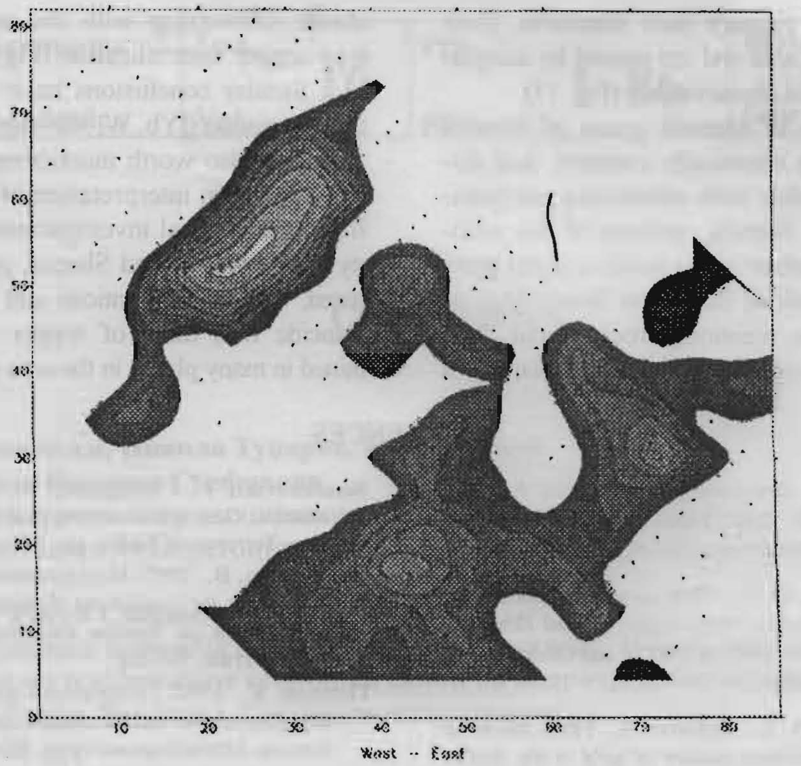

Fig. 17. Borov Dol. Secondary halo ([Yb, W, Nb] Ag, Ga) association

DISCUSSION AND CONCLUSION

Based on aforementioned it can be said that the method and statistics applied had a positive result on distinguishment of several characteristic types of geochemical associations (according to primary and secondary haloes of distribution) that undoubtedly have a common geochemical and genetic relationship. Such deduction is proved by the geochemical maps shown for individual geochemical groups of elements according to primary and secondary haloes of dispersion.

If one looks at the geochemical isolines of individual associations distinguished according to primary, dispersion haloes (Figs. 7–11), one can see that maximal intensity isolines were determined in the south part of the isoline or in the area of the Borov Dol deposit. It can be best seen for associations ([Zr, Y, B, Ti] Nb), that coincides the copper mineralization in the Borov Dol deposit (Fig. 8).

Unlike this, the [Pb, Zn, Sn] association demonstrates in the southeast part of the isoline (Fig. 9), which geologically and metallogenetically coincides the area of the vicinity of the village of Petrino where occurrences of Pb, Zn, Ba mineralization has been disclosed.

The (B, Mn, Ni) Co, Cr association displays destroyed types of isolines with no direct coincidence with other associations with the exception of a small part related to the immidiate area of the Borov Dol deposit (Fig. 10).

Particular attention with primary dispersion haloes should be paid to the [Ga, Ag, Yb] association which does not display almost any relationship with other associations of the primary group (Figs. 7–11), but its maximas of isolines concentrate on the distal northwestern parts of the terrane under consideration – the terrain that belongs to Pilav Tepe and Shopur (Fig. 11).

Associations distinguished according to secondary dispersion haloes are very similar, but with certain specific characteristics (Fig. 12–17). However, the most striking spatial traits are displayed by the ([Cu, Y] Mo) association with isolines of north–south extension and its maximum in the south part corresponding to the area of the Borov Dol deposit. In the north, the association clearly coincides the Popova Shapka Cu-occurrences (Fig. 13).

The [Pb, Zn, Sn] association here does not extend its maximum to the north (near the Damjan occurrences) particularly to north–west which spatially belongs to the Shopur mineralization area (Fig. 14).

The isolines of the ([Ti, V] Sc) exhibit an unusual position extending WE–SW most probably obscuring some of the primary fault structures. Such structures exist in the area and are proved by analysis of scanograms and field obeservations (Fig. 15).

The association of element group of ferrides ([Ni, Cr, Co] Mn) is chemically constant, and display spatial relationship with ultrabasics, carbonatites and pyroxenes. Namely, isolines of this association are more common in the south-western parts of the terrane or south of Brest and Borov Dol, or the area where above mentioned rocks occur. It is obvious that this association does not display a closer relationship with the areas with porphyry type copper mineralization (Fig. 16).

Similar conclusions have been obtained from the association ([Yb, W, Nb] Ag, Ga) given in Fig. 17.

It is also worth mentioning that the methodology applied in interpretation of the results obtained from geochemical investigations of the wider vicinity of Borov Dol and Shopur, gave the results anticipated, and the associations and groups distinguished coincide with those of copper mineralization determined in many places in the area investigated.

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Резиме

ТИПОВИ НА ГЕОХЕМИСКИ АСОЦИЈАЦИИ ВО РЕОНОТ БОРОВ ДОЛ–ШОПУР:

ИНТЕРПРЕТАЦИЈА НА ПОДАТОЦИТЕ СПОРЕД ПРИМАРНИ И СЕКУНДАРНИ ОРЕОЛИ

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Клучни зборови: Боров Дол–шопурски реон; геохемиска асоцијација; интерпретација; статистичка анализа; примарни и секундарни ореоли

Во трудот се прикажани статистичките пресметки на резултатите од геохемиски испитувања на примарните и секундарните ореоли на расејување извршени на површина од околу 40 km^2 на подрачјето Боров Дол–Шопур (бучимски руден реон). Испитувањата се вршени по мрежа 500 x 200 m, од страна на истражувачи од ИМГРЕ – Москва и од рудникот Бучим. Добиените резултати најнапред се интерпретирани според методот на „Геоскан", а во рамките на овој труд според методот на „кластерна анализа" и „факторна анализа" или според методот на Кајзер.

Врз база на комплексните статистички пресметки, корелациони зависности и групирања на поедини елементи според вариограми, факторни разложувања и дендограми, издвоени се следните типови асоцијации:

I. Според податоците на кластерната анализа се издвоени:

а) Според примарните ореоли на расејување:

(Pb, Zn, Sn); [(Ga, Ag), Yb]; (Ni, Co, Cr); [(Ti, Zr, Y) Nb];

б) Според секундарните ореоли на расејување:

[Ni, Cr, Co) Mn]; [(Ti, V) Sc]; [(Yb, Nb) Ag]; (W, Ga); (Cu, Y)Mo; (Pb, Zn, Sn).

II. Според податоците на факторната анализа се издвоени:

а) Според примарните ореоли:

[Zr, Y, B, Ti) Nb]; (Sr); (Pb, Zn, Sn); (Ga, Ag, Yb); (B, Mn, Ni) Co, Cr;

б) Според секундарните ореоли:

[(Ni, Cr, Co) Mn]; [(Yb, W, Nb) Ag, Ga]; [(Ti, V) Sc]; (Pb, Zn, Sn); (Cu, Y, Mo).

За посебно одбележување е геохемиската асоцијација (Pb, Zn, Sn) која јасно се дефинира и во двете групи, како и (Cu, Y, Mo) како карактеристична асоцијација за секундарните ореоли на расејување.

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