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Research Article

GEOCHEMICAL PROPERTIES OF PRE-MESOZOIC FORMATIONS OF THE SOUTH NURATAU MOUNTAINS (WESTERN UZBEKISTAN)

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ABSTRACT
The extent of element enrichment (concentration) was compared with the elements' regional background values in a determination of the geochemical properties of pre-Mesozoic formations. The abilities of elements to migrate (redistribute) and the average regional background element contents were determined. The range of background values was distinguished using a distribution histogram of element contents. Visual analysis of such histograms is effective for the identification of geochemical thresholds under the condition of multimodal distribution.

Keywords: *Geochemical Properties, Regional Background, Concentration Level, Geochemical Associations, Southern Nuratau, Pre-Mesozoic Formations, 1:200,000 Scale*

INTRODUCTION
The study of rock geochemical properties is an important aspect of regional studies designed to identify prospective ore-bearing territories. The formation of rocks enriched primarily with low-Clarke-value elements predetermines the appearance of geochemically specialized blocks of territory in which the mobilization of low-Clarke metals and concentration of their ores occurred as a result of later tectonic, magmatic, metasomatic, hydrothermal, and other processes. Appropriate geochemical properties of rock are a necessary, although not the only, factor required for the mineralization of a particular ore-formation type, which occurs mainly due to these characteristics. The modern concept of the "geochemical properties" of geological formations encompasses the geodynamic regime of rock complex formation, hierarchy of geological bodies as units of analysis, ontogeny and phylogeny, petrochemical characteristics, type of statistical distribution of elements and their isotopes, productive facies, mineral carriers and their parageneses and associations, and experimental physical and chemical systems (Jabin, Kudryavtsev, Filatov et al., 1995). This approach reflects the multifactorial nature of ore formation processes, and in this case, geochemical properties as forecasting elements (cycles) are integral characteristics. The investigation of geochemical properties is part of the analysis of gold-bearing area formation for the purposes of forecasting and identifying functional relationships among geological conditions, metasomatic conditions, and ore formation.

MATERIALS AND METHODS
The Nuratau Mountains are a system of Alpine sedimentary uplifts and depressions with northwestern strike in the Tien Shan that plunge regularly from southeast to northwest. The region is transitional from linearly extended Nuratau ridges and troughs of South Tien Shan to Kyzylkum brachystructures. Geographically, it includes the spurs of the North and South (Aktau, Karatau) Nuratau. They differ from the Kyzylkum structure mainly in their very strong transverse compression and thick shear components.
The geochemical properties of South Nuratau formations have been investigated in individual areas of the territory, as well as in portions of sections of stratified complexes and intrusive rocks. This research has also provided information about the geochemical characteristics of the sedimentary–metamorphic strata of the Karatau Mountains (Bertman *et al.*, 1990). However, no map of the geochemical properties of the southern Nuratau pre-Mesozoic formations is currently available, and most quantitative estimates of geochemical properties have been limited by the indicators used, i.e., average grades of elements.

RESULTS AND DISCUSSION

The materials presented in this study were derived from the available geological and geochemical information for the southern Nuratau territory relevant to rock geochemical properties.

The cartographic materials of Koloskova (2015) and Abduazimova (2002) served as the basis for the compilation of a schematic geochemical map at 1:200,000 scale. The extent of element enrichment was compared with the regional background within the limits of determination of the geochemical properties of the pre-Mesozoic formations. Average regional background element contents were determined. The range of background values was distinguished using the histogram distribution of element grades. Visual analysis of such histograms is effective for the identification of geochemical thresholds under the condition of multimodal distribution. Given the relatively regular sampling of the area, samples from background aggregates formed the main peak on the histogram. Samples from the debris cone and accumulation areas formed secondary peaks, separated from the background aggregates by significant minimums.

The regional background of elements for the central part of southern Nuratau was calculated based on information from Khan (1997), and that for the entire southern Nuratau territory was calculated based on information from Koloskova (2015) and Movlanov (2006). The obtained background element content values and the boundaries of background aggregates often differed by up to one order due to different sensitivities of element definitions (Table 1). Deviations in the backgrounds of most elements, mainly decreases relative to Clarke values, were noted. The regional background-1 (of Samarkand Geologia) and regional background-2 (based on an Institute mineral resources database) values were used to assess element accumulation levels.

Geochemical Specialization

Average grades for the allocated units were rated according to the regional background to assess the accumulation of elements. The element concentration factor served as the basis for the geochemical characterization of rock complexes. In the statistical analysis, prevailing concentration factors of elements were classified as below background (<0.8), near background (0.8–1.5), poorly specialized (1.5–2.2), and specialized (>2.2).

An important indicator of geochemical properties, in addition to absolute element contents, is the homogeneity (or inhomogeneity) of metal distribution in the geological environment, which indicates the intensity of redistribution processes and the migration ability, as expressed by variation factors. Element distribution is characterized as homogeneous (variation factor 0.6–0.8), inhomogeneous (0.8–1.2), extremely inhomogeneous (1.2–1.8), and contrast (>1.8). The homogeneity (inhomogeneity) of geochemical complexes is classified as slightly differentiated (variation factor 0.5–0.8), differentiated (0.81–1.2), and intensively differentiated (>1.2).

Correlation matrices were analyzed to identify significant geochemical associations among elements. Correlation factor values higher than twice the parameter threshold value for the investigated samples were adopted in the estimation. Factor analysis was also performed using the principal component method.

Stratigraphic Subdivisions

The geochemical features of the following stratigraphic subdivisions of sedimentary rock complexes (SRCs) in the southern Nuratau, including typical cross sections with the same names and structural formation sub-zones, have been studied: the typical Aktau–Malguzar SRC (Darasai C_2?dr and Aktau S_2-C_2?ak suites), the Nuratau–Lyatoband SRC (Jazzbulak S_1dž, Nakrutskaya S_1nkr, Badamchalin Obd, and Kalsarinskaya $Є_{2\text{-}3}$kl suites), the Koytash–Zaaminsky structural–material complexes (Karatash S_1kr, Tansaray $O_{2\text{-}3}$tn, and Jalatar $O_{1\text{-}2}$dž, suites, and the Tamdytau–Nuratinsky SRC (Karakarginskaya $O_{1\text{-}2}$kr suite) (Koloskova, 2007).

The geochemical characterization of the Shurak granite–adamellite intrusive complex (Shuraksky C_3š-biotite, amphibole-biotite granites, and adamellites; and Darasai $C_{2\text{-}3}$dr gneissoid granodiorites, quartz diorites, diorites, and gabbro subcomplexes) was based on information from Yudalevich (1984) and the results of our research.

Table 1: The values of the regional geochemical background of some elements in Pre-Mesozoic formations of Southern Nuratau (n- 0.001 %, Au - g/t)

Elements	Database of the central part of the Southern Nuratau *					Database of the Southern Nuratau**				
	Number of samples ***	Boundaries of the background area		Region background	The variation factor		Boundaries of the background area		Region background-2	The variation factor
		from	to				from	to		
Ag	8159	0.03	0.1	0.046	0.24	766	0.004	0.011	0.008	0
As	6842	1	7	3.51	0.38	971	1	4	1.12	0.36
Au	6731		≤ 0.02	0.004	1.53	1068		≤ 0.01	0.003	0.59
Ba	n/a	n/a	n/a	n/a	n/a	826		≤ 20	9.96	0.17
Be	8241		≤ 0.5	0.17	0.15	1289		≤ 1	0.49	0.54
Bi	8149		≤ 0.5	0.30	0.08	1085		≤ 0.1	0.059	0.34
Cd	8229		≤ 0.5	0.27	0.20	1169		≤ 0.1	0.013	0.89
Co	7977	0.5	2	1.12	0.37	1008	0.4	2	0.89	0.48
Cr	7837	2	15	7.03	0.34	969	5	15	7.89	0.23
Cu	7572	3	8	5.42	0.23	1184	0.5	7	2.16	0.68
Ga	7351	0.5	2	0.97	0.34	1020	0.4	5	1.70	0.65
Ge	8142		≤ 0.2	0.11	0.36	1197		≤ 0.2	0.062	0.45
Li	8206		≤ 8	5.07	0.09	1083	0.5	3	0.71	0.66
Mn	7858	10	100	46.99	0.42	1057	1	20	6.16	0.75
Mo	7803		≤ 1	0.51	0.29	753	0.1	1	0.36	0.77
Nb	8042		≤ 1	1.00	0.00	1292		≤ 1	0.21	1.70
Ni	8020	1	7	3.99	0.34	943	0.5	5	2.04	0.58
P	8067		≤ 70	51.73	0.17	1094		≤ 60	24.76	0.53
Pb	7641	0.6	6	2.03	0.63	1113	0.1	2	0.52	0.78
Sb	8071		≤ 2	1.10	0.22	1169		≤ 0.6	0.10	0.21
Sn	7817	0.2	0.7	0.44	0.25	931	0.1	0.7	0.29	0.61
Ti	n/a	n/a	n/a	n/a	n/a	1067	10	200	60.42	0.59
V	7638	1	20	7.33	0.58	924	1.5	15	4.16	0.49
W	7985		≤ 1	0.72	0.21	1274		≤ 0.5	0.13	0.52
Zn	7292	5	15	8.28	0.31	939	0.8	5	1.53	0.52
	7558		20	8.69	0.38					

** Local gold prospecting database with exploration of additional sites (50 in the Khalbashinskaya area, central southern Nuratau ridges, 1999–2002) (Khan et al., 2002), and 8,255 bedrock samples from the central laboratory of Samarkand Geologia.*

*** Local database on topic #585 "Identification of gold prospecting areas in southern Nuratau for geological and geochemical features" for 2001–2005, and 1,331 bedrock samples from the Laboratory of Physical and Chemical Methods of Research.*

**** Number of samples within the boundaries of the background area among the total number of samples in the databases.*

Belousova investigated the geochemical properties of suites and rock types in the stratified deposits of the Karatau Mountains, with consideration of statistical parameters of the first and second kind. She classified some Karakarginsky, Karataş, Nakrut, and Badamchalin suites as potentially ore bearing and noted the geochemical donor properties of the Badamchalin and Nakrutsky suites.

For comparison with the ore-bearing potentials of these suites, we present the results of our geochemical studies in Nuratau (Koloskova, 2007) (Tables 2 and 3, Figures 1 and 2), including geochemical properties, variation factors, concentrations and accumulations.

Karatash Suite (sampling index KZ-Kar-S_1): The sediments of the suite are poorly specialized in several siderophile elements (Ti, V, Cr). Intensive redistribution of elements and superimposed gold–tungsten and sulfosalt (?)–silver geochemical associations are reflected in the grade dispersion of corresponding elements, variation factor values, and associations of the main factors (1 and 4).

Tansaray Suite (index KZ-Kar-$O_{2\text{-}3}$): The suite has near-background levels of most elements. The geochemical accumulation spectrum includes Ba, Ti, V, and Zn, with low variation factor values. The first factor is associated with rock type, and the second and third factors have ore-bearing associations.

Jalatar Suite (index KZ-Kar-$O_{1\text{-}2}$): This suite is poorly specialized in Co, Cr, Ti, V, and Zn and has irregular distributions of Au, Co, Mn, Pb, and W.

Nakrutskaya Suite (index NL-Kar-S_1): This suite has above-background concentrations of Cr, Ti, V, and Zn, with low variation factors, whereas the distributions of other elements are associated with sub-background average contrast-type distribution, reflecting superimposition.

Badamchalinskaya Suite (index NL-Kar-$O_{1\text{-}2}$-I): This suite is characterized by weak above-background concentrations of Au, As, Ba, Co, Ga, Mn, Pb, and Zn, and practically all elements with epigenetic processes have contrast-type distribution. Geochemical associations of many elements are correlated, which complicates meaningful interpretation.

Karakarginskaya Suite (index TN-Kar-$O_{1\text{-}2}$): This suite is characterized by the syngenetic accumulation of Cr, Ti, V, and other elements slightly exceeding the regional background and showing contrast distribution. Correlated geochemical associations of the main factors suggest a connection with emanation halos accompanying granitoid massif formation. The geochemical features of sedimentary deposits not altered by hydrothermal processes were studied in several areas (Tables 2 and 3, Figures 1 and 2), mainly sections of the Nuratau–Lyatoband Complex.

*Kalsarinskaya Suite*_(NL-Karak-$Є_{2\text{-}3}$-1, 2): The accumulation series includes Ti, V, and Cr, and sometimes Zn, Cu, P, As, and Mn. The contrast-type distribution of Ag, As, Au, Bi, Cd, Ge, Mo, Nb, and V is associated with increased variation factor values, dispersion, asymmetry, and excess. In contrast, the same statistical parameters for Co, Cr, Ga, Ni, Sn, Ti, and Zn reflect relatively homogeneous distribution. The distribution of Au and associated ore-bearing elements Ag, Pb, Sb, W, and Bi varied significantly at sub-background average content levels. The siderophilic elements Ti, V, Cr, Co, and Cu are correlated with the first factor.

Badamchal Suite (index NL-Karak-O): The suite has geochemical features similar to those of the Kalsarin Suite, including average element contents, statistical distribution features, and geochemical associations of the first and second factors (Table 4, Figures 3 and 4).

Nakrut and Jazzbulak suites (indices NL-Ak-S_1-1, 2, 3; NL-Karak-S_1-1, 2): The geochemical characteristics of these suites reflect heterogeneity of element distributions against the regional background, with increases and decreases in average grades (Tables 4 and 5, Figure 3). Increases in average grades of Ag, Au, Bi, Cu, Mn, Pb, Ti, V, Zn, and Sn relative to those in the Kalsarinskaya and Badamchalinskaya suites were noted frequently. Correlated geochemical associations of the first factor reflect the presence of lithophilic (Sn, Mo, Mn, P, Ga), siderophilic (Ti, Cr, V, Ni), and chalcophilic elements.

Metamorphogenic quartz formations retain the element distribution tendencies of the host rocks (Table 4, Figures 3–5). Increased concentrations of Au, Mo, Mn, and P with contrast distribution of were noted.

Table 2: Variation factors of element contents in stratified sequences of the Karatau Mountains of the southern Nuratau Ridges
[statistical processing of the local database of geochemical materials by Belousova, reported in Abduazimova *et al.*, (2004)]

Element	Variation factors of elements contents					
	S_1 kr	O_{1-2} tn	O_{1-2} dz	S_1 nkr	O_{1-2} bd	O_{1-2} kr
Ag	0.019	0.009	0.009	0.028	0.179	0.021
As	2.345	1.3	1.3	7.086	5.665	2.874
Au	0.008	0.005	0.005	0.004	0.008	0.011
Ba	49.345	66.2	48	60.085	64.643	55.026
Bi	0.087	0.043	0.233	0.192	0.189	0.096
Co	1.484	1.834	3.614	2.663	2.559	1.951
Cr	15.919	10.72	16.571	12.093	8.943	14.162
Cu	3.93	3.173	4.36	4.114	5.208	4.074
Ga	1.854	1.955	15.157	3.969	2.302	3.751
Ge	0.345	0.193	0.796	0.393	0.283	0.225
Mn	37.471	37.233	71.857	50.908	73.57	62.251
Mo	0.385	0.142	0.05	0.1	0.578	0.343
Nb	3.955	1.194	1.286	1.484	1.087	0.959
Ni	1.166	1.625	3.357	1.901	1.423	1.845
Pb	3.647	2.851	5.559	5.551	13.834	5.126
Sn	0.545	0.249	0.609	0.415	0.37	0.474
Ti	657.381	467.33	617.14	600.65	390.018	585.84
	12.831	12.487	23.429	19.039	18.43	21.13
W	22.002	0.15	1.446	0.162	0.357	0.22
Zn	6.974	13.08	11.814	17.251	20.629	12.655
Number of samples	42	15	7	153	56	268

S_1 kr	karatashskaya	Koytash-Zaaminskiy	
O_{1-2}bd	badamchalinskaya		
O_{1-2} tn	tansarayskaya		
O_{1-2} dz	djalatarskaya		Nurata-Lyatobandskiy
S_1nkr	nakrutskaya		
O_{1-2}kr	karakarginskaya	Complex	Tamditau-Nuratinskiy

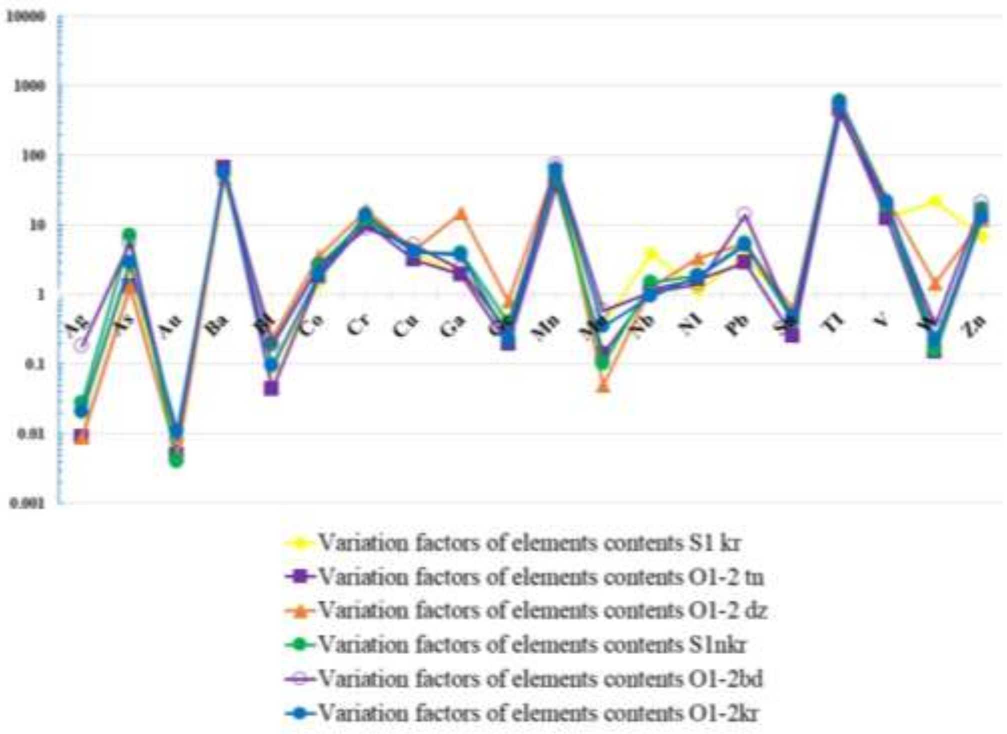

Fig. 1. Values of variation factors of elements contents

Table 3: Variation factors of elements contents in stratified sequences of Karatau mountains of the Southern Nuratau ridges
(statistical processing of local database of geochemical materials by Belousova to the report of Abduazimova and others. 2004)

Element	Variation factors of elements contents					
	S_1 kr	O_{1-2} tn	O_{1-2} dz	S_1nkr	O_{1-2}bd	O_{1-2}kr
Ag	0.874	1.056	0.441	1.661	3.693	1.276
As	1.979	0.152	0.407	1.839	2.208	1.433
Au	1.846	0.1	0.845	2.105	2.234	4.283
Ba	0.616	0.168	0.248	0.993	0.724	0.773
Bi	0.762	0.638	0.542	0.769	1.177	0.815
Co	0.466	0.842	0.205	1.903	1.492	0.531
Cr	0.906	0.889	0.177	0.351	0.792	0.452
Cu	1.038	0.268	0.852	1.254	0.68	1.219
Ga	0.496	0.492	1.742	1.756	0.966	0.6
Ge	0.495	0.669	0.144	0.76	0.826	0.962
Mn	1.207	0.856	0.975	0.583	0.819	1.639
Mo	1.95	1.192	0.1	1.561	1.433	1.496
Nb	2.801	0.252	0.176	0.981	0.839	0.447
Ni	0.301	1.259	0.244	1.098	1.19	0.752
Pb	0.531	0.656	1.224	0.95	3.31	0.689
Sn	1.326	0.396	0.222	0.513	1.223	0.367
Ti	0.335	0.213	0.112	0.225	0.471	0.278
V	0.238	0.292	0.163	0.445	0.75	0.818
W	5.066	0.1	0.58	0.568	2.627	3.448
Zn	0.33	0.539	0.183	0.538	3.189	0.534
Number of samples	42	15	7	153	56	268

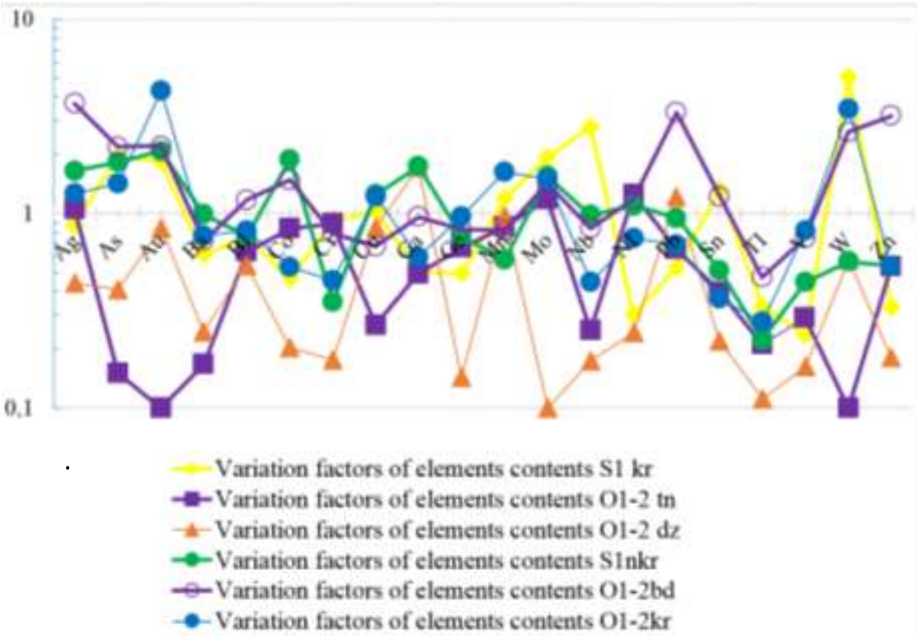

Fig. 2. Values of variation factors of elements contents

Stratified units of the suite: In total: **541** samples

S_1 kr karatashskaya
O_{1-2} bd badamchalinskaya
O_{1-2} tn tansarayskaya
O_{1-2} dz djalatarskaya
S_1 nkr nakrutskaya
O_{1-2} kr karakarginskaya
O_{1-2} kr karakarginskaya

Koytash-Zaaminskiy
Nurata-Lyatobandskiy
Complex | Tamditau-Nuratinskiy
Complex | Tamditau-Nuratinskiy

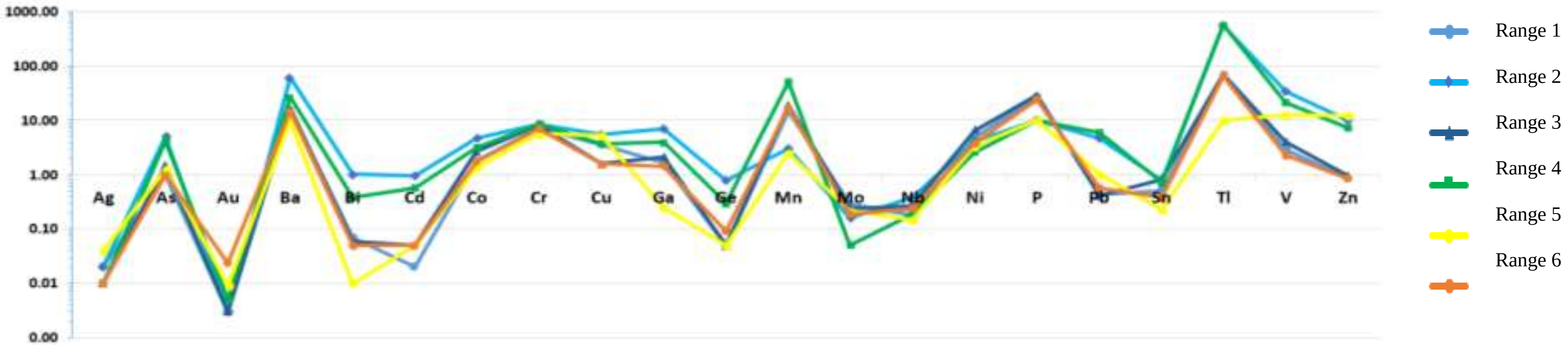

Figure 3: The graph of the distribution of the average content of elements in the sedimentary strata of the mountains of Karakchatau range of the Southern Nuratau (legend of the graph as per table 5)

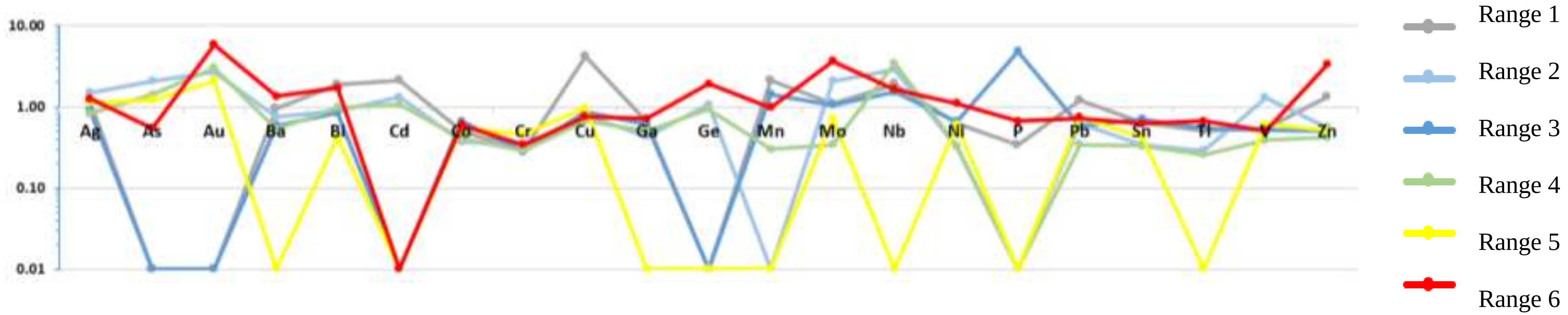

Figure 4: Graph of the coefficient of variation of the content of elements in the sedimentary strata of the mountains of Karakchatau

Table 4: Statistical parameters of the distribution of elements in the stratified strata of the Aktau Mountains of the South Nuratau Ridge

Element	Nurata-Lyatobandskiy (NL) sedimentary complex (SC)												Koytash-Zaaminskiy (KZ) SC			Granodiorite	
	Badamchalinskaya suite			Nakrutskaya suite						Djazbulakskaya suite			Karatashskaya suite			Shurakskaya (Sh) suite	
	NL-Ak-O			NL-Ak-S1$_{-1}$			NL-Ak-S1$_{-2}$			NL-Ak-S1$_{-3}$			KZ-Ak-S$_{1-2}$			Sh-Ak-C$_3$	
	A-grade	Disp.	Var. f.	A-grade	Disp.	Var. f.	A-grade	Disp.	Var. f.	A-grade	Disp.	Var. f.	A-grade	Disp.	Var. f.	A-grade	Var. f.
Ag	0.02	0.02	0	0.04	0	1.24	0.01	0	1.15	0.04	0	0.56	0.04	0	1.04	0.02	1.29
As	19.87	19.37	5.3	7.22	624.64	2.95	11.47	3.11	1.47	3.35	0.93	0.29	1.25	1.25	0.89	1.78	1.33
Au	0.013	0	0.01	0.014	0.06	7.34	0.004	0	2.46	0.003	0	2.23	0.048	0.01	1.46	0.004	1.57
Ba	14	13.72	5.46	18.84	271.93	0.85	16.34	86.19	0.78	5	0	0	27.9	4.76	0.65	32.22	0.69
Bi	0.06	0.06	0	0.24	0.06	1.01	0.06	0	0.3	0.05	0	0	0.05	0	0.25	0.05	0
Co	0.66	0.65	0.06	1.18	0.8	0.75	0.6	0.04	0.34	1.12	0.16	0.35	1.21	0.66	0.62	1.11	0.51
Cr	6.36	6.4	2.55	9.88	84.36	0.88	6.16	3.29	0.3	7.16	1.82	0.19	6.53	2.36	0.24	4.33	0.31
Cu	3.53	3.44	10.23	4.4	15.74	0.87	6.09	57.77	1.2	5.09	1.64	0.25	2	0.65	0.39	1.04	0.74
Mn	3.47	3.35	3.39	6.74	18.02	0.61	3.47	2.76	0.47	42.57	0.38	0.57	5.21	17.16	0.71	2.89	0.51
Mo	0.2	0.19	0.08	0.55	0.68	1.38	0.16	0.03	1.04	0.3	0.04	0.61	0.15	0.05	1.23	11.78	0.59
Ni	4.15	4.09	12.59	2.56	3.51	0.72	5.19	42.65	1.2	3.27	1.38	0.36	2.58	6.53	0.89	2.31	0.76
P	23.33	21.86	9.09	30.88	238.03	0.5	17.89	26.83	0.62	1.3	0.66	0.61	30	4.76	0.36	38.89	0.27
Pb	0.38	0.37	0.03	0.55	0.23	0.83	0.39	0.18	1.01	0.42	0.01	0.24	1.36	0.59	0.56	2.33	0.34
Sn	0.2	0.19	0.03	1.23	1.74	1.03	0.21	0.03	0.85	8.37	26.2	0.6	0.38	0.07	0.65	0.98	0.2
V	6.76	6.37	1.07	3.59	4.65	0.59	3.48	15.69	1.04	0.31	0.03	0.52	4.05	0.79	0.22	2.11	0.51
Zn	1.84	1.77	1.36	1.8	9.94	1.59	1.59	0.46	0.42	5.44	5	0.41	1.47	0.55	0.5	1.44	0.44
Number of samples	45 range 1			149 range 2			73 range 3			105 range 4			21 range 5			11 range 6	

NOTES: A-grade- truncated average grade; Var. f. – variation factor; Disp. – distribution dispersion

Mean content

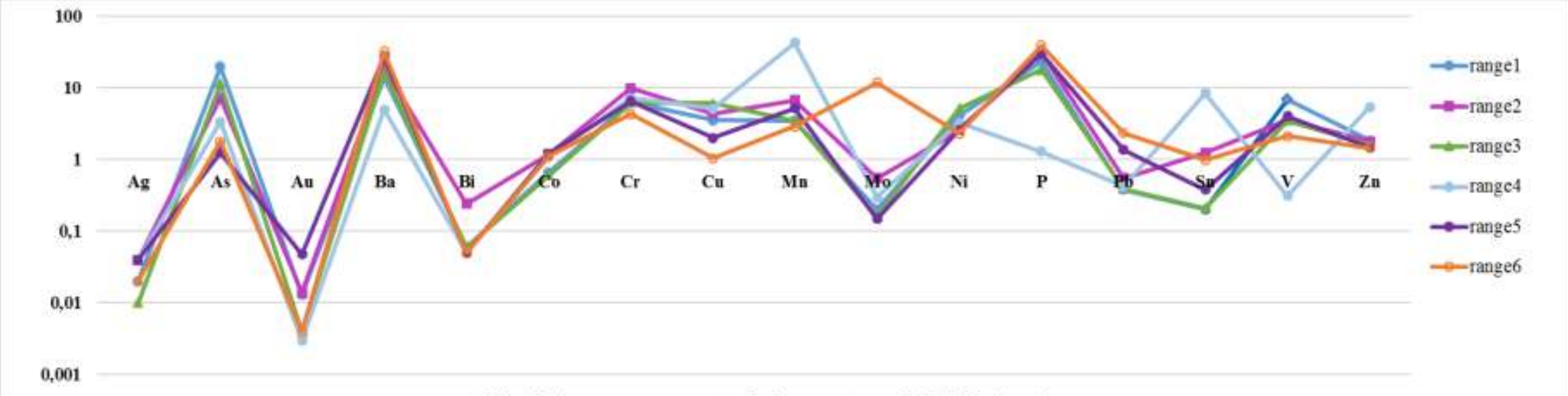

Fig. 5. Average content of elements n x 0.001% Au g/t

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Table 5: **Variation factors of elements contents in the stratified sequences of Karatau mountains of the Southern Nuratau Ridge** (staging of local data basis (LDB) of geochemical materials)

Element	Nurata-Lyatobandskiy (NL) sedimentary complex (SC)																
	Kalsarinskaya suite						Badamchalinskaya suite			Nakrutskaya suite			Djazbulakskaya suite			Metamorphogenic silicification	
	NL-Karak-C_{2-3-1}			NL-Karak-C_{2-3-2}			NL-Karak-O			NL-Karak-S_{1-1}			NL-Karak-S_{1-2}				
	A-grade	Disp.	Var. f.	A-grade	Disp.	Var. f.	A-grade	Disp.	Var. f.	A-grade	Disp.	Var. f.	A-grade	Disp.	C-var.	M-con.	C-var.
Ag	0.02	0.00	1.12	0.02	0.00	1.50	0.01	0.00	0.89	0.01	0.00	0.83	0.04	0.00	1.13	0.01	1.26
As	1.00	0.00	0.01	5.13	209.96	2.08	1.50	0.00	0.01	4.22	45.73	1.41	1.27	2.91	1.22	1.00	0.54
Au	0.003	0.00	0.01	0.003	0.00	2.71	0.00	0.00	0.01	0.01	0.00	3.01	0.01	0.00	2.07	0.024	5.85
Ba	15.22	244.60	0.95	61.39	2235	0.75	16.54	97.45	0.59	26.49	202.60	0.53	10.00	0.00	0.01	14.66	1.36
Bi	0.07	0.03	1.89	1.04	0.98	0.90	0.06	0.00	0.85	0.38	0.16	0.99	0.01	0.00	0.42	0.05	1.73
Cd	0.02	0.00	2.13	0.94	1.99	1.33	0.05	0.00	0.01	0.57	0.44	1.07	0.05	0.00	0.01	0.05	0.01
Co	1.78	0.86	0.51	4.73	3.09	0.37	2.68	3.26	0.67	3.16	1.67	0.41	1.37	0.60	0.56	1.72	0.60
Cr	7.20	4.28	0.29	8.65	7.80	0.33	8.35	5.32	0.28	8.49	5.92	0.29	5.69	6.90	0.46	6.96	0.34
Cu	3.57	1008	4.18	5.59	21.36	0.80	1.60	2.25	0.87	3.63	6.67	0.67	5.20	28.78	0.97	1.59	0.76
Ga	1.66	1.21	0.66	7.05	9.07	0.43	2.11	1.66	0.61	3.94	4.16	0.51	0.25	0.00	0.01	1.43	0.72
Ge	0.05	0.00	0.01	0.77	0.79	1.07	0.05	0.00	0.01	0.30	0.10	0.94	0.05	0.00	0.01	0.09	1.92
Mn	14.72	1900	2.14	3.00	0.00	0.01	18.83	986.10	1.44	50.81	230.60	0.30	2.50	0.00	0.01	17.25	0.99
Mo	0.29	0.11	1.09	0.16	0.16	2.09	0.24	0.07	1.06	0.05	0.00	0.34	0.22	0.03	0.72	0.19	3.64
Nb	0.18	0.13	1.91	0.38	2.35	2.88	0.27	0.18	1.52	0.19	2.31	3.49	0.15	0.00	0.01	0.24	1.64
Ni	4.96	9.80	0.63	4.09	1.78	0.32	6.55	19.63	0.66	2.59	0.71	0.33	3.42	4.41	0.60	3.84	1.10
P	26.74	82.27	0.34	10.00	0.00	0.01	28.85	1668	4.86	10.00	0.00	0.01	10.00	0.00	0.01	24.38	0.67
Pb	0.44	0.38	1.21	4.70	8.80	0.62	0.41	0.06	0.59	5.98	4.16	0.34	1.04	0.60	0.74	0.58	0.73
Sn	0.51	0.11	0.64	0.77	0.07	0.34	0.83	0.36	0.71	0.72	0.06	0.33	0.23	0.01	0.43	0.38	0.63
Tl	67.96	1184	0.51	546	25392	0.29	69.73	1532	0.55	567.20	206.00	0.26	10.00	0.00	0.01	65.81	0.67
V	2.88	2.55	0.55	34.51	2658	1.29	4.06	4.53	0.52	21.33	68.25	0.39	12.51	60.09	0.61	2.27	0.51
Zn	0.84	1.84	1.33	9.80	31.13	0.56	0.97	0.25	0.51	7.14	9.02	0.42	12.26	41.35	0.52	0.86	3.29
Number of samples	48 - range 1			49 - range 2			54 - range 3			38 - range 4			100 - range 5			75 - range 6	

NOTES: A-grade- truncated average grade; Var. f. – variation factor; Disp. – distribution dispersion

Geochemical associations were observed in the first (As–Zn–Mo–Ag), second (Sn–V–Co–Ti–Cr), and third (Mn–Ba–Ag–Au) factors.

The distribution of chemical elements in the Aktau and Darasai rocks of the Aktau–Malguzar sedimentary complex (with below-background concentrations of most elements) is homogeneous, as reflected by low variation factor values.

In the granitoids of the Darasai and Shurak subcomplexes, with below- and sub-background average grades of most elements, increases in average grades relative to regional background values were observed for Ba, Mo, P, Pb, Sn, and Li.

Spatiotemporal analysis of the geochemical features of the studied stratigraphic and intrusive subdivisions of the structural–material associations of southern Nuratau rocks enabled the identification of five types of geochemical complex:

I) $Є_2$-$O_{1\text{-}2}$: Weakly specialized, siderophilic (Ni, Zn, Cu, Co, V, Cr, Ti), intensively differentiated complexes, typically with epigenetic redistribution, loss of genetic ore elements (Au, Ag, As), and locally increased grades of P and Mn.

II) $O_{2\text{-}3}$: Near-background, siderophilic (Ti, V, Zn), and slightly differentiated complexes.

III) S_1: Weakly specialized, oxyphilic–chalcophilic–siderophilic (V, Cr, Ti, Ni, Zn, Cu, Ag, Pb, Ba, P, Sn, Mo), differentiated complexes with epigenetic concentrations of Au, Ag, As, Cu, and Pb and other elements reflecting ore formation processes.

IV) S_2-C_2?: Below-background complexes with homogeneous element distributions.

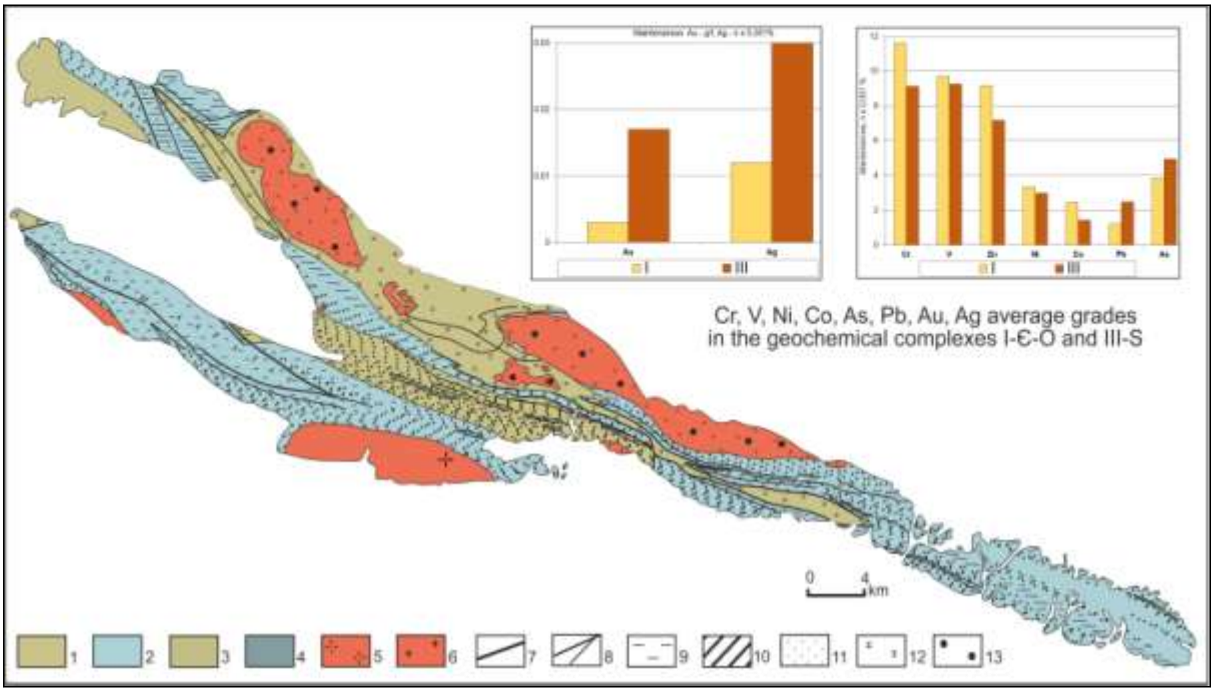

Fig. 6. South Nuratau geochemical rock complex properties

Sedimentary rock complexes (SRCs), including typical sections of structural formation subzones with the same names: 1, Aktau–Malguzar; 2, Nuratau–Lyatoband; 3, Koytash–Zaaminsky; 4, Tamdytau–Nurata. intrusive complexes: 5, Karatau leucogranite P_1; 6, Shuraksky granite–adamellite C_2-P_1. Tectonic faults: 7, overthrust zones between SRCs; 8, sub-concordant and crosscutting tectonic faults of various genetic types. Geochemical complexes: 9, I) $Є_2$-$O_{1\text{-}2}$, weakly specialized, siderophilic (Ni, Zn, Cu, Co, V, Cr, Ti), intensively differentiated; 10, II) $O_{2\text{-}3}$, near-background, siderophilic (Ti, V, Zn), slightly differentiated; 11, III) Si, weakly specialized, oxyphilic–chalcophilic–siderophilic (V, Cr, Ti, Ni, Zn, Cu, Ag, Pb, Ba, P, Sn, Mo), differentiated; 12, IV) S_2-C_2 ?, below-background values with homogeneous element distributions; 13, V) $C_{2\text{-}3}$, sub-background values with homogeneous and inhomogeneous distributions in correlated geochemical associations of lithophilic elements (Sn, Li, Mo, Mn, P, Ba).

V) C_{2-3}: Below-background complexes with homogeneous–inhomogeneous (irregular) element distributions, typically with correlated geochemical associations of lithophilic elements (Sn, Li, Mo, Mn, P, Ba).

The spatial distribution of geochemical complexes in the sedimentary, metamorphic, and intrusive complexes in southern Nuratau is apparent due to its block structure, which developed during the post-collisional stage of the territory's development.

Geochemical Evolution

The differences in geochemical complexes in temporal terms reflect the geochemical evolution trend of pre-Mesozoic sedimentation (Figure 6). This temporal trend in geodynamic sedimentation environments is characterized by a shift from essentially siderophilic early element complexes to siderophilic–chalcophilic complexes with low lithophilic element contents. The degree of differentiation of the geochemical complexes, which is an overall statistical indicator of the migration ability of elements within rock associations, is reduced.

The Karakchatau Mountains, as an integral part of the regional South Nurata Shear Zone, are composed of intensively dislocated pre-Mesozoic formations, represented by two main rock types: (1) sedimentary–metamorphosed terrigenous, metavolcanic, siliceous, and carbonate rocks of $Є_{2-3}$-S age; and (2) magmatic dike formations with mid-basic and acidic compositions of S_2-P age and volcanic pipes of alkaline basaltic rocks of more recent age (T). Features of the tectonic structures include the prevailing west–northwestern to northwestern strike of early tectonic structures and the northeastern and north–northwestern strikes of later block-forming tectonic faults. Favorable geological and structural conditions for gold mineralization are associated with areas of long-term tectonic–magmatic activation in metalliferous sediments of contrasting lithological composition. The location of gold-ore occurrence is under clear stratigraphic control, associated with Cambrian and Ordovician sediments (Kalsarinsky and Badamchalin suites). These suites could be sources of gold in the processes of ore formation.

Thus, regional geochemical properties truly reflect the geological evolution of a territory as a whole, as well as its developmental features at individual stages. The study of rock geochemical properties is a traditional approach in regional geochemistry. It is multifunctional and has multiple components, and various methodological approaches are utilized.

CONCLUSION

This study was conducted under the framework of the project "Allocation of Prospective Gold Prospecting Areas in South Nuratau Based on a Set of Geological and Geochemical Criteria." Based on case studies and field observations, local forecasting based on a set of geological and geochemical criteria, representing ore-controlling factors of geological genetic models of gold mineralization and informative geochemical characteristics, was performed, and prospective target areas and local areas for gold–quartz and gold–sulfide–quartz types of endogenous mineralization were identified.

An analysis of the predicted results showed that the main gold-bearing prospects are in the Karatauk ore zone, whereas the forecasts for the Pashattau, Bakhiltau, Aktau, and Karakchatau mountains are less significant, but are steadily replenished in various versions of forecast maps.

Recommended methods of prospecting in the dedicated areas include advanced specialized prospecting, searches in under-studied prospective structures, and in-depth searches and evaluations in mineralized zones with extensive and uneven gold mineralization.

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