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Application of Multivariate Statistical Analysis for Delineation of Prospective Geochemical Anomalies in Providenskaya Area (Chukotka, Russia)

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Abstract The secondary geochemical field structure was modelled on the basis of the lithogeochemical dispersion trains of the Providenskaya Area of the Chukotka Peninsula. The factor and cluster analysis were applied to interpret the nature of geochemical anomalies. It was proved that a range of anomalies were prospective for gold-silver, polymetallic, tin, and tungsten deposit allocation.

1. Introduction
The intensity and degree of potential are the main features of ore-associated geochemical anomalies (GA). The intensity is usually assessed by a multiplicative index. The degree of potential is assessed by a complex of favorable geological prerequisites and geochemical characteristics [1]. The methods of a multivariate statistical analysis including the factor and cluster analyses may be used to characterize the GA inner structure and estimate the degree of potential [1], [2].

2. Research technique
The current research is based on the results of dispersion train lithogeochemical sampling in the Providenskaya Area of the Chukotka Autonomous Region (Russia) (Figure 1). 2288 samples of a sandy-sludge alluvial fraction were analyzed. The content of chemical elements was determined in the laboratory of the East-Chukotka Geological Expedition with the use of following methods. A fire assay finish and an atomic absorption method were used for gold and silver, an X-ray spectral one for uranium and thorium; a chemical one for copper, lead, zinc, and tin. The multivariate statistical analysis was carried out by Statistica software of StatSoft company.

3. Research results
The territory under consideration is formed by the variously dislocated and metamorphosed Archean, Rifean, and Paleozoic marine sediments, the volcanogenic continental Mesozoic formations, and the unconsolidated Quaternary sediments (Figure 2).

The Archean is represented by deeply metamorphosed rocks of Penkigney series: various gneisses, marbles, amphibolites, crystalline schists. The Riphean rocks are metamorphosed limestones, porphyrites, crystalline schists, metasiltstones, metasandstones, and rare thin interbeddings of spilite. The Paleozoic sediments include Devonian argillaceous slates and limestones.

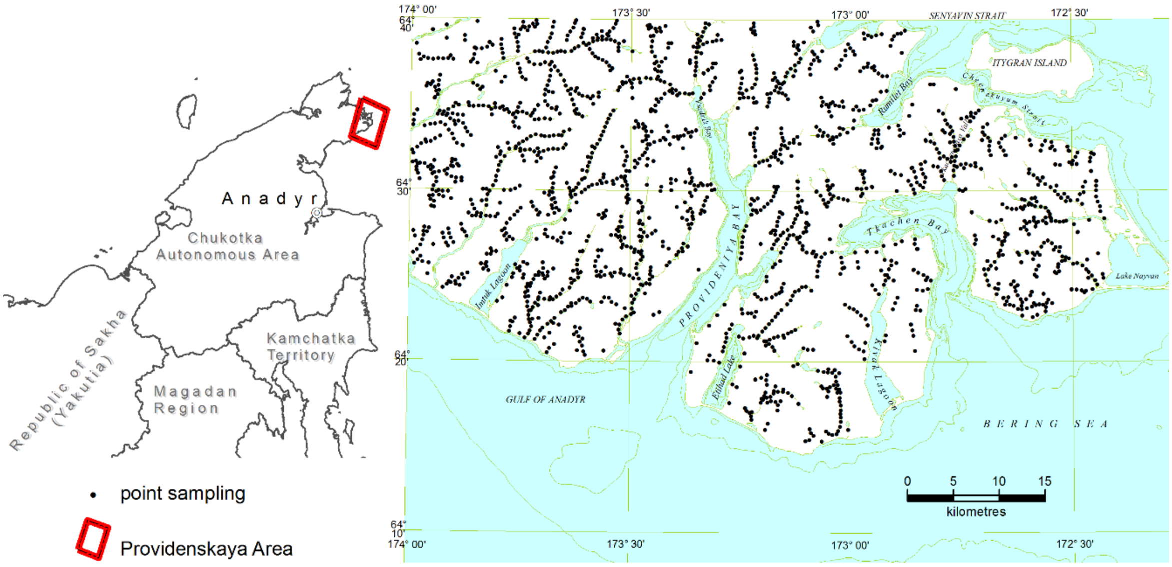

Figure 1. Survey map of the study area

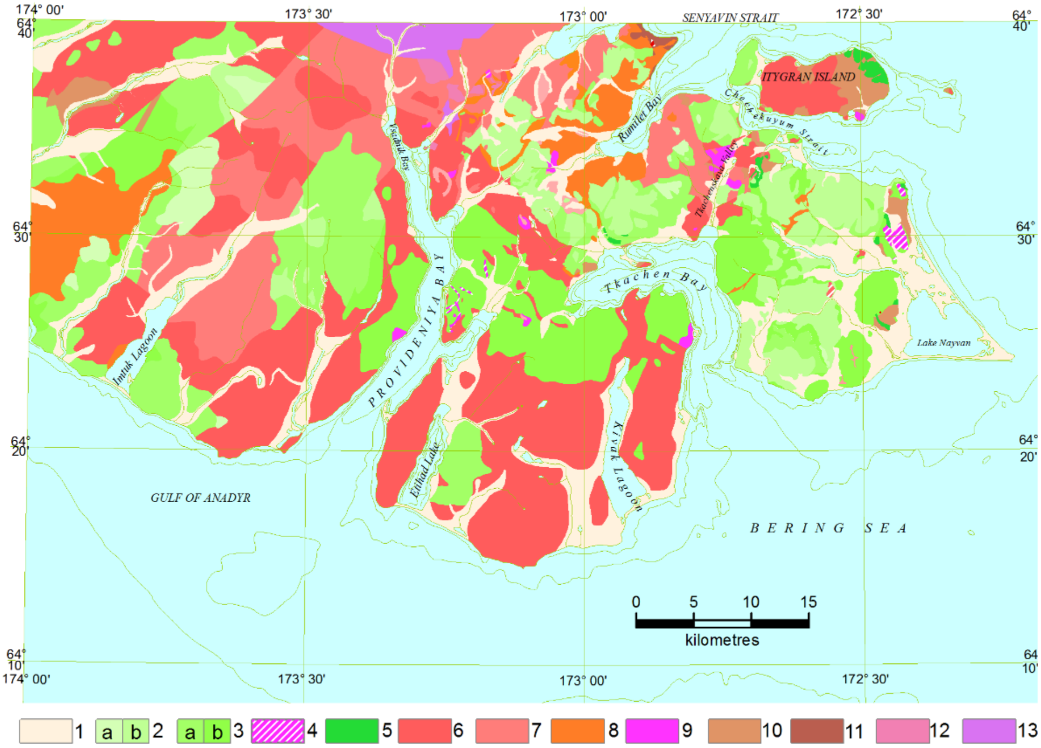

Figure 2. Geological map:

Legend: 1 – Quarternary; Cretaceous: 2 - Upper. a - Coniacian. Providens set, b - Turonian. Leurvaam suite; 3 - Lower. a - Hauterivian. Amgen set, b - Argyt set; 4 - Subvolcanic bodies. Argyt volcanic complex. Andesite; Plutonic bodies: 5 - Erguveem complex. Gabbro; 6 - Taureran complex. Granodiorite; 7 - Leurvaam complex. Granite; 8 - Leurvaam complex. Leucogranite; 9 - Providens complex. Diorite; Devonian: 10 - Ikychuren suite; 11 - Tanatap suite; 12 - Riphean. Kelkhin series; 13 - Archean. Penkigney series.

All the mentioned rocks are covered by the Cretaceous volcanites of felsic, intermediate, and rarely mafic composition that belong to the Okhotsk-Chukotsky Volcanogenic Belt. The Quarternary sediments are presented by marine, glacial, glaciofluvial, lacustrine, alluvial, and deluvial sediments.

The methods of multivariate statistics are widely used for the genetic interpretation of anomalous geochemical fields. Generally, these methods are the factor and cluster analysis [3], [4], [5], [6]. The geochemical fields linked with the ore deposit formation are also clearly distinguished in the multivariate geochemical field structure [7], [8], [9], [10].

The authors studied six factors during the factor analysis that contribute 60% to the total dispersion (Table). The factor values were calculated for each sampling point.

The first factor illustrates 18% of the total dispersion variation. Ti, Sc, V, Mn, Co, and Zr play a major role in the factor feature structure. According to the factor elemental composition and its location, it probably characterizes the least altered host rocks (Figure 3).

Table. Matrix of factor weights.

Substances	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
Au	-0.01	0.86	-0.07	-0.03	-0.06	-0.02
Ag	-0.03	0.94	0.02	0.04	0.09	-0.05
Pb	-0.09	0.30	0.29	0.29	0.28	-0.06
As	0.00	-0.06	0.14	0.46	0.04	0.04
Cr	0.03	0.00	0.00	0.01	0.00	0.90
V	0.72	0.06	-0.25	0.42	-0.10	0.12
Ni	0.12	0.05	0.00	-0.05	0.02	0.92
Mn	0.70	0.12	0.10	-0.17	0.15	0.21
Ba	0.41	-0.08	0.00	0.36	-0.16	-0.07
Nb	-0.03	-0.05	0.80	0.14	0.02	-0.05
Mo	-0.01	0.05	0.32	0.12	0.24	0.08
Sn	-0.07	-0.06	0.00	0.22	0.75	-0.04
Cu	0.19	0.89	-0.03	-0.02	0.02	0.23
Zn	0.26	0.46	0.21	0.13	0.30	0.04
Sc	0.79	0.04	0.14	0.02	-0.04	0.14
Y	0.03	-0.01	0.80	0.06	-0.04	-0.05
Ga	0.06	-0.02	0.21	0.79	-0.11	-0.11
W	0.35	0.03	-0.21	0.14	0.45	0.11
Co	0.57	0.24	-0.15	0.03	0.06	0.62
Ge	0.01	0.07	-0.09	0.47	0.14	0.11
Bi	0.05	0.18	-0.04	-0.12	0.78	0.07
Ti	0.85	0.03	-0.07	0.15	-0.01	0.04
Be	-0.06	-0.04	0.49	-0.32	0.59	0.02
Zr	0.52	-0.02	0.51	-0.25	0.08	0.08
Li	0.21	0.04	-0.11	0.70	0.15	0.04

The second factor defined by Au, Ag, and Cu is unambiguously treated as the main ore-bearing one. More perspective anomalous zones can be distinguised according to the factor intensity, spatial and associative patterns of monoanomalies. One of such anomalies is situated in the area of Rumilet Bay, where complex ore anomalies have been identified. The anomalies in the area of Endogurov Promontory and further along the Annyuvaam River include monoanomalies of gold, silver, zinc, partially lead and copper. The anomaly in the Tkachenskaya Valley is coherent with the anomalies of gold, silver, and copper. The anomalies in the vicinity of Senyavin Highland include monoanomalies of gold, silver, and copper. All the selected anomalies belong to the ore-associated GA (Figure 3).

Several ore formations can be presumed by the content of chemical elements. They are considered to be a gold-silverore formation, a polymetallic (lead-zinc) with silver one, and a polymetallic skarn one at the current stage of work.

The third factor illustrates 10% of total dispersion variation. This factor predominantly influences yttrium, niobium, zirconium, beryllium, and to a lesser extent, molybdenum and lead. The granitoid Rumilet and Kyndlyagak Massives are characterized by the anomalous values of this factor. They belong to the subalkaline granites of the second phase of the Leurvaam complex (Figure 3). Both massives are spatially coherent with the monoanomalies of niobium and beryllium. The yttrium anomaly is observed in the Kyndlyagak Massive, and the zirconium and molybdenum one in the Rumilet Massive. The outstanding high values of the third factor also occur in the Mainykvyn River headwaters (the Oleniy Stream) and in the Tkachenskaya Valley that might indicate the presence of similar subalkaline granites at these locations.

The set of elements with strong positive bonds can be regarded as a sign of feldspar metasomatism in this factor. The researchers of the region have proposed the hypothesis of a metasomatic origin of the Rumilet Massive granites. The anomalies overlaying the volcanogenic rocks may indicate that the similar metasomatic processes occur in the volcanites as well.

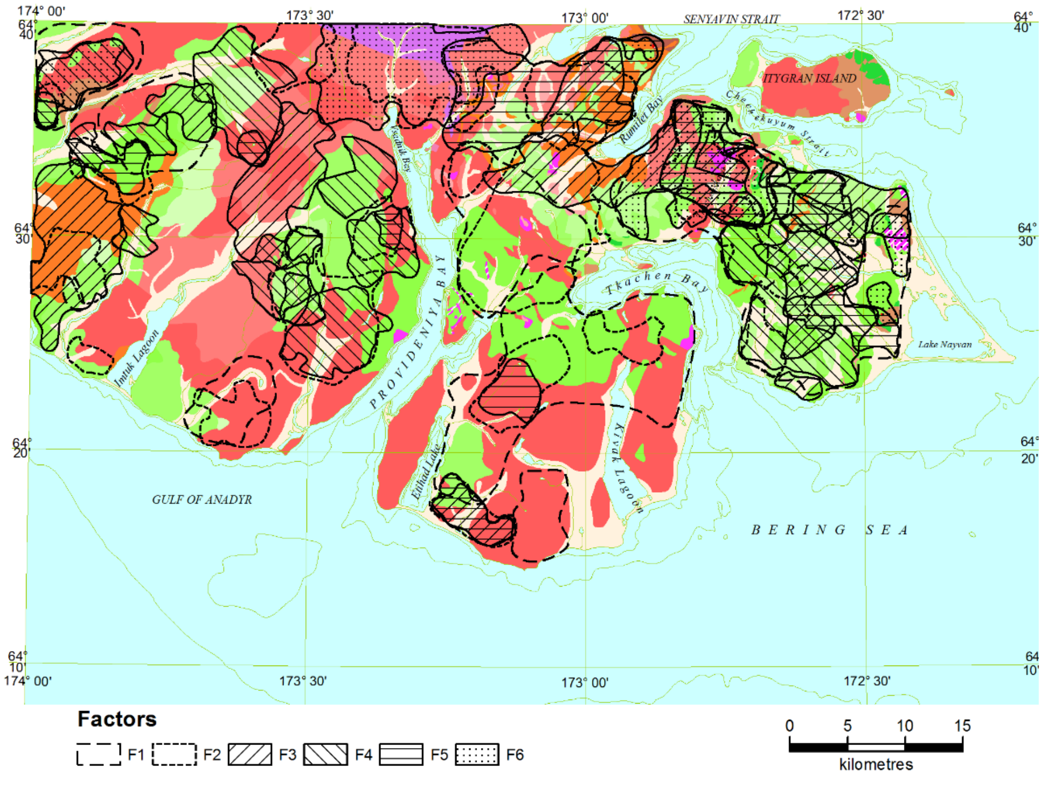

Figure 3. Allocation of factor anomalies in Providenskaya area

The forth factor contains 10% of information. It has a significant positive bond with gallium, lithium, germanium, arsenium, vanadium, barium, lead and a negative one with beryllium and zirconium. Geologically these anomalies are aligned with the zones of volcanite floods (e.g. the largest anomaly on the Chaplin Peninsula). These anomalies mainly coincide with the complex GA associated with ore mineralization, but they apparently are of petrogenic nature.

The fifth factor has strong correlations with bismuth, tin, beryllium, slightly weaker ones with tungsten, zinc, lead, and the weakest ones with molybdenum. The largest anomaly stretches from the Udobnaya River to Rumilet Bay. It is spatially aligned with monoanomalies of bismuth, tin, beryllium, lead, zinc, and partially molybdenum. Three intensive lesser-scale anomalies are outlined on the right bank of the Sineveem River (the Lysaya mountain), in the vicinity of Endogurov Promontory, and alongside the Ulhum River. The anomalies of the fifth factor are almost completely included in the selected GA associated with ore mineralization. Generally, a range of significant elements in this factor is characteristic for tungsten (quartz-forsterite) and/or tin ore formation. This may indicate that the intensity and prospects of GA increases.

The analysis of the sixth factor feature structure shows that this factor load is determined by the nickel, chrome, and cobalt concentration. The factor geological position coincides with the areas of the Paleozoic and Riphean-Archean rocks development. The most intensive and extensive anomaly is situated in Vsadnik Bay headwaters, the Pervomaisky Stream, the Ulev and Udobnaya rivers. This anomaly is formed by the ablation of disintegrated material from Senyavin Highland of the Riphean-Archean Vostochno-Chukotskiy Massive. The anomalies of the sixth factor are largely included in the selected (primarily by a multiplicative factor) geochemical anomalies associated with ore mineralization.

As a result of cluster analysis, five clusters of chemical elements are distinguished: cluster 1 – Ag, Cu, Au; cluster 2 – Pb, Zn, Li, Ga, W, Ge, As, Mo; cluster 3 – Nb, Y, Sn, Bi, Be; cluster 4 – Cr, Ni; cluster 5 – V, Ti, Co, Mn, Sc, Ba, Zr. The multiplicative anomalies were calculated according to the elements grouped in clusters. The gradations of four classes were visually selected, and then the anomalous areas were outlined for each cluster.

The cluster and factor analyses allow carrying out the more unbiased division of geochemical anomalies into petrogenic and ore-associated ones. The combination of the second and fifth factors can be a reliable indicator of the intensity and degree of potential of selected ore-associated anomalies.

4. Conclusion

Complex geochemical fields were outlined in the Providenskaya Area of the Chukotka Peninsula. These fields are generated by metamorphic, magmatic, volcanic, and hydrothermal-metasomatic rock formations. The associations of correlated chemical elements selected by the multivariate statistical methods indicate that various types of ore forming occur in the area. The delineation of complex anomalies provides an opportunity to localize the prospective areas of gold-silver, polymetallic, tin, and tungsten deposits.

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