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On ore-bearing capacity of Chuya anticlinorium granitoids (Baikal fold mountain area)

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Abstract. The article presents the results of a petrochemical recalculation study of ore-bearing capacity of the Chuya anticlinorium granitoids in Baikal fold mountain area (BFMT). It is shown that the early Proterozoic granitoids of Kuanda and Chuya-Kodar complexes composing the anticlinorium core are not sufficiently studied in mineralogical terms and, according to the geological survey data (GSD), are identified as barren formations, while the geological maps of the research area mark the presence of different ore mineral resources, the contiguous zones being Bodaibo province (gold-bearing) and Mama province (muscovite-bearing). Based on the available chemical tests data, petrochemical ore-bearing capacity modules have been defined using the known techniques and original charts by Z.G. Karajeva and B.N. Permyakov. In the chart by Z.G. Karajeva, most of the test samples fall into the field of the modified leukocratonic granitoids being mother rocks for the molybdenum, wolfram and tin deposits of the silicate and polymetallic formations as well as for the mica-bearing and partially, rare metal pegmatites. In the classification by B.N. Permyakov, the favorable combination of the petrochemical modules observed for most of the test samples allows referring them to various types of the granitoid fields with tin-wolfram-molybdenum mineralization. The conclusion is that further study of the granitoids is necessary to evaluate the geological position of the potentially ore-bearing facies and their fraction in the examined complexes.

1. Introduction

Baikal fold mountain territory (BFMT) is characterized by diverse magmatogene formations [1, 2, 3], its largest areas featuring different-age granitoids associated with the core parts of the anticlinorium structures (Chuya, Tonoda, Konkudera-Mamakan and Nechera).

The geological position and petrography of the complexes have been described in detail in multiple publications [1, 2, 3]. However, the mineragenic character of the various complexes magmatites is not yet thoroughly studied and therefore, is of a polemic character. In particular, this concerns Chuya anticlinorium that, together with Tonoda and Nechera anticlinorium structures form the external zone of the early Proterozoic formations [2]. The mineragenic character of the Konkudera-Mamakan anticlinorium granitoids has been clearly defined, referring them to the mother rocks for the gold-bearing deposits of Bodaibo province. As for the Chuya anticlinorium granitoids, there has been almost no research done, though the GSD-200 data indicate the presence of tin, uranium and gold both on the south-east and north-west (Malaya Chuya, Chaya et al.) slopes of the Chuya mountain range [1, 2, 3], the contiguous zones being gold-bearing (Bodaibo province) and muscovite-bearing (Mama province).
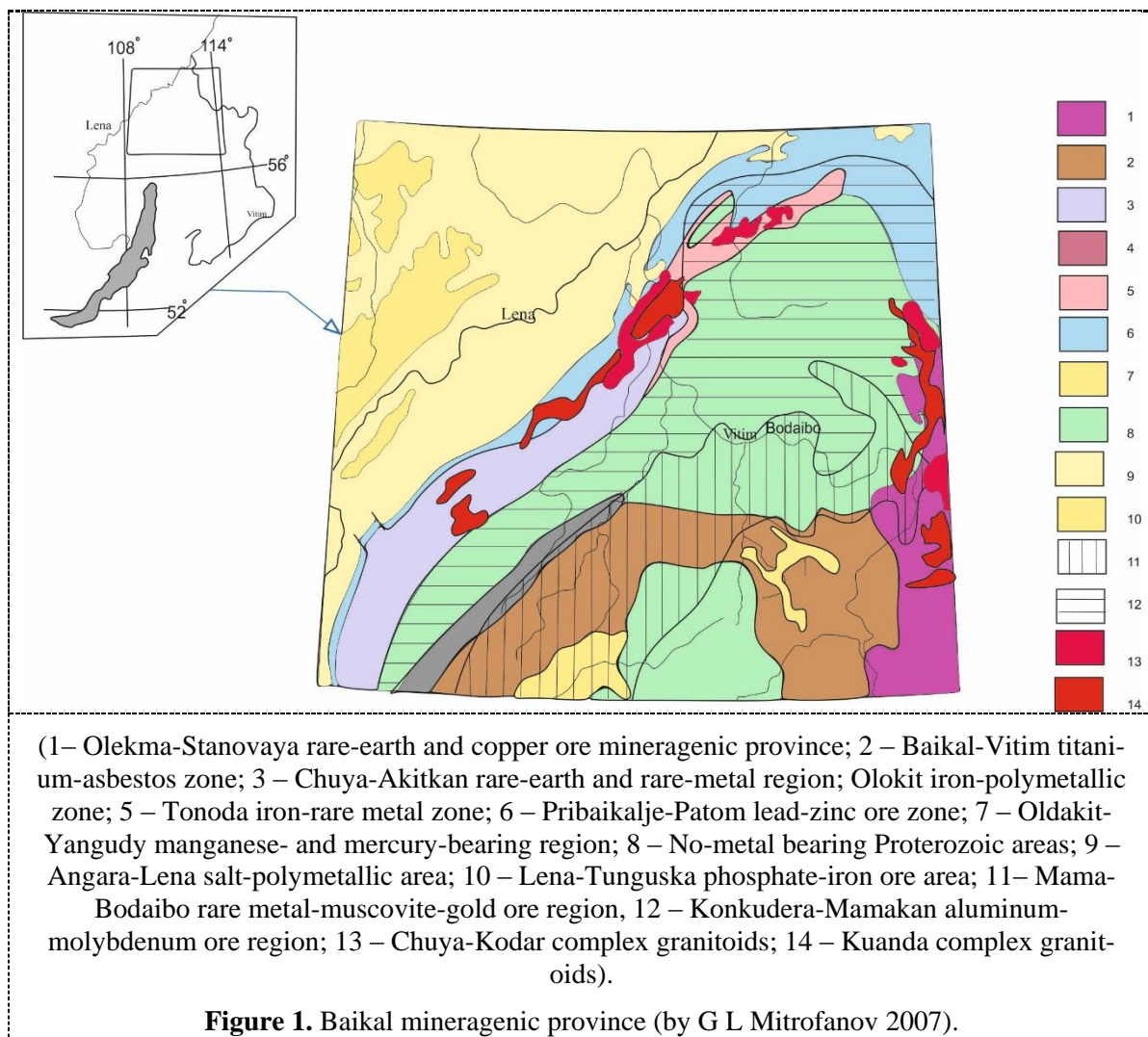
2. Materials and methods

The available specific techniques using petrochemical criteria allow a more grounded evaluation of the ore-bearing capacity of the Chuya anticlinorium granitoids.

A database [DB] has been created using the granitoids chemical test results, petrochemical ore-bearing modules have been defined following the methods by Z.G. Karajeva [4] и B.N. Permyakov [5], and their reference chart position has been analyzed.

3. Research results and analysis

According to the conventional magmatism chart by L.I. Salop [2], the Chuya granitoids field is mainly represented by the early Proterozoic Kuanda granite-gneiss rocks and Chuya-Kodar granitoids outcrops in Chuya-Akitkan rare-earth and rare-metal region (Figure 1).

(1– Olekma-Stanovaya rare-earth and copper ore mineragenic province; 2 – Baikal-Vitim titanium-asbestos zone; 3 – Chuya-Akitkan rare-earth and rare-metal region; Olokit iron-polymetallic zone; 5 – Tonoda iron-rare metal zone; 6 – Pribaikalje-Patom lead-zinc ore zone; 7 – Oldakit-Yangudy manganese- and mercury-bearing region; 8 – No-metal bearing Proterozoic areas; 9 – Angara-Lena salt-polymetallic area; 10 – Lena-Tunguska phosphate-iron ore area; 11– Mama-Bodaibo rare metal-muscovite-gold ore region, 12 – Konkudera-Mamakan aluminum-molybdenum ore region; 13 – Chuya-Kodar complex granitoids; 14 – Kuanda complex granitoids).

Figure 1. Baikal mineragenic province (by G L Mitrofanov 2007).

Kuanda granite gneiss and granitoids are present mostly within the external Chuya zone of baikalids and compose different-size solids protruded according to the tectonic structure of the metamorphic lower Proterozoic series. In the Bolshaya Chuya and Chaya river basins, they have a northeast orientation, and in Kodar-Udokan zone (the Kuanda, Chaya and Kalara rivers basins), north-west orientation. Further to the east, similar magmatites are registered by D.S. Korzhinsky in Stanovik-Djugdjura are under the name of *ancient-stan granites* [2]. As a rule, granites have a distinct gneiss

texture the direction of which in many cases coincides with the stratum orientation in the bearing rocks and in general repeats its tectonic pattern. Inside the granite solid masses, there are substrate xenolites and skialiths, sometimes, with indistinct, sometimes, with clear boundaries.

Chuya-Kodar complex granitoids lie in the field of Kuanda granite gneiss in the core part of the anticlinorium as batholite-type big solid masses (Chuya-Vitim, Haivergin, South Kevakta, etc.) having a somewhat oblong shape and stretched according to the fold structure strike. In the north-east direction, the granites are significantly overlapped by the upper Proterozoic deposits.

In the publications on BFMT geology, multiple silicate tests results are considered for different rock complexes, including Chuya anticlinorium granitoids, that have been used as a basis for the petrochemical database developed [6]. The database covers 26 tests of Kuanda and 18 tests of Chuya-Kodar complex, the recalculation allowing a preliminary estimate of the complexes ore-bearing capacity.

There are a few known methods of evaluating granitoids ore-bearing capacity, the methods by Z.G. Karajeva [4] B.N. Permyakov [5] seeming to be most grounded ones.

The method by Z.G. Karajeva [4] aims at evaluating ore-bearing capacity of the rare-metal granitoids modified due to the sodium metasomatism processes, using the processed results of 1,200 chemical tests by B. Sayan. It includes the ratios of alkaline and earth metals and making a binary chart in coordinates A=Na+K-Ca (abscissa axis), B=(Na-Ca)/K (ordinate axis) calculated in atomic quantities. The typical chart (Figure 2) empirically defines 10 granitoids fields with different mineralization depending on the modules relation:

1. Non-modified granodiorites – A=100-130, B=0.65-0.8.
2. Non-modified monzonites and adamellites – A=130-165, B=0,35-0,7.
3. Non-modified granites A=165-190, B=0.65-0.8,
4. Non-modified alaskites – A=200-220, B=0.7-0.9.
5. Modified granosienites (with casseterite-sulphide, molybdenum, wolfram and polymetallic mineralization) – A>200, B=0.1-1.0.
6. Modified biotite и leucocratic granites (mother rocks for W, Mo, Be, Sn deposits of the sylicate and polymetallic formations, mica-bearing and partially, rare-metal pegmatites) – A=100-160, B>0.85.
7. Modified granites-alaskites (mother rocks for silicate and quartz deposit formations, rare-metal and crystal-bearing pegmatites) – A=200-220, B>0.95.
8. Granite mother rocks for W, Mo, Be deposits - A=100-160, B>0.85.
9. Tantalum-bearing granitoids with lithium mica – A=>220, B>1.1.
10. Tantalum-bearing granitoids with alkaline dark-color minerals – A>220, B>1.1.

On the whole, the ore-bearing granitoids have higher A and B module values.

Table 1. The Karajeva modules for the granitoids of Chuya anticlinorium.

Kuanda complex									Chuya-Kodar complex					
№№	Modules*		№№	Modules		№№	Modules		№№	Modules		№№	Modules	
sample	A	B	sample	A	B	sample	A	B	sample	A	B	sample	A	B
1к	205	0.79	10к	176	1.11	19к	174	0.50	1ч	180	0.94	10ch	178	0.84
2к	258	1.77	11к	111	6.59	20к	215	11.37	2ч	126	0.62	11ch	186	1.83
3к	113	2.12	12к	202	3.06	21к	179	0.70	3ч	184	0.93	12ch	185	0.66
4к	171	2.28	13к	109	1.92	22к	191	1.70	4ч	130	1.33	13ch	175	0.81
5к	124	1.16	14к	178	1.64	23к	95	5.91	5ч	86	0.36	14ch	148	0.56
6к	131	0.58	15к	181	5.21	24к	170	2.06	6ч	136	0.34	15ch	179	0.58
7к	88	6.46	16к	203	0.46	25к	205	1.04	7ч	163	0.62	16ch	158	0.77
8к	129	1.20	17к	191	1.02	26к	195	1.09	8ч	142	0.82	17ch	171	0.63
9к	175	3.13	18к	197	1.12				9ч	149	0.41	18ch	147	0.86

*Color-marked are high A and B modules values corresponding to the field of potential ore-bearing granites

The method has been tested when studying the archaic (by L.I. Salop) granite-gneiss-magmatite complexes of Priolkhonje [8] which in the above chart tend to fall into the field of mother rock granites for tin, wolfram, molybdenum deposits of silicate and polymetallic formations, rare-earth and rare-metal pegmatites. The data agree with the results of the specific mineragenic tests done by V.S.

Malykh and T.S. Michailova [7].

The Karajeva petrochemical modules for the granitoids of Kuanda and Chuya-Kodar complexes are presented in Table 1 and in Figure 2.

(Large-size figures are the field numbers for the granitoids with different mineragenic loads).

Figure 2. Position of the granitoids of Chuya-Kodar (red color) and Kuanda (blue color) complexes in the Karajeva chart
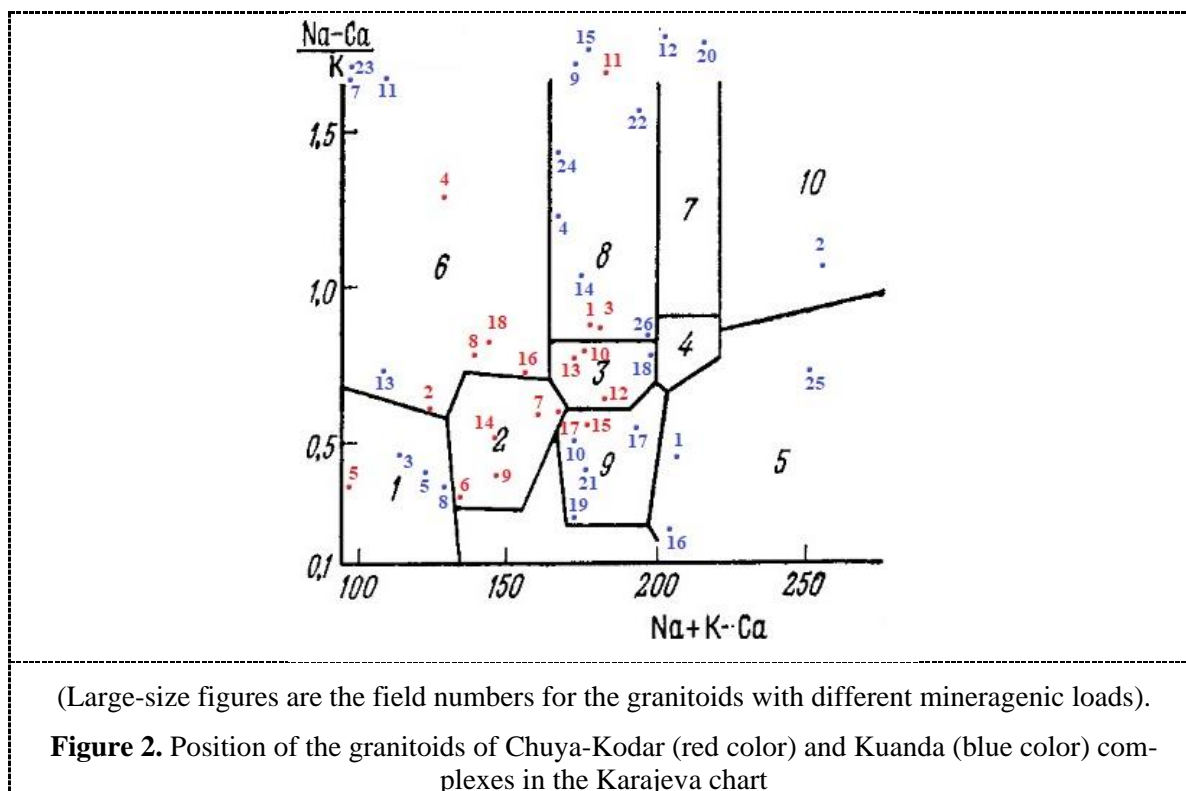
Table 1 and Figure 2 show that most of the samples (color-marked) have high values of module A (100–92% of the Kuanda samples and 94% of the Chuya-Kodar samples) and module B (0.80 – 81% of the Kuanda samples and 39% of the Chuya-Kodar samples), which is characteristic of ore-bearing granitoids. And the favorable ratio of module A and B is observed for 64% of the samples (including 73% of the Kuanda samples and 50% of the Chuya-Kodar samples) which as Figure 2 shows, fall into the field of the mother rocks for *wolfram, molybdenum, beryllium and tin*, as well as *mica-bearing and rare-metal pegmatites.*

Table 2. Limit values of the petrochemical modules of ore-bearing capacity for Zabaikalje granitoids by B.N. Permyakov [4].

Mineralization type	Petrochemical modules				
	q	c	a	f	n
I. Gold-polymetallic and polymetallic	0.49-0.60	0.12-0.31	0.65-0.80	0.32-0.53	0.59-0.76
II. Gold-molybdenum	0.62-0.70	0.15-0.24	0.72-0.85	0.32-0.52	0.49-0.66
III. Molybdenum	0.70-0.785	0.105-0.20	0.65-0.80	0.44-0.70	0.535-0.69
IV. Molybdenum-wolfram	0.74-0.76	0.01-0.07	0.90-1.01	0.70-0.825	0.52-0.61
V. Wolfram and fluorite	0.74-0.785	0.01-0.09	0.78-1.01	0.70-0.92	0.46-0.57
VI. Tin-wolfram и alkaline-rare metal	0.785-0805	0.02-0.08	0.75-1.00	0.59-0.97	0.49-0.61
VII. Niobium-fluorine, wolfram-niobium and fluorine	0.805-0.83	0.01-0.08	0.75-0.91	0.74-0.93	0.46-0.61

The method by B.N. Permyakov [5] is based on the study of the ore-bearing granitoids of Zabaikalje and includes calculation of the reference petrochemical modules: silica (**q**), calcareousness (**c**), alkalinity (**a**), ferruginosity (**f**) и alkalinity type (**n**). The modules reflect the ratios of atomic quantities for the main petrogenic elements:

- silica module q=[Si –(Na+K+Ca+Mg+∑Fe)] / Si,
- calcareousness module c=Ca/(Ca+Na+K),
- alkalinity module a=(Na+K)/Al,
- ferruginosity f=∑Fe/(∑Fe+Mg),
- alkalinity type module n=Na/(Na+K).

The limit module values for the ore-bearing granitoids of Zabaikalje are given in Table 2.

The results of the Permyakov petrochemical modules calculation for Kuanda and Chuya-Kodar granitoids are presented in Table 3.

Table 3. The Permyakov modules values for the Chuya anticlinorium granitoids.

Sample number	Modules*					Sample number	Modules					Sample number	Modules				
	q	c	a	f	п		q	c	a	f	п		q	c	a	f	п
Kuanda complex																	
1к	0.70	0.09	0.68	0.73	0.38	10к	0.74	0.13	0.74	0.72	0.45	19к	0.80	0.08	0.68	0.67	0.27
2к	0.61	0.13	1.03	0.65	0.59	11к	0.74	0.27	0.58	0.52	0.82	20к	0.77	0.04	0.79	0.77	0.92
3к	0.68	0.26	0.65	0.76	0.57	12к	0.72	0.10	0.84	0.74	0.73	21к	0.79	0.07	0.72	0.76	0.36
4к	0.67	0.16	0.86	0.89	0.64	13к	0.76	0.20	0.62	1.00	0.57	22к	0.79	0.03	0.68	0.23	0.62
5к	0.76	0.17	0.53	0.97	0.44	14к	0.76	0.11	0.71	0.47	0.57	23к	0.80	0.20	0.49	0.59	0.82
6к	0.72	0.18	0.72	0.82	0.22	15к	0.79	0.07	0.61	0.58	0.83	24к	0.80	0.10	0.68	0.71	0.64
7к	0.78	0.27	0.43	0.66	0.81	16к	0.78	0.08	0.74	0.67	0.26	25к	0.79	0.07	0.78	0.37	0.47
8к	0.75	0.19	0.68	0.83	0.44	17к	0.76	0.11	0.81	0.53	0.44	26к	0.81	0.05	0.81	1.00	0.50
9к	0.75	0.11	0.65	0.47	0.73	18к	0.78	0.07	0.76	0.67	0.49						
Chuya-Kodar complex																	
1ch	0.74	0.09	0.60	0.76	0.53	7ch	0.73	0.11	0.73	0.71	0.46	13ch	0.77	0.12	0.70	0.70	0.52
2ch	0.68	0.24	0.72	0.74	0.58	8ch	0.76	0.16	0.66	0.77	0.55	14ch	0.79	0.12	0.58	0.73	0.44
3ch	0.73	0.09	0.63	0.78	0.53	9ch	0.74	0.16	0.70	0.71	0.43	15ch	0.78	0.09	0.71	0.50	0.43
4ch	0.75	0.19	0.60	0.97	0.67	10ch	0.75	0.13	0.74	0.69	0.54	16ch	0.80	0.09	0.64	0.76	0.49
5ch	0.74	0.28	0.52	0.71	0.55	11ch	0.75	0.09	0.77	0.73	0.68	17ch	0.80	0.09	0.73	0.91	0.45
6ch	0.71	0.23	0.78	0.69	0.48	12ch	0.80	0.07	0.62	0.63	0.44	18ch	0.83	0.08	0.58	0.84	0.51

*Color-marked are high A and B module values corresponding the fields of potential ore-bearing granites

Table 3 shows that most samples (color-marked) have positive values of different modules, which is characteristic of ore-bearing granitoids:
- silica (q) - 100% of Kuanda and Chuya-Kodar samples,
- calcareousness (c) - 81% of Kuanda and 100% of Chuya-Kodar samples,
- alkalinity (a) - 69% of Kuanda and 56% of Chuya-Kodar samples,
- ferruginosilty (f) - 85% of Kuanda and 89% of Chuya-Kodar samples,
- alkalinity type (n) - 42% of Kuanda and 83% of Chuya-Kodar samples.

However, the favorable combination of the five modules is only observed for 34% of the samples (including 27% of Kuanda samples and 44% of Chuya-Kodar samples) that fall into the fields of different-type ore-bearing granitoids with tin-wolfram-molybdenum-rare metal mineralization. As the value fields of some modules for different granites overlap, we cannot refer this or that sample to a certain type of mineragenic associations.

4. Discussion

The calculation of the ore-bearing capacity modules for Kuanda and Chuya-Kodar complexes granitoids using the methods by Z.G. Karajeva [4] and B.N. Permyakov [5] and the test results presented in Tables 1-3 and Figure 2, allow us to identify the granitoids as mainly (except a few samples) potential ore-bearing formations.

In Figure 2, most of the samples fall into the field of the mother rocks for *wolfram, molybdenum, berillium and tin*, as well as *mica-bearing and rare metal pegmatites.*

By the combination of the Permyakov modules, most of the samples tend to fall into the fields of ore-bearing granitoids with tin-wolfram-molybdenum-rare metal.

The above defined petrochemical dependencies appear to be non-random as to the south-east of Chuya-Vitim solid body, there is Mama province, one of the biggest mica-bearing pegmatite provinces which to the south-west changes into the kindly rare metal pegmatite fields: Chaya, Kutim, et al. [7].

5. Conclusions

The use of the Karajeva and the Permyakov petrochemical modules in evaluating ore-bearing capacity of Kuanda and Chuya-Kodar complexes allow us to recommend the presented method for evaluating ore-bearing capacity of other granitoid complexes in BFMT and other regions on the condition that a representative sample of the silicate tests is available. Besides, additional study of the granitoids is needed to define and refine on the potential of different phases and facies of the rocks.

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