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Comparative Geochemistry of Granitoids and Metamorphic Country Rocks in the Western Angara–Vitim Batholith, Western Baikal Area

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Abstract—This paper presents materials of granitoids from the western Angara–Vitim batholith and the country gneisses and migmatites of the Talanchan Metamorphic Complex. The granitoids of the older intrusive phases of the Barguzin Complex are characterized by high dispersions in the contents of most trace element. The similarities in their trace-element signatures to those of metavolcanics of the Talanchan Group indicate that the latter could have served as a source of the granitoid melts. The increase in the K, Rb, Sn, Be, and REE contents from granitoids of the older phase of the Barguzin Complex to the main phase of this complex and further to the granites of the Zazin Complex is a result of melt fractionation which simultaneously became more uniform and acquired Eu minima. The group of calc-alkaline diorites is identical in composition to the metavolcanics and probably complements the latter. Metagabbro of normal alkalinity and synplutonic subalkali gabbro of the Oshurkov type are distinguished by composition and the relationships with the country gneisses and granitoids.

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INTRODUCTION

The Angara–Vitim granitoid batholith, one of the largest massifs in Asia, occupies a key position in the structure of the Baikal mountain region. A combination of multiphase plutons and small intrusions from 10 to 3400 km^2 in area are exposed at the modern surface over an area of about 135 000 km^2. The granitoid rocks vary in composition from monzonite, quartz monzonite, and granodiorite of the older phase to biotite granite and leucogranite of the younger phases. The Barguzin, Vitimkan, Chivyrkui, and Zazin granitoid complexes were recognized by previous researchers over the vast area of the batholith. Now the three former complexes are combined into one Barguzin Complex, as opposed to the Zazin Complex of leucogranites of elevated alkalinity. The Late Carboniferous age of the Angara–Vitim batholith has been established recently [1, 2]. The chemical composition of the granitoids was studied in detail by Litvinovskii *et al.* [3, 4], but only in the northeastern portion of the batholith. In addition to the main intrusive complexes, minor intrusions varying from gabbrodiorite to granite porphyry in composition occur in the western part of the batholith. In the process of geological mapping, they were provisionally referred to as the Mesozoic Gudzhir Complex, which was recognized in the Dzhida Zone of the Baikal region. Because no reliable dates are available for the igneous rocks in the western Angara–Vitim batholith, the comparative geochemical study of these rocks and their correlation with the country metamorphic rocks of the Talanchan, Chernogrivskaya, and Katkovskaya sequences are of primary importance.

V.A. Makrygina and Z.I. Petrova studied the geochemistry of the metamorphic rocks intruded by the Angara–Vitim batholith in order to correlate the metamorphic Talanchan Complex with the Ol'khon Complex. They have established that 80% of the gneisses belonging to the Talanchan Group and Chernogrivskaya Formation are interpreted based on geochemical signatures, as metaandesites, basaltic metaandesites, and less abundant metabasalts of calc-alkaline series typical of mature island arcs [5]. The rest of the rocks are composed of andesitic metagraywackes and marbles. This metamorphic sequence is readily correlated with the Anga Formation of the Ol'khon Complex, which was previously regarded as metaigneous rocks of a mature island arc [6]. The intrusive analogues of the island-arc volcanics are the multiphase granitoid plutons of the Khaidai Complex, which were also found in the Anga Formation. Their age should be refined, but available dates (~570 Ma obtained from whole-rock Rb–Sr isochron [6] and ~1200 Ma [7]) are older than the metamorphic event.

†Deceased.

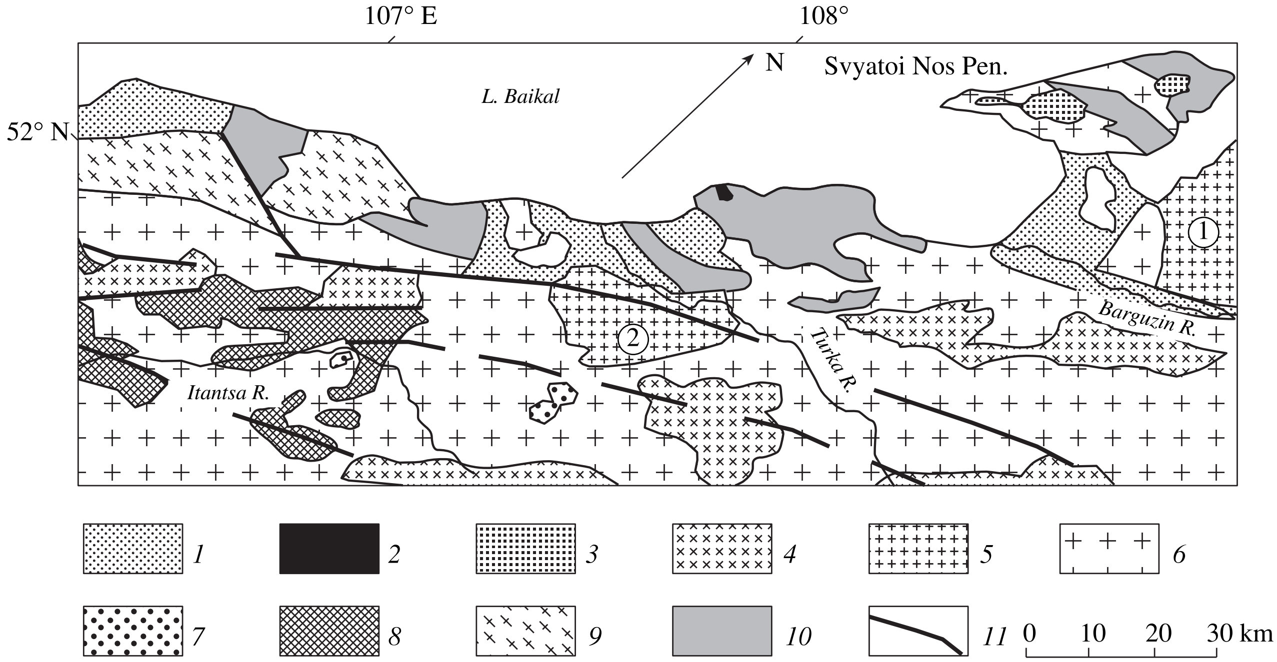

Fig. 1. Geological scheme of the eastern coast of Lake Baikal from the Svyatoi Nos Peninsula to the Selenga River (modified after V. G. Belichenko). (*1*) Quaternary sediments; (*2*) Mesozoic rare-metal granite, the Bezymyanny pluton; (*3–6*) granitoids of the Angara–Vitim batholith: (*3*) svyatonosite; (*4*) granite of the Zazin Complex; (*5*) early and (*6*) main intrusive phases of the Barguzin Complex; (*7*) subalkali gabbro; (*8*) rocks of the Selenga Group; (*9*) migmatites and (*10*) gneisses and schists of the Talanchan Metamorphic Complex; (*11*) faults.

We attempted to find intrusions of the island-arc type in the eastern coast of Lake Baikal and sampled all varieties of igneous rocks for this purpose. Due to the poor exposures and abundant granitoids of the Angara–Vitim batholith, this task was extremely difficult to accomplish. To identify the target plutons, we addressed to geochemical data. The material obtained by Makrygina and Petrova (samples VB) was combined with the voluminous geochemical data set on the western Angara–Vitim batholith collected by V.S. Antipin and colleagues (samples BKL); the latter data have been published only partly.

GRANITOIDS OF THE ANGARA–VITIM BATHOLITH

In subdividing the granitoid rocks of the batholith, we follow Litvinovskii *et al.* [4]. Their scheme provides for the two-stage emplacement of the Barguzin Complex. Granitoids of the early stage, with the Nesterikha pluton (600 km^2) as the reference intrusive body, comprise of monzonite, quartz monzonite, and granodiorite. The still larger Turka pluton, which is located farther to the south, consists of granitoids belonging to the early and main intrusive phases of the Barguzin Complex described in detail by Antipin and his colleagues (Fig. 1). The granitoids of the first intrusive phase are distinguished for porphyritic textures with large (2 × 4 cm) phenocrysts of K–Na-feldspar, although some of the rocks are equigranular. The orientation of feldspar phenocrysts is commonly almost parallel. In addition to alkali feldspar, these granitoids contain plagioclase $An_{25–30}$, quartz, hornblende, and magnesian biotite. Titanite, apatite, zircon, magnetite, and allanite are the accessory minerals.

Basic bodies of an ungeometric shape and as large as a few dozen meters across are typical inclusions in the early granitoids [4]. It is commonly accepted that the early granitoids are exposed over an area not less than 10% of the Angara–Vitim batholith. This value is probably a light underestimate, because similar Late Paleozoic monzonite, monzodiorite, syenite, and porphyritic granitoids make up the enormous Chivyrkui pluton that extends for 280 km from the mouth of the Barguzin River to the northern extremity of Lake Baikal. According to our observations, the granitoids of the older stage have intrusive contacts with the country metamorphic rocks and are, in turn, intruded by the granitoids of the main stage. At the same time, Litvinovskii *et al.* [4] described the gradual transitions between the country migmatites and granodiorite of the older stage and noted the widespread gneissic textures of the granodiorites. The extent of migmatization was not evaluated, and it remained unclear whether this phenomenon is of regional abundance and was related to metamorphism of the country rocks or was brought about by contact metamorphism that accompanied the emplacement of the batholith.

Table 1. Chemical composition of representative samples and average chemical compositions of the consecutive intrusive phases of granitoids belonging to the Barguzin Complex in the western Angara-Vitim batholith

Component	BKL267	BKL268	BKL269	BKL290	BKL291	BKL549	BKL550	1(15)	BKL265	BKL266	BKL292	BKL294	BKL295	BKL272	2(15)
SiO_2	62.95	64.25	65.12	66.27	61.47	66.83	64.28	64.27	69.4	69.14	64.65	67.12	69.6	71.46	70.94
TiO_2	0.54	0.52	0.44	0.56	0.82	0.39	0.54	0.61	0.32	0.43	0.67	0.54	0.47	0.25	0.32
Al_2O_3	16.25	16.25	16.85	16.2	16.5	16.87	17.37	16.61	15.35	14.7	16.2	15.9	15.2	14.65	14.8
Fe_2O_3	2.43	2.45	1.23	1.73	3.03	1.42	1.83	1.92	1.22	1.57	2.23	1.92	1.42	1.22	1.24
FeO	2.86	2.68	2.05	2.05	2.95	1.79	2.23	2.4	1.52	1.61	2.59	1.7	1.16	1.16	1.13
MnO	0.12	0.1	0.08	0.08	0.11	0.07	0.09	0.1	0.09	0.08	0.1	0.07	0.06	0.07	0.06
MgO	1.9	1.8	1.1	1.3	2	0.9	1.3	1.56	0.6	0.7	1.6	0.9	0.6	0.5	0.56
CaO	3.9	3.4	3	3.2	4.2	3.2	3.5	3.25	2	2.1	3.6	2.3	1.5	1.3	1.62
Na_2O	3.81	3.73	3.89	4.18	3.82	4.38	4.46	4.16	4.74	3.81	3.94	3.94	3.94	3.89	3.85
K_2O	3.79	3.79	4.86	3.76	4.24	3.36	3.78	3.82	4.04	4.6	3.26	4.58	4.95	4.35	4.75
P_2O_5	0.24	0.22	0.17	0.22	0.31	0.17	0.2	0.22	0.14	0.14	0.22	0.13	0.13	0.13	0.11
LOI	0.84	0.38	0.54	0.2	0.53	0.64	0.46	0.54	0.28	0.31	0.63	0.61	0.66	0.3	0.31
Total	99.63	99.57	99.33	99.75	99.98	100.02	100.04	99.46	99.7	99.19	99.69	99.71	99.69	99.28	99.69
Li	34	32	24	42	36	29	30	30	56	34	42	38	19	9	28
Rb	130	140	150	120	230	74	100	126	130	190	120	120	190	90	152
Ba	1300	1200	1000	970	1100	1700	2100	1395	960	800	940	1700	1800	1300	1200
Sr	890	850	1100	1000	890	810	1100	932	800	670	950	1000	410	690	648
Pb	30	40	40	20	43	26	18	26.8	20	40	24	33	24	42	47
Zn	110	140	62	12	100	45	56	83	54	72	100	98	35	72	148
Sn	6.9	12	9.5	2.3	15	5.3	2.4	7.7	5.9	10	5	11	1.7	6.2	9.7
Be	2	2.5	2.1	1.35	4	1.6	2.2	2.6	2.55	1.9	2.2	2.2	2	1.2	1.6
Cu	40	23	14	14	35	13	6.7	22	13	28	19	34	23	35	20
Co	9.6	5.7	4.6	6.2	12	4.5	1	8.5	4.6	5.1	7.9	5.8	4.6	5.8	4.3
Ni	10	4	4	6.8	7.2	3	1.9	5.6	3.5	4.5	7.5	4.3	4.9	8.3	4.7
Cr	9.1	9.7	6.4	10	21	11	4.8	9.5	8	5.5	3.8	7.8	9.1	7.8	7.3
V	100	64	41	110	110	43	6.5	71.5	45	48	110	59	35	32	31.3
Sc	17	7.2	6	9.3	16	4.2	1	5.8	3.7	5.5	11	4	3	3.7	7.2
Zr	160	160	110	105	n.a.	n.a.	n.a.	182	190	120	220	215	220	140	178
Hf	4	4.7	2.7	2.7	″	″	″	5.8	6	4	5	5	4.5	3.3	5.1
Nb	5.5	2.6	1.6	1	″	″	″	8	4.7	2.6	9.5	6	7	4	6.5
Ta	0.5	0.7	0.2	0.3	″	″	″	0.8	0.6	1	1	1.3	0.6	0.5	0.8
Mo	2	3.1	1.7	0.15	5.1	0.9	1.3	2.1	0.4	2.3	2.8	2	0.6	0.9	0.9
F	580	1200	700	600	1300	900	1500	1090	500	600	780	1200	460	350	535
B	7	25	15	3.8	19	4.4	4.1	13.8	6.9	11	27	5.3	3.5	2.7	4.4

Note: 1(15) average of monzonites and granodiorites of the first phase of the Barguzin Complex; 2(15) average of granites of the second phase; BKL267–295 are samples from the Turka pluton; BKL549 and 550 are samples from the Nesterikha pluton. Major oxides are given in wt %, trace elements are in ppm; numerals in parentheses are the numbers of samples.

Table 2. Chemical composition of representative samples and average chemical composition of samples belonging to the Zazin Complex

Component	BKL440	BKL438	BKL431	BKL449	BKL464	BKL459	Aver. (19)
SiO_2	65.4	71.72	72.99	74.8	71.33	73.42	71.24
TiO_2	0.46	0.25	0.15	0.24	0.36	0.24	0.28
Al_2O_3	16.6	14.38	15.01	13.14	14.46	14.49	15.09
Fe_2O_3	2.12	0.82	1.02	0.72	1.12	0.32	0.99
FeO	1.07	0.8	0.44	0.62	0.62	1.16	0.65
MnO	0.06	0.11	0.08	0.08	0.11	0.1	0.09
MgO	0.9	0.3	0.2	0.2	0.4	0.4	0.3
CaO	1.5	0.9	0.5	1.1	1	1.3	0.98
Na_2O	4.99	4.38	4.32	3.03	4.12	3.08	4.1
K_2O	6.16	5.27	5.16	5.57	5.71	5.2	5.69
P_2O_5	0.11	0.06	0.05	0.04	0.09	0.07	0.06
LOI	0.2	0.44	0.46	0.32	0.66	0.45	0.47
Total	99.57	99.43	100.38	99.86	99.98	100.23	99.94
Li	20	37	44	26	17	18	26.7
Rb	150	271	270	270	130	230	221
Ba	880	471	240	510	490	460	501
Sr	280	192	140	340	160	110	212
Pb	22	34	34	25	24	43	33.7
Zn	25	27	33	23	42	45	30.3
Sn	4	11	4.6	3.2	7.4	8.3	9.4
Be	3.4	7.45	3.8	3.4	2.4	4.5	3.85
Cu	3	3	5.4	3	3	8.3	5.3
Co	4.6	3.6	1.3	3.7	3.3	4.2	3.1
Ni	6.8	5.8	4.5	2.3	4.4	4.8	4.5
Cr	9.6	8.3	5.7	3.7	6.3	8.4	6.5
V	47	19	11	9	15	16	16
Sc	2.7	3.1	1.4	2	4.6	5.4	3.8
Zr	n.a.	190	170	220	180	140	180
Hf	″	6.5	5	5.5	6.5	5.5	6
Nb	″	19	16	20	12.5	12	15.9
Ta	″	1.2	1	1.7	0.9	0.7	1.1
Mo	0.8	0.4	0.5	1.3	0.8	0.7	0.78
F	700	350	300	400	600	500	443
B	3.6	3.2	1	3.3	3.7	5.5	3.8

Note: BKL431–449 are samples from the Angyr pluton; BKL459 and 464 are samples from the Kurba pluton. Major oxides are given in wt %, trace elements are in ppm; numerals in parentheses are the numbers of samples.

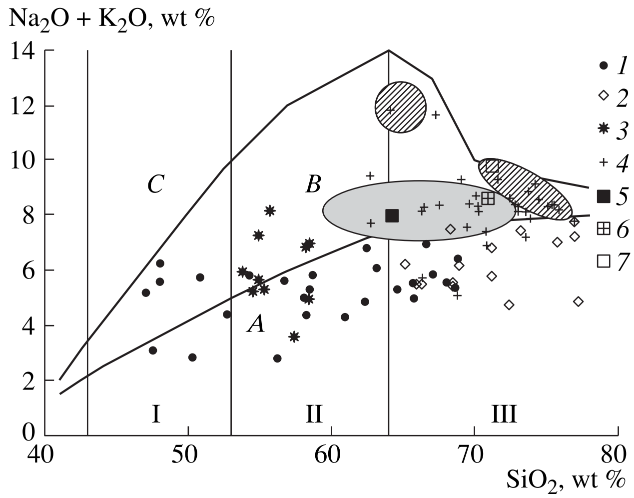

Fig. 2. TAS classification diagram [12]. (*1*) Gneisses and schists (metavolcanics) of the Talanchan Metamorphic Complex; (*2*) migmatites; (*3*) diorites and (*4*) granitoids (samples VB); (*5, 6*) average compositions of granitoids belonging to (*5*) 1st and (*6*) 2nd phases of the Barguzin Complex and (*7*) Zazin Complex and fields of their composition (shaded), after V.S. Antipin (samples BKL). (I–III) basic, intermediate, and acid igneous rocks; *A, B*, and *C* are the fields of rocks of normal alkalinity, subalkaline, and alkaline rocks, respectively.

The rocks of the second (main) intrusive phase occupy the largest volume of the Angara–Vitim batholith and are characterized by wide-structural variations at a little varying composition. The allochthonous facies of biotite and biotite–amphibole granite and less abundant granodiorite, occasionally porphyritic, are widespread in the western portion of the batholith. In the marginal parts of intrusive bodies, the rocks are often characterized by a linear orientation of biotite, amphibole, and other minerals, up to the formation of a taxitic texture. Granites are composed of K–Na-feldspar, often with a microcline lattice, sodic plagioclase $An_{15–22}$, quartz, biotite with a higher Fe/(Fe + Mg) ratio, and sporadic hornblende. Titanite, magnetite, zircon, apatite, allanite, and ilmenite are common accessory minerals. The autochthonous facies of the granitoids described by Litvinovskii *et al.* [4] in the eastern portion of the batholith are spatially related to large roof pendants of metamorphic rocks.

The granitic rocks of the Zazin Complex occur as a number of plutons and small intrusions largely in the southern Angara–Vitim batholith. The Zazin (3200 km^2), Kurba (3100 km^2), Ubukun (3000 km^2), Dzhidotoi (2600 km^2), and the Lower Uda (1500 km^2) plutons are the largest. According to Reif [8], the rocks of the Zazin Complex also may be subdivided into two intrusive phases. The older of these phases comprises granite and quartz syenite that are cut by small intrusions of biotite granite and leucogranite of the younger phase. In general, the rocks of this complex are more uniform in composition and structure in comparison with granitoids of the Barguzin Complex.

Despite the diversity in the structural features of the intrusive rocks, geophysical data demonstrate that all of them are exposures of a single granitoid pluton [4] in the central part of the vast Late Paleozoic Barguzin–Vitim igneous province. Separate intrusions of monzodiorite, subalkali granite porphyry, and rare-metal Li–F granites, as well as dike suites of ongonites, topazites, and other rocks (Bezymyanny, Kharagul, Urugudei intrusions and Utulik dike suite) occupy a different position in the framework of this province, along with abundant occurrences of alkaline igneous rocks; all these igneous rocks are also of Late Paleozoic age.

METAMORPHIC ROCKS

Outcrops of the Talanchan Group (Chernogrivskaya, Krestovskaya, and Katkovskaya formations) extend along the eastern coast of Lake Baikal. Farther to the northeast, the metamorphic rocks are traceable in the Svyatoi Nos Peninsula (Svyatoi Nos Formation) and in the Davsha River basin. Since these rocks are products of a single episode of amphibolite-facies metamorphism, it is convenient to combine them spatially into the Talanchan Metamorphic Complex. Thus the Talanchan and Chernogrivskaya formations are geochemically identical to the Anga Formation, and the Krestovskaya, Katkovskaya, and Svyatoi Nos formations are correlated with the Ol'khon sequence of the Ol'khon Metamorphic Complex [5]. The rather monotonous Talanchan Sequence consists largely of intensely migmatized biotite–amphibole and amphibole–biotite plagiogneisses. The huge granitic gneissic dome in the Sukhaya and Talanchanka interfluve, where the granite gneisses and migmatites do not reveal any relations to the intrusive granites, is the epicenter of migmatization. The degree of granitization decreases toward the Turka granitic pluton, which is a constituent of the Angara–Vitim batholith, although the older intrusive phase of this batholith exhibits an orientation of its mafic minerals, probably as a result of melt motion during crystallization. Crosscutting contacts are observed between the amphibole gneiss of the Chernogrivskaya Formation and the main intrusive phase of the Turka pluton. At the Svyatoi Nos Peninsula, the carbonate rocks and schists are cut by diorite, monzonite, and granite.

The Chernogrivskaya Formation is distinguished by the predominance of amphibole gneisses and amphibolites. According to the geochemical data, their protoliths likely correspond to island-arc tholeiites. The gneisses and schists of the Katkovskaya Formation are closer in composition to the metavolcanics of the Talanchan Group. The metamorphic sequences were described in detail in [5]. In this paper, we present the average compositions of

Table 3. Trace elements, ppm in K-Na-feldspars from granitoids of the Angara-Vitim batholith and from metamorphic rocks

Sample number	K, %	Na, %	Rb	Ba	Sr	Pb	K/Rb
	Barguzin Complex, the first phase						
BKL267	10.2	1.49	360	8200	1600	44	283
BKL268	11.4	1.14	380	5400	1100	72	300
BKL269	10.9	1.16	370	6300	1200	63	295
BKL271	11.2	1.31	300	10000	1400	33	373
BKL292	11	1.5	360	8000	860	43	306
BKL180	11.3	0.89	300	10000	1100	60	377
BKL191	10.8	1.31	440	4000	950	39	245
Average	11	1.26	360	7415	1170	50	305
	Barguzin Complex, the second phase						
BKL265	10.2	1.91	360	7800	960	42	283
BKL266	11.8	1.14	460	4400	1100	65	256
BKL290	11.1	1.31	320	7600	780	34	347
BKL294	11.7	1.14	300	6600	1200	67	390
BKL295	10.6	1.26	450	7400	600	74	236
BKL182	11.3	1.05	550	3900	550	39	205
BKL184	10.7	1.16	440	4400	990	26	243
BKL220	11.1	0.88	320	5100	520	33	347
Average	11.1	1.23	400	5900	840	48	278
	Zazin Complex						
BKL431	10.7	1.15	660	1100	160	26	162
BKL438	10.3	1.71	510	1600	220	34	202
BKL449	10.5	1.41	600	1600	340	22	175
BKL455	10.3	1.54	480	1600	130	43	214
BKL460	10.5	1.56	660	1290	175	39	159
BKL464	11.2	1.22	300	1800	230	23	373
BKL466	10.2	1.86	200	1200	170	24	510
Average	10.5	1.49	490	1455	205	30	214
	Katkovskaya Formation						
Gneiss	10.8	0.9	210	16000	1000	43	514
	Talanchan Group						
Subalkali diorite	10	1.47	130	7800	1300	30	769
Migmatite	11.2	1.26	230	6100	840	27	487
Leucogranite	11.4	1.3	320	3000	570	69	356

Table 4. Trace elements, ppm in biotites from granitoids of the Angara-Vitim batholith and from metamorphic rocks

Sample number	K, %	Na, %	Rb	Li	Cs	Ba	Sr	Pb	Zn	Sn	K/Rb
	Barguzin Complex, the first phase										
BKL180	7.15	0.12	630	240	120	1500	68	14	350	8.4	113
BKL188	7	0.13	1100	680	100	470	50	15	480	8	64
BKL191	6.7	0.13	980	510	50	700	60	21	330	7.9	68
	Barguzin Complex, the second phase										
BKL182	6.3	0.33	1100	1200	55	600	50	18	290	12	56
BKL184	7.45	0.12	1200	470	30	440	41	13	390	17	62
	Katkovskaya Formation										
Gneiss	7.6	0.12	520	220	20	1300	74	12	370	22	146
	Chernogrivskaya Formation										
Gneiss	6.35	0.27	320	96	6	2500	50	6.1	250	5.3	198
	Talanchan Group										
Gneiss	7.15	0.12	280	140	11	9000	56	0.8	540	14	255

the most abundant rocks and their complete geochemical characteristics.

The age of metamorphic rocks in the eastern Baikal region has practically not been determined as of yet. Only one date of 490 Ma is available for zircon from a conformable vein of pegmatoid granite hosted in granite gneiss near the Dukhovaya River (I.K. Kozakov, personal communication). This date probably records the time when metamorphism and granitization was completed and is very important because it testifies to a much older age of the migmatization of gneisses than the time of batholith emplacement. The model Nd age of granitoids ranges from 1540–1660 Ma in the southwestern party of the batholith to 1964–2200 Ma in its northern part [9]. These estimates indicate the age of the protolith that occurs deep in the crust and suggests that the granitoids were derived from the Paleoproterozoic crust in the north of the region and from the Mesoproterozoic crust in the south.

The Selenga Group that crops out to the south, in the Itantsa River basin consists of intercalating actinolite, chlorite, and carbonaceous schists, quartzites, and dolomitic marbles (Fig. 1) [5]. This group was metamorphosed under conditions of greenschist and epidote-amphibolite facies and has a geochemical signature quite different from that of the Talanchan Complex rocks. The metamorphic rocks are cut by monzonitic–granitic plutons with a great contribution of gabbroids. These plutons are related to the Barguzin Complex by composition and age; the age of granite at the confluence of the Itantsa and Koma rivers was estimated at 286 ± 1.1 Ma [1].

It is worth considering more closely the frequent association of granitoids and basic rocks described in detail by Litvinovskii *et al.* [4] in the northern part of the batholith. The study area contains diverse basic rocks. As is clearly seen in the coastal cliffs of Lake Baikal, migmatites often contain relict mafic and ultramafic bodies that underwent boudinage and amphibolization. In the process of granitization, pyroxenites experienced replacement by hypersthene with the formation of so-called hyperites, which are exposed at the Bezymyanny and Povalishin promontories (Table 2, VB22). This phenomenon is more typical of granulite-facies conditions and widely developed in boudins of gabbro in charnockites and enderbites of the Sharyzhalgai Block in the southwestern Baikal area and in the Boguchan granulite zones in the northern Baikal area [10, 11]. The larger plutons of amphibolized gabbro (Telegina River) are designated in geological maps as the Muya Complex. Near-parallel dikes of fine-grained biotite-bearing gabbro are conformable with migmatized gneisses. These dikes are transected by thin granitic veinlets making up a reticulate structure, which is interpreted as a result of the partial remelting of migmatites at contacts with incompletely crystallized basic melt. Medium-grained biotite-bearing gabbro accounts for a large volume in disintegrated rock blocks among the granitoids of the Barguzin Complex in the upper tributaries of the Itantsa River. Contacts between the granitic and gabbroic rocks are sharp but without

Table 5. Chemical composition of diorites and granites belonging to the calc-alkaline series; average compositions of tholeiitic metabasalts (amphibole gneisses) of the Chernogrivskaya Formation [1(2)], basaltic metaandesites [2(7)], and metaandesites [3(8)] of the Talanchan and Katkovskaya sequences

Component	VB186	VB143	VB180	VB224	VB228	VB233	VB105	VB114	1(2)	2(7)	3(8)
SiO_2	54.91	58.43	56	57.39	55.33	54.47	68.77	73.55	48.89	57.9	66.88
TiO_2	0.97	0.75	0.68	0.89	1.04	0.45	0.33	0.21	0.59	0.84	0.52
Al_2O_3	15.77	16.78	16.07	9.73	14.86	16.41	15.85	14.17	20	16.56	15.3
Fe_2O_3	0	3.07	2.5	3.71	3.76	2.12	1.42	0.63	3.77	3.24	1.53
FeO	4.85	4.49	5.39	4.9	4.13	4.31	2.51	1.44	5.67	4.89	3.07
MnO	0.13	0.11	0.11	0.29	0.19	0.12	0.09	0.04	0.17	0.14	0.09
MgO	5.07	3.07	5.28	5.34	4.17	4.09	1.03	0.37	5.8	3.08	1.7
CaO	7.74	6.67	7.24	13.1	9.48	10.55	3.92	1.62	10.6	6.49	4.06
Na_2O	3.24	3.25	3.78	3.17	4.42	4.43	4.08	3.4	2.78	4.11	4.11
K_2O	2.39	1.71	1.24	0.41	0.9	0.82	1.01	3.8	0.19	1.53	1.62
P_2O_5	0.34	0.29	0.16	0.24	0.19	0.2	0.15	0.05	0.11	0.33	0.18
LOI	1.35	0.73	0.89	0.26	0.89	1.42	0.45	0.16	1.09	0.37	0.52
Total	96.76	99.35	99.34	99.43	99.36	99.39	99.61	99.44	99.66	99.48	99.58
Li	15	20	10	27	8	18	16	13	6	10	12
Rb	79	35	45	2	10	18	22	66	1	35	29
Ba	885	725	200	370	880	950	525	3350	110	603	779
Sr	1760	700	612	566	1073	724	645	378	600	725	606
Pb	3.6	13	6.9	11	14	7.4	6.5	15	1.3	4.8	6
Zn	120	97	82	150	73	68	110	33	123	87	68
Sn	1.2	2.1	2.3	2.7	1.1	0.4	1.2	1	1.15	2.2	1.6
Be	0.9	0.7	1.75	12	2.9	1.25	1.1	0.9	1	1.35	0.8
Cu	8.9	42	24	11	19	18	42	15	32	39	28
Co	26	18	32	19	4.8	1	4.5	2	24	14	10
Ni	27	16	34	91	74	56	5.1	2	33	15.4	14
Cr	160	48	59	210	180	100	3	3	43	27	27
V	170	190	290	230	260	270	19	3	170	162	82
Sc	23	17	30	35	43	46	5.1	2	n.a	22	14
La	26	24	3	37	24	9.9	19	34	6	22	24
Ce	60	62	15	71	52	29	28	49	15	51	49
Nd	35	47	8	43	37	9	20	21	8.6	24	23
Yb	2.2	2.6	0.5	3.6	4.3	2.6	1	1	1.4	2.2	1.6
Y	16	20	15	25	29	10	12	10	11	16	15
Zr	169	143	63	240	124	135	134	155	40	124	166
Mo	0.3	0.6	0.5	1.7	2.7	0.5	0.9	0.6	0.3	0.72	0.76
Ag	0.25	0.12	0.1	0.05	0.06	0.04	0.08	0.04	n.a.	0.04	0.08
F	380	500	110	520	580	270	1100	200	190	470	937
B	19	18	15	9.6	1	1	80	2.9	3.2	4.7	3.5

Note: (VB105) Dukhovaya River; (VB143–186) tributaries of the Itantsa River; (VB224–233) Svyatoi Nos Peninsula; (VB114) Telegina River. Major oxides are given in wt %, trace elements are in ppm; numerals in parentheses are the numbers of samples.

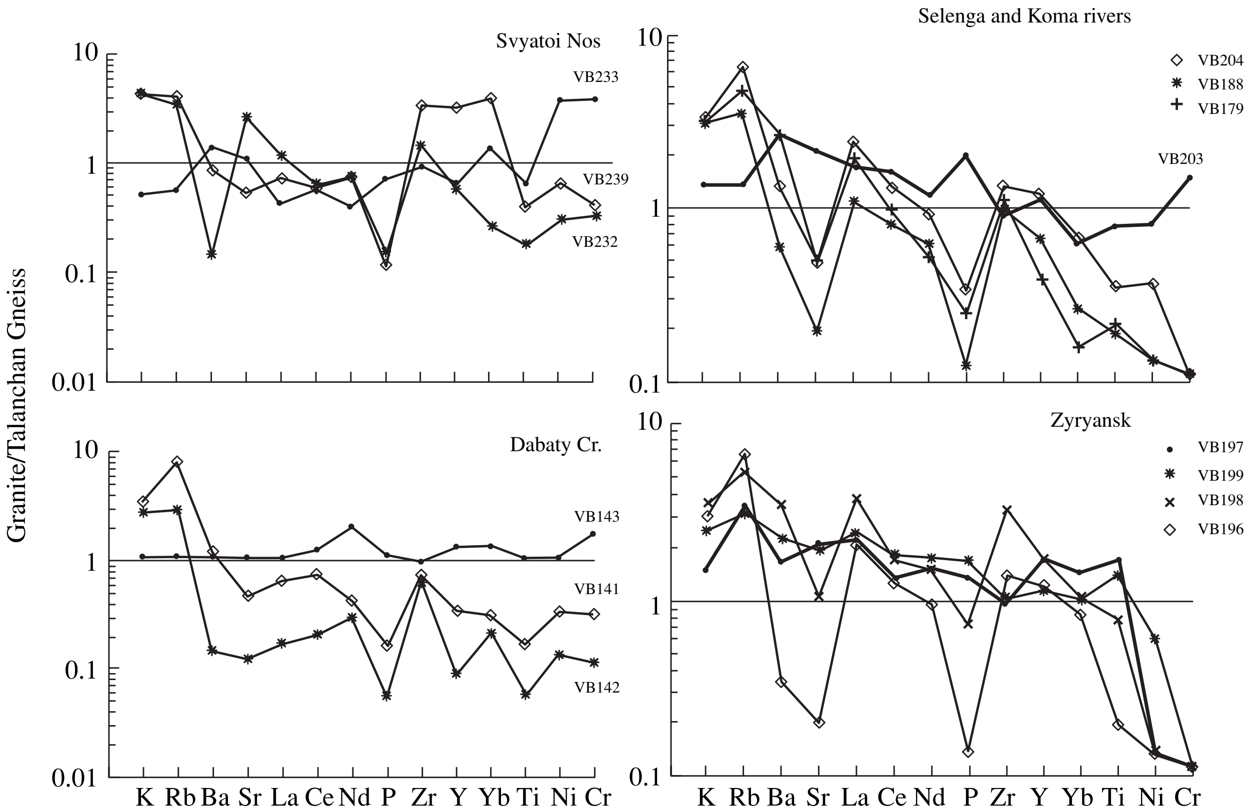

Fig. 3. Spidergrams for selected samples of diorites (dots) and granitoids for various localities in the study area normalized to the average composition of the Talanchan Gneiss.

chilled zones. Thus, the two groups of basic rocks, metavolcanics and metagabbro, occur as country rocks. The formation of postmetamorphic, most likely synplutonic basic rocks could have been related to "the injections of basic melt into granitoid magma at various stages of its crystallization" [4].

GEOCHEMISTRY OF GRANITIC, BASIC, AND COUNTRY ROCKS

Representative chemical compositions of selected samples and the average compositions of granitoids of the Barguzin and Zazin complexes from the western part of the Angara–Vitim batholith are listed in Tables 1 and 2. The older intrusive phase of the Barguzin Complex consists largely of monzonite and granodiorite, silica contents ranging from 60 to 67 wt %, sodium prevailing over potassium, and with typically elevated Ba, Sr, V, Zr, F, and B contents. The main intrusive phase is noted for a less variable granitic composition, K prevailing over Na, elevated Rb, Pb, Zn, and Sn contents, and low concentrations of Ba, Sr, Be, Co, Ni, Cr, V, as well as Zr, Nb, F, and B. In the TAS classification diagram, the granitoids of these two phases make up a common field at the boundary between the rocks of normal alkalinity and subalkaline, and are distinguished by mean compositions (Fig. 2, [12]). The Zn and Sn contents are widely scattered; samples with anomalously high contents of Zn (as high as 1900 ppm) and Sn (as high as 340 ppm) were found among samples of the main phase. In general, the geochemical characteristics of granitoids pertaining to these phases typically have high dispersions.

The granites of the Zazin Complex notably differ from the granitoides of the early phase of the Barguzin Complex and are somewhat closer to the granites of the main phase (Table 2). Along with sporadically occurring syenite, biotite granite and leucogranite are abundant; their compositions define a rather compact field in the subalkaline region (Fig. 2). The very high K and elevated Rb, Nb, Be, and Sn contents are combined with very low Ba and Sr concentrations.

The geochemical difference between Barguzin and Zazin granitoids is pronounced especially clearly when the alkali feldspars contained in these rocks are compared (Table 3). The K–feldspar from granites of the Zazin Complex is markedly enriched in Rb and depleted in Ba, Sr, and Pb; its K/Rb ratio is lower in compliance with the evolved character of these rocks. The potassium feldspar from the second phase of the Barguzin granitoids only tends to be enriched in Rb and depleted in Ba and Sr. Biotite from these granites is distinguished by elevated Rb and Sn contents (Table 4).

K–Na-feldspars and biotites from the gneisses of the Talanchan and Katkovskaya formations are close trace-element composition to the same minerals from the early phase of the Barguzin Complex except the anomalously high Ba content (1.6 wt %) in the feldspar from gneiss of the Katkovskaya Formation. The alkali feldspar from the rocks of the Talanchan Group reveals enrichment in Rb and Pb from diorite to migmatite and leucogranite, and the Ba and Sr contents simultaneously decrease. Biotite from gneisses of the Talanchan and Chernogrivskaya sequences is depleted in Li, Rb, Cs, and Pb and highly enriched in Ba relative to biotite from the Barguzin Granite. It may be stated that alkali feldspars and micas from the Barguzin granitoids, especially belonging to the early intrusive phase, are close in composition to the same minerals from the gneisses and migmatites of the Talanchan Metamorphic Complex. In the process of magma fractionation, this similarity was obliterated as is demonstrated by the granites of the Zazin Complex.

In general, compositions of granitoids from the Angara–Vitim batholith plot into the field of subalkaline rocks near its lower boundary. The compositions of the country gneisses of the Talanchan Complex vary from metabasalts and basaltic metaandesites to metaandesites and correspond to the rocks of normal alkalinity (Table 5; Fig. 2). The field of granites of normal alkalinity also includes migmatites and some granite samples (Fig. 2). The dioritic rocks bear an intrusive appearance and differ from the monzonites of the Barguzin Complex in having low K content, high Ba and especially high Sr contents and in being enriched in elements of the iron group (Table 5). We suggest that they may be older island-arc igneous rocks complementary to the metavolcanics. This suggestion can be validated by geochronological data. The geochemical signature of these rocks does not contradict this interpretation; the trace-element composition of the dioritic rocks normalized to the mean composition of the Talanchan basaltic andesite are close to unity (Fig. 3).

Making use of the same spidergrams, one can see that granites of the subsequent intrusive phases of the Barguzin Complex demonstrate a progressive enrichment in K, Rb, Ba, and, to a lesser extent, LREE relative to the Talanchan Gneiss, along with depletion in Nb, P, Ti, Ni, and Cr (Figs. 3 and 4a; [13]). This indicates that rocks like the Talanchan Gneiss could have been a source for the Barguzin Granite, if alkalis had been gained. Fractionation related to the formation of the Zazin Granite was more intense and was accompanied by the loss of Ba, Sr, P, and Ti, while the concentrations of K, Rb, Be, Sn, and REE increased (Fig. 4a).

The REE patterns in gneisses of the Talanchan Complex are typical of basaltic andesites and andesites of the calc-alkaline island-arc series (Fig. 4b). The REE patterns in granitoids of the Angara–Vitim batholith have previously been considered by Antipin *et al.* [13]. Here we demonstrate the variations in the average REE contents, which slightly increase from the first to the second intrusive phase (Table 6; Fig. 4b). The REE patterns in granites of the Zazin Complex are fractionated most strongly, and the increase in the REE sum is accompanied by a distinct Eu minimum. The narrowing of the La/Yb range from granitoids of the first phase of the Bargyzin Complex (12.9–41.1) to the second phase (17.5–31.8) and, particularly, to granites of the Zazin Complex (20.3–27.8) provides evidence that the melts became progressively more homogeneous.

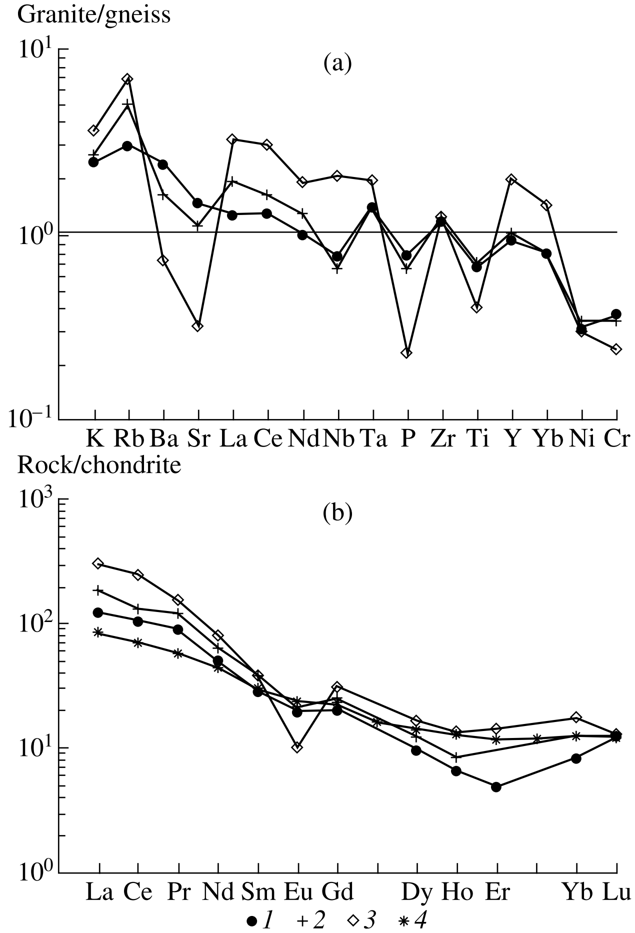

Fig. 4. (a) Spidergram of average compositions of granitoids (samples BKL) normalized to the average composition of the Talanchan Gneiss. (b) Average REE compositions of granitoids and gneisses normalized to C1 chondrite [14]. (*1*) and (*2*) granitoids belonging to the 1st and 2nd phases of the Barguzin Complex, (*3*) granites of the Zazin Complex; (*4*) gneisses.

The basic rocks metamorphosed together with host gneisses and synplutonic basic injections are closely related to granites of the batholith and are sharply distinct. The metagabbro belongs to the low-alkaline tholeiitic series, but is enriched in K, Rb, Ba, Sr and depleted in Ti and HREE relative to N-MORB (Table 7;

Table 6. REE, ppm in granitoids and gabbro from the western Angara-Vitim batholith and in gneisses of the Talanchan Group

Rock	Sample number	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Granite Barguzin Complex, the 1st phase	BKL267	38	110	13	32	6.2	1.5	5.9	n.a.	3.2	0.65	n.a.	n.a.	1.8	0.55
	BKL268	36	86	13	33	7	1.5	7.2	″	3.9	0.7	″	″	2.8	0.6
	BKL269	28	69	8.9	22	4.6	0.94	4.3	″	2.3	0.4	″	″	1.8	0.45
	BKL272	26	51	5.5	15	2.7	1.05	3.5	″	1.6	0.1	″	″	0.53	0.1
	BKL482	38	63	10	27	5	1.65	4.2	″	2.7	0.35	1.4	″	1.4	0.2
	BKL549	30	57	8.4	27	3.7	0.64	2.3	″	2.2	0.15	0.2	″	1	0.15
the 2nd phase	BKL265	28	57	8	19	4.1	0.54	3.8	″	2.5	0.63	n.a.	″	1.6	0.3
	BKL266	32	68	8	23	4.6	0.59	4.3	″	2.7	0.43	″	″	1.5	0.3
	BKL290	35	70	9.8	26	6	1.3	5.1	″	2.3	0.2	″	″	1.1	0.15
	BKL291	50	105	16	49	7.3	1.85	4	″	2.9	0.5	″	″	2.2	0.3
	BKL292	35	77	9.6	24	5	1.4	4.4	″	1	0.2	″	″	1.5	0.15
	BKL294	60	110	15	39	9.3	1.4	8.2	″	3.1	0.2	″	″	2	0.3
	BKL295	68	81	11	27	3.8	1.3	6	″	1	0.2	0.35	″	0.41	0.1
Zazin Complex	BKL431	48	83	7.8	19	3	0.34	3.5	″	2.3	0.25	1.6	″	1.8	0.15
	BKL459	74	125	15	42	8.2	0.45	10	″	5.8	1.15	3.2	″	3.4	0.4
	BKL464	73	210	17	49	6	0.82	7	″	5.6	1	3.3	″	3.6	0.43
	BKL438	64	105	12	29	4.5	0.7	5	″	2.8	0.56	n.a.	″	2.3	0.25
	BKL449	100	240	21	50	6.8	0.57		″	4.1	0.8	3.5	″	3.6	0.36
Gabbro	VB29	13.4	32.94	4.64	20.85	4.6	1.49	4.21	0.52	3.01	0.58	1.57	0.22	1.45	0.19
	VB177	7.64	13.61	1.59	5.76	1.18	0.79	1.14	0.14	0.71	0.13	0.38	0.06	0.32	0.05
	VB34	21.48	48.84	6.61	28.33	5.25	1.91	4.86	0.59	3.24	0.62	1.61	0.2	1.38	0.2
Subalkali gabbro	VB100	42.57	102.34	13.28	56.72	11.45	3.48	11.69	1.44	8.34	1.59	4.59	0.59	3.87	0.51
	VB101	44.73	107.73	14.56	62.69	12.78	3.65	12.31	1.54	8.18	1.65	4.21	0.56	3.58	0.51
	VB159	84.92	191.25	24.49	99.51	17.73	5.26	15.72	1.81	9.24	1.62	4.15	0.5	3.05	0.42
Gneiss	Aver. 8	19.73	42.85	5.39	20.24	4.51	1.34	4.53	0.6	3.5	0.72	1.9	0.3	2.07	0.3

Table 7. Chemical composition of representative samples and average chemical compositions of two types of gabbro from the eastern coast of Lake Baikal

Component	VB22	VB29	VB26	VB32	VB177	VB178	Aver. 8	VB127	VB100	VB101	Aver. 11	VB159	VB160	VB162	Aver. 6
SiO_2, wt %	52.1	50.62	51.11	45.6	46.21	49.86	48.18	45.29	44.97	43.23	46.33	40.73	40.71	48.58	46.19
TiO_2	0.47	0.69	0.57	0.82	0.74	0.63	0.77	2.07	1.81	2.04	1.35	2.98	3.29	1.69	2.13
Al_2O_3	6.27	7.03	12.88	16.58	17.2	14.15	14.28	16.11	18.55	17.66	15.7	16.29	15.97	17.03	17.31
Fe_2O_3	2.11	2.56	2.67	5.54	3.56	3.94	3.88	5.01	3.86	6.32	3.85	7.7	8.07	4.03	5.34
FeO	6.91	5.92	5.56	6.37	7.36	8.62	6.57	7	8.8	8.44	6.63	7.54	7.72	6.11	6.42
MnO	0.18	0.16	0.16	0.25	0.11	0.2	0.22	0.19	0.2	0.18	0.17	0.15	0.17	0.15	0.15
MgO	23.65	15.65	11.79	8.1	11.7	7.52	10.48	6.05	5.38	5.42	7.59	6.04	6.45	5.36	5.18
CaO	4.56	13.05	9.99	10.99	7.84	11.72	10.62	8.85	8.87	9.35	9.3	10.37	10.85	8	8.59
Na_2O	1.03	1.33	2.4	2.59	2.36	2.38	2.44	3.83	3.21	2.92	3.1	3.4	2.99	3.77	3.77
K_2O	0.37	0.39	0.57	0.43	0.37	0.23	0.45	1.69	1.93	1.71	1.88	1.26	0.98	2.27	1.84
P_2O_5	0.3	0.22	0.19	0.18	0.07	0.03	0.26	1.69	0.7	1.13	0.76	2.12	2.22	0.94	1.22
LOI	1.33	1.73	1.53	2.06	1.32	0.01	1.23	0.96	0.5	0.54	0.81	0.42	0.5	1.15	0.91
Total	99.28	99.35	99.42	99.51	98.84	99.29		98.74	98.78	98.94		99	99.92	99.08	
Li, ppm	8	4	10	9	4	4	7	16	12	9	13.5	4	2	17	15
Rb	3	3	3	3	3	2	3	10	38	32	39	14	7	56	46
Ba	430	100	100	100	530	160	100	1590	1420	1275	1013	1600	1400	1735	1488
Sr	540	500	1030	440	380	240	538	2975	1320	1450	1410	1790	2044	1630	1711
Pb	1	1.4	1.4	1.6	1.6	1.9	1.4	4.4	4.5	5.5	7.8	5.2	3.8	11	10
Zn	90	57	76	119	180	140	113	140	180	210	140	170	1000	260	357
Sn	1.4	2	1.2	1.9	2.2	1.1	1.9	2.8	3.4	4.9	3.2	3	1.6	3.8	2.9
Be	0.8	0.6	1	0.7	0.8	0.25	0.83	1.4	1.5	1.4	1.5	1.6	1.5	2	1.6
Cu	67	200	62	19	74	19	54	55	29	47	55	54	57	32	39
Co	83	51	10	48	86	4.9	34.5	28	27	29	34	37	41	32	31
Ni	1200	770	240	98	230	7	162	45	4.7	4.7	89	11	12	39	16
Cr	2300	2000	180	220	68	13	478	92	3	8.8	392	3	3	55	29
V	98	150	120	240	200	3	205	180	250	230	200	260	290	240	228
Sc	21	40	27	41	9.1	2	32	20	18	18	26	15	15	20	16.5
Zr	160	50	40	40	15	15	46	135	76	130	126	90	88	104	188
Mo	0.54	0.69	0.49	0.65	0.8	0.8	0.52	0.8	0.4	0.3	0.8	0.6	2.2	1.1	1.4
Ag	0.04	0.07	0.05	0.15	0.15	0.15	0.08	0.23	0.1	0.15	0.14	0.24	0.14	0.3	0.22
F	600	600	425	1300	60	230	1004	1700	1560	1700	1389	1700	1900	1150	1291
B	1	3.1	3	2.4	11	11	2.7	14	24	2.9	15.7	3.2	5.1	12	11.1
H_2O^+	0.94	1.27	1.31	1.62	0.96	n.a.	1.28	1.33	1.18	0.88	1.16	n.a.	1.12	1.18	1.15
H_2O^-	0.2	0.11	0.05	0.05	0.21	″	0.1	0.21	0.06	0.05	0.11	″	0.2	0.17	0.18
CO_2	0.57	0.77	0.8	0.79	0.68	″	0.73	0.03	0.03	0.03	0.21	″	0.03	0.1	0.06
S	0.1	0.28	0.05	0.04	0.12	″	0.12	0.04	0.04	0.15	0.06	″	0.01	0.02	0.01

Note: (VB22–29) metapyroxenite (hyperite); (VB26–32) metagabbro, Povalishin Cape; (VB177, 178) gabbro, Koma River; (VB101–127) subalkali gabbro, Gorevoi Utes Promontory and Dukhovaya River; (VB159–162) subalkali gabbro, Burla River. Numerals in parentheses are the numbers of samples.

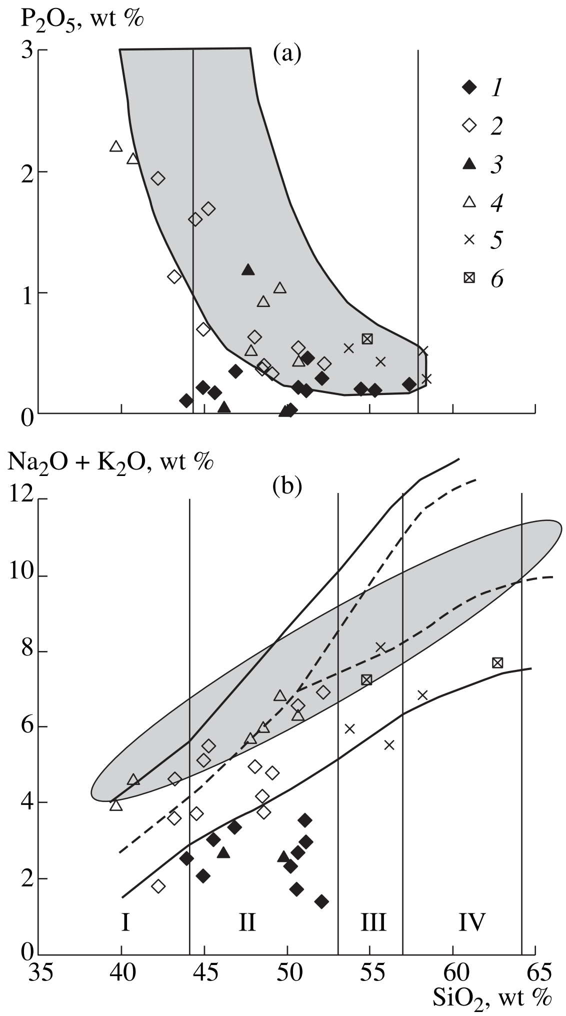

Fig. 5. (a) P_2O_5 vs. SiO_2, wt % and (b) $Na_2O + K_2O$ vs. SiO_2, wt %. (*1, 2*) basic rocks in the Talanchan Metamorphic Complex; (*3, 4*) gabbro in the Selenga Group; (*5*) syenite in the Talanchan Metamorphic Complex; (*6*) syenite in the Selenga Group; (*1, 3*) are basic rocks of normal alkalinity; (*2, 4*) are basic rocks of elevated alkalinity; field of gabbro belonging to the Oshurkov Complex is shown as shaded area.

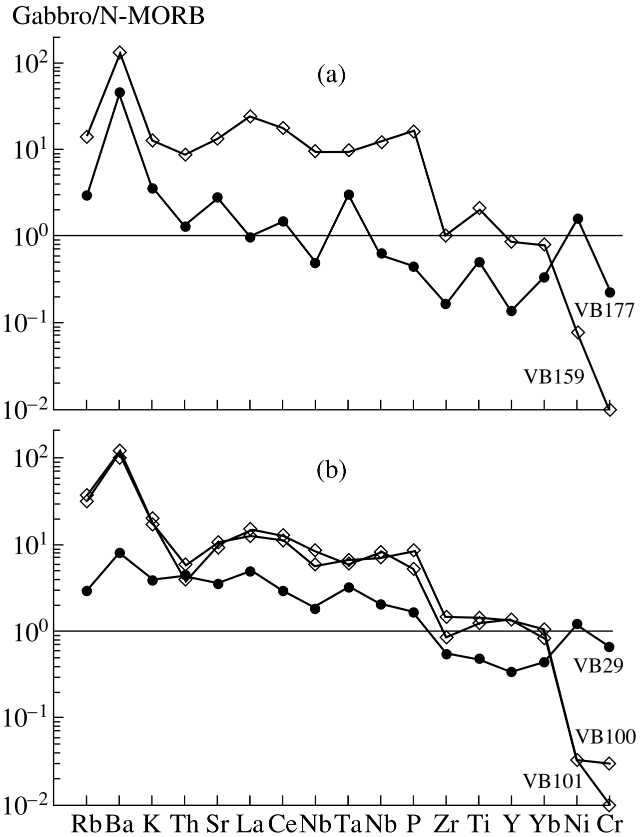

Fig. 6. Spidergrams of gabbroic rocks of normal (dots) and elevated (diamonds) alkalinity in (a) Selenga Group and (b) Talanchan Metamorphic Complex normalized to N-MORB.

Figs. 5 and 6), and thus is close to island-arc and backarc tholeiites. The postmetamorphic subalkaline gabbroic rocks are characterized by high K and Ba contents and very high Ti, P, Sr, and F contents, which are comparable with the compositions of gabbro belonging to the intraplate Oshurkov Complex (Fig. 5, [15]). In contrast to the metagabbro, they are depleted in Ni and Cr, and enriched in V. The patterns of subalkali gabbro in the spidergrams are localized much higher than those of N-MORB and metagabbro for all elements (Fig. 6). The REE patterns of the synplutonic gabbro are also located higher than those of the metagabbro and are nearly parallel to the latter (Fig. 7). The pronounced Sr–F and Sr–P correlation in subalkali gabbro (Fig. 8) testifies to the concentration of these elements in apatite, which occurs in this rock in a great amount, similarly to the gabbro of the Oshurkov Complex.

DISCUSSION

The Angara–Vitim batholith was identified for the first time by Salop [16] and was regarded as Early Proterozoic at that time. Based on geological and geochronological evidence, Litvinovskii *et al.* [3], ascribed the Barguzin Complex to the Early Paleozoic, and the Zazin Complex was attributed to the Middle Paleozoic. In light of these data, the formation of the giant granitoid body was interpreted as a result of the closure of the Paleoasian ocean, which was related to the Caledonian collision of the passive margin of the Siberian continent with continental blocks of central Mongolia [17, 18]. The Late Carboniferous age (298 ± 8 Ma) was first established for subalkaline granitoids of the Chivyrkul pluton, which were attributed to the Barguzin Complex [19]. Our recent U–Pb isotopic data, together with [1, 2], testify to a Late Carboniferous age of the Angara–Vitim granitoid batholith, which ranges from 282 to 339 Ma [1]. There are no distinct difference in age

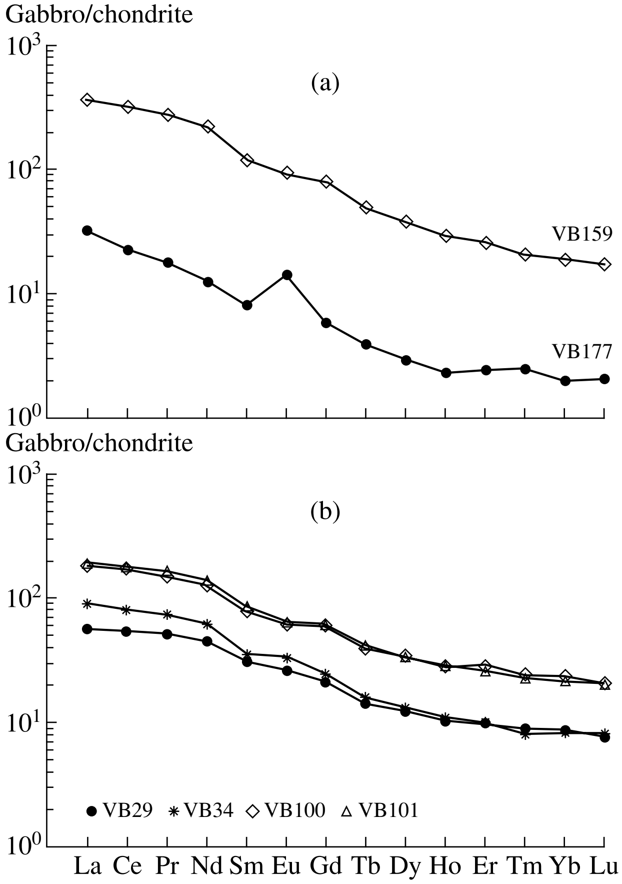

Fig. 7. REE patterns of gabbro of various alkalinity. (a) Selenga Group, (b) Talanchan Metamorphic Complex.

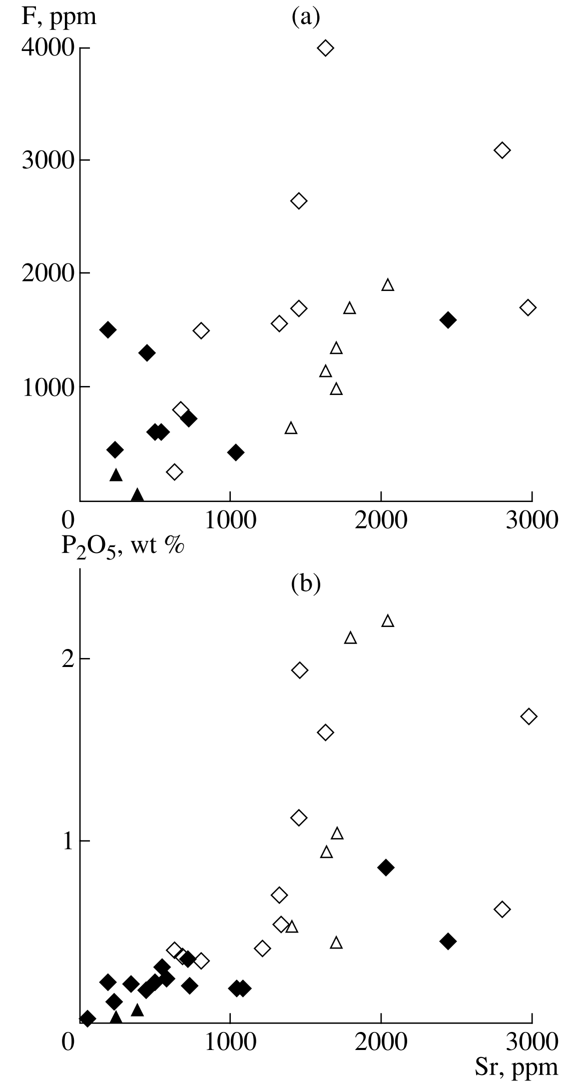

Fig. 8. (a) F vs. Sr and (b) P_2O_5 vs. Sr in calc-alkaline and subalkaline gabbro. See Fig. 5 for the legend.

between the Barguzin and Zazin granitoids. Conversely, the evolved leucogranites of the Zazin Complex often reveal an older age than those of the Barguzin granitoids. Thus, geochronological data indicate that the formation of the batholith was not related to Caledonian collision, but occurred later.

A comparison of geochemistry of granitoids belonging to the Barguzin Complex with the composition of the prevalent gneisses of the Talanchan Metamorphic Complex confirms the suggestion that the granitoids were generated by the melting of those crustal rocks. This is clearly seen from both the spidergrams and the chondrite-normalized REE patterns. The gneisses and migmatites are depleted in K, Rb, and Ba relative to the granitoids of the Barguzin and Zazin complexes (Fig. 9). Either the gain of alkali metals or the partial melting was required to transform the metamorphic rocks into granite. The data points of the migmatites partly plot into the field of the Barguzin granitoids (older phase), showing that the granitoid might be the product of the total melting of the migmatites. The compositions of the granites are progressively enriched in K_2O and Rb relative to Ba, as a result of magma fractionation. The compositions of granitic rocks sampled along tributaries of the Itantsa River fall in the common field of these rocks from the Angara–Vitim batholith, whereas the data points of the diorite plot into a separate field of gneisses (Fig. 2).

The Zn content decreases from the gneisses to migmatites, while the granitoids of the Barguzin Complex are distinguished by the highest contents of this element, which reveals the widest dispersion in the second intrusive phase, as is also typical of Sn and Be (Fig. 10a). This might indicate the additional and nonuniform reworking of the melts by solutions enriched in these elements. Lead is markedly gained in granites relative to gneisses. The P_2O_5 and TiO_2 contents progressively decrease from gneiss and diorite to younger granitoids (Fig. 10b). Thus, according to all geochemical signatures, the diorites may be regarded as intrusive analogues of metavol-

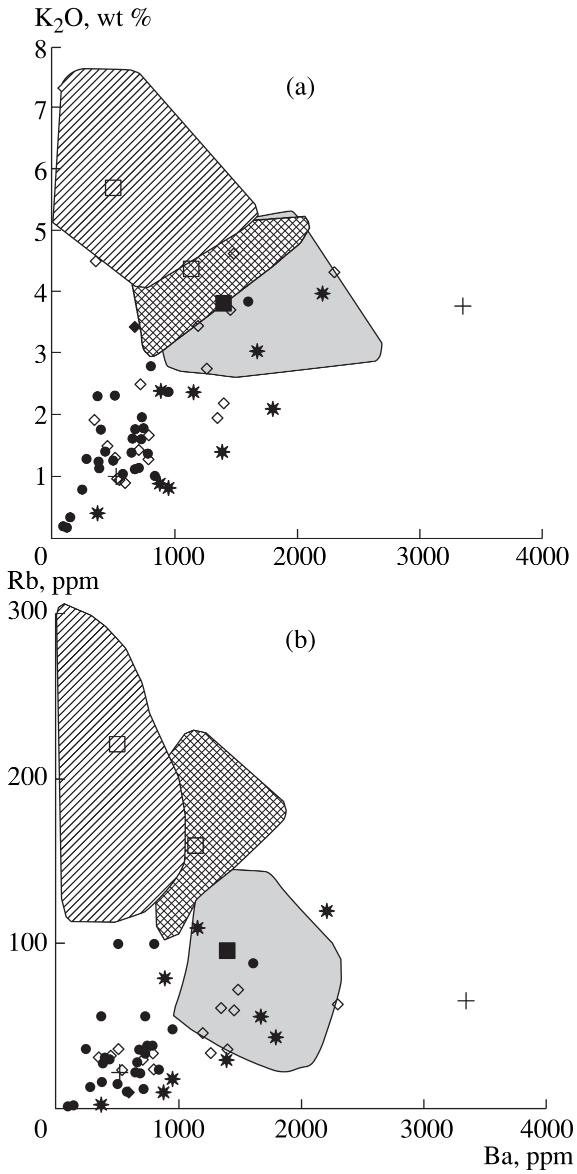

Fig. 9. (a) K_2O vs. Ba and (b) Rb vs. Ba in gneisses, migmatites, diorites, and granitoids of the Angara–Vitim batholith. See Fig. 2 for legend.

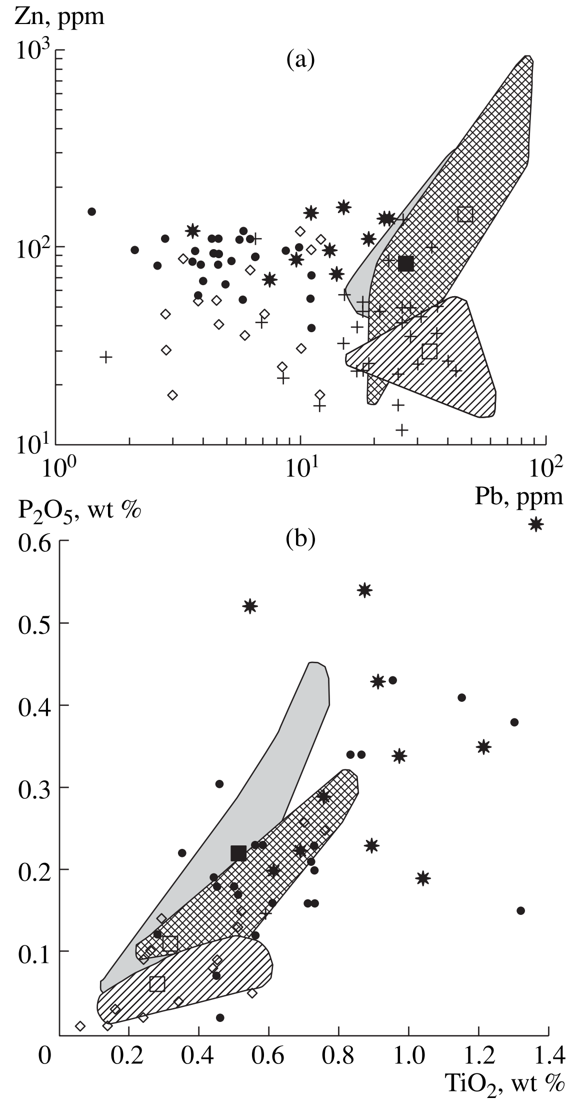

Fig. 10. (a) Zn vs. Pb and (b) P_2O_5 vs. TiO_2 in gneisses, migmatites, diorites, and granitoids of the Angara–Vitim batholith. See Fig. 2 for legend.

canics of the Talanchan Group and differ from granitoids of the Angara–Vitim Batholith.

In the series of intrusive phases of granitoids in the western Angara–Vitim batholith, the rocks become more uniform from the older to younger varieties, and the dispersion of most trace elements, including REE, decreases from the Barguzin Complex to the Zazin Complex.

CONCLUSIONS

The geochemical signatures of the rock outcropping in the eastern coast of Lake Baikal and geochronological data, unfortunately incomplete, allow us to interpret the evolution of this block as follows. A mature island arc with intense volcanic activity that produced tholeiitic basalts, basaltic andesites, and andesites occurred here in the Riphean, as testified by the monotonous, metavolcanic, gneissic, sequence of the Talanchan Metamorphic Complex. Intrusive analogues of the metavolcanics are high-Ba and high-Sr diorites of the calc-alkaline series and low-alkaline basic rocks. Toward the Svyatoi Nos Peninsula, the metavolcanics give way to a sequence of marbles, quartzites, diopside and two-pyroxene schists, which are similar with the Ol'khon Group in composition. The protolith of these rocks is regarded as sediments of a marginal sea. In the epoch of the Caledonian collision, the island-arc and backarc rocks underwent strong tectonization. The block was attached to the Siberian Craton and experienced amphibolite-facies (granulite-facies in the Svyatoi Nos Peninsula) metamorphism. During the retrograde stage (490 Ma), the rocks were intensely granitized.

In the Devonian and Carboniferous, under the effect of a mantle diapir or plume [1, 2], the previously amalgamated terranes were broken up, with episodes of intraplate alkaline volcanism confined to narrow rift zones. This igneous activity, gradually shifted from the northeast to southwest, and was manifested in the Devonian, Carboniferous, Mesozoic, and Cenozoic [2, 20]. It may be suggested that the local rift-controlled intraplate magmatism was caused by the formation of a vast reservoir of basic melts localized in the lower crust. This "furnace", as it was referred to by Litvinovskii, gave rise to the melting of the upper crust and the formation of the Angara–Vitim batholith. This is supported by the close geochemical similarity of granitoids and country gneisses, wide compositional variations of the early intrusive phases of the batholith, and the more uniform composition of the evolved later granites of the Zazin Complex. Thereby, all of the intrusive phases were formed within a narrow time span as a result of multisource melting at various depths and the fractionation of melts eventually produced leucogranites and their rare-metal varieties.

The intrabatholith basic rocks, which are indicators of a deep-seated chamber of the basic melt that intruded migmatites along fractures giving rise to their contact fusion and cut through the granitoids of the batholith, are consistent with the above interpretation. These basic injections are similar in composition to gabbroids of the younger Oshurkov Complex and actually are equivalents of volcanics localized within intraplate rifts.

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REFERENCES

1. V. V. Yarmolyuk, S. V. Budnikov, V. I. Kovalenko, *et al.*, "Geochronology and Geodynamic Setting of the Angara–Vitim Batholith," Petrologiya **5** (5), 451–466 (1997) [Petrology **5** (5), 401–414 (1997)].
2. V. V. Yarmolyuk and V. I. Kovalenko, "Geodynamic Environments of Batholith Origin in the Central Asian Foldbelt," Geol. Geofiz. **44** (12), 1305–1320 (2003).
3. B. A. Litvinovskii and A. N. Zanvilevich, *Paleozoic Granitoid Magmatism in Western Transbaikalia* (Nauka, Novosibirsk, 1976) [in Russian].
4. B. A. Litvinovskii, A. N. Zanvilevich, A. M. Alakshin, *et al.*, *The Angara–Vitim Batholith: The Largest Granitoid Pluton* (Ob"ed. Inst. Geol. Geophys. Mineral., Sib. Otd. Ross. Akad. Nauk, Novosibirsk, 1992) [in Russian].
5. V. A. Makrygina and Z. I. Petrova, "Geochemistry of Metamorphic Complexes of Eastern Coast of Lake Baikal and Their Correlation with Rocks of the Western Coast," Geokhimiya, No. 5, 485–502 (2005) [Geochem. Int. **43**, 438–455 (2005)].
6. V. A. Makrygina, T. P. Gantimurova, and Z. I. Petrova, "Andesite Magmatism and Its Place in the Geological History of the Ol'khon Area, Western Baikal Region," Geokhimiya, No. 12, 1266–1279 (2000) [Geochem. Int. **38** (12), 1161–1174 (2000)].
7. F. A. Letnikov, V. A. Khalilov, and V. B. Savel'eva, "Isotopic Dating of Endogenic Processes in the Ol'khon Area," Dokl. Akad. Nauk **344** (1), 96–100 (1995).
8. F. G. Reif, *Physicochemical Conditions of the Origin of Large Granitoid Plutons in the Eastern Baikal Area* (Nauka, Novosibirsk, 1976) [in Russian].
9. V. V. Yarmolyuk, V. I. Kovalenko, V. P. Kovach, *et al.*, "Nd-Isotopic Systematics of Western Transbaikalian Crustal Protoliths: Implications for Riphean Crust Formation in Central Asia," Geotektonika, No. 4, 3–20 (1999) [Geotectonics **33** (4), 271–286 (1999)].
10. Z. I. Petrova and V. I. Levitskii, *The Petrology and Geochemistry of Granulite Complexes of the Baikal Region* (Nauka, Novosibirsk, 1984) [in Russian].
11. V. A. Makrygina, E. G. Konnikov, L. A. Neimark, *et al.*, "The Age of the Granulite–Charnockite Complex in the Nyurundukan Formation, Northern Baikal Area: A Geochronological Paradox," Dokl. Akad. Nauk **332** (4), 917–920 (1993).
12. *Igneous Rocks* (Nauka, Moscow, 1983), Vol. 1, Parts 1 and 2 [in Russian].
13. V. S. Antipin, A. V. Goreglyad, V. I. Kovalenko, and S. V. Budnikov, "Rare Earth Element Distribution in the Late Paleozoic Granitoid Rocks of the Angara–Vitim Batholith," Dokl. Akad. Nauk **357** (5), 667–670 (1997) [Dokl. Earth Sci. **357A** (9), 1366–1369 (1997)].
14. S.-S. Sun and W. F. McDonough, "Chemical and Isotopic Systematics of Oceanic Basalts: Implications for Mantle Composition and Processes," in *Magmatism in the Oceans Basins*, Geol. Soc. Spec. Publ., No. 42, 313–345 (1989).
15. B. A. Litvinovskii, A. N. Zanvilevich, V. F. Posokhov, *et al.*, "New Data on the Structure and Age of the Oshurkov Alkali Gabbro–Syenite Pluton, Transbaikalia," Geol. Geofiz. **39** (6), 730–744 (1998).
16. L. I. Salop, *Geology of the Baikal Mountain Area*, Vol. 1: *Stratigraphy* (Nedra, Moscow, 1964) [in Russian].
17. L. P. Zonenshain and A. M. Gorodnitskii, "Paleozoic and Mesozoic Reconstructions of Continents and Oceans," Geotektonika, No. 2, 3–25 (1978).
18. I. V. Gordienko, G. V. Andreev, and A. N. Kuznetsov, *Paleozoic Magmatic Rock Associations in the Sayan–Baikal Mountain Area* (Nauka, Moscow, 1978) [in Russian].
19. L. A. Kozubova, S. L. Mirkina, A. G. Rublev, and A. P. Chukhonin, Dokl. Akad. Nauk SSSR **251** (4), 948–951 (1980).
20. A. A. Vorontsov and V. V. Yarmolyuk, "The Northern Mongolia–Transbaikalian Multistage Rift System: Evolutionary Stages, Melt Sources, and Geodynamics," in *Proceedings of the II All-Russian Symposium on Volcanology and Paleovolcanology* (Yekaterinburg, 2003), pp. 201–205 [in Russian].