Late-paleozoic granitoid complexes of the southwest Primorye: geochemistry, age and typification

A A Veldemar, G M Vovna

Far East Geological Institute Far Eastern Branch of Russian Academy of Sciences, 159, Prospekt 100-letiya, Vladivostok 690022, Russia

E-mail: veldemar@fegi.ru, gala1367@mail.ru

Abstract. The article presents the first data of geochemical studies of the Late Permian granitoids of the Gamov Complex located in the southwestern part of the Voznesenskiy terrane. The purpose of the study was to identify the main geochemical features of the Late Paleozoic granitoids of the southwestern Primorye, which in the future will allow us to draw conclusions about the petrogenesis of these granitoids. Elemental analysis of 20 samples was carried out, conducted statistical and mathematical processing of the data, have been constructed representative diagrams and graphs for this group of rocks. Elemental analysis was performed by atomic emission (ICP-AES) and inductively-coupled-plasma (ICP-MS) mass spectrometry, at the Analytical Center FEGI FEB RAS.

1. Introduction

The Late-Paleozoic Gamov complex of granitoids located in the south-west of Primorye is an object of investigation (figure 1). In the tectonic viewpoint, the Gamov complex is located in the southwestern part of the Voznesenskiy terrane. The complex is represented by a gabbro-diorite-granodiorite-plagiogranite-granite rock association that forms the Gamov batholith. Due to tectonic faulting and overlapping by later formations, it is exposed by scattered fragments of up to 120 km^2. The complex breaks, hornfels, sections granitizing the Reshetnikovskaya and Barabashsky formations of the upper Permian, and is overlapped by the Upper Triassic Talminskaya series [3].

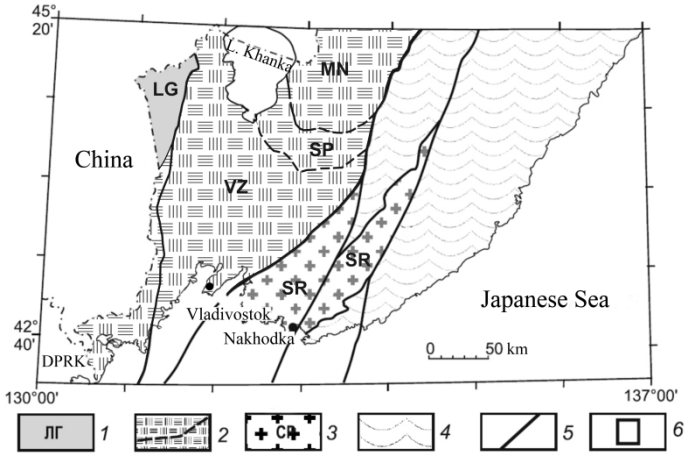

Figure 1. Scheme of terranes of the Southern Primorye region [2] with changes.
1 - Laoelin-Grodekovsky (LG) late Paleozoic terrane; 2 - terranes of the Bureya-Khanka Early Paleozoic orogenic belt: Matveevsko-Nakhimovsky (MN), Spassky (SP), Voznesensky (VZ); 3 - Sergeevsky (SR) terrain; 4 - terranes of the Late Mesozoic Sikhote-Alin orogenic belt; 5 - faults; 6 - area of research.

Three phases are distinguished in the structure of the Gamov granitoid batholith. The first is gabbro, gabbro-diorites and diorites. The second is biotite-hornblende-quartz granodiorites and plagiogranites. The third phase includes dikes and veins of aplite-like granites, leucogranites and pegmatites [3].

2. Materials and methods

Elemental analysis of 20 samples was carried out at the Analytical Center of the Far Eastern Geological Institute, FEB RAS. Major-element compositions (excepting SiO_2 and H_2O^-) were determined by atomic emission spectroscopy with inductively coupled plasma mass ICP-OES spectrometer iCAP 6500Duo (Thermo Scientific Corporation, USA). SiO_2 and H_2O^- contents were determined using a standard weighting (gravimetric) method. Trace element and REE abundances were measured by inductively coupled plasma mass ICP-MS spectrometry Agilent 7500C (Agilent Technologies, USA). The precision of the analyses was generally 2-5% for major oxides, and 5-10% for trace and REE elements. The correctness of the results is confirmed by the analysis of international and Russian standard samples of JG-3, JB-3, JA-2 (Japan) and SG-3 (GSO No. 3333-85, Russia).

3. Results and discussion

The contents of major components, rare and rare-earth elements in representative samples of the main species of rocks are given in the table (table 1). On the classification diagram ($Na_2O + K_2O$) - SiO_2, the points of the compositions of rocks of the Gamov massif are located in the fields of granodiorites, granites, leucogranites (figure 2). The rocks are mainly magnesian, peraluminous, potassium-sodium series. By the ratio of K_2O and SiO_2, the rocks refer to the calcic and calc-alkalic series.

According to the classification of Whalen [9] (figure 2E, F) and Maeda [6] (figure 2G) the figurative points of granitoids of the Gamov complex are located in the S and I types of granite.

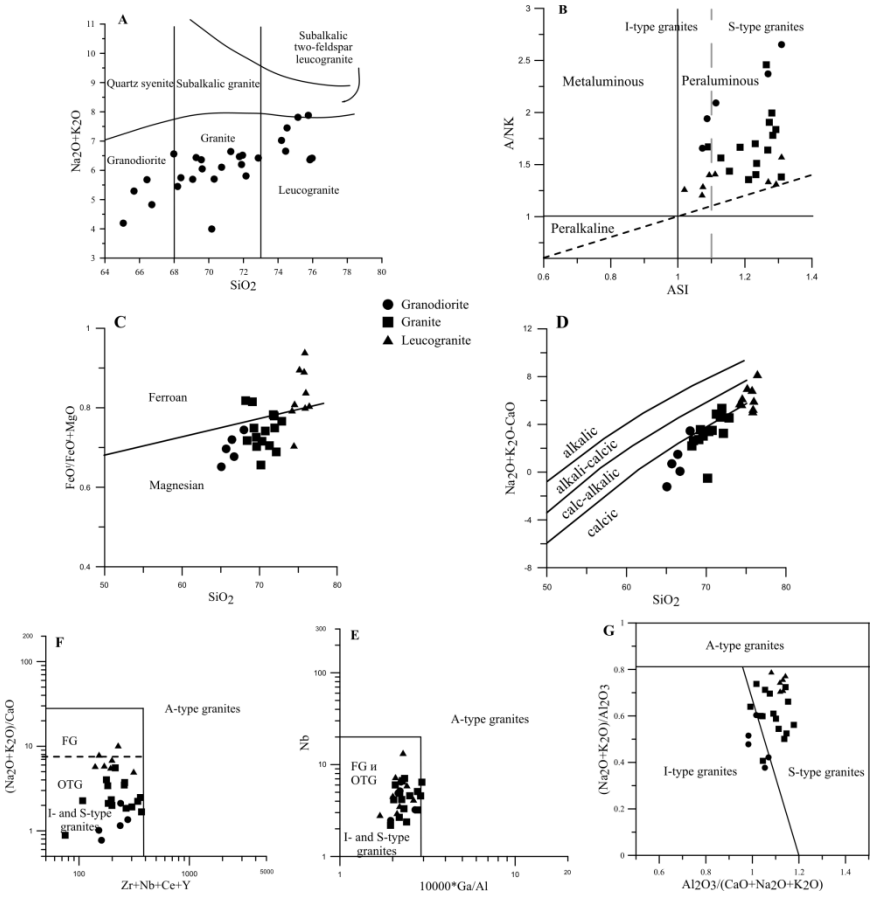

Figure 2. Geochemical discrimination diagrams for granitoids of the Gamov complex.
A - SiO_2 – (Na2O+K_2O) [1];
B - ASI – A/NK, где ASI = Al_2O_3/(Na_2O+K_2O+CaO-1.67P_2O_5), A/NK = Al_2O_3/(Na_2O+K_2O) [7];
C - SiO_2 – FeO^t/(FeO^t+MgO) [5];
D - SiO_2 – Na_2O+K_2O+CaO [5];
E - 10000*Ga/Al – Nb [9];
F - Zr+Nb+Ce+Y – (Na_2O+K_2O)/CaO [9]: FG- fractionated felsic granites, OTG- unfractionated granites;
G – Al_2O_3/(CaO+Na_2O+K_2O) – (Na_2O+K_2O)/Al_2O_3 [6].

Table 1. Chemical compositions of granitoids of the Gamov Complex

Element	А-54	А-55а	К-7-9	3-56а	К-7-7	Г-11-5	Т-52	Ал-18	Т-50	Л-16	К-26а	К-7-8
	1	2	3	4	5	6	7	8	9	10	11	12
SiO_2	65,68	66,43	67,98	68,20	69,27	70,17	70,31	71,27	74,20	74,44	75,15	75,75
TiO_2	0,56	0,52	0,51	0,53	0,48	0,34	0,40	0,41	0,20	0,17	0,12	0,12
Al_2O_3	15,47	15,18	14,83	15,63	14,56	14,88	14,54	13,82	13,26	13,87	13,57	13,34
Fe_2O_3	5,03	4,90	4,60	5,10	4,18	2,94	3,45	3,31	1,92	1,92	1,68	1,43
MnO	0,09	0,08	0,07	0,07	0,06	0,04	0,05	0,05	0,04	0,02	0,02	0,02
MgO	1,97	1,72	1,43	1,02	1,26	1,39	1,23	1,25	0,46	0,73	0,18	0,16
CaO	4,59	4,19	3,10	3,25	2,88	4,50	2,30	1,78	1,26	0,96	0,76	0,99
Na_2O	2,97	2,98	3,29	3,44	3,12	3,08	3,55	4,32	3,23	5,89	3,63	3,56
K_2O	2,32	2,70	3,28	2,01	3,32	0,92	2,15	2,32	3,79	0,76	4,19	4,32
P_2O_5	0,08	0,08	0,08	0,11	0,09	0,04	0,09	0,09	0,04	0,02	0,04	0,02
LOI	0,90	0,86	0,42	0,51	0,57	1,43	1,45	1,22	1,25	0,97	0,46	0,3
Sum	99,79	99,63	99,85	100,11	99,84	99,81	99,66	99,89	99,65	99,78	99,79	100,14
Be	1,13	0,90	1,66	1,89	1,08	0,85	1,04	0,93	1,03	1,96	1,31	1,01
Sc	16,4	15,3	13,5	16,1	11,4	4,9	6,3	7,9	4,5	4,1	4,1	3,1
V	87,94	82,09	86,93	55,08	74,78	73,44	46,84	44,40	15,43	12,31	6,66	14,59
Cr	173,2	134,5	150,6	174,8	144,7	257,1	118,8	126,9	5,53	6,33	18,13	201,6
Co	11,22	10,78	9,78	6,14	8,36	9,47	6,60	6,02	2,15	2,28	1,21	1,67
Ni	6,70	4,72	7,26	8,92	7,09	9,79	6,06	3,67	2,49	2,12	2,42	5,64
Cu	10,13	45,22	26,82	42,54	15,16	25,53	4,86	8,32	1,57	25,53	6,73	9,37
Zn	49	50,5	59	87,8	47,7	37,2	49,2	24,5	28,9	32,1	18,8	25,9
Ga	17,56	17,70	17,51	19,34	15,96	15,31	22,58	14,84	16,93	15,55	16,31	14,65
Rb	74,97	90,37	191,44	73,74	164,89	30,17	95,22	49,11	105,02	19,81	117,49	138,34
Sr	192,3	195,3	169,9	205,3	165,8	378,4	437,7	346,7	209,4	334,6	126,9	98,3
Y	25,49	28,53	31,62	40,53	27,42	5,29	17,89	13,78	26,08	13,64	31,62	22,45
Zr	169,3	179,9	151,0	203,2	254,9	47,73	217,2	197,7	110,0	146,0	119,6	77,11
Nb	4,89	5,17	6,46	7,08	6,01	2,19	6,44	4,15	5,95	2,98	6,55	7,32
Mo	7,17	6,50	8,17	9,93	7,39	13,30	6,36	6,14	0,03	0,45	0,44	11,49
Cd	0,01	0,09	0,19	0,29	0,35	0,18	0,13	0,09	0,07	0,40	<DL	<DL
Sn	2,23	3,00	1,18	3,04	1,39	0,17	1,95	0,12	2,34	2,30	2,06	3,14
Cs	1,59	1,76	12,76	2,47	12,11	1,73	2,54	1,28	1,89	0,66	1,65	3,40
Ba	366,9	525,7	393,9	397,2	406,6	284,4	648,6	850,7	521,9	197,1	693,3	711,8
La	16,49	29,68	31,52	51,63	32,13	8,11	55,43	24,84	25,05	20,20	32,97	24,84
Ce	36,45	62,84	49,10	117,63	52,38	19,68	118,59	43,55	51,34	36,32	68,68	45,03
Pr	4,33	6,66	6,46	13,61	6,37	2,45	12,20	4,52	5,57	3,96	7,84	4,69
Nd	16,35	24,69	24,94	52,25	24,70	9,56	41,30	15,32	20,99	12,92	27,86	16,90
Sm	3,34	4,23	4,68	9,95	4,73	2,00	7,04	2,33	3,66	2,44	6,81	3,40
Eu	0,87	0,76	0,95	1,09	0,94	0,45	0,83	0,81	0,47	0,59	0,72	0,48
Gd	3,96	4,72	4,99	9,20	4,02	1,35	5,04	2,59	4,25	2,40	5,65	3,53
Tb	0,65	0,79	0,86	1,31	0,80	0,17	0,67	0,34	0,68	0,29	0,97	0,59
Dy	4,31	4,75	5,66	6,96	4,24	0,92	3,05	1,99	3,79	1,93	5,34	3,64
Ho	0,94	0,99	1,23	1,50	1,15	0,20	0,57	0,55	0,75	0,37	1,20	0,81
Er	2,69	2,83	3,83	4,39	2,67	0,44	1,94	1,45	2,45	1,42	3,16	2,21
Tm	0,36	0,44	0,51	0,65	0,40	0,08	0,23	0,18	0,39	0,14	0,50	0,32
Yb	2,44	3,02	3,44	4,29	3,25	0,52	1,64	1,41	2,72	1,09	3,38	2,00
Lu	0,38	0,42	0,47	0,54	0,34	0,11	0,25	0,25	0,40	0,17	0,47	0,31
Hf	4,75	5,11	4,86	6,17	7,65	2,35	5,43	5,16	3,99	3,44	4,05	2,78
Ta	0,48	0,49	0,56	0,72	0,57	0,26	0,45	0,33	0,61	0,05	0,72	0,77
W	5,88	5,27	6,31	7,60	6,49	9,05	4,21	4,85	0,34	0,21	0,52	9,69
Pb	9,41	9,39	19,40	11,54	17,60	9,93	12,45	3,09	16,19	8,38	16,02	23,06
Th	8,37	8,84	22,27	18,66	19,62	7,65	24,14	10,50	17,56	8,45	18,51	15,08
U	1,38	1,51	3,02	2,63	3,03	1,64	1,99	1,72	2,40	0,79	2,80	2,70

Note: The content of oxides in mass%, microelements in g / t.
<DL- value below detection limit
1-3 - granodiorites, 4-8 - granites, 9-12 - leucogranites

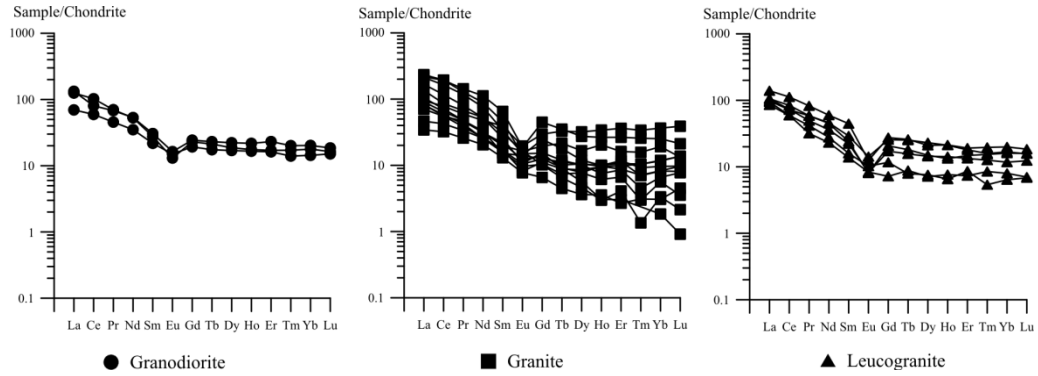

Figure 3. The REE distribution spectra in granitoids of the Gamov complex are normalized by the chondrite composition [8].

REE patterns of granites (figure 3) are characterized by an enrichment of light rare earth elements (LREE) $(La/Yb)_N$ = 2,44-32,92 and the presence of a negative Eu anomaly (Eu/Eu* = 0.35-0.84), which is typical for granites formed due to crustal sialic sources. Granitoids of the Gamov complex are significantly enriched with large-ion lithophiles (LILE) - Cs, Rb, Ba, K, and high field strength elements (HFSE) -Th and U (figure 4).

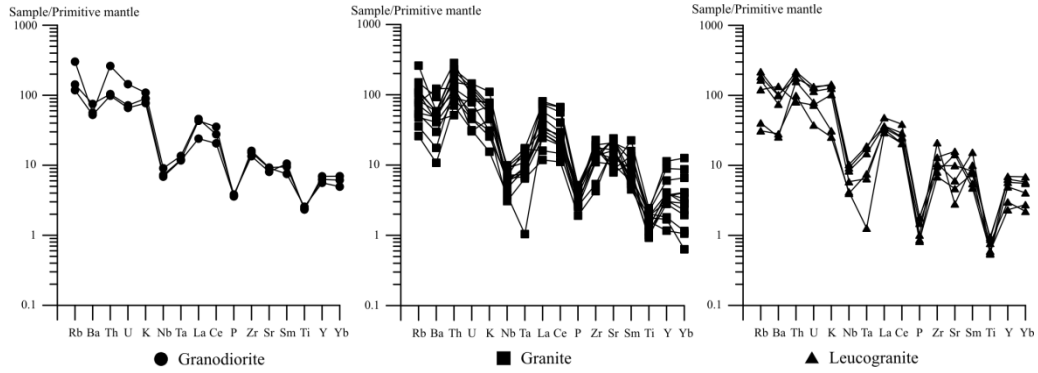

Figure 4. Trace element spidergrams for granitoids of the Gamov complex are normalized by the composition of the primitive mantle [8].

Radiological K/Ar dating in the petrotip (Gamov Peninsula), in biotite and amphibole, correspond to 251 and 252 Ma [3]. Definitions of Chinese geologists U/Pb method in contiguous territories give an age of 254 million years, which corresponds to the late Permian time [3]. The latest U-Pb isotope studies of zircons (SHRIMP-II method) [4] established that the age of the Gamov massif is 260 ± 2 million years, which confirms by the earlier obtained Late Permian age.

4. Conclusions

Late-Paleozoic granitoids of the Gamov complex form a series of granodiorite-granite-leucogranite. Refer to magnesian, peraluminous, calcic and calc-alkalic varieties. They have elevated concentrations of light rare earth elements and large-ion lithophile elements. Correspond to granites of I and S types.

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