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GEOLOGY

The Uspensk Intrusion in South Primorye as a Reference Petrotype for Granitoids of the Transform Continental Margins

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Identification of the granitoid complexes as petrotypes of definite tectonic settings remains one of the most important geological problems taking into account the large volume of fundamental tectonic and applied regional works. To the present, the granitoids of within-plate environments, island arcs, subduction-related continental margins, and collisional settings have been substantiated and studied in detail [1–3 and others]. At the same time, the granitoid associations of transform plate boundaries have been studied significantly less well.

Transform continental-margin settings (Californian-type complex settings) related to subsidence of the oceanic ridge beneath a continent with the formation of slab windows and wide development of strike-slip faulting were distinguished for the first time at the western margin of North America [4 and others]. A similar regime was later substantiated for the Early Cretaceous and Paleogene stages of the Sikhote Alin evolution [5, 6]. Unlike the Californian coast, the transform margin setting in the Russian Far East was not complicated by mantle plumes that were unrelated to subduction. Therefore, this region is a unique object for distinguishing magmatic complexes typical of the transform–continental setting.

The composition and genesis of volcanic complexes that are typomorphic for this setting are characterized in detail in [6, 7]. However, identification of the indicator granitoid complexes is a difficult issue. The main problem was to substantiate reliably the fact that the granitoid intrusions were formed simultaneously with large-scale strike-slip faulting due to repeated deformations and a high degree of tectonic reworking of the granitoids.

This work is devoted to geological geochronological study of the granitoids of the Uspensk Massif in southern Primorye. In our opinion, this massif can serve as a reference petrotype for granitoids formed in a transform continental-margin setting.

The Uspensk Massif is located in southern Primorye at the coast of the Sea of Japan and extends over 40 km (average width 10 km) from Krakovka to Kievka bays. The present erosion level is located mainly close to the roof part. Geologically, the massif composes a large fold formed by strike-slip displacement along the Central Sikhote Alin fault. The granitoids cut and metamorphose the terrigenous–siliceous rocks of Jurassic accretionary prism, as well as the gabbro gneisses and amphibolites of the Early Paleozoic (?) Sergeev Complex, which overlie the accretionary prism as a tectonic nappe. The rocks of the Uspensk Massif are intruded by granitoids of the Late Cretaceous Lazovsk Complex and dikes of the Late Cretaceous (Cenomanian) Egerevsk Complex.

The Uspensk Massif [8] is characterized by a syntectonic nature, which is expressed in the ubiquitous gneissosity of the rocks and abundant cataclasis, as well as a common deformation style of the granitoids and framework, "synkinematic" contacts, and the presence of numerous xenoliths of host rocks (roof pendants) that are conformable with the general deformation trend (Fig. 1).

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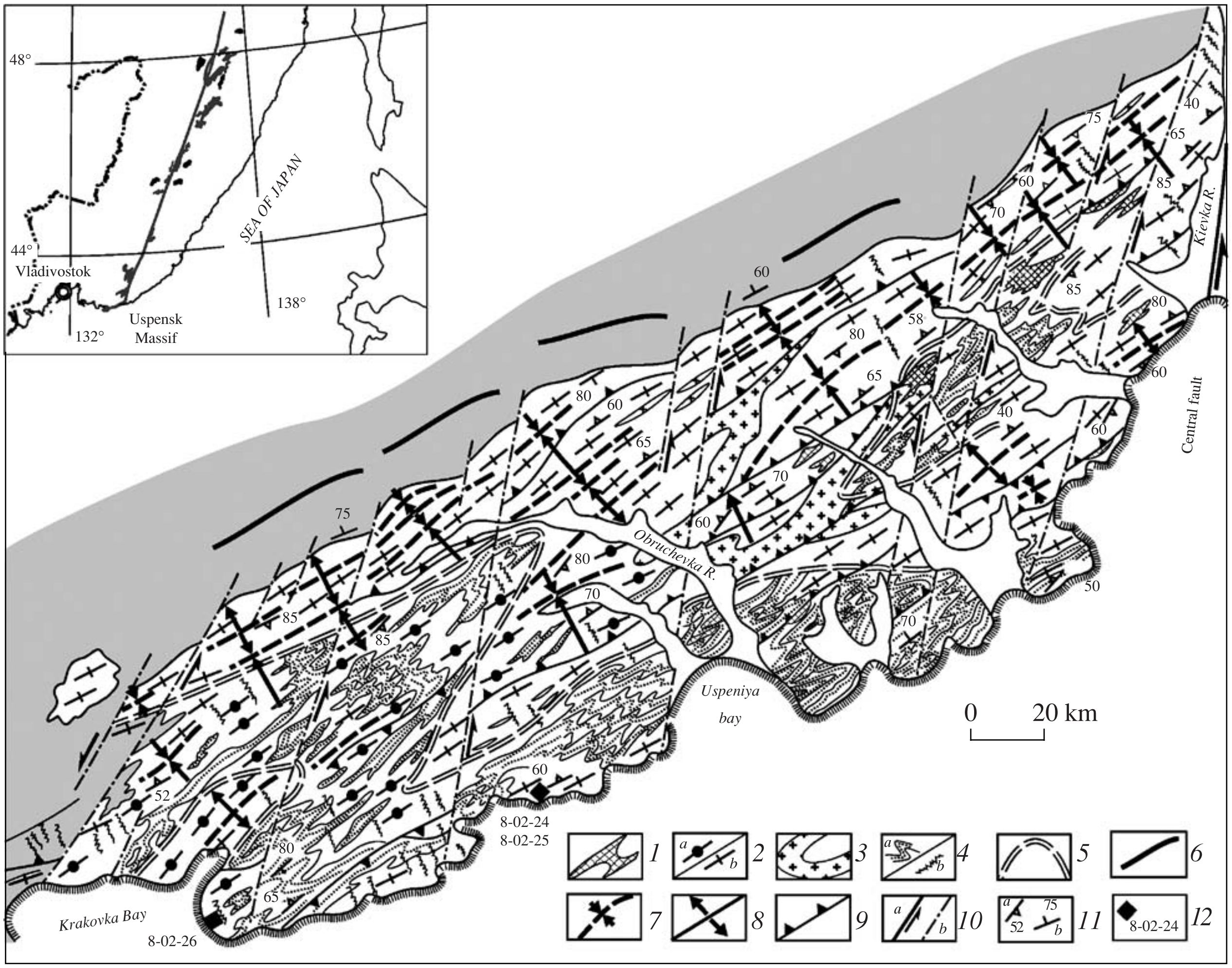

Fig. 1. Structural scheme of the Uspensk granite massif. Compiled by P.L. Nevolin using materials of geological mapping, scale 1 : 50 000 (S.V. Kovalenko, 1995). (1) Remains of Early Paleozoic gabbroids. Intrusive rocks: (2) garnet-bearing granites (a) and granodiorites (b); (3) leucogranites; (4) terrigenous schistose rocks (a) and Paleogene basic dikes (b); (5) boundaries of fold systems formed by remains of host rocks among granites; (6) predominant direction of fold axis in the host rocks beyond the intrusion; (7, 8) axes of pseudofolds formed by layering in granites: (7) synforms, (8) antiforms; (9) thrusts; (10) strike-slip faults of (a) first order (Central fault) and (b) second order; (11) strike and slip of layering in granites (a) and layering and schistosity in the xenoliths of host rocks (b); (12) geochronological sampling locality.

The massif consists of three intrusive phases (from early to late): (1) garnet–two-mica and garnet–biotite granite–leucogranites; (2) coarse-grained biotite granites; and (3) medium-grained biotite (± amphibole) granodiorites and melanogranites. Numerous dikes and small bodies of vein series (aplites, pegmatites, granodiorite porphyries, diorite porphyrites, leucogabbro, and lamprophyres) crosscut all aforementioned varieties. The contacts between individual varieties (excluding vein rocks) are typically unavailable for direct observation. However, the presence of xenoliths of leucocratic granitoids in the more melanocratic rocks indicates their phase relations and the basic-to-acid evolution.

Chemically, the granitoids of the Uspensk Massif typically correspond to potassic (normal alkaline) rocks with elevated Al_2O_3 contents, which is typical of S-type granites (after [11]). At the same time, some mineralogical (the presence of intermediate plagioclase and the sporadic absence of amphibole and accessory allanite) and petrogeochemcial (the ubiquitous presence of Al-undersaturated varieties with an agpaitic index up to 0.85; elevated contents of REE, Sr, Ba, and P in the granodiorites) features make them similar to the monzonitoid series of crustal–mantle genesis.

Samples for isotope dating were taken from garnet-bearing granites near Sysoev Cape (sample 8-02-26) and from biotite granodiorites east of Tsukanov Bay (samples 8-02-24 and 8-02-25).

Zircons extracted from these samples are similar. They are represented by colorless, mainly transparent, prismatic, well-shaped grains with distinct prismatic

Results of the U–Pb isotopic study of zircons from granitoids of the Uspensk Massif, Primorye

Ordinal no.	Fraction, µm	Weight, mg	Content, µg/g		Measured isotope ratios		
			Pb	U	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$
Sample 8-02-26							
1	Mixture, –125 + 75	1.05	15.38	970.2	1580	0.0574 ± 8	10.675 ± 80
2	Coarse, –125 + 100	0.9	14.06	908.5	1570	0.0574 ± 8	10.174 ± 80
3	Medium, –100 + 75	1.04	12.53	792.4	2080	0.0551 ± 5	9.418 ± 40
Sample 8-02-24							
1	Coarse, +100	0.94	10.39	671.3	1750	0.0564 ± 2	9.279 ± 21
2	Medium, –100	1.07	11.9	759.9	2050	0.0552 ± 11	9.121 ± 70
3	–125 + 75, 10 h, SD	3.22			2146	0.0556 ± 9	3.278 ± 15
Ordinal no.	Fraction, µm	Isotope ratios		*Rho*	Age, Ma		
		$^{207}Pb/^{235}U$	$^{206}Pb/^{238}U$		$^{207}Pb/^{235}U$	$^{206}Pb/^{238}U$	$^{207}Pb/^{206}Pb$
Sample 8-02-26							
1	Mixture, –125 + 75	0.1077 ± 30	0.0162 ± 28	0.68	104 ± 3	104 ± 2	104 ± 5
2	Coarse, –125 + 100	0.1041 ± 30	0.0157 ± 28	0.67	100 ± 3	100 ± 2	103 ± 5
3	Medium, –100 + 75	0.1059 ± 28	0.0160 ± 30	0.81	102 ± 3	102 ± 2	104 ± 4
Sample 8-02-24							
1	Coarse, +100	0.1030 ± 28	0.0155 ± 2	0.81	99 ± 3	99 ± 2	101 ± 4
2	Medium, –100	0.1041 ± 27	0.0157 ± 2	0.93	100 ± 3	100 ± 2	105 ± 4
3	–125 + 75, 10 h, SD	0.1131 ± 25	0.0170 ± 2	0.77	109 ± 3	109 ± 2	112 ± 4

Note: All errors are given at 2σ level. (SD) Selective dissolution.

and pyramidal faces. Some coarse grains contain inclusions of ore mineral.

U–Pb isotopic dating was conducted at the Vernadsky Institute of Geochemistry and Analytical Chemistry using the technique described in [12]. To analyze grains, zircons were separated into size fractions 100–125 and 75–100 µm. Six zircon fractions were analyzed. One fraction from sample 8-02-24 was treated with selective acid leaching to expose the ancient component [13].

Results of U–Pb isotopic studies are shown in the table and Fig. 2.

Five analyzed zircon fractions yielded practically concordant U–Pb ages. All three fractions from garnet–biotite leucogranites (sample 8-02-26) define an upper intercept age of 103.3 ± 2.4 Ma (Fig. 2a). Two fractions from granodiorite (sample 8-02-24) yield slightly younger (but within error limits) similar $^{206}Pb/^{238}U$ and $^{207}Pb/^{235}U$ ages within 99–100 Ma. A five point discordia defines a U–Pb age of 103.8 ± 4.6 Ma (Fig. 2b). Selective dissolution of zircon from granodiorites (sample 8-02-24) revealed ancient lead with a $^{207}Pb/^{206}Pb$ residue age of 112 Ma. Two fractions of granodiorites define a discordia with an upper intercept at 99 ± 2 Ma. Including data on selectively leached zircons, they define intercept ages of 87 ± 27 and 124 ± 37 Ma.

Thus, the crystallization age of garnet-bearing granites of the Uspensk Massif is 103.3 ± 2.4 Ma, while granodiorites and melanogranites have slightly younger ages.

The $^{40}Ar/^{39}Ar$ step heating data of biotite from granodiorites (sample 8-02-25) yields a distinct plateau (Fig. 3) with an age of 77.5 ± 1.0 Ma (released ^{39}Ar 99%). Biotite from garnet-bearing granite (sample 8-02-26) defines a discordant age spectrum, in which three former stages yield an intermediate plateau at 68.4 ± 0.9 Ma (released ^{39}Ar 43%). Thus, biotites yield significantly younger (Late Cretaceous) ages. Since the biotite K–Ar closure temperature is about 330–360°C [14], the obtained Campanian–Maastrichtian data increasing in the northeastern direction presumably

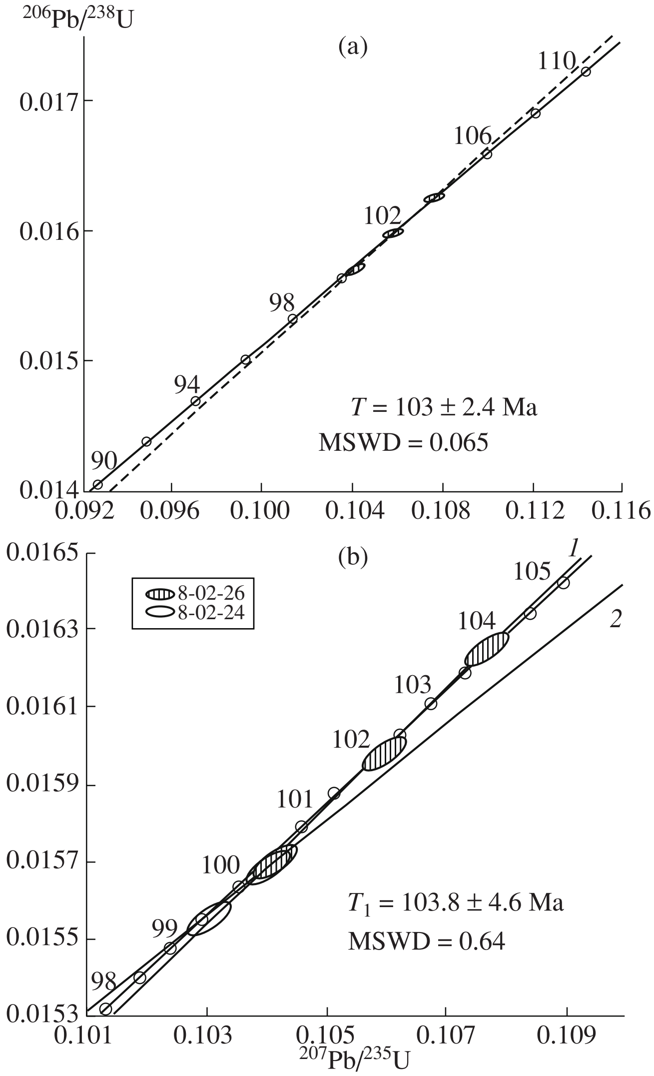

Fig. 2. U–Pb isotopic concordia diagram demonstrating results of radiological dating of the granitoids of the Uspensk Massif. (a) garnet–biotite granite (sample 8-02-26); (b) total discordia for granodiorite 8-02-24 and garnet–biotite granite 8-02-26.

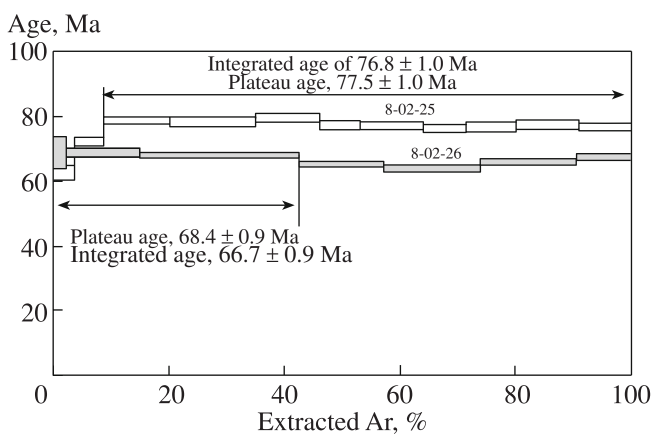

Fig. 3. Results of $^{40}Ar/^{39}Ar$ isotopic dating of biotites from the rocks of the Uspensk Massif: open spectrum is biotite from granodiorite (sample 8-02-25) and filled spectrum is biotite from garnet–biotite granite (sample 8-02-26).

reflect a tectonothermal event that was superimposed on the already solidified granitoids due to intrusion of the granitoids of the Lazovsk Complex.

Thus, the granitoids of the Uspensk Massif were formed in the Early Albian, which coincides with the age of the transform continental margin in Primorye and related large-scale displacements along the Central Sikhote Alin fault. Therefore, the Uspensk Massif can be regarded as the reference pluton for identifying indicator features and formation conditions of the granitoid complex in this geotectonic setting.

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