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GEOLOGY

First SHRIMP U–Pb Zircon Dating of Magmatic Complexes in the Southwestern Primor'e Region

Academician **A. I. Khanchuk**[a], Corresponding Member of the RAS **V. G. Sakhno**[a], and **A. A. Alenicheva**[b]

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The eastern segment of the Central Asian orogenic belt is represented by structures of the southwestern Primor'e region: Voznesenskii Terrane with the Late Proterozoic–Cambrian passive continental margin and Laoelin–Grodekovo Terrane of the island-arc back part [1].

Previously, it was established that the Voznesenskii Terrane hosts the Grodekovo batholith composed of the Silurian Shmakovka–Grodekovo granitoid complex [2].

Recent thorough studies of this complex in the southwestern Primor'e region revealed massifs of Late Permian–Early Jurassic granitoids in the western part of the Grodekovo batholith correlative with the Ryazanovka and Gvozdevo complexes developed in the southern part of this region (Fig. 1) [3]. It was established that the Ryazanovka Complex contains gold mineralization, which put forward the problem of estimating the gold resource potential of this area. Of interest is also the activity scale of Silurian granitoid magmatism in the entire region. In this connection, its granitoid complexes have been studied using the SHRIMP U–Pb chronological method.

Three different-age complexes are definable in the Grodekovo batholith: Late Silurian–Devonian Grodekovo, Late Permian Ryazanovka, and Early Jurassic Gvozdevo [2, 3, and others]. According to the last works, the Grodekovo Complex composed of coarse-grained biotite–hornblende granites constitutes most of the batholith. The Ryazanovka Complex is represented by biotite–hornblende diorite–granodiorite–granite intrusive bodies. Intrusions of the Gvozdevo Complex are of limited distribution, being largely known from the northern part of the batholith, where they are composed of biotite granites, leucogranites, and granite–porphyries. The first two complexes belong to the Na series, while the Gvozdevo complex is attributed to the potassic–low-calcic one. Granitoids of the Ryazanovka Complex contain gold-ore occurrences of the gold–quartz–sulfide type. Its black shales are characterized by gold-sulfide mineralization. All these finds provided grounds for defining the Primor'e gold-ore minerogenic zone [4].

The spatial overlapping of the Grodekovo magmatic complex and the Primor'e gold-ore minerogenic zone implies a genetic connection between magmatism and mineralization. The relationships between igneous rocks in the Grodekovo batholith and their age, as well as that of gold mineralization, have been discussed in many works. The previous age estimates largely obtained by K–Ar and Rb–Sr methods are usually ambiguous, which caused uncertainty about the timing of magmatism development, the gold resource potential, and the geodynamic nature of the region in question [5].

In this communication, we present the first results of U–Pb dating of zircons from magmatic complexes by the SHRIMP method. The U–Pb age was determined at the Center of Isotopic Studies of the Karpinskii All-Russia Research Institute of Geology.

As is known, the SHRIMP method is the most accurate for local dating of rocks. In addition, age measurements were accompanied by determination of the REE, Th, and U concentrations in zircons. Zircons for geochronological studies were sampled at 16 sites of the region from all the magmatic complexes (Fig. 1, table). At least 10 zircon grains were analyzed in each sample.

In the northern part of the batholith, zircons were sampled from the Ryazanovka and Gvozdevo granitoid complexes, one of which exhibits gold mineralization. Two samples were taken from the Gvozdevo Complex (9761-2 and 4990, Tsirkovyi Massif) previously dated back to the Early Jurassic (table, Fig. 2). Zircons from these samples are long-prismatic, transparent, 90–100 μm long with the elongation coefficient ranging from 1.5 to 2.5. Based on two samples,

[a] *Far East Geological Institute (DVGI), Far East Division, Russian Academy of Sciences, pr. Stoletiya Vladivostoka 159, Vladivostok, 660022 Russia*
e-mail: v_sakhno@mail.ru
[b] *Karpinskii All-Russia Research Institute of Geology, Srednii pr. 74, St. Petersburg, 199106 Russia*
e-mail: antonina_alenicheva@vsegei.ru

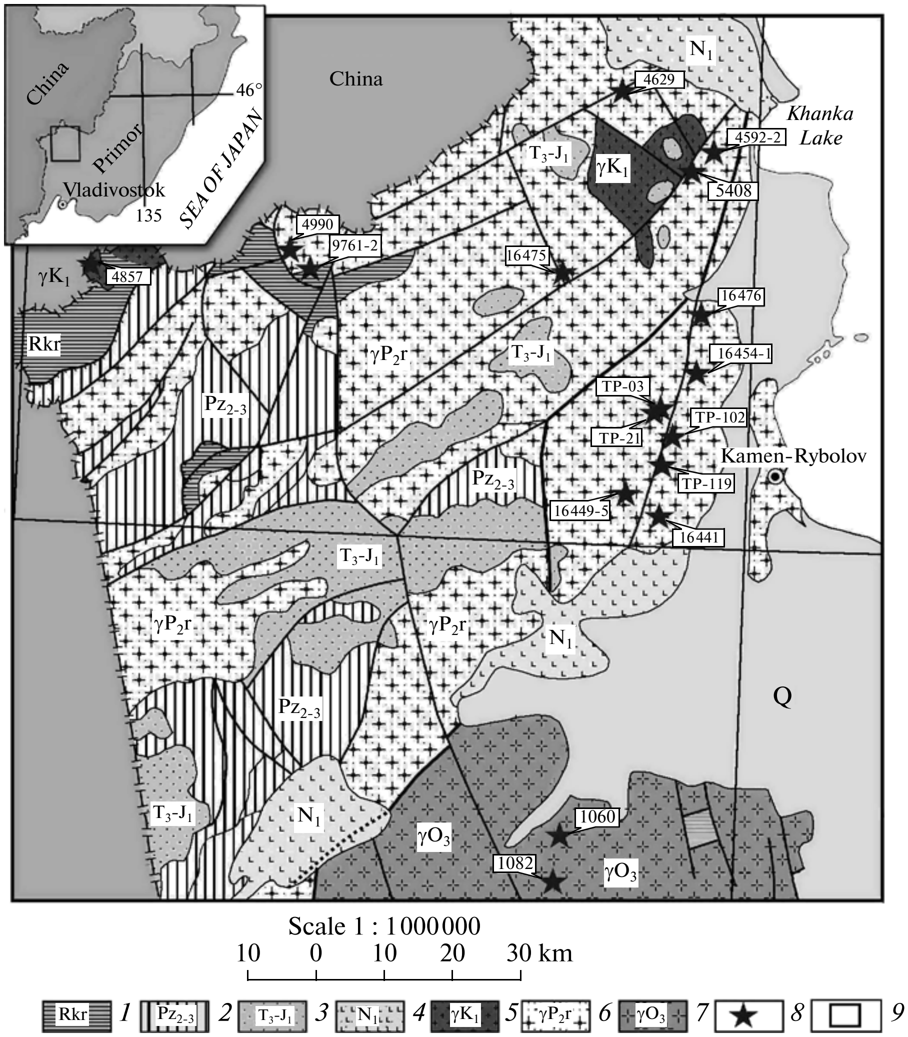

Fig. 1. Schematic distribution of granitoid complexes in the southwestern Primor'e region, after [3] modified. (*1*) Basement (metamorphic, sedimentary–volcanogenic, and volcanic formations and complexes); (*2*) Middle–Upper Paleozoic (Pz_{2+3}) sedimentary–volcanogenic and volcanogenic complexes and formations (Kordon, Vladivostok, Barabash, and others); (*3*) Mesozoic (Upper Triassic and Lower Jurassic) sedimentary and volcanogenic rocks; (*4*) Cenozoic and Recent sedimentary–volcanogenic rocks; (*5–7*) granitoid complexes: (*5*) Tatiba (γK_1), (*6*) Ryazanovka (γP_2r), (*7*) Voznesensk (γO_3); (*8*) sampling sites for U–Pb geochronological studies and their numbers (table); (*9*) the study area in the inset.

age of the complex is determined as varying from 266 ± 3.0 to 265.6 ± 3.0 (Fig. 2).

Ten samples were taken from different areas of the Grodekovo batholith (Fig. 1) to characterize granitoid rocks of the Grodekovo Complex, which was previously considered to be Silurian in age. The diagram with concordia demonstrates geochronological results obtained for granitoids from this complex based on $^{206}Pb/^{238}U$ values in zircons (Figs. 2c–2j). Judging from the average weighted U–Pb value, the age of granitoids of the Grodekovo Complex varies from 268.6 ± 3.0 to 247.6–248.0 Ma (Early Triassic), although most of the obtained ages may be united into three clusters: (1) 260.0 ± 7.5–263.8 ± 7.5 Ma; (2) 252.7 ± 2.9–255.7 ± 2.8 Ma; (3) 247.6 ± 2.5–248.0 ± 2.0 Ma.

Samples 4592-1 and TR-102 yielded two bimodal clusters with ages of 261 ± 3–247 ± 6 and 268 ± 2–248.0 ± 2.4 Ma (table). They correspond to the main period of granitoid magmatism. Such ages can be explained by either an insignificant loss of radiogenic lead or prolonged formation of an intrusion with the subsequent capture of older zircons, which is evident from high variations in the MSWD values. In the Tera–Wasserburg diagrams with concordia, these deviations are illustrated by error ellipses (1σ) (Figs. 2j–2l).

No Silurian granitoids were detected among igneous rocks from this part of the Grodekovo batholith dated by the U–Pb method. Granites of the Gvozdevo Complex sampled from the Tsirkovyi Massif, which were previously considered to be Early Jurassic in age [2, 3], are dated back to the Early–Late Permian by this method (table).

U–Pb zircon-based ages obtained for granitoids from magmatic complexes of the southwestern Primor'e region by the SHRIMP method

Sample	Coordinates		Complex, massif (m)	Rock, mineral composition	$^{206}Pb/^{238}U$, Ma	Number of grains/number of determinations
	N	E				
9761-2			Ryazanovka, Tsirkovyi (m)*	Granite, Bi	266 ± 3	10/10
4990	44°54′29″	131°22′26″	Ryazanovka, Tsirkovyi (m)*	The same	265.6 ± 3	11/11
5408	45 02 34	131 53 50	Ryazanovka	Granodiorite, Bi–Hb	260.1 ± 3	10/10
TP-21			The same	Granite, Bi	260.1 ± 3	10/10
TP-119			"	Granodiorite, Hb–Bi	268 ± 3	10/10
4592-2			"	Granite, Hb–Bi	a) 261 ± 3	7/10
			"	The same	б) 247 ± 6	3/10
16476	44 54 25	131 56 30	"	Granite, Hb–Bi	263.8 ± 7.5	9/11
16454-1	44 50 10	131 55 40	"	The same	252.7 ± 2.9	10/10
TP-03	44	131	"	Granodiorite, Hb–Bi	247.6 ± 2.5	10/10
TP-102			"	Diorite, Hb–Bi	a) 248 ± 2.4	8/10
			"	The same	б) 268 ± 2.0	2/10
16475	44 55 35	130 24 21	"	Granite, Hb–Bi	260.0 ± 7.5	10/10
164495			"	The same	255.7 ± 2.5	10/10
16441	44 45 50	131 52 00	"	"	254.4 ± 3.0	8/10
4629	44 58 42	131 24 21	Dike	Diorite–porphyry, Hb	208 ± 2.0	10/10
1060	44 23 57	131 47 37	Voznesensk*	Leucogranite, Bi	449.6 ± 5.3	10/10
1082	44 20 39	131 46 20	Voznesensk*	The same	451 ± 5.2	11/11

* Hereinafter, names of complexes are given after [3].

The U–Pb ages obtained for igneous rocks correspond to the Late Permian–Early Triassic crystallization period. They specify the previously determined formation period of these rocks (Silurian–Jurassic) and allow them to be correlated with the Ryazanovka Complex.

Thus, several phases are definable among granitoids attributed to the Permian Ryazanovka Complex: (1) early (Early–Late Permian), represented by potassic granitoids with ages of 265.0 ± 0.3–266.0 ± 3.0 Ma in the northwestern part of the batholith (Tsirkovyi Massif); (2) main, reflected in K–Na granites, granodiorites, and diorites dated at approximately 260.1 ± 3.0 Ma; and (3) late (K–Na granites and granodiorites) dated back to 255.7 ± 2.5–247.0 ± 6.0 Ma. The obtained results are illustrated well by the distribution histogram of U–Pb data points with the probability density curve (Fig. 3a) and ellipses (Fig. 3b).

Samples 1060 and 1082 were taken from granitoids of the Voznesensk block (terrane) characterized by wide development of leucocratic muscovite and biotite varieties, the protolithion type included. The block also contains fluoric greisens. Samples taken from intrusions of biotite and Li–F protolithion granites yielded a Rb–Sr and Sm–Nd age of 450 Ma.

The U–Pb zircon dating revealed that granitoids should be attributed to the Late Ordovician (table). The average weighted data obtained for 10 and 11 zircon grains extracted from two samples provide insignificant deviation (Figs. 2m, 2n).

The analysis of all the U–Pb zircon ages obtained for the granitoids provides grounds for the following inferences.

(1) No Silurian and Early Jurassic ages previously assumed for the Grodekovo and Gvozdevo complexes developed in the northern part of the southwestern Primor'e region (Grodekovo batholith) are confirmed.

(2) The Ryazanovka Complex is widespread among granitoids.

(3) New isotopic data cast doubts on the Silurian age of the Grodekovo batholith as a single magmatogenic structure.

(4) They also indicate significant development of the Late Permian granitoid magmatism with high gold resource potential in this region, which makes its economic prospects substantially more promising.

Late Paleozoic granitoids are observable west of the region under consideration, where they constitute plutons in spacious northeastern regions in China and

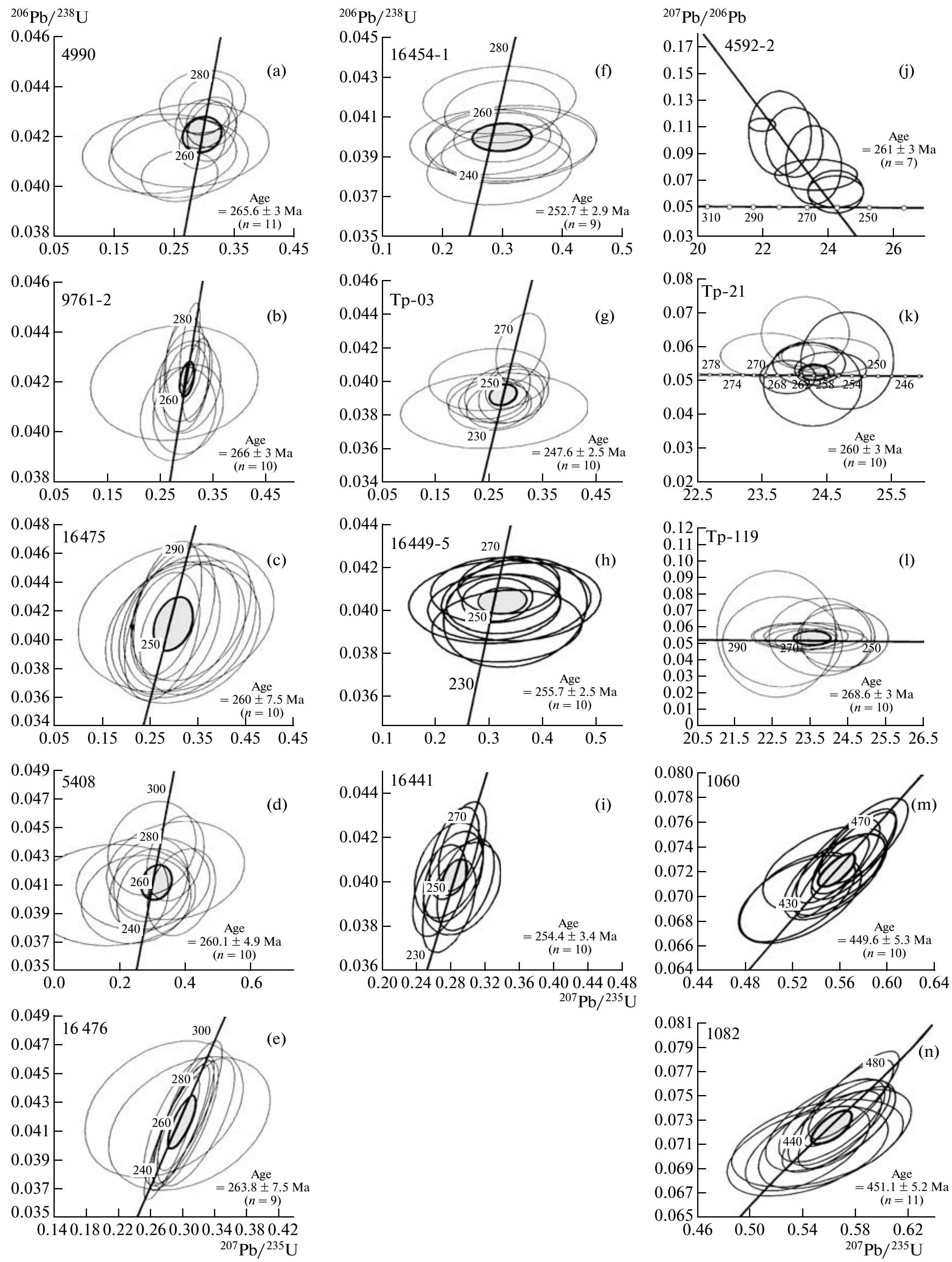

Fig. 2. Diagrams with concordia for granitoids from different areas of the southwestern Primor'e region. Average weighed results are given (table); in Figs. 2a–2l, they are shown as ellipses contoured by the thickened line. Individual analyses are illustrated by ellipses contoured by thin lines and reflecting errors (2σ). Scales for different errors are variable. Errors are best illustrated by diagrams of the $^{207}Pb/^{206}Pb - ^{238}U/^{206}Pb$ ratios (Figs. 2j–2l) (error ellipses are 1σ). In Figs. 2m, 2n, Tera–Wasserburg diagrams illustrate clusters of data on zircons from the Late Ordovician Voznesensk block (terrane).

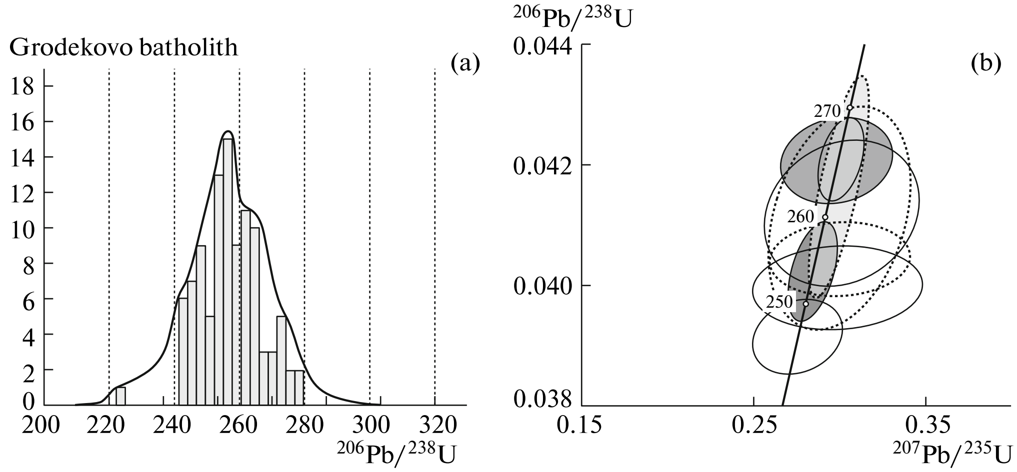

Fig. 3. (a) Histogram illustrating the distribution of U–Pb ages and probability density curves compiled using the ISOPLOT program [8]; (b) Tera–Wasserburg diagram demonstrating some clusters of ages determined for zircons from the Late Permian–Early Triassic Ryazanovka granitoid complex reflecting multistage formation of intrusions discussed in the text.

Mongolia along the northern boundary of the Hercynian orogenic belt (paleoocean).

It should be emphasized that the new U–Pb ages of zircons allow a slightly different interpretation of the geodynamic regime in the region under consideration and cast doubts on the collisional origin of granitoids. No crystals with inherited Precambrian xenogenic nuclei, which would indicate the anatectic nature of melts borrowed from the lower crustal protolith during its melting, are identified among the zircons analyzed (>150 grains). Thus, Permian granitoids are riftogenic in origin; they were formed in the rear part of the island arc. The Late Permian Voznesensk granitoids demonstrate features of intraplate magmatism.

Similarly to other world regions, the Late Permian–Early Triassic magmatism of southwestern Primor'e reflects global geodynamic reorganization, namely, the onset of the Pangea breakup, which was marked by the formation of rifts and extensive eruption of Pangean flood basalts in Siberia (P–T–J), southwestern China (P–T), and other domains [6, 7, and others]. In the Central Asian belt, this stage was marked by extensive granitoid magmatism and explosive volcanism, which was accompanied by intense blowouts of carbon-bearing gases. The last process was responsible for catastrophic consequences: drastic environmental changes, formation of anoxic settings in the oceans and on the shelf, extinction of organisms, and greenhouse effects that stimulated accumulation of black shales and gold sorption in carbonaceous sediments with the subsequent formation of gold ore deposits during intrusion of granite massifs.

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