ISSN 1028-334X, Doklady Earth Sciences, 2006, Vol. 409A, No. 6, pp. 888–892. © Pleiades Publishing, Inc., 2006.
Original Russian Text © E.B. Sal'nikova, A.M. Larin; A. B. Kotov, A.P. Sorokin, A.A. Sorokin, S.D. Velikoslavinsky, S.Z. Yakovleva, A.M. Fedoseenko, Yu.V. Plotkina, 2006, published in Doklady Akademii Nauk, 2006, Vol. 409, No. 5, pp. 652–657.

The Toksko–Algomin Igneous Complex of the Dzhugdzhur–Stanovoi Folded Region: Age and Geodynamic Setting

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Received March 15, 2006

DOI: 10.1134/S1028334X06060110

The Dzhugdzhur–Stanovoi mobile belt (DSMB) represents one of the most intricate tectonic structures of the Siberian Craton.[1] In addition to strongly metamorphosed complexes that are traditionally referred to as the Early Precambrian, the DSMB comprises abundant Phanerozoic plutonic and volcanic rock complexes related to development of the Central Asian, Mongol–Okhotsk, and Pacific orogenic belts. Diverse manifestations of this magmatism and presumed structural–metamorphic reworkings of different-age (Precambrian–Mesozoic) igneous rocks in the course of subduction, accretion, and collision processes poses the problem of reliable discrimination of oldest rocks among metamorphic complexes of the DSMB basement. In this connection, geochronology of assumed old plutonic complexes that are characterized by distinct geological relationships with metamorphic rocks is a first-priority task in comprehensive investigations of the DSMB system.

According to recent concepts [2], main features of the geological structure of the assumed Early Precambrian basement of the DSMB are determined by two major types of tectonic structures: (i) granulite blocks (Dambuka, Larba, Sivakan–Tok, Chogar, and others) and (ii) intervenient tectonic zones of rocks of the Stanovoi Complex metamorphosed to the amphibolite facies. In the available correlation schemes [3], structures of both these types are attributed, without sufficient substantiation, to the Lower or Upper Archean.

Granitoids of the Toksko–Algomin Complex first defined and most widespread in the Kupurin tectonic zone (Fig. 1) are traditionally considered the oldest ones among igneous rocks of the DSMB [3]. These granitoids intrude rocks of the Stanovoi Complex. Rocks of both complexes are folded, subjected to amphibolite metamorphism, and intruded by synmetamorphic ultrametagenic granites of the Late Stanovoi Complex. Recent geochronological studies [4] revealed, however, that granites have the Early Cretaceous (not Early Precambrian, as suggested in [2]) age. Therefore, it is logical to assume that the Stanovoi Complex was metamorphosed in the Early Cretaceous rather than the Early Proterozoic, as it is accepted by the majority of researchers [2, 3]. For solving this problem, it is very important to date the Toksko–Algomin Complex, which would allow us to establish the lower age limit of high-temperature metamorphism of the Stanovoi Complex and estimate the upper age limit of its formation, at least at first approximation.

Igneous rocks of the Toksko–Algomin Complex constitute diverse (in size and morphology) intrusions ranging from relatively small stratiform and even dike-shaped bodies to large massifs (>1000 km^2). Because of superimposed structural–metamorphic reworkings under conditions of high-temperature amphibolite facies, in most cases, intrusive bodies of the Toksko–Algomin Complex have nearly parallel contacts with planes of host rocks of the Stanovoi Complex while the rocks are transformed into orthogneisses and crystalline schists of various compositions.

In terms of chemical composition, igneous rocks of Toksko–Algomin Complex vary from gabbro to granodiorite. However, particular massifs of this complex are usually dominated by calc-alkaline diorites and quartz diorites characterized by the distinct prevalence of sodium among alkalis (Na_2O/K_2O = 3.87–1.65), lower

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[1] Following [1], we consider the DSMB as a structure bordered by the Dzheltulak suture zone on the west, Stanovoi fault on the north, and the Mongol–Okhotsk foldbelt on the south.

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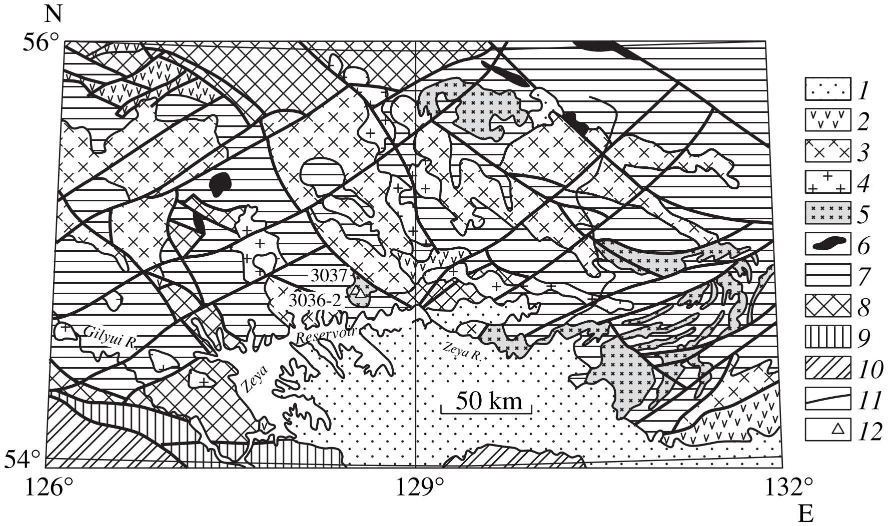

Fig. 1. Schematic geological structure of the western Dzhugdzhur–Stanovoi folded region. (*1*) Quaternary sediments of the Zeya Depression; (*2*) Cretaceous volcanosedimentary complexes of superimposed depressions; (*3*) granitoids of the Tynda–Bakaran Complex (K_1); (*4*) synmetamorphic reomorphic granites of the Late Stanovoi Complex (K_1); (*5*) igneous rocks of the Toksko–Algomin Complex (T_2); (*6*) layered mafic–ultramafic intrusions of the Luch Complex (T_1); (*7*) metasedimentary and metavolcanic rocks of the Stanovoi Complex (PR_1?); (*8*) granulite blocks (AR_2); (*9*) Ust'-Gilyui zone of the Selenga–Stanovoi superterrane; (*10*) Mongol–Okhotsk foldbelt; (*11*) major fractures; (*12*) sampling sites for geochronological studies.

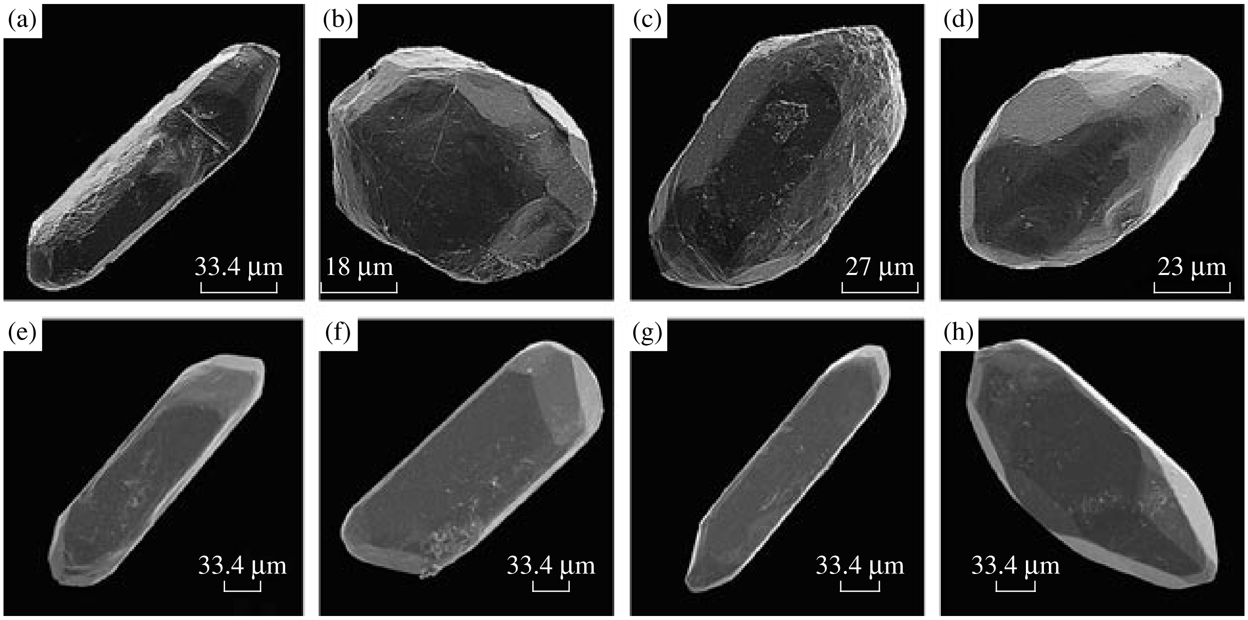

Fig. 2. Photomicrograph of zircon crystals (ABT-55 scanning electron microscope, secondary electron images). (a–d) Diorite from the Toksko–Algomin Complex (sample 3037); (e–h) two-mica pegmatite (sample 3036-2).

alumina content (A/CNK = 0.78–0.99), low agpaitic coefficient (NK/A = 0.39–0.67), low mafic index (FeO*/(FeO* + MgO)) = 0.53–0.71), and low contents of the majority of incoherent elements, except for Ba and Sr. Against the background of low REE contents, igneous rocks of the Toksko–Algomin Complex are enriched in LREE, as compared with HREE (La 25.3 ppm, Yb 1.09 ppm, La/Yb_N 14.6), and characterized by the absence of Eu anomaly. In discrimination diagrams, their data points fall into the field of island-arc and I-type granites. Massifs of the Toksko–Algomin Complex belong to plutons of the andesitic series and they formed, most likely, in the island-arc or active continental-margin settings.

The U–Pb geochronological study was carried out for the following rocks (Fig. 1): (1) relatively massive

Results of the U–Pb zircon dating of diorites of the Toksko–Algomin Complex and two-mica pegmatite

Ord. no.	Fraction (μm) and its characteristic	Weight, mg	Content, μg/g		Isotopic ratio		
			Pb	U	^{206}Pb/^{204}Pb	^{207}Pb/^{206}Pb(a)	^{208}Pb/^{206}Pb(a)
Diorite from the Toksko–Algomin Complex (sample 3037)							
1	>100	1.11	2.54	55.7	431	0.0520 ± 3	0.1991 ± 1
2	<70	6.67	2.30	50.3	801	0.0537 ± 1	0.2035 ± 1
3	>100, A 10%	5.96	2.29	50.5	561	0.0528 ± 1	0.1830 ± 1
4	–100 + 70, A 20%	3.57	1.89	42.8	574	0.0506 ± 3	0.2140 ± 1
Two-mica pegmatite (sample 3036-2)							
5	<70	1.68	6.29	154	785	0.0931 ± 1	0.0576 ± 1
6	>150	1.63	10.0	112	1521	0.1239 ± 1	0.0537 ± 1
7	–100 + 60, ac. tr.	–*	U/Pb = 21.1		839	0.1000 ± 1	0.0608 ± 1
8	>150, ac. tr.	–*	U/Pb = 14.2		5552	0.1178 ± 1	0.0557 ± 1

Ord. no.	Fraction (μm) and its characteristic	Isotopic ratio		*Rho*	Age, Ma		
		^{207}Pb/^{235}U	^{206}Pb/^{238}U		^{207}Pb/^{235}U	^{206}Pb/^{238}U	^{207}Pb/^{206}Pb
Diorite from the Toksko–Algomin Complex (sample 3037)							
1	>100	0.2761 ± 15	0.0385 ± 1	0.43	248 ± 1	244 ± 1	285 ± 12
2	<70	0.2935 ± 5	0.0396 ± 1	0.76	261 ± 1	251 ± 1	359 ± 3
3	>100, A 10%	0.2820 ± 6	0.0388 ± 1	0.69	252 ± 1	245 ± 1	318 ± 3
4	–100 + 70, A 20%	0.2608 ± 16	0.0374 ± 1	0.22	235 ± 1	237 ± 1	221 ± 14
Two-mica pegmatite (sample 3036-2)							
5	<70	0.4950 ± 11	0.0386 ± 1	0.81	408 ± 1	244 ± 1	1489 ± 2
6	>150	1.4642 ± 29	0.0857 ± 2	0.95	916 ± 2	530 ± 1	2014 ± 1
7	–100 + 60, ac. tr.	0.6099 ± 12	0.0442 ± 1	0.95	483 ± 1	279 ± 1	1625 ± 1
8	>150, ac. tr.	1.1196 ± 22	0.0689 ± 1	0.96	763 ± 2	430 ± 1	1923 ± 1

Note: (a) Isotopic ratios corrected for procedure blank and common lead; (A 10%) amount of substance removed by the air abrasion of zircon; (ac. tr.) residual zircon after acidic treatment; asterisk designates that the zircon weight was not determined; (*Rho*) coefficient of ^{207}Pb/^{235}U–^{206}Pb/^{238}U correlation. Error values (2σ) correspond to the last significant digit. Accessory zircon was extracted in line with the standard technique using heavy liquids. Decomposition of zircons and chemical extraction of Pb and U were carried out using the modified Krogh's method [5]. The procedure blank during the investigation did not exceed 50 ng for Pb. Isotopic compositions of Pb and U were determined with a Finnigan MAT-261 mass-spectrometer in the static regime or using the electron multiplier (coefficient discrimination for Pb was 0.32 ± 0.11amu). Experimental data were processed using programs PbDAT and ISOPLOT [6, 7]. Standard values of uranium decay constant were used for age calculations [8]. Corrections for common lead were introduced in correspondence with model values [9].

unmigmatized diorites of the Toksko–Algomin Complex (sample 3037) taken from a stratiform body (~500-m thick) that occurs among crystalline schists and gneisses of the Shtykzhan and Dzhigdala formations of the Stanovoi Complex exposed in the southeastern part of the Ilikan tectonic zone; (2) two-mica pegmatites (sample 3036-2) taken from a partly boudined vein that crosses crystallization schistosity in diorites of the Toksko–Algomin Complex and crystalline schists of the Shtykzhan Formation.

Diorites of the Toksko–Algomin Complex. Accessory zircon extracted from diorites of the Toksko–Algomin Complex (sample 3037) is represented by subhedral colorless transparent crystals of the oval, prismatic, subordinate long-prismatic, and acicular habit. The crystal habit is determined by combinations of prisms {100}, {110} and bipyramids {111}, {112} (Figs. 2a–2d). The internal structure of zircon crystals is characterized by magmatic zoning and abundance of mineral and fluid inclusions that are usually concentrated in central areas of grains, where relicts of inherited cores are also detected. Zircon grains vary from 40 to 200 μm in size (K_{el} = 1.5–4.0).

Four weighed samples of the purest zircon crystals from fractions >100, –100+70, and <70 μm were used for U–Pb measurements. Zircon grains from two samples (table, nos. 3 and 4) were subjected to air abrasion [10]. As is evident from the table and Fig. 3, the examined zircon is generally characterized by an insignificant discordance and its data points form a regression line, the lower intercept of which with concordia corresponds to the age of 238 ± 2 Ma, while the upper intercept with concordia corresponds to the age of 1627 ± 200 Ma (MSWD = 0.93). The location data points of zircon near the lower intercept with concordia suggests an insignificant contribution of the older inherited component of radiogenic lead. Zircon from sample 3037 is of magmatic origin, which is evident from its morphological characteristics. Hence, the obtained value of 238 ± 2 Ma can correspond to the timing of crystallization of melts that served as sources for diorites of the Toksko–Algomin Complex.

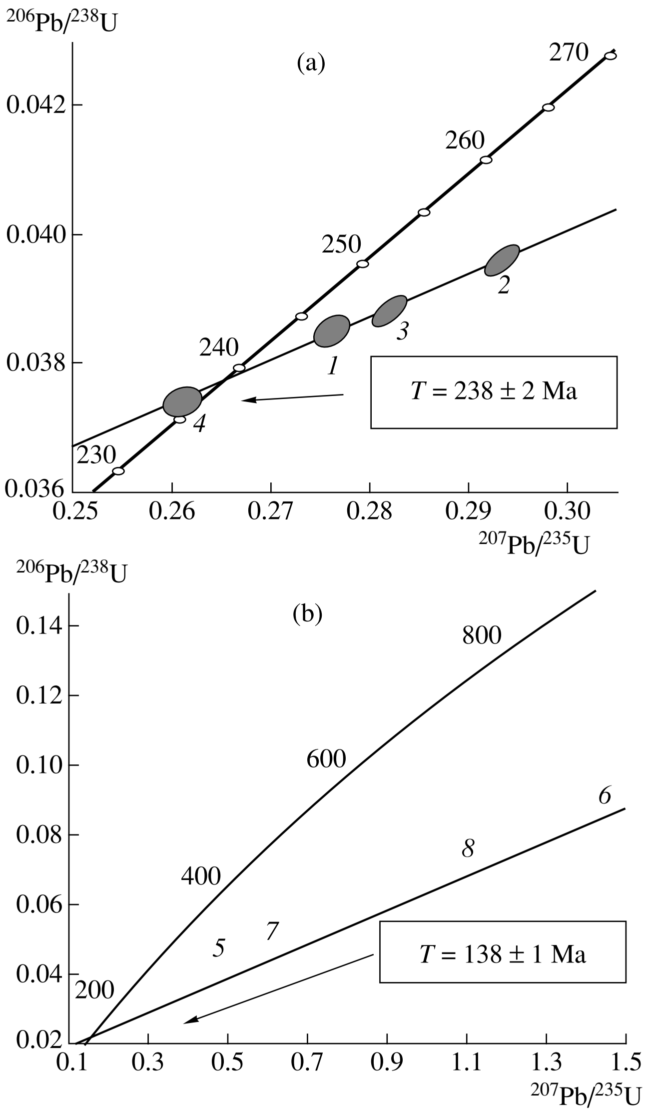

Fig. 3. Diagram with concordia for zircons from (a) diorite of the Toksko–Algomin Complex (sample 3037) and (b) two-mica pegmatite (sample 3036-2). Number of points correspond to ordinal numbers in the table.

Two-mica pegmatites. Accessory zircons extracted from two-mica pegmatites (sample 3036-2) are represented by subhedral and subordinate euhedral transparent colorless crystals of the prismatic and long-prismatic habit that is determined by combinations of a prism {100} and bipyramids {111}, {112}, and {221} (Figs. 2e–2h). Zircon grains do not show zoning in the transmitted light, but their central domains enclose fluid and solid inclusions. Zircon grains range from 40 to 300 μm in size ($K_{el} = 3.3$).

The purest zircon crystals from fractions >150, –100 + 60, and <70 μm were used for U–Pb measurements. Zircon grains from fractions >150 and –100 + 60 (table, nos. 7 and 8) were subjected to acidic treatment [11]. As follows from Fig. 3b, data points of zircon form discordia and are located near its intersection with concordia corresponding to age of 138 ± 1 Ma. The upper intercept with concordia corresponds to the age of 2278 ± 5 Ma (MSWD = 0.38). Such a disposition of data points of zircon is most likely related to the presence of the older component of radiogenic lead in zircon grains (core relicts unidentified in the transmitted light). Taking into consideration the magmatic origin of examined zircon, there are grounds to consider the resulted age value of 138 ± 1 Ma as the timing of zircon crystallization and, correspondingly, crystallization age of two-mica pegmatites.

The obtained data indicate that the Toksko–Algomin Complex is of the Middle Triassic (rather than Archean, as was thought previously) age and the regional high-temperature amphibolite metamorphism, which is superimposed on rocks of both the Toksko–Algomin and Stanovoi complexes, is also of the Mesozoic (not Early Precambrian) age. Two-mica pegmatites (138 ± 1 Ma old) are age analogues of synmetamorphic ultrametagenic granites of the Late Stanovoi Complex (138–140 Ma). The formation of these pegmatites was most likely related to later stages of ultrametamorphism of the Stanovoi Complex.

Thus, the formation of igneous rocks of the Toksko–Algomin Complex represents the earliest manifestation of Phanerozoic magmatism in the DSMB and marks the beginning of an episode of subduction of the Mongol–Okhotsk paleocean lithosphere under the southeastern margin of the Siberian continent. In adjacent structures of the Selenga–Stanovoi superterrane, the syncontemporaneous magmatism was quite different: the closure of the Paleozoic ocean was accompanied by the formation of intraplate alkali and subalkaline granites and bimodal volcanic series [12]. Absence of correlation between manifestations of magmatism within these two large continental blocks of eastern Asia (Selenga–Stanovoi and Dzhugdhur–Stanovoi superterranes) up to the Early Cretaceous implies that these tectonic units developed autonomously in the terminal Paleozoic and Early–Middle Mesozoic. The present-day Dzheltulak suture zone, which passes between these superterranes, was occupied by an oceanic basin at that time.

Age analogues of the Toksko–Algomin Complex are missing also in the southern continental framing of the eastern Mongol–Okhotsk belt, where the granitoid magmatism was most intense in the Early Permian [13] and Early Triassic [14]. Manifestations of magmatism were synchronous on both sides of this structure only since the Early Cretaceous [15]. Therefore, we can assume that the oceanic basin existed until the Early Cretaceous. However, it should be kept in mind that the Mongol–Okhotsk belt is lacking oceanic complexes younger than the Middle Jurassic. Jurassic depressions developed along the Mongol–Okhotsk suture are presumably orogenic structures [1].

ACKNOWLEDGMENTS

We are grateful to N.N. Petruk, chief geologist of the Amurgeologiya Federal Unitary Geological Enterprise, who donated materials for this study and made useful remarks concerning the results.

This work was supported by the Russian Foundation for Basic Research (project nos. 03-05-64893, 04-05-64810, 05-05-65081, 05-05-65128, and 05-65-64242), the Foundation for the Support of Leading Scientific Schools (NSh-615.2003.05), the Earth Sciences Division of the Russian Academy of Sciences (programs "The Central–Asian Foldbelt: Geodynamics and Formation Stages of the Earth's Crust" and "Isotopic Systems and Isotopic Fractionation in Natural Processes"), the Russian Science Support Foundation, the Presidium of the Far East Division of the Russian Academy of Sciences (projects "Age Levels of Mesozoic Magmatism and Mineralization at the Southern Margin of the Siberian Craton" and "Stages and Mechanisms of the Continental Crust Formation in the Eastern Segment of the Mongol–Okhotsk Belt and Its Surroundings").

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