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GEOLOGY

New Age Data on Precambrian Volcanic Rocks of the Khakdon Group, Eastern Kolyma Region

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The Riphean sections of the Kolyma terrane have been studied by different authors for many years. However, the absence of reliable geochronological dates, complex pattern of tectonic setting, and low degree of exposure led to the appearance of different tectonic schemes [1, 2]. The most detailed scheme was developed by Tkachenko [3, 4], who distinguished two (eastern and western) types of Riphean sections. The presumably Upper Riphean Khakdon terrigenous–volcanogenic sequence, which is reliably identified due to the wide abundance of volcanic rocks, appears to be an important marker for the correlation of sections in the eastern part of the Kolyma terrane. However, analogues of the Khakdon Group are absent in the western part of the Kolyma terrane.

The Late Riphean age of the Khakdon Group is determined by its position in the section (Fig. 1). It discordantly overlies different beds of the Ossalin, Chebukulakh, and Yukagir groups, which are correlated with the Middle–Upper Riphean Kerpyl, Lakhanda, and lower Ui groups at the southeastern margin of the Siberian Craton [1, 5]. It is overlain by the Uyankan terrigenous sequence, which consists of often cross-bedded quartzose and feldspar–quartz sandstones intercalating with thinner siltstones and shale beds. The Uyankan Group is overlain by Vendian deposits with sharp unconformity at the base. Thus, based on stratigraphic position, the Khakdon and Uyankan groups are correlated with the middle and upper parts of the Ui Group at the southeastern margin of the Siberian Craton. The lower and middle parts of the Ui Group contain numerous sills with U–Pb and Sm–Nd ages varying within 1000–940 Ma [6, 7].

The Khakdon Group is exposed at three isolated places (Fig. 1). A sufficiently well exposed stratotype area is located in the northern Kolyma terrane along the upper reaches of the Kamenka River. The relations of the Khakdon Group with underlying and overlying complexes were established by mapping, but no contacts were found.

The thickness of the Khakdon Group varies from 300 to 1400 m. The rocks experienced pervasive metamorphism, whose intensity widely varies but probably nowhere exceeds the greenschist facies. Volcanic rocks are mainly represented by rhyolites, basalts of elevated alkalinity, and trachytes in some places. Mafic rocks are also characterized by high Ti and P contents [4]. In terms of the major element composition, the volcanic rocks of the Khakdon Group are close to the magmatic rocks of the prerift stage or to the earliest stages of continental rifting.

The U–Pb dating was carried out for two rhyolite samples (1657-16 and 1657-18) taken from adjacent lava flows in the southernmost exposures of the Khakdon Group in the Stolbovaya River basin (Fig. 1). Heavy fractions containing numerous zircon grains were extracted by the conventional heavy liquid technique (Fig. 2). Zircons in both samples are similar and represented by light pink and cherry, subeuhedral and euhedral, prismatic zircons of hyacinth and zircon habits. The grain surface is thin-cellular and slightly dissolved. The grains show a zoned internal structure with fluid and ore inclusions. The crystals are 30–150 μm long (K_{el} = 3.0–3.5). In cathodoluminescent rays, most crystals have homogenous structure, while zoned zir-

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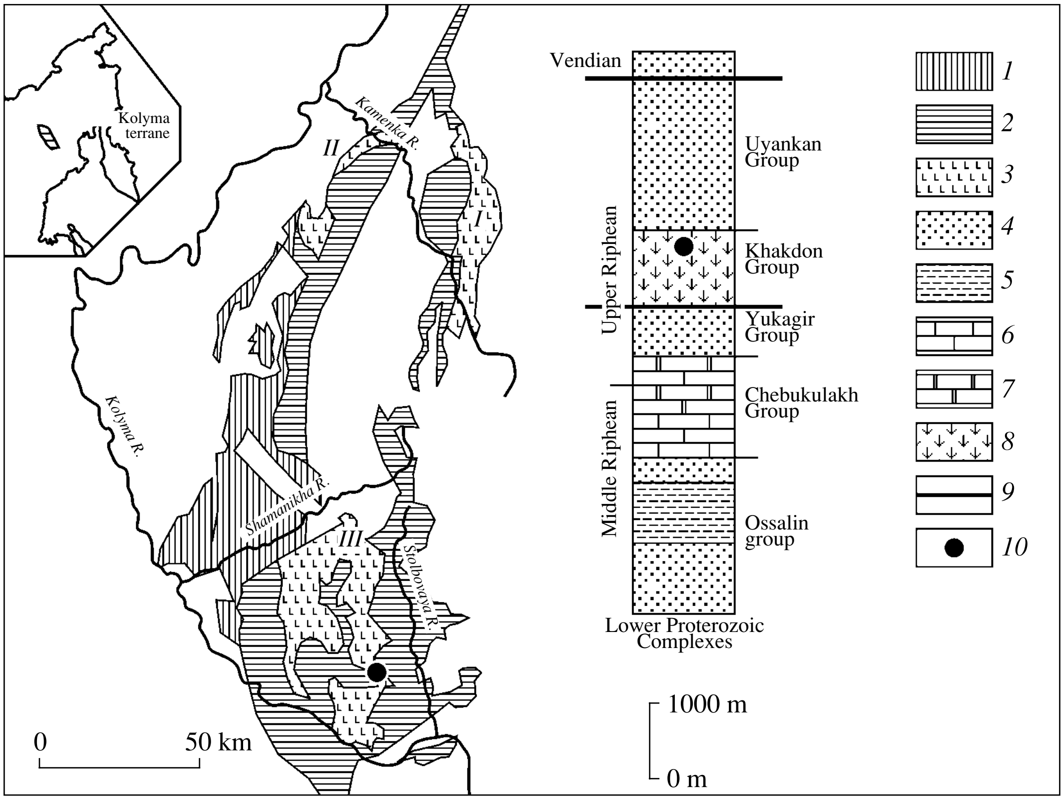

Fig. 1. Geological scheme and stratigraphic column of the Riphean complexes of the Kolyma terrane (modified after [3, 4]). Scheme of the development of the pre-Vendian sequences: (*1*) Riphean, section of the western type, (*2*) Riphean (including Lower Proterozoic blocks), section of the eastern type, (*3*) Khakdon Group. Roman numerals denote fields of the Khakdon Group: (*I*) upper reaches of the Kamenka River (stratotype area), (*II*) lower and middle reaches of the Syapyakine and Kamenka rivers, (*III*) Shamanikha and Stolbovaya rivers basin. Stratigraphic column (section of the eastern type): (*4*) quartzite–sandstones with shale intercalations, (*5*) shales, (*6*) limestones, (*7*) dolomites, (*8*) volcanic rocks and tuffs, (*9*) angular unconformity, (*10*) regional and stratigraphic positions of samples taken for isotope–geochronological studies.

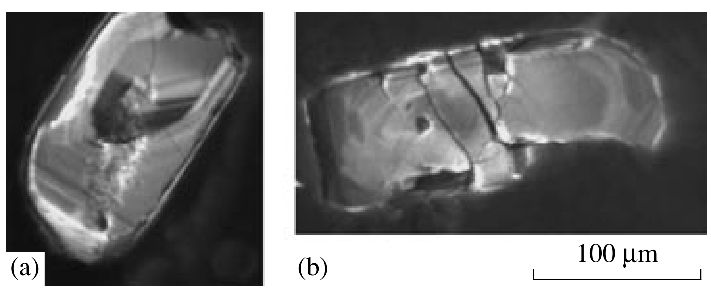

Fig. 2. Microimages of zircons taken for isotope–geochronological investigations, samples 1657-16 (a) and 1657-18 (b).

cons show vague zoning. Recrystallized domains are present in both the central and the marginal parts of the crystals. In some grains, the central parts are darker than the rims and resemble cores. The Th/U ratio in all grains is more than 0.5 (from 1.32 to 0.55), which, together with zircon morphology, points to magmatic genesis of the zircon grains [8]. Hand-picked zircons were mounted in epoxy resin together with TEMORA and 91500 zircon standards. Then, the grains were polished up to approximately half thickness. Areas (points) for dating were chosen using optical (transmitted and reflected light) and cathodoluminescence images of zircon grains, which demonstrate their internal structure and zoning.

U–Pb zircon dating was conducted on a SHRIMP-II ion microprobe at the Center of Isotope Research, Karpinskii All-Russia Research Institute of Geology (table, Fig. 3). We analyzed 17 grains (11 grains from sample 1657-16 and 6 grains from sample 1657-18). The SHRIMP-II U–Pb isotope ratios were measured using the standard technique [9] (intensity of the primary beam of negatively charged oxygen ions 4 nA, crater diameter 18 μm). Obtained data were processed with SQUID software [10]. The U–Pb ratios were normalized to the TEMORA zircon standard value of 0.0668, which corresponds to an age of 416.75 Ma [11]. Errors of single analysis (ratios and ages) are given at the 1σ level, errors of calculated concordant ages and intercepts with concordia are given at the 2σ level. Concordia diagrams were constructed using the ISOPLOT/EX software.

Most of the obtained isotope ratios are grouped near concordia and close to concordant values (table, Fig. 3). The discordance is <5% in 10 zircons, 5–10% in 4 zircons, and >10% in only 3 grains. The isotope ratios of all 17 grains define a single discordia with upper intercept at 1710 ± 21 Ma and lower intercept at 207 ± 220 Ma. The discordia is characterized by relatively low MSWD (1.2), which indicates that all grains were derived from a common source. These data, together with the magmatic origin of all analyzed zircon grains, suggest that the upper intercept represents the crystallization age of magmatic melt and eliminate the probability of the entrainment of zircons from host sedimentary and metamorphic rocks. Hence, the value of 1710 ± 21 Ma is the crystallization age of the analyzed rhyolite flows of the Khakdon Group. Owing to great error in the determination of the lower intercept age (207 ± 220 Ma), the obtained timing of isotope system disturbance cannot be correlated with any geological events.

The results of the isotope–geochronological study indicate a Paleoproterozoic (1710 ± 21 Ma) rather than Late Riphean age of volcanic rocks of the Khakdon Group in the Shamanikha and Stolbovaya rivers. This dating is sharply inconsistent with the modern stratigraphic scheme (Fig. 1) and suggests two interpretations. According to the first interpretation, the entire Khakdon Group has a Paleoproterozoic age and the existing stratigraphic scheme should be revised. According to the second interpretation, compositionally close volcanic complexes of different ages were erroneously included in the Khakdon Group in different areas. In this case, the Khakdon Group in the stratotype area (upper reaches of the Kamenka River) can be a Late Riphean sequence. However, its analogues are missing in the Shamanikha and Stolbovaya rivers basin and volcanic rocks exposed in this basin represent a part of the Lower Proterozoic sequence. This problem can be solved by further isotope–geochronological studies, but the interpretation seems to be more probable.

In any case, data on the Paleoproterozoic age of the volcanic complex in the Shamanikha and Stolbovaya rivers basin are of great importance in understanding the structure and evolution of the Kolyma terrane. Let us consider some of them in details.

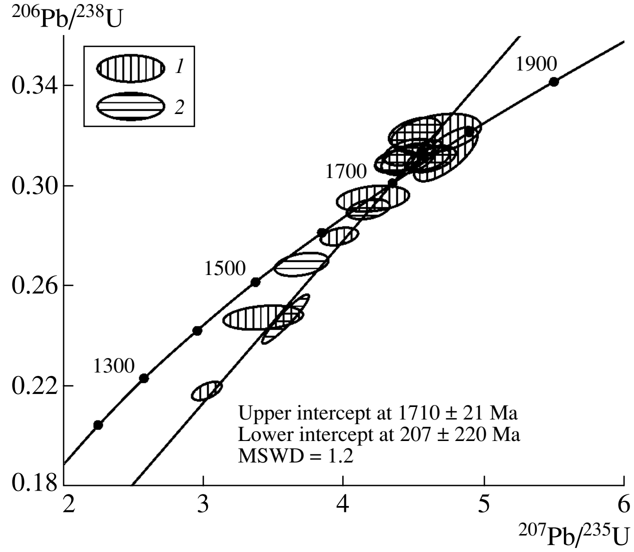

Fig. 3. Concordia diagram for zircons from rhyolites of the Khakdon Complex. Location of samples (*1*) 1657-16 and (*2*) 1656-18 are shown in Fig. 1. Isotope data are presented in the table.

First, Lower Proterozoic volcanic rocks in the Shamanikha and Stolbovaya rivers basin are located above the Riphean terrigenous–carbonate sequences of the Chebukulakh and Yukagir groups, suggesting the wide development of low-angle thrusts. Despite poor exposure of rocks, relations observed between them indicate that the thrust structure was sealed by Vendian rocks, pointing to intense fold–thrust deformation at the end of the Riphean.

Second, Late Riphean rifting was less developed than previously assumed [3, 4] and concurrent volcanism developed only in the northern part of the Kolyma terrane.

Third, rhyolites with an age of 1710 ± 21 Ma are coeval within error limits to granites in this region. The zircon age of granites determined by thermal emission mass spectrometry varied from 1700 ± 30 to 1750 ± 50 Ma [12]. In the Rb–Nb + Y diagram, their data points are plotted in the field of within-plate granites, which is consistent with the inferred relation of the coeval volcanic complex with rifting. A similar U–Pb age (1700–1740 Ma) was obtained for the Ulkan Complex at the southeastern Aldan Shield, which also was formed in the within-plate setting [13]. Thermal emission dating of zircons yielded approximately simultaneous (1735 ± 50 Ma) values for intrusive complexes of unknown tectonic nature at the western margins of the Okhotsk Massif [14]. Thus, within-plate magmatism was widespread in the terminal Paleoproterozoic at the southeastern margin of the Siberian Craton and in the eastern Precambrian blocks. Hence, the Aldan Shield, Okhotsk Massif, and Kolyma terrane were parts of a single continent at the end of the Paleoproterozoic.

Results of the Pb--U isotope study of zircons from samples 1657-16 and 1657-18

Point no.	$^{206}Pb_c$, %	Content, g/t			$^{232}Th/^{238}U$	Isotope ratios						*Rho*	Age, Ma		*D*, %
		$^{206}Pb^*$	U	Th		(1) $^{207}Pb^*/^{206}Pb$	±%	(1) $^{207}Pb^*/^{235}U$	±%	(1) $^{206}Pb^*/^{238}U$	±%		(1) $^{206}Pb/^{238}U$	(1) $^{207}Pb/^{206}Pb$	
1657-16.1	0.64	17.9	66	67	1.03	0.1036	2.5	4.45	2.8	0.3117	1.4	0.475	1749 ± 21	1689 ± 46	–4
1657-16.1.1	0.61	26.6	99	113	1.18	0.1027	2.6	4.41	2.8	0.3114	1.1	0.387	1747 ± 16	1673 ± 47	–4
1657-16.4.1	0.05	73.5	271	152	0.58	0.1057	1.0	4.599	1.2	0.3157	0.65	0.538	1769 ± 10	1726 ± 19	–2
1657-16.4.2	0.24	33.3	124	84	0.70	0.1073	1.7	4.612	1.9	0.3116	0.95	0.489	1749 ± 14	1755 ± 31	0
1657-16.5.1	0.24	26.6	98	107	1.13	0.1028	2.4	4.45	2.7	0.3143	1.1	0.424	1762 ± 17	1675 ± 45	–5
1657-16.6.1	0.31	31.4	167	192	1.19	0.1008	1.9	3.037	2.3	0.2185	1.2	0.521	1274 ± 14	1639 ± 36	22
1657-16.7.1	1.43	25.0	97	78	0.83	0.1029	3.9	4.21	4.0	0.2965	1.1	0.283	1674 ± 17	1678 ± 72	0
1657-16.7.2	0.49	43.5	179	159	0.92	0.1024	2.0	3.962	2.1	0.2807	0.82	0.383	1595 ± 12	1668 ± 37	4
1657-16.8.1	0.27	17.9	66	69	1.08	0.1093	2.2	4.72	3.2	0.3135	2.3	0.712	1758 ± 35	1788 ± 41	2
1657-16.9.1	2.31	19.6	90	74	0.85	0.1004	5.1	3.44	5.3	0.2487	1.3	0.240	1432 ± 16	1631 ± 96	12
1657-16.11.1	0.82	13.3	48	49	1.06	0.1050	4.2	4.66	4.5	0.3220	1.6	0.361	1799 ± 26	1714 ± 78	–5
1657-18.1.2	0.68	39.0	154	167	1.12	0.1037	2.2	4.17	2.4	0.2916	0.91	0.373	1650 ± 13	1691 ± 41	2
1657-18.2.1	0.40	22.6	81	70	0.89	0.1012	2.5	4.50	2.7	0.3224	1.2	0.427	1801 ± 18	1647 ± 46	–9
1657-18.3.1	0.78	24.4	104	94	0.93	0.0996	3.1	3.70	3.3	0.2695	1.1	0.343	1538 ± 16	1617 ± 58	5
1657-18.4.1	0.24	51.6	242	245	1.04	0.1051	1.2	3.59	2.9	0.2475	2.6	0.915	1426 ± 34	1716 ± 21	17
1657-18.7.1	0.69	37.8	141	75	0.55	0.1019	2.2	4.37	2.4	0.3109	0.92	0.382	1745 ± 14	1660 ± 41	–5
1657-18.8.1	0.10	26.5	99	126	1.32	0.1075	2.3	4.61	2.5	0.3114	1.1	0.431	1747 ± 17	1757 ± 41	1

Note: Errors are given at the 1σ level. (Pb_c, Pb*) Common and radiogenic lead, respectively. The standard was calibrated with an error of 0.34%. (*Rho*) Error correlation of U/Pb; (*D*) discordance calculated as 100(1 – $^{206}Pb/^{238}U$ age)/($^{207}Pb/^{206}Pb$ age)). (1) Correction for common lead is based on the measured ^{204}Pb.

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