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GRANITES OF THE GERDIZ MASSIF (POLAR URALS): NEW DATA

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Petrographic, petrochemical and preliminary geochemical (ICP MS) and isotope geochemical (O_{Zrn} , Sm-Nd, (Lu-Hf) $_{Zrn}$) data allow us to consider granitoids of the Gerdizsky massif as forming in an intraplate setting and represent A-type with crust-mantle characteristics. The new U-Pb (SIMS) geochronologic data show that the granitoids of the northern part of the Gerdizsky massif in the northern Urals are (496±7) Ma.

Keywords: A-type granites, isotopic and geochemical characteristics, Gerdiz massif, Polar Urals.

ГРАНИТОИДЫ ГЕРДИЗСКОГО МАССИВА (ПОЛЯРНЫЙ УРАЛ): НОВЫЕ ДАННЫЕ

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Петрографические, петрохимические и полученные первые геохимические (ICP MS) и изотопно-геохимические (O_{Zrn} , Sm-Nd, (Lu-Hf) $_{Zrn}$) данные позволяют рассматривать гранитоиды Гердизского массива как внутриплитные образования А-типа с корово-мантийными характеристиками. На основе новых U-Pb (SIMS)-данных возраст гранитоидов Гердизского массива (северная часть) соответствует (496 ± 7) млн лет.

Ключевые слова: граниты А-типа, изотопно-геохимические характеристики, Гердизский массив, Полярный Урал.

Introduction

Granitoids of the large Gerdizsky massif are exposed along the Paetarka and Gerdizshor rivers in the Polar Urals. Structurally they are located in the northern part of the block Marunkeu where they are found intruding the highly metamorphosed rocks of the Khanmenkhoyskaya suite (PR₁hn). The massif extends in a north-east direction covering a region of about 15×6 km parallel to the general strike of the folded structures and granitoids cross-cut metamorphic fabrics (fig. 1).

The new generation of maps [1] show that two types of magmatic rocks are present in the Gerdizskiy massif: the Evyuganskiy migmatite-plagiogranite (mpγPR₁e), granite gneiss (γγPR₁e) and Syadatayakhinskiy granite (γV-Є₁s) complexes. This article discusses the Evyuganskiy complex rocks (fig. 1). According to the legend [5], the granitoids of the Evyuganskiy complex are Early Proterozoic and the Syadatayakhinskiy complex is Vendian-Cambrian. The age of granitoids of the Evyuganskiy complex was determined by geological data (conglomerates at the base of the overlying Nyaroveyskaya series contain pebbles of similar composition granitoids and plagiogranites to those exposed along Paetarka Creek of the Lapta-Yaha River) as well as by geochronological determinations (1.73–2.22 billion. years) [1]. The age of the granitoids of the Syadatayakhinskiy complex was determined using only geological data. Data on the geological structure of the massif, the petrographic characterization and chemical composition of the granitoids can be found

in works of V. I. Okhotnikov, L. V. Mahlaev, V. A. Dushin and in our earlier work on these rocks [1, 3, 4, 7, 8, 9].

Materials and methods of research

The data for the study were obtained by us during a field trip to the northern part of the Gerdizskiy Massif (Evyuganskiy complex), exposed along the Pesaveyyaha River in 2014.

Research was conducted in the Center for Collective Use of Scientific Equipment of UB RAS «Geonauka» (IG Komi SC UB RAS): samples were analyzed by the classical chemical method and the X-ray fluorescence method in the chemical laboratory; the analysis of minerals was performed on a TESCAN VEGA 3 electron microscope with an X-max energy dispersive spectrometer (Oxford instruments); the description of thin sections was conducted on a polarizing microscope Olympus BX51; monofraction of zircons was selected (crushing, division, allocation of non-magnetic fraction, bromforming).

The content of the elements is determined by the method of ICP-MS in the Central Laboratory of VSEGEI (St. Petersburg). Zircon analyzed for U-Pb (SIMS) isotopic ages in the Stanford — U.S. Geological Survey micro analysis center (SUMAC) at Stanford University using a sensitive high-resolution ion microprobe (SHRIMP RG). A preliminary evaluation of the backscattered electron and cathodoluminescent image was also performed at Stanford University using a scanning electron microscope Jeol 5600 to guide

Table 1. Chemical composition (wt. %) and content of rare elements (ppm) of granitoids of the Gerdiz massif (northern part)

Таблица 1. Химический состав (мас. %) и содержание элементов примесей (г/т) для гранитоидов Гердизского массива (северная часть)

Компоненты Components	A41/14	A52/14	A34в/14	A54/14	A34а/14	A51/14	A35/14	A53/14
SiO ₂	69.9	73.2	73.58	74.24	75.62	76.3	77.28	79.64
TiO ₂	0.6	0.31	0.32	0.033	0.19	0.093	0.059	0.078
Al ₂ O ₃	14.66	13.04	12.76	14.82	12.39	12.54	12.25	10.49
FeO	1.4	1.3	0.99	0.38	1.02	0.6	0.42	0.57
MnO	0.039	0.034	0.026	0.04	0.019	0.01	0.018	0.011
CaO	2.17	1.24	0.93	0.4	0.93	0.4	0.4	0.4
MgO	2.17	0.2	0.51	0.1	0.1	0.3	0.1	0.1
K ₂ O	3.58	5.06	4.76	3.7	3.69	4.42	4.52	4.26
Na ₂ O	3.09	3.53	3.49	5.07	3.73	3.51	3.83	3.24
P ₂ O ₅	0.15	0.042	0.06	0.1	0.033	0.012	0.009	0.009
П.п.п.	1.77	0.85	1.04	0.64	1.14	0.71	0.59	0.51
Сумма	100.95	99.72	99.55	99.66	99.6	99.34	100.08	99.83
FeO _{tot}	2.82	2.22	2.08	0.52	1.76	1.05	1.03	1.09
H ₂ O	0.19	0.21	0.15	0.17	0.13	0.17	0.17	0.25
CO ₂	0.13	0.1	0.1	0.13	0.29	0.1	0.1	0.1
Характеристические отношения / Characteristic ratios								
Ga/Al	—	3.13	2.79	—	—	2.92	3.21	2.47
K/Rb	—	328.16	263.43	—	—	485.89	111.67	225.25
Rb/Sr	—	1.49	3.42	—	—	13.18	43.81	10.13
a. i.	0.61	0.87	0.85	0.83	0.82	0.84	0.91	0.95
Fe*	0.42	0.86	0.70	0.74	0.91	0.66	0.85	0.86
Na ₂ O+K ₂ O	6.67	8.59	8.25	8.77	7.42	7.93	8.35	7.50
Na ₂ O/K ₂ O	0.86	0.70	0.73	1.37	1.01	0.79	0.85	0.76
ASI	1.15	0.97	1.02	1.15	1.05	1.11	1.03	0.98
Элементы примеси / Impurity elements								
V	—	12.1	11.3	—	—	9.6	7.34	7.9
Cr	—	23.9	26.2	—	—	22.9	24.5	25.6
Co	—	1.65	1.29	—	—	0.5	0.5	0.5
Ni	—	10.2	7.28	—	—	6.05	6.68	6.54
Cu	—	5.25	3.13	—	—	18.6	5.85	2
Zn	—	46.1	27.7	—	—	24.6	27.1	26.4
Ga	—	20.3	18.1	—	—	18.9	20.8	16
Rb	—	128	150	—	—	199	336	157
Sr	—	85.9	43.9	—	—	15.1	7.67	15.5
Y	—	42.8	38.9	—	—	34.3	27.2	31.7
Zr	—	316	181	—	—	143	121	103
Nb	—	17.3	12	—	—	19.7	37.6	16.2
Mo	—	2.14	2.84	—	—	1.76	1.41	1.56
Sn	—	5	6.65	—	—	5.22	15.2	4.61
Cs	—	0.93	0.77	—	—	0.72	1.53	0.4
Ba	—	732	183	—	—	181	16.5	41
La	—	124	60.4	—	—	8.96	5.7	17
Ce	—	221	116	—	—	35	16.2	50
Pr	—	25.1	12.5	—	—	2.52	2.23	5.09
Nd	—	78	44	—	—	8.05	8.57	18
Sm	—	12.8	7.46	—	—	2.3	2.61	4.69
Eu	—	1.46	0.56	—	—	0.15	0.061	0.12
Gd	—	11.1	7.58	—	—	2.95	3.06	3.99
Tb	—	1.46	1.05	—	—	0.67	0.61	0.64
Dy	—	7.53	6.71	—	—	5.18	4.44	5.09
Ho	—	1.63	1.49	—	—	1.25	0.98	1.16
Er	—	4.32	3.83	—	—	3.71	3.25	3.4
Tm	—	0.67	0.55	—	—	0.65	0.55	0.51
Yb	—	3.82	3.45	—	—	3.97	3.8	3.5
Lu	—	0.64	0.5	—	—	0.57	0.63	0.56
Hf	—	9.77	5.58	—	—	5.56	5.63	4.04
Ta	—	1.22	1.06	—	—	2.37	3.82	1.39
Pb	—	32.8	28.4	—	—	26	19.9	30.5
Th	—	24.2	22.6	—	—	25.6	25.5	19.1
U	—	2.4	2.01	—	—	1.7	2.08	1.58

Note: «—» not determined, Fe* — iron index ($Fe_{tot}/(Fe_{tot}+Mg)$), a. i. — agpait index ($(Na+K)/Al$), ASI — $[Al/Ca - 1.67P + Na + K]$

Примечание: «—» не определялось, Fe* — индекс железистости ($Fe_{tot}/(Fe_{tot}+Mg)$), а. и. — агапитовый индекс $(Na + K)/Al$, ASI — $[Al/Ca - 1.67P + Na + K]$

Fig. 1. Schematic geological map of Gerdizsky massif [4]: 1 — Quaternary deposits undivided, 2 — fine-grained granite, 3 — coarse-grained granite, 4 — microcline granite, 5 — precambrian shales

Рис. 1. Схематическая геологическая карта северо-восточной части Гердизского массива по [4]: 1 — четвертичные отложения нерасчлененные, 2 — мелкозернистый гранит, 3 — крупнозернистый гранит, 4 — микроклиновый гранит, 5 — докембрийские сланцы

Table 2. Results of U-Pb-isotope studies of zircons and crystallization temperature
Таблица 2. Результаты U-Pb-изотопных исследований и температуры кристаллизации в исследованных цирконах

Зерно, Кратер Grain, crater	$^{206}\text{Pb}_c$, %	Содержания, мкг Content, mkg			^{232}Th	Возраст, млн лет Age Ma		D, %	Изотопные отношения Isotope ratios			Rh_0	T (°C) (1.0/0.7)
		$^{206}\text{Pb}^*$	U	Th		^{238}U	$^{206}\text{Pb}/^{238}\text{U}$	$^{207}\text{Pb}/^{206}\text{Pb}$	$^{207}\text{Pb}/^{206}\text{Pb}$	$^{207}\text{Pb}/^{235}\text{U}$	$^{206}\text{Pb}/^{238}\text{U}$		
7.1ц	0.06	25.2	395	228	0.6	461.5±19.2	445.1±25.9	-4	0.0558±1.2	0.57±4.4	0.074±4.2	1	726
8.1к	0.16	22.6	337	223	0.68	484.8±18.7	509.9±24.8	5	0.0575±1.1	0.62±4.1	0.078±3.9	1	687
10.1ц	0.51	73.9	1091	686	0.65	489.1±8.8	493.2±84.3	1	0.0571±3.8	0.62±4.2	0.079±1.8	0.4	697
1.1ц	0.18	13.5	196	147	0.77	494.8±12.9	516.9±55.8	4	0.0577±2.5	0.64±3.7	0.080±2.7	0.7	728
5.1ц	0	20.3	296	105	0.37	495.4±12.8	469.8±28.3	-6	0.0565±1.3	0.62±2.9	0.080±2.6	0.9	645
3.1к	0.24	32.8	475	270	0.59	498.8±13.9	512.0±26.0	3	0.0576±1.2	0.64±3.1	0.080±2.9	0.9	679
6.1к	0.08	14.6	211	83	0.41	498.9±12.2	536.1±30.9	7	0.0582±1.4	0.65±2.9	0.081±2.5	0.9	694
9.1ц	0.02	24.5	354	227	0.66	499.8±12.8	488.8±23.5	-2	0.0570±1.1	0.63±2.8	0.081±2.6	0.9	682
2.1к	0.46	20.8	300	195	0.67	500.9±15.4	648.6±253.0	23	0.0613±11.8	0.69±12.2	0.081±3.0	0.2	714
4.1к	0.13	21.6	310	150	0.5	502.2±9.3	535.9±23.6	6	0.0582±1.1	0.65±2.2	0.081±1.9	0.9	698

Note: Isotopic ratios and ^{206}Pb contents are corrected for the measured ^{204}Pb . D — discordance: $D = 100 \times [\text{age } (^{207}\text{Pb}/^{206}\text{Pb}) / \text{age } (^{206}\text{Pb}/^{238}\text{U}) - 1]$. Rh_0 is the correlation coefficient between the $^{206}\text{Pb}/^{238}\text{U}$ and $^{207}\text{Pb}/^{235}\text{U}$ isotope ratio determination errors.

Примечание: Изотопные отношения и содержания ^{206}Pb скорректированы по измеренному ^{204}Pb . D — дискордантность: $D = 100 \times [\text{возраст } (^{207}\text{Pb}/^{206}\text{Pb}) / \text{возраст } (^{206}\text{Pb}/^{238}\text{U}) - 1]$. Rh_0 — коэффициент корреляции между ошибками определения изотопных отношений $^{206}\text{Pb}/^{238}\text{U}$ и $^{207}\text{Pb}/^{235}\text{U}$

spot placement on individual zircons. The isotope composition of oxygen in zircons was measured at the Institute of Nuclear Physics of the SB RAS (Ulan-Ude). The isotope composition of samarium-neodymium was obtained at IGGD RAS (St. Petersburg). The isotopic composition of hafnium was determined at the Institute of Geology and Mineral Resources (Tianjin, China). Details of the instrumental conditions and analytical procedures for Hf isotope analyses have been described by Genget al. [14]

Research results

Granitoids are observed as thin, mostly layered bodies among the metamorphosed rocks of the frame. The granites are pink and light gray, gneissic, medium-grained to fine-grained granoblastic, lepidogranoblastic and cataclastic texture (fig. 2). The rocks are composed of K-feldspar (microcline) — 20–25 %, plagioclase (albite) 25–35 %, quartz 30–35 %, mica (muscovite) 5–10 %. Secondary minerals: chlorite, calcite. Accessory: epidote (clinozoisite (contents of the

Table 3. Hf isotope composition of zircons
Таблица 3. Изотопный состав Hf в цирконах

Зерно, кратер Grain, crater	T (млн лет) T (Ma)	$^{176}\text{Yb}/^{177}\text{Hf}$	2σ	$^{176}\text{Lu}/^{177}\text{Hf}$	2σ	$^{176}\text{Hf}/^{177}\text{Hf}$	2σ	$\varepsilon\text{Hf}(0)$	$\varepsilon\text{Hf}(t)$	T_{DM} (млрд лет) (Ga)	T_{DM2} (млрд лет) (Ga)	$f_{(\text{Lu}/\text{Hf})}$
1.1ц	495	0.022002	0.000200	0.000835	0.000007	0.282571	0.000016	-7.1	3.48	0.96	1.09	-0.97
2.1к	501	0.030654	0.000317	0.001154	0.000007	0.282610	0.000019	-5.7	4.87	0.91	1.03	-0.97
3.1к	499	0.035339	0.000795	0.001350	0.000029	0.282588	0.000018	-6.5	4	0.95	1.07	-0.96
4.1к	502	0.021205	0.000035	0.000832	0.000001	0.282557	0.000014	-7.6	3.12	0.98	1.12	-0.97
5.1ц	495	0.048500	0.001541	0.001858	0.000058	0.282544	0.000020	-8.1	2.16	1.03	1.16	-0.94
6.1к	499	0.027934	0.000102	0.001070	0.000004	0.282609	0.000014	-5.8	4.82	0.91	1.03	-0.97
7.1ц	461	0.033142	0.000419	0.001262	0.000017	0.282606	0.000017	-5.9	3.86	0.92	1.05	-0.96
9.1ц	500	0.032910	0.000137	0.001274	0.000005	0.282600	0.000015	-6.1	4.45	0.93	1.05	-0.96
10.1ц	489	0.042890	0.000202	0.001655	0.000003	0.282545	0.000015	-8	2.15	1.02	1.16	-0.95

Note: $\varepsilon\text{Hf}(0) = (((^{176}\text{Hf}/^{177}\text{Hf})_s / (^{176}\text{Hf}/^{177}\text{Hf})_{\text{CHUR},0} - 1) \times 1000$

$\varepsilon\text{Hf}(t) = (((^{176}\text{Hf}/^{177}\text{Hf})_s - (^{176}\text{Lu}/^{177}\text{Hf})_s \times (e^{\lambda t} - 1)) / ((^{176}\text{Hf}/^{177}\text{Hf})_{\text{CHUR},0} - (^{176}\text{Lu}/^{177}\text{Hf})_{\text{CHUR}} \times (e^{\lambda t} - 1))) - 1 \times 1000$

$\text{TDM} = 1/\lambda \times \ln(1 + ((^{176}\text{Hf}/^{177}\text{Hf})_s - (^{176}\text{Hf}/^{177}\text{Hf})_{\text{DM}}) / ((^{176}\text{Lu}/^{177}\text{Hf})_{\text{DM}} - (^{176}\text{Lu}/^{177}\text{Hf})_{\text{DM}}))$

$\text{TDM}_2 = T_{\text{DM}} - (T_{\text{DM}} - t) f_C - f_S / (f_C - f_{\text{DM}})$

$f_{\text{Lu}/\text{Hf}} = (^{176}\text{Lu}/^{177}\text{Hf})_s / ((^{176}\text{Lu}/^{177}\text{Hf})_{\text{CHUR}} - 1)$

where $(^{176}\text{Lu}/^{177}\text{Hf})_s$ and $(^{176}\text{Hf}/^{177}\text{Hf})_s$ are the measured values of samples $(^{176}\text{Lu}/^{177}\text{Hf})_{\text{CHUR}} = 0.0332$ and $(^{176}\text{Hf}/^{177}\text{Hf})_{\text{CHUR},0} = 0.282772$ [11, 12]; $(^{176}\text{Lu}/^{177}\text{Hf})_{\text{DM}} = 0.0384$ and $(^{176}\text{Hf}/^{177}\text{Hf})_{\text{DM}} = 0.28325$ [15], t is the crystallization age of the zircon, and $\lambda = 1.867 \times 10^{-11} \text{yr}^{-1}$ [10, 16]. T_{DM} and T_{DM2} are single-stage DM model and two-stage DM2 model ages, respectively. f_C, f_S , and f_{DM} are the $f_{\text{Lu}/\text{Hf}}$ values of the crustal source, the sample and the depleted mantle, respectively. In our calculations, $f_C = -0.72$ ($^{176}\text{Lu}/^{177}\text{Hf} = 0.015$ in average continental crust) and $f_{\text{DM}} = 0.16$ ($^{176}\text{Lu}/^{177}\text{Hf} = 0.0384$ [15]).

Примечание: $\varepsilon\text{Hf}(0) = (((^{176}\text{Hf}/^{177}\text{Hf})_s / (^{176}\text{Hf}/^{177}\text{Hf})_{\text{CHUR},0} - 1) \times 1000$

$\varepsilon\text{Hf}(t) = (((^{176}\text{Hf}/^{177}\text{Hf})_s - (^{176}\text{Lu}/^{177}\text{Hf})_s \times (e^{\lambda t} - 1)) / ((^{176}\text{Hf}/^{177}\text{Hf})_{\text{CHUR},0} - (^{176}\text{Lu}/^{177}\text{Hf})_{\text{CHUR}} \times (e^{\lambda t} - 1))) - 1 \times 1000$

$\text{TDM} = 1/\lambda \times \ln(1 + ((^{176}\text{Hf}/^{177}\text{Hf})_s - (^{176}\text{Hf}/^{177}\text{Hf})_{\text{DM}}) / ((^{176}\text{Lu}/^{177}\text{Hf})_{\text{DM}} - (^{176}\text{Lu}/^{177}\text{Hf})_{\text{DM}}))$

$\text{TDM}_2 = T_{\text{DM}} - (T_{\text{DM}} - t) f_C - f_S / (f_C - f_{\text{DM}})$

$f_{\text{Lu}/\text{Hf}} = (^{176}\text{Lu}/^{177}\text{Hf})_s / ((^{176}\text{Lu}/^{177}\text{Hf})_{\text{CHUR}} - 1)$

где $(^{176}\text{Lu}/^{177}\text{Hf})_s$ и $(^{176}\text{Hf}/^{177}\text{Hf})_s$ измеренные значения в образце $(^{176}\text{Lu}/^{177}\text{Hf})_{\text{CHUR}} = 0.0332$ and $(^{176}\text{Hf}/^{177}\text{Hf})_{\text{CHUR},0} = 0.282772$ [11, 12]; $(^{176}\text{Lu}/^{177}\text{Hf})_{\text{DM}} = 0.0384$ and $(^{176}\text{Hf}/^{177}\text{Hf})_{\text{DM}} = 0.28325$ [15], t — возраст кристаллизации циркона и $\lambda = 1.867 \times 10^{-11} \text{yr}^{-1}$ [10, 16]. T_{DM} — одностадийный возраст модели и T_{DM2} — двухстадийный возраст. f_C, f_S, f_{DM} и $f_{\text{Lu}/\text{Hf}}$ значения короче всего источника, образца и деплетированной мантии, соответственно. В наших расчетах $f_C = -0.72$ (используя среднюю величину $^{176}\text{Lu}/^{177}\text{Hf} = 0.015$) и $f_{\text{DM}} = 0.16$ ($^{176}\text{Lu}/^{177}\text{Hf} = 0.0384$) [15].

Fig. 2. Cataclastic (a) and lepidogranoblast (b) texture (Kfs – K-feldspar, Mus – muscovite, Q – quartz)

Рис. 2. Катакластическая (a) и лепидогранобластовая (b) структура (Kfs – КПШ, Mus – мусковит, Q – кварц)

clinozitosite mineral from 0.67 to 0.88)) apatite (fluorapatite (3–4 wt. % F), zircon, allanite, garnet (spessartine-grossular-almandin), thorite, fluorite, titanite and ore mineral is represented by magnetite [6]. All minerals are confirmed by microprobe analyzes.

The rocks studied have SiO_2 content 69.9 to 79.64 wt. % and a high amount of alkali ($\text{Na}_2\text{O} + \text{K}_2\text{O}$, ranging from 7.42 to 8.59 wt.%), and belong to the family of granites according to the rocks petrochemical classification (fig. 3a and 3b). Moderately alkaline series are moderately potassic rocks rich in alumina ($\text{ASI} = 0.97\text{--}1.15$). The content of titanium is very low ($\text{TiO}_2 = 0.09\text{--}0.32$ wt. %). With increasing amounts of silica, the content of ($\text{K}_2\text{O} + \text{Na}_2\text{O}$), CaO and FeO, TiO_2 , decrease; the content of Al_2O_3 , P_2O_5 is slightly reduced (Tab. 1).

Rocks are characterized by a low total content of rare earth elements (mean value) – 200 ppm. REE spectra (fig. 3c) is characterized by a slight predominance of LREE over HREE ((La/Yb) $_N$ – 7.9) with low Eu values ($\text{Eu}/\text{Eu}^* = 0.19$). Spider diagrams of the rocks under study (fig. 3d) show that they are enriched with large-ion elements (Rb, Th) and have similar or slightly increased content of highly charged elements (Ce, Zr, Sm, Yb). According to the classification, granitoids belong to the A-type granites, based on the characteristic relationship [13].

We conducted additional isotope-geochronological studies. Zircons present in the sample are medium in size, up to 200 microns CE (coefficient of extension): 1: 4, 1: 5, whitish, white-yellow, translucent, of short-prismatic habit,

Fig. 3. Diagrams $\text{SiO}_2\text{--Na}_2\text{O}+\text{K}_2\text{O}$ (a), diagrams Ab-An-Or (b), spectra of rare earths (c) and diagram multi-elemental (d)

Рис. 3. Диаграмма $\text{SiO}_2\text{--Na}_2\text{O}+\text{K}_2\text{O}$ (a), диаграмма О' Коннера Ab-An-Or (b), спектры распределения РЗЭ (c), мультиэлементная диаграмма (d)

Fig. 4. Cathodoluminescence image of zircon from granites (A52-14) numbers dating grains and analysis of craters (a); Diagram for zircon A52-14 — (b). The coordinates of points — the center of the ellipse of error (2σ). Concordant age for coherent groups of 10 definitions — (496.2 ± 7.1) million years (2σ , STD (standard deviation) = 0.85)

Рис. 4. Катодолюминесцентные изображения цирконов из гранитов (A52-14) с номерами датированных зерен и аналитических кратеров (a); диаграмма для цирконов обр. A52-14 — (b). Координаты точек — центры эллипсов погрешностей (2σ). Конкордантный возраст для когерентной группы из 10 определений — (496.2 ± 7.1) млн лет (2σ , СКВО=0.85)

Fig. 5. Spectra of REE distribution in analyzed zircons from granitoids of the Gerdiz massif

Рис. 5. Спектры распределения РЗЭ в цирконах из гранитоидов Гердизского массива

with inclusions and numerous cracks. Cathodoluminescent images of zircons show rough oscillatory zoning in the margins of zircons and wide homogeneous central zones (fig. 4a). The contents of U (ppm) are highly variable from 196 to 1091, but are generally at 300. The content of Th varies within a tighter range of 83–270.

The calculated $^{206}\text{Pb}/^{238}\text{U}$ zircon crystallization age was determined from 10 points on sample A52/14 (tab. 2). The results range in ages from 461.5 ± 19.2 to 502.2 ± 9.3 Ma (fig. 4b). The calculated weighted mean age of 10 zircon analyses was 494.9 ± 7.9 Ma (2σ , MSWD = 0.53, probability — 0.85). This calculated concordia age for the coherent group from all 10 definitions is 496.2 ± 7.1 Ma (2σ , MSWD = 0.85, the probability of concordance - 0.721) is within uncertainty of the weighted average (fig. 4b). The trace elements contents are similar, indicating that the analyzed zir-

cons are comagmatic (fig.5). Their formation temperature estimated by the Ti content in zircon [17] varies over a wide range from 645 to 728 °C (at $a_{\text{SiO}_2} = 1$ and $a_{\text{TiO}_2} = 0.7$).

The concordant age obtained corresponds to the Late Cambrian. The identified age of metagranitoids of the Ingilorskiy massif is similar and is 487.3 ± 7.4 [9]. A Paypudynsky rhyolite complex ($\lambda\epsilon 3\text{-O}1pp$) of the same age level is known in the Polar Urals, which is the felsic component of bimodal rift magmatism in the Polar Urals [2].

The Sm-Nd data of granite sample A52/14, (Sm (12.79 ppm), Nd (82.98 ppm), $^{147}\text{Sm}/^{144}\text{Nd}$ (0.0932), $^{143}\text{Nd}/^{144}\text{Nd}$ (0.512338), $\epsilon\text{Nd}(0)$ (−5.9), $\epsilon\text{Nd}(T)$ (+0.7), TDM (1029), TDM2 (1181)) [8] indicate that the source of these rocks was either mantle with a significant component of older crust as a contamination. The oxygen isotopic composition of zircons from granitoids (zircon from sam-

ple A52/14) is characterized by low values of +6.9 ‰ [8] – has core values.

The isotopic data of Hf (tab.3), calculated on age εHf (T), is characterized by positive values from + 4.87 to +2.15, which indicate a crust-mantle source (which agrees well with $\varepsilon\text{Nd}(t)$, on the data presented above) and young model age.

Isotope-geochemical ($\varepsilon\text{Nd}(t)$, OZrn , $\varepsilon\text{Hf}(t)\text{Zrn}$) data allow us to characterize the source of the melts

Conclusions

Thus, according to new petrologic, geochemical, geochronologic and isotopic data, granitoids of the northern part of the Gerdizskiy massif have intraplate characteristics and document that they mark the process of rifting that existed in the late Cambrian along the margin of the East European continent.

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