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Age of Zircons from Diamond-Bearing Lamproites of the East Sayan as an Indicator of Known and Unknown Endogenous Events in the South Siberian Craton

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Diamond-bearing lamproites are reported in the limits of the Urik-Iya graben (southwestern flank of the Siberian Craton) (Fig. 1a), where they compose a series of steeply dipping veins hosted in schists and sandstones of the Paleoproterozoic Urik and Ingashi formations [1] (Fig. 1b). All these bodies on aggregate are considered as the Ingashi field. The thickness of veins is 0.1 to 1.0 m, with the average value 15–20 cm. The length of veins is several hundreds of meters, and their general strike is 280°–300°. The maximal length (850 m) was discovered for vein no. 1 Iskra.

The age of lamproite veins was initially determined by the Rb–Sr method on the whole rock as the Mesoproterozoic (1268 ± 30 Ma) [2]. The relatively small error of the obtained value suggested its validity, despite the fact that the study was carried out for a significantly carbonized variety of lamproites, where preservation of the initial Rb–Sr system was questionable. Thus, the age of diamond-bearing lamproites of East Sayan was assumed as the Precambrian for more than 20 years. This dating gained special importance in the late 20th century, with respect to intensive international studies of the formation and breakup of the supercontinent Rodinia. The available dating of lamproites (1268 Ma) agreed well with the age of the big McKenzie dike swarm in North Canada. This point suggested that both complexes belong to a common endogenous event and allowed researchers to interpret this combination as a reflection of the mantle plume effect that touched marginal areas of two ancient cratons, the Siberain and North American (Laurentia), joined in the structure of the supercontinent Rodinia [3]. However, the validity of the dating mentioned above based on lamproites of East Sayan was questionable for both Russian and international researchers, so geochronological study of these rocks using modern methods was started. In the framework of the present study, samples of diamond-bearing lamproites (ING-1 and ING-2) were collected in the Ingash field, from vein no. 1 Iskra and then zircons from these samples were studied to define their U–Pb age. The U–Pb age was determined at Curtin University of Technology (Perth, Australia) on a SHRIMP II instrument with a BR266 standard by the standard technique [4]. Data processing was carried out using the SQUID software [5]; for plotting the concordia diagrams, the ISOPLOT software was used.

The contents of the main petrogenic oxides in the studies were as follows (ING-1/ING-2, mass %): SiO_2 = 42.93/43.64; TiO_2 = 3.70/3.60; Al_2O_3 = 4.66/4.69; $Fe_2O_3^*$ = 12.62/12.22; MnO = 0.44/0.39; MgO = 19.98 / 20.36; CaO = 3.87 / 3.27; Na_2O = 0.18/0.19; K_2O = 1.60/1.69; P_2O_5 = 2.25/1.93. The Zr contents in the studied samples are 1187 and 1140 g/t, respectively, while the REE contents are 2018 and 1897 g/t, respectively.

Among the zircons extracted from both samples, there are colorless and colored varieties. The sizes of the grains varies from 50 to 10 μm. In terms of size and morphology, crystals differ from each other, and their elongation ranges from 1:1 to 4:1. In the cathode luminescence images, we can see various patterns of the internal structures for zircon grains. U–Pb isotopic studies were carried out for 30 zircon grains (39 measurements) from ING-1 sample and for three grains from ING-2 sample. Since both samples were collected from the same dike, we can consider them jointly. On the basis of isotopic ratios, and with the peculiarities of the internal structure of the zircon grains taken into account, several age groups were distinguished.

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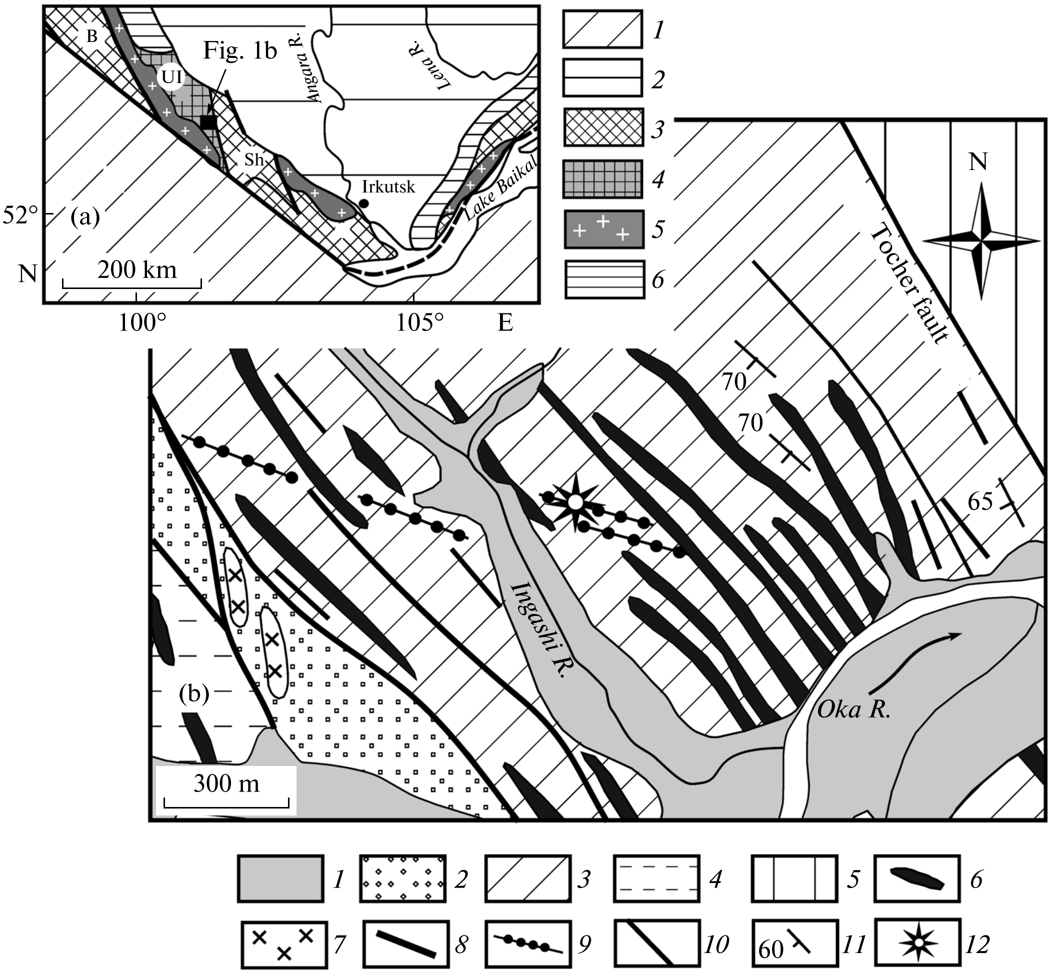

Fig. 1. The principal geological structures of the South Cis-Baikal Region (a) and the scheme showing the geological structure of the Urik-Iya graben, area of the Ingashi River mouth (b). Notations for panel (a): (*1*) structures of the Central Asian Fold Belt; (*2*) Phanerozoic sedimentary cover; (*3*) uplifts of the Siberian Craton basement (B and Sh are Biryusa and Sharyzhalgai uplifts, resectively; Archean–Proterozoic rocks); (*4*) Urik-Iya graben (Proterozoic rocks); (*5*) Paleoproterozoic granitoids; (*6*) Neoproterozoic sediments. Notations for panel (b): (*1*) Quaternary alluvial deposits; (*2*) Ermasokha Fm. (Lower Riphean); (*3*) undifferentiated Urik and Ingashi formations (Lower Proterozoic); (*4*) undifferentiated Bolsherechenskaya and Daldarma formations (Early Proterozoic); (*5*) Early Precambrian complexes of the Sharyzhalgai uplift of the Siberian Craton basement; (*6*–*9*) intrusive complexes: (*6*) gabbro-diabases of the Angaul complex (~1913 Ma [7]), (*7*) granitoids of the Chernaya Zima complex (~1530 Ma [15]), (*8*) gabbro-dolerites of the Nersa complex (~740 Ma [9]), (*9*) series of lamproite veins; (*10*) faults; (*11*) bedding occurrence; (*12*) sampling point.

The three most ancient zircon grains have the $^{207}Pb/^{208}Pb$ ages of 2530 ± 13, 2333 ± 7, and 2066 ± 17 Ma, respectively (Fig. 2). These values can be interpreted as the maximal age of xenogenic zircons from the analyzed lamproite sample.

The first group (group 1 in Fig. 2) of zircons for which the mean weighted age value was calculated includes six grains of different sizes (100–200 μm) and morphology. This group includes the grains having elongation from 1:1 to 4:1 and demonstrating both oscillatory zonality and no signs of internal zonality. The Th/U ratios in these zircons are 0.11 to 1.20. All these parameters on aggregate suggest that this group incorporates zircons of both igneous and metamorphic genesis. The mean weighted $^{207}Pb/^{206}Pb$ age of zircons from this group is 1854 ± 10 Ma (MSWD = 3.5). The high MSWD value supports the suggestion that the group incorporates zircons with statistically different ages; however, more precise dating for this group is not possible. The datings for this group of zircons generally cover the time interval between 1.85 and 1.89 Ga (Table 1) and likely reflect the ages of rocks from the Paleoproterozoic igneous and metamorphic complexes, from which the xenogenic material was trapped.

Three zircons united into the second group (group 2 in Fig. 2) have an age close to 750 Ma. The analyzed zircons are crystals of idiomorphic or irregular shapes (100–200 μm) and characterized by igneous zonality in the cathode luminescent images. These zircons

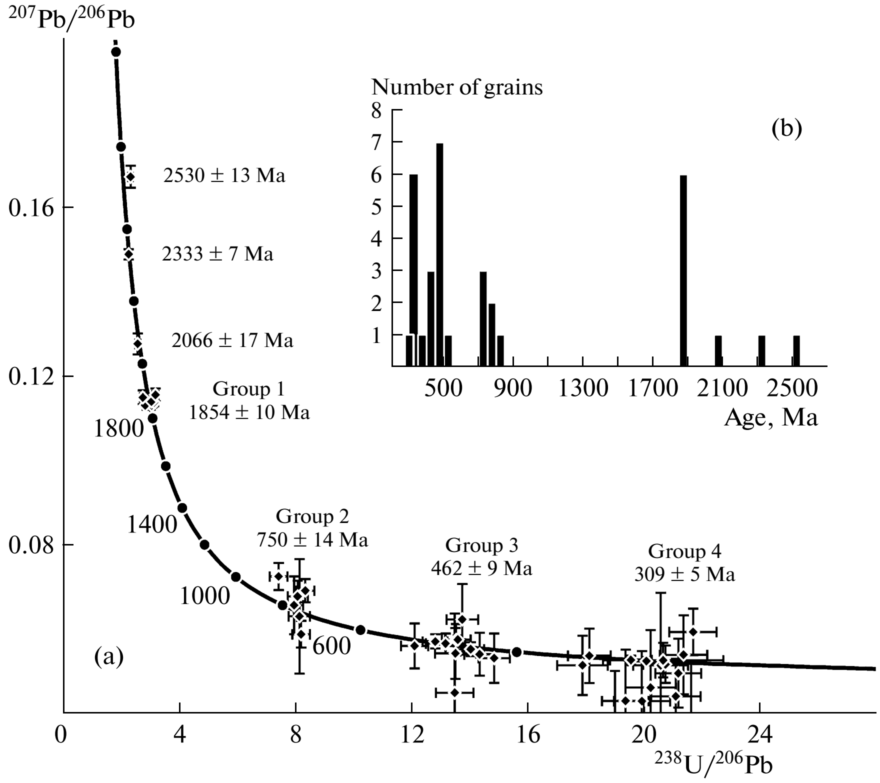

Fig. 2. The concordia diagram of $^{238}U/^{206}Pb$–$^{207}Pb/^{206}Pb$ age (a) and the histogram of ages (b) for zircons from lamproites of the Ingashi field (ING-1 and ING-2 samples).

have low U and Th contents and a narrow interval of the Th/U ratio (0.58–0.86) (Table 1). The calculated concordant $^{206}Pb/^{238}Pb$ age of zircons from this group is 749 ± 26 Ma (MSWD = 1.5), while their mean weighted $^{206}Pb/^{238}U$ age is 750 ± 14 Ma (MSWD = 0.44). The value 750 ± 14 Ma can be interpreted as the most accurate estimate of the crystallization age for zircons from the igneous rock complexes, where zircons were trapped by the melt that formed vein no. 1 of the Ingashi field.

The third group (group 3 in Fig. 2) includes 11 analyses on ten zircons; in the diagram, points of these analyses are clustered near the concordia. Zircons of this group (100–200 μm, elongation from 2:1 to 4:1) are characterized by mostly oscillatory zonality. The Th/U ratio is 0.46–1.0; however, we found the lowered value of this parameter (0.02) for one grain (ING-1-23; Table 1), caused by the low thorium content. The calculated value of the concordant age on eight points is 462 ± 9 Ma (MSWD = 4.8), while the mean weighted $^{206}Pb/^{238}U$ age is 760 ± 11 Ma (MSWD = 2.5). The higher MSWD value may be caused by the fact that not one but two or more zircon populations that crystallized in the rocks belonging to different geological complexes are included in this group.

The youngest group (group 4 in Fig. 2) incorporates 11 zircon grains, whose $^{206}Pb/^{238}U$ ages fall within the interval 330–290 Ma. For five of these grains, the measurements were carried out twice in order to check these relative young dates. All the analyzed grains are represented by crystals (100–220 μm, elongation 2:1) having the igneous zonality seen in cathode luminescent images. Excluding two crystals, the zircons from this age group demonstrate low Th and U contents (Table 1). The calculated value of the concordant age on 11 points is 309 ± 5 Ma (MSWD = 0.007), while the mean weighted $^{206}Pb/^{238}U$ age is 308 ± 7 Ma (MSWD = 2.7). We suppose that the concordant age 309 ± 5 Ma corresponds best to the age of crystallization of these youngest zircon grains found in the rocks composing vein no. 1 of the Ingashi field. With the presence of zircons being a nontypical feature for lamproite magmas, we rather interpret all the analyzed grains as xenogenic (i.e., trapped from the host rocks). The ages of particular xenogenic zircons and united groups of zircons from the analyzed samples and their possible sources are given in Table 2.

The first consequence of the obtained results is that the studied rocks of the Ingashi diamond-bearing field cannot be older than 300 Ma. Therefore, the Mesozoic age of these rocks, supposed earlier, as well as their correlation to basites of the McKenzie Province (North American Craton), cannot be used for paleogeographic reconstructions of Rodinia [3].

Another important point is that the age of both particular zircons and their groups directly corresponds to

Table 1. The results of U–Pb dating for zircons from lamproites of the Siberian Craton's south flank (ING-1 and ING-2 samples)

Sample, crystal, crater	U, g/t	Th, g/t	Th/U	f_{206}, %	Isotopic ratios				Age, Ma			
					$^{238}U/^{206}Pb$	±1σ	$^{207}Pb/^{206}Pb$	±1σ	$^{206}Pb/^{238}U$	±1σ	$^{207}Pb/^{206}Pb$	±1σ
ING1-1	87	128	1.53	0.282	2.58776	0.04685	0.12766	0.00124	2106	33	2066	17
ING1-2	258	299	1.20	0.054	2.75806	0.04694	0.11502	0.00082	1994	29	1880	13
ING1-3	93	34	0.38	1.309	19.92730	0.48118	0.04309	0.00592	316	7	–162	341
ING1-3b	107	39	0.38	1.586	20.22518	0.43347	0.04629	0.00681	311	7	13	354
ING1-4	312	239	0.79	0.067	13.17450	0.33531	0.05675	0.00117	472	12	482	46
ING1-5	212	118	0.58	1.308	19.35468	0.40068	0.04312	0.00605	325	7	–160	349
ING1-6	177	75	0.44	0.804	20.65434	1.03062	0.05277	0.00204	305	15	319	88
ING1-6b	152	57	0.39	0.553	21.35469	0.40525	0.05404	0.00466	295	5	373	194
ING1-7	79	110	1.43	2.012	18.99747	0.41049	0.03936	0.00545	331	7	–392	360
ING1-8	162	72	0.46	0.337	13.53896	0.24898	0.05759	0.00187	459	8	514	71
ING1-9	91	59	0.67		8.35146	0.15860	0.06923	0.00138	729	13	906	41
ING1-9b	53	39	0.75		8.08774	0.17094	0.06788	0.00184	752	15	865	56
ING1-9c	91	51	0.58	0.765	8.20872	0.15225	0.05890	0.00158	741	13	563	58
ING1-10	95	48	0.52	0.554	13.74586	0.27078	0.06242	0.00417	453	9	689	142
ING1-11	110	75	0.70	0.249	12.10626	0.23416	0.05613	0.00265	512	10	458	105
ING1-11r	63	35	0.57	1.524	13.48706	0.32144	0.04506	0.00937	461	11	–52	506
ING1-12	51	36	0.74	1.200	8.14588	0.18373	0.06313	0.00679	746	16	713	229
ING1-12b	87	65	0.78	0.310	7.96317	0.15650	0.06577	0.00342	763	14	799	109
ING1-13	174	54	0.32		21.68115	0.40693	0.05947	0.00275	291	5	584	100
ING1-13b	136	60	0.46	0.920	21.08579	0.42429	0.04420	0.00445	299	6	–99	247
ING1-14	175	126	0.75	0.443	14.33951	0.25915	0.05418	0.00255	435	8	378	106
ING1-15	85	33	0.41	0.280	20.56755	0.47450	0.05153	0.00859	306	7	264	383
ING1-16	65	54	0.86		7.43060	0.15455	0.07258	0.00161	814	16	1002	45
ING1-17	103	62	0.62	0.029	13.51349	0.35277	0.05439	0.00300	460	12	387	124
ING1-18	169	68	0.42	0.635	21.17847	0.39610	0.04970	0.00408	297	5	181	191
ING1-19	2584	483	0.19	0.049	2.84293	0.04403	0.11313	0.00018	1943	26	1850	3
ING1-20	510	494	1.00	0.137	14.03915	0.22719	0.05537	0.00083	444	7	427	33
ING1-21	154	71	0.47	0.499	20.73455	0.38388	0.05179	0.00221	304	5	276	98
ING1-22	412	93	0.23	0.022	2.34078	0.04231	0.16725	0.00128	2293	35	2530	13
ING1-23	326	7	0.02		12.81358	0.21221	0.05721	0.00083	484	8	499	32
ING1-24	633	302	0.49	0.029	13.59363	0.21780	0.05765	0.00052	458	7	516	20
ING1-25	1118	1432	1.32		20.07807	0.31831	0.05257	0.00045	313	5	310	19
ING1-26	2330	1183	0.52	0.201	19.54278	0.35823	0.05278	0.00053	322	6	319	23
ING1-27	1665	184	0.11	0.217	3.15365	0.04898	0.11379	0.00043	1776	24	1861	7
ING1-28	201	86	0.44	0.078	3.06181	0.05035	0.11400	0.00072	1822	26	1864	11
ING1-29	1097	275	0.26	0.019	3.06995	0.04854	0.11312	0.00029	1818	25	1850	5
ING1-30	240	114	0.49	0.014	2.27657	0.03986	0.14888	0.00062	2347	34	2333	7
ING2-1	210	98	0.48	0.076	3.20199	0.05247	0.11561	0.00075	1752	25	1889	12
ING2-2	92	47	0.53	2.136	21.60779	0.46315	0.03873	0.00662	292	6	–435	449
ING2-3	148	76	0.53	0.412	14.84644	0.27100	0.05324	0.00291	420	7	339	124

Note: f_{206} is the proportion of common ^{206}Pb in total measured ^{206}Pb; all ratios are corrected to common lead using the measured $^{204}Pb/^{206}Pb$ values.

Table 2. Ages of zircons from lamproites of the Ingashi field

Age of zircons, Ma	Likely source of xenogenic zircons and its location	Reference
~2530	Granites of the Kitoi complex (Siberian Craton south)	[6]
~1890	Diabases of the Angaul complex (Siberian Craton south)	[7]
~1854	Granites of the Sayan complex (Siberian Craton south)	[8]
~ 750	Diabases of the Nersa complex (Siberian Craton south)	[9]
~ 460	Granitoids of the Tannu-Ola and Sarkhoi complexes (CAFB)	[10]
~330–290	Granitoids of different complexes, including the Angara-Vitim batholith (CAFB)	[11, 12]

the endogenous events that occurred within the studied territory in a broad time interval covering more than 2.2 Ga. In addition to this, only some of these age categories can be interpreted with the use of datings obtained for the geological complexes of the Siberian Craton's south flank, within which the Ingashi diamond-bearing lamproite field is located (Fig. 1b).

Interpretation of the obtained results suggests that the analyzed samples contain both zircons from Precambrian complexes composing the Siberian Craton's south flank (Fig. 1) and Paleozoic zircons. Geological complexes of this age are not known at present in the Siberian Craton, probably because they have not been cut by the modern erosional sections yet. However, igneous complexes of the Early (460 Ma) and Late (330–290 Ma) Paleozoic are widespread in the Central Asian Fold Belt (CAFB) (Fig. 1a; Table 2). Obviously, in contrast to the CAFB, the thick and consolidated crust of the Siberian Craton prevented penetration of the Paleozoic magmas to the surface and, thus, limited the zone of their crystallization in the lithosphere's depth (Urik-Iya graben).

The age clusters obtained on the basis of zircons demonstrate how investigation of the same sample of lamproite can reveal the entire dynamics of the endogenous activity in the vast territories of the Siberian Craton's south flank and in the adjacent CAFB areas from the Archean (~2.5 Ga) to the Late Paleozoic (~290 Ma). The presented results are in good consistency with the modern data [13, 14] indicating the possibility of revealing zircons of different ages in ultrabasic and basic rocks.

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