

Specifics of geological composition, geochemistry and geochronology of rocks from the Kresty alkaline-ultrabasic massif (Maimecha-Kotui province, Polar Siberia)

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Abstract. In this work, we demonstrate new data that allows us to accurate geochronological ranges of formation of the Kresty alkaline-ultrabasic massif, which is considered to be a satellite of the Gulinian giant pluton. We also interpreted geological, geochemical and isotope-geochemical data obtained earlier for major varieties of this volcanic-plutonic association taking into account new geochronological results, as well as considered new aspects/information on matter source of alkaline-ultrabasic massifs from this province. One of the main aspects is interaction of Siberian super plume matter with hosting substrate of Siberian craton continental crust.

1. Introduction

The Maimecha-Kotui province (MKP) is one of the unique geological objects in Polar Siberia. Its geotectonic position is caused by formation of continental Khatanga rift at the boundary between Siberian Craton and Taimyr orogen. One of the important structural elements of its spatial localization is transform fault complicated by large gravity anomaly with its center in Gulinian giant pluton. Many authors think that opening of Ob-Zaisansk Ocean was initiated by local intrusion of plume material in this particular point/location [1]. However, we think that this episode/event is only a local “finger plume”, which promoted formation of a unique mineral province. Such transform fault of Khatanga rift system controls one more large ore node, which corresponds to Norilsk-Talnakh copper-nickel deposits too. What makes the Kresty province unique is that it is spatially adjacent to Gulinian pluton, whose sizes exceed all known intrusive bodies in the Maimecha-Kotui province. Main intrusive phases/stages of the Kresty Massif are represented by ultramafic rocks with normal alkalinity (olivinites, veprlites, pyroxenites, and its ore-bearing kinds), as well as melilitic rocks like kugdites and melilitolites and monticellitolites. Among dykes we see nepheline and alkaline syenites, as well as alkaline granosyenites and granites. We have obtained new geochronological data on perovskites and zircons from these rock varieties. These data confirmed its formation at Permian-Triassic boundary. An important aspect of this massif formation is industrial concentrations of noble metals (gold and platinoids up to 20 g/t), which are found in some rock varieties undergone secondary metasomatic changes. This aspect is extremely important in further studying of the Kresty Massif.

2. Geological setting and internal structure of studied object

Composition of the Kresty volcanic-plutonic structure (KVPS) is determined by the spatial superposition of volcanic fluxes of melanephelinite, intrusive bodies of olivinite-pyroxenite and melilitolite-monticellitolite series, and the dykes of thachydolerites, subalkaline syenites and granosyenites, alkaline picrites and lamprophyres. By geophysical data, the Kresty Massif has a round shape in plane about 6 km in diameter with a steep dip of contacts (*Fig. 1*) [2]. Like the Gulinian pluton, the massif is covered over 2/3 of its area by Cenozoic deposits of the Khatanga depression.



The bulk of its volume is formed by ultra- mafic rocks with normal alkalinity. Melilite and monticellite rocks are located over the periphery of the olivinite core and form a series of small autonomous bodies. Their later introduction is confirmed by active contact affect onto ultramafic rocks, which led to production of hybrid variations like melilite and perovskite-enriched olivinites and uncompahgrites. The dyke derivatives break through the massif rocks of zonal extension along the boundary of the plutonic and volcanic associations.

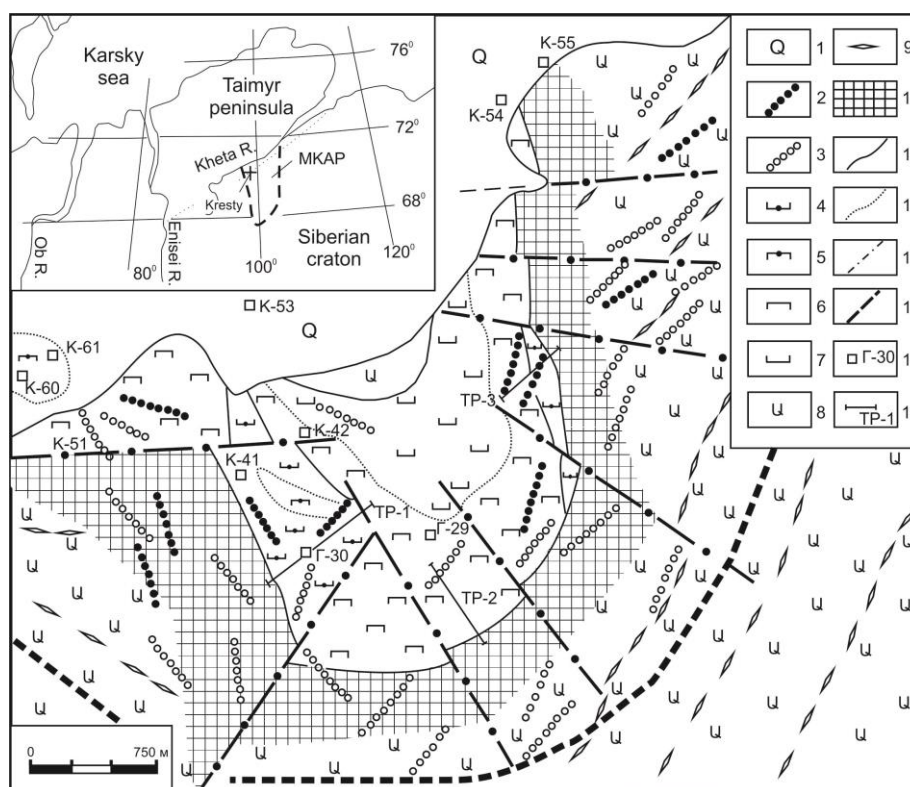


Figure 1. Scheme of geological structure of the Kresty Massif. The inset shows the geographical position of the Maimecha-Kotui province (MKP) and the Kresty volcanoplutonic structure (KVPS) [2].

1- loose deposits, KZ; 2 -9. - KVPS rocks, MZ_1 dykes of alkaline syenites and granosyenites (2), of trachydolerites and trachyandesites (3), kugdites and melitholites (4), monticellitites (5), banded olivinite-wehlite-clinopyroxenite complex (6), olivinites (7), melanephelinites (8), and local fluxes of melanephelinite clastolavas (9); 10 – chertaureol within the host effusive mass; 11 – geological boundaries; 12 –bound areas between petrophical variations within intrusive bodies; 13 – faults; 15 – KVPS boundaries by gravity data; 15 – boreholes and their Nos; 16 – ditches and their Nos.

By their petrochemical parameters, the KVPS rocks conform to those of tholeiite (dunites, wehlite, and clinopyroxenites), subalkaline (trachydolerites, trachyandesites, and syenitoids), and alkaline series (melilitolites, monticellitites, nephelinites, and alkaline picrites), mainly of potassium–sodium specialization. These rocks, as all MKP magmatites, are characterized by high concentrations of most of trace elements comparable to numbers in oceanic island basalts (OIB), which confirms plume nature of magmatism in the province. Heterogeneity of the products of tholeiite and alkaline series is well pronounced in the behavior of the most magmatophilic elements (Nb, Ta, Th, Sr, LREE) concentrated mainly in alkaline melts. The content of REE and La/Yb ratio increase subsequently in series from olivinites and wehlrites to pyroxenites, nephelinites, and melilitolites, reaching maximum in monticellitites. The dykes of syenites and trachydolerites show moderate concentrations of lanthanides

comparable to ultrabasic rocks of normal alkalinity, which negates thereby the model of differentiation from a single parent melt. The fractionation degree of rare elements increases in following series: “volcanites → dyke formation → main intrusive phases”, at the same time obvious negative anomalies of Rb, Ba, Sr, Nb, Zr, Hf, and Ti appear in olivine-rich variations.

Geochemical heterogeneity of the KVPS rocks is also traced in the parameters of the neodymium and strontium isotope composition, whose variations indicate autonomous matter sources for associations of normal and high alkalinity [3]. However, a valid Sm–Nd isochrone line was obtained only for the whole rock compositions of olivine, wherlites, and two pyroxenites, yielding the age of 251 ± 20 Ma ($\epsilon_{\text{Nd}}(T) = +2.0$). Alkaline ultramafic rocks show higher primary $^{143}\text{Nd}/^{144}\text{Nd}$ ratios ($\epsilon_{\text{Nd}}(T) = +2.4 \div 3.1$), whereas decreased values of this parameter (from -0.6 to -15.9) are typical for trachyandesites and syenitoids. The probable heterogeneity of the sources of rock associations is also shown in the values of the T_{DM} model age. Compared to the small intrusions of alkaline syenites (~ 2.36 Ga), younger dates were found for melanephelenites and monticellitites (~ 590 – 620 Ma). The isotope composition of strontium shows a wider variability with I_0 values ranging from 0.7035 – 0.7037 (for nephelinites, melilitolites, and monticellitites) and 0.7038 – 0.7041 (for olivinites, wehrlites, and pyroxenites) to 0.705 – 0.708 (for trachydolerites and alkaline syenites). The ratios of oxygen isotopes in whole-rock compositions and in rock-forming pyroxene ($\delta^{18}\text{O} = +1.1 \div 4.9$ ‰) suggest considerable interaction of the rocks with meteor waters permeating probably as deep as 500 m.

3. Analytical techniques

New U–Pb isotopic data on zircon grains was studied. It represents two intrusive phases of the Kresty massif, including one of the main rock types like kugdites and vein types of rocks like alkaline syenites. Zircons from this object were analyzed with SHRIMP-II microprobe at the Russian Geological Research Institute named after A.P. Karpinsky (St. Petersburg) using a standard technique with a spot diameter of $18\text{ }\mu\text{m}$. The internal structure of mineral grains was determined with cathodoluminescent images taken on ABT55 scanning electron microscope in a usual operating mode. Data was processed with SQUID software. The U/Pb ratios were normalized to the value of 0.0668 of the TEMORA standard zircon. The errors of isotope ratio and age measurements were within $\pm 1\sigma$, and the errors in calculation of concordant ages and intersections with concordia were within $\pm 2\sigma$. The plots with concordia were built using the ISOPLOT/Ex software.

4. Results and Discussion

Our study has given new proof of these very short-term intrusive events being connected to Siberian plume. Our new geochronological data is demonstrated in *Table 1–2* and *Fig. 2–3*.

Table 1. U-Pb data for kugdites of the Kresly massif

Spot	% ²⁰⁶ Pb _e	ppm ^U	ppm Th	²³² Th/ ²³⁸ U	ppm ²⁰⁶ Pb*	(2) ²⁰⁶ Pb/ ²³⁸ U Age	Total ²³⁸ U/ ²⁰⁶ Pb	±%	Total ²⁰⁷ Pb/ ²⁰⁶ Pb	±%	(1) ²³⁸ U/ ²⁰⁶ Pb*	±%	(1) ²⁰⁷ Pb*/ ²⁰⁶ Pb*	±%	(1) ²⁰⁷ Pb*/ ²³⁵ U	±%	(1) ²⁰⁶ Pb*/ ²³⁸ U	±%	err corr		
1	T-3.1.1	20.20	19	213	11.86	0.800	254	5	19.89	1.8	0.2131	1.9	25.73	3.0	0.025	83	0.14	83	0.0391	3.0	.037
2	T-3.2.1	20.84	18	250	14.73	0.751	250	5	20.05	2.0	0.2181	1.9	27.04	3.4					0.0372	3.4	
3	T-3.3.1	62.03	21	140	6.93	1.800	241	10	9.95	1.7	0.5479	1.2	30.70	6.5					0.0338	6.5	
4	T-3.4.1	24.92	13	278	21.58	0.581	242	5	19.67	2.0	0.2505	2.0	26.95	3.6	0.028	92	0.15	92	0.0374	3.6	.039
5	T-3.5.1	21.55	17	243	15.14	0.727	253	5	19.60	1.9	0.2239	2.2	26.88	3.4					0.0375	3.4	
6	T-3.6.1	22.48	48	265	5.73	2.020	242	4	20.31	1.5	0.2310	1.3	26.09	2.1	0.054	22	0.289	23	0.0385	2.1	.091
7	T-3.7.1	23.86	15	266	18.16	0.679	252	6	19.13	2.0	0.2424	2.2	24.91	3.7	0.058	45	0.32	45	0.0404	3.7	.082
8	T-3.8.1	19.81	16	259	16.45	0.693	251	5	20.17	1.9	0.2099	2.3	25.54	3.0	0.039	52	0.21	52	0.0393	3.0	.058
9	T-3.9.1	20.28	16	242	15.24	0.702	251	5	20.10	1.9	0.2136	2.3	26.49	3.3					0.0380	3.3	
10	T-3.10.1	22.35	15	266	18.93	0.642	253	6	19.42	2.0	0.2303	2.2	26.03	3.3					0.0387	3.3	
11	T-3.11.1	16.57	23	223	9.90	0.961	253	5	20.82	1.9	0.1840	2.0	25.55	2.6	0.032	48	0.175	48	0.0393	2.6	.054
12	T-3.12.1	22.82	15	257	18.14	0.650	253	6	19.31	2.1	0.2341	2.2	27.80	3.8					0.0363	3.8	
13	T-3.13.1	23.88	14	311	22.94	0.628	251	6	19.15	2.2	0.2425	2.2	26.48	3.7					0.0380	3.7	
14	T-3.14.1	22.29	16	265	17.65	0.654	241	6	20.39	2.1	0.2295	2.3	26.83	3.3	0.033	68	0.17	68	0.0375	3.3	.049
15	T-3.15.1	22.22	16	259	16.72	0.681	244	6	20.17	2.3	0.2290	2.2	27.90	3.9					0.0362	3.9	

(2) Common Pb corrected by assuming $^{206}\text{Pb}/^{238}\text{U}-^{207}\text{Pb}/^{235}\text{U}$ age-concordance.

Kugdite ages were determined on perovskite grains, which is one of the main accessory minerals of this rock. Despite small error, the age (249 ± 3.4 Ma) corresponds fully to the Paleozoic-Mesozoic boundary. More accurate dating was obtained from zircons for another rock variety (alkaline syenite type), which represents one of the latest phases of dyke complex formation in this intrusive massif (Table 2, Figure. 3).

T-3

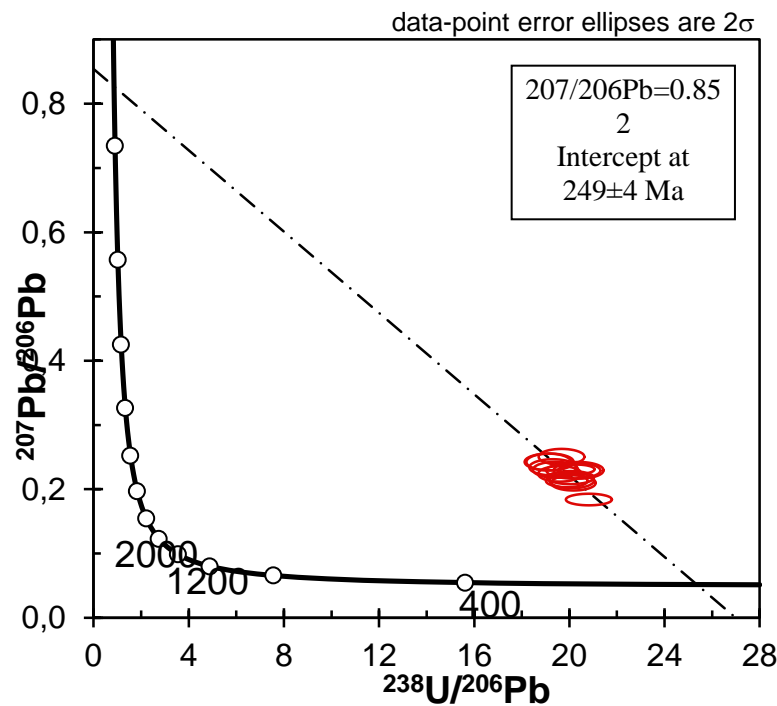


Figure 2. U-Pb plot for kugdites of the Kresty massif.

Table 2. U-Pb data for alkaline syenites of the Kresty massif

Spot	% ²⁰⁶ Pb e	ppm U	ppm Th	²³² Th / ²³⁸ U	ppm ²⁰⁶ Pb *	(1) ²⁰⁶ Pb / ²³⁸ U Age	(1) ²⁰⁷ Pb / ²³⁵ Pb Age	% Dis- cor- dant	(1) ²³⁸ U/ ²⁰⁶ Pb*	± %	(1) ²⁰⁷ Pb* / ²⁰⁶ Pb*	± %	(1) ²⁰⁷ Pb* / ²³⁵ U	± %	(1) ²⁰⁶ Pb* / ²³⁸ U	± %	err corr			
1	G-29-390.4.1	0.21	735	457	0.64	24.8	248	1.7	198	81	-20	25.52	0.7	0.0501	3.5	0.2705	3.6	0.0392	0.7	.200
2	G-29-390.10.1	0.17	881	636	0.75	29.7	248	1.8	294	66	18	25.5	0.7	0.0522	2.9	0.2822	3.0	0.0392	0.7	.249
3	G-29-390.2.1	0.26	985	641	0.67	33.6	250	1.5	179	73	-29	25.26	0.6	0.0497	3.1	0.2710	3.2	0.0396	0.6	.194
4	G-29-390.6.1	0.26	1198	898	0.77	41.2	252	1.4	321	70	27	25.05	0.6	0.0528	3.1	0.2908	3.1	0.0399	0.6	.184
5	G-29-390.7.1	0.20	703	315	0.46	24.2	253	1.7	231	77	-9	25.01	0.7	0.0508	3.3	0.2799	3.4	0.0400	0.7	.206
6	G-29-390.1.1	0.11	1182	937	0.82	40.7	253	1.2	290	44	15	24.99	0.5	0.0521	1.9	0.2874	2.0	0.0400	0.5	.247
7	G-29-390.9.1	0.20	738	504	0.71	25.4	253	1.7	323	73	27	24.96	0.7	0.0529	3.2	0.2921	3.3	0.0401	0.7	.212
8	G-29-390.5.1	0.11	1299	1063	0.85	44.8	254	1.3	259	51	2	24.93	0.5	0.0514	2.2	0.2843	2.3	0.0401	0.5	.234
9	G-29-390.11.1	0.13	978	694	0.73	34	255	1.3	171	52	-33	24.76	0.5	0.0495	2.2	0.2755	2.3	0.0404	0.5	.237
10	G-29-390.8.1	0.00	1358	1019	0.78	47.4	257	1.5	219	43	-15	24.62	0.6	0.0505	1.9	0.2829	2.0	0.0406	0.6	.302
11	G-29-390.3.1	0.21	111	42	0.39	16.2	1008	10	959	65	-5	5.91	1.1	0.0710	3.2	1.6570	3.3	0.1692	1.1	.328

Errors are 1-sigma. Pb_c and Pb* indicate the common and radiogenic portions, respectively.

Error in Standard calibration was 0.29% (not included in above errors but required when comparing data from different mounts).

(1) Common Pb corrected using measured ²⁰⁴Pb.

Errors are 1-sigma; Pb_c and Pb* indicate the common and radiogenic portions, respectively.

Error in Standard calibration was 0.29% (not included in above errors but required when comparing data from different mounts).

(1) Common Pb corrected using measured ²⁰⁴Pb.

Ages of alkaline syenites determined on accessory zircon grains turned out to be more accurate, considering range of possible errors. Real age values correspond to the same values of 252 ± 1.0 Ma (Fig. 3).

G-29-390

n=9 (6e3)

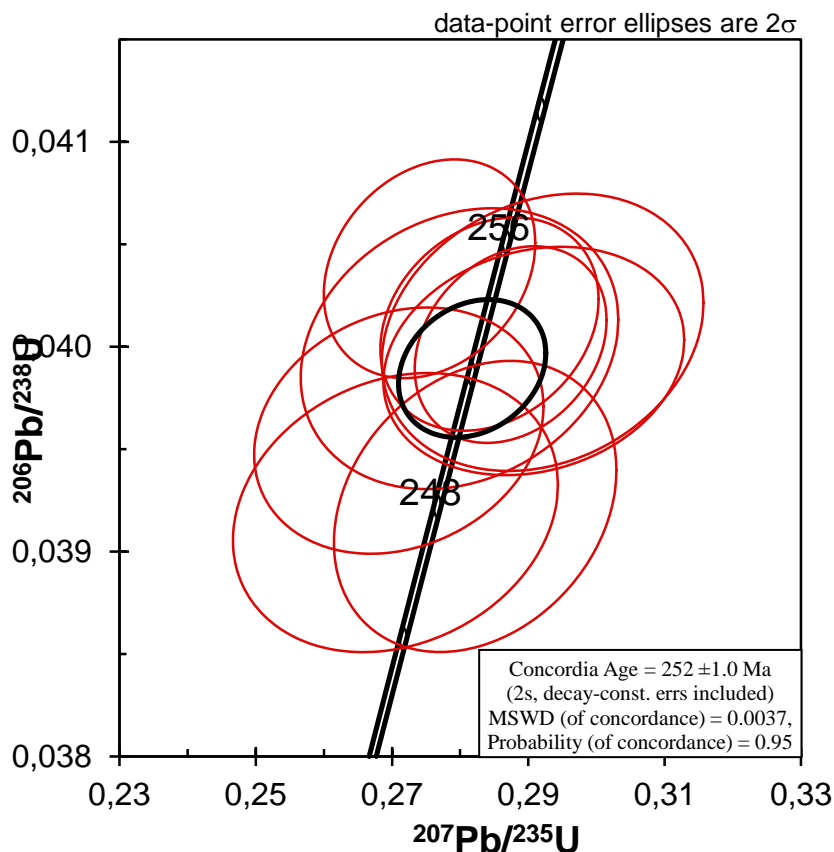


Figure 3. The plot for alkaline syenites of the Kresty Massif.

Patterns in isotopic evolution of KVPS rocks are obviously shown on $\epsilon_{Nd}(T)$ - $\epsilon_{Sr}(T)$ diagram, where composition points of petrographic varieties of Maimecha-Kotui province form composition field expanding in a fan-like pattern from moderately depleted mantle of HIMU and PREMA type into the area of enriched sources EMI and EMII. Boundaries between them coincide with lines of mixing of lower crust (LC) and upper crust (UC) matters (mixing in ratios from LC:UC = 10:1 to LC:UC = 1:10) [3]. At the same time, isotope compositions of tholeiitic and alkaline magma products show noticeable discreteness only at the base of the Mesozoic volcanogenic mass/thickness (Pravoboyarsk, Onkuchansk and Tyvankitsk series) or in separate intrusive bodies (Kugda massif) distant from assumed “finger plume” center. As they get closer to the “finger plume” center, composition fields of magmatic rocks move closer to each other and subsequently move towards area of depleted mantle substrates. Similar variations of isotope composition with certain level of Sr enrichment are also seen in flood basalts from Norilsk region [9]. We can assume that it might indicate lower permeability of mantle matter and its interaction with brines of sedimentary cover of the platform.

By their isotope composition, volcanic and plutonic KVPS varieties take intermediate position between their analogues in the Gulinian and Kugda massifs in a relatively narrow contrast range between the alkaline and tholeiite derivatives. This is quite consistent with the scale of their spatial distance from the probable center of “finger plume”. The most complete coincidence of isotope

parameters was observed in ultrabasic and alkaline rocks, as well as in carbonatites of the Gulinian pluton. The approximating point of convergence of variation trends conforms to the values of $\varepsilon_{\text{Nd}}(T) = +5$ and $\varepsilon_{\text{Sr}}(T) = -15$, which are close to the characteristics of the PREMA source [5]. Taking into account extreme depths (>200 km) of the generation of primary alkaline–ultrabasic MKP melts [6], the leading role of the homogenous PREMA-type mantle substrate [10] in the processes of their generation seems to be the most valid. This conclusion may be confirmed by the parameters of lead isotope composition in basalts of the Putorana Plateau representing the geochemical peculiarity of the prevailing component of the Siberian (North Asian) superplume [1]. Despite the fact that the $\varepsilon_{\text{Nd}}(T)$ and $\varepsilon_{\text{Sr}}(T)$ values in these rocks indicate a chondritic matter source, the $^{206}\text{Pb}/^{204}\text{Pb}$ (18.3), $^{207}\text{Pb}/^{204}\text{Pb}$ (15.5), and $^{208}\text{Pb}/^{204}\text{Pb}$ (38.0) ratios conform precisely to the PREMA matter. A deviation from the defined trend was registered exclusively in the late small intrusions (dolerites, syenites, and granites) formed under active interaction with the crust matter, or with its direct melting. A similar model of the formation of hypabyssal rocks of similar Sr and Nd isotope parameters is accepted for the Early-Mesozoic A-type granitoids, as well as for the lamproites from Taimyr Peninsula and Altai Mountains formed simultaneously with final stages North Asian superplume evolution [6].

Thus, the example of the Kresty volcanoplutonic structure raises a question whether or not two or more plume sources participated in formation of the studied rock associations from the Maimecha–Kotui province. Evidently, a single mantle matter existed conforming to PREMA matter in isotope composition. The multiplicity observed for magmatic complexes may have been caused by different scale plume–lithosphere interactions during exhumation/raise of melts along the Yenisei–Khatanga rift zone in the northern periphery of Siberian craton. Due to thermal activation of crust under the plume impact, the role of the mantle component in magmatic evolution decreased subsequently/successively [7].

The new data that we obtained proves “short-term” formation of intrusive complexes within Maimecha–Kotui province and their temporal correlation with volcanic eruptions in this region. Close ages for alkaline phase of the Kresty Massif and dykes completing its formation suggest short-term magmatic events, which defined one of the largest changes in organic world of our planet at Paleozoic–Mesozoic boundary.

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