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Paleogeodynamics

THE EARLY PALEOZOIC BASITE MAGMATISM IN THE NORTHEASTERN SIBERIAN CRATON

A. I. Kiselev[1], B. B. Kochnev[2], V. V. Yarmolyuk[3], V. I. Rogov[2], K. N. Egorov[1]

[1] *Institute of the Earth's Crust, Siberian Branch of RAS, Irkutsk, Russia*
[2] *A.A. Trofimuk Institute of Petroleum Geology and Geophysics, Siberian Branch of RAS, Novosibirsk, Russia*
[3] *Institute of Geology of Ore Deposits, Petrography, Mineralogy and Geochemistry of RAS, Moscow, Russia*

Abstract: The Early Cambrian tectonomagmatic activation is manifested in the northeastern passive margin of the Siberian Craton within the area of the Olenek uplift, as well as in the Kharaulakh segment of the Verkhoyansk fold-thrust belt that was thrusted onto the craton in the Mesozoic. In the Olenek uplift, igneous rocks occur as basite diatremes, small basalt covers, dolerite dykes and sills intruded into the overlying Upper Vendian carbonate sediments. Stratiform bodies of explosive breccias are present in basal sandstones at the bottom of the Lower Cambrian sediment section. According to the zircon-based U-Pb datings [*Bowring et al., 1993*], the age of explosive basite breccias samples from the Olenek uplift (543.9±0.24 Ma) correlates with the age of potash-rhyolites (534.6±0.5 Ma) from the basal Lower Cambrian conglomerates in the Kharaulakh uplift section. The geodynamic evolution of the northeastern margin of the Siberian craton at the end of the Vendian and the beginning of the Cambrian periods is reflected not only in the magmatism, but also in the thicknesses and facial characteristics of the correlating sediments of the regional passive sea basins [*Pelechaty et al., 1996*]. The northern and eastern margins of the craton were subject to progressive uplifting at the end of the Vendian, which resulted in dewatering and paleokarsting. Uplifting was associated with the formation of siliceous clastic shelf sediments in the southern margin of the basin and the explosive and intrusive basite magmatic activations in the Olenek uplift and rhyolite bimodal-basite magmatic activation in the Kharaulakh uplift. The observed Vendian-Cambrian stratigraphic relations and manifestations of the basite magmatism suggest that at the northeastern margin of the craton, the lithosphere was subject to stretching. The assumed rift volcanic-sedimentary associations are thin and represent the southern, the most remote part of the shoulder of the rift developed (in present-day coordinates) along the northern margin of the Siberian Craton. The chemical specificity of the Lower Cambrian basites and their mantle sources, the bimodal rhyolite-basalt magmatism, and the Vendian-Cambrian sedimentation history provide sufficient arguments to consider the Early Paleozoic rifting and the associated magmatic activation as consequences of the plume–lithosphere interaction in the northeastern Siberian Craton. The paleoreconstructions [*Sears, 2012; Khudoley et al., 2013*] suggest that the main rifting events occurred due to the lithosphere breakup through the junction zone of the Siberian and North American cratons which existed in the Early Cambrian. It is also assumed that the breakup was accompanied by the formation of a large igneous province which relics are present in the basin complex of the Canadian Cordillera in North America, as well as in the Olenek and Kharaulakh uplifts. The Early Paleozoic rifting and magmatism may reflect the final phase of the disintegration of the Rodinia supercontinent fragments.

Key words: Siberian Craton; basic magmatism; rifting; plume; geochemistry; Sr-Nd isotopic composition of basic rocks

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Раннепалеозойский базитовый магматизм на северо-востоке Сибирского кратона

А. И. Киселев[1], Б. Б. Кочнев[2], В. В. Ярмолюк[3], В. И. Рогов[2], К. Н. Егоров[1]

[1] *Институт земной коры СО РАН, Иркутск, Россия*

[2] *Институт нефтегазовой геологии и геофизики им. А.А. Трофимука СО РАН, Новосибирск, Россия*

[3] *Институт геологии рудных месторождений, петрографии, минералогии и геохимии РАН, Москва, Россия*

Аннотация: Раннекембрийская тектономагматическая активизация проявлена на северо-восточной пассивной окраине Сибирского кратона в пределах Оленекского поднятия, а также в Хараулахском сегменте форланда Верхоянского складчато-надвигового пояса, надвинутого на кратон в мезозое. Магматические образования на Оленекском поднятии выражены в виде базитовых трубок взрыва, небольших покровов базальтов, а также даек и силлов долеритов, прорывающих и перекрывающих верхневендские карбонатные отложения. На базальных песчаниках в основании разреза нижнекембрийских отложений участками присутствуют стратиформные тела эксплозивных брекчий. Возраст эксплозивных брекчий Оленекского поднятия, определенный U-Pb методом по цирконам [*Bowring et al.*, *1993*], имеет значение 543.9±0.24 млн лет и коррелируется с возрастом гальки калиевых риолитов (534.6±0.5 млн лет) из базальных нижнекембрийских конгломератов в разрезе Хараулахского поднятия. Геодинамическая эволюция северо-восточной окраины Сибирского кратона в конце венда и начале кембрия отражена не только в магматизме, но и в мощностях и фациальных характеристиках коррелятных отложений региональных пассивных морских бассейнов [*Pelechaty et al., 1996*]. В конце венда обращенные к северу и востоку внешние части окраины кратона испытали прогрессивное воздымание, приведшее к осушению и образованию палеокарста. С поднятием связано образование кремнекластических шельфовых осадков в южной окраине бассейна, а также эксплозивный и интрузивный базитовый магматизм на Оленекском поднятии и бимодальный риолит-базитовый магматизм на Хараулахском поднятии. Наблюдаемые венд-кембрийские стратиграфические соотношения и проявления базитового магматизма свидетельствуют о том, что литосфера северо-восточной окраины кратона вовлекалась в растяжение. Отнесенные к рифтовым вулканогенно-осадочные ассоциации являются маломощными и представляют южную, наиболее удаленную, часть плеча рифта, который развивался (в современных координатах) по северному краю Сибирского кратона. Вещественная специфика нижнекембрийских базитов и их мантийных источников, наличие бимодального риолит-базальтового магматизма в совокупности с историей венд-кембрийского осадконакопления являются достаточным основанием, позволяющим рассматривать раннекембрийский рифтогенез и сопряженный с ним магматизм как следствие плюм-литосферного взаимодействия на северо-востоке Сибирского кратона. В соответствии с палеореконструкциями [*Sears, 2012; Khudoley et al., 2013*] можно предполагать, что основные рифтогенные события были порождены литосферным расколом, прошедшим через зону сочленения Сибирского и Северо-Американского кратонов, существовавшую в раннем кембрии. Предполагается, что раскол сопровождался образованием крупной магматической провинции, реликты которой сохранились в бассейновых комплексах канадских Кордильер Северной Америки, а также в пределах Оленекского и Хараулахского поднятий. Возможно, раннепалеозойский рифтогенез и магматизм отражают завершающую фазу распада фрагментов суперконтинента Родиния.

Ключевые слова: Сибирский кратон; базитовый магматизм; рифтогенез; плюм; геохимия; Sr-Nd изотопный состав базитов

1. Introduction

The Siberian Craton is the most ancient structure in northeastern Eurasia. Its lithosphere stabilized in the Paleoproterozoic, around 1.9 GA B.P. [*Rosen et al.*, *2006*]. In the course of its evolution, this craton was repeatedly involved in various continental agglomerations and separated from them in the course of supercontinental breakups. Imprints of these events are found in heterochronous basite magmatism features, including the Late Precambrian dyke swarms formed during the breakup of Rodinia and reflecting, at least, the Neoproterozoic age of the eastern and southern craton margins [*Gladkochub et al*., *2010a, 2010b*]. The Early Paleozoic tectonomagmatic activation was less marked. In the southern areas of the craton, dolerite dikes intruded into the Paleoproterozoic granitoides and granite-gneiss rock complexes within the Urik-Iya graben, Biryusa and Goloustnoe edges of the craton basement [*Gladkochub et al*., *2007*].

In the northeastern Siberian Craton, the Early Paleozoic magmatism was confined to the Olenek uplift

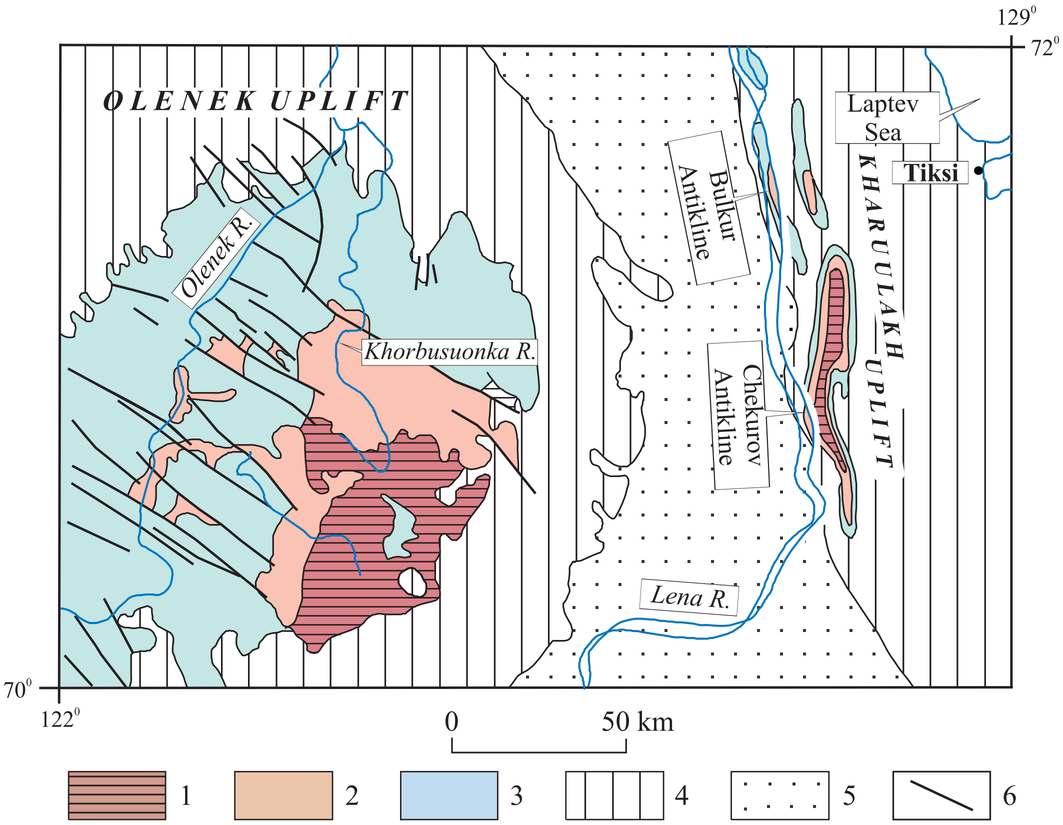

Fig. 1. Simplified geological map of the Olenek and Kharaulakh uplifts in the northeastern Siberian Craton (based on the geological map of the Siberian platform and adjacent territories, scale 1:1,500,000, published in 1999). *1* – Riphean; *2* – Vendian; *3* – Lower Cambrian; *4* – Carbon-Jurassic; *5* – Carboniferous sediments; *6* – faults.

Рис. 1. Схема геологического строения Оленекского и Хараулахского поднятий на северо-востоке Сибирского кратона (на основе геологической карты Сибирской платформы и сопредельных территорий, масштаб 1: 1500000, 1999 г.). *1–5* – осадочные отложения: *1* – рифейские, *2* – вендские, *3* – нижнекембрийские, *4* – карбон-юрские, *5* – меловые; *6* – разломы.

and the Kharaulakh segment of the Verkhoyansk fold-thrust belt (the lower reaches of the Lena river) (Fig. 1). [*Kiselev et al., 2012a*; *Khudoley et al., 2013*]. The Olenek uplift is a unique area that underwent repeated mantle magmatism activations with diverse facial and material features. In this region, early basite magmatism events took place in the Mesoproterozoic and Lower Cambrian [*Shpunt et al., 1982*; *Wingate et al., 2009*]. In the Middle Paleozoic, as well as in the Permian-Triassic, basic and kimberlite magmatism were coincident in space and time. The final phase of the Phanerozoic magmatism is evidenced by the Jurassic-Cretaceous kimberlite dykes and diatremes [*Brachfogel, 1984*].

In the mid 1950s, coarse greenish-gray conglomerates (diamictite-like rocks) of the Middle Lower Cambrian were discovered in the Kersyuke river valley (Olenek uplift) [*Zhuravlev, Sorokov, 1954*]. Later on, basic magmatism features, including diatremes and bedded deposits, were found and dated to the final stage of the Olenek uplift development in the Precambrian. B.R. Shpunt and his colleagues shared these views concerning the age of magmatism in this region [*Shpunt et al., 1982*; *Shpunt, Shamshina, 1989*].

In late 1960s, detailed studies of the Khorbusuonka river basin (Fig. 2) revealed a wide facial diversity of the products of basite magmatism, which age was assumed as the beginning of the Paleozoic, and the three analyses yielded the first data on chemical compositions of dolerites and basalts [*Leonov, Gogina, 1968*]. The first reliable dating of explosive breccias sampled from the Khorbusuonka river basin (543.9±0.24 Ma) was obtained by the zircon-based U-Pb method. It correlates with the age of potassium rhyolite (534.6±0.5 Ma) from the Lower Cambrian basal conglomerates overlain by basalts in the area of the Kharaulakh uplift [*Bowring et al., 1993*].

Volcanic activity in the Olenek uplift is evidenced by abundant diatremes (tuff breccias) and dolerite dykes intruding into the Khatyspyt and Turkut formations of the Khorbusuon series, as well as the lower and middle

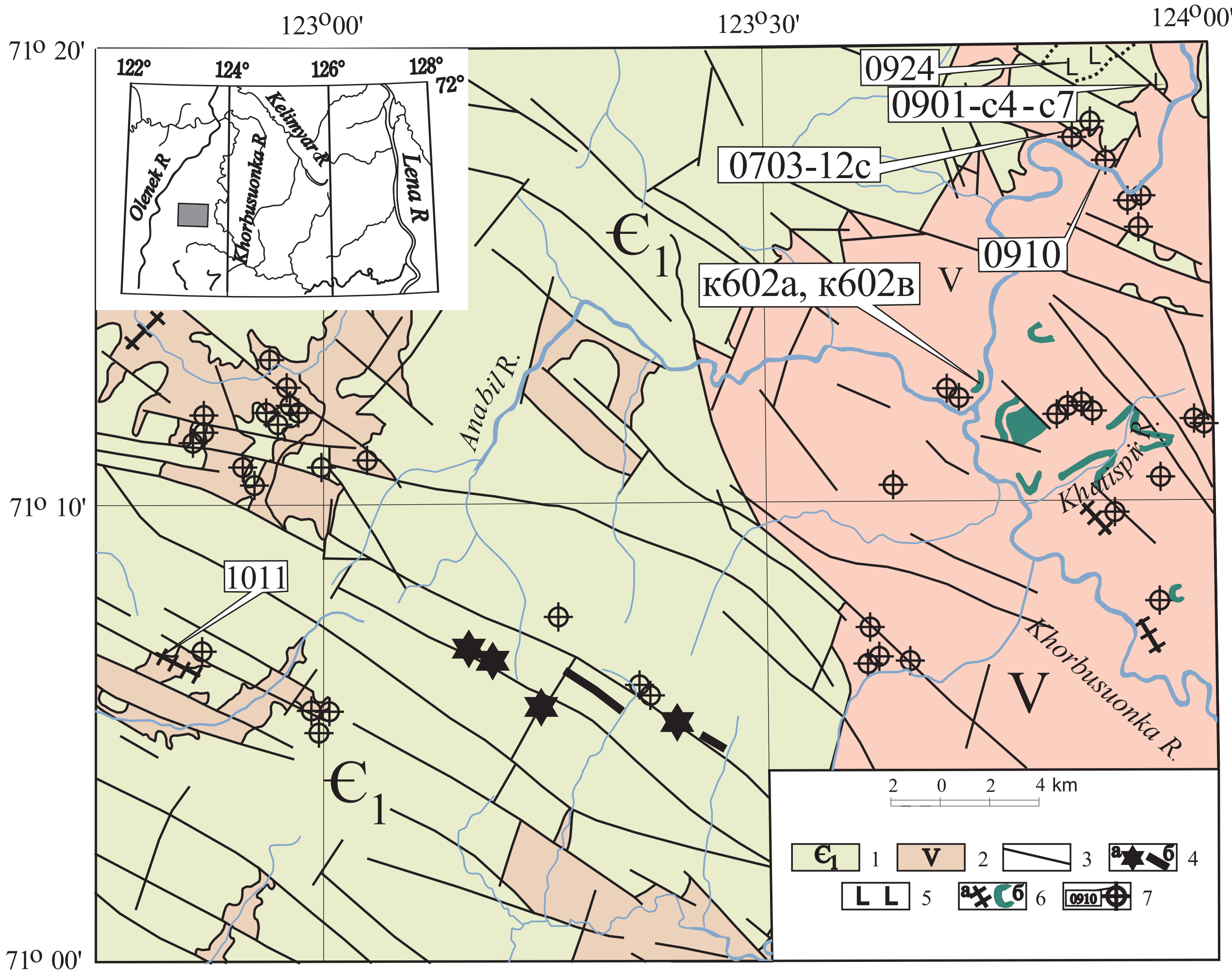

Fig. 2. The scheme showing locations of magmatic associations in the Khorbusuonka river valley (Olenyek lift). *1* – Lower Cambrian sediments; *2* – Vendian sediments; *3* – faults; *4* – Mesozoic kimberlite pipes (a) and dikes (b). Lower Cambrian rocks: *5* – basalt cover fragments; *6* – dolerite dikes (a) and sills (b); *7* – basite diatremes. Numbers in boxes correspond to sampling sites. The inset shows the study area.

Рис. 2. Схема расположения магматических ассоциаций в бассейне р. Хорбусуонка (Оленекское поднятие). *1* – нижнекембрийские отложения; *2* – вендские отложения; *3* – разломы; *4* – трубки (а) и дайки (б) мезозойских кимберлитов. Нижнекембрийские образования: *5* – фрагменты покровов базальтов; *6* – дайки (а) и силлы (б) долеритов; *7* – базитовые трубки взрыва. Цифры в квадратах соответствуют местам отбора образцов. На врезке показан район исследований.

parts of the Syrargalakh formation of the Kessyusin series. Besides, the Khatyspyt formation contains dolerite sills, and basalt covers overlie the Turkut formation, which corresponds stratigraphically to the Syargalakh formation. The field observations show that tuff breccias and semidiamict rocks were formed after the accumulation and lithification of the Turkut sediments, but synchronously with the accumulation of the lower and middle beds of the Syargalakh formation of the Kessyusin series, which contain small skeletal relics (*Anabarites trisulcatus*) of the Vendian zone. Ichnofossil *Treptichnus pedum* was found in the upper part (near the top) of the formation. According to the International Stratigraphic Scale, its first occurrence marks the base of the Fortunian stage of the Cambrian period [*Rogov et al., 2015*].

Our paper presents the following observations based on the geochemical (ICP-MS) and isotope geochemical (Sr-Nd) data on basites sampled from the Olenek and Kharaulakh uplifts: (1) The geochemical characteristics of the basites are similar to those of oceanic island basalts (OIB). Positive values ε_{Nd} for the basites in the Sr-Nd isotopic system suggest that a moderately depleted mantle was the source of initial melts for these basites. (2) The Early Cambrian magmatic activation and specificitying in the northeast Siberian craton was due to the plume-lithosphere interaction (hot spots) and, according to the paleocontinental reconstructions [*Sears*, *2012*; *Khudoley et al*., *2013*], manifested locally at the passive margin along the transform boundary between Siberia and North America in the late Vend and at the beginning of the Paleozoic. (3) The earlier reported "potassium alkaline volcanic rocks" (high-K trachydolerites, clastolavas, and tuffs) of the Olenek uplift do not reflect their primary magmatic origin as such rocks are the products of low-temperature metasomatic potassium-enrichment of the medium alkaline basites, tuff breccias and tuffs, and the petrgenetic interpretations should take this into account.

2. Facial manifestations of magmatism

The Olenek uplift. Diatremes, dikes and dolerite sills are abundant in the northwestern slope of the Olenek uplift and in the basin of the middle-stream Khorbusuonka river and the Khorbusuonka-Olenek watershed. Basalt covers are small and rare.

Diatremes are located within the limits of the primarily NW-trending main faults and the feathering fractures (Fig. 2). In the study area, almost 100 diatremes [*Leonov, Gogina*, *1968*; *Shpunt, Shamshina*, *1989*] intrude into the Khatyspyt and Turkut formations of the Khorbusuon series and the lower part of the Syargalakh formation of the Kessyusin series. The diatremes are filled with explosive breccias, tuffs and clastolavas. The explosive breccias contain clasts (up to 1.5 m), specifically of limestone, dolomite, sandstone, siltstone, detrital quartz, volcanic tuff and basalt. Basalt fragments (up to 10 cm, rarely more than 10 cm) display hyalopilitic and microlitic structures and predominantly amygdaloidal and porous-slag-like textures.

Craters of the diatremes are surrounded by stratiform semidiamict rocks (hereinafter, breccias) that conformably overlie sandstones of the lower beds of the Syargalakh formation and are conformably overlain by interbedded sandstones and aleurolites of the Mattai formation of the Kessyusin series. The breccia bodies are up to 30 m thick.

Basalt covers are confined to the Khorbusuonka river basin and located on the northern slope of the Tas-Neleger mountain in the direct vicinity of explosive rocks in the Tas-Yuryakh stream valley (sample 0924, see Fig. 2). In the volcanogenic part of the section, lava sheets of varying thickness are alternating with tuffaceous interlayers which thickness ranges from 0.5–1.5 m to 10–11 m. The basalts display an amygdaloidal texture and a fine porphitic structure.

Single phenocrysts of plagioclase (1–1.5 mm) or their glomeroporphyritic aggregates are immersed in the matrix consisting of thin plagioclase laths, clinopyroxene grains and ore minerals (magnetite, titanomagnetite, and, rarely, rutile). The plagioclase laths are often oriented in one direction and reflect the dynamics of lava flows. It should be noted that in some cases, the plagioclase laths in the basalts (sample 0901-C5, Table 1) are pseudomorphically replaced with water-clear low-temperature K-feldspar (perhaps, sanidine?). Chlorite, carbonate, hydromica, zeolites and iron hydroxides are present among the secondary minerals in the basalts.

Hypabyssal rocks in the Khorbusuonka river basin are represented by dykes and dolerite sills. Dolerite bodies intruding into the Upper Vendian Khatyspyt and Turkut formations are also observed in this area. An almost 60 m thick dolerite sill in the Khatyspyt stream valley, a right tributary of the Khorbusuonka river, has been studied by B.V. Oleynikov in detail [*Oleinikov et al*., *1983*]. The main rock-forming minerals in dolerites are plagioclase and clinopyroxene, and olivine replaced with bowlingite and iddingsite is present in smaller amounts (3–7 %), as well as titanomagnetite and ilmenite (3–5 %). The matrix is represented by a hydromicaceous aggregate, chlorite, rare chalcedony quartz and K-feldspar. Along with the sills, steeply dipping and primarily NW-trending dolerite dikes are present in the study area. The features of the Lower Cambrian magmatic activation in the cumulative section of the Olenek uplift for the Vend and Cambrian are shown in Fig. 3.

The Kharaulakh uplift. The Vendian-Cambrian sedimentary rocks are outcropped in the lower reaches of the Lena river, where it crosses the Chekurov and Bulkur anticlines within the limits of the Kharaulakh uplift (see Fig. 1). In this area, the Vendian (Kharayutekh formation) and Lower Cambrian (Tyuser formation) sediments are observed on the left bank of the Lena river [*Bowring et al*., *1993*]. The Vendian deposits are represented by deep-water bituminous limestones that are gradually replaced with shallow-water oolitic-intraclastic dolomites (a 30 m thick bed). These carbonate rocks are unconformably overlain by the Cambrian basal beds represented by shallow-water glauconite sandstones, quartz sandstones and shales, as well siliceous-clastic sediments (sandstones, and shales). These rocks are unconformably replaced with fluvial conglomerates, which composition is almost exclusively dominated by pebbles of quartz-feldspar porphyres of the volcanic and/or hypabyssal origin. The porphyries belong to the family of potash-rhyolites. According to [*Shpunt et al*., *1982*], potash-rhyolites consist of a finely crystallized ferruginous glassy matrix with phenocrysts of quartz and K-feldspar. The contents of petrogenic elements are as follows (wt %.): SiO_2 – 72.54, TiO_2 – 0.324, Al_2O_3 – 11.64, Fe_2O_3 – 2.38, FeO – 1.77, Mn – 0.02, MgO – 0.50, CaO – 0.40, Na_2O – 0.75, K_2O – 8.66, P_2O_5 – 0.09, ignition loss – 0.80; total – 99.87. In the family of potash-rhyolites, these rocks are characterized by the maximum content of potassium in

Т а b l e 1. **Chemical compositions of basites sampled from the Olenek and Kharaulakh uplifts**

Т а б л и ц а 1. **Химический состав базитов Оленекского и Хараулахского поднятий**

Component	Samples from the Olenek uplift									Samples from the Kharaulakh uplift					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	0910	K602B	K602A	1011	0924	0901-C5	0901-C6	0901-C7	0703-12C	8-2	8-4	8-10	(6-6)	(6-8)	(6-10)
SiO_2	42.53	42.10	43.85	42.95	45.49	44.05	44.05	43.80	45.15	46.40	43.19	45.11	46.57	46.61	46.60
TiO_2	4.25	4.25	4.47	4.33	4.03	3.89	4.06	4.18	4.44	3.59	3.56	3.61	3.65	3.71	3.68
Al_2O_3	13.65	14.00	12.50	13.80	13.25	12.70	13.05	13.40	14.05	13.88	14.13	14.21	14.03	14.6	13.76
Fe_2O_3	6.65	3.32	5.18	5.58	7.05	4.50	5.32	5.09	5.71	4.75	6.61	5.96	4.38	6.44	5.26
FeO	7.71	7.48	9.36	8.65	6.75	9.34	8.22	8.59	8.02	8.40	8.30	8.22	9.38	6.3	8.4
MnO	0.1	0.01	0.2	0.2	0.42	0.2	0.2	0.2	0.2	0.18	0.18	0.29	0.32	0.28	0.24
MgO	7.73	12.95	6.20	7.67	6.31	7.62	7.28	8.06	6.70	5.88	7.97	7.39	6.35	6.58	7.25
CaO	8.15	1.24	8.07	8.14	11.58	8.26	9.12	9.97	10.3	10.99	6.14	8.66	9.87	9.34	8.08
Na_2O	1.85	0.08	0.23	2.09	2.30	1.33	3.02	1.97	2.36	2.26	0.44	2.04	2.56	2.88	2.57
K_2O	0.69	5.32	5.53	0.72	0.69	3.69	1.00	0.67	0.58	1.00	5.78	1.57	0.93	0.88	1.6
P_2O_5	0.42	0.44	0.48	0.45	0.47	0.44	0.47	0.47	0.51	0.38	0.35	0.41	0.38	0.36	0.36
H_2O-	3.15	1.81	0.91	2.14	0.43	0.78	1.24	1.28	0.85						
п.п.п.	2.97	6.75	3.21	3.03		3.40	2.88	2.59	1.33	1.91	3.39	3.10	1.63	1.86	2.4
CO_2	0.14	0.37	0.22	0.70	0.78	0.19	0.43	0.20	0.30						
Сумма	99.99	99.93	100.41	100.35	100.48	100.39	100.34	100.47	100.5	99.62	100.04	100.57	100.05	99.84	100.02
Rb	5.30	39.00	27.00	8.10	8.50	22.00	9.20	9.60	13.70	12.44	30.53	36.07	13.84	18.55	11.64
Sr	559.0	116.0	2873.0	419.0	400.0	1338.0	367.0	398.0	959.0	395.80	367.92	356.37	383.83	429.45	363.79
Y	21	23	23	24	24	23	25	26	23	35.61	35.32	30.02	31.50	34.7	36.53
Zr	189.0	183.0	186.0	216.0	206.0	197.0	211.0	212.0	189.0	357.23	186.52	238.67	226.83	345.7	305.66
Nb	21	20	21	22	22	20	22	23	20	27.65	27.00	26.05	21.88	31.07	28
Cs										16.00	0.20	1.60	0.34	0.15	0.2
Ba	243.0	150.0	875.0	212.0	203.0	787.0	235.0	219.0	268.0	98.85	199.38	180.33	108.45	18.71	23.91
La	13.30	14.60	16.00	16.00	16.00	16.00	16.00	18.00	15.00	18.76	18.37	17.92	19.87	18.71	23.91
Ce	34	37	38	40	40	38	39	45	38	46.79	43.61	41.92	46.23	45.57	49.79

Table 1 (end)

Таблица 1 (окончание)

Component	Samples from the Olenek uplift									Samples from the Kharaulakh uplift					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	0910	K602B	K602A	1011	0924	0901-C5	0901-C6	0901-C7	0703-12C	8-2	8-4	8-10	(6-6)	(6-8)	(6-10)
Pr	5.0	5.2	5.5	5.6	5.7	5.6	5.7	6.2	5.4	6.89	5.82	5.24	5.71	5.91	5.89
Nd	24.0	25.0	27.0	27.0	27.0	26.0	28.0	29.0	26.0	26.88	22.22	22.67	21.87	23.13	24.95
Sm	5.90	6.10	6.50	6.60	6.70	6.40	6.70	7.10	6.30	6.89	6.68	5.96	6.37	6.68	6.73
Eu	2.3	2.4	2.4	2.8	2.0	2.4	2.7	2.9	2.5	1.61	2.31	1.81	2.11	2.01	2.26
Gd	6.10	6.60	7.00	7.10	7.30	6.40	6.50	7.70	6.50	7.11	6.75	5.80	6.58	6.34	6.91
Tb	0.87	0.94	0.97	1.02	1.01	0.92	0.99	1.11	0.92	1.07	1.02	0.91	0.92	0.99	1.05
Dy	4.88	5.40	5.60	5.50	5.80	5.30	5.60	5.90	5.50	6.24	5.96	5.16	5.52	5.85	6.33
Ho	0.93	0.98	1.03	1.04	1.05	0.99	1.05	1.13	0.98	1.17	1.14	1.12	1.04	1.1	1.19
Er	2.25	2.40	2.54	2.65	2.63	2.45	2.69	2.74	2.50	3.10	2.93	2.67	2.73	2.85	3.09
Tm	0.28	0.32	0.33	0.33	0.34	0.33	0.34	0.37	0.32	0.43	0.38	0.37	0.36	0.39	0.41
Yb	1.76	1.88	2.05	2.05	2.15	2.00	2.00	2.19	2.04	2.57	2.31	1.93	2.21	2.35	2.59
Lu	0.24	0.28	0.31	0.31	0.32	0.30	0.31	0.33	0.30	0.37	0.35	0.32	0.33	0.34	0.36
Hf	4.85	4.88	5.30	5.30	5.40	5.20	5.20	5.70	4.80	6.96	3.77	4.84	4.71	6.53	5.92
Ta	1.33	1.33	1.40	1.47	1.47	1.37	1.45	1.52	1.34	1.61	1.57	1.48	1.19	1.62	1.45
Pb	0.80	0.49	0.49	1.03	1.33	0.80	1.57	2.06	1.09	6.45	4.65	3.49	3.23	1.81	3.61
Th	1.00	1.03	1.04	1.14	1.19	1.23	1.27	1.32	1.14	2.11	1.91	1.80	1.41	2.09	2.21
U	0.3	0.6	0.3	0.4	0.5	0.6	0.5	0.5	0.4	0.57	0.35	0.35	0.47	0.56	0.66
$^{87}Sr/^{86}Sr$					0.704355			0.704751	0.707933	0.704298	0.708214	0.70565			
$^{143}Nd/^{144}Nd$					0.512725			0.512740	0.512760	0.512772	0.512781	0.512869			
εNd (T=540 Ma)					4.97			5.40	5.90	5.50	3.71	7.13			

N o t e. (1–4) – dolerites and (5–9) – basalts from the Khorbusuonka river valley, (10–15) – basalts from the Kharaulakh uplift [*Kiselev et al., 2012b*]. Silicate analyses were performed at the Institute of Earth's Crust SB RAS, Irkutsk (analyst G.V. Bondareva). Potassium-sodium series of dolerite (1, 4) and basalts (5, 7, 8, 9, 10, 13, 14, 15). Potassium series of sanidine-containing dolerites (2, 3) and basalts (6, 11, 12). Oxides are given as wt % elements (g/t). The trace element compositions were analyzed by the ICP-MS method using ELEMENT-II instrument (analyst S.V. Panteeva, Baikal Analytical Center ISC SB RAS, Irkutsk). $^{87}Sr/^{86}Sr$ и $^{143}Nd/^{144}Nd$ were determined with the use of a Finnigan MAT 262 mass spectrometer (analysts V.A. Vladimirova and V.V. Yarovaya, Institute of Geochemistry SB RAS, Irkutsk).

П р и м е ч а н и е. (1–4) – долериты и (5–9) – базальты бассейна р. Хорбусуонка, (10–15) – базальты Хараулахского поднятия [*Kiselev et al., 2012b*]. Силикатные анализы выполнены в Институте земной коры СО РАН (аналитик Г.В. Бондарева). Калиево-натриевая серия долеритов (1, 4) и базальтов (5, 7, 8, 9, 10, 13, 14, 15). Калиевая серия санидинсодержащих долеритов (2, 3) и базальтов (6, 11, 12). Окислы приведены в мас. %, элементы – в г/т. Состав элементов-примесей определен методом ICP-MS на приборе ELEMENT-II в Байкальском аналитическом центре ИНЦ СО РАН (аналитик С.В. Пантеева). $^{87}Sr/^{86}Sr$ и $^{143}Nd/^{144}Nd$ определены на Finigan MAT 262 (аналитики В.А. Владимирова, В.В. Яровая).

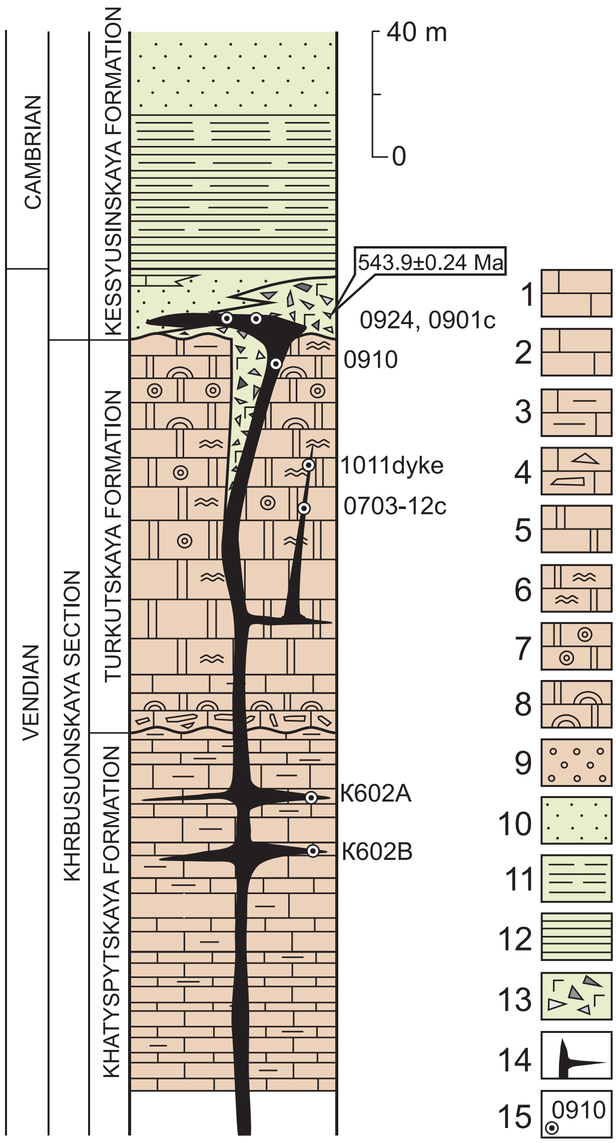

Fig. 3. Manifestations of the LowerPaleozoic magmatism in the cumulative section of the Olenek Uplift (Khorbusuonka river area) for the Vendian and Cambrian.

1–4 – limestone (massive, bituminous, clayous, disantigrated); *5–8* – dolomitolite (*5* – massive and micritous, *6* – belaminitous, *7* – spheroaggregatous, *8* – stromatolito-biogermnous); *9* – gravelites, *10* – sandstones; *11* – aleurolites; *12* – argillites; *13* – tufabreccia; *14* – dolerite intrusions and basalt covers (samples 0924, and 0901c); *15* – locations of the samples in the section.

Рис. 3. Проявления нижнекембрийского магматизма в сводном разрезе венда и кембрия Оленекского поднятия (бассейн р. Хорбусуонка).

1–4 – известняки (массивные, битуминозные, глинистые, обломочные); *5–8* – доломитолиты: *5* – массивные и микритовые, *6* – биоламинитовые, *7* – сфероагрегатные, *8* – строматолито-биогермные; *9* – гравелиты; *10* – песчаники; *11* – алевролиты; *12* – аргиллиты; *13* – туфобрекчии; *14* – интрузии долеритов и покровы базальтов (0924, 0901c); *15* – местоположение образцов в разрезе.

relation to sodium. The uniform clasts are indicative of the local primary source. The conglomerates are overlain by two basalt flow layers (10 and 28 m). The rocks have a porphyritic texture. Phenocrysts of plagioclase are present, often in the form of glomeroporphyritic secretions (Fig. 4). The matrix has an ophitic structure and consists of plagioclase, clinopyroxene, titanomagnetite, olivine pseudomorphically substituted by bowlingite (<5 %), and biotite (1–2 %). Chlorite dominates among the secondary minerals. The basalts are overlain by sandy limestones (2 m) with the Lower Cambrian fauna.

According to the zircon-based U-Pb datings, the absolute age of potash-rhyolites (534.6±0.5 Ma) correlates with the age of explosive basite breccias (543.9±0.24 Ma) in the Vend-Cambrian Khorbusuon section in the Olenek uplift [*Bowring et al., 1993*]. The joint occurrence of the rhyolite clasts and the basaltic cover in the Vendian-Cambrian section of the Chekurov anticline is a sedimentological evidence of the Lower Cambrian bimodal volcanism in the Kharaulakh uplift [*Shpunt et al., 1982*; *Pelechaty et al., 1996*].

Besides the basalts, the Early Cambrian group of rocks includes dolerite sills intruded into the Riphean and Vendian sediments. The largest sills are located in the core of the Chekurov anticline. The Verkhnekharayutekh sill (65 m thick) and the Semimetrovy sill are observed in a rock outcrop among the Vendian sediments of the Kharayutekh formation on the left bank of the Lena river. The sills' margins are composed of mirodolerites that are replaced (towards the bodies' center, Fig. 4), with ophitic and poikilophitic dolerites consisting of plagioclase, clinopyroxene, pseudomorphically substituted olivine (5–7 %), titanomagnetite, and ilmenite [*Oleinikov et al., 1983*]. Inside the intrusive body, there are pegmatoid schlieren of dolerites containing K-feldspar. The absolute age datings of the Verkhnekharayutekh and Semimetrovy sills are 449±13 and 508±13 Ma, respectively. With account of a low reliability of the K-Ar method for dating ancient

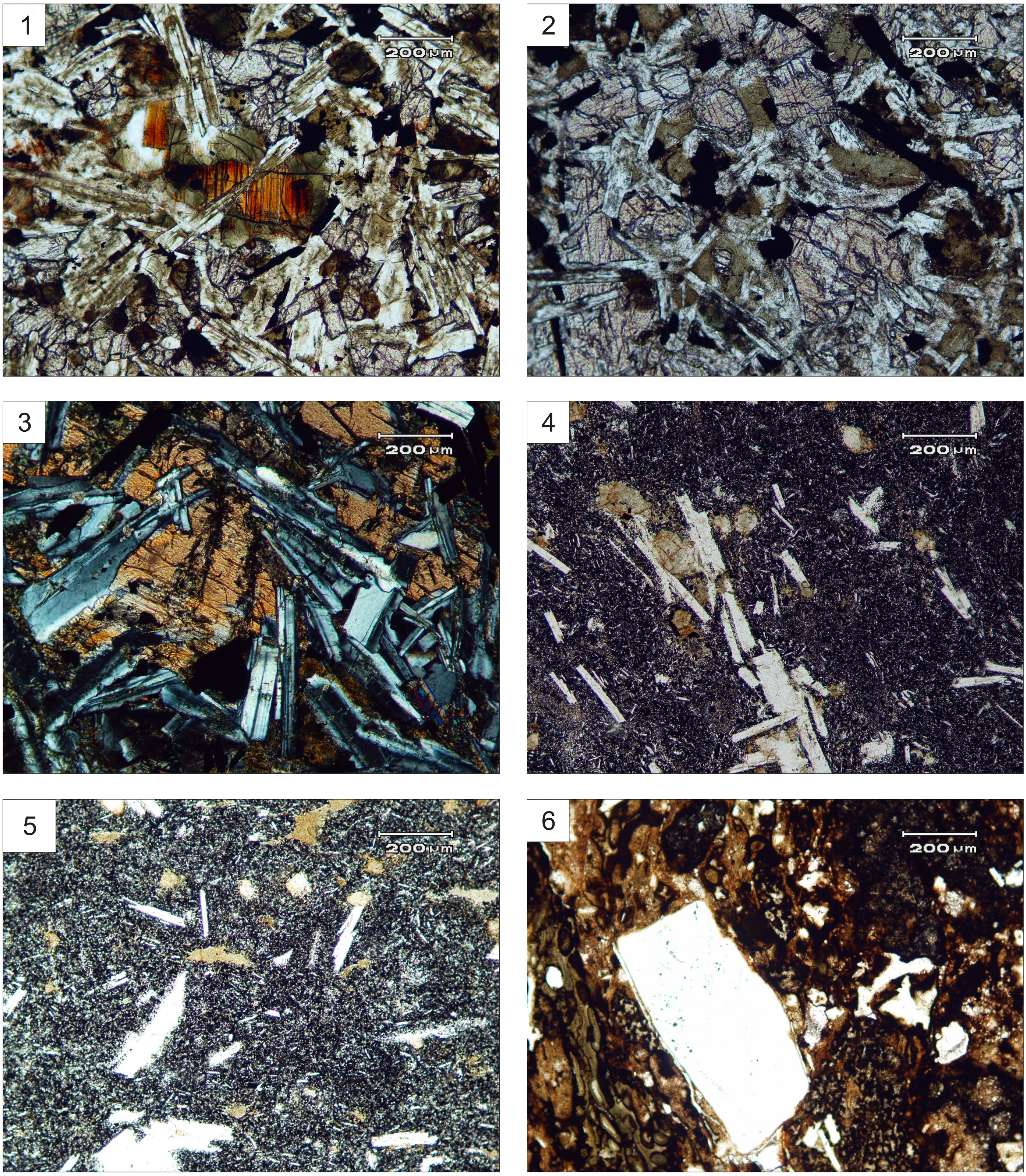

Fig. 4. Microphotographs of basites sampled from the Kharaulakh (*1*) and Olenek (*2*–*6*) uplifts.

(*1*) Samples 8-10 – biotite-bearing basalt from the lava bed (Biskeybit stream); (*2*) sample K602A – dolerite; (*3*) sample 1011 – dolerite; (*4*) sample 0924 – basalt with microporphyric secretions of plagioclase; (*5*) sample 0901-5 – basalt (plagioclase phenocrysts are pseudomorphically replaced with water-clear K-feldspar; (*6*) sample 4/08-9 – explosive breccia (plagioclase phenocrysts in the basalt fragment are pseudomorphically replaced with K-feldspar). Locations of the basite samples in the field and their positions in the Vendian-Cambrian section are shown in Figs. 2 and 3, respectively.

Рис. 4. Микрофотографии базитов Хараулахского (*1*) и Оленекского (*2*–*6*) поднятий.

(*1*) Обр. 8-10 – биотитсодержащий базальт из лавовой толщи (рч. Бискэйбит); (*2*) Обр. К602А – долерит; (*3*) Обр. 1011 – долерит; (*4*) Обр. 0924 – базальт с микропорфировыми выделениями плагиоклаза; (*5*) Обр. 0901-5 – базальт (вкрапленники плагиоклаза псевдоморфно замещены водянопрозрачным калиевым полевым шпатом; (*6*) Обр. 4/08-9 – эксплозивная брекчия (вкрапленники плагиоклаза в обломке базальта псевдоморфно замещены калиевым полевым шпатом). Местоположение образцов базитов на местности, а также их положение в венд-кембрийском разрезе показаны соответственно на рис. 2 и 3.

rocks, the sills can be generally dated as the Early Paleozoic.

3. Analytical methods

The mineral and elemental compositions of the cryptocrystalline matrix in the effusive rocks, explosive breccias and tuffs were determined with the use of a Carl Zeiss Axio Imager A1 microscope and a Tescan MIRA3 scanning electron microscope, respectively. The rock composition was studied by the classical wet-chemistry method (analyst G.V. Bondareva, Institute of the Earth's Crust SB RAS, Irkutsk). Trace elements were analyzed by the ICP-MS method (analyst S.V. Panteeva, Baikal Analytical Center ISC SB RAS, Irkutsk). The ICP-MS measurement accuracy data was confirmed by reanalyses according to BHVO-1 SRM standard and did not exceed 4.5 % for the majority of the elements, except Ho and Sm (5–7 %), and Tm, Yb, and Pb (8–10 %). A Superprobe JXA-820 Jeol microanalyzer (analyst L.F. Suvorova, Institute of Geochemistry SB RAS, Irkutsk) and a D8 Advance, Bruker X-ray diffractometer (analysis M.N. Rubtsova, Institute of Earth's Crust, Irkutsk) were used to determine the chemical and phase compositions of feldspars. The Sr and Nd isotopic compositions of basites were determined with the use of a Finigan MAT 262 mass spectrometer (analysts V.A. Vladimirova and V.V. Yarovaya, Institute of Geochemistry SB RAS, Irkutsk). The measured Sr and Nd isotopic compositions were normalized to $^{87}Sr/^{86}Sr$=0.1194 and $^{146}Nd/^{144}Nd$=0.7219. The long-term repeated measurements of $^{87}Sr/^{86}Sr$ for Sr under SRM NBS 987 standard and ^{143}/Nd/^{144}Nd for Nd under La Jolla standard yielded average values of 0.710300±0.000019 and 511848 ± 0.000006, respectively.

4. Petrochemical characteristics of magmatic rocks

Basites of the Olenek uplift are generally charactererized by a high content of titanium (3.9–4.5 wt %, see Table 1). Both in the basalt covers and dolerite intrusions, low-K (0.7–1.0 wt % K_2O) and high-K (3.7–5.5 wt % K_2O, Table 1) basic rocks are conventionally distinguished. Formally, considering the value of Na_2O/K_2O ratio, the basites of the Olenek uplift belong to the potassium-sodium (samples 0910, 1011, 0924, 0901-C6, 0901-C7, and 0703-12C, see Table 1) and potassium basalt series (samples K-602A, K-602B, and 0901-C5, see Table 1). Basalts of the Kharaulakh uplift also belong to the potassium-sodium and potassium basalt series (samples 8-4, and 8-10, see Table 1) and were considered as typical basalt lava, regardless of considerably varying contents of potassium and other elements (except titanium, phosphorus, and, to a lesser extent, iron) in the basalts. It was assumed that differences in the initial compositions of the rocks even within the same basaltic cover were related to their hydrothermal conversion during intrusion in underwater conditions [*Shpunt et al., 1982*]. However, the presence of igneous biotite in the basalt compositions (sample 8-10, see Table 1 and Fig. 4) may reflect a local substance heterogeneity of the extruded melts (probably related to contamination of the Vendian carbonate rocks) and the presence of high-K portions with high VOC contents.

In the high-K basites of the subvolcanic cover and explosive facies, K-feldspar microphenocrysts are represented by water-clear K-feldspar that pseudomorphically replaced plagioclase. It is noteworthy that this mineral cannot be generated by crystallization of the initial melt of basalts and dolerites because sodium (Na_2O<0.05 wt %) and calcium (CaO <0.05 wt %) are virtually absent in its composition. In the 'igneous' K-feldspar, the content of Na_2O amounts to 4–5 wt % [*Deer et al., 1966*]. It seems unlikely that the primary igneous K-feldspar may be selectively preserved in the association with the low-temperature paragenesis (chlorite, hydromica minerals, and calcite) in basites and explosive breccias. Most probably, K-feldspar was formed under conditions of a low-temperature metasomatic alteration of basalts, dolerites and explosive breccias [*Hughes, 1988*; *Kuzmichev et al., 2005*].

In the study area, metasomatism occurred locally as evidenced by the presence of both high-K basites and the basites with a typical relatively low alkali content (Table 1). In these least altered basites, the content of Na is higher than K. With the increasing content of K_2O (to ±6 wt %), the content of Na_2O decreases to tenths of a percent, while the cumulative alkalinity increases to 7 wt %. This is primarily reflected by the euhedral replacement of plagioclase grains with transparent K-feldspar (Table 2, see Fig. 4), which is an evidence in favor of its low-temperature hydrothermal-metasomatic origin in the potassium basites and their explosive analogues.

A similar origin is suggested for the locally present potassium basites among dolerites, basalts and explosive breccias in the Middle Paleozoic Vilyui-Markha dike swarm of dolerites [*Kiselev et al., 2004, 2009, 2014*]. Intrusions of basaltic melts into the craton cover were associated with heating of the sediment beds' margins, increasing discharge of heated underground mineralized waters along faults, and hydrothermal mineralization. Large thermal gradients at the basite intrusion locations could lead to the occurrence of local systems with convective circulation of solutions.

Depending on the lithology of the sedimentary rocks, the solutions were further enriched by various elements, such as magnesium and calcium from dolo-

T a b l e 2. **Chemical compositions of feldspars in the basalts of the explosive breccia (1–6, sample 0919/1001) and lava (7–9, sample 0924).**

Т а б л и ц а 2. **Химический состав полевых шпатов в базальтах из эксплозивной брекчии (1–6, обр. 0919/1001) и лавового покрова (7–9, обр. 0924)**

Oxide	Measurements in crystals								
	1	2	3	4	5	6	7	8	9
SiO_2	65.998	65.98	64.736	66.272	65.38	64.774	54.41	54.55	53.48
TiO_2	<0.05	<0.05	<0.05	<0.05	0.082	<0.05	0.04	0.21	0.01
Al_2O_3	17.417	17.621	17.789	17.571	18.34	18.113	28.03	27.62	28.23
FeO	0.305	0.346	0.235	0.269	0.37	0.214	0.91	0.92	0.74
MnO	<0.06	<0.06	<0.06	<0.06	<0.06		0	0.07	0
MgO	<0.06	<0.06	<0.06	<0.06	0.12	<0.06	0.25	0.00	0
CaO	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	12.16	12.56	13.58
Na_2O	<0.05	<0.05	0.051	<0.05	0.054	0.094	3.75	3.71	3.79
K_2O	16.438	16.475	17.055	16.312	16.464	16.32	0.45	0.34	0.2
Сумма	100.417	100.529	99.927	100.508	100.845	99.559	100	99.97	100.01

N o t e. 1–6 – K-feldspar, 7–9 – plagioclase. A Superprobe JXA-820 Jeol microanalyzer was used (analyst L.F. Suvorova, Institute of Geochemistry SB RAS, Irkutsk).

П р и м е ч а н и е. 1–6 – калиевый полевой шпат, 7–9 – плагиоклаз. Определения выполнены на микроанализаторе Superprobe JXA-820 "Jeol" (Институт геохимии СО РАН, аналитик Л.Ф. Суворова).

mitolites and limestones, or potassium from clay marl and aleuropelites. Potential suppliers of potassium could also be the Vendian and Lower Cambrian aquifers in the sedimentary cover of the craton, i.e. Ca-Mg chloride brines which potassium content amounts to 1.0 g/l [*Alekseev*, *2000*].

In our opinion, the interaction between the potassium-enriched solutions and the margins of the intrusive dolerite bodies, the basalt covers and the basite fraction of the diatremes was accompanied by the local metasomatic transformation of normal mildly alkaline basic rocks (samples 1, 4, 5, 7, 8, and 10, see Table 1) into high-K basites (samples 2, 3, 6, 11, and 12, see Table 1). Under this scenario, the discrete occurrence of potassium rock varieties should be mainly determined by the component compositions of both the solutions and the associated sedimentary rocks in their interaction areas. It should be noted that, all other conditions being equal, the enrichment of basites by potassium is also dependent on the degree of their disintegration. The content of K_2O amounts to 5.96 wt % in the explosive breccia of basites from the diatreme (sample 0910/1001, Table 3), while it is only 0.69 wt % in dolerites from the dike intruded into this breccia. In general, the studied basites of the potassium series correspond to potassic spilites (poenites) containing low-temperature K-feldspar [*Hughes*, *1988*].

The tuff breccias and tuffs with a minimal amount of terrigenous components have high contents of K_2O (4.2–5.9 wt %, Table 3) and anomalously low contents of Na_2O (0.1–0.9 wt %). The microprobe analyses revealed that microporphiric phenocrysts in basalt clasts from the tuff breccias are represented by fresh water-clear K-feldspar. The analyses of the tuff breccias with the use of a Tescan MIRA3 scanning electron microscope also showed quite a high content of fine cryptocrystalline K-feldspar in the tuff breccia matrix.

Explosive products of basalt magmatism, i.e. tuff breccias with varying contents of potassium (2.82–5.96 wt % K_2O, Table 3), were (in our opinion, erroneously) classified in some earlier studies into a separate formational group of potassic alkaline rocks, which was viewed as "a missing link between kimberlites and alkaline basaltoids" [*Shpunt, Shamshina*, *1989*, p. 682], but the origin of spatially related coeval basalts and dolerites, which potassium contents varied in nearly the same range, was not discussed.

5. Discussion of results

From a general review of the chemical compositions of basites, it can be hardly suggested that the locally observed variable alkaline contents in the basalts, dolerites and tuff breccias correspond to those in the melt during the eruption and subsequent crystallization. With regard to the interactions of the initial melts with the host rocks, the above-described petrochemical specificity of the Cambrian basalts and dolerites does not reflect their initial material specificity in relation to LILE (Rb, K, Na, Ba, and Sr) that are termed in geochemistry as 'quite mobile' in any geological processes. Conversely, during various superimposed processes, the least mobile element is titanium ('highly charged element') which content allows considering the initial material specificity of the basites and their source. Our results (see Table 1) and the data in [*Shpunt et al.*, *1982*, *Oleinikov et al.*, *1983*] show that in the variously

Т a b l e 3. **Chemical compositions of tuff breccias and tuffs from the Khorbusuonka and Kersyuke river basins**

Т а б л и ц а 3. **Химический состав туфобрекчий и туфов бассейнов рек Хорбусуонка и Керсюке**

Item #	1	2	3	4	5	6	7	8	9	10
Component	0910/1001	0905/1002	0905/1(1)	0602/21	0602/1	0903/22	0903/2	0710/3	710/1005	0912/1001
SiO_2	33.46	24.45	82.98	36.63	31.45	46.23	44.03	40.66	39.98	35.23
TiO_2	2.11	1.49	0.86	2.38	2.64	1.46	1.83	1.26	3.17	1.46
Al_2O_3	8.05	6.20	5.95	9.40	9.25	6.75	8.55	6	10.80	7.25
Fe_2O_3	0.74	1.99	1.23	6.26	2.77	5.83	2.26	4.16	3.35	0.89
FeO	2.25	3.98	0.93	1.61	2.42	1.43	4.47	2.58	3.14	1.76
MnO	0.06	0.11	0.01	0.05	0.03	0.16	0.09	0.14	0.03	0.16
MgO	9.32	12.39	1.03	7.22	4.53	2.63	7.22	4.85	6.24	6.19
CaO	15.06	17.81	1.45	12.01	19.69	16.55	13.04	16.49	13.51	19.05
Na_2O	0.07	0.07	0.13	0.09	0.07	0.14	0.86	0.15	0.86	0.11
K_2O	5.96	2.82	2.88	4.18	5.35	2.61	1.83	2.61	4.7	4.68
P_2O_5	0.31	0.22	0.2	0.38	0.4	0.25	0.28	0.18	0.4	0.23
H_2O-	0.16	0.62	0.21	0.45	0.13	0.43	0.41	0.37	0.56	0.19
п.п.п.	0.36	1.98	1.35	2.73	0.06	2.2	3.31	1.75	2.75	1.32
CO_2	22.44	26.65	1.28	16.87	20.83	13.66	11.92	18.92	10.16	21.96
Сумма	100.35	100.29	100.48	100.26	99.56	100.33	100.37	100.14	99.65	100.48

N o t e. 1–2 – tuff breccias, 3 – tuff breccia matrix (2) without large clasts, 4–5 – tuff breccias from the top (4) and bottom (5) of the vein body, 6–7 – diamictites (redeposited tuff breccias), 8–10 – diamictites (lapilli tuffs). 0910/1001 etc. – sample numbers. The analyses were carried out in the Institute of the Earth's Crust SB RAS (analyst G.V. Bondareva).

П р и м е ч а н и е. 1–2 – туфобрекчии, 3 – матрикс туфобрекчии (2) без крупных обломков, 4–5 – туфобрекчии из кровли (4) и подошвы (5) жильного тела, 6–7 – диамиктиты (переотложенные туфобрекчии), 8–10 – диамиктиты (лапиллиевые туфы). 0910/1001 и др. – номера образцов. Анализы выполнены в Институте земной коры СО РАН (аналитик Г.В. Бондарева).

altered basites, the Ti content is high and varies insignificantly.

According to the Zr/TiO_2–Nb/Y classification diagram (Fig. 5) compared to the diagram SiO_2–(Na_2O+K_2O), the influence of the secondary rock alteration is minimal, and the basalts and dolerites are grouped in the field of alkaline basalts near the boundary with the field of subalkaline (tholeiitic) basalts. Dolerites from the sills are generally isochemical to basalts and differ from the latter in a higher degree of alterations of the initial composition, especially at the top of the intrusive bodies. At some locations, the penetration rocks show the secondary enrichment of the initial dolerites by magnesium and potassium and lower contents of calcium and strontium or higher contents of strontium. In the dolerite sill (0.7–1.2 m thick) located at the left side of the Khorbusuonka river basin (samples K602A, and K602B, see Fig. 1), the contents of strontium and barium amount to 2873 ppm 875 ppm, respectively, with 5.33 wt % K_2O (sample K602B, see Table 1), and the contents of magnesium (6.2 wt %) and calcium (8.07 wt. %) correspond to weakly altered dolerites (see Fig. 4).

The weakly altered dolerites (samples 0910, and 1011, see Table 1) are composed of plagioclase, clinopyroxene, pseudomorphically replaced olivine (to 3 %), titanomagnetite, and ilmenite. In these rocks, the K_2O content does not exceed 0.8 wt %. Dolerites from the dikes (unlike dolerites from the sills) were not subject to significant secondary alterations. Relatively low Mg contents in the studied rocks suggest that their initial melts were significantly fractionated before ascending to the surface. Besides, a small degree of partial melting of the mantle source of basaltic magma cannot be excluded.

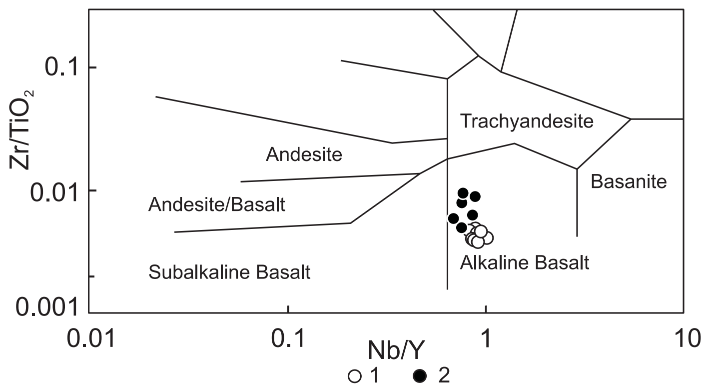

Fig. 5. Early Paleozoic dolerites and basalts of the Olenek and Kharaulakh uplifts plotted on the classification diagram Zr/TiO_2–Nb/Y [*Winchester, Floyd, 1977*].

Рис. 5. Положение нижнекембрийских базитов Оленекского и Хараулахского поднятий на классификационной диаграмме Zr/TiO_2–Nb/Y [*Winchester, Floyd, 1977*].

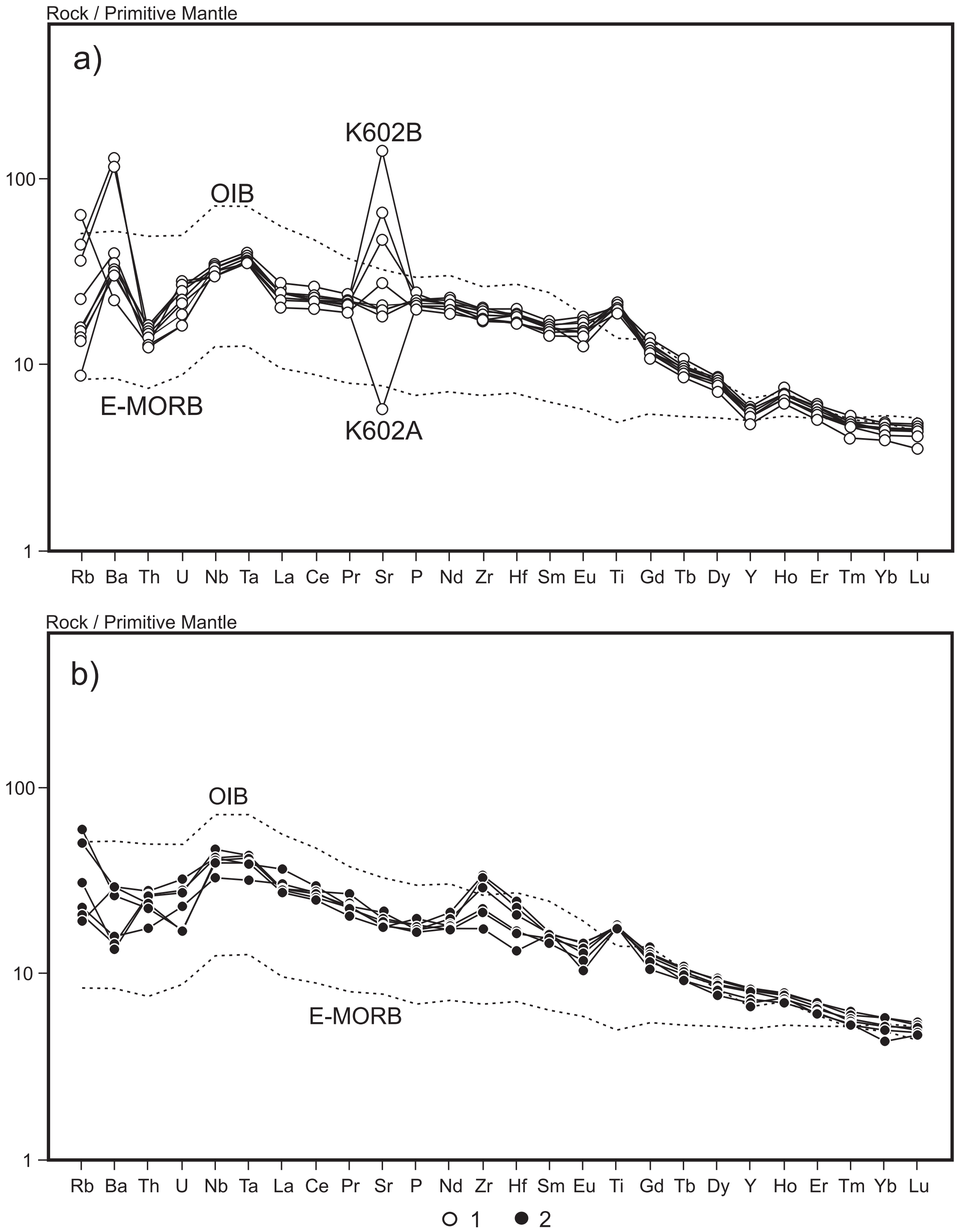

Fig. 6. Primitive mantle normalized [*Sun, McDonough, 1993*] trace elements for the Lower Paleozoic dolerites and basalts of the Olenek (*a*) and Kharaulakh (*b*) uplifts.

Рис. 6. Содержание элементов-примесей в нижнекембрийских долеритах и базальтах Оленекского (*a*) и Хараулахского (*b*) поднятий, нормализованных к составу примитивной мантии по [*Sun, McDonough, 1993*].

The multi-element diagram (Fig. 6 *a*, *b*) clearly shows widely varying concentrations of mobile LILE (Rb, Ba, and Sr) in the compositions of the basalts and dolerites, mainly due to fluid-rock interactions. The contents of rubidium and barium are typically high in the high-K basites. The contents of less mobile highly charged elements (Th, Zr, Hf, Nb, and Ta) are relatively moderate, being determined by the composition of the deep source, contamination and fractional crystallization of the initial melts. The studied rocks are characterized by element distribution spectra between EMORB and OIB compositions, tending to the latter. In

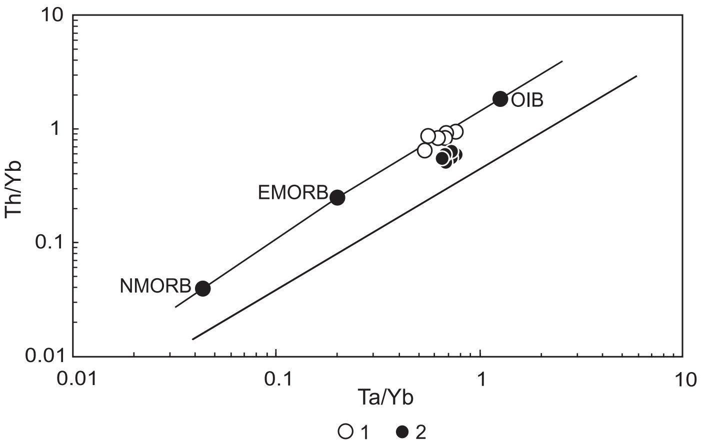

Fig. 7. Th/Yb vs Ta/Yb [*Pearce, 1983*] plot for the Lower Paleozoic dolerites and basalts of the Olenek uplift (*1*) and basalts of the Kharaulakh uplift (*2*) [*Kiselev et al., 2012b*].

Рис. 7. Положение нижнекембрийских базитов Оленекского и Хараулахского поднятий на диаграмме Th/Yb–Ta/Yb [*Pearce, 1983*]. *1* – долериты и базальты Оленекского поднятия; *2* – базальты Хараулахского поднятия [*Kiselev et al., 2012b*].

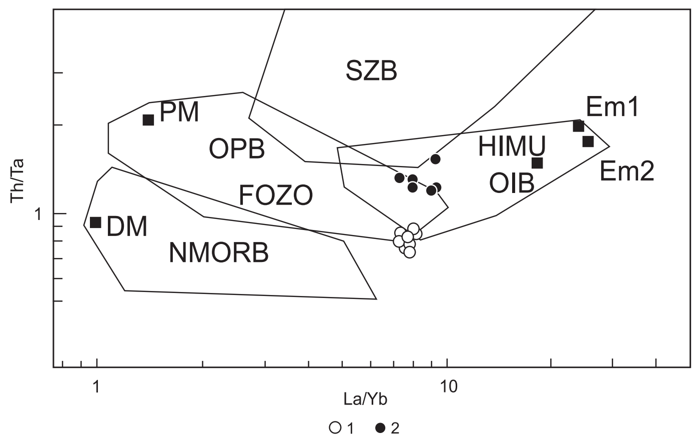

Fig. 8. Th/Ta vs La/Yb plot [*Tomlinson, Condie*, 2001] for the Lower Paleozoic dolerites and basalts of the Olenek (*1*) and the Kharaulakh (*2*) uplifts.

Рис. 8. Положение нижнекембрийских базитов Оленекского и Хараулахского поднятий на диаграмме Th/Ta–La/Yb] [*Tomlinson, Condie, 2001*].

general, the low-angle position in the multielement diagram showing the rare-earth elements distribution in the basites (Fig. 6, *a*, *b*) corresponds to a weakly fractionated type. The $(La/Yb)_N$ value is 5.3–5.8 for the basites of the Olenek uplift, and 5.3–6.7 for the basalts of the Kharaulakh uplift [*Kiselev et al.*, *2012*]. The absence of (Nb, and Ta) minimums in the diagram (Fig. 6, *a*, *b*) excludes a significant contaminating influence of the crust on the composition of initial melts.

In the Th/Yb–Ta/Yb diagram, the studied rocks fall in the mantle trend characterizing the variations of indicative element ratios between OIB and EMORB (Fig. 7). In Th/Ta–La/Yb diagram, basites are concentrated in the OIB field and at the boundary between the OIB and OPB fields (Fig. 8). High Th/Ta ratios in the mantle magmatism products are usually ascribed to the influence of crustal contamination or the involvement of the recycled lithosphere in the mantle magma generation zones, whereas low Th/Ta and high La/Yb ratios are characteristic for the environments of mid-ocean ridges and oceanic islands [*Tomlinson, Condie*, *2001*]. The basites of the Olenek and Kharaulakh uplifts fall in the OIB field, between the common component of the mantle magmas of mid-oceanic ridges and oceanic islands (FOZO) and sources representing the enriched mantle (EM 1, EM 11, and HIMU). The above indicative ratios suggest that the magmatic activation in the Olenek and Kharaulakh uplifts was associated with an OIB source. However, this does not exclude the involvement of a recycled MORB component in the magma generation.

Our analyses yielded ε_{Nd} values (T=540 Ma) and $^{87}Sr/^{86}Sr$ ratios for the igneous rocks – 3.7–5.9 and 0.704335–0.708214, respectively. Three samples with the low contents of radiogenic strontium fall into the depleted quadrant of the OIB field (Fig. 9). In our opinion, the high contents of radiogenic strontium in the other three samples are not their initial magmatic characteristics, but result from the contaminating in-

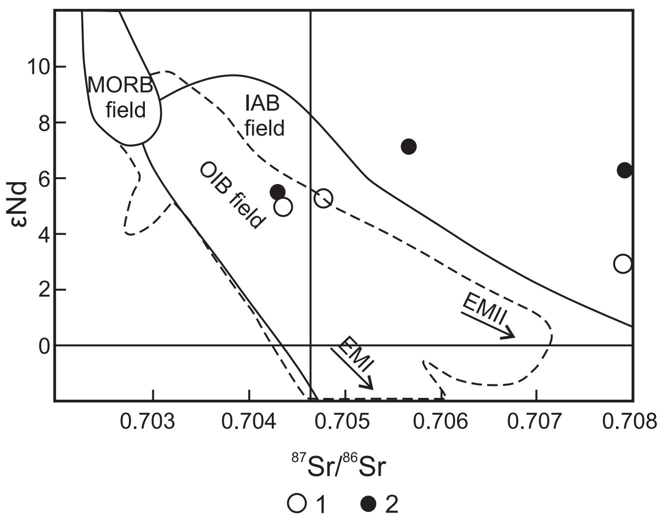

Fig. 9. ϵ_{Nd}–$^{87}Sr/^{86}Sr$ diagram [*White, Duncan*, 1996] for dolerite dykes of the Olenek (*1*) and basalts of the Kharaulakh uplifts (*2*).

Рис. 9. Диаграмма ϵ_{Nd}–$^{87}Sr/^{86}Sr$ для базальтов Оленекского (*1*) и Хараулахского поднятий (*2*) [*White, Duncan, 1996*].

fluence of evaporites contained in the Turkut formation on the intruding basalt melts during their acesent to the surface. Positive values of ε_{Nd} (see Table 1) suggest that the studied igneous rocks were generated by melting of a moderately depleted mantle source.

6. Conclusion

In the course of its evolution, the Siberian Craton as a part of the large continental agglomerations was repeatedly involved in the continental breakup processes. The most prominent events took place in the late Neoproterozoic (690–650 Ma) when Siberia and Laurentia were disconnected due to the breakup of Rodinia. Their split is evidenced by the alkaline ultrabasic massifs with carbonatites, which chain along the craton edge from the Yenisei ridge, along its southwestern and southern periphery and further along its eastern boundary. This event was associated with the formation of the Ingili, Arbarastah and Tomtor massifs [*Vladykin et al*., *2014*] that shaped the eastern margins of the craton. Later on, the craton margins did not change significantly. For instance, branches of the Devonian Vilyui rift system give evidence that the eastern margins maintained the same shape in the Devon [*Kiselev et al*., *2012b*]. The fact that the rift zones are confined to the craton margins reflects the high sensitivity of the latter to sublithospheric impacts.

Obviously, the Early Cambrian occurrences of magmatism in the Olenek and Kharaulakh uplifts are among the events of the same category, related to the intraplate activity at the craton margins. The magmatic activation took place in the marginal areas of the craton and was confined to the fault system along the craton boundary. The analyses show geochemical characteristics typical of magmatism of hot mantle spots. This magmatic impulse was relatively shallow in the uplifted area, but most likely, much stronger on the other side of the craton boundary, as evidenced by changes in thicknesses and lithofacial characteristics of the Vendian-Cambrian rocks near the Olenek uplift, which suggest that the northeastern (in present-day coordinates) margin of the craton was subject to stretching. The paleoreconstructions [*Sears*, *2012*; *Khudoley et al*., *2013*] suggest that the main rifting events occurred due to the lithosphere breakup through the junction zone of the Siberian and North American cratons, which existed in the Early Cambrian. It is also assumed that the breakup was accompanied by the formation of a large igneous province which relics are present in the basin complex of the Canadian Cordillera in North America, as well as in the Olenek and Kharaulakh uplifts. Thus, the material specificity of the Lower Cambrian basites and their mantle sources, the bimodal rhyolite-basalt magmatism, and the Vendian-Cambrian sedimentation history provide sufficient arguments to consider the Early Paleozoic and the associated magmatic activation as consequences of the plume–lithosphere interaction in the northeastern Siberian Craton. The interaction took place after the breakup of Rodinia, during joint drifting of the Siberian Craton and the North American continent (Laurentia) over the African hot mantle field [*Vladykin et al*., *2014*]. The Early Paleozoic rifting and magmatism may reflect the final phase of the disintegration of the Rodinia supercontinent fragments.

The isotope-geochemical specificity of the studied basites suggests that a moderately depleted mantle of a relatively uniform composition was the source of such basites. There are strong arguments to conclude that the so-called “potassium alkaline rocks”, noted in previous publications [*Shpunt, Shamshina*, *1989*] among the Lower Cambrian igneous rocks of the Olenek uplift, are the product of the low-temperature metasomatic alteration of basalts, dolerites and explosive breccias.

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Kiselev, Aleksandr I., Doctor of Geology and Mineralogy, Lead Researcher
Institute of the Earth's Crust, Siberian Branch of RAS
128 Lermontov street, Irkutsk 664033, Russia
Tel.: 8(3952)425434; ✉ e-mail: akiselev@crust.irk.ru

Киселев Александр Ильич, докт. геол.-мин. наук, в.н.с.
Институт земной коры СО РАН
664033, Иркутск, ул. Лермонтова, 128, Россия
Тел.: 8(3952)425434; ✉ e-mail: akiselev@crust.irk.ru

Kochnev, Boris B., Candidate of Geology and Mineralogy, Senior Researcher
A.A. Trofimuk Institute of Petroleum Geology and Geophysics, Siberian Branch of RAS
3 Acad. Koptyug prosp., Novosibirsk 630090, Russia
Tel.: +7(383)3333329; e-mail: KochnevBB@ipgg.sbras.ru

Кочнев Борис Борисович, канд. геол.-мин. наук, с.н.с.
Институт нефтегазовой геологии и геофизики им. А.А. Трофимука СО РАН
630090, Новосибирск, проспект академика Коптюга, 3, Россия
Тел.: +7(383)3333329; e-mail: KochnevBB@ipgg.sbras.ru

Yarmolyuk, Vladimir V., Doctor of Geology and Mineralogy, Academician of RAS, Head of Laboratory
Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry of RAS
35 Staromonetnyi per., Moscow 109017, Russia
Tel.: (499)2308230

Ярмолюк Владимир Викторович, докт. геол.-мин. наук, академик РАН, заведующий лабораторией
Институт геологии рудных месторождений, петрографии, минералогии и геохимии РАН
119017, Москва, Старомонетный пер., 35, Россия
Тел.: (499)2308230

Rogov, Vladimir I., Junior Researcher
A.A. Trofimuk Institute of Petroleum Geology and Geophysics, Siberian Branch of RAS
3 Acad. Koptyug prosp., Novosibirsk 630090, Russia
Tel.: +7(383)3639191; e-mail: RogovVI@ipgg.sbras.ru

Рогов Владимир Игоревич, м.н.с.
Институт нефтегазовой геологии и геофизики им. А.А. Трофимука СО РАН
630090, Новосибирск, проспект академика Коптюга, 3, Россия
Тел.: +7(383)3639191; e-mail: RogovVI@ipgg.sbras.ru

Egorov, Konstantin N., Candidate of Geology and Mineralogy, Head of Laboratory
Institute of the Earth's Crust, Siberian Branch of RAS
128 Lermontov street, Irkutsk 664033, Russia
e-mail: egorov@crust.irk.ru

Егоров Константин Николаевич, канд. геол.-мин. наук, заведующий лабораторией
Институт земной коры СО РАН
664033, Иркутск, ул. Лермонтова, 128, Россия
e-mail: egorov@crust.irk.ru