Features of geology and composition of rocks from the alkaline-gabbroid University massif (NE Kuznetsk Alatau ridge, Siberia)

A A Mustafayev¹, I F Gertner¹, P A Serov²
National research Tomsk State University, Lenin Avenue 36, Tomsk, 634050, Russia¹
Kola scientific center of the Russian Academy of sciences, Fersman Street 14, Apatity, 184209, Russia²

E-mail: labspm@ggf.tsu.ru

Abstract. This paper discusses specifics of petrography and structural tectonic position of the alkaline-gabbroid University massif, which is a sort of analogue of the Kiya-Shaltyr deposit of nepheline ores in this area that was very slightly eroded. In this work, we will also present new precise analytical data on rare and trace element distribution in major intrusive phases of this geological object, and also isotope dating on the basis of Sm-Nd method.

1. Introduction
The University Massif is one of the least studied objects in alkaline-gabbroic association on the Northern slope of Kuznetsk Alatau also known as Mariinsk taiga (local term for this area). It was discovered during prospecting works by geologists of Martaiga geological prospecting expedition operation and employees of Tomsk State University in 1981-1987. Up until now, some researchers think that this geological object does not exist (verbal message from leading geologist of “WestSibgeologsurvey” A.N. Uvarov). However, during magnetometric survey, above ground and drilling works in 1987 they were able to outline and obtain samples of holocrystalline rocks correlating to main intrusive phases of Kiya Shaltyr and other adjacent alkaline-basic massifs in this region. In many ways, the University intrusive is unique due to its geotectonic location and geomorphological settings of the bedding formation.

2. Geotectonic location and formation ages of alkaline-gabbroid magmatism in Northern part of Kuznetsk Alatau
There are two structural compositional levels in geological composition of this territory. Lower level is composed by Vendian-Early Cambrian dislocated sediments, which are developed fragmentally in the areas of the most erosional cross section and are represented by carbonate sediments with layers of effusive-sedimentary rocks. They are grouped in narrow linear folds with N-E and sub meridional (near N-S) trends, thus correlating to main structures of the region. Upper structural level is represented by volcanogenic formations usually dated as Middle Cambrian. It contains basaltic and andesite rocks, their tufas and high Mg lava breccia. Effusive distribution fields are enriched with alkaline and subalkaline dykes. It is typical for these level sediments to have quite flat inclination
(falling angles) of 15-30°. The region has complex block-type composition caused by many disjunctive destructions of different type submeridional trend [13]. There are over 20 expressions of alkaline rocks in this region, which are of certain interest in exploring nepheline ore deposits of different categories (figure 1).

Figure 1. The scheme of placement alkaline basic massifs in geological structures of a northern part of Kuznetsk Alatau [1]
1 – deposits of the Kuznetsk carboniferous deflection; 2 – terrigenous deposits Devonian detyeroorogennic of hollows; 3 – volcanogenic deposits Devonian detyeroorogennic of hollows and grabens; 4 – Ordovician deposits of the Taydonsky graben; 5 – carbonaceous and volcanogenic deposits of the lower and middle Cambrian; 6 – silicous and slate, volcanogenic and carbonaceous deposits of the top rifeya-lower Cambrian; 7 – average rifeya-high metamorphic complexes of the Tomsk ledge; 8 – superalkalinity granites; 9 – granites of a normal causeticity; 10 – moderate and alkaline gabbroic and syenite; 11 – basits of ophiolit association; 12 – ultramafita of ophiolites association; 13 – thrust; 14 – dumpings; 15 – other tectonic violations; 16 – geological borders; 17 – belts of milkings alkaline basites series; 18 – massifs of the alkaline and main breeds (1 – Kiya-Shaltyr, 2 – University, 3 – Belogorsk, 4 – Svetlinsky, 5 – Podtayginsky, 6 – "Kiysky exits", 7 – Kurgusulsky, 8 – Batanayulsky, 9 – Verkhnepetropavlovsky, 10 – Cheremushinsky, 11 – Goryachegorsky, 12 – Zagorny, 13 – Dedovogorsky, 14 – Motley, 15 – Malosemenovsky, 16 – Tuluyulsky and Medvedkinsky, 17 – Malokiyashaltursky, 18 – Velvet and Kiysky, 19 – Andryushkina the small river, 20 – Uchkuryupsky, 21 –. Bald, 22 – stream Dmitriyevsky).
One of the typical features of structural localization for these objects is dyke belts with certain trends, which connect real intrusive massifs. Generally speaking, the largest intrusions are located at the intersection of N-W and near N-S trended dyke belts or near them, which correlates to more permeable “magma plumbing systems and “magma concentration” systems or structures. Last ones are considered to be lithological and structural border between Vendian-Cambrian carbonate folded association and overlapping Middle Cambrian volcanogenic bedding thickness. This conclusion is also confirmed by concentration of majority of alkaline-gabbroic intrusives in carbonate substrate.

Only intrusive massifs located in central part of this region (adjacent to Kiya-Shaltyr deposit) correspond fully to criteria of Early Devonian magmatism in Mariinsk Taiga.

3. Specific features of geological composition and petrographic variety variance of the University Massif
In the modern erosional cross section, University Massif is barely exposed; it is located in lower part of relief and overlapped by a high thickness layer of mellow sediments (from 1 to 10 m). Under these conditions, it was extremely challenging to outline the massif and determine features of its geological composition. In order to do so, detailed above ground magneto metric survey was carried out along with major mining operations and core drilling. On a map (figure 2), it is a body stretched in meridional (near N-S) direction (its length is 2.5 km, its width is from 0.2 to 0.6 km), whose structure is significantly complicated by tearing strains. Relationships with host rocks are ambiguous. It is thought that there are mostly tectonic contacts with gabbro and plagiogranites in the Voskresensk intrusion. With limestones from the Ust-Kundatsk Formation, there were fragments of intrusive contacts found, and both tectonic and active magmatic boundaries were seen with vulcanite’s of the Berikul Formation. In the active contact zone, marling and hornfelsing and propylitic alteration were noticed. Main intrusion phase of the massif is represented by a subalkaline gabbroic body, whose petrographic composition is similar to poikilitic basites of the Kiya-Shaltyr Massif. Other phases are feldspar and feldspar-free foydolites, subalkaline and alkaline gabbroic, nepheline and alkaline syenites that compose many small and sometimes thick (up to 10-30 m) dykes, as well as holocrystalline theralites and ijolites represented by “isometric” body on the eastern side of the massif.

Subalkaline gabbroic, which compose main body of the first intrusive phase, have quite uniform mineral composition and differ mostly in degree of crystallinity. Main rock-forming minerals are olivine, basic plagioclase (An_{50-54}), Ti-bearing augite, biotite and titanium magnetite; accessory minerals are usually apatite and sphene. It has hypidiomorphic-granular texture with elements of poikilo-ophytic and poikilitic textures.

Basic foydolites and theralites have smooth transitions from one to another with different variations in content of nepheline, plagioclase, olivine and pyroxene. Major difference in composition of foydolites and alkaline basites is that nepheline grains have higher degree of idiomorphism than feldspar. Medium-coarse grain theralites of the second intrusive body on the Eastern side demonstrate characteristics of secondary feldspathoids development in plagioclase, whose basicity lowers down to oligoclase-andesine in this paragenesis. This indirectly confirms hybrid nature of these formations. Taking into consideration that there are diluvial drops of almost completely feldspar-free medium-grain ijolites in association with these rocks, we can assume active interaction of later feldspatoid melt with early intrusion stage gabbroids. Additional prove of these rocks belonging to second phase of massif formation is presence of many small dykes if feldspar ijolites and nepheline camptonites (tamaraites) breaking through subalkaline gabbroic of main body and which can be considered as vein facies of feldspar ijolites.
Figure 2. Scheme of a geological structure of the University massif [7]

1 – quarternary alluvial deposits; 2 – middle Cambrian, berekulsky suite: and – basalts, andesitobasalts, dacites, lavobreccia, their tuffs; 3 – lower Cambrian, lips kundatsky suite: and – limestones, batts, interlay siliceous and batts, – marbles limestones; early Devonian kiisky (goryachegorsky) alkaline gabbro complex: 4 – 5 – high-alkaline dyke: 4 – and – mikroijolita, – urtit porphyries, 5 - feldspathic rocks: and – shallow and microgranular ijjolita, - medium-grained ijjolita, in nepheline kamptonita; 6 – alkaline compact-grained porfirovidny gabbros of the facies of endocontact; 7 – leucoteraita with lenses the feldspathic of ijjolit; 8 – the gabbro containing nepheline: and – to 5 and – up to 15%; 9 – early Paleozoic Voskresensky intrusion: gabbro, granodiorita, plagiogranita; 10 – tectonic violations: and – traced, - estimated; 11 – geological borders: and – traced, – gradual.

Ultrabasic foeydolites within the massif and its adjacent areas are represented by dykes with low thickness (from tens of cm to couple meters). They are mostly located in Western part of University Massif breaking through gabbroic and effusives of Berikulsk association. By compositional and textural characteristics, we can classify them in four main groups: a) phenocryst-free microijolites; b) ijjolite-porphyrs with nepheline inclusions from 10 to 30%; c) urtit-porphyrs (with nepheline inclusions 50-70%); d) microijolites with large inclusions (“xenoliths”) of holocrystalline urtites, rarely pegmatoid ijolites and microijolites. “Xenogenic” nature of last ones is suggested based on observations of similar variety of Kiya-Shaltyr deposit dykes, which have sharp contacts with ore body rocks and specific isotopic-geochemical characteristics [3].

In general, composition patterns of University massif and its rock associations let us assume that this object can be considered as slightly eroded alkaline-gabbroid massif formed on lithological boundary of Early Cambrian carbonate and Middle Cambrian volcanogenic formations.
4. Geochemical characteristics of rocks and geodynamic setting for their formation
Main characteristic of petrogenic oxide distribution in high-alkaline rocks from Northern slope of Kunetsk Alatau is their discreteness demonstrated on «Na$_2$O+K$_2$O–SiO$_2$» diagram (figure 3). Variation trends plotted for 13 massifs of this region correspond/correlate to at least three types of petrographic magmatic series:
   a) Subalkaline gabbroids – moderate alkaline syenites;
   b) Teralites – basic foydolites – nepheline syenites;
   c) Feldspar-free melteigites – ijolites – urtites.

Figure 3. The petrochemical chart "Na2O+K2O-SiO2" (for breeds of alkaline massifs of Kuznetsk Alatau [3])
Legends: (A) variation curves of the ultramain foidolit; (B) variation curves of the main foidolit; (C) variation curves of alkaline gabbroic. Alkaline massifs: 1, Kiya-Shaltyr; 2, University; 3, Belogorsk; 4, Svetlinsky; 5, Podtayga; 6, Kiisky exits; 7, Kurgusul-Listvenny; 8, Batanayula; 9, Verkhnepetrovavlovsky; 10, Cheremushinsky; 11, Goryachegorsky; 12, Bolshe-Taskylsky; 13, Dedovogorsky; 14, mountain Pestraya.

Different combinations of mentioned series are observed in different geological objects. For example, only rocks of the first series (A) are typical in Barkhatno-Kiya and Dedovogorsky massifs, only second series (B) in Goryachegorsky massif, and exclusively rocks from third series (C) are present in Svetlinsk massif. There are objects with contrast monolithic chemistry (like Kiya-Shaltyr, Upper Petropalovsk, Kurgusul-Listvenny massifs) or more diversified massifs, which contain products of all three series. The University intrusive belongs to last ones; it has subalkaline gabbroic, teralites and basic foydolites, as well as ijolity-urtite dyke series. Chemical composition and concentrations of trace elements of representative rock varieties in the studied object are listed in Table 1. Petrogenic oxides were diagnosed analyzed by wet chemical methods and XRF, and rare and trace elements were studied by ICP MS method in Analytic center of geochemistry of nature systems in National Research Tomsk State University.
Table 1. Representative chemical compositions of magmatic breeds of the University massif

| Oxide      | 1       | 2       | 3       | 4       | 5       |
|------------|---------|---------|---------|---------|---------|
| SiO₂       | 36/147  | 41/84.0 | 8A      | UN-1    | KC-7/1  |
| TiO₂       | 44.98   | 47.80   | 46.46   | 41.93   | 41.17   |
| Al₂O₃      | 0.95    | 1.055   | 1.27    | 0.375   | 0.49    |
| Fe₂O₃      | 15.11   | 19.58   | 14.71   | 25.96   | 28.5    |
| MgO        | 11.198  | 9.11    | 11.34   | 2.89    | 4.53    |
| CaO        | 8.929   | 4.315   | 6.92    | 2.09    | 2.4     |
| Na₂O       | 14.63   | 14.19   | 10.53   | 6.41    | 7.96    |
| K₂O        | 2.96    | 2.8     | 4.23    | 10.35   | 10.24   |
| P₂O₅       | 0.95    | 0.39    | 2.43    | 9.26    | 3.28    |
| LOI        | 0.093   | 0.051   | 0.5     | 0.301   | 0.44    |
| Sum        | 99.8    | 99.29   | 99.65   | 99.566  | 99.01   |

Infrequent elements

|        | 1 | 2 | 3 | 4 | 5 |
|--------|---|---|---|---|---|
| Cr     | 224,1975 | 37,8801 | 55,7850 | 38,8518 | 19,8222 |
| Ni     | 55,6799  | 29,2340  | 7,2418  | 6,2617  | 12,1023 |
| V      | 155,2618 | 42,9117  | 11,7179 | 8,5373  | 63,7576 |
| Co     | 48,4729  | 34,3551  | 12,1484 | 9,1979  | 14,2550 |
| Cs     | 0.7782   | 0.4699   | 0.9851  | 0.6854  | 11,6256 |
| Rb     | 23,4988  | 37,9099  | 41,1832 | 53,8740 | 100,1275|
| Ba     | 302,811  | 345,7155 | 725,5941| 395,4535| 280,1494|
| Sr     | 537,59   | 1075,04  | 885,38  | 1063,35 | 35,6995 |
| Nb     | 9,3328   | 10,4365  | 41,2114 | 12,6448 | 5,8020  |
| Ta     | 0,5891   | 0,7326   | 2,4440  | 0,9502  | 0,4298  |
| Zr     | 123,5396 | 95,0487  | 275,6794| 81,0037 | 69,0379 |
| Hf     | 2,6788   | 1,5559   | 3,9573  | 0,8246  | 2,2212  |
| Y      | 22,3645  | 17,2153  | 45,2998 | 14,8354 | 8,2749  |
| Th     | 2,7176   | 2,4501   | 7,0018  | 3,2981  | 4,1883  |
| U      | 1,9170   | 2,2620   | 5,4251  | 3,1508  | 1,3037  |
| Sc     | 23,6218  | 6,1947   | 0,8634  | 0,5078  | 5,7854  |
| Σ TR   | 111,3    | 94,37    | 245,97  | 103,58  | 79,185  |
| La/Yb  | 9.691    | 9.588    | 10.277  | 12.419  | 17.76   |

Note. 1 – melanocratic gabbro; 2 – leucocratic gabbro; 3 – theralit; 4 – urtit porphyry; 5 – the urtit xenolith from urtit porphyry. Content of oxides (weight %) and infrequent elements (ppm) of RFA and ICP-MS. in “Analytical center of a geochemistry of natural systems” of NI TGU (Tomsk).

Transition elements (siderophile and chalcophile like Cr, Ni, Mn, V, Co, Sc, Cu, Zn). We observe quite low concentrations of these elements in the massif rocks. Their enrichment accumulation level comparing to contents in C1 (chondrite) standard [5]. Is generally under one, except for Sc, Ti, and V (figure 4).
We can see on the diagram “sharp” negative anomalies for iron-group elements (Cr, Co, Ni)– their concentrations are 3 to 1000 times less than in chondritic component, and insignificant positive anomalies for (Ti, Sc, V), whose concentrations in average are 1.5 to 20 times higher than in CI standard (table 2).

Rocks in the massif demonstrate the following pattern of transit element distributions. In genetic sequence “leucocratic - melanocratic gabbro”, concentrations of all elements decrease from samples 41/84.0 to 36/147.0. Moreover, comparing with gabbroic in leucotheralite (sample 8A), urtite porphyry (sample UN-1) and xenolith (sample KC-7/1) has higher concentrations of transit elements. It should also be noted that there is high concentration of zinc in sample KC-7/1 (ijolite with xenolith of urtite) comparing to other samples.

Specific characteristics of trace element behavior in rocks of University massif are shown on multielemental diagrams demonstrating patterns of REE, LILE and HFSE distribution. When plotted these graphs plots, primary analytical data was normalized by CI and OIB standards according to [9].

Spectrum graphs of lanthanide distributions for rocks from University massif are characterized by very tight ratios of light to heavy elements (figure 5). They are almost parallel to each other and correspond to La/Yb ratios of 10 to 18. Total REE enrichment accumulation level corresponds to the following. The least depleted ones are urtite inclusions (“xenoliths”) from ijolite dykes (sample KC-7/1) that correlates to the data on urtites from Kiya-Shaltyr intrusive [10]. In urtite porphyry, concentration of these elements is a little higher, and it keeps increasing in subalkaline gabbroic. At the same time, melanocratic gabbro is more enriched in rare earth elements than leucocratic gabbro. In last one, a week positive anomaly of Europium is observed. Such pattern can be explained by cumulative segregation of nepheline in foydolites and plagioclase in gabbroids as early crystallization stages of the melts.
Table 2. Distribution of infrequent and rare earths in breeds of the University massif

| Rock            | 36/147.0 | 41/84.0 | UN-1 | 8A   | 8A   | KC-7/1 |
|-----------------|----------|---------|------|------|------|--------|
| Elements        | 1        | 2       | 3    | 4    | 5    | 6      |
| Be              | 1,503    | 1,615   | 2,819| 5,217| 4,907| 0,752  |
| Sc              | 23,622   | 6,195   | 0,508| 0,863| 0,861| 5,785  |
| Ti              | 4851,3   | 3369,1  | 1795,4| 3176,9| 3314,6| 2094,2 |
| V               | 155,3    | 42,912  | 8,537| 11,718| 10,830| 63,758 |
| Cr              | 224,2    | 37,880  | 38,852| 55,785| 55,505| 19,822 |
| Co              | 48,473   | 34,355  | 9,198| 12,148| 12,643| 14,255 |
| Ni              | 55,680   | 29,234  | 6,262| 7,242| 7,993| 12,102 |
| Cu              | 42,795   | 21,524  | 15,711| 18,815| 20,431| 43,856 |
| Zn              | 106,0    | 63,5    | 52,1 | 139,9| 163,0| 943,6  |
| Ga              | 17,17    | 14,74   | 20,26| 24,97| 26,11| 5,757  |
| Rb              | 23,50    | 37,91   | 53,87| 41,18| 42,04| 100,13 |
| Sr              | 537,6    | 1075,0  | 1063,4| 885,4| 899,9| 35,7   |
| Y               | 22,365   | 17,215  | 14,835| 45,300| 44,745| 8,275  |
| Zr              | 123,5    | 95,05   | 81,00| 275,7| 281,5| 69,04  |
| Nb              | 9,333    | 10,436  | 12,645| 41,211| 42,890| 5,802  |
| Cs              | 0,778    | 0,470   | 0,685| 0,985| 1,015| 11,626 |
| Ba              | 302,9    | 345,7   | 395,5| 725,6| 796,6| 280,1  |
| La              | 20,98    | 17,91   | 21,76| 48,93| 47,96| 18,97  |
| Ce              | 44,48    | 37,76   | 44,58| 101,63| 101,74| 31,46  |
| Pr              | 5,205    | 4,514   | 4,919| 9,161| 9,104| 3,737  |
| Nd              | 21,23    | 17,56   | 17,85| 44,12| 43,30| 14,33  |
| Sm              | 4,545    | 3,395   | 3,097| 8,532| 8,541| 2,746  |
| Eu              | 1,321    | 1,385   | 1,039| 2,717| 2,630| 0,721  |
| Gd              | 4,412    | 3,191   | 2,732| 8,088| 8,041| 2,144  |
| Tb              | 0,700    | 0,516   | 0,432| 1,334| 1,316| 0,320  |
| Dy              | 4,267    | 3,124   | 2,619| 8,311| 8,095| 1,926  |
| Ho              | 0,881    | 0,663   | 0,578| 1,788| 1,761| 0,379  |
| Er              | 2,440    | 1,908   | 1,690| 5,094| 5,039| 1,063  |
| Tm              | 0,357    | 0,295   | 0,268| 0,784| 0,769| 0,162  |
| Yb              | 2,165    | 1,867   | 1,752| 4,761| 4,806| 1,068  |
| Lu              | 0,317    | 0,285   | 0,264| 0,715| 0,706| 0,163  |
| Hf              | 2,679    | 1,556   | 0,825| 3,957| 4,065| 2,221  |
| Ta              | 0,589    | 0,733   | 0,950| 2,444| 2,507| 0,430  |
| Th              | 2,718    | 2,450   | 3,298| 7,002| 6,717| 4,188  |
| U               | 1,917    | 2,262   | 3,151| 5,425| 5,692| 1,304  |

Note. Breeds are presented: melanocratic gabbro – 36/147; leucocratic gabbro – 41/84.0; urtit porphyry – UN-1; leucotherait – 8A; ijolit with “xenolith” urtit porphyry – KC 7/1. Concentrations of minerals (ppm) are determined by the ICP-MS method in “Analytical center of a geochemistry of natural systems” of NI TGU (Tomsk).
Figure 5. Distribution of rare earths in breeds of the University massif
36/147,0 – melanocratic gabbro; 41/84,0 – leucocratic gabbro; 8A – leucotheralit; UN-1 – urtit porphyry; KC 7/1 – an urtit xenolith from urtit porphyry. The maintenance of REE is normalized on CI [9].

Maximum level of enrichment accumulation is in leucotheralites, whose graph plot is kind of isolated. It could be the result of mixing of magmatic melts with different compositions.

Multi-elemental graphs plots spectrums normalized by average OIB composition show following patterns. Foydolites (samples KC-7/1 and UN-1) demonstrate quite fast sharp depletion in most rare elements comparing to OIB standard (figure 6a). Higher concentrations are seen in LILE and U. Similar behavior is observed in multi-elemental graphs for subalkaline gabbroic, but at a slightly higher concentrations of rare elements (figure 6b).

The closest to OIB graph is distribution in leucotheralites (sample 8A), where there is no fast enrichment in Sr. In general, presence of distinct negative anomalies of Nb, Ta, Hf and Ti with steep positive peaks of Rb, Sr and U indicate quite complex geodynamic setting for formation of Devonian alkaline rocks in Mariinsk taiga. It is very possible that generation of primary magmas took place in setting of active thermal interaction of mantle plumes and lithosphere mantle with further participation of crust matter and crust fluids [4].

Therefore, specifics of trace element distributions in rocks from University massif allow us to correlate them with analogue products from Kiya-Shaltry and adjacent massifs (Dedogorsk and Belogorsk). Deficiency in niobium, tantalum, hafnium (appear as steep negative anomalies) along with generally lower mantle plume component normalized to OIB, as well as local enrichment in LILE (Sr, Rb, Ba) suggest complex geodynamic settings of alkaline-basic magmatism in central part of Kuznetsk Alatau in Early Devonian. Similar conclusions were made by D.N. Voitenko while interpreting geochemistry of rocks from Kiya-Shaltry massif [10].
Figure 6. Patterns rare elements in breeds of the University massif
(a) Foidolita: UN-1 – urtit porphyry; KC 7/1 - "xenolith" of the urtit from ijolit porphyry.
(b) The gabbro, therait: 36/147,0 – melanocratic gabbro; 41/84,0 – leucocratic gabbro; 8 A – leucoteralit. Contents the rare of elements are normalized on OIB [9].

5. Isotopic dating
Sm-Nd method. Sm and Nd isotopic composition was measured on 7-channel solid-phase mass spectrometer Finnigan-MAT 262 (RPQ) in static double strand mode using rhenium and tantalum strands [8]. Average ratio of $^{143}\text{Nd}/^{144}\text{Nd}$ in La Jolla standard during period of measurements was $0.512081±13$ (N = 11) (Table. 3). Errors in values of $(2 \sigma)$ $^{147}\text{Sm}/^{144}\text{Nd}$ do not exceed 0.5 %, and 0.005 % for $^{143}\text{Nd}/^{144}\text{Nd}$. During calculation of primary isotopic ratios and $\varepsilon_{\text{Nd}}, \varepsilon_{\text{Sr}}, T_{\text{Nd}}$ (DM) values, modern parameters of model standard reservoirs CHUR ($^{143}\text{Nd}/^{144}\text{Nd} = 0.512638$, $^{147}\text{Sm}/^{144}\text{Nd} = 0.1967$) and depleted mantle (DM) ($^{143}\text{Nd}/^{144}\text{Nd} = 0.51315$, $^{147}\text{Sm}/^{144}\text{Nd} = 0.2137$) were applied [2].
Table 3. Isotope structure of Sm-Nd in the gabbro of the University massif

| Exemplar | Concentration, mkg/g | Isotope relations | $T_{DM}$, million years | $\varepsilon_{Nd}(T)$ |
|----------|----------------------|------------------|------------------------|----------------------|
| Sm       | Nd                   | $^{147}\text{Sm}/^{144}\text{Nd}$ | $^{143}\text{Nd}/^{144}\text{Nd}$ | $C36/147$ |
| WR       | 3.42                 | 0.1353           | 0.512808±9             | 498 ±7.3            |
| Pl       | 1.531                | 0.0978           | 0.512709±16            |                      |
| Ol       | 4.49                 | 0.2050           | 0.513051±10            |                      |
| Px       | 4.18                 | 0.1682           | 0.512922±8             |                      |
| $C41/84.0$|                     |                  |                        |                      |
| WR       | 1.769                | 0.1433           | 0.512907±12            | 492 ±8.7            |
| Pl       | 0.588                | 0.1033           | 0.512797±9             |                      |
| Ol       | 4.49                 | 0.1841           | 0.513041±25            |                      |
| Px       | 2.43                 | 0.2165           | 0.513160±12            |                      |

Note. $C36/147$ – melanocratic gabbro, $C41/84.0$ – leucocratic gabbro.

Isochrones were built by D. York’s method [14] using Isoplot/Ex software [6]. More precise Sm-Nd isochrones were obtained by mineral phases and whole rock compositions of two samples of subalkaline gabbroid (figure 7).

![Figure 7. Sm-Nd mineral isochrones on subalkaline gabbroid of the University massif. Measurements were taken by a reference technique [8].](image)

One of the biggest surprises during this research was the actual age of studied gabbroids, which is 498–492 ±23-28 Ma. Such expression of alkaline magmatism in this region took place exclusively in western part of Mariinsk Taiga and was recorded in alkaline-gabbroid association of Upper-Petropavlovsk Massif [11]. Dating alkaline rocks by Sm-Nd isotope method nowadays is quite complicated because variations in $^{147}\text{Sm}/^{144}\text{Nd}$ values do not exceed 0.09-0.11 range.

However, we can assume that alkaline formation occurred in Devonian and Silurian (380 – 430 Ma), and its age corresponds to the main stage of foil dolite expression in this part of the region.

There are certain prerequisites for this assumption. First, the xenoliths/autoliths of full-crystalline urtites, like the ores of the Kiya-Shaltyr deposit, are periodically present in the dike bodies of ijolites.
Their structural features correspond to several phases of the formation of this object, including microijolites and their pegmatite varieties, which are diagnosed in the body of urtites of the Kiya-Shaltyrsky massif. The age of the Kiya-Shaltyr rocks is confirmed by data on different isotopic systems (U-Pb, Sm-Nd, Rb-Sr) and corresponds to the time interval of 390-405 Ma. At second, in the diagnosis of the age of nepheline from the Kiya-Shaltyr ores by the Ar-Ar method, not quite adequate, but very interesting data were obtained, reflecting the likely crystallization of nepheline at an early stage in an intermediate magmatic chamber (figure 8). The first plateau corresponds to the age of about 430 Ma. It is quite possible that the spatial combination of sub-alkaline gabbro and foidolites is due to the introduction of heterogeneous magmatic melts in close channels.

![Ar-Ar isochron diagram for the age determination of nepheline age in urtites of Kia-Shaltyr massif. Exemplar: KSH 20/7a – nepheline.](image)

Figure 8. Ar-Ar isochron diagram for the age determination of nepheline age in urtites of Kia-Shaltyr massif. Exemplar: KSH 20/7a – nepheline.

An important element in studying University massif is its intermediate structural location between western and eastern sectors of areas of high alkalinity magmatism expression on the Northern slope of Kuznetsk Alatau, which were formed during long period of time (507-265 Ma) according to recent geochronological research [12]. We assume a case of several stages pulses of high-alkalinity magmatism within this geological object. More detailed studying will promote design of geodynamic model of high-aluminous alkaline magmas formation under settings of mantle plume activity in folded structures of ancient continent margins.

6. Conclusion
The results of conducted research let us make following conclusions, which reflect necessity of further studying of alkaline-gabbroid University massif. First, this object is of big interest for justifying locations of nepheline ore deposits in this region. Specifics of its geological composition and location at the border between two associations of carbonate and volcanogenic series, which have very different dislocation levels and petrographic material compositions, allow us to understand study composition of upper part of intrusive front of alkaline-gabbroic magmatism. Second, broad petrographic and petrochemical rock-forming variety provides for reconstruction of genesis process of high-aluminous minerals in magmatic complexes of this region. Third, detail geochemical testing promotes development of a more accurate geodynamic model of high-alkalinity magmatism expression in folded structures of Northern and Central Asia. We also assume different age for gabbro and foidolites of the University massif.
This work was carried out with the support of the grant of the RSF № 18-17-00240.

References

[1] Shokalsky S.P., Babin G.A., Vladimirov A.G., etc. 2000 Correlation of magmatic and metamorphic complexes of the western part of the Altai-Sayansk folded region (Novosibirsk: Siberian Branch of the Russian Academy of Science publishing house, GEO branch) p 187

[2] Faure G. 1989 Fundamentals of isotope geology (M.: World) p 590

[3] Gertner I. F., Vrublevsky V. V., Voitenko D. N. et al. 2007 Plume-related alkaline basic magmatism of the Kuznetsk Alatau: The Goryachegorsk complex (Migmatism and metallogeny of the Altai and adjacent large igneous provinces with an introducing essay on the Altaiids. IAGOD Guidbook Series 16. London, UK: CERCAMS/NHM) pp 141-153

[4] Gertner I. F., Vrublevsky V. V., Tishin P. A., etc. 2013 Temporary boundaries, sources of magmas and the formational status Paleozoic the feldshpatoidnykh of intrusions of the Northeast of Kuznetsk Alatau Proc. of Geodynamic evolution of a lithosphere of the Central Asian relative frame belt (from the ocean to the continent) Issue 11 (Irkutsk: Institute of crust of the Siberian Branch of the Russian Academy of Science) pp 71-73

[5] Langmuir, C.H., Hanson, G.N., 1980. An evaluation of major element heterogeneity in the mantle sources of basalt Philos. Trans. R. Soc. A297 pp 383-407

[6] Ludwig K.R. 1999 User’s manual for Isoplot/Ex, Version 2.10. A geochronological toolkit for Microsoft Excel. Vol.1 (Berkeley Geochronology Center Special Publication) p 46

[7] Osipov P. V., Makarenko N.A., Korchagin S.A., etc. 1988 New alkaline gabbroid the ore bearing massif in Kuznetsk Alatau Geology and geophysics 11 pp 79-82

[8] Serov P.A., Ekimova N.A., Bayanova T. B., Mitrofanov F. P. 2014 Sulphidic minerals – new geochronometers at Sm-Nd dating of a rudogenez of the intrusions of Baltic Shield stratified the mafit-ultramafitovykh Lithosphere 4 pp 11-21

[9] Sun S., McDonough W.F. 1989 Chemical and isotopic systematics of oceanic basalts: implications for mantle composition and processes (Migmatism in the ocean basins / Eds. Saunders A.D.& Norry M.J.) Geol. Soc. Special Publ. 42 pp 313-345

[10] Voytenko D.N. 2003 Mikrostruktur of urtit of Kia-Shaltyrsky Pluton (Kuznetsk Alatau) Proc. of All-Russian scientific conference Geologists of the 21st century (Saratov: SO EAGO publishing house) pp 28-31

[11] Vrublevskii V. V., Gertner I. F., Gutierrez-Alonso G. et al. 2014 Isotope (U-Pb, Sm-Nd, Rb-Sr) geochronology of alkaline basic plutons of the Kuznetsk Alatau. Russian geology and Geophysics Geologiya I Geofizika 55 pp 1264-1277

[12] VrublevskiiV. V., Grinev O. M., Izokh A. E., Travin A. V. 2016 Geochemistry, isotope triad (Nd-Sr-O), and 40Ar-39Ar age of Paleozoic alkaline mafic intrusions of the Kuznetsk Alatau (by the example of the Beloya Gora pluton) Russian Geology and Geophysics 57(3) pp 464-472

[13] Yesin S. V., Korchagin S.A., Yesina O.A., Gertner I. F. 1987 Nepheline ore rocks of sites University 1 and 2 (Kuznetsk Alatau) Alkaline and subalkaline breeds of Kuznetsk Alatau: the collection of articles (Ed. M.P. Kortusov. Tomsk: Tomsk publishing house university) pp 74-82

[14] York D. 1966 Least squares fitting of straight line Can. J. Phys. 44 pp 1079-1086