GEODYNAMICS & TECTONOPHYSICS

PUBLISHED BY THE INSTITUTE OF THE EARTH'S CRUST
SIBERIAN BRANCH OF RUSSIAN ACADEMY OF SCIENCES

2017 VOLUME 8 ISSUE 4 PAGES 1035–1047 ISSN 2078-502X

https://doi.org/10.5800/GT-2017-8-4-0331

Paleogeodynamics

DURATION OF GRANITOID MAGMATISM IN PERIPHERAL PARTS OF LARGE IGNEOUS PROVINCES (BASED ON ^{40}AR/^{39}AR ISOTOPIC STUDIES OF ALTAI PERMIAN-TRIASSIC GRANITOIDS)

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Abstract: In large igneous provinces (LIP) of fold areas, granitoid rocks are dominant, while mantle-derivated rocks play a subordinate role in rock formation. If magma emissions are impulsive, it may take 25–30 million years for a LIP to form and take shape. In this paper, we present the results of ^{40}Ar/^{39}Ar isotopic studies of Permian-Triassic granitoids in the Altai region, Russia, and clarify the evolution of this region located at the periphery of the Siberian LIP. These granitoids are very diverse and differ not only in their rock set, but also in the composition features. In the study region, the granodiorite-granite and granite-leucogranite association with the characteristics of I- and S-types as well rare metal ore-bearing leucogranites are observed along with gabbro- and syenite-granite series, including mafic and intermediate rocks with the A2-type geochemical features. The ^{40}Ar/^{39}Ar data obtained in our study suggest that most of the studied granitoids intruded within a short period of time, 254–247 Ma. This timeline is closely related to the formation of granitoids in the Kuznetsk basin and dolerite dikes in the Terekta complex (251–248 and 255±5 Ma, respectively), as well as intrusions of lamproite and lamprophyre dikes of the Chuya complex (245–242 and 237–235 Ma). Thus, we conclude that the Altai Permian-Triassic granitoids are varied mainly due to the evolution of mafic magmatism.

Key words: geochronology; Ar/Ar dating; granitoid magmatism; Altai

RESEARCH ARTICLE

Recommended by E.V. Sklyarov

Received: March 20, 2017
Revised: June 20, 2017
Accepted: September 14, 2017

For citation: *Gavryushkina O.A., Travin A.V., Kruk N.N.*, 2017. Duration of granitoid magmatism in peripheral parts of large igneous provinces (based on ^{40}Ar/^{39}Ar isotopic studies of Altai Permian-Triassic granitoids). *Geodynamics & Tectonophysics* 8 (4), 1035–1047. doi:10.5800/GT-2017-8-4-0331.

Длительность гранитоидного магматизма периферических частей крупных изверженных провинций (по данным $^{40}Ar/^{39}Ar$ изотопных исследований пермотриасовых гранитоидов Алтая)

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Аннотация: В складчатых областях крупные изверженные провинции (LIP) характеризуются резким преобладанием гранитоидов при подчиненной роли пород мантийного генезиса. Длительность формирования отдельных LIP может достигать 25–30 млн лет при импульсном характере магматизма. В работе конкретизируется схема формирования одного из периферических сегментов Сибирской LIP на основе $^{40}Ar/^{39}Ar$ изотопных исследований пермотриасовых гранитоидов Алтая, которые резко различны не только по набору пород, но и по особенностям их состава. Наряду с габбро- и сиенит-гранитными сериями, включающими основные и средние породы с геохимическими характеристиками пород А2-типа, на этом рубеже проявлены гранодиорит-гранитные и гранит-лейкогранитные ассоциации с характеристиками I- и S-типа, а также рудоносные редкометалльные лейкограниты. Результаты $^{40}Ar/^{39}Ar$ датирования свидетельствуют о том, что внедрение большинства изученных интрузий гранитоидов Айского, Теранжикского, Тархатинского, Белокурихинского и Синюшенского массивов, Точильненского и Осокинского штоков-сателлитов произошло в короткий промежуток времени – 254–247 млн лет. Фиксируется достаточно тесная временная связь формирования гранитоидов с формированием траппов Кузнецкого бассейна и долеритовых даек терехтинского комплекса (251–248 и 255±5 млн лет соответственно), с внедрением даек лампроитов и лампрофиров чуйского комплекса (245–242 и 237–235 млн лет). Таким образом, разнообразие пермотриасовых гранитоидов Алтая определяется, в первую очередь, эволюцией базитового магматизма.

Ключевые слова: геохронология, Ar/Ar датирование, гранитоидный магматизм, Алтай

1. Introduction

In recent years, much attention was paid to intraplate magmatism associated with mantle plumes and superplumes existing independently of the processes in the upper mantle. The term *large igneous province* (LIP) has been introduced to describe such magmatism occurrence with the volume of igneous material up to $n \cdot 10^6$ km^3. The LIPs in craton blocks are almost entirely comprised by mafic-ultramafic rocks: traps, layered intrusions (often associated with industrial Cu-Ni mineralization), carbonatites, lamproites, etc. In contrast, granitoids are dominant in the LIPs in fold areas, while mantle-derivated rocks play a subordinate role in rock formation.

Initially, it was suggested that a LIP can develop within a very short period of time (1–2 Ma). However, recent studies have shown that, if magmatism occurs irregularly, it may take 25–30 Ma for a LIP to form and take shape [*Large Igneous Provinces Commission, 2017*]. In addition, changing of magmatism type in space and time is clearly observed for long-lived LIPs.

The general scheme describing the evolution of LIPs and formation of the magmatic associations was proposed based on the data on Asian LIPs [*Dobretsov et al., 2010*; *Hoa et al., 2016*]. This scheme assumes four stages as follows.

(1) Initial stage: lithospheric uplift due to the arrival of a deep mantle plume at the lithosphere base; initiation of rifting with alkaline-mafic, alkaline-picritic and carbonatite magmatism.

(2) Main stage: lateral spreading of the upwelling plume beneath the lithosphere, accompanied by partial melting of the lithosphere; large-scale eruption of traps (picrites and basalts); bimodal magmatism at the periphery of LIPs.

(3) Heating of the crust and large-scale crust-mantle interactions; formation of gabbro-granite associations, granitoid batholiths, and emplacement of synplutonic and mingling dikes.

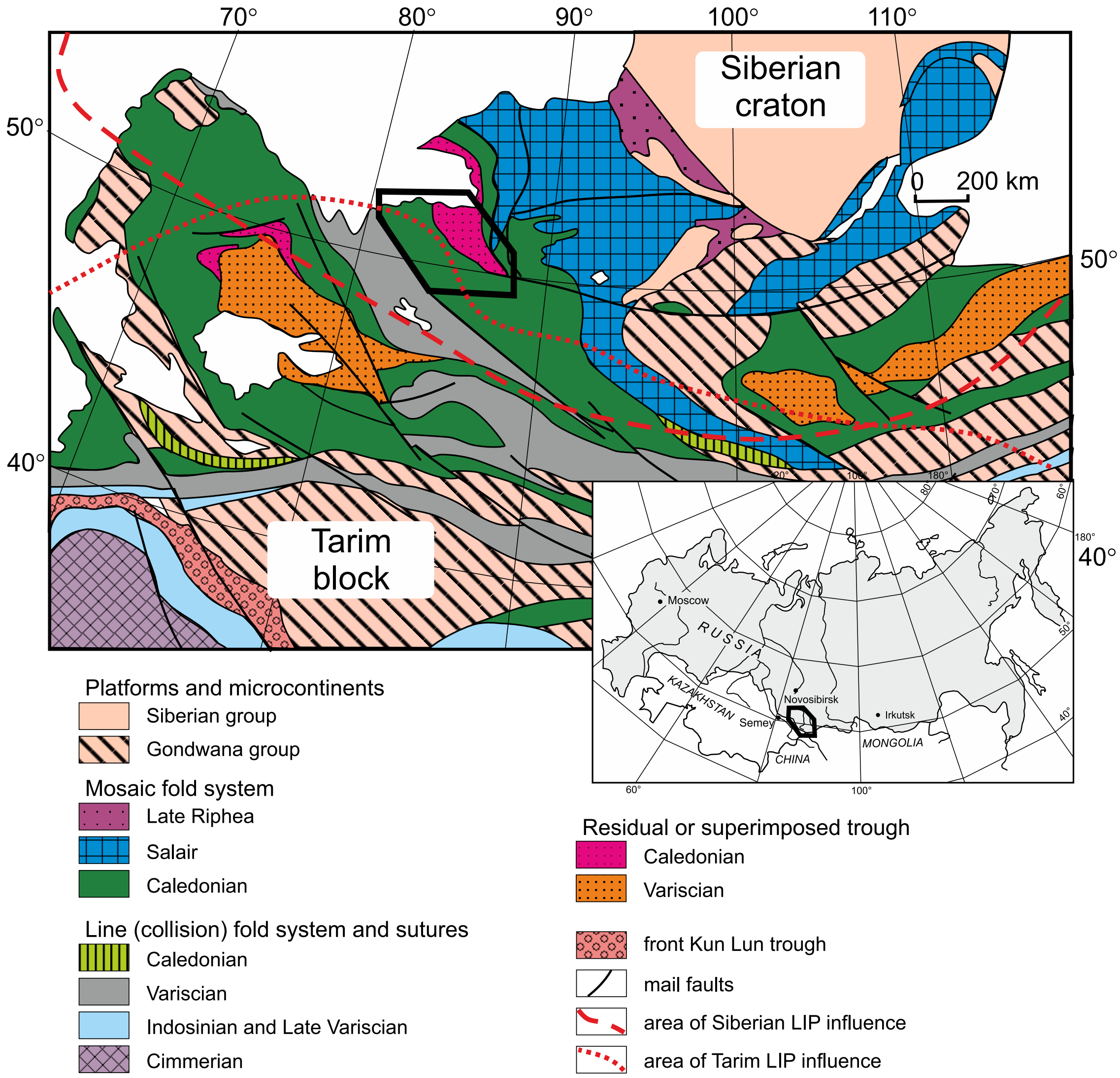

Fig. 1. Gorny Altai tectonic setting in the Central Asian Fold Belt (after [*Mossakovsky et al., 1993*]). Insert – geographical scheme (the studied area is contoured).

Рис. 1. Тектоническая позиция Горного Алтая (выделен контуром) в структуре Центрально-Азиатского складчатого пояса (использована тектоническая схема Центральной Азии [*Mossakovsky et al., 1993*]). На врезке – географическая схема (район исследований выделен контуром).

(4) Regressive stage: production of rare-metal granitoids and dike belts of lamprophyre, elvan and ongonite.

This model implies a time lag between mafic magmatism of the main stage and the granitoid intrusion. Such time lag was considered in several works [*Hoa et al., 2016; etc.*]. However, the number of high-precision dates of granitoids from LIPs is limited, and it is not clear whether this time lag is typical of all the LIP in fold areas or it is a special case.

To make one more step to solving this complex problem, we perform systematic $^{40}Ar/^{39}Ar$ isotopic studies of Permian-Triassic granitoids from the Altai region, one of the peripheral segments of the Siberian LIP.

2. Geological setting

The Permian-Triassic Siberian LIP is one of the largest areas of intraplate magmatism in Asia [*Dobretsov, 1997, 2003; Yarmolyuk et al., 2000; etc.*] (Fig. 1). On the Siberian platform, it is represented by the large areas of traps, layered mafic-ultramafic massifs associated with Cu-Ni mineralization (including the unique Norilsk and Talnakh intrusions) and carbonatites occurrences. In the neighbouring areas of the Central Asian Fold Belt (CAFB), including Altai, Kuznetsk Alatau, Gornaya Shoriya, Salair, North and West Kazakhstan, and North Mongolia, the Permian-Triassic magmatism is mainly evidenced by granitoids [*Vladimirov et al., 1997, 2001; Yarmolyuk et al., 2000*], and the volume of granitoids is more than 10 times bigger than the amount of coeval basites [*Dobretsov et al*., *2005*].

In the Altai region, the Permian-Triassic endogenic activity is manifested in the formation of dike belts, lamproites and lamprophyres of the Chuya complex (in two stages, 245–242 and 237–235 Ma [*Vasyukova et al., 2011*]), and toleites and alkaline basalts of the Terekta complex (255±5 Ma ago [*Borisenko et al., 2010*]). In the adjacent Kuznetsk basin, there are local occurrences of traps dated 251–248 Ma [*Kruk at al., 1999; Buslov et al., 2010; Nastavko et al., 2012*]. Granitoid and gabbro-granite intrusions are more abundant. According to the previous U/Pb and Rb/Sr dating, their age varies from 254 to 230 Ma [*Vladimirov et al., 1997, 2001*].

The intraplate nature of the Permian-Triassic magmatic complexes is confirmed by their geologic setting. The magmatism areas are discordant to the older geological structures. The intrusions are confined to major faults and the sites of their intersections that are typically cross linking.

The petrographic and geochemical features of the Altai Permian-Triassic granitoids are widely variable. Based on regional mapping, six complexes of granitoids and gabbro-granite series of nearly the same ages were distinguished [*Shokalsky et al., 2000*] (Fig. 2). The petrotypical massifs covered by our studies are briefly described below.

Altai Permian-Triassic granitoids. The *Aya massif* located in the northern Gorny Altai (Fig. 2) has an irregular shape and occupies an area of around 70 km^2. The host rocks are Cambrian volcanic-carbonate deposits, Middle Devonian volcanites and Late Devonian granitoids. The western part of the massif is composed of medium-grained amphibole-biotite-clinopyroxene syenites and quartz syenites. Amphibole-biotite granosyenites are emplaced in the southern part of the massif. The bulk of this intrusive structure consists of biotite granites (Fig. 3). The younger intersecting bodies are composed of two-mica leucogranites and aplites [*Vladimirov et al., 1997; Kruk et al., 1998*]. Syenites are of the medium alkalinity series (Fig. 4) with high contents of LILE, HFSE and Sr; granitoids are of the lower alkalinity series and, based on their composition, correspond to I2-type rocks. According to [*Kruk et al., 1998*], these granitoids result from interactions of syenitic magma and partial melting of the continental crust.

The *Terandzhik massif* in the southeastern Gorny Altai (Fig. 2) has a roundish shape and occupies an area of around 4 km^2. Granitoids intrude the Early – Middle Paleozoic Kurai complex metamorphic rocks [*Kuibida et al., 2014*]. The western part of the massif is composed of medium-grained pyroxene-amphibole monzogabbro and monzonites. The main part of the massif consists of coarse- to medium-grained pyroxene-amphibole monzodiorites, quartz monzodiorites and quartz syenite (Fig. 3). The small stock in the central part of the massif is biotite-amphibole granosyenites, and the younger intersecting bodies are composed of biotite granites. The massif rocks are of the medium alkalinity series (Fig. 4), enriched in LILE, HFSE and REE, and correspond to A2-type rocks [*Semyonov et al., 2010*].

The *Tarkhata massif* in the southern Gorny Altai is an isometric body that crops out over an area of 3 km^2. The host rocks are Cambrian-Ordovician flyschoid deposits, transformed near the contact into biotite-cordierite-hypersthene hornfels. The marginal areas of the massif are composed of fine-grained biotite-amphibole-pyroxene monzodiorites and syenite. Its central part contains middle-grained biotite-amphibole granosyenites and monzogranites (Fig. 3). Granitoids are enriched in LILE, HFSE, REE and 'transitional' elements. According to [*Krupchatnikov et al., 2015*], they results from differentiation of lamprophyre magmas.

The *Savvushka massif* in the northern Rudny Altai (Fig. 2) is a drop-shaped large intrusion elongated in the northwest direction. Its area amounts to almost 200 km^2. Granitoids intruded the Late Silurian – Middle Devonian terrigenous and volcanic-terrigenous deposits, as well the Late Devonian granitoids. The intrusion is mainly composed of porphyric leucocratic biotite granites (Fig. 3). In the central part of the massif, biotite-hornblende granodiorites crop out. There are inclusions and zenoblocks of more mafic rocks, from fine- to medium-grained biotite-hornblende monzodiorites and quartz monzodiorites. The rocks are of the continuous medium alkalinity series (Fig. 4). Based on the petrochemical and rare-element composition, monzodiorites and granodiorites are A-type granites, and leucocratic granites correspond to I-type rocks.

The *Aturkolsky massif* is located in the southeastern Gorny Altai close to the border with West Sayan (Fig. 2). This isometric intrusion has high-dipping intrusive contacts and crops out over an area of 110 km^2. The host rocks are the Late Cambrian – Early Ordovician turbidities. The western and eastern parts of this massif are composed of the Middle Devonian volcanogenic-terrigenous rocks. The massif is mainly composed of coarse-grained porphyric biotite granosyenites and monzogranites (Fig. 3). Granosyenites are of the medium alkalinity series (Fig. 4), enriched in K (up to 7 % K_2O), LILE, HFSE and REE, and correspond to A2-type rocks. Monzogranites have lower concentrations of noncoherent elements and are of I2-type. According to [*Kruk et al., 2017*], granitoids result from partial melting of the dominantly metabasite continental crust with limited amounts of lamprophyric magmas.

The *Belokurikha massif* is located in the northern Gorny Altai to the west of the Aya massif (Fig. 2). It is a large laccolith-shaped body elongated in the sublatitu-

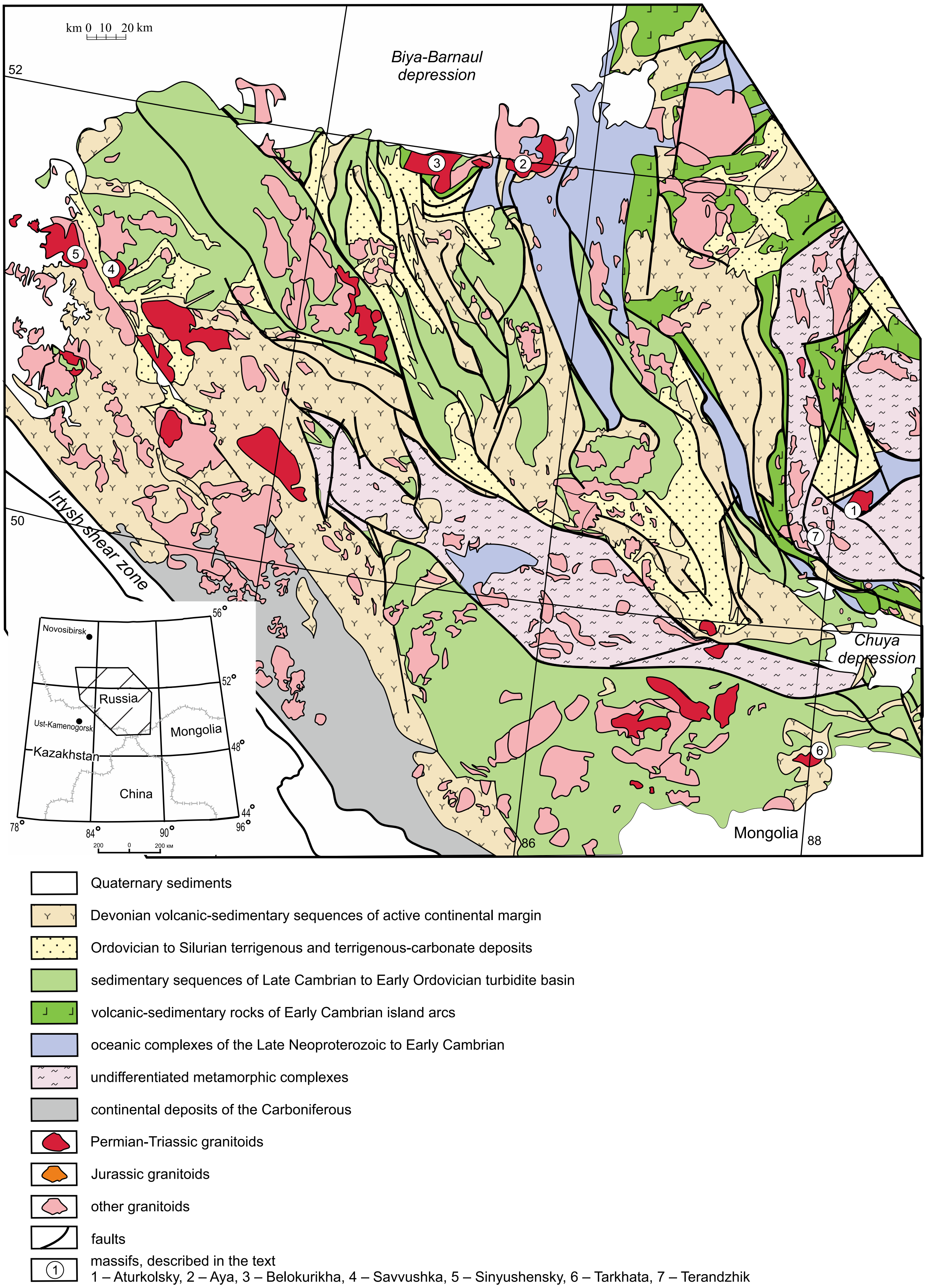

Fig. 2. Permian-Triassic intrusions in the Altai geological structure.

Рис. 2. Положение пермотриасовых интрузивов в геологической структуре Алтая.

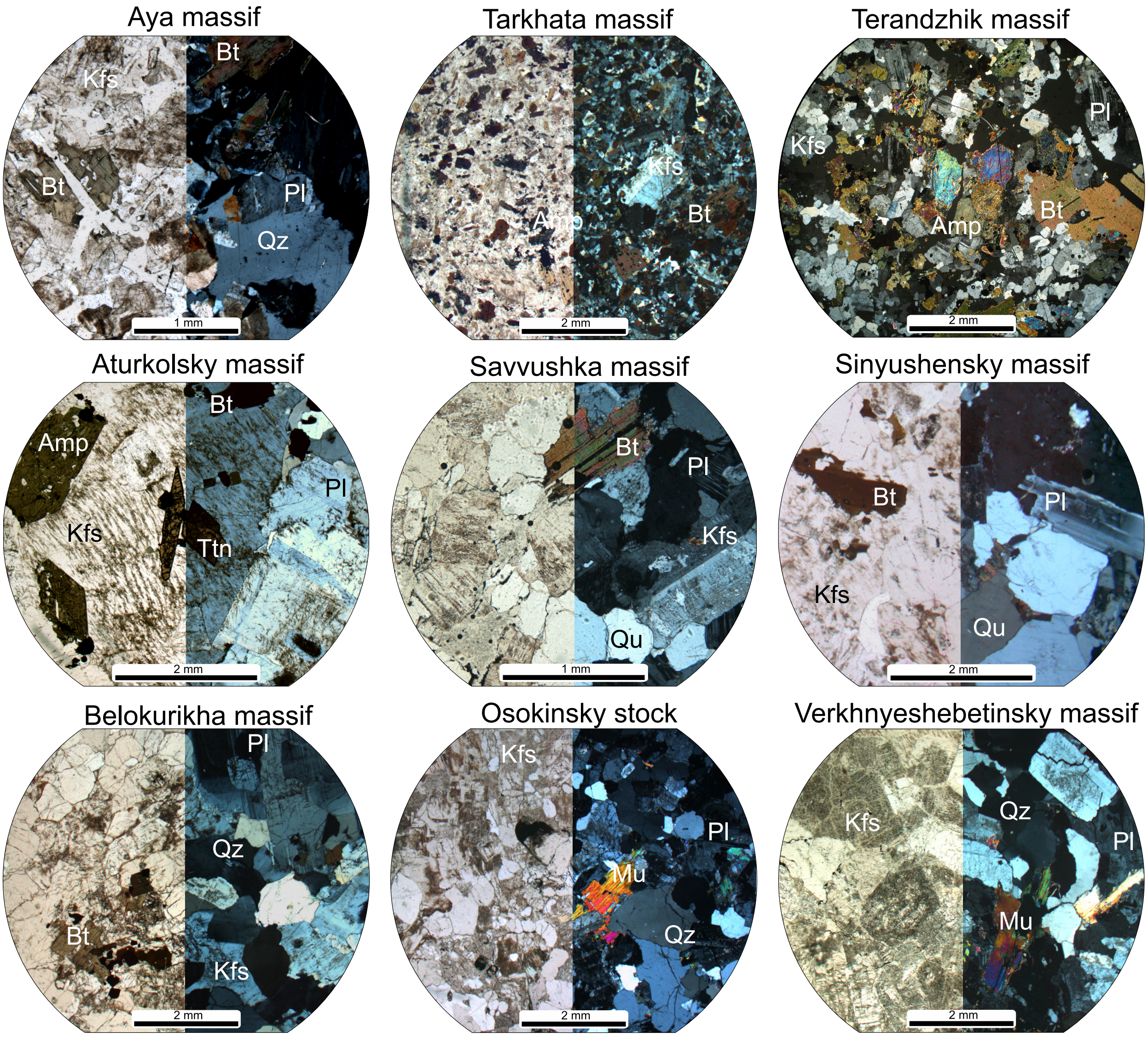

Fig. 3. Petrographic features of the Altai Permian-Triassic granitoids. Photos: right – cross-polarized light, left – plane polarized light.

Рис. 3. Петрографические особенности пород изучаемых пермотриасовых массивов гранитоидов Алтая. Для каждого фото: правая часть – николи скрещены, левая – параллельны.

dinal direction. The massif is mainly composed of medium-coarse-grained porphyric biotite granites that intruded the Early – Middle Paleozoic metamorphic rocks, Late Cambrian – Early Ordovician turbidities and Late Devonian granitoids. Middle-grained porphyric melanogranites and granodiorites are observed as inclusions in biotite granites. The late phase is represented by fine- to medium-grained porphyric biotite (Fig. 3), two-micas leucogranites, aplites, and pegmatites. These rocks form transverse bodies among granitoids of the Belokurikha massif and compose two isolated stocks in its frame (Osokinsky and Tochil'nensky stocks, 25 and 15 km^2, respectively). The granitoids have an increased potassium content, are slightly oversaturated in alumina (Fig. 4), and correspond to S-type rocks, based on rare element composition. Leucocratic granitoids are enriched in F, Li, Rb, Cs, Mo, W, associating with Mo-W mineralization.

The *Sinyushensky massif* in the northwestern Gorny Altai is a dome-shaped body with steeply dipping contacts. It occupies an area of almost 100 km^2 (Fig. 2). The host rocks are Late Devonian granitoids in its northern part, and the Early – Middle Paleozoic terrigenous and terrigenic-carbonate deposits in the western, southern and eastern parts. The intrusion is composed of porphyric leucocratic granites (Fig. 3) that are coarse-grained in the northern part of the massive, but middle-grained in the central and western parts. The late phase is represented by rare fine-grained two-mica leucogranites, aplites and pegmatites. The granitoids

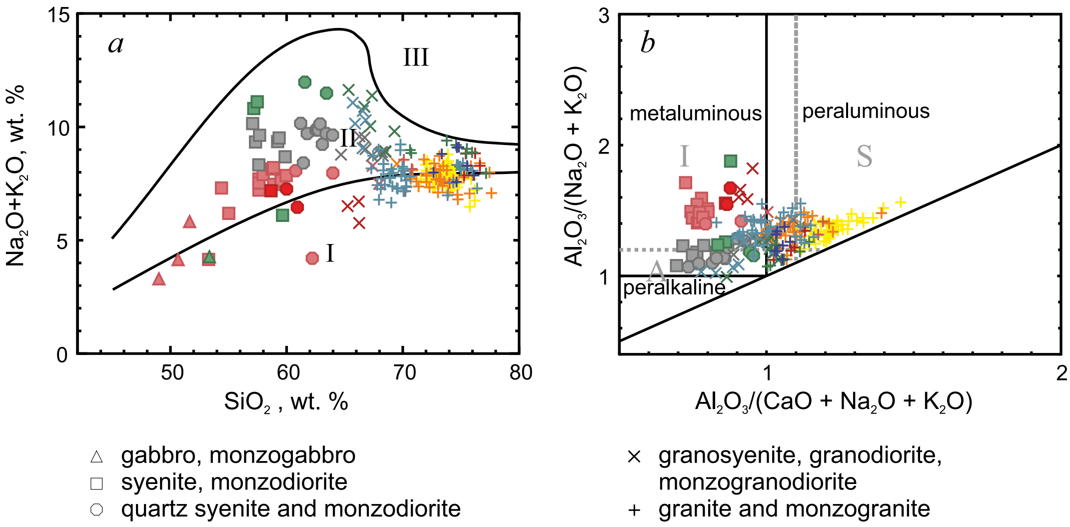

Fig. 4. Major-element diagrams for the studied Altai Permian-Triassic granitoids. Colour codes of massifs: green – Ayas, pink – Terandzhik, grey – Tarkhata, red – Savvushka, light blue – Aturkolsky, orange – Belokurikha, blue – Sinyushensky, yellow – Verkhneshebetinsky. *a* – TAS diagram; field boundaries after [*Le Maitre, 1989*]; *b* – Shand index (molar) after [*Maniar, Piccoli, 1989*].

Рис. 4. Петрохимические диаграммы для пород изучаемых пермотриасовых массивов гранитоидов Алтая. Айский массив – значки зеленого цвета, Теранжикский – розового, Тархатинский – серого, Саввушинский – красного, Атуркольского – голубого, Белокурихинского – оранжевого, Синюшенского – синего, Верхнешебетинского – желтого. *a* – TAS-диаграмма (поля составов пород: I – нормальной щелочности, II – умеренно-щелочных, III – щелочных. Границы полей приведены в соответствии с [*Le Maitre, 1989*]; *b* – диаграмма «$Al_2O_3/(CaO+Na_2O+K_2O)$ – $Al_2O_3/(Na_2O+K_2O)$» (молекулярные количества [*Maniar, Piccoli, 1989*].

correspond to the normal alkalinity series (Fig. 4). They are enriched in potassium, slightly oversaturated in alumina, and, based on petrochemical features, correspond to S-type rocks [*Vladimirov et al., 1997*; *Kruk et al., 2016*]. The granitoids are also characterized by the slightly elevated LILE, LREE and F concentrations. According to [*Kruk et al., 2016*], the formation of the Sinyushensky massif granitoids was driven by melting of the rocks in the upper crust due to the heat and fluids of crystallizing alkaline-mafic magmas.

The *Verkhneshebetinsky massif* in the western Gorny Altai (Fig. 2) is an isometric body that occupies an area of 57 km^2. It has intrusive contacts and intrudes Late Cambrian and Ordovician sedimentary rocks, as well as Devonian granitoids. The massif is composed of coarse-medium-grained porphyric leucocratic two-mica granites and contains garnet and tourmaline (Fig. 3). The granites have a high potassium content, are oversaturated in alumina (Fig. 4), F, Li, Rb, Cs, Be, W, accompanied by Be-W mineralization [*Vladimirov et al., 1997*].

Thus, the Permian-Triassic granitoids are sharply different not only in their rock set, but also in the composition features. We distinguish three types of associations: (1) gabbro- and syenite-granite series, including syenites and monzonites of A2-type (Tarkhata, Aya and Terandzhik massifs), (2) granodiorite-granite and granite-leucogranite associations with rocks of I- and S-types (Aturkolsky and Savvushka massifs), and (3) rare-metal ore-bearing granite-leucogranite series (Belokurikha, Sinyushensky and Verkhneshebetinsky massifs, and Osokinsky and Tochil'nensky stocks).

3. Method of studies

The geochronological studies were carried out for the rocks that are most widespread in the petrotypical massifs: monzodiorite (Terandzhik massif), monzogranodiorite (Tarkhata massif), melanogranite (Aturkolsky massif), granite (Aya, Savvushka and Belokurikha massifs), leucogranite (Sinyushensky and Verkhneshebetinsky massifs, and Osokinsky stock), pegmatite (Tochil'nensky stock) (Fig. 3). Samples were taken from the outside of the endocontact zones at a distance of more than 200 m from the transversal dikes and late intrusions. Non-altered rocks were chosen by visual inspection of outcrops and thin sections.

The monofractions of rock-forming minerals (micas, amphiboles) were separated from the rocks using conventional techniques of magnetic and density separation. The final separation of monomineralic fractions was carried out under an optical microscope. Microprobe analysis controlled the preservation of rock-building minerals.

$^{40}Ar/^{39}Ar$ dating of Permian-Triassic granitoids, Altai region, Russia

Результаты Ar-Ar исследований пермотриасовых гранитоидов Алтая

Complex	Massif	Rock	Mineral	Age, Ma
Aya syenite-granosyenite-leucogranite	Aya	granite	biotite	250±2.8
Terandzhik gabbro-monzodiorite-granosyenites-granite	Terandzhik	monzodiorite	amphibole biotite	248±2.1 246±1.1
Tarkhata granosyenite-monzodiorites	Tarkhata	monzogranodiorite	amphibole biotite	254±3.7 246±2.5
Aturkolsky granodiorite-granite	Aturkolsky	melanogranite	biotite	245±2.6
Belokurikha granite-leucogranite	Belokurikha Osokinsky stock Tochil'nensky stock Verkhnyeshebetinsky	granite leucogranite pegmatite leucogranite	biotite muscovite muscovite muscovite	250±2.7 250±3.5 247±3.0 241±2.4
Sinyushensky granodiorite-granite-leucogranite	Sinyushensky Savvushka	leucogranite granite	biotite biotite	248±1.0 244±1.1

The $^{40}Ar/^{39}Ar$ dating was performed at V.S. Sobolev Institute of Geology and Mineralogy SB RAS (Novosibirsk, Russia) according to the method described in detail in [*Travin et al., 2009*]. The samples of monomineralic fractions and monitor samples (biotite MCA-11 OSO no. 129-88) were placed into quartz ampoules, which were then sealed under vacuum. Biotite MCA-11 (All-Russia Institute of Mineral Resources) was certified as a $^{40}Ar/^{39}Ar$ monitor with the use of the muscovite Bern 4m and biotite LP-6 internationally certified standards [*Baksi et al., 1996*]. The quartz ampoules with samples were irradiated in the Cd-coated channel of a BBP-K type reactor at the Institute of Nuclear Physics (Tomsk, Russia). The gradient of the neutron flux did not exceed 0.5 % of the sample size. Stepwise-heating experiments were carried out in a quartz reactor with an external heater. Corrections for interfering argon isotopes, that formed during irradiation of Ca and K, were conducted using the following coefficients determined from the irradiated samples of pure salts: $(^{39}Ar/^{37}Ar)_{Ca}$=0.000891±0.000003, $(^{36}Ar/^{37}Ar)_{Ca}$= =0.000446±0.000004, $(^{40}Ar/^{39}Ar)_{K}$=0.089±0.001. Ar was purified using Ti and ZrAl SAES getters. The isotopic composition of Ar was measured by Noble Gas 5400 (Micromass) and Argus (GV-Instruments) mass spectrometers. The errors quoted correspond to ±1σ.

4. Results

The results of our investigation are given in Table and Fig. 5. All spectra of the studied mineral fractions show a clearly pronounced plateau that marks the age of isotope system closure. Taking into account the fact that the studied granitoids massifs formed in meso-abyssal conditions at small depths, there are grounds to expect that the obtained datings, especially the amphibole dating (closure temperature ~550 °C) should be close to the age of the massifs' formation. For micas, closure of the K/Ar isotope system may be lagging behind by a few million years, depending on the rate of cooling and exhumation [*Travin et al., 2014*].

Our estimations show the age of 254–247 Ma for biotite and amphibole from the Aya, Terandzhik, Tarkhata, Belokurikha and Sinyushensky granitoids massifs and the Tochil'nensky and Osockinsky stocks. The dates for biotite from the Aturkolsky massifs (245±2.6 Ma and 244±1.1 Ma, respectively) are close to this age (within the estimation error). A slightly younger age (241±2.4 Ma) is estimated for muscovite of the rare metal granites from the Verkhneshebetinsky massif.

5. Discussion

The obtained data suggest that mafic-ultramafic and granitoid magmatism events were synchronous in the Altai area of the Siberian LIP. There was not any time lag between the main peaks of mafic and granitoid magmatism: both occurred in the short period of time, 254–247 Ma.

There is no significant correlation between the rock set and the association type of the granitoid series and their age, and the emplacement periods of granitoids of different types overlap almost completely. Besides, there is a close spatial and temporal relationship between the formation of granitoids and emplacement of the mafic dikes and intrusions. Thus, most of the dated granitoids were emplaced synchronically with the formation of traps in the Kuznetsk basin and the dolerite dikes of the Terekta complex, which are abundant in the Altai region. The age of the granitoids from the

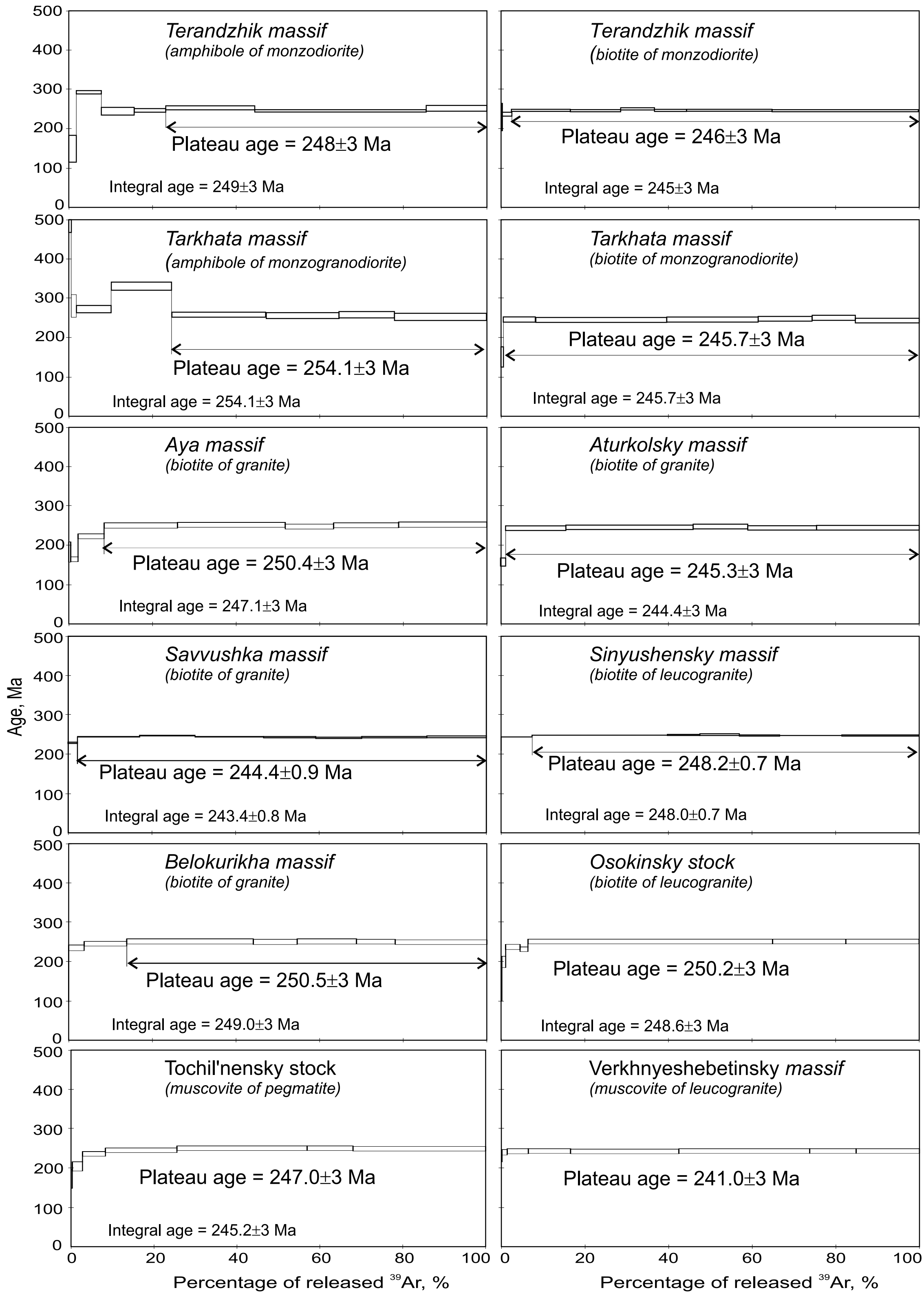

Fig. 5. $^{40}Ar/^{39}Ar$ isotope dating of the Altai Permian-Triassic intrusions.

Рис. 5. Результаты $^{40}Ar/^{39}Ar$ исследований пермотриасовых гранитоидов Алтая.

Tarkhata and Aturkolsky massif correlates with the age of the Chuya complex lamproites and lamprophyre dikes in the southern and southeastern Gorny Altai. The close relation between the granitoids and basites of gabbro- and syenite-granite massifs (Terandzhik, Aya and Savvushka massifs) is also confirmed by the geological studies. Thus, the diversity of the Altai Permian-Triassic granitoids is mainly due to the evolution

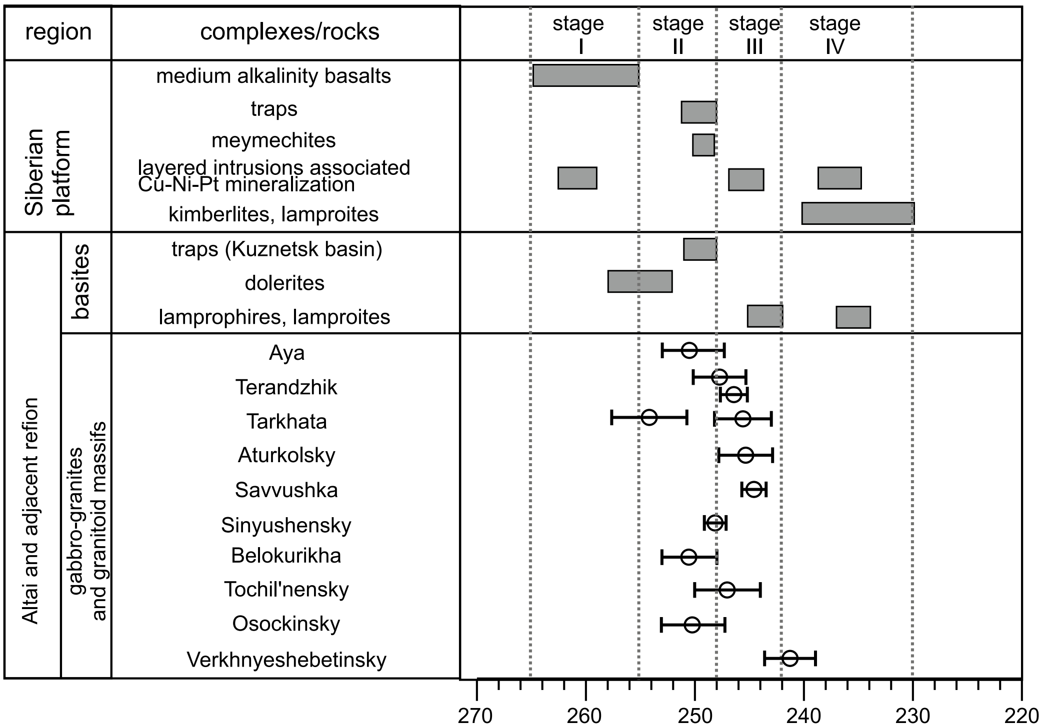

Fig. 6. Correlation between the Permian-Triassic magmatism stages estimated for the Siberian platform and the Altai region of the Central Asian Fold Belt. Modified after [*Dobretsov et al., 2010; Borisenko et al., 2010; Buslov et al., 2010; Vasyukova et al., 2011; Malitch, Latypov, 2011; Reichow et al., 2009*]. See the description of stages 1 to 4 in the text.

Рис. 6. Корреляция возрастных рубежей пермо-триасового магматизма Сибирской платформы и Алтайского сектора ЦАСП. Использованы данные [*Dobretsov et al., 2010; Borisenko et al., 2010; Buslov et al., 2010; Vasyukova et al., 2011; Malitch, Latypov, 2011; Reichow et al., 2009*]. Характеристику стадий I–IV см. в тексте.

of mafic magmatism. The high-rare metal leucogranites from the Verkhneshebetinsky massif are the only exception. These granites are younger (241±2 Ma) and do not associate with basites. Perhaps, such a 'delay' was due to the necessity of a long-term evolution of magma in the upper crust for achieving the high content of rare metals.

The relation of the ages of magmatic associations in the Siberian platform and the Altai region in CAFB also show the synchronization of magmatic activity. Three stages of magmatism development are distinguished for the Siberian platform: 265–255, 251–248 and 243–230 Ma. These stages correspond to the initial (1), main (2) and regressive (4) stages in the generalized LIP magmatism evolution scheme (Fig. 5). Dolerite dike complexes, sills, basalt flows and small differentiated mafic intrusions associated with Cu-Ni mineralization correspond to the initial stage. The second stage is characterized by the large-scale occurrence of traps. At the same time, alkaline mafic and alkaline ultramafic magmatism takes place in the central part, and alkaline mafic dike complexes are formed in the peripheral areas. The diverse composition magmatism (kimberlites, lamprophyres) in the marginal areas of the Siberian platform is related to the final stage.

The main peaks of magmatic activity in the Siberian platform and Altai region are almost synchronous (Fig. 6). Nevertheless, there are some differences between them. Firstly, the time scale of formation of the magmatic associations in the Altai region of CAFB is sufficiently shorter than that of the Siberian platform magmatism. In the Altai region, magmatism of the initial and regressive stages is almost absent. Secondly, the formation of granitoid associations is not limited to stage 3. A significant portion of granitoids was formed synchronously with the extruded traps. Granite-leucogranite intrusions that do not contain mafic rocks are present among them. Thirdly and finally, according to our estimations, granitoid magmatism (including rare metal one) finished slightly earlier then mantle magmatism.

6. Conclusion

The bulk of the Permian-Triassic granitoids in the Altai region of the Siberian LIP was formed synchronously with the peak of mafic magmatism in the short period of time, 254–247 Ma.

Our estimations do not show any correlation between the age and types of the granitoid series. The granitoids are highly varied due to the specific compositions of associated basites.

In the Gorny Altai region of CAFB, the Permian-Triassic endogenous activity took place within a shorter time interval that in the Siberian platform. Indicators of the early (initial) and final (regressive) stages are practically lacking in this region.

7. Acknowledgments

The study was supported by the Ministry of Education and Science of the Russian Federation (Project 14.Y26.31.0018) and RFBR (Project 16-05-00077 mol_a).

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