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Duration of Young (Pliocene) Intrusive Magmatism in the Tyrnyauz Ore Field, Northern Caucasus: New K–Ar and Rb–Sr Data

V. A. Lebedev, Corresponding Member of the RAS I. V. Chernyshev, A. V. Chugaev, and M. M. Arakelyants

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The Tyrnyauz W–Mo deposit in the Northern Caucasus is well known as not only a unique ore object, but also a region of the Late Pliocene plutonic magmatism. The Eldzhurtinsky granite massif localized within the deposit is one of the world's youngest exposed plutonic bodies. This fact together with specific features of the Tyrnyauz ore deposit attracted the attention of geochronologists and other investigators.

Since the middle of the 20th century, researchers have published many articles devoted to isotope geochronology of mineralization and young intrusions in this region [1–7], with more detailed data on Eldzhurtinsky Massif. However, some problems of age of neointrusions in the Tyrnyauz area remained unsolved. This paper is devoted to one of such problems, namely the timing of volcanic activity termination in the Turnyauz ore field.

The Tyrnyauz ore field is located in the northern part of the high-altitude Peredovoi range within the deep-seated Pshekish–Tyrnyauz suture zone, which is composed of the Middle Devonian–Early Jurassic volcanosedimentary rocks (Fig. 1) [8].

The Tyrnyauz ore field incorporates diverse subvolcanic and plutonic rocks, which are divided into rock complexes of paleointrusions and neointrusions [8, 9]. Paleointrusions include sheeted bodies and dikes of ultramafic rocks, gabbro spessartites, as well as quartz diorite porphyries and plagioporphyries. Neointrusions are represented by the Eldzhurtinsky granite massif and the network of crosscutting rhyolite bodies (necks and dikes) and the younger glassy rocks (vitrophyres).

Issues of the age of small plagiogranite (leucogranite) stocks and veins in the Tyrnyauz ore field and their affiliation to paleointrusions or neointrusions have been debated for a long time [9]. Our K–Ar data [10] on the Pauk and Samolet massifs revealed the rejuvenation of isotopic systems of plagiogranites under the thermal effect of the Eldzhurtinsky granite. The positive correlation of the K–Ar age of plagiogranites with distance from Eldzhurtinsky Massif indicates their pre-Cenozoic age and affiliation to paleointrusions.

The main representative of neointrusions is the Eldzhurtinsky granite massif, which is traced along the Central Fault in the Baksan River valley as individual outcrops and extends beneath nearly the entire ore field. The massif rocks are represented by porphyric biotite granites. Petrographic observations [11] showed that the magmatic melt emplacement can be divided into four intrusive phases.

The pioneer work of researchers of the Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry, Moscow [3] based on new methodical achievements of L.L. Shanin marked the beginning of successful application of K–Ar method for dating Late Neogene–Quaternary magmatic rocks and made it possible to obtain the reliable evidence for Late Pliocene age of the Eldzhurtinsky granite. Their later works [1] confirmed this conclusion and refined the K–Ar biotite datings of the Eldzhurtinsky granite. Several works published in recent decade [4–7] scrutinized the geochronology of this massif. It was established that K–Ar and Rb–Sr ages of the Eldzhurtinsky granite massif vary throughout the section from 2.2–2.5 Ma at its roof to 1.8–2.0 Ma at the present-day erosion level and reaches 1.2–1.4 Ma in the borehole at a depth of 3800 m as a result of the ongoing intense uplift of the Greater Caucasus. The uplift promoted exhumation of the Eldzhurtinsky Massif over more than 1 km in 2–3 Ma. According to thermochronological models, formation of the pluton began approximately 2.5 Ma ago [6] and completed ~2.1 ± 0.1 Ma ago after the emplacement of late aplite dikes, which crosscut other rocks of the massif [5]. This presumably indicates the multistage formation of the Eldzhurtinsky Massif for several hundreds of thousand years.

The Eldzhurtinsky granite massif is crosscut by three necks and numerous high-angle dikes of subvolcanic rhyolites. The youngest rocks of the Tyrnyauz ore field are small vitrophyre dikes, which intrude rhyolites. According to Afanas'ev [2], these rocks occasion-

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Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry, Russian Academy of Sciences, Staromonetnyi per. 35, Moscow, 119017 Russia;
e-mail: leb@igem.ru

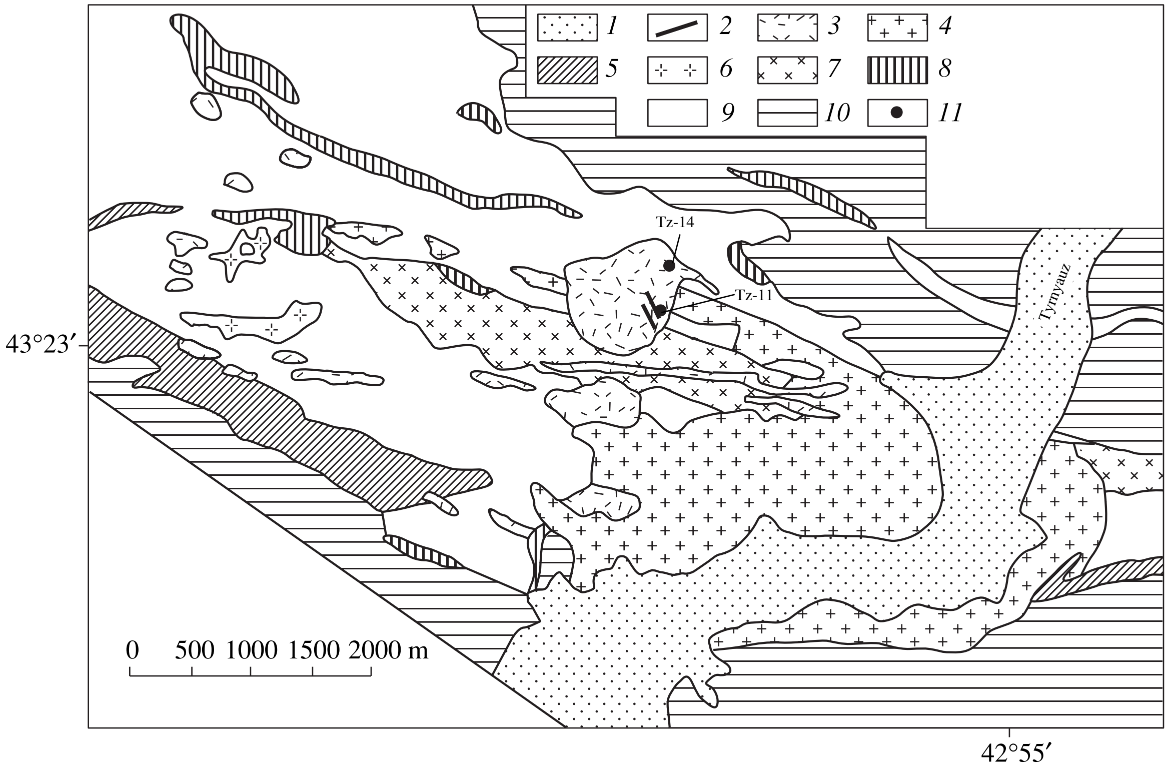

Fig. 1. Schematic geological map of the Tyrnyauz ore field (after A.V. Pek and O.V. Kononov). (*1*) Quaternary sediments; (*2–4*) Pliocene magmatic complex; (*2*) vitrophyre dike; (*3*) necks, dikes, and volcanic breccias of rhyolites, (*4*) biotite granites of the Eldzhurtinsky Massif; (*5*) Early Jurassic sedimentary rocks; (*6*) plagiogranites of the Pauk and Samolet massifs (Paleozoic?); (*7*) Paleozoic tonalities and plagiogranites; (*8*) ultramafic rocks (Paleozoic?); (*9*) Middle Devonian–Upper Carboniferous volcanosedimentary rocks; (*10*) Paleozoic metamorphic rocks (crystalline schists, gneisses, and migmatites); (*11*) sampling location.

ally misnamed in literature as vitroandesites reflect Quaternary volcanism widely developed in the Elbrus area. The previous K–Ar whole-rock dating of the Tyrnyauz rhyolites and vitrophyres yielded 1.65 ± 0.15 and 1.55 ± 0.2 Ma, respectively, thus indicating their younger age as compared to the Eldzhurtinsky granite [1].

The present paper considers the results of comprehensive K–Ar and Rb–Sr isotopic-geochronological study of the Tyrnyauz rhyolites and vitrophyres based on all monomineral fractions that can be separated and used for subsequent analysis.

We carried out the isotopic study of rhyolite (Sample Tz 14) taken from the Severnyi neck, ~500 m north of the upper station of the cable-way and vitrophyre (Sample Tz 11) sampled from a dike (1–1.5 m) located near the road between the upper station of the cable-way and Mukulan quarry (Fig. 1). Petrographic characteristics of young rocks from the Tyrnyauz area are reported in [9]. Table 1 shows that the studied samples are high-K rhyolites containing 72.8–73.2 wt % SiO_2, 7.2–7.4 wt % (Na_2O + K_2O), and 3.9–4.6 wt % K_2O (Table 1). We separated biotite, sanidine, plagioclase, and microcrystalline groundmass fractions from Sample Tz-14. Biotite, orthopyroxene, volcanic glass, and plagioclase fractions were extracted from Sample Tz-11. Plagioclase from the vitrophyre was separated by heavy liquid technique into two density fractions. The heavy fraction contained plagioclase and its intergrowths with quartz. All mineral components of samples Tz-14 and Tz-11 lack any signs of secondary alteration, with the exception of partial devitrification of glass in the vitrophyre.

During K–Ar dating, the radiogenic Ar content was measured on a highly sensitive low-blank MI-1201 IG apparatus. The K content was analyzed with flame spectrophotometry. The Rb and Sr isotopic compositions were analyzed on a multichannel Micromass Sector 54 mass spectrometer.

The results of isotopic dating of the young rocks of the Tyrnyauz ore field are given in Table 2. It is seen that K–Ar data on all components of Sample Tz-14 are plotted within narrow range of 1.85–2.0 Ma. In the $^{40}K/^{36}Ar$–$^{40}Ar/^{36}Ar$ diagram (Fig. 2), the data points define an isochron (MSWD = 0.7), whose slope corresponds to an age of 1.96 ± 0.02 Ma, with initial $^{40}Ar/^{36}Ar$ ratio corresponding, within the error limit, to atmospheric value. This fact indicates the absence of excess Ar in dated components of rhyolite and made it possible to consider the K–Ar age of 1.96 Ma as corresponding to the crystallization age. The obtained age is similar to previously published data of 1.65 ± 0.15 Ma [1].

The Rb–Sr study of Sample Tz-14 showed that phenocrysts from rhyolite have identical initial Sr isotopic composition. In the correlation diagram, they define an

Table 1. Chemical composition of rocks of the Tyrnyauz ore field, wt %

Sample	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	S
Tz-14	73.16	13.99	0.37	2.61	0.05	0.73	1.55	2.84	4.59	0.10	0.01
Tz-11	72.79	13.84	0.43	2.78	0.05	0.74	2.06	3.26	3.91	0.13	0.01

Note: Analyses were performed by X-ray method on a Philips PW 2400 spectrometer in the Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry, Moscow (A.I. Yakushev and T.M. Marchenko, analysts). Major oxides were recalculated to 100%.

Table 2. Results of isotopic–geochronological study of Pliocene rocks of the Tyrnyauz ore field

Analyzed material	K,% ± σ	$^{40}Ar_{rad}$, ng/g ± σ	$^{40}Ar_{air}$, % in sample	K–Ar age, Ma ± 1.6σ	Rb, ppm	Sr, ppm	$^{87}Rb/^{86}Sr$ ± ± 2σ	$^{87}Sr/^{86}Sr$ ± ± 2σ
Tz-14, rhyolite, Severnyi neck								
Sanidine	9.92 ± 0.07	1.38 ± 0.05	22.8	2.00 ± 0.10	294	370	2.304 ± 7	0.70709 ± 7
Biotite	7.18 ± 0.06	0.96 ± 0.04	44.7	1.93 ± 0.10	685	4	497.8 ± 1.3	0.72054 ± 5
Groundmass	4.45 ± 0.03	0.57 ± 0.03	35.7	1.84 ± 0.10	377	103	10.64 ± 3	0.70741 ± 5
Plagioclase	1.92 ± 0.02	0.26 ± 0.013	60.8	1.94 ± 0.10	130	325	1.166 ± 4	0.70699 ± 6
Tz-11, vitrophyre, dike in the Severnyi rhyolite neck								
Biotite	7.28 ± 0.06	0.96 ± 0.04	60.3	1.90 ± 0.10	620	14	130.3 ± 4	0.71037 ± 4
Glass	3.54 ± 0.03	0.36 ± 0.015	71.6	1.48 ± 0.10	217	214	2.94 ± 1	0.70677 ± 3
Plagioclase (light fraction)	1.94 ± 0.02	0.275 ± 0.013	65.7	2.04 ± 0.10	58	604	0.279 ± 1	0.70688 ± 5
Plagioclase (heavy fraction) + quartz	1.12 ± 0.02	0.159 ± 0.005	90.1	2.05 ± 0.15	–	–	–	–
Pyroxene	0.35 ± 0.02	0.047 ± 0.003	84.7	1.95 ± 0.20	24	13	5.42 ± 2	0.70719 ± 5

isochron (MSWD = 1.9) with an age of 1.92 ± 0.10 Ma at $(^{87}Sr/^{86}Sr)_0 = 0.7070 \pm 0.0004$ (Fig. 2). The data point of groundmass lies above the isochron, probably indicating the contamination by radiogenic ^{87}Sr from host rocks.

The coincidence of obtained K–Ar and Rb–Sr isotopic datings suggests that the Tyrnyauz rhyolite has an age of approximately 1.95 Ma. Thus, there is no significant gap between emplacement of rhyolite bodies (necks and dikes) and late intrusive phases of the Eldzhurtinsky granite. The compositional similarity of rhyolites and granites of the Eldzhurtinsky Massif [9] indicates that subvolcanic rhyolite bodies with distinct features of volcanic pipes or volcanic breccias formed during the penetration of residual granitic melt through the crystallized upper part of the massif.

The K–Ar datings obtained for vitrophyre components from Sample Tz-11 also fall in a narrow range of 1.90–2.05 Ma. The exception is the age of glass, which is significantly younger (1.48 ± 0.10 Ma) than the phenocrysts. In the $^{40}K/^{36}Ar$–$^{40}Ar/^{36}Ar$ diagram (Fig. 2), the data points of phenocrysts define an isochron (MSWD = 0.3) with an age of 1.93 ± 0.03 Ma, with initial Ar isotopic composition corresponding to atmospheric values within the error limit. The data point of the glass lies below the isochron. The atmospheric values of initial $^{40}Ar/^{36}Ar$ ratio indicate the absence of excess Ar in the phenocrysts from vitrophyres. Hence, the dating of 1.93 Ma is interpreted as emplacement age of vitrophyre dikes. The younger K–Ar age of glass (1.48 Ma) and the previously obtained K–Ar whole-rock data on vitrophyre (1.55 ± 0.2 Ma) [1] resulted from partial loss of radiogenic Ar during postmagmaic devitrification of the glass.

The Rb–Sr study of Sample Tz-11 revealed the nonequilibrium initial Sr isotopic composition of its mineral components, which can partially be related to devitrification of the rock glass. The Rb–Sr biotite age calculated at initial $^{87}Sr/^{86}Sr = 0.7069 \pm 0.0005$, which corresponds to the Sr isotopic composition in phases with a low Rb/Sr ratio, is 1.9 ± 0.3 Ma, which is identical, within the error limit, to the K–Ar dating on vitrophyres.

The results of K–Ar and Rb–Sr datings indicate that vitrophyres formed approximately 1.90–1.95 Ma ago; i.e., they are a few tens of thousand years younger than the rhyolite bodies. Vitrophyre dikes intruded mainly rhyolite bodies, which presumably served as the most permeable pathways in the granite massif. It should be noted that initial Sr isotopic compositions in rhyolites and vitrophyres estimated from minerals with low Rb/Sr ratio (0.70688 ± 5 and 0.70699 ± 6, respectively) are nearly identical (Table 2), thus indicating the common source for both rock types. These values are nearly similar to the initial $^{87}Sr/^{86}Sr$ values obtained for the

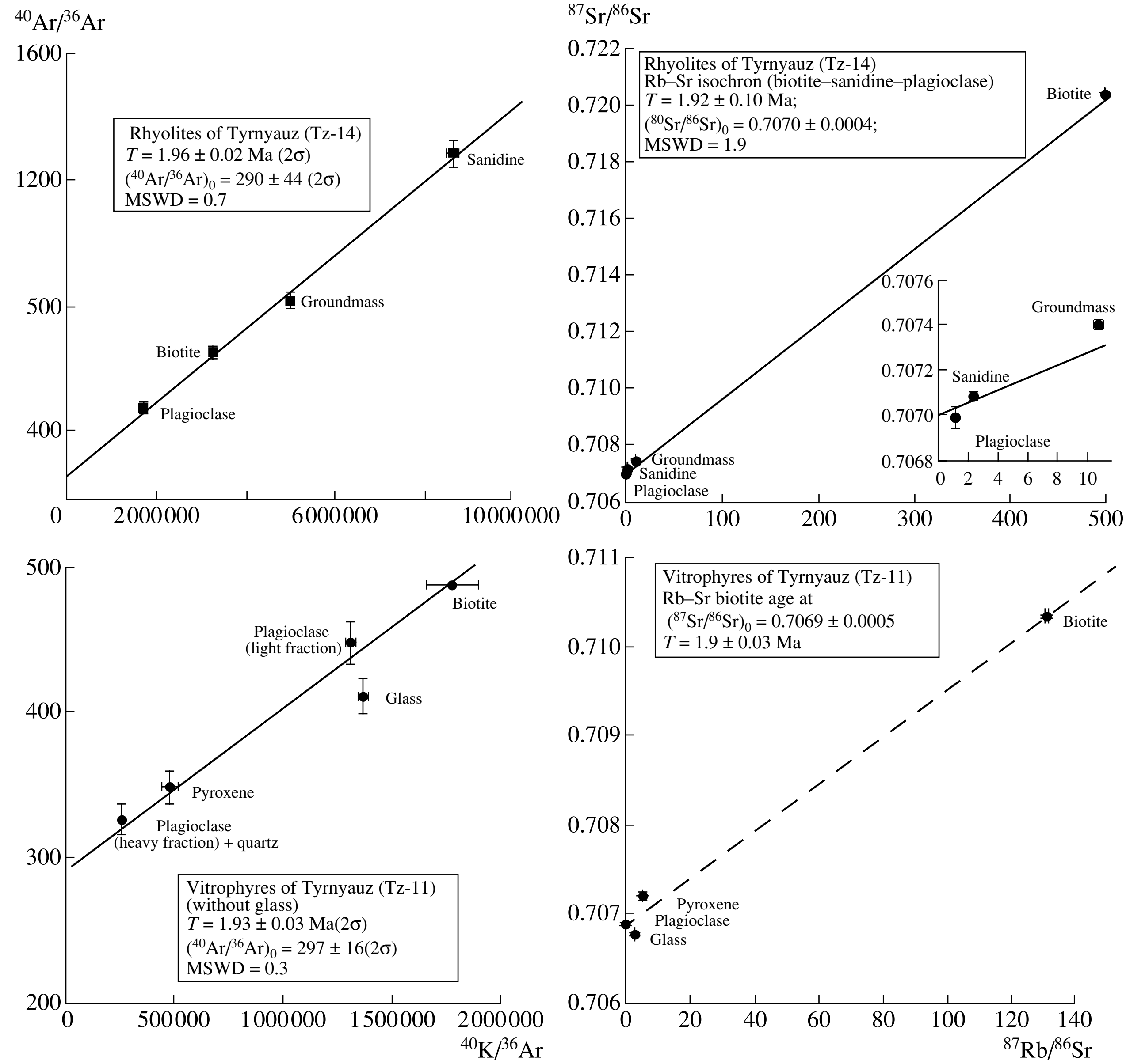

Fig. 2. K–Ar and Rb–Sr isotopic diagrams for samples Tz-11 and Tz-14.

Eldzhurtinsky granite (0.70685 ± 3 [4]) and aplite dikes (0.70690 ± 7 [5]).

The isotopic-geochronological study of the young magmatic rocks of the Tyrnyauz ore field showed that magmatism in this region terminated ~1.90–1.95 Ma ago after the emplacement of vitrophyre dikes. These dikes are not related to volcanism of the Elbrus center, as previously suggested [2], since volcanic activity in the Elbrus area began about 900 ka ago, whereas the Elbrus Volcano originated no earlier than 250 ka ago [12]. The Eldzhurtinsky granite massif and the network of subvolcanic rhyolite bodies and vitrophyre dikes, which crosscut the rhyolite bodies, formed without significant temporal gaps within the interval of 1.9–2.5 Ma; i.e., these events lasted no more than 600 ka. All young magmatic rocks of the Tyrnyauz ore field are characterized by narrow age interval, similar chemical composition, and identical initial $^{87}Sr/^{86}Sr$ isotopic ratios, suggesting their formation from a common magmatic source and relation to a single Late Pliocene volcano-plutonic complex.

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