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GEOLOGY

Middle Paleozoic Rhyolite of the Gorny and Rudny Altai: Geochronology and Composition

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Abstract—The paper reports the results of geological, geochemical, and isotope–geochronological studies of subvolcanic rhyolites of NW Gorny Altai and Rudny Altai, which belong to the large Hercynian volcanic systems: Altai-Minusa and Altai–Salair, respectively. U–Pb zircon dating revealed two age groups: ~410–405 and 390–381 Ma. The isotope–geochemical characteristics of the rhyolites demonstrate high $\varepsilon_{Nd}(T)$ from +2.6 to 6.0 with relatively young model ages T(DM) = 851–966 Ma in Rudny Altai and older model ages, up to 1266 Ma, in NW Gorny Altai. The rhyolites show transitional geochemical signatures between within-plate and island-arc felsic magmas. The results obtained are consistent with two-stage evolution of volcanism and its migration from the continent to the ocean.

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In the western Central Asian Orogenic Belt, the transition from the Caledonian to the Hercynian orogeny was accompanied by deformations of the Siberian passive margin and fragmentation of its terrane–orogenic framing into the Rudny and Gorny Altai, Altai–Mongolian, Tom–Kolyvan, Salair, and other tectonic blocks [1]. The extended volcanic belts formed at that time are discordant to each other and emphasize the common "nested" lens-shapted segmented structure of the fold belt and the shadow contours of Caledonian blocks in plan (Fig. 1). The volcanic belts are ascribed to the large Altai–Minusa (D_{1-2}) and Altai–Salair (D_1–C_1) systems [2, 3]. Volcanism of the first system reflects the incipient continental rifting on the NW Siberian margin, which is thought to have been initiated in the early Emsian [4]. In its Altai segment (NW Gorny Altai), volcanism began earlier from the basaltic andesite–andesite–dacitic andesite–dacite series, and was completed by the emplacement of subvolcanic rhyodacites–rhyolites of the Korgon–Aksai and Kholzun–Sarymsakty volcanic belts (Fig. 1) [5]. The Altai–Salair System was former later, in the Late Emsian, in a convergent setting [2]. The volcanism of its frontal part (Rudny Altai) was characterized by large-scale eruptions of mainly felsic volcanic rocks and syngenetic emplacement of subvolcanic rhyolites of the Melnichno–Sosnovsky Complex [6]. Thus, the continental-margin rift-related magmatism occurred immediately before the formation of the earliest supra-subduction volcanic complexes. This study addresses subvolcanic intrusions in the junction zone of these systems in order to reconstruct the spatiotemporal evolution of magmatism related to the deformation of the Caledonian Orogen during the initial stage of the active continental margins.

Photos of polished thin sections of the subvolcanic rhyolites sampled for geochronological studies are shown in Fig. 2. In the Korgon volcanic belt, rhyolites were taken from the eponymous complex in the SE endo- and exocontact of the Shchebnyukha granitic massive, in the tributaries of the middle reaches of the Kumir River. Rhyolite porphyries of the Kholzun volcanic belt were taken from the Khaydun and Korgon

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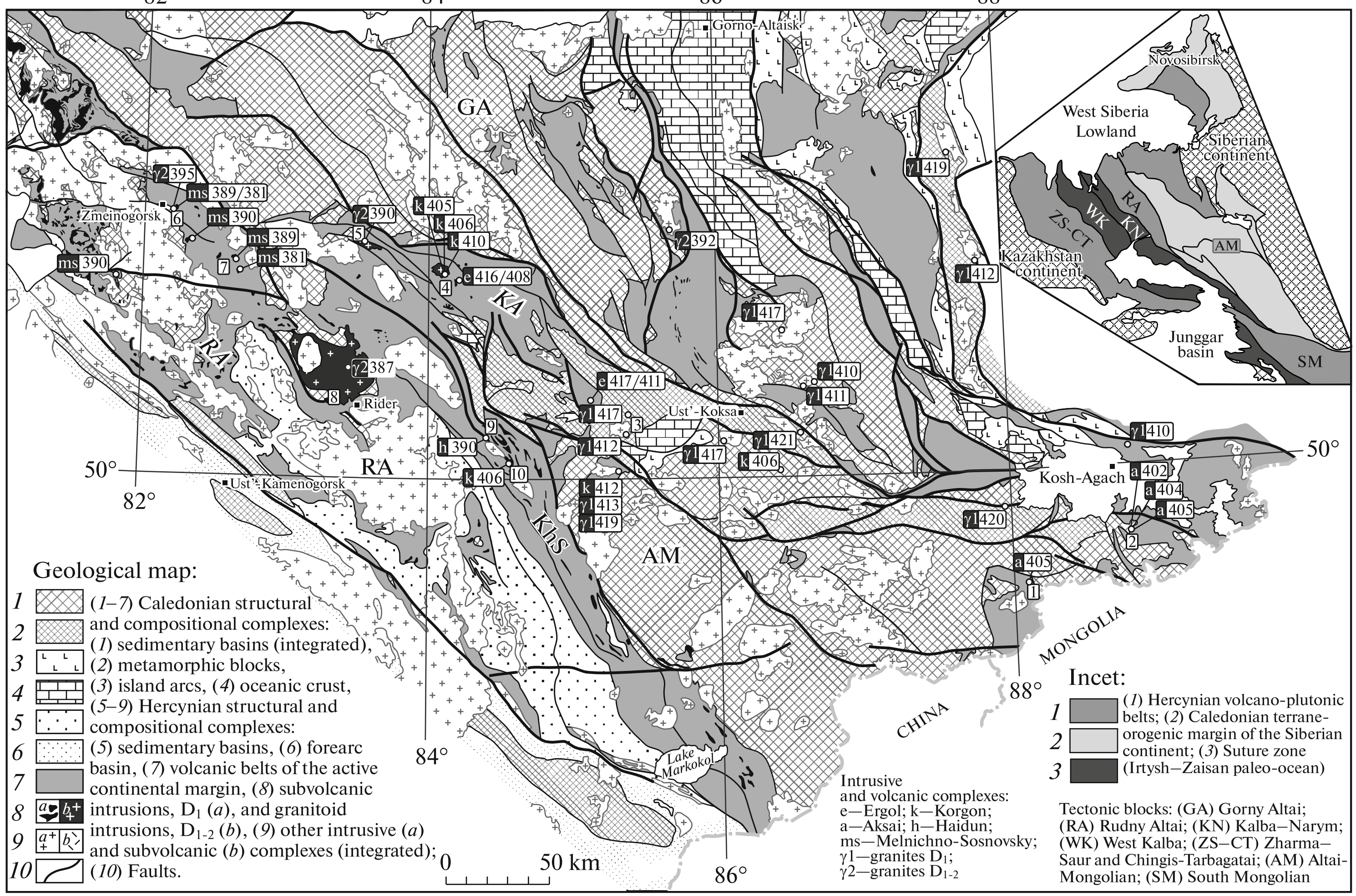

Fig. 1. Structural–geological scheme of the western Altai–Sayan fold belt showing the distribution of volcanic belts. The scheme and inset were compiled using data from [5–7]. Volcanic belts: (*RA*) Rudni Altai; (KA) Korgon–Aksai; (*KhS*) Kholzun-Sarymsakty. Sampling sites: (*1*) Aksai, (*2*) Kalguty, (*3*) Koksa, (*4*) Kumir, (*5*) Korgon, (*6*) Tigirek, (*7*) Zmeinogorsk, (*8*) Rider, (*9*) Khamir, (*10*) Chernevaya. Boxed numerals show the age values (Ma): numerals by italics are ages according to GSR-200 data, numerals in common type are the author's data; two groups of concordant ages in the sample are displayed after the slash.

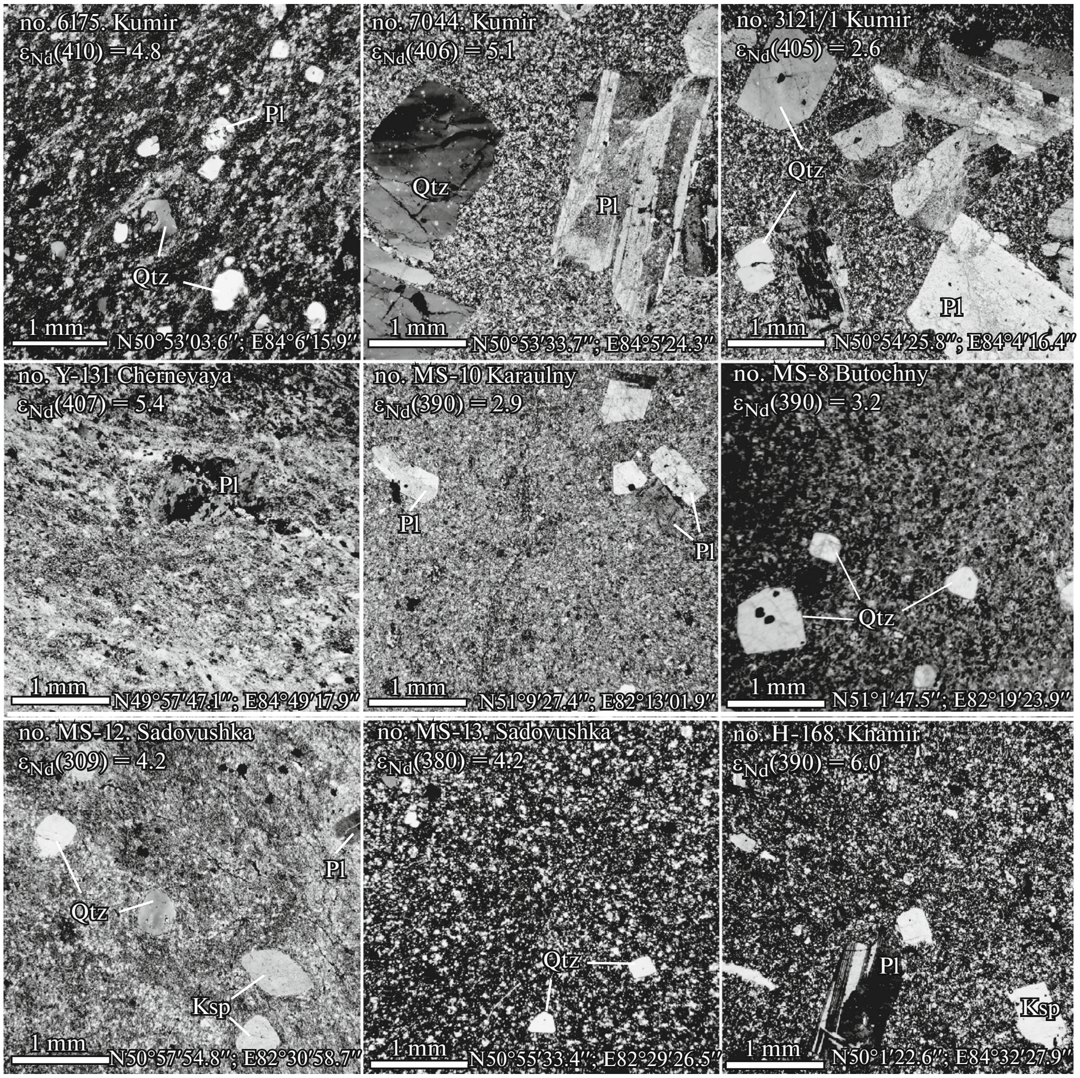

Fig. 2. Photos of polished thin sections of subvolcanic rhyolites from Rudny Altai and NW Gorny Altai. Crossed nicols. Minerals: (Pl) plagioclase, (Qtz) quartz, (Ksp) K-feldspar.

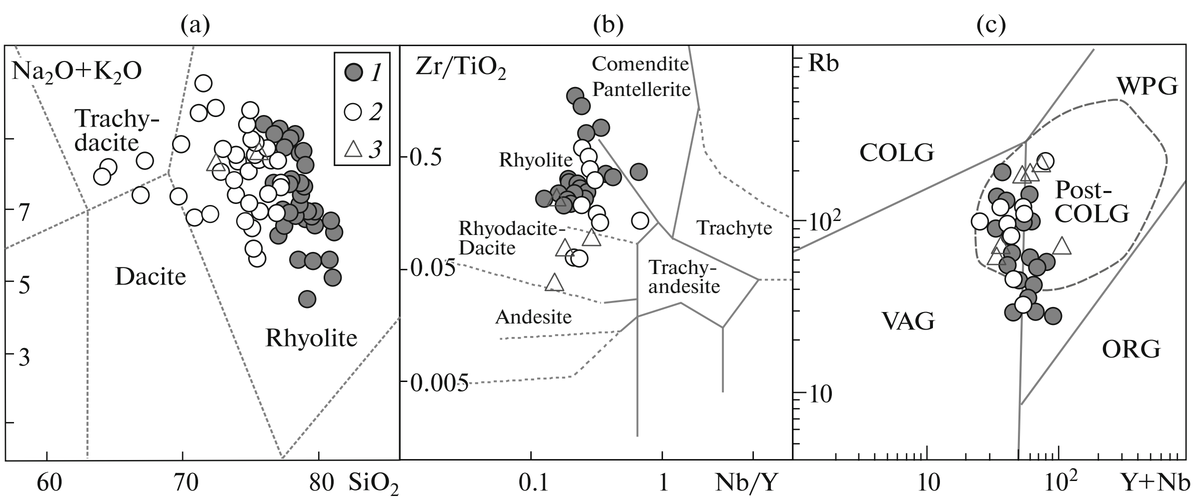

Fig. 3. Diagrams for subvolcanic rhyolites from Rudny Altai and NW Gorny Altai. (a) TAS classification diagram; (b) Nb/Y–Zr/TiO_2 diagram for altered volcanic rocks; (c) Pearce discriminant diagram Rb–(Y+Nb). Fields of granitoid compositions: (COLG) syncollision; (WPG) within plate, (ORG) oceanic ridges, (VAG) volcanic arcs. Subvolcanic complexes in legend: (*1*) Melnichno–Sosnovsky; (*2*) Korgon; (*3*) Khaydun.

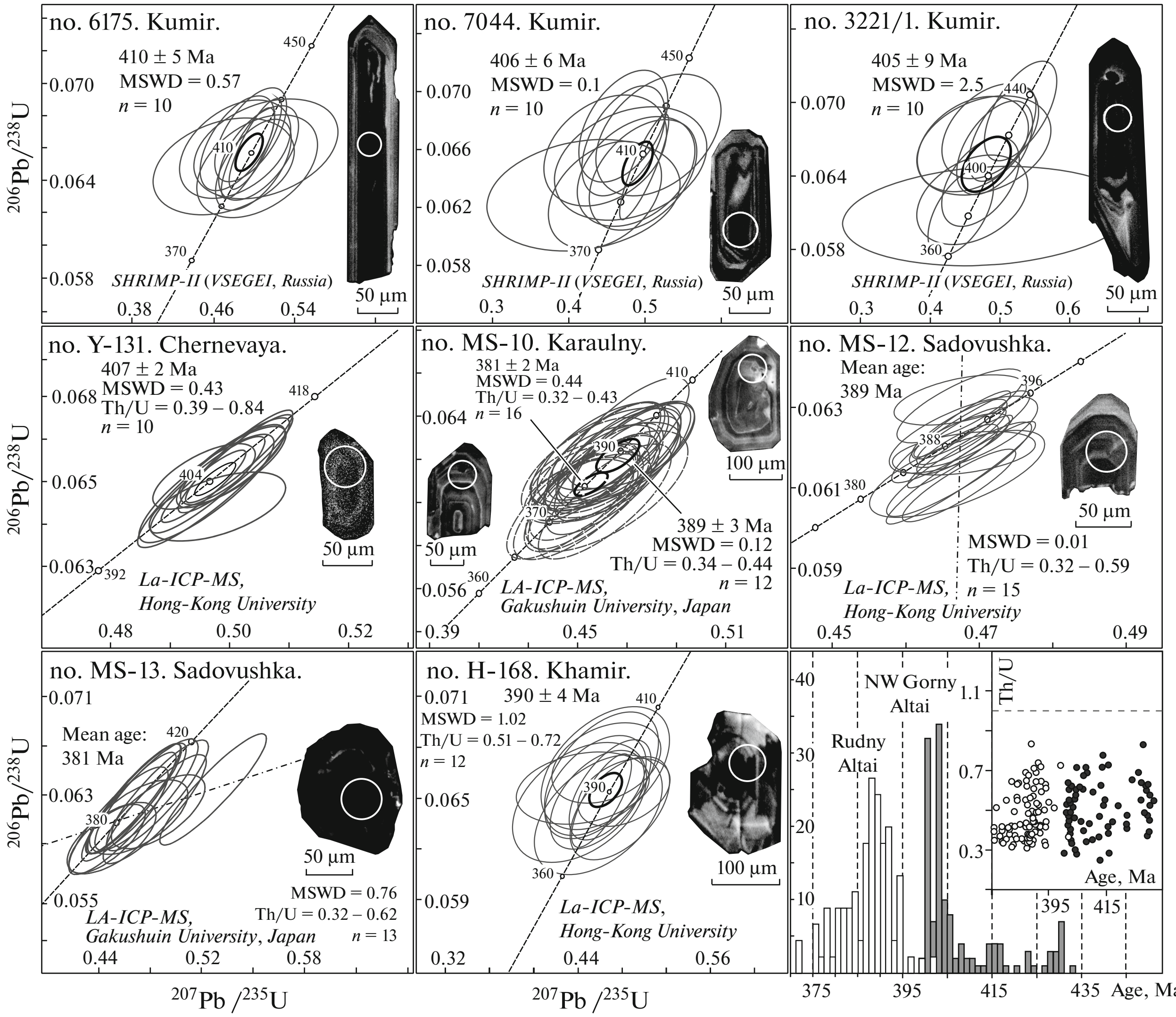

Fig. 4. Concordia diagram showing the results of U–Pb isotope dating and cathode-luminescence images of zircons from subvolcanic rhyolites of Rudny Altai and NW Gorny Altai. The ages of zircons from samples MS-10, MS-13, E-168 were determined by I.Y. Safonova at Gakushuin University (Japan) by using an Agilent 8800 single-collector triple quadrupole ICP-MS (Agilent Tech., Santa Clara, USA) coupled to a NWR-213 Nd: YAG LA system (ESI, Portland, USA). The isotope U–Pb ages of zircons from samples MS-12 and Y-131 were determined by M.L. Kuibida at Hong Kong University (China) by the LA–ICP–MS method on the NuPlasmaHR (NuInstruments, UK) instrument equipped with the LA-system (RESOlutionM-50 193 nm, ResoneticsLLC, United States). The U–Pb ages of zircons from samples 6175, 7044, and 3121/1 were obtained on the IMS apparatus at the Center for Isotope Study, Karpinskii All-Russia Research Institute (VSEGEI), St. Petersburg, analyst N.I. Gusev. Sample authors: MS-10, MS-12, MS-13, E-168, 7144 (M.L. Kuibida); Y-131 (V.A. Yakovlev); 6175 (V.A. Krivchikov); and 3121/1 (A.P. Selin). Morphogenetic analysis of zircons was performed by I.Y. Vasyukova at the Center for Collective Use, Institute of Geology and Mineralogy, Siberian Branch, Russian Academy of Sciences (Novosibirsk). CL-images of zircons were made on a JSM-6510LV (Jeol Ltd) scanning electron microscope at the Analytical Center for Multi-element and Isotope Study, Siberian Branch, Russian Academy of Sciences, analysts N.S. Karmanov and M.V. Khlestov.

complexes on the Khamir and Chernevaya rivers, respectively. Rhyolites of the Rudny Altai volcanic belt (Zmeinogorsk district) were taken from the Melnichno-Sosnovsky Complex, in the volcanic structures of the Karaulny, Butochny, and Sadovushka mounts.

The studied rocks from the volcanic belts of NW Gorny Altai and Rudny Altai differ in some petrochemical characteristics (in wt %; Fig. 3): SiO_2 (64–77 and 75–81), Al_2O_3 (11.78–16.27 and 10.26–12.5). Formally, they are ascribed to the K–Na calc-alkaline series, frequently with high $K_2O + Na_2O$ (4.34–9.34 and 5.62–10.55) and wide variations of Na_2O/K_2O (0.34–2.02 and 0.03–5.41), respectively. At the same time, the Nb/Y and Zr/Ti ratios in them correspond to those of rhyolites of the "normal" type. In terms of Y + Nb (34–90 ppm) values, they are transitional between island-arc and within-plate felsic magmas.

The rhyolites have high $\varepsilon_{Nd}(T)$ from +2.6 to +6.0 values with relatively young model ages T_{DM} = 851–966 Ma in Rudny Altai and with older model ages, up to 1266 Ma, in NW Gorny Altai.

The preliminary results of isotope LA–ICP–MS and SHRIMP-II dating, cathode–luminescence (CL) images of zircons, and Th/U ratios are shown in the U–Pb concordia diagrams (Fig. 4). Zircons from the rhyolites of the Melnichno-Sosnovsky Complex, Rudny Altai, yielded two distinct concordant ages, which are, however, indistinguishable within the measurement error: 389 and 381 Ma. The close age of 390 Ma was obtained for the rhyolites of the Khaydun Complex. All ages correspond to the age of initial magmatism in the Rudny Altai. All zircons from the rhyolites of the Korgon Complex, NW Gorny Altai, yielded close ages within 405–410 Ma, which correspond to the age of the initial rift-related magmatism [4].

The results are consistent with two-stage evolution of volcanism and its oceanward migration on the Siberian active margin [10], by analogy with the mechanism of formation of "extensional accretionary orogens" [11]. It is highly likely that the initial continental margin rifting was caused by the activity of a mantle plume beneath the Early Devonian passive margin [4]. Rifting could also have been caused by the "external" influence according to the mechanism of the West Pacific transform continental margin [12] or have resulted from the uninterrupted drift and rotation of the Siberian continent [13]. We believe that the volcanism of this stage was related to the formation of the continental margin back-arc basin during initiation of the Altai active margin of the Siberian continent [10]. Volcanism of the second stage (Early–Middle Devonian) was likely related to the island-arc rifting by analogy with the Okinawa Trough or the Taupo Rift [11]. The Altai system has a relatively short evolution history (~50 Ma), because the convergence of the Kazakhstan and Siberian continental plates led to accretionary–collisional processes and ocean closure [14, 15].

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