ISSN 1028-334X, Doklady Earth Sciences, 2014, Vol. 454, Part 2, pp. 136–139. © Pleiades Publishing, Ltd., 2014.
Original Russian Text © R.A. Terentiev, K.A. Savko, A.V. Samsonov, A.N. Larionov, 2014, published in Doklady Akademii Nauk, 2014, Vol. 454, No. 5, pp. 575–578.

GEOLOGY

Geochronology and Geochemistry of Acid Metavolcanites, Losevo Series, Voronezh Crystalline Massif

R. A. Terentiev[a], K. A. Savko[a],
Corresponding Member of the RAS A. V. Samsonov[b], and A. N. Larionov[c]

Received October 1, 2013

DOI: 10.1134/S1028334X14020172

The Losevo structural-formation zone is a part of the East Sarmatian orogen [8] in the junction of the Sarmatian and Volgo-Uralian segments of the East European Craton [9]. This structural-formation zone is composed of rocks of the Losevo Series, which contains metavolcanites of the contrast basalt–plagiorhyolite and polymodal basalt–andesite–plagiorhyolite associations among the metaterrigenous units [5]. Accumulation of the Losevo Series is referred to both the Late Archean (in this case, the similarity of the Losevo structural-formation zone and greenstone belts of the Kursk magnetic anomaly is implied [1, 3]) and the Early Proterozoic (similarity between the Losevo Series and Vorontsovo Series [2, 4]). Due to the absence of unambiguous evidence for both suggestions, the modern scheme of stratigraphy and magmatism for the Voronezh crystalline massif attributes the age of the Losevo Series to the Early Archean to Late Proterozoic [7].

To solve the problem regarding the age and geodynamical position of the lower (Strelitsa) stratum of the Losevo Series, which includes the contrast volcanism products, mineralogical–petrographic, petrochemical, geochemical, and isotopic studies of the metamorphized acid rocks from the reference section have been carried out.

Plagiodacites, their differentiates (plagiorhyodactes and plagiorhyolites), and facial analogs (tuffs) compose the upper parts of the Strelitsa stratum section, where they interbeds with greenstone rocks (metabasites of T-MORB type tholeiite series [5]). Contacts between rocks are clear and sharp; in the near-contact zones of paleoeffusive and paleosubvolcanic bodies, metabasite inclusions (lenses of up to 2 × 4 cm in size) are presented. The predominant part of acid rocks possesses a relic porphyritic texture. Impregnations are represented by quartz and plagioclase (the latter dominates). Granoblastic and lepidogranoblastic groundmass consists of quartz (40–60 vol %), albite–oligoclase (50–30), sericite (10–15), and chlorite and epidote (0–10). In the zones of higher *P*–*T* metamorphism conditions, paragenetic biotite appears near quartz and plagioclase.

In terms of the petrochemical composition, the discussed rocks belong to the syngenetic series of pla-

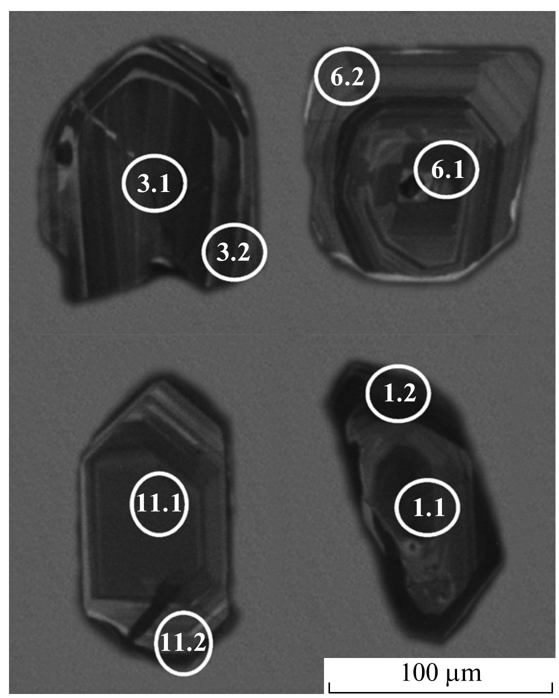

Fig. 1. Zircons in metaplagiorhyolite of the Losevo Series (cathode luminescence image). The two uppermost grains are with igneous zonality in marginal parts, both crossing the zonality in the grain center (grain no. 3) and concordant with it (grain no. 6). The lower grains are with azonal (dark zones) growth rims. Numbers of analytical points correspond to those in the table.

[a] *Voronezh State University, Voronezh, Russia*
[b] *Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry, Russian Academy of Sciences, Moscow, Russia*
[c] *Karpinskii All-Russia Research Geological Institute, St. Petersburg, Russia*
e-mail: terentiev@geol.vsu.ru, terentiev-geol@mail.ru

The results of U–Pb isotope studies of zircons from metaplagiorhyolite (Strelitsa stratum, Losevo Series; borehole no. 7782, 188.5–193.0 m depth, sample no. T-7)

Grain no., analytical point	$^{206}Pb_c$, %	U, g/t	Th, g/t	$^{232}Th/^{238}U$	$^{206}Pb^*$, g/t	(1) Age $^{206}Pb/^{238}U$, Ma	(1) Age $^{207}Pb/^{206}Pb$, Ma	*D*, %	(1) $^{207}Pb^*/^{206}Pb^*$	±, %	(1) $^{207}Pb^*/^{235}U$	±, %	(1) $^{206}Pb^*/^{238}U$	±, %	Error correlation
Azonal parts (point 9.1 is in the center, the rest are in rims)															
9.1	0.16	171	163	0.99	57.9	2140 ± 15	2133 ± 19	–0.3	0.1327	1.10	7.200	1.3	0.3936	0.81	0.599
15.2	0.15	267	49	0.19	90.6	2141 ± 13	2139 ± 15	–0.1	0.1331	0.87	7.228	1.1	0.3939	0.72	0.641
7.2	0.21	444	85	0.20	146.0	2080 ± 14	2155 ± 14	3.6	0.1343	0.81	7.049	1.1	0.3807	0.79	0.696
11.2	0.83	236	50	0.22	77.3	2060 ± 15	2161 ± 27	4.9	0.1347	1.50	6.990	1.8	0.3765	0.86	0.487
1.2	0.38	291	42	0.15	89.2	1958 ± 10	2172 ± 14	11.0	0.1356	0.81	6.635	1.0	0.3548	0.61	0.603
Zonal parts (central parts of grains and rims)															
16.1	0.23	243	94	0.40	82.1	2134 ± 13	2163 ± 15	1.4	0.1349	0.88	7.300	1.1	0.3924	0.71	0.631
5.1	0.29	64	28	0.45	21.9	2144 ± 20	2164 ± 30	0.9	0.1350	1.70	7.340	2.1	0.3947	1.10	0.539
1.1	0.22	109	72	0.68	35.8	2080 ± 14	2165 ± 23	4.1	0.1351	1.30	7.090	1.5	0.3809	0.77	0.510
8.1	–	409	246	0.62	138.0	2129 ± 12	2168 ± 11	1.9	0.1353	0.64	7.300	0.9	0.3913	0.66	0.716
3.2	1.26	153	104	0.70	53.5	2168 ± 15	2171 ± 25	0.1	0.1355	1.40	7.470	1.6	0.3998	0.84	0.510
3.1	2.57	85	58	0.71	29.5	2125 ± 17	2173 ± 39	2.3	0.1357	2.30	7.310	2.4	0.3905	0.92	0.377
15.1	0.41	220	92	0.43	70.3	2033 ± 13	2176 ± 18	7.0	0.1359	1.00	6.946	1.3	0.3707	0.75	0.584
5.2	1.93	132	66	0.52	40.3	1923 ± 18	2180 ± 44	13.4	0.1362	2.50	6.530	2.8	0.3476	1.10	0.394
11.1	0.13	135	72	0.55	46.6	2172 ± 16	2193 ± 22	1.0	0.1372	1.20	7.580	1.5	0.4006	0.87	0.574
14.1	0.14	71	24	0.35	23.9	2124 ± 30	2194 ± 30	3.3	0.1374	1.70	7.390	2.4	0.3903	1.70	0.703
10.1	0.53	67	43	0.66	23.9	2226 ± 21	2196 ± 38	–1.3	0.1375	2.20	7.820	2.5	0.4124	1.10	0.455
6.2	0.81	55	22	0.42	18.1	2083 ± 23	2198 ± 42	5.5	0.1376	2.40	7.240	2.7	0.3814	1.30	0.465
17.1	0.02	200	32	0.16	67.7	2140 ± 14	2199 ± 15	2.7	0.1377	0.85	7.478	1.1	0.3938	0.74	0.658
6.1	0.03	72	44	0.63	24.5	2152 ± 20	2199 ± 27	2.1	0.1377	1.50	7.530	1.9	0.3964	1.10	0.584
17.2	0.02	291	66	0.23	99.7	2163 ± 13	2200 ± 13	1.7	0.1378	0.73	7.575	1.0	0.3987	0.68	0.682
9.2	0.20	55	21	0.39	18.1	2079 ± 21	2204 ± 31	6.0	0.1381	1.80	7.250	2.1	0.3807	1.20	0.552
7.1	–	133	68	0.53	46.5	2199 ± 17	2206 ± 20	0.3	0.1383	1.10	7.750	1.5	0.4065	0.90	0.618
12.1	–	87	53	0.62	29.7	2148 ± 18	2229 ± 22	3.8	0.1402	1.30	7.650	1.6	0.3955	0.97	0.600
Relatively ancient fragment															
4.2	0.07	249	133	0.55	101.0	2486 ± 15	2724 ± 13	9.6	0.1880	0.79	12.190	1.1	0.4705	0.71	0.666
4.1	0.05	200	187	0.96	82.8	2532 ± 15	2730 ± 12	7.8	0.1886	0.71	12.510	1.0	0.4811	0.72	0.713

Errors are in the interval of 1σ; Pb_c and Pb* mean common and radiogenic lead, respectively; (1) means correction to Pb_c based on the measured ^{204}Pb value; *D* is the discordance 100 · [($^{207}Pb/^{206}Pb$ age)]/($^{206}Pb/^{238}U$ age)] – 1; calibration error is 0.29. Analyses were made at the Center for Isotopic Studies, Karpinskii All-Russia Research Geological Institute; analyst A.N. Larionov.

giodacite–plagiorhyodacite–plagiorhyolite (SiO_2 = 64.8–73.5 wt%) and to the family of high-alumina ($Al_2O_3/(CaO + Na_2O + K_2O)$ = 2.1–6.9), low alkali ($Na_2O + K_2O < 7$ wt %) rhyodacites with low K_2O/Na_2O ratio (<0.5).

Plagiorhyolites are 40–50 times richer in such LILE as Rb, Ba, and K relative to the primitive mantle and possess highly fractionated REE spectra ($(La/Yb)_N$ 21 ± 4) without Eu anomalies (Eu/Eu* = 1.0 ± 0.13), and a high Sr/Y ratio (74 ± 22). The closest analog of the metamorphized acid rocks from the Losevo Series Strelitsa stratum are plagiodacites–plagiorhyolites of suprasubduction settings (high-silica adakites [11]). The geochemical appearance of plagiorhyolites and their association with T-MORB basalts [5] and thick greywacke strata, accumulated by avalanche-like sedimentation under the conditions of a narrow rapidly developing deep water basin [6], suggest that the Strelitsa stratum of the Losevo Series formed under conditions corresponding to those in modern marginal seas.

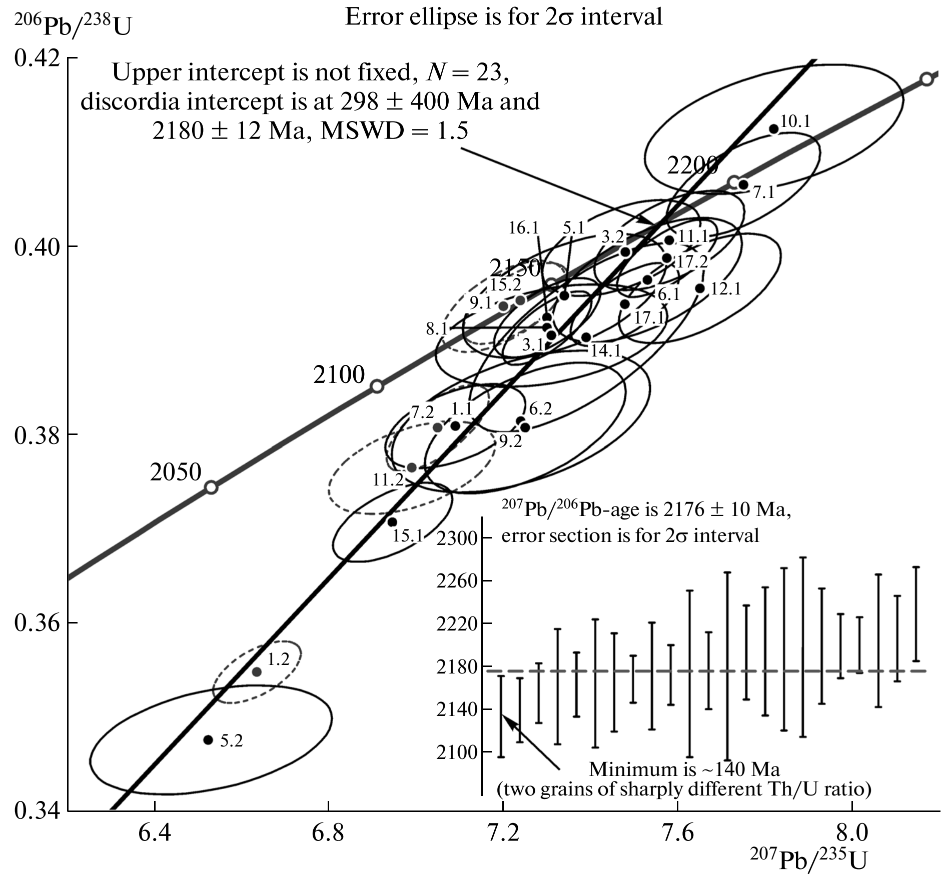

Fig. 2. U–Pb isotope ratios and $^{207}Pb/^{206}Pb$ age distribution (in the inset) for zircons from metaplagiorhyolites (borehole no. 7782, 188.5–193.0 m depth). Gravity centers of error ellipses for isotope ratios are shown with points: black are zonal and gray are azonal parts of grains. Numbers of analytical points correspond to those in the table.

Dating of the Strelitsa stratum formation is based on the results of SIMS U–Pb analyses on zircons from volcanogenic-type plagiorhyolite collected in borehole no. 7782 at 188.5–193.0 m depth. Analyses were carried out at the Center for Isotope Studies, Karpinskii All-Russia Research Geological Institute, on a SHRIMP-II ion microprobe using the technique described in [10].

The zircons extracted from the ~800-g sample (about 20 grains) are represented by semitransparent crystals and crystal fragments, predominantly with abrasion tracks. The presence of abrasion tracks, jointly with the variety of morphological shapes of zircons (prismatic, short-prismatic, and isometric crystals), suggests the xenogenic nature of the zircons in the examined sample.

In terms of the inner structure, the studied zircons are close to each other and are characterized by fine oscillatory zonality (Fig. 1) suggesting their initially igneous origin. Five zircon grains contain repeated-growth rims, which are isotropic in cathode luminescent light. The boundaries between isotropic rims and zonal parts of the grains are clear, sometimes rough, with the tracks of reabsorption of the central parts.

All zircons have moderate Th and U concentrations, Th/U = 1–0.15 and usually lower in the outer parts of crystals. Grains are characterized by a high U content and Th/U < 0.1, which are typical for highly differentiated granites and migmatites, have not been found.

In terms of age, the zircons are quite uniform. One grain of Archean age is distinct from the group of the remaining crystals examined: 23 analyses in the central and marginal parts of 14 grains have an average weighted $^{207}Pb/^{206}Pb$ age of 2176 ± 10 Ma, MSWD = 1.5, which corresponds to the upper discordia intercept (2180 ± 12 Ma, MSWD = 1.5) within the error limits (Fig. 2). However, in analyzing the $^{207}Pb/^{206}Pb$ ages, we can detect poor discreteness in the age distribution with clustering near 2.20, 2.17, and 2.14 Ga (table); this suggests the presence of several nearly coeval groups of zircons in plagiorhyolites.

The obtained isotope-geochronological data, combined with the morphological peculiarities of zircons, indicate the presence of xenogenic zircons of clastogenic origin in the plagiorhyolites. The presence of these xenogenic zircons could be related either to trapping of terrigenous sediments underlying the volcanogenic stratum by a rhyolite melt or to supply of the weathered detrital material during accumulation of the volcanogenic stratum drilled by borehole no. 7782.

The problem regarding the age of acid volcanism of the Losevo Series is, however, not solved unambiguously. With the results on two grains taken into consideration, it can only be supposed that these volcanites are not older than 2140 Ma. In this case, based on petrogeochemical data, gabbroids from the Rozhdestvenskii complex (isotope age is about 2120–2130 Ma) and tholeiites from the Strelitsa stratum are comagmatic. The difference in composition of protoliths for the Losevo Series and Voronstovo Series (joining the Losevo Series in the east) [6] at close isotope ages confirms that the stratons belong to different segments of the East European Craton [5].

The obtained U–Pb dates of zircons indicate the leading role played by the Paleoproterozoic sources when are forming the terrigenous deposits of the Losevo Series and are in good agreement with the isotope-geochemical characteristics of plagiorhyolites (εNd_{2140} is from +1.8 to +2.9, $(^{87}Sr/^{86}Sr)_{2140}$ is 0.70129–0.70232); these characteristics suggest that a juvenile Paleoproterozoic source of magmas produced plagiorhyolites, with a minimal fraction of an Archean crustal component [8].

The geochemical and isotope data given above allow us to make the following conclusions.

(1) Plagiorhyolites of the Strelitsa stratum, Losevo Series, formed under a suprasubduction setting, judging by their chemical composition.

(2) The Strelitsa stratum of the Losevo Series formed in the Paleoproterozoic, not earlier than 2140 Ma BP, under a setting corresponding to that of modern marginal seas.

(3) The isotope-geochemical data indicate a juvenile Paleoproterozoic source of acid magmas and predominance of Paleoproterozoic sources when forming the terrigenous deposits, with the minimal fraction of the Archean crustal component.

REFERENCES

1. N. I. Golivkin, I. N. Leonenko, V. D. Polishchuk, et al., in *Geology, Mineragenic Analysis, Petrology, and Metallogenic Specialization of the Crystalline Units of East European Craton* (Izd. Voronezh. Univ., Voronezh, 1972), pp. 9–11 [in Russian].
2. S. I. Gorbunov, Yu. S. Zaitsev, and N. M. Chernyshov, Sov. Geol., No. 10, 8–25 (1969).
3. Yu. S. Zaitsev, Izv. Akad. Nauk SSSR, Ser. Geol., No. 11, 23–30 (1979).
4. I. N. Leonenko, N. I. Golivkin, Yu. S. Zaitsev, et al., in *Geologiya, petrologiya i metallogeniya kristallicheskikh obrazovanii Vostochno-Evropeiskoi platformy* (Nedra, Moscow, 1976), Vol. 1 [in Russian].
5. R. A. Terentiev, Vestn. Voronezh. Univ., Ser. Geol, No. 1, 81–94 (2005).
6. R. A. Terentiev, Vestn. Voronezh. Univ., Ser. Geol, No. 1, 127–138 (2013).
7. N. M. Chernyshov, A. Yu. Al'bekov, and M. V. Ryborak, Vestn. Voronezh. Univ., Ser. Geol, No. 2, 33–40 (2009).
8. A. A. Shchipanskii, A. V. Samsonov, A. Yu. Petrova, and Yu. O. Larionova, Geotectonics **41**, 38–62 (2007).
9. S. V. Bogdanova, R. Gorbatschev, and R. G. Garetsky, in *Encyclopedia of Geology* (Elsevier, Amsterdam, 2005), Vol. 2, pp. 34–49.
10. A. N. Larionov, V. A. Andreichev, and D. G. Gee, Mem. Geol. Soc. London **30**, 69–74 (2004).
11. H. Martin, R. H. Smithies, R. Rapp, and J.-F. Moyen, Lithos **79**, 1–24 (2005).

Translated by N. Astafiev