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GRANITOIDS OF THE ZACHATIVKA-FEDORIVKA ANTICLINE IN THE MANGUSH SYNCLINORIUM: GEOCHEMICAL FEATURES, ORIGIN, AND AGE (AZOV DOMAIN OF THE UKRAINIAN SHIELD)

The Paleoproterozoic crust formation in the Azov domain remains underexplored. In the Neoarchean-Paleoproterozoic, the Azov segment of the Archean crust was fragmented by large rift structures. This stage is associated with the formation of Neoarchean-Paleoproterozoic sedimentary-volcanic complexes of the Central Azov Series (2.76-2.22 Ga) and extensive granitoid magmatism. The research aimed at studying granitoid intrusions in the Zachativka-Fedorivka anticline in the Mangush synclinorium of the Central Azov region from the geochemical perspective. Granitoids of the Zachativka-Fedorivka anticline in the Mangush synclinorium include granitoids and later pegmatoidal granites. Plagiogranitoids are moderate-potassium rocks of the K-Na series, with predominance of Na_2O over K_2O and low Rb/Sr ratio (0.03). They are divided into plagiogranites with low contents of HFS elements and positive europium anomalies and granodiorites with higher contents of HFS elements and predominantly negative europium anomalies. The U-Pb age of titanite from granodiorites is 2028±47 Ma. This age corresponds to the closure of the U-Pb isotope system of titanite and thus reflects the minimum age of granodiorite. The $^{207}Pb/^{206}Pb$ age of zircon from granites is 2.07-2.09 Ga. The formation of the Paleoproterozoic granitoids of the Central Azov may be related to the activization of the mantle beneath the Azov domain during the formation of the East Sarmatian orogen at ca. 2.1 Ga. They could have formed because of partial melting of the lower crust because of underplating of mafic melts. The 2.05 Ga old vein bodies of pegmatoidal subalkaline granites, were probably formed at the stage of collision of the Sarmatia and Volga-Ural continents.

Keywords: *Azov domain, Ukrainian Shield, Mangush synclinorium, granitoids, Paleoproterozoic, East Sarmatian orogen, foreland, collision, isotopic age, titanite, zircon, monazite.*

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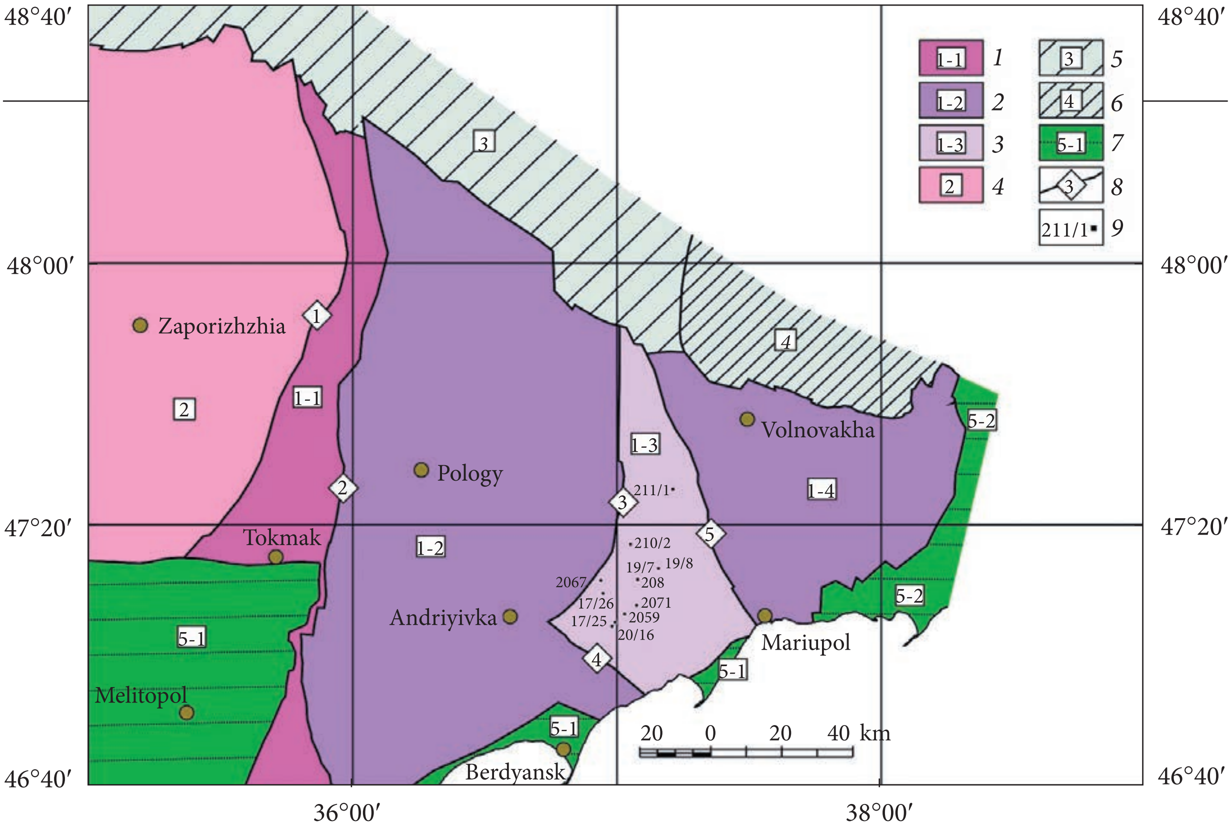
Introduction. The Paleoproterozoic crust formation in the Azov domain remains poorly explored. The Mesoarchean (3.2-2.8 Ga) craton, which also included the Azov crustal segment, was fragmented by large rift structures in the end of the Neoarchean [11, 18]. This stage is associated with the formation of Neoarchean-Paleoproterozoic sedimentary-volcanic complexes of the Central Azov Series (2.76-2.22 Ga) [1, 2] and extensive granitoid magmatism. At 2.20-2.14 Ga, the Azov domain was in the foreland of the East Sarmatian orogen [10, 15]. As a result of collisional processes at 2.1-2.0 Ga, the Sarmatia and Volga-Ural continents merged [15]. The stages of the merging of the Sarmatia and Volga-Ural continents are well-studied in the eastern part of the Voronizh Crystalline Massif (VKM) (Saratov and Samara region). The geological processes of this stage have not yet been explored in the Azov domain.

The research aimed at studying the intrusions of plagiogranites-granodiorites and alkaline-rich granites in the Zachativka-Fedorivka anticline in the Mangush synclinorium of the Central Azov region from the geochemical perspective to reconstruct the geological processes associated with the unification of the Sarmatia and Volga-Ural continents.

Methodology. Silicate analyzes of rocks took place at the M.P. Semenenko Institute of Geochemistry, Mineralogy and Ore Formation of the National Academy of Sciences of Ukraine (IGMOF of NAS of Ukraine). The contents of rare and trace elements were determined using inductively coupled plasma mass spectrometry (ICP-MS) at the Institute of Microelectronics Technology and High Purity Materials of the Russian Academy of Sciences (IPTM RAS) and in IGMOF of NAS of Ukraine. The analyzes correctness was controlled by measuring international and Russian standard samples GSP-2, VM, SGD-1A, and ST-1. Errors in determining the concentrations ranged from 3 to 5 wt.% for most elements. The internal structure of zircon was studied in thin sections under the ECLIPSE LV100 POL microscope. Monazite, zircon, and titanite were dated by the TIMS U-Pb isotope method at the Department of Radiogeochronology, IGMOF. To determine the content of U and Pb, a mixed $^{235}U + ^{206}Pb$ tracer was used. The MI-1201AT eight-collector mass spectrometer was applied to perform Pb and U isotope analyzes in the multi-collector static mode. The Pb Dat and ISOPLOT programs were used for the mathematical processing of experimental data [8, 9].

Geological structure of the study area. The Mangush synclinorium is located between the Saltych and Kalchyk-Kalmius anticlinories of the Azov Domain of the Ukrainian Shield. It is bounded by the Central Azov fault zone in the west and the Maloyanisol tectonic zone in the east (Fig. 1, *a*, *b*). This structure was formed on the Archean basement during Paleoproterozoic and is composed of sedimentary-volcanogenic rocks of the Central Azov Series. The Mangush synclinorium is complicated by folds; the largest of those are (from west to east) the Berestivka and Rozivka synclines, the Zachativka-Fedorivka anticline, and the Maloyanisol and Boev-Mangush synclines [4, 5] (Fig. 1). In this structure, the supracrustal rocks of the Central Azov Series have the form of conformable lenticular units up to several hundred meters thick and up to 5-6 km long [14]. Anticlinal structures are composed of pink migmatites and pinkish grey migmatites; among the latter, bands of grey migmatites and metabasites are observed [4]. The Zachativka-Fedorivka anticline is the largest one. It is a folded structure oriented in the NNW direction with linear type plicative forms and can be traced as a S-like strip from the northern coast of the Sea of Azov for about 85 km. It is 3-5 to 14 km wide. Small bodies of undeformed post-collision microcline-plagioclase granites can also be seen in the Mangush synclinorium.

Results. *Petrological characteristics of granodiorites* (sample 17/26). Sample from the outcrops of the Gurzhiy tract on the right bank of the Berda river (N47°09'24.1''; E36°56'24.1'' sample 17/26) show a slightly oriented texture. They are cut through by veins of pegmatoidal granites, which intruded the already deformed rock (i.e., in post-collision setting). Hypidiomorphic granodiorites, with oriented texture are composed of feldspar (oligoclase) — 66%, quartz — 20%, hornblende — 7%, clinopyroxene — up to 2%; biotite — 5%; titanite — fractions of a percent; ore minerals, apatite, and zircon — in single grains. Clinopyroxene and hornblende are partly replaced by biotite. Similar in composition granodiorites are also expo-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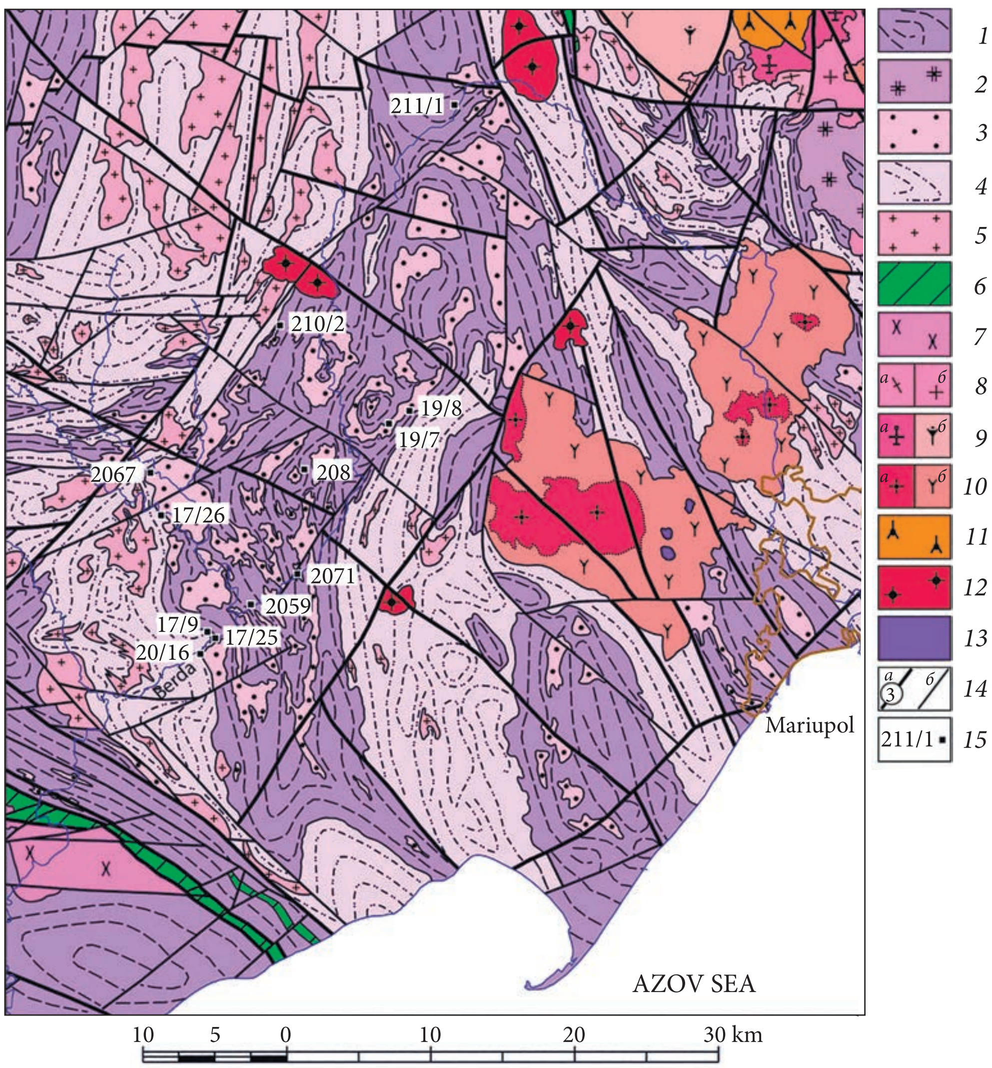
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Fig. 2. Outcrop of dislocated granodiorites (right bank of the Berda river, 800 m upstream from the Kalaytanivka village (sample 17/25). Granodiorites are intruded by pegmatoid plagioclase-microcline granites

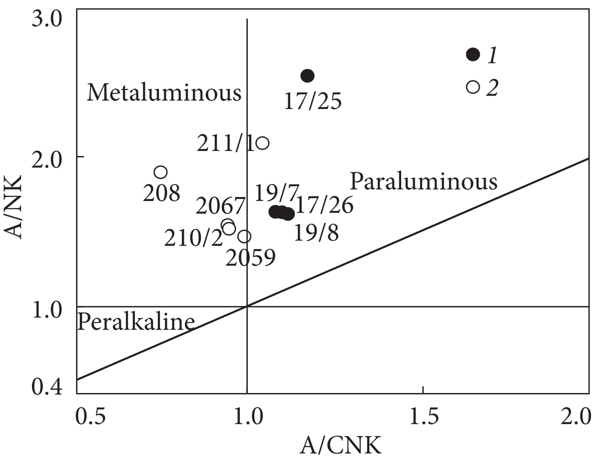

Fig. 3. Diagram A/NK — A/CNK after Shand (1943) [16] for granitoids of the Zachativka-Fedorivka anticline in the Mangush synclinorium. A/NK molar ratio $Al_2O_3/(Na_2O + K_2O)$; A/CNK — molar ratio Al_2O_3 / $(CaO + Na_2O + K_2O)$

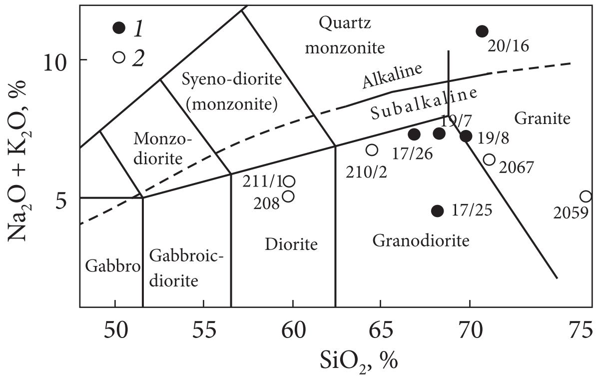

Fig. 4. TAS diagram diagram after Middlemost (1985) [10] for the Paleoproterozoic granitoids of the Zachativka-Fedorivka anticline in the Mangush synclinorium: *1* — studied granitoids; *2* — here and in the following diagrams data from [2]

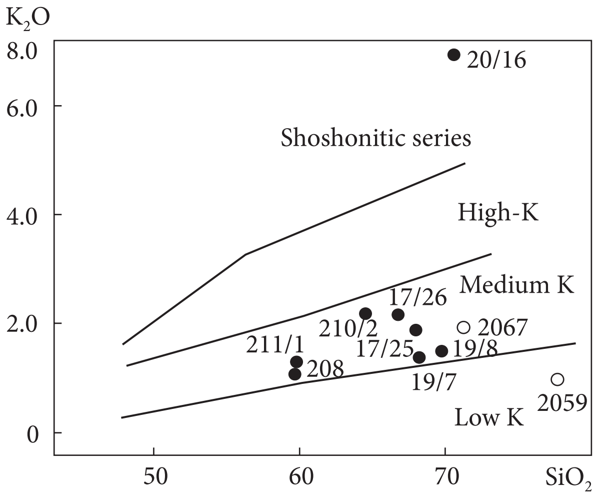

Fig. 5. Diagram SiO_2 — K_2O after Pecerillo and Taylor (1976) [13] for granitoids of the Zachativka-Fedorivka anticline in the Mangush synclinorium

sed in the Kalaytanivka village (sample 17/25) (Fig. 2).

The analyzed rocks are peraluminous (Fig. 3), plot as granodiorites and granites (Fig. 4) and belong to calc-alkaline series [3] (Fig. 5; Table 1).

Granodiorites have a low content of Rb (19.4 ppm) and a high content of Sr (314 ppm),

◄ *Fig. 1. a* — Simplified geological sketch of the eastern part of the Ukrainian Shield. Structures of the Ukrainian Shield and adjacent depressions, their number (number in the rectangle) (*1-7*): Azov Domain (*1-4*): *1* — Orekhiv-Pavlohrad structure (*1-1*), *2* — West-Azov anticlinorium (*1-2*), East Azov anticlinorium (*1-4*); *3* — Central Azov synclinorium (*1-3*); *4* — Middle-Dnieper Domain (*2*); *5* — Dnieper-Donets basin (*3*); *6* — Folded Donbas (*4*); *7* — Peri-Black Sea basin (*5-1*) and Azov-Kuban basin (*5-2*); *8* — major faults and their numbers (number in a rhombus): Orekhiv-Pavlohrad (*1*), West-Azov — (*2*), Rozivka-Katerynivka — (*3*), Mykolaivka — (*4*), Maloyanisol — (*5*); *9* — outcrops and their numbers (sampling sites). *b* — Schematic geological map of the Central Azov region [4]: *1* — West Azov Series, Upper-Tokmak unit; *2* — Tokmak complex — charnockite-enderbite; *3* — Remivka? complex (plagiogranite, plagiomigmatite); *4* — Dragoon unit, Temryuk and Demyanivka suites; *5* — Karatyuk complex — plagiogranite; *6* — Osypenkovo Series; *7* — Maksymivka association — granodiorite; *8* — Anadol complex (*a* — migmatite, *b* — granite); *9* — Khlibodarivka complex (*a* — granite, *b* — syenite); *10* — South Kalchyk complex (*a* — granite, *b* — syenite); *11* — Oktyabrsky complex — gabbro, syenite; *12* — Kamyani Mohyly complex — granite; *13* — small Hercynian Paleozoic intrusions; *14* — faults (*a* — main, *b* — subordinate); *15* — outcrops and their numbers (sampling sites)

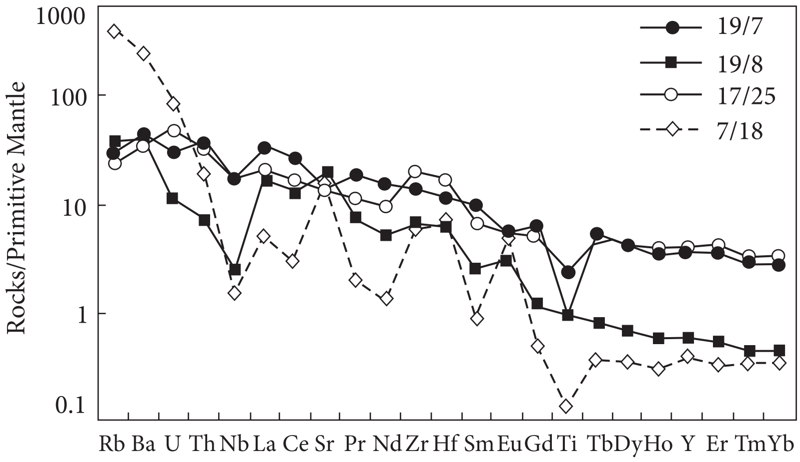

Fig. 6. Primitive-mantle normalised multielement patterns for Paleoproterozoic granitoids of the Zachativka-Fedorivka anticline in the Mangush synclinorium [19]

low Rb/Sr ratio (0.06) (Table 2). Negative Nb and Ti anomalies can be seen on the primitive-mantle-normalized multielement diagram (Fig. 6). Chondrite (C1)-normalized REE pattern show moderate differentiation $(La/Yb)_N = 11.5$) with a negative europium anomaly — $Eu/Eu^* = 0.71$ (Fig. 7). The restite phase of the magmatic source probably contained clinopyroxene, amphibole, and plagioclase.

Titanite characteristics. Titanite crystals from one sample (17/26) were separated for U-Pb dating. Titanite grains are usually shapeless, with

Table 1. **Chemical composition of granitoids of the Zachativka-Fedorivka anticline in the Mangush synclinorium, wt.%**

Component	1/19/7	2/19/8	3/17/25	4/17/26	5/208	6/2067	7/2059	8/210/2	9/211/1	1020/16
SiO_2	68.15	69.91	68.20	66.78	59.82	71.04	77.65	64.52	59.92	70.50
TiO_2	0.21	0.20	0.51	0.35	1.32	0.30	0.20	0.70	1.32	0.029
Al_2O_3	18.25	17.46	16.64	17.22	14.92	14.25	11.35	15.13	17.27	16.85
Fe_2O_3	2.16	1.80	4.88	3.56	2.96	0.95	1.60	1.75	3.64	0.86
FeO	—	—	—	—	4.75	1.99	1.85	3.46	1.94	—
MnO	0.02	0.02	0.08	0.05	0.16	0.03	0.01	0.10	0.09	0.005
MgO	0.52	0.46	1.21	1.47	2.63	1.74	0.40	2.53	2.57	—
CaO	3.13	2.75	4.20	2.99	6.81	3.30	2.0	3.54	4.45	0.367
Na_2O	5.90	5.68	2.81	5.10	4.01	4.40	4.05	4.56	4.37	3.07
K_2O	1.42	1.48	1.80	2.16	1.10	1.90	0.95	2.20	1.30	7.99
P_2O_5	—	—	—	—	0.22	0.12	0.07	0.26	0.40	0.014
H_2O^-	—	—	0.06	—	0.16	0.06	0.01	0.15	1.11	—
LOI	—	—	0.80	—	0.85	0.22	0.27	0.81	1.58	—
Total	99.76	99.76	101.19	99.67	99.71	100.30	100.39	99.71	99.96	99.70
Mg#	30.8	33.3	33	45	38.7	51.8	17.9	47.4	47.1	—
A/NK	1.62	1.61	2.55	1.61	1.9	1.54	1.46	1.53	2.1	1.24
A/CNK	1.08	1.10	1.17	1.11	0.74	0.93	0.99	0.93	1.04	1.19

N o t e. 1 — granite, outcrop at the right bank of beam Vodyana, under the power line, in 700 m upstream the Fedorivka village (smp. 19/7); 2 — granite, outcrop at the right bank of beam Vodyana, below the dam (smp. 19/8); 3 — granodiorite, outcrop on the right bank of the Berda river upstream the Kalaytanivka village (smp. 17/25); 4 — granodiorite, outcrop on the beam Gurzhiy (smp. 17/26); 5 — quartz diorite, outcrop at the mouth of the Panasiv beam, at 1 km downstream the Zeleny Yar village (smp. 208); 6 — tonalite, Karatyuk massif, Sadovy farm, open pit (smp. 2067); 7 — trondhjemite, Starodubivka village, outcrop at the right bank of the Karatyuk river (smp. 2059); 8 — granodiorite, outcrop at the right bank of the beam Zelinska (150 m above the road (smp. 210/2); 9 — tonalite, upper reaches of the Kalchyk river, 1 km upstream the Vyshnyuvate village (smp. 211/1); 10 — pegmatoid granite, outcrop at the left bank of the beam near the southern part of the Kalaytanivka village (smp. 20/16) Mg# = 100 · Mg/(Mg + Fe) (molar ratio), A/NK is the molar ratio of $Al_2O_3/(Na_2O+K_2O)$, A/CNK is the molar ratio of $Al_2O_3/(CaO + Na_2O + K_2O)$.

Table 2. **The element concentrations in granitoids of the Zachativka-Fedorivka anticline in the Mangush synclinorium, ppm**

Component	1/ 19/7	2/ 19/8	3/ 2067	4/ 2059	5/ 210/2	6/ 211/1	7/ 208	8/ 17/25	9/ 20/16
Li	—	—	16.3	12.4	22.1	26.4	11.4	18.7	4.9
Be	—	—	1.2	0.8	1.6	1.0	0.8	1.1	0.5
Sc	1.5	1.6	4.2	7.0	13.4	7.2	7.9	6.9	0.2
V	—	—	39.5	5.4	65.6	72.2	57.2	61.1	7.9
Cr	—	—	32.1	35.6	68.7	34.1	13.7	32.4	5.8
Co	—	—	6.5	3.6	12.0	14.7	7.6	9.1	0.6
Ni	—	—	24.4	9.4	42.3	33.9	13.7	25.5	5.4
Cu	—	—	31.8	22.3	21.4	15.1	19.2	16.4	25.4
Zn	—	—	39.0	31.6	66.4	86.5	100	92.4	20.3
Rb	23.2	15.7	54.6	18.4	57.1	54.8	14.4	19.4	256
Sr	431.7	498	502	162.3	640.5	515	280	314	346
Y	2.7	2.2	6.6	8.8	18.6	12.8	18.1	17.1	1.8
Zr	80.0	90.7	118	80.2	99.4	269	224	150	69.2
Nb	1.8	2.0	3.3	7.2	6.9	11.9	11.5	12.0	1.1
Mo	—	—	1.2	0.8	0.5	1.0	1.1	0.7	0.7
Cs	0.2	0.1	0.7	0.1	0.4	0.8	0.1	0.3	1.3
Ba	272.8	415.2	425	166.8	577.3	474	252	310	1750
La	11.52	11.53	10.9	21.94	30.43	18.9	13.6	22.5	3.6
Ce	22.75	24.73	23.1	38.69	56.54	50.6	27.6	46.8	5.3
Pr	2.01	2.44	2.7	4.14	6.75	4.7	3.0	5.1	0.53
Nd	6.97	9.16	11.0	17.09	29.45	18.4	12.5	20.2	1.8
Sm	1.08	1.45	2.0	3.71	6.91	3.5	2.9	4.3	0.38
Eu	0.52	0.54	0.70	0.66	1.69	1.0	0.9	0.92	0.87
Gd	0.70	1.015	1.8	2.62	4.97	3.2	3.0	3.7	0.29
Tb	0.09	0.11	0.26	0.41	0.77	0.45	0.52	0.55	0.04
Dy	0.52	0.49	1.2	2.05	3.88	2.3	3.1	3.0	0.26
Ho	0.10	0.09	0.23	0.31	0.64	0.45	0.6	0.55	0.05
Er	0.26	0.20	0.63	0.82	1.86	1.3	2.0	1.7	0.16
Tm	0.03	0.03	0.08	0.13	0.29	0.18	0.24	0.21	0.03
Yb	0.22	0.16	0.55	0.83	1.86	1.2	1.6	1.4	0.18
Lu	0.04	0.02	0.08	0.10	0.22	0.17	0.21	0.19	0.03
Hf	1.9	2.4	3.2	2.0	2.2	6.4	5.0	3.6	2.2
Ta	0.2	0.1	0.2	0.2	0.19	1.0	0.5	1.0	0.1
W	—	—	0.5	0.5	0.1	0.2	0.2	0.1	0.2
Pb	6.7	6.0	7.9	3.6	5.9	6.3	5.9	6.7	22.6
Th	0.6	1.2	1.2	2.8	1.8	3.6	2.8	3.2	1.6
U	0.2	0.2	0.2	0.2	0.2	0.4	1.0	0.6	1.8
Σ REE	46.80	51.97	55.23	93.50	146.26	106.35	71.77	111.12	13.52
Eu/Eu*	1.81	1.37	1.13	0.64	0.88	0.92	0.93	0.71	0.80
$(La/Yb)_N$	37.56	51.70	14.2	19	11.8	11.3	6.1	11.5	14.3
Sr/Y	160.5	227.4	76	18	34	40	15	18	192
K/Rb	431	664	245	364	271	167	537	653	220
Rb/Sr	0.05	0.03	0.27	0.11	0.09	0.1	0.05	0.06	0.74
Rb/Ba	0.09	0.04	0.13	0.11	0.1	0.12	0.06	0.06	0.15

N o t e. Analyzes 1, 2 — performed in IGMOF of NAS of Ukraine, Kyiv; analyzes 3-9 — in Institute of Microelectronics Technology and High-Purity Materials RAS, Russia.

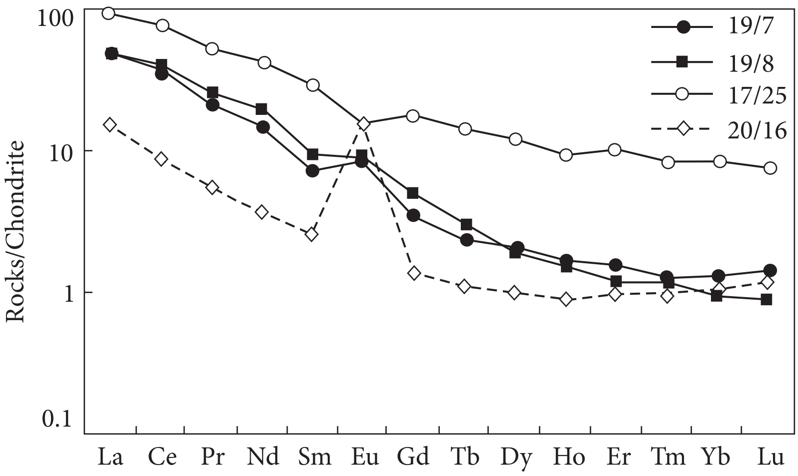

Fig. 7. Chondrite (C1) normaliesed REE patterns for Paleoproterozoic granitoids of the Zachativka-Fedorivka anticline in the Mangush synclinorium [19]

a non-uniform color from yellowish-brown to light brown. Zircon forms tiny rounded transparent grains of light-pink color.

The geochronological studies were based on titanite. According to the obtained geochronological data, the U-Pb isochron age of the titanite from the granodiorites of the Gurzhiy tract site (sample 17/26) is 2025 ± 47 Ma (Table 3, Fig. 8).

The obtained age characterizes the closure of the uranium-lead isotope system in titanite and thus reflects the minimum age of granodiorite.

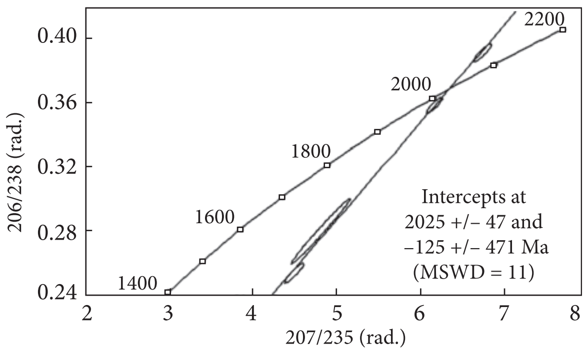

Fig. 8. U-Pb discordia diagram for titanite from granodiorite (sample 17/26)

Table 3. **U and Pb content and Pb isotope composition in titanite from granodiorite (Gurzhiy beam, sample 17/26)**

Titanite fraction	Concentrations, ppm		Isotope ratios					Isotope ages, Ma		
	U	Pb	$^{206}Pb/^{204}Pb$	$^{206}Pb/^{207}Pb$	$^{206}Pb/^{208}Pb$	$^{206}Pb_r/^{238}U$	$^{207}Pb_r/^{235}U$	$^{206}Pb_r/^{238}U$	$^{207}Pb_r/^{235}U$	$^{207}Pb/^{206}Pb$
2627, undivided	47,079	36,482	138,2	4,5356	0,99890	0,35899	6,17019	1977	2000	2023
2628a, >0.07	39,305	39,363	84,5	3,5506	0,87935	0,392205	6,75389	2133	2079	2027
2630, <0.04	80,898	54,0519	100,2	3,8540	0,76069	0,254243	4,47775	1460	1726	2067
2628, >0.07	42,134	28,915	96,7	3,8292	0,89063	0,280570	4,79907	1594	1784	2015

Table 4. **U and Pb content and Pb isotope composition for zircons from granites (Vodyana beam, samples 19/7, 19/8)**

Zircon fraction	Concentrations, ppm		Isotope ratios					Isotope ages, Ma		
	U	Pb	$^{206}Pb/^{204}Pb$	$^{206}Pb/^{207}Pb$	$^{206}Pb/^{208}Pb$	$^{206}Pb_r/^{238}U$	$^{207}Pb_r/^{235}U$	$^{206}Pb_r/^{238}U$	$^{207}Pb_r/^{235}U$	$^{207}Pb/^{206}Pb$
Sample 19/7 (zircon), granite, Vodyana beam										
2749, undivided	439,421	109,629	2270	7.3921	9.0228	0.231298	4.13324	1341.3	1660.9	2092.6
Sample 19/8 (zircon), Vodyana beam										
2751, undivided	1344.68	473,938	14510	7.7676	7.6272	0.324753	5.72956	1812.9	1935.84	2070.11

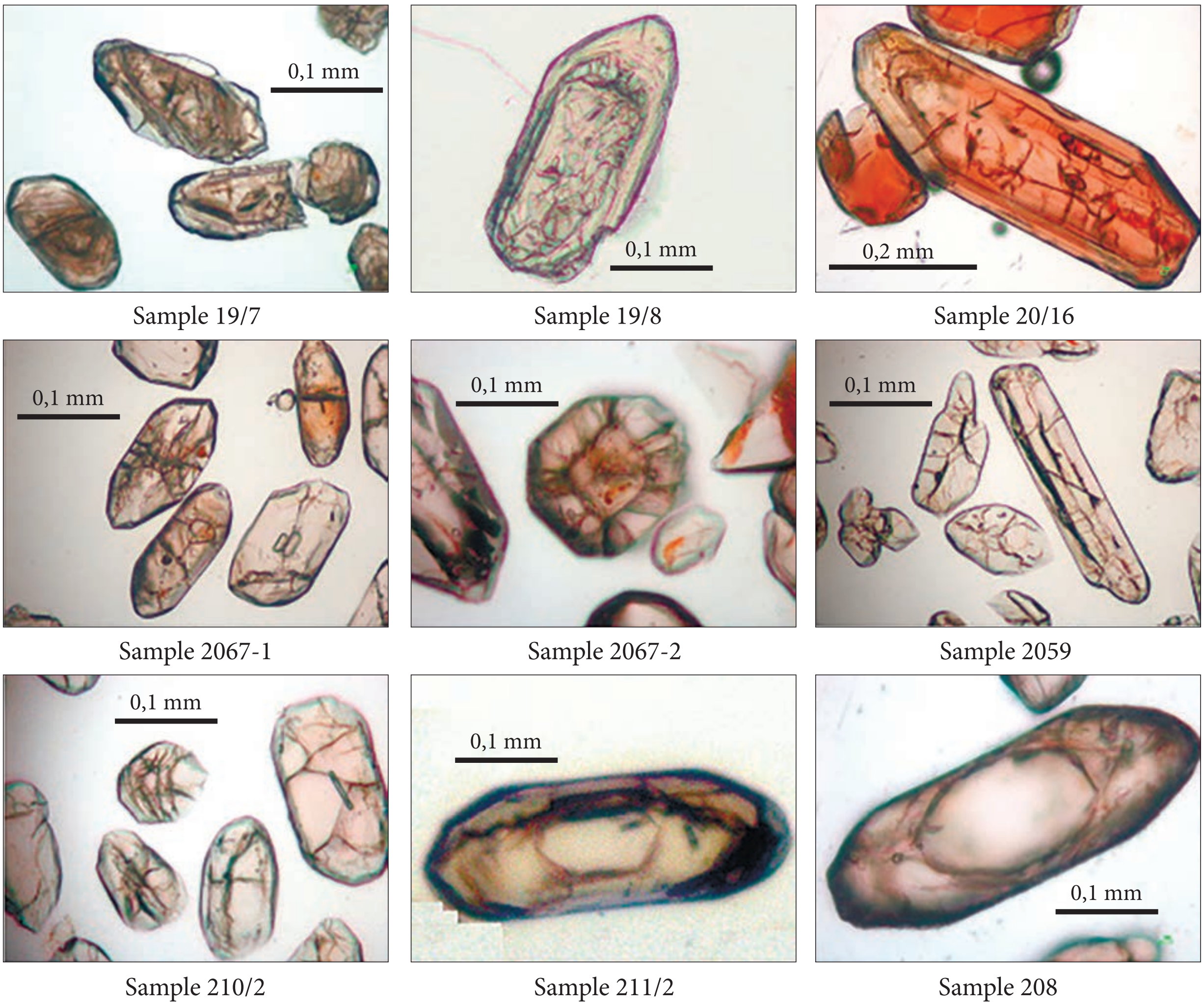

Fig. 9. Microscopic images of zircon crystals from granitoids of the Zachativka-Fedorivka anticline in the Mangush synclinorium. Microscope ECLIPSE LV100 POL

Petrography of leucocratic granites (outcrop on the right bank of the Vodyana Bay, 700 m upstream from the village of Fedorivka — N47°13'08,2"; E37°08'47,2"), sample 19/7. Leucocratic granites are light gray, medium-grained, hypidiomorphic, composed of plagioclase (oligoclase) — 70-75%, quartz — 15-20%, K-feldspar — 10-15%, biotite — 3%, apatite, zircon and titanite — as accessory component. Myrmekite in plagioclase marks the subsolidus alterations.

The leucocratic granites are peraluminous (Fig. 3), plot as granodiorites (Fig. 4) and belong to calc-alkaline series [3] (Fig. 5, Table 1).

Leucocratic granites have a low content of Rb (23.2 ppm) and a high content of Sr (431.7 ppm), low Rb/Sr (0.05) (Table 2). Negative Nb, Ti, Sr, and Eu anomalies can be seen on the spider

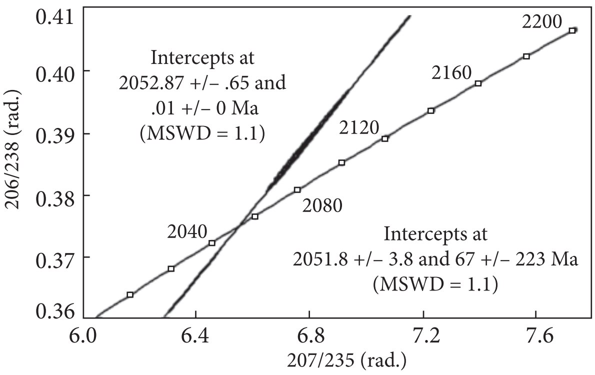

Fig. 10. U-Pb discordia diagram for monazite from subalkaline granites, sample 20-16

diagram (Fig. 6). Chondrite (C1)-normalized REE pattern show highly differentiation ($(La/Yb)_N$ = 37.6) with a positive europium anomaly, Eu/Eu* = 1.81 (Fig. 7).

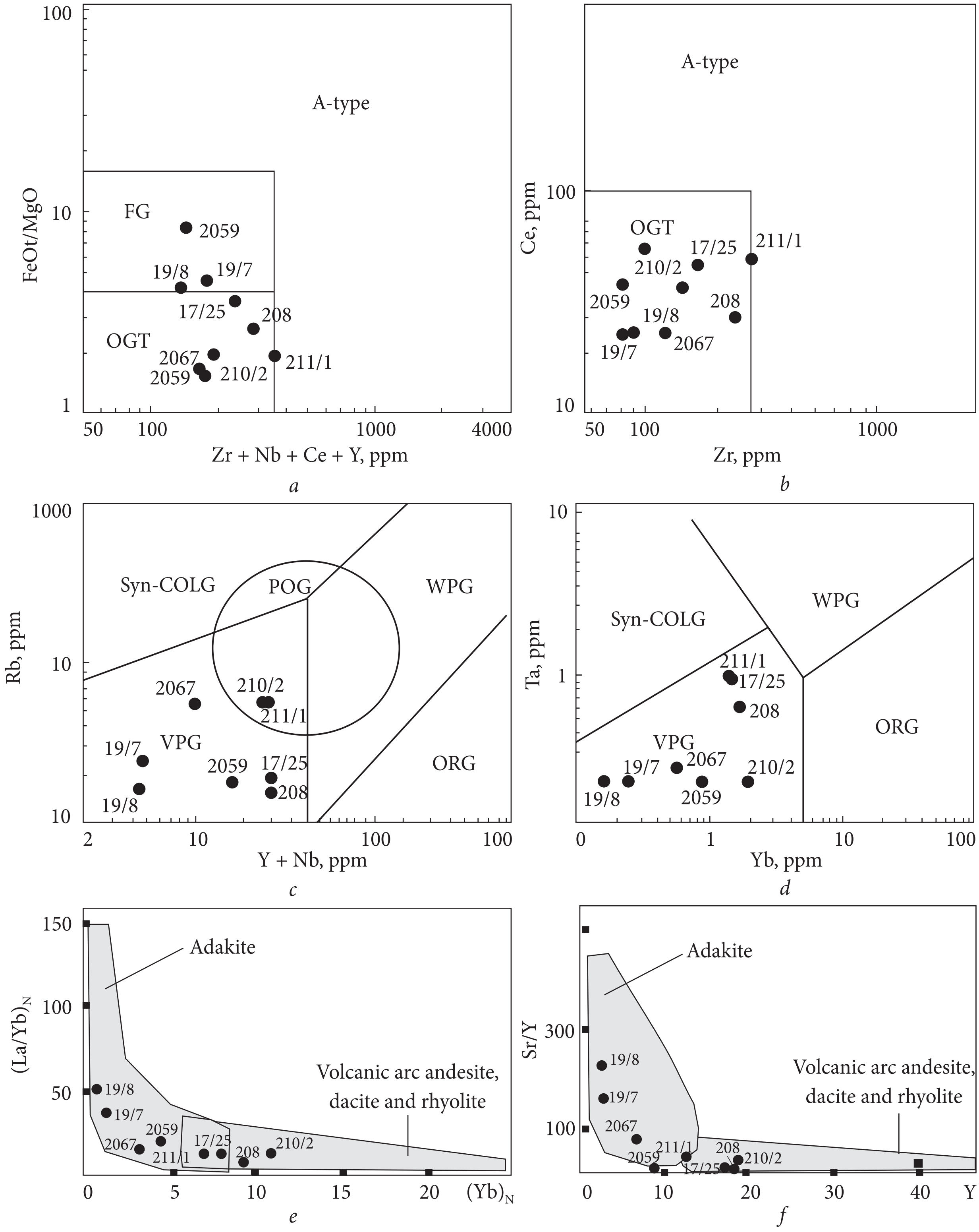

Fig. 11. Discrimination diagrams: *a* — FeO*t*/MgO — Zr-Nb-Ce-Y and *b* — Ce-Zr [20 for the plagiogranitoids]. FG — fractionated granites; OGT — unfractionated M, I and S-type granites; *c, d* — tectonic discrimination diagrams for granitoid rocks [12]: VAG — volcanic arc granites, Syn-COLG — syn-collisional granites, WPG — within-plate granites; ORG — ocean ridge granites; post — COLG — post-collisional granites; *e* — $(La/Yb)_N$—Yb_N and *f* — Sr/Y—Y — diagrams for plagiogranitoids. Fields in the diagram from [6]

They were probably formed during the melting of metabasites. The restite phase of the magmatic source probably contained garnet and/or amphibole.

Zircon characteristics. Zircon crystals from leucogranites (sample 19/7) are long prismatic, with partially rounded ridges and pinkisch in colour. According to the obtained geochronological data, the $^{207}Pb/^{206}Pb$ zircon age is 2092.6 Ma (Tab-le 4). The studied zircon grains contain cores (Fig. 9). Thus, the obtained age may be too old with respect to the time of granite formation.

Petrography of granites (outcrop at the right bank of the Vodyana Bay, below the dam — N47°13'35.9"; E37°9'31.9", sample 19/8). Granites are light grey, slightly pinkisch, medium-grained, hypidiomorphic, composed of plagioclase (oligoclase) — 82%, quartz — 15%, biotite — 5-7%, apatite, zircon and titanite — as accessory component. Myrmekite in plagioclase marks the subsolidus alterations.

The analyzed rocks are peraluminous (Fig. 3), plot as granites (Fig. 4) and belong to calc-alkaline series [3] (Fig. 5; Table 1). Granites has a low content of Rb (15.7 ppm) and a high content of Sr (498 ppm), low Rb/Sr (0.03) (Table 2). Negative Nb and positive Sr and Eu anomalies can be seen on the spider diagram (Fig. 6). Chondrite (C1)-normalized REE pattern show strong REE differentiation ($(La/Yb)_N$ = 51.5) with a positive europium anomaly, Eu/Eu* = 1.37 (Fig. 7).

Zircon characteristics. Zircon crystals are short-prismatic and partly rounded. They are light brown, translucent. The U-Pb age of zircon is 2070.11 Ma (Table 4). The studied zircon grains contain cores (Fig. 9). Thus, the obtained age may be too old with respect to the time of granite formation.

Petrography of pegmatoidal granites (outcrop at the left side of the ravine at its mouth into the Berda river, near the southern outskirts of the village Kalaytanivka — N47°04.218'; E36°58.814', sample 20/16). In this outcrop, an intrusive contact of pegmatoidal granites with calciphyre of the Temryuk Formation of the Central Azov Series is observed. Pegmatoidal granites are composed of oligoclase crystals (80%) having up to 2 × 1 cm in size. Smaller crystals of K-feldspar, quartz, and muscovite occur between them. Large oligoclase crystals are intergrown with quartz. The analyzed rocks are peraluminous (Fig. 3), plot as granites (Fig. 4) and belong to shoshonitic series (Fig. 5, Table 1).

Pegmatoidal granites have high Rb (256 ppm) and Sr (346 ppm) contents, high Rb/Sr ratio (0.74) (Table 2). A negative Nb anomaly and positive Sr and Eu anomalies can be seen on the spider diagram (Fig. 6). Chondrite (C1)-normalized REE pattern show moderate differentiation ($(La/Yb)_N$ = 14.3) with a slightly negative europium anomaly, Eu/Eu* = 0.8 (Fig. 7).

Monazite characteristics. Monazite and zircon have been separated from subalkaline granites (sample 20/16). Shapeless crystals of monazite are brownish to yellow, translucent. Zircon grains are elongated, prismatic, translucent. They contain inclusions of apatite microcrystals and, probably, gas-fluid inclusions (Fig. 9). For that reason, geochronological studies were carried out on monazite. The $^{207}Pb/^{206}Pb$ age of monazite from pegmatoid granites (sample 20/16) is 2051.8 ± 3.8 Ma (Table 5, Fig. 10).

This age represents the minimum age limit for the sedimentary rocks of the Temryuk Formation of the Central Azov Series. The authors [7] esti-

Table 5. **The content of U and Pb and Pb isotope composition in monazite from pegmatoidal granite (Bezimenna beam, Kalaytanivka village, sample 20/16)**

Monazite fraction	Contents, ppm		Isotope ratios					Age, Ma		
	U	Pb	$^{206}Pb/^{204}Pb$	$^{206}Pb/^{207}Pb$	$^{206}Pb/^{208}Pb$	$^{206}Pb_r/^{238}U$	$^{207}Pb_r/^{235}U$	$^{206}Pb_r/^{238}U$	$^{207}Pb_r/^{235}U$	$^{207}Pb/^{206}Pb$
2804, light yellow	7239	14563	611.2	6.7467	0.21522	0.39036	6.8202	2124	2088	2052.9
2805, the same	3886	7148	818.9	7.0067	0.23476	0.38540	6.7328	2101	2077	2052.7
2806, light yellow, Transparent	5997	11850	1200	7.2669	0.21729	0.39189	6.8472	2132	2092	2053.0
2807, light yellow	6169	11907	412.0	6.3052	0.22758	0.38606	6.7408	2105	2078	2051.8
2808, dark yellow	7018	13368	464.0	6.4458	0.23033	0.38650	6.7561	2107	2080	2053.7

mated the time of deposition of carbonate rocks of the Temryuk Formation applying the Rb-Sr and Sm-Nd isotope systematics of marbles and calciphyres. According to these data, carbonate sediments were deposited in the interval of 2.0-2.3 Ga. Our new data allows us to set the limits of the formation of carbonate rocks of the Temryuk Formation between 2.3 and 2.05 Ga.

Geodynamic setting of plagiogranitoids formation. Granitoids of the Zachativka-Fedorivka anticline characterized by high ratio K/Rb (431-664) and low- Rb/Sr (0.03-0.06) and Rb/Ba (0.04-0.09), what is typical of M-type [20] granites (Table 2). The analyzed rocks are characterized as undivided M, I, S type granites (Fig. 11, *a*, *b*). They show the features of volcanic islands arc (Fig. 11, *c*, *d*), with negative Nb and Ti anomalies (Fig. 6). Plagiogranites of the Zachativka-Fedorivka anticline plot as adakites and island-arc rocks (Fig. 11, *e*, *f*). According to the obtained geochemical data, they could have formed during the melting of the lower crust under the influence of plumes in the Paleoproterozoic.

Conclusions. Granitoids of the Zachativka-Fedorivka anticline in the Mangush synclinorium include plagiogranitoids and later pegmatoidal granites. Plagiogranitoids are moderate-potassium rocks of the K-Na geochemical series, predominance Na_2O over K_2O and low Rb/Sr. They are divided into plagiogranites with low contents of HFS elements and positive europium anomalies and granodiorites with higher contents of HFS elements and predominantly negative europium anomalies. The U-Pb age of titanite from granodiorites is 2028 ± 47 Ma. This age corresponds to the closure of the U-Pb isotope system of titanite and thus reflects the minimum age of granodiorite. The $^{207}Pb/^{206}Pb$ age of zircon from granites is 2.07-2.09 Ga. The formation of the Paleoproterozoic plagiogranitoids of the Central Azov may be related to the activization of the mantle beneath the Azov domain during the formation of the East Sarmatian orogen at ca. 2.1 Ga [11, 18]. They could have formed because of partial melting of the lower crust because of underplating of mafic melts. The 2.05 Ga old vein bodies of pegmatoidal subalkaline granites, were probably formed at the stage of collision of the Sarmatia and Volga-Ural continents.

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ГРАНІТОЇДИ ЗАЧАТІВСЬКО-ФЕДОРІВСЬКОЇ АНТИКЛІНАЛІ МАНГУШСЬКОГО СИНКЛІНОРІЮ: ГЕОХІМІЧНІ ОСОБЛИВОСТІ, ПОХОДЖЕННЯ І ВІК (ПРИАЗОВСЬКИЙ ДОМЕН УКРАЇНСЬКОГО ЩИТА)

Етап палеопротерозойського короутворення на Приазовському домені Українського щита залишається недостатньо вивченим. У неоархеї-палеопротерозої Приазовський сегмент архейської кори був фрагментований великими рифтогенними структурами. З цим етапом пов'язане формування неоархей-палеопротерозойських осадово-вулканогенних комплексів центральноприазовської серії (2,76—2,22 млрд рр.) та потужний гранітоїдний магматизм. Мета роботи — геохімічне вивчення інтрузій гранітоїдів Зачатівсько-Федорівської антикліналі Мангушського синклінорію Центрального Приазов'я. В Зачатівсько-Федорівській антикліналі Мангушського синклінорію виділяють плагіогранітоїди та пізніші пегматоїдні граніти. Плагіогранітоїди є помірно калієвими породами, калій-натрієвої петрохімічної серії, з переважанням Na_2O над K_2O і низьким відношенням Rb/Sr (до 0.03). Серед них виокремлюють плагіограніти з низьким вмістом високозарядних елементів з позитивними європієвими аномаліями та гранодіорити з більшим вмістом високозарядних елементів та переважно негативними європієвими аномаліями. U-Pb вік титаніту з гранодіоритів 2028 ± 47 млн рр. Цей вік характеризує час закриття уран-свинцевої ізотопної системи титаніту, отже, відображає мінімальний вік гранодіориту. Свинець-свинцевий вік циркону з гранітів балки Водяна — 2,07—2,09 млрд рр. Свинець-свинцевий вік монациту з пегматоїдних гранітів — 2,05 млрд рр. Формування інтрузій палеопротерозойських плагіогранітоїдів Центрального Приазов'я може бути пов'язане з активізацією мантії під Приазовським доменом під час формування Східно-Сарматського орогену ~2,1 млрд рр. тому. Вони могли утворитися внаслідок часткового плавлення нижньої кори внаслідок андерплейтингу базитових розплавів. Жильні тіла пегматоїдних сублужних гранітів, віком 2,05 млрд рр. утворилися, імовірно, на етапі колізії Сарматського та Волго-Уральського континентів.

Ключові слова: Приазовський домен, Український щит, Мангушський синклінорій, гранітоїди, палеопротерозой, Східно-Сарматський ороген, форланд, колізія, ізотопний вік, сфен, циркон, монацит.