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THE AGE OF SEDIMENTARY-VOLCANOGENIC ROCKS OF THE CHORTOMLYK IRON DEPOSIT, THE MIDDLE DNIPRO DOMAIN OF THE UKRAINIAN SHIELD

The greenstone belts in the Middle Dnipro Domain of the Ukrainian Shield comprise sedimentary-volcanogenic rocks of the Konka and Bilozerka Groups separated by a unconformity. The Konka Group is composed mainly of volcanic rocks varying in composition from ultrabasic to felsic composition with subordinate sedimentary rocks, while the Bilozerka Group is composed of sedimentary rocks with a small amount of felsic volcanic rocks. Three associations of ferruginous-siliceous rocks have been identified in the greenstone rocks of the Middle Dnipro Domain. These are the ferruginous-siliceous-mafic and ferruginous-siliceous-keratophyre (schist-jaspilite-tholeiite) associations in the Konka Group and the transitional ferruginous-siliceous-shale to ferruginous-siliceous-keratophyre association in the Bilozerka Group, which many researchers compare with the ferruginous-siliceous formations of Kryvyi Rih Group. The rocks of the early ferruginous-siliceous-mafic association (Konka Group) are found among the volcanogenic rocks with a komatiite-tholeiitic association. These rocks are intruded by 3.08-3.0 Ga-old plagioclase granites of the Sura Complex. In the younger ferruginous-siliceous-keratophyre (schist-jaspilite-tholeiite) association (Bilozerka Group), ferruginous-siliceous deposits are interlayered with sedimentary and tuffaceous rocks and reach a thickness of up to 350 m. The Chortomlyk iron ore deposit, which is located in the Chortomlyk Greenstone Belt, is confined to this rock association. The ages of the iron-bearing rocks has not been constrained to date. We dated 60 detrital zircon grains from quartz-amphibole schists sampled at a section of sedimentary-volcanogenic rocks of the Chortomlyk deposit. Fifty-three analyzed crystals yielded an age of 3.08-3.12 Ga; six crystals were dated at 3.08-3.06 Ga, and one crystal at 3.18 Ga.

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They all have low U contents (1.4-20 ppm), while the Th/U ratio falls in the range of 0.3-0.9, indicating a likely magmatic origin. Sedimentary-volcanogenic rocks of the Chortomlyk iron ore deposit could been formed on a marine shelf near uplifted highs of plagioclase granites of the Sura Complex (dated at 3.08-3.06 Ga), or near volcanoes of the same age. Thus, the sedimentary-volcanogenic rocks of the Chortomlyk iron deposit are younger than the rocks of the Konka Group. Similar detrital zircon ages were previously obtained from the ferruginous-siliceous association of the Bilozerka Group in the Bilozerka Greenstone Belt (3.05 Ga) and the Vysokopillya Greenstone Belt (3.06 Ga). Thus, the ferruginous-siliceous-mafic association formed before the plagioclase granites of the Sura Complex, while the ferruginous-siliceous-keratophyre (schist-jaspilite-tholeiite) association was formed after the emplacement of the plagioclase granites.

Keywords: *Middle Dnipro Domain, Chortomlyk greenstone belt, sedimentary rocks, Konka Group, detrital zircon, Chortomlyk iron deposit, schist-jaspilite-tholeiite association, U-Pb age.*

Introduction. Sedimentary rocks are a common component of the Archean greenstone belts and can reach a thickness of up to several kilometers (Condi, 1983). They record information regarding the depositional environment, age and, in the case of the clastic rocks, the provenance. In the Middle Dnipro Domain of the Ukrainian Shield, the Chortomlyk, Vysokopillya, Verkhivtseve, Sura, Konka, Bilozerka, Sofiivka and several smaller greenstone belts are known. They are often considered as rifts developed in the Palaeoarchean-Mezoarchean basement of the Auly Group rocks (Bobrov et al., 2002; Semenenko et al., 1978; Semenenko et al., 1967). The greenstone belts are composed of sedimentary-volcanogenic rocks of the Konka and Bilozerka Groups, that are separated by a unconformity (Semenenko et al., 1967). The Konka Group is composed mainly of volcanic rocks varying in composition from ultrabasic to felsic, with subordinate sedimentary rocks, while the Bilozerka Group is composed of sedimentary rocks with a small amount of felsic volcanic rocks (Semenenko et al., 1967; Strueva et al., 1979). The rocks of the Konka Group are cut by plagioclase granites of the Sura Complex (3.08-3.0 Ga) (Shcherbak et al., 2006), while the Bilozerka Group is not cut by granite intrusions (Semenenko et al., 1967). Three associations of ferruginous-siliceous rocks have been identified in the greenstone belts of the Middle Dnipro Domain. These are the ferruginous-siliceous-mafic and ferruginous-siliceous-keratophyre (schist-jaspilite-tholeiite) associations in the Konka Group and the transitional ferruginous-siliceous-shale to ferruginous-siliceous-keratophyre association in the Bilozerka Group, which many researchers compare with the ferruginous-siliceous formations of Kryvyi Rih Group (Semenenko et al., 1978; Semenenko et al., 1967; Sivoronov et al., 1990). The rocks of the early ferruginous-siliceous-mafic association are a few tens of meters thick and are found among the volcanogenic rocks of the komatiite-tholeiitic association. They are older than 3.08 Ga. In the younger ferruginous-siliceous-keratophyre association, the ferruginous-siliceous deposits are interlayered with sedimentary and tuffaceous rocks. In the Chortomlyk greenstone belt, it reaches a thickness of up to 350 m (Semenenko et al., 1978). The age of the ferruginous-siliceous rocks in this formation remained unknown.

Geological structure of the studied area.

The Chortomlyk greenstone belt is a northeast-trending syncline with a total width of 15-18 km and an area of up to 500 km^2 (Semenenko et al., 1978; Semenenko et al., 1967) (Fig. 1). It is affected by folding and faulting. The flanks of the structure are composed of metamorphosed volcanic rocks of basic and ultrabasic composition (Sura Formation of the Konka Group; komatiite-tholeiite association) (Bobrov et al., 2002; Koliy et al., 1991; Semenenko et al., 1967). They have a steep (45-80°) dip towards the centre of the syncline. The middle of the syncline is composed of less metamorphosed rocks, including metamorphosed felsic to intermediate volcanic rocks, quartz-sericite, quartz-chlorite, and other varieties of schists belonging to the Chortomlyk Formation (dacite-andesite-tholeiite association) (Bobrov et al., 2004; Bobrov et al., 2002; Malyuk et al., 1989; Semenenko et al., 1978; Semenenko et al., 1967).

The initial stages of the eruption of the komaiite-tholeiitic association (the Sura Formation) were confined to the linear deep fault zones, exceeding 30 km in length (Kornienko et al., 2001; Semenenko et al., 1967). In contrast, the eruption of dacite-andesite-tholeiitic volcanogenic rocks of the Chortomlyk Formation was associ-

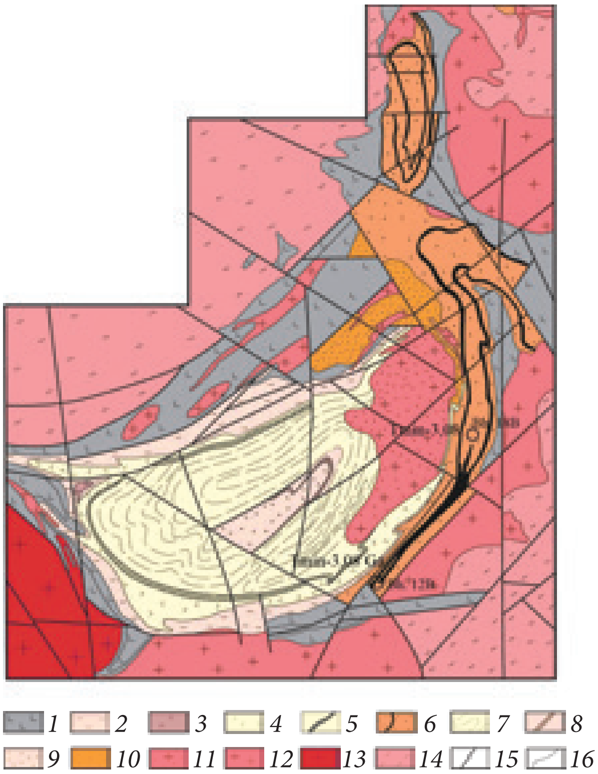

Fig. 1. Schematic geological map of Chortomlyk greenstone belt modified from (Bobrov et al., 2004; Kornienko et al., 2001). *Metakomatiite association: 1* — complex KT-1; *2* — complex KT-2; *3* — dunite-harzburgite association; *4* — complex KT-3; *5* — complex KT-4; *6* — complex of shale-jaspilite-tholeiite; *7* — metadacite-tholeiite-andesite association: *8* — lower complex; *9* — upper complex; *10* — rhyodacite and tonalite-plagioclase granite association; *11* — subvolcanic facies; *12* — hypabyssal facies; *13* — granite of the Tik massif; *14* — granite-gneissic basement; *15* — faults; *16* — geological boundaries

ated with central-type volcanoes (Bobrov et al., 2004; Bobrov et al., 2002; Kushinov et al., 1988; Kornienko et al., 2001). The youngest are the felsic volcanic rocks of the Solone Formation, distributed within three large volcanogenic fields located around the Novomykolaivka plagioclase granite massif (Bobrov et al., 1993a; Bobrov et al., 1993b). The stratigraphic and formational affiliation of the sedimentary and volcanic rocks of the Chortomlyk iron ore deposit, according to the materials of various geological exploration works, is not unambiguous. According to the results of geological mapping carried out within the Chortomlyk structure of such types of geological exploration works as large-scale (1: :50,000) deep geological mapping (GGK), geological additional study of areas (GDP) and geological and predictive mapping (GPK) according to Bobrov O. all rock assemblages containing ferruginous quartzites belong to the litho-facies series of jespilite-silica-schist formation types (Konka stratigraphic level).

The Chortomlyk iron deposit is confined to the syncline, which can be traced along the southeastern side of the greenstone belt up to 18 km (Kochanov et al., 1969; Semenenko et al., 1978; Semenenko et al., 1967). The iron deposit is located in the southern part of this structure. The ferruginous rocks comprise three layers with a maximum thickness of 300 m for the eastern (lower), 22 m for the middle, and 85 m for the western (upper) layers. A characteristic feature of this unit is rhythmic alternation of packages of chemogenic ferruginous-siliceous (jasper), chemogenic-sedimentary (biotite-carbonate-chlorite-quartz schist with magnetite and cummingtonite) and tuffaceous-sedimentary rocks. The lowermost metasedimentary rock unit (20-50 m), which overlies amphibolites of the Sura Formation, can be traced throughout the ore strata and is characterised by a variable composition. It is composed of (muscovite, biotite, amphibole, chlorite, plagioclase, quartz) schists, quartzite, quartz metasandstones, tuffaceous metasandstones, plagioclase metatuffs, and green schists. The ferruginous rocks are overlain by metamorphosed mafic, intermediate and felsic volcanic rocks, quartz-chlorite and quartz-sericite schists (Semenenko et al., 1978; Semenenko et al., 1967).

Research Objectives. The history of the formation of the greenstone belts in the Middle Dnipro Domain is still poorly studied. The lower part of the section, which is mainly composed of metamorphosed basalts and komatiites of the Sura Formation, does not contain zircon, except for the interlayers of sedimentary and tuffaceous rocks that can bear zircon (Strueva et al., 1979). Of particular interest are the rocks of the ferruginous-siliceous association, which are important markers within the Early Precambrian regionally. The purpose of our work was to determine the age limit of the formation of the ferruginous-siliceous-keratophyre (schist-jaspilite-tholeiite) associationin the Middle Dnipro Domain, which hosts the Chortomlyk iron deposit. Early studies attributed the sedimentary-volcanogenic section of the Chortomlyk iron ore deposit to the Upper Bazavluk Group (B_2^1) (Se-

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menenko et al., 1967) which is composed of sedimentary and felsic effusive rocks with subordinate basic volcanic rocks and chemogenic ferruginous-siliceous sediments. Later, these rocks were attributed to the shale-jaspilite-tholeiite association and assigned to the Konka Group (Sivoronov et al., 1990). To solve this problem, we dated detrital zircon from quartz-amphibole schists from the section of the sedimentary-volcanogenic rocks of the Chortomlyk iron deposit (drillhole 12-B) (Fig. 1).

Research methods. Zircon was separated from the quartz-amphibole schist (sample 85-231) using a shaking table, heavy liquids, and a magnetic separator to produce a heavy non-magnetic fraction. Zircons were hand-picked under a binocular microscope and their morphology was studied under an optical microscope. The U-Th-Pb analyses were conducted by laser ablation-inductively coupled mass spectrometry (LA-ICP-MS) on crystals in epoxy mounts at the Department of Geology, Trinity College, Dublin, Ireland. A Photon Machines Analyte Excite 193 nm ArF excimer laser-ablation system with a HelEx 2-volume ablation cell, coupled to an Agilent 7900 mass spectrometer was employed. Line scans on NIST612 standard glass were used to tune the instrument, by obtaining a Th/U ratio close to unity and low oxide production rates (i.e., ThO^+/Th^+ typically <0.15%). A circular laser spot of 24 μm, a repetition rate of 11 Hz and a fluence of 2.25 J/cm^2 were employed. The helium carrier gas was fed into the laser cell at ~0.4 l/min^1, and was mixed with ~0.6 l/min Ar make-up gas and 11 ml/min N_2. Each analysis comprised 27.3 s of ablation (300 shots) and 12 s of wash out time and the latter portions of the washout were used for baseline measurements. The data reduction of raw U-Th-Pb isotopic data was undertaken using the freeware IOLITE package (Paton et al., 2011), with the "Vizual Age" data reduction scheme (Petrus et al., 2012). The primary U-Pb zircon calibration reference material was 91500 zircon (^{206}Pb-^{238}U age of 1065.4±0.6 Ma (Wiedenbeck et al., 1995; Wiedenbeck et al., 2004) and the secondary reference materials were Plešovice zircon (^{206}Pb-^{238}U age of 337.13 ± 0.37 Ma (Slama et al., 2008) which yielded an age of 338.7 ± 1.0 Ma (^{206}Pb-^{238}U age weighted mean age, n = 109) and WRS 1348 zircon (^{206}Pb-^{238}U age of 526.26 ± 0.70 (Pointon et al., 2012) which

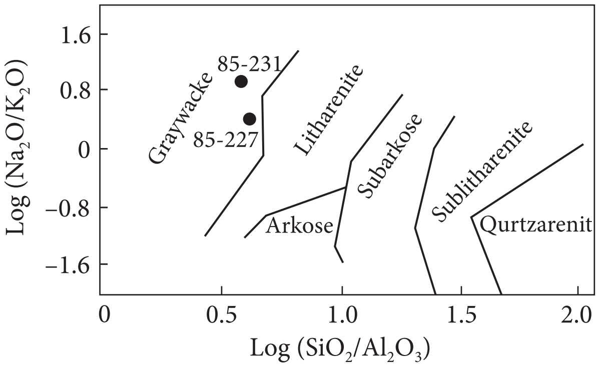

Fig. 2. log(SiO_2/Al_2O_3) — log(Na_2O/K_2O) (Pettijohn et al., 1976) biplot for quartz-amphibole schists from the sedimentary-volcanogenic rocks of the Chortomlyk iron deposit

Table 1. **Chemical composition of quartz-amphibole schists from sedimentary-volcanogenic rocks of the Chortomlyk iron deposit, %**

Oxides	1/ 85-227	2/ 85-231
SiO_2	67.18	50.15
TiO_2	0.44	1.28
Al_2O_3	13.07	13.38
Fe_2O_3	1.72	1.57
FeO	2.60	8.15
MnO	0.05	0.14
MgO	3.02	7.26
CaO	4.72	6.50
Na_2O	3.72	3.50
K_2O	1.45	0.35
P_2O_5	0.03	0.06
S_{tot}	0.13	0.08
H_2O^-	<0.01	<0.01
LOI	2.33	7.80
Σ	100.46	100.22

N o t e. 1 — quartz-amphibole schist, drillhole 12-B, depth 164.3-168 m (sample 85-227); 2 — quartz-amphibole schist, drillhole 12-B, depth 228-229 m (sample 85-231). Chemical analyses were performed in the laboratory of the M.P. Semenenko IGMOF of NAS of Ukraine.

yielded an age of 526.6 ± 2.0 Ma (^{206}Pb-^{238}U age weighted mean age, n = 130). Final ages were calculated using Isoplot (Ludwig, 2011).

Geochemistry of the dated metasedimentary rocks.

On a log(SiO_2/Al_2O_3) — log(Na_2O/K_2O) diagram (Pettijohn et al., 1976), quartz-amphibole schists plot in the field of greywacke (Table 1, Fig. 2) and, thus, they are immature sedimentary rocks. The REE pattern is weakly differentia-

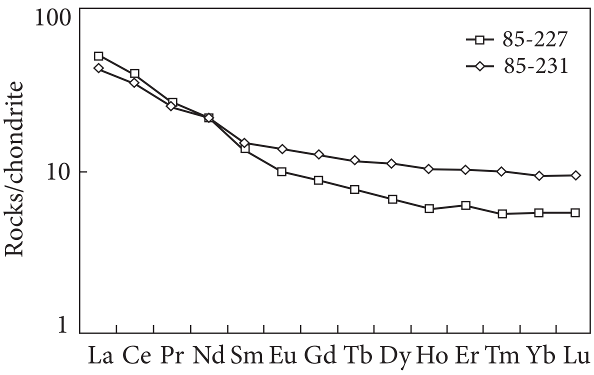

Fig. 3. Chondrite-normalized REE pattern for the quartz-amphibole schists for the sedimentary-volcanogenic rocks of the Chortomlyk iron deposit. Chondrite composition after (Sun, McDonough, 1989)

ted $(La/Yb)_N$ = 4.6-9.31. Eu/Eu* — 0.89-1.01 (Table 2, Fig. 3). They are enriched in Cu (63-109 ppm) and Zn (49.6-54.3 ppm).

Results of mineralogical and geochronological studies of zircon.

Quartz-amphibole schist (sample 85-231). Short-prismatic crystals with an aspect ratio of c. 2 prevail (70%), while crystals with an aspect ratio of 3-4 make up to 30% of the detrital zircon population (Fig. 4). The edges of zircon crystals are often rounded. The zircon crystals reveal thin oscillatory zoning and can reach 0.10× ×0.25 mm in size. The zircon is light-brown, transparent to opaque (Fig. 5, *a*, *b*, *c*). Needle-like apatite inclusions are often observed.

In this study, a total of 60 zircon crystals were dated (Table 3, Fig. 6). Of these, 53 crystals yielded ages of 3.08-3.12 Ga; 6 crystals were dated at 3.06-3.08 Ga and one crystal was 3.18 Ga old. The zircon has low uranium U content (1.4-20 ppm); three crystals contain up to 30-43 ppm of U. The Th/U ratio is 0.3-0.9. The crystals with discordant ages have higher U, Th, and Pb concentrations than those with concordant dates.

Discussion of the results and conclusions. Based on the geochemical data, quartz-amphibole schists from the sedimentary-volcanogenic succession of the Chortomlyk iron deposit correspond to greywackes. The Th/U ratio in zircon (0.3-0.9) indicates the magmatic nature of their source. Results of the U-Pb dating of detrital zircon demonstrate a uniform distribution of the obtained ages. In combination with the homogeneous zircon appearance and relatively

Table 2. **Trace element composition of the quartz-amphibole schists from sedimentary-volcanogenic rocks of the Chortomlyk iron deposit, ppm**

Component	1/ 85-227	2/ 85-231	Component	1/ 85-227	2/ 85-231	Component	1/ 85-227	2/ 85-231
Bi	9.9	9.8	Ag	BDL	BDL	Lu	0.14	0.24
Be	0.60	0.41	Cd	"	"	Hf	3.4	2.9
Sc	9.0	20.6	Sn*	1.7	1.7	Ta	0.41	3.3
V	60	138	Sb	0.24	0.76	W	1.0	0.87
Cr	26.7	70.8	Te	BDL	BDL	Re	BDL	BDL
Co	12.9	23.8	Cs	3.1	1.8	Ir	"	"
Ni	31.9	68	Ba	667	287	Pt	"	"
Cu	62.1	109	La	12.2	10.2	Au	"	"
Zn	54.3	49.6	Ce	23.9	21.4	Hg	—	—
Ga	16.8	18.3	Pr	2.5	2.4	Tl	0.41	0.67
As	0.21	4.2	Nd	9.8	10.0	Pb	3.7	3.1
Se	BDL	<1.3	Sm	2.1	2.3	Bi	0.089	0.14
Rb	66.1	71.1	Eu	0.57	0.81	Th	4.9	3.4
Sr	77.0	44.4	Gd	1.8	2.6	U	1.2	1.0
Y	9.7	14.2	Tb	0.29	0.44	ΣREE	57.41	57.32
Zr	141	97.7	Dy	1.7	2.8	$(La/Yb)_N$	9.31	4.6
Nb	4.3	17.7	Ho	0.33	0.58	Eu/Eu*	0.89	1.01
Mo	1.2	2.2	Er	1.0	1.7	Th/U	4.08	3.4
Rh	BDL	BDL	Tm	0.14	0.25			
Pd	"	"	Yb	0.94	1.6			

N o t e. BDL stands for below the detection limit.

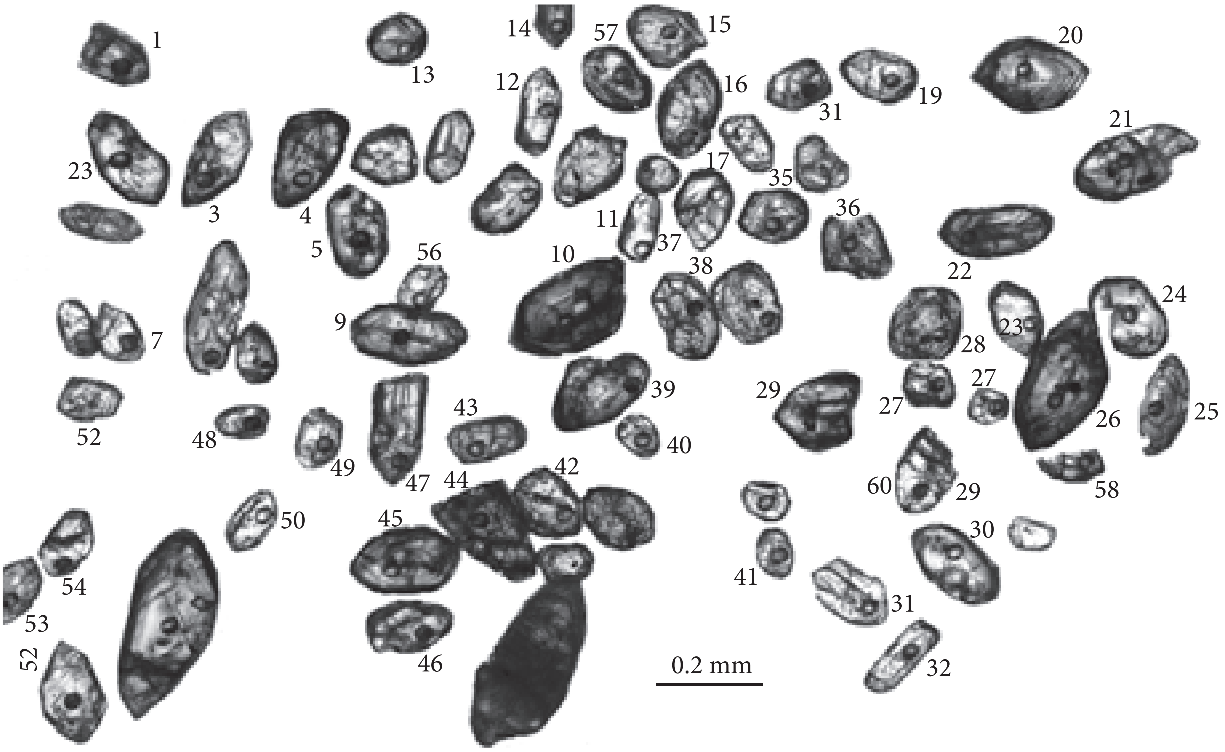

Fig. 4. Optical images of the studied detrital zircon crystals from quartz-amphibole schist (sample 85-231, Chortomlyk greenstone structure, Dh. 12-B, depth 149.8-154.5 m), with indicated numbers of U-Pb analyses (see Table 3)

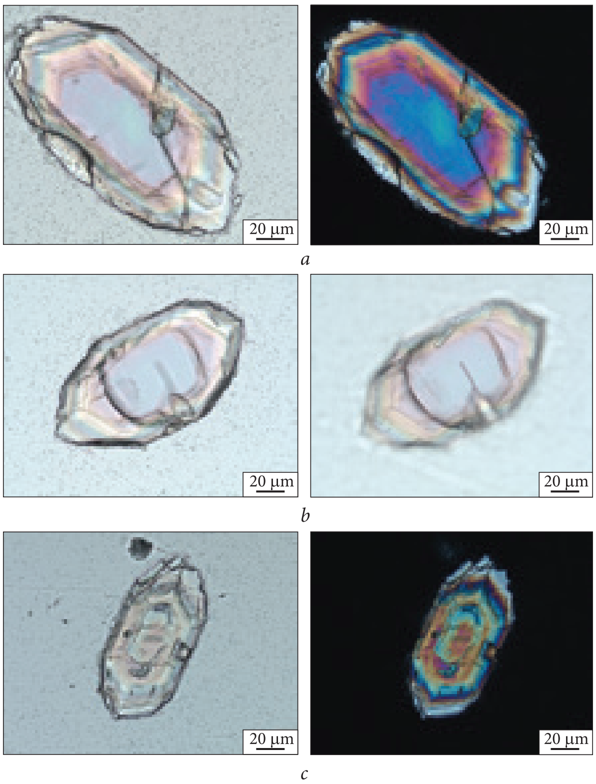

Fig. 5. Microscopic images (*a*, *b*, *c*) of zircon crystals from quartz-amphibole schist (sample 85-231, Chortomlyk greenstone structure, drillhole 12-B, depth 149.8-154.5 m), Microscope ECLIPSE LV100 POL

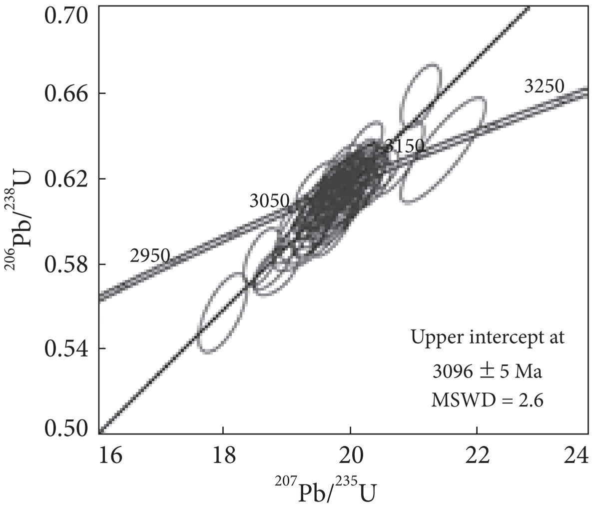

Fig. 6. U-Pb concordia diagram for detrital zircon from the quartz-amphibole schist (Chortomlyk greenstone belt, drillhole 12-B, depth 149.8-154.5 m)

poor rounding, it indicates a local uniform source of the detritus. It should be noted that zircon from the previously studied quartz-chlorite-carbonate schist sampled at the drillhole 18B, depth 216.7-242.8 m, sample 85-247 (Fig. 1) yielded more heterogeneous and old ages. One of the dated grains had an age identical to those

Table 3. **Results of U-Pb dating of detrital zircon from quartz-amphibole schist from sedimentary-volcanogenic rocks of the Chortomlyk iron deposit, Chortomlyk greenstone belt (sample 85-231)**

#	Concentration, ppm			Th/U	Isotope ratio							Isotope age, Ma					
	U	Th	Pb		$^{207}Pb/^{235}U$	2σ	$^{206}Pb/^{238}U$	2σ	Rho	$^{207}Pb/^{206}Pb$	2σ	$^{207}Pb/^{235}U$	2σ	$^{206}Pb/^{238}U$	2σ	$^{207}Pb/^{206}Pb$	2σ
1	295	220	327	0.7	19.86	0.26	0.6090	0.0100	0.82	0.2334	0.0025	3084	13	3065	40	3075	17
2	242	103	153	0.4	20.18	0.37	0.6160	0.0100	0.65	0.2361	0.0031	3103	18	3103	40	3098	20
3	245	107	146	0.4	19.55	0.24	0.5976	0.0091	0.63	0.2368	0.0032	3068	12	3019	37	3096	21
4	270	111	157	0.4	18.88	0.30	0.5758	0.0094	0.56	0.2370	0.0037	3034	15	2930	38	3101	24
5	80	56	86	0.7	19.66	0.47	0.6020	0.0130	0.70	0.2347	0.0040	3072	23	3037	51	3086	28
6	229	117	149	0.5	19.33	0.33	0.6010	0.0100	0.64	0.2362	0.0041	3057	17	3032	41	3091	28
7	318	260	327	0.8	18.65	0.24	0.5820	0.0110	0.57	0.2321	0.0030	3023	13	2956	45	3066	21
8	365	335	465	0.9	18.84	0.25	0.5771	0.0083	0.78	0.2372	0.0021	3033	13	2936	34	3103	15
9	140	99	137	0.7	19.86	0.24	0.6120	0.0100	0.75	0.2358	0.0025	3083	12	3074	41	3090	17
10	94	38	49	0.4	19.89	0.27	0.6081	0.0081	0.27	0.2355	0.0040	3087	13	3061	32	3086	27
11	249	122	162	0.5	20.09	0.22	0.6123	0.0074	0.64	0.2372	0.0028	3097	11	3078	29	3100	19
12	177	138	192	0.8	19.63	0.27	0.6060	0.0090	0.33	0.2349	0.0049	3073	13	3054	36	3084	33
13	231	147	197	0.6	19.92	0.28	0.6188	0.0091	0.74	0.2354	0.0027	3088	13	3103	36	3087	18
14	285	172	226	0.6	19.48	0.27	0.6053	0.0097	0.88	0.2336	0.0024	3066	13	3041	35	3077	16
15	141	72	102	0.5	19.83	0.30	0.5970	0.0120	0.78	0.2387	0.0032	3083	15	3018	46	3110	21
16	302	197	266	0.7	19.41	0.21	0.5909	0.0072	0.68	0.2374	0.0021	3062	10	2992	29	3104	14
17	170	86	118	0.5	19.86	0.38	0.6040	0.0130	0.75	0.2365	0.0037	3084	18	3043	52	3096	25
18	219	140	196	0.6	21.58	0.56	0.6320	0.0200	0.85	0.2481	0.0037	3164	26	3150	79	3177	22
19	360	294	428	0.8	20.11	0.21	0.6188	0.0078	0.42	0.2350	0.0027	3098	10	3104	31	3088	19
20	172	84	130	0.5	20.36	0.28	0.6217	0.0089	0.74	0.2375	0.0025	3107	13	3115	35	3102	17
21	390	233	369	0.6	19.74	0.75	0.6050	0.0240	0.82	0.2376	0.0045	3076	37	3046	97	3102	30
22	245	215	418	0.9	21.22	0.26	0.6570	0.0120	0.60	0.2332	0.0031	3148	12	3253	47	3073	21
23	189	84	129	0.4	19.83	0.21	0.6118	0.0071	0.59	0.2348	0.0027	3082	10	3076	29	3083	18
24	162	82	144	0.5	20.28	0.31	0.6244	0.0096	0.68	0.2356	0.0026	3103	15	3126	38	3089	18
25	226	113	188	0.4	20.05	0.37	0.6110	0.0120	0.71	0.2403	0.0034	3092	18	3078	48	3120	23
26	192	74	130	0.4	20.23	0.22	0.6260	0.0089	0.71	0.2349	0.0026	3104	11	3137	36	3084	18
27	259	113	197	0.4	20.20	0.22	0.6166	0.0085	0.71	0.2387	0.0026	3100	10	3095	34	3114	18
28	302	190	321	0.6	20.02	0.31	0.6187	0.0085	0.53	0.2380	0.0036	3091	15	3104	34	3105	24
29	209	92	164	0.4	20.85	0.34	0.6280	0.0140	0.76	0.2409	0.0034	3136	15	3137	56	3124	23
30	218	79	139	0.4	19.79	0.25	0.6097	0.0083	0.65	0.2349	0.0028	3083	12	3067	33	3086	19

30	218	79	139	0.4	19.79	0.25	0.6097	0.0083	0.65	0.2349	0.0028	3083	12	3067	33	3086	19
31	125	54	99	0.4	19.93	0.38	0.6130	0.0120	0.56	0.2351	0.0038	3086	19	3082	48	3089	25
32	443	287	539	0.6	19.46	0.24	0.5939	0.0096	0.64	0.2363	0.0029	3066	12	3004	39	3093	19
33	197	69	130	0.4	20.09	0.29	0.6180	0.0110	0.77	0.2347	0.0025	3094	14	3099	42	3085	18
34	326	162	307	0.5	20.28	0.38	0.6160	0.0110	0.56	0.2403	0.0036	3103	18	3091	45	3120	24
35	245	103	197	0.4	19.93	0.23	0.6154	0.0086	0.67	0.2352	0.0025	3087	11	3090	35	3086	17
36	267	118	236	0.4	19.85	0.43	0.6090	0.0110	0.84	0.2330	0.0022	3083	21	3064	44	3072	16
37	154	41	81	0.3	19.89	0.20	0.6122	0.0072	0.38	0.2361	0.0029	3085	10	3078	29	3092	19
38	223	113	190	0.5	18.02	0.32	0.5560	0.0150	0.65	0.2335	0.0039	2990	17	2846	64	3074	27
39	261	85	175	0.3	19.94	0.23	0.6201	0.0085	0.54	0.2328	0.0022	3087	11	3109	34	3070	15
40	195	81	158	0.4	19.99	0.26	0.6194	0.0093	0.77	0.2344	0.0024	3090	13	3111	36	3081	16
41	186	106	236	0.6	19.71	0.31	0.6070	0.0100	0.81	0.2358	0.0024	3076	15	3057	40	3090	16
42	229	71	138	0.3	20.22	0.26	0.6230	0.0100	0.77	0.2352	0.0028	3101	12	3120	40	3086	19
43	323	81	171	0.3	19.85	0.22	0.6158	0.0082	0.47	0.2362	0.0026	3085	11	3092	33	3093	17
44	158	55	112	0.3	19.34	0.31	0.5910	0.0100	0.58	0.2369	0.0035	3058	16	2999	43	3097	24
45	202	70	153	0.3	20.13	0.39	0.6110	0.0120	0.74	0.2398	0.0034	3096	19	3071	46	3117	22
46	160	60	120	0.4	19.86	0.23	0.6159	0.0081	0.57	0.2345	0.0025	3085	11	3092	32	3081	17
47	367	170	352	0.5	19.56	0.30	0.6148	0.0097	0.66	0.2321	0.0025	3068	15	3094	40	3065	17
49	305	159	294	0.5	19.13	0.24	0.5887	0.0080	0.77	0.2371	0.0023	3047	12	2983	32	3099	15
50	222	67	143	0.3	19.93	0.28	0.6224	0.0099	0.68	0.2326	0.0034	3087	14	3119	39	3073	23
51	300	110	223	0.4	19.79	0.27	0.5992	0.0095	0.60	0.2399	0.0027	3080	13	3025	38	3118	18
52	150	56	117	0.4	19.65	0.33	0.6050	0.0120	0.68	0.2343	0.0037	3077	17	3050	46	3080	25
53	286	114	239	0.4	20.30	0.25	0.6331	0.0096	0.69	0.2312	0.0027	3105	12	3166	39	3059	19
54	290	134	287	0.5	19.97	0.45	0.6110	0.0140	0.68	0.2384	0.0043	3087	22	3080	52	3106	29
55	268	82	175	0.3	19.95	0.47	0.6150	0.0150	0.83	0.2344	0.0029	3084	23	3084	59	3083	19
56	279	115	223	0.4	19.49	0.24	0.6021	0.0096	0.68	0.2355	0.0027	3066	12	3037	39	3092	19
57	144	42	90	0.3	20.44	0.35	0.6221	0.0091	0.46	0.2377	0.0033	3111	17	3117	36	3108	24
58	390	234	470	0.6	19.84	0.29	0.6110	0.0100	0.81	0.2369	0.0024	3082	14	3075	41	3098	16
59	560	379	731	0.7	19.80	0.22	0.6079	0.0089	0.72	0.2367	0.0024	3082	11	3065	35	3098	16
60	293	141	265	0.5	19.74	0.29	0.6016	0.0090	0.58	0.2375	0.0033	3077	14	3035	36	3101	22

found in this study, while other grains were dated at 3.19-3.17 Ga and 3.23 Ga (Artemenko et al., 2014). These older age scan be also explained by local sources. For instance, an age of 3.19-3.18 Ga was obtained for tonalite gneiss in the basement of the Chortomlyk greenstone structure (Samsonov et al., 1996). We assume that sedimentary-volcanogenic rocks of the Chortomlyk iron deposit were accumulated in a shallow (shelf) sea basin near uplifted highs of plagioclase granite, or near the central-type volcanoes. They were formed either soon after the formation of the TTG of the Sura Complex which was dated at 3.08 Ga (Shcherbak et al., 2006), or their accumulation occurred simultaneously with volcanic eruptions of the same age. Similar ages were obtained for the ferruginous-siliceous association of the Bilozerka Group in the Bilozerka greenstone belt, the age of detrital zircon from which is 3.05 Ga (Bibikova et al., 2010), and in the Vysokopillya greenstone belt, in which detrital zircon yielded an age of 3.06 Ga (Artemenko et al., 2020). Thus, the sedimentary-volcanogenic rocks of the Chortomlyk iron deposit are younger than rocks of the Konka Group. Thus, the ferruginous-siliceous-mafic associations were formed before the emplacement of plagioclase granites of the Sura Complex (3.0-3.08 Ga), and the ferruginous-siliceous-keratophyre (shale-jaspilite-tholeiitic) associations formed after the formation of the Sura Complex.

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REFERENCES / ЛІТЕРАТУРА

Artemenko, G.V., Shumlyanskyy, L.V., Bekker, A.Yu., Demedyuk, V.V. and Gogolev, K.I. (2014), *Geol. Journ.,* No. 3 (348), Kyiv, pp. 74-82 [in Russian]. https://doi.org/10.30836/igs.1025-6814.2014.3.138269

[Артеменко, Г.В., Шумлянский, Л.В., Беккер, А.Ю., Демедюк, В.В., Гоголев, К.И. (2014), *Геол. журн.* № 3(348). С. 74—82.]

Artemenko, G.V., Shumlyanskyy, L.V. and Wilde, S.A. (2020), *Geol. Journ.,* No. 2 (371), Kyiv, pp. 3-17. https://doi.org/10.30836/igs.1025-6814.2020.2.199105

Bibikova, E.V., Claesson, S., Fedotova, A.A., Artemenko, G.V. and Illinskii, L. (2010), *Geochem. Int.,* Vol. 48, pp. 845-861. https://doi.org/10.1134/S0016702910090016

Bobrov, A.B. (1993), *Geol. Journ.,* No. 5, Kyiv, pp. 23-32 [in Russian].

[Бобров, А.Б. (1993), *Геол. журн.* № 5. С. 23—32.]

Bobrov, A.B. (1993), *Geol. Journ.,* No. 6, Kyiv, pp. 47-58 [in Russian].

[Бобров, А.Б. (1993). *Геол. журн.* № 6. С. 47—58.]

Bobrov, O.B., Sivoronov, A.O., Hurskyi, D.S., Pavlun, M.M. and Liakhov, Yu.V. (2004), *Geological and genetic typification of gold deposits in Ukraine,* UkrDGRI, Kyiv, 367 p. [in Ukrainian].

[Бобров, О.Б., Сіворонов, А.О., Гурський, Д.С., Павлунь, М.М., Ляхов, Ю.В. (2004), *Геолого-генетична типізація родовищ золота в Україні.* Київ: УкрДГРІ. 367 с.]

Bobrov, O.B., Sivoronov, A.O., Malyuk, B.I. and Lysenko, O.M. (2002), *Coll. sci. works UkrDGRI,* No. 1-2, pp. 46-67.

[Бобров, О.Б., Сіворонов, А.О., Малюк, Б.І., Лисенко, О.А. (2002), *Зб. наук. пр. УкрДГРІ.* № 1—2. С. 46—67.]

Condi, *K.* (1983), *Archaean greenstone belts,* Mir, Moscow, 390 *p*. [in Russian].

[Конди, К. (1983), *Архейские зеленокаменные пояса.* Москва: Мир. 390 с.]

Kochanov, E.N., Mogilevets, I.I., Romaniy, S.D. and Holostoy, L.D. (1969), *Report on preliminary exploration of the Chertomlyk deposit of ferruginous quartzites,* Trest Dneprogeologiya, Bilozirska GRE, Mikhailovka village [in Russian].

[Кочанов, Е.Н., Могилевец, И.И., Романий, С.Д., Холостой, Л.Д. (1969), *Отчет о предварительной разведке Чертомлыкского месторождения железистых кварцитов.* Трест "Днепрогеология", Белозерская компл. ГРЭ, пгт Михайловка.]

Kushinov, N.V. and Kuz, V.D. (1988), *Report of the Chortomlyk detachment on the results of deep geological mapping* at a scale of 1:50,000, carried out in 1984-1988, within the Chortomlyk structure. Sheets: Л-36-9-Б-б, в, г; Л-36-9-Г-а, в; Л-36-21-А-а, б; Л-36-21-Б-а, NGRE, Yuzhukrgeologiya [in Russian].

[Кушинов, Н.В., Кузь, В.Д. (1988), *Отчет Чертомлыкского отряда о результатах глубинного геологического картирования м-ба* 1 : 50 000, проведенного в 1984—1988 гг. в структуре Чертомлыка. Листы: Л-36-9-Б-б, в, г; Л-36-9-Г-а, в; Л-36-21-А-а, б; Л-36-21-Б-а. НГРЭ, Южукргеология.]

Koliy, V.D., Sivoronov, A.A., Bobrov, A.B. and Nekryach, A.I. (1991), *Geol. Journ.,* No. 4 (259), Kyiv, pp. 28-40 [in Russian].

[Колий, В.Д., Сиворонов, А.А., Бобров, А.Б., Некряч, А.И. (1991), *Геол. журн.* № 4 (259). С. 28—40.]

Kornienko, A.I., Petko, V.N. and Romanyuk, P.M. (2001), *Mineral. resources of Ukraine,* No. 2, Kyiv, pp. 6-10 [in Russian].

[Корниенко, А.И., Петько, В.Н., Романюк, П.М. (2001), *Мінерал. ресурси України.* № 2. С. 6—10.]

Ludwig, K.R. (2011), Isoplot v. 4.15: *A Geochronological Toolkit for Microsoft Excel,* Berkeley Geochronology Center Special Publ., 4, 75.

Malyuk, B.I., Sivoronov, A.A. and Kushinov, N.V. (1989), *Geol. Journ.,* No. 4, Kyiv, pp. 81-93 [in Russian].

[Малюк, Б.И., Сиворонов, А.А., Кушинов, Н.В. (1989), *Геол. журн.* № 4. С. 81—93.]

Paton, C., Hellstrom, J., Paul, B., Woodhead, J. and Hergt, J. (2011), *J. Anal. At. Spectrom.,* Vol. 26, pp. 2508-2518. https://doi.org/10.1039/C1JA10172B

Petrus, J.A. and Kamber, B.S. (2012), *Geostand. and Geoanal. Research.,* Vol. 36, Iss. 3. https://doi.org/10.1111/j.1751-908X.2012.00158.x

Pettijohn, F., Poter, P. and Seaver, R. (1976), *Sands and sandstones,* Transl. engl., Mir, Moscow, 535 p. [in Russian].

[Петтиджон, Ф.Дж., Поттер, П., Сивер, Р. (1976), *Пески и песчаники.* Сер. "Науки о Земле". Т. 67. Пер. с англ. Москва: Мир. 535 с.]

Pointon, M.A., Chew, D.M., Ovtcharova, M., Sevastopulo, G.D. and Crowley, Q.G. (2012), *J. Geol. Soc., London,* Vol. 169, Iss. 6, pp. 713-721. https://doi.org/10.1144/jgs2011-092

Samsonov, A.V., Chernyshev, I.V., Nutman, A.P. and Compston, W. (1996), *Precam. Res.,* Vol. 78, Iss. 1-3, pp. 65-78. https://doi.org/10.1016/0301-9268(95)00069-0

Shcherbak, N.P., Artemenko, G.V., Lesnaya, I.M. and Ponomarenko, A.N. (2005), *Geochronology of the Early Precambrian of the Ukrainian Shield. Archaean,* Nauk. dumka, Kyiv, 242 p. [in Russian].

[Щербак, Н.П., Артеменко, Г.В., Лесная, И.М., Пономаренко, А.Н. (2005), *Геохронология раннего докембрия Украинского щита. Архей.* Киев: Наук. думка. 242 с.]

Semenenko, M.P. (ed.) (1978), *Ferrous-siliceous formations of the Ukrainian Shield,* Vol. 1, Nauk. dumka, Kyiv, 326 p. [in Russian].

[Семененко, Н.П. (ред.) (1978), *Железисто-кремнистые формации Украинского щита.* Киев: Наук. думка, Т. 1. 326 с.]

Semenenko, N.P., Boyko, V.L., Bordunov, I.N., Ladieva, V.D. and Makukhina, A.A. (1967), *Geology of sedimentary-volcanogenic formations of the Ukrainian Shield* (*Central part*), Nauk. dumka, Kyiv, 380 p. [in Russian].

[Семененко, Н.П., Бойко, В.Л., Бордунов, И.Н., Ладиева, В.Д., Макухина, А.А. (1967), *Геология осадочно-вулканогенных образований Украинского щита (Центральная часть).* Киев: Наук. думка. 380 с.]

Sivoronov, A.A., Smogolyuk, A.G. and Bobrov, A.B. (1990), in: *Ferrous-siliceous formations of the Precambrian of the European part of the USSR. Greenstone belts and the role of volcanism in the formation of deposits*, Nauk. dumka, Kyiv, pp. 14-24 [in Russian].

[Сиворонов, А.А., Смоголюк, А.Г., Бобров, А.Б. (1990), *Типы метаморфизованных формаций зеленокаменных комплексов. Группа вулканогенных образований.* В кн.: Железисто-кремнистые формации докембрия Европейской части СССР. Зеленокаменные пояса и роль вулканизма в образовании месторождений. Киев: Наук. думка. С. 14—24.]

Sláma, J., Košler, J., Condon, D.J., Crowley, J.L., Gerde, A., Hanchar, J.M., Horstwood, M.S., Morris, G.A., Nasdala, L. and Norberg, N. (2008), *Chem. Geol.,* Vol. 249, Iss. 1-2, pp. 1-35. https://doi.org/10.1016/j.chemgeo.2007.11.005

Strueva, O.M. and Skarzhinskaya, T.A. (1979), *Geol. Journ.* (1979), Vol. 39, No. 3, Kyiv, pp. 73-89 [in Russian].

[Струева, О.М., Скаржинская, Т.А. (1979), *Геол. журн.* **39**, № 3. С. 73—89.]

Sun, S.S. and McDonough, W.F. (1989), *Magmatism in the Ocean Basins,* in Saunders, A.D. and Norry, M.J. (eds), *Geol. Soc. Spec. Publ.,* No. 42, pp. 313-345.

Wiedenbeck, M., Alle, P., Corfu, F., Griffin, W.L., Meier, M., Oberli, F., Von Quadt, A., Roddick, J.C. and Spiegel, W. (1995), *Geostand. Newslett,* Vol. 19, Iss. 1, pp. 1-23. https://doi.org/10.1111/j.1751-908X.1995.tb00147.x

Wiedenbeck, M., Hanchar, J.M., Peck, W.H., Sylvester, P., Valley, J., Whitehouse, M., Kronz, A., Morishita, Y., Nasdala, L., Fiebig, J., Franchi, I., Girard, J.-P., Greenwood, R.C., Hinton, R., Kita, N., Mason, P.R.D., Norman, M., Ogasawara, M., Piccoli., P.M., Rhede, D., Satoh, H., Schulz-Dobrick, B., Skår, Ø., Spicuzza, M.J., Terada, K., Tindle, A., Togashi, S., Vennemann, T., Xie, Q. and Zheng, Y.F. (2004), *Geostand. and Geoanal. Research,* Vol. 28**,** pp. 9-39. https://doi.org/10.1111/j.1751-908X.2004.tb01041.x

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ВІК ОСАДОВО-ВУЛКАНОГЕННИХ ПОРІД ЧОРТОМЛИЦЬКОГО ЗАЛІЗОРУДНОГО РОДОВИЩА, СЕРЕДНЬОПРИДНІПРОВСЬКИЙ БЛОК УКРАЇНСЬКОГО ЩИТА

Зеленокам'яні пояси Середньопридніпровського блоку складені осадово-вулканогенними породами конкської і білозерської серій, розділених стратиграфічним неузгодженням. Конкська серія складена переважно вулканогенними породами від ультраосновного до кислого складу з підпорядкованою кількістю осадових порід, а білозерська — осадовими породами з незначною кількість вулканогенних порід кислого складу. В зеленокам'яних структурах визначено три стратиграфічні рівні, на яких наявні досить потужні товщі залізисто-кременистих порід. У конкській серії виділені залізисто-кременисто-метабазитова та залізисто-кременисто-кератофірова (сланцево-джеспіліт-толеїтова формація), а в білозерській — перехідна залізисто-кременисто-сланцева до залізисто-кременисто-кератофірової, яку багато дослідників зіставляють із залізисто-кременистими утвореннями криворізької серії. Породи ранньої залізисто-кременисто-метабазитової формації знаходяться серед вулканогенних порід коматиїт-толеїтової формації. Ці породи прорвані плагіогранітоїдами сурського комплексу (3,0—3,08 млрд рр.). У пізнішій залізисто-кременисто-кератофіровій (сланцево-джеспіліт-толеїтовій) формації залізисто-кременисті відклади перешаровуються з осадовими і туфогенними породами і досягають потужності 350 м. У Чортомлицькій зеленокам'яній структурі з нею пов'язане Чортомлицьке залізорудне родовище. Вік цієї формації залишався невідомим. Автори датували 60 кристалів циркону з кварц-амфіболових сланців із розрізу осадово-вулканогенних порід Чортомлицького залізорудного родовища. З них 53 кристали циркону мають вік 3,08—3,12 млрд рр.; шість — 3,06—3,08 і один кристал — 3,18 млрд рр. Високе значення відношення Th/U циркону — 0,3—0,9 вказує на магматичну природу порід їхнього джерела. Осадово-вулканогенні породи Чортомлицького залізорудного родовища могли утворитись на морському шельфі поблизу підняттів, складених плагіогранітоїдами, або поблизу вулканів центрального типу. Вони утворились або після вкорінення плагіогранітів ТТГ сурського комплексу 3,08 млрд рр. тому, або одночасно з виверженнями вулканів того ж віку. Отже, осадово-вулканогенні породи Чортомлицького залізорудного родовища є молодшими за породи конкської серії. Подібні дані отримано для теригенних порід із залізисто-кременистої формації білозерської серії у Білозерській (Bibikova et al., 2010) та Високопільській (Artemenko et al., 2020) зеленокам'яних структурах, вік детритового циркону яких становить 3,05 і 3,06 млрд рр. відповідно. Тобто залізисто-кременисті породи залізисто-кременисто-базитової формації утворились до формування плагіогранітоїдів сурського комплексу (3,0—3,08 млрд рр.), а залізисто-кременисто-кератофірова (сланцево-джеспіліт-толеїтова) формація сформувалась після їх утворення.

Ключові слова: Середньопридніпровський блок, Чортомлицький зеленокам'яний пояс, осадові породи, конкська серія, детритовий циркон, Чортомлицьке залізорудне родовище, сланцево-джеспіліт-толеїтова формація, U-Pb вік.