Introduction. In the Ukrainian Shield, rocks of the Earth’s early crust were found in the Azov and Dniester-Bouh regions [1-3]. In the Dniester-Bouh region, they are highly metamorphosed and represented by enderbites and mafic crystalline schists with an age up to 3.8 Ga. A special feature of the Azov Domain is a relatively weak metamorphism of Archean rocks, not exceeding the epidote-amphibolite and amphibolite facies. Here, tonalites with ages of 3.67, 3.5, and 3.3 Ga have been identified. Metaterrigenous rocks in the Soroki greenstone structure (GS) and Neoarchean to Palaeoproterozoic troughs contain detrital zircon of Paleoarchean and Eoarchean ages from 3.3 to 3.8 Ga [4], which indicate the presence of yet undiscovered ancient rocks in the

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Stages in evolution of Earth’s crust
recorded by the Huliaipole block
of the West Azov area (4.0-2.0 Ga)

Presented by Academician of the NAS of Ukraine O.M. Ponomarenko

The U-Pb age of zircon populations from metadacite of the Huliaipole Suite was determined using the LA-ICP-MS method as 3085-2850 and 3700-3360 Ma. In addition, two crystals of zircon were discovered with an age of more than 3800 Ma. According to geological and geochronological data, the Huliaipole Block, 30 × 50 km in size, is composed of rocks and relics of the Hadean, Archean, and Palaeoproterozoic eons. The oldest nucleus of the Azov Domain was probably formed from 3.97 to 3.3 Ga ago. In the Mesoarchean (3.2-3.0 Ga), it became a part of the Middle Dnieper-Azov-Kursk granite-greenstone terrane. Felsic and intermediate volcanics of the Huliaipole Suite could have formed due to the melting of the sialic crust, including rocks of the Hadean and Archean age, as a result of the underplating of basic melts during the formation of the Neoarchean to Paleoproterozoic rift structures.

Keywords: West Azov, Huliaipole block, Hadean, Archean, Paleoproterozoic, Ukrainian Shield, U-Pb age.

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Azov Domain. Some researchers previously suggested that the most ancient granulite-gneissic complexes of the Azov and Dniester-Bouh domains, as well as the Voronezh Crystalline Massif, are fragments of one of the most ancient protocratons [2]. Author of work [5] suggested a model for the autonomous evolution of the “Early Archean cores” of the Azov and Dniester-Bouh domains, which is confirmed by new geological data.

**Geological structure of the study area.** The Azov Domain is a part of a larger Mesoarchean (3.2-3.0 Ga) craton, fragments of which are preserved in the eastern part of the Ukrainian Shield and as a block of the Kursk Magnetic Anomaly (KMA). In the Neoarchean-Palaeoproterozoic time, it was fragmented into several tectonic blocks: Vovcha, Remivka, Huliaipole, Bilotserkivka, and Saltych. The Huliaipole block is 30 × 50 km in size. To the west, north, and east, it is bordered by the Orekhiv-Pavlohrad structure, the Vovcha and Remivka blocks, respectively (Fig. 1, a). The Huliaipole and Remivka blocks are separated by the Hauchur fault of northwestern orientation, to which the Mesoarchean Kosivtsevo greenstone structure is confined. To the south, the Huliaipole Block is bordered by the Bilotserkivka Synclinorium and Korsak-Stulneve Anticlinorium. Analyzing the geological and structural position of greenstone belts in this area, which are characterized by a concentric shape and distinct confinement to faults, B.Z. Berzenin was the first to conclude that they formed on the Paleoarchean granulite-gneissic basement above the mantle plume [7]. The northern part of the Huliaipole Block is composed of the tonalite-trondhjemite-granodiorite (TTG) rock association, which contains remnants of greenstone structures, while the central and southern parts are almost completely composed of younger granitoids. In the central part of the Huliaipole Block, the Huliaipole syncline (3.5 × 9 km) of the NW orientation occurs [8]. Syncline limbs are steeply deeping to the center at an angle of 50-70°. According to geophysical data, the depth of the fold extent is estimated at 2.1-2.3 km. This structure is composed of volcano-sedimentary rocks of the Huliaipole Suite, about 1700 m thick, unconformably overlaying the Archean TTG. The Huliaipole Suite is subdivided into three subsuites. The lower one (250 m thick) is composed of two-mica and andalusite-staurolite quartzites and schists; the middle one (450 m thick) consists of mainly ferruginous quartzites and metavolcanics of felsic and intermediate composition; the upper one (1000 m thick) is composed of biotite schists, often graphite-bearing, sometimes high-alumina quartzites and quartzite schists with flysch-like alternations. To a limited extent, meta-andesites and felsic metavolcanics are also found in the lower Huliaipole and upper Huliaipole subsuites [6]. The volcanics reach 70 m in thickness. From the margins to the center of the structure, there is a lateral replacement of ferruginous quartzites by metavolcanics. In the same direction, in the lower and upper subsuites, clay-rich facies are replaced by sandy ones. The U-Pb (TIMS) age of the multi-grain detrital zircon fractions from quartzites of the Lower Huliaipole Subsuite is 2.9 ± 0.1 Ga; the time of metamorphism of the rocks of the Huliaipole Suite is estimated at 2.14 Ga [9].

**The Mesoarchean (3.2-3.0 Ga).** The Kosivtseve and Haychur greenstone belts are composed of metamorphosed rocks of the jaspilite-komatiite-tholeiite association (the Kosivtseve unit), which is correlated with the Sura Suite of the Konka Series of the Middle Dnieper Domain [10]. Metamorphosed peridotite komatiites of the Kosivtsevo Greenstone Belt belong to the undepleted alumina type: CaO/Al₂O₃ = 1.23 and Al₂O₃/TiO₂ = 11.61. Ni content in the Kosivtsevo Greenstone Belt peridotite komatiites reaches 841 ppm and Cr content is up to 2540 ppm. Amphibolites correspond to tholeiitic basalts. The metabasalts are characterized by a flat un-
differentiated pattern of REE (La/Yb)N ~1.0. The REE concentrations in metabasalts of the Kosivtseve Greenstone Belt is 10 times chondrite content [11].

The TTG intrusions in the northern part of the Huliaipole Block are composed of sodium diorites and trondhjemites, and quartz diorites and tonalites of the potassium-sodium series. The U-Pb age of tonalites is 3.0 Ga, and that of trondhjemites is 2.92 Ga. According to Sm-Nd
Stages in evolution of Earth’s crust recorded by the Huliaipole block of the West Azov area (4.0-2.0 Ga)

data, they were derived from a depleted ($\varepsilon_{\text{Nd}}(T) = 0 \text{ to } +2.6$; $T_{\text{Nd}}(\text{DM}) \approx 3.0 \text{ Ga}$) mantle and do not have “ancient crustal roots” [11]. Tonalites and trondhjemites are characterized by an average and very high degree of REE differentiation - $(\text{La/Yb})_N = 7.7$ and 133, respectively.

**The Neoarchean-Paleoproterozoic (2.8-2.0 Ga)**. The Neoarchean-Paleoproterozoic formations are represented by volcano-sedimentary rocks of the Huliaipole Suite and granitoids of the Dobropillya and Anadol complexes.

**Granitoids of the Dobropillya Complex** are confined to the Haychur and Dobropillya faults and to the southern margin of the Remivka Block. They are sharply discordant to the structure of the region and are represented by quartz diorites, plagioclase granites, and granodiorites of the potassium-sodium series, containing a large amount of pyroxenite, gneiss, and plagioclase granite xenoliths. According to the geological and geochemical data, the granitoids of the Dobropillya Complex were formed due to the melting of the older TTGs with a magma source characterized by $T_{\text{Nd}}(\text{DM}) = 3.0-2.93 \text{ Ga}$ [11]. The U-Pb isotope zircon age of granitoids of the Dobropillya Complex is 2040 Ma [12]. Inherited zircon has an age up to 3400 Ma.

**The Anadol Complex**. Small intrusions of two-feldspar granites are widespread in the Haychur area of the Ternuvate structure. In terms of chemical composition, they correspond to the subalkaline chemical group of felsic rocks of the potassium-sodium series. REE are highly differentiated with $(\text{La/Yb})_N = 16.94$, $\text{Yb}_N = 8.47$, and a prominent negative europium anomaly ($\text{Eu}/\text{Eu}^* = 0.39$). According to geochemical data, two-feldspar granites were derived from a crustal source. The U-Pb isotope monazite age of two-feldspar granites is 2190 Ma [13].

**Felsic metavolcanics of the Huliaipole Suite**. In the Huliaipole syncline, intermediate and felsic metavolcanics are closely associated with the Banded Iron Formation (BIF). Their age has not yet been studied. Zircon from meta-andesites and felsic metavolcanics of the Huliaipole Suite is very heterogeneous, which indicates their crustal derivation.

**The Hadean-Paleoarchean (4.0-3.4 Ga)**. The presence of ancient crust in the Huliaipole Block is indicated by the large number of xenoliths in the granitoids of the Dobropillya Complex and the ubiquitous presence of xenocrystic zircon [14]. The Paleoarchean age of 3.3 Ga for xenocrystic zircon (multiple zircon grain method) was determined by [14] and of 3.4 Ga (SHRIMP U-Pb method) by [12]. A large amount of xenocrystic zircon was also found in metamorphosed andesites and dacites of the Huliaipole Suite. This zircon has been dated in this study using the LA-ICP-MS method. For the most ancient zircons, the age was also confirmed by secondary ion mass spectrometry (SIMS).

The sampled interval is composed of metadacites (sample 89-388, drill-hole 625-B, int. 424.4-429.4 meters) (Fig. 1, b, 1, c). The structure of the rock is blastoporphyritic with a lepidograno-blastic structure of the groundmass (Figs. 2, a, b, c). Phenocrysts are represented by albite. Phenocrysts are often granular and transformed into an aggregate of fine grains. Secondary minerals in phenocrysts are represented by biotite, sericite, muscovite, chlorite, carbonate, and magnetite. The bulk is composed (%): quartz + albite 75-77 %, biotite 20-22 %, chlorite — fractions of %, muscovite — single grains, magnetite — up to 1 %; apatite — 3-5 %, titanomorphite — fractions of %, zircon — single grains. Quartz and albite form aggregates of isometric grains 0.02 mm in size. Biotite and chlorite are unevenly distributed, forming clusters of elongated lenticular and irregular shape. Patchy segregations of magnetite, zircon, and titanomorphite are confined to biotite accumulations. An interesting feature of the rock is the high content of apatite (up to 5 %).
Fig. 2. Photomicrographs of thin sections of metadacites of the Huliaipole Suite, drill-hole 625-B: a – sample 89-384, depth 424.8 m; b – sample 89-385, depth 427.4 m; c – sample 89-386, depth 428.6 m. Images were taken using a polarizing microscope ECLIPSE LV100 POL. Crossed analyzers

Fig. 3. Primitive mantle-normalized multi-element diagram for meta-andesites and metadacites of the Huliaipole Suite — a. Chondrite-normalized REE pattern for meta-andesites and metadacites of the Huliaipole Suite — b
Geochemistry. In terms of chemical composition, the metavolcanics of the Huliaipole Suite correspond to low-Mg (0.23-0.35) andesites and dacites of the normal series, potassium-sodium series (Table 1). On the SiO$_2$-K$_2$O diagram, they fall into the fields of high-K andesites and dacites of the calc-alkaline series. They have high content of Sr (743-816 ppm), Ba (1400-2116 ppm), and moderate content of Rb (97-103 ppm) (Table 1). The content of transition elements,

Table 1. Chemical composition of metavolcanics of the Huliaipole Suite

| %      | 89-156 | 89-463 | 89-381 | 89-388 | ppm       | 89-156 | 89-463 | 89-381 | 89-388 |
|--------|--------|--------|--------|--------|-----------|--------|--------|--------|--------|
| SiO$_2$| 60.70  | 62.58  | 63.98  | 65.70  | Ge        | –      | –      | –      | –      |
| TiO$_2$| 0.74   | 0.46   | 0.47   | 0.57   | Y         | 8.19   | 8.17   | 7.0    | 7.5    |
| Al$_2$O$_3$| 14.60 | 13.74  | 13.36  | 13.93  | Nb        | 6.49   | 4.82   | 5.0    | 6.7    |
| Fe$_2$O$_3$| 0.35  | 0.72   | 0.65   | 1.41   | Zr        | 160    | 116.4  | 162.6  | 190    |
| FeO    | 4.70   | 3.60   | 3.38   | 3.38   | Hf        | –      | 3.48   | 3.3    | 4.9    |
| MnO    | 0.08   | 0.06   | 0.05   | Сл.    | U         | 1.41   | 1.83   | 1.4    | 1.4    |
| MgO    | 1.90   | 2.26   | 1.24   | 1.79   | Th        | 6.71   | 7.25   | 5.6    | 6.5    |
| CaO    | 5.10   | 3.96   | 3.50   | 3.62   | Sn        | –      | 0.70   | –      | 1.1    |
| Na$_2$O| 4.30   | 5.34   | 3.78   | 3.78   | Sb        | –      | 0.12   | –      | 0.25--  |
| K$_2$O | 3.52   | 3.60   | 6.00   | 3.18   | La        | 32.50  | 29.05  | 35.9   | 38.3   |
| S$_{66al}$| 0.30  | 0.23   | 0.24   | 0.13   | Ce        | 62     | 57.07  | 68.1   | 76.0   |
| P$_2$O$_5$| 0.36  | 0.24   | 0.10   | 0.24   | Pr        | 7.07   | 6.36   | 7.60   | 7.9    |
| CO$_2$ | 2.69   | 2.24   | 0.07   | 1.30   | Nd        | 26.60  | 24.87  | 26.7   | 29     |
| H$_2$O-| Сл.    | 0.08   | 0.12   | Сл.    | Sm        | 4.75   | 4.15   | 4.52   | 4.5    |
| LOI    | 0.34   | 0.56   | 2.64   | 0.59   | Eu        | 1.70   | 1.26   | 1.23   | 1.1    |
| Sum    | 99.68  | 99.67  | 99.58  | 99.62  | Gd        | 3.61   | 3.81   | 3.14   | 3.4    |
| #mg    | 0.27   | 0.35   | 0.23   | 0.28   | Tb        | 0.49   | 0.39   | 0.36   | 0.41   |
| Ppm    | –      | –      | –      | –      | Dy        | 1.98   | 2.11   | 1.45   | 1.6    |
| Cs     | –      | 18.53  | –      | 4.8    | Ho        | 0.30   | 0.38   | 0.23   | 0.26   |
| Li     | –      | 14.88  | –      | 23     | Er        | 0.73   | 1.09   | 0.60   | 0.66   |
| Be     | –      | 1.94   | –      | 1.4    | Tm        | 0.092  | 0.14   | 0.08   | 0.088  |
| Rb     | 97.10  | 96.90  | 102.6  | 174    | Yb        | 0.51   | 0.95   | 0.53   | 0.54   |
| Sr     | 816    | 742.9  | 812.1  | 647    | Lu        | 0.072  | 0.14   | 0.06   | 0.08   |
| Ba     | 1400   | 1953   | 2116   | 2327   | Mo        | –      | 0.83   | 0.2    | 0.49   |
| V      | 64.50  | 64.78  | 67     | 42.5   | Ag        | –      | 70.43  | <0.1   | –      |
| Cr     | 21.30  | 70.42  | –      | 41.7   | Ta        | 0.37   | –      | 0.3    | 0.42   |
| Co     | 7.29   | 12.55  | 9.6    | 7.5    | Pb        | –      | 17.70  | 9.5    | 19.2   |
| Ni     | 15     | 33.61  | 27.2   | 19.3   | W         | –      | 0.44   | –      | 7.5    |
| Cu     | –      | 26.93  | 17.4   | 30.2   | (La/Yb)$_N$| 45.7  | 21.9   | 48.6   | 50.9   |
| Zn     | –      | 70.31  | 60     | 58.2   | Eu/Eu*  | 1.26   | 0.97   | 1.0    | 0.97   |
| Ga     | –      | 47.55  | –      | 16.6   | Nb/La    | 0.20   | 0.17   | 0.14   | 0.17   |
| As     | –      | 2.13   | –      | 0.48   | Nb/Ce    | 0.11   | 0.08   | 0.07   | 0.09   |
| Sc     | –      | 18.53  | –      | 4.1    | Th/Yb    | 13.2   | 7.4    | 10.6   | 12     |

Note: 1 — meta-andesite, drill-hole 636-B, depth 384.5-384.7 m (sample 89-156); 2 — meta-andesite, drill-hole 795-B, depth 392-395.7 m (sample 89-463); 3 — meta-andesite, drill-hole 625-B, depth 424.4-429.4 m (sample 89-388); 4 — metadacite, drill-hole 625-B (sample 89-381). Silicate rock analyses were carried out at IGMOF of the NAS of Ukraine, Kyiv. Contents of rare and trace elements were determined using the ICP-MS method at IMTM RAS, Chernoholovka, Russia. #mg = MgO/(MgO + FeO*).
Fig. 4. 

a: Cathodoluminescence images of the studied zircon crystals from metadacites of the Huliaipole Suite. Shown are numbers for analyzes and ages based on isotopic ratio $^{207}\text{Pb}/^{206}\text{Pb}$ (Drill-hole 625-B, depth 424.4 - 429.4 meters, sample 89-388).

b: U-Pb diagram with concordia for zircons from metadacites of the Huliaipole Suite (Drill-hole 625-B, depth 424.4 - 429.4 meters, sample 89-388).

c: Hf isotope systematics of zircons from metadacites of the Huliaipole Syncline. Zircons from other rock complexes of the Ukrainian Shield are shown for comparison. 1 — Eoarchaean enderbite of the Dniester-Bouh Series [2]; 2 — mafic granulite of the Dniester-Bouh Series [15]; 3 — Archaean metasediments of the Azov Domain [16]; 4 — Bouh Series quartzite [9]; 5 — Metavolcanics of the Huliaipole Suite.
Ni (15-33.6 ppm) and Cr (21.3-70.42 ppm), are close to their content in TTGs. Negative anomalies of Nb and Ti are highlighted on the multi-element diagram (Fig. 3, a). Rare earth elements in meta-andesites and metadacites are highly differentiated — $(\text{La/Yb})_N = 21.9–50.9$ (Fig. 3, b). The sample 89-156 shows a prominent positive europium anomaly, $\text{Eu/Eu}^* = 1.26$; the rest of sample lack positive europium anomaly. The high Th/Yb ratio (7.4-13.2) and low Nb/La (0.14-0.20) indicate contamination with crustal material (Table 1). Geochemical data indicate derivation of metavolcanics of the Huliaipole Suite from the crustal magma source bearing ancient TTGs.

**Geochronology.** The LA–ICP–MS method was used to determine the U–Pb age and Hf isotopic composition in zircons from metadacites of the Huliaipole Suite (sample 89-388) (Fig. 4, a). A total of 36 zircon crystals was analyzed (Table 2). The age of the most ancient zircons was also confirmed by dating with the secondary ion mass spectrometry (SIMS) method.

According to the data obtained, two main populations of zircon can be distinguished (Fig. 4, b). The first population includes a group of zircons with an age in the range of 3085-2850 Ma. The Hf isotopic composition varies within wide limits: 5 crystals have $\epsilon\text{Hf}$ values from 6.2 to −0.5; other 6 have values from −7.5 to −21 (Fig. 4, c). Thus, zircons of this group come from rocks of different genesis: some of them were of juvenile origin, while others were formed as a result of the processing of the ancient crust. The second population includes zircons with an age of 3700-3360 Ma, which also have variable Hf isotope characteristics: from juvenile ($\epsilon\text{Hf}$ up to 1.6) and negative $\epsilon\text{Hf}$ values (down to −7.7 at an age of 3705 Ma).

In addition, two zircon crystals with the age of more than 3800 Ma were found (3805 Ma with $\epsilon\text{Hf} = −3.3$, and 3971 Ma with $\epsilon\text{Hf} = −1.3$). These zircons are the most ancient found in the Ukrainian Shield. Their isotopic characteristics indicate the presence of Hadean material within the Azov Domain of the Ukrainian Shield. The minimum model age for the crystallization of this material, calculated at $\text{Lu/Hf} = 0$ for zircons with the lowest $\epsilon\text{Hf}$ values in each age population, is about 4.1 Ga (Fig. 4, c).

**Discussion of the results.** The two main zircon populations found in metavolcanics of the Huliaipole Suite are similar in their U-Pb and Hf isotopic characteristics to zircons from the Archean metasedimentary rocks of the Soroki Greenstone Belt of the Azov Domain [2], as well as zircons from quartzites of the Bouh Group of the Dniester-Bouh Domain of the Ukrainian Shield [17]. At the same time, the older (3700-3360 Ma) zircon population corresponds in age and isotopic composition to zircons from the Eoarchean enderbites of the Dniester-Bouh Domain [2, 17].

Another intriguing observation: similarly to the iron-bearing metasedimentary successions of the Middle Dnieper Domain, no zircons younger than ca. 2800 Ma were found in the greenstone belts of the Azov Domain, and in the metavolcanics of the Huliaipole Suite (e.g., [4, 18], which supports common geological history of these two domains in the Neoarchean and Paleoproterozoic.

Finally, among the detrital zircons from the metasedimentary rocks of the Soroki Greenstone Belt of the Azov Domain [2], one zircon crystal corresponds to the most ancient zircon crystals from the metavolcanic rocks of the Huliaipole Suite in terms of isotopic and geochemical characteristics, and has a minimum hafnium model age of about 4.1 Ga. Thus, the Azov Domain of the Ukrainian Shield holds high promise for the search for Hadean zircons and the study of the early evolution of Earth.

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Table 2. Results of U-Pb isotope dating of zircons from metadacites of the Huliaipole Suite arranged in descending order of $^{207}$Pb/$^{206}$Pb ages (Drill-hole 625-B, depth 424.4–429.4 meters, sample 89-388)

| # analysis  | Concentration, ppm | U | Th | Th/U | $^{207}$Pb/$^{235}$U | 2σ | $^{208}$Pb/$^{238}$U | 2σ | Rho | $^{207}$Pb/$^{206}$Pb | 2σ |
|-------------|---------------------|---|----|------|----------------------|----|----------------------|----|-----|----------------------|----|
| 89-388-18   | 176                 | 109 | 0.62 | 49.900 | 2.507 | 0.84 | 0.03 | 0.98 | 0.424 | 0.011 |
| 89-388-29   | 61                  | 38  | 0.62 | 42.280 | 1.157 | 0.79 | 0.02 | 0.98 | 0.389 | 0.008 |
| 89-388-17   | 165                 | 96  | 0.58 | 44.000 | 1.409 | 0.81 | 0.02 | 0.97 | 0.388 | 0.008 |
| 89-388-14   | 148                 | 76  | 0.51 | 37.430 | 1.096 | 0.77 | 0.02 | 0.99 | 0.356 | 0.007 |
| 89-388-16   | 188                 | 73  | 0.39 | 37.060 | 0.923 | 0.76 | 0.02 | 0.99 | 0.356 | 0.007 |
| 89-388-22   | 295                 | 74  | 0.25 | 37.080 | 0.980 | 0.75 | 0.02 | 0.98 | 0.354 | 0.007 |
| 89-388-20   | 171                 | 136 | 0.79 | 38.590 | 1.232 | 0.79 | 0.02 | 0.98 | 0.354 | 0.007 |
| 89-388-9    | 276                 | 85  | 0.31 | 36.400 | 2.412 | 0.76 | 0.05 | 0.99 | 0.350 | 0.007 |
| 89-388-25   | 245                 | 15  | 0.06 | 36.250 | 0.910 | 0.74 | 0.02 | 0.96 | 0.349 | 0.007 |
| 89-388-34   | 490                 | 7   | 0.01 | 33.720 | 1.009 | 0.71 | 0.02 | 0.99 | 0.339 | 0.007 |
| 89-388-10   | 357                 | 122 | 0.34 | 31.390 | 0.822 | 0.70 | 0.02 | 0.97 | 0.330 | 0.006 |
| 89-388-6    | 48                  | 16  | 0.33 | 34.070 | 0.984 | 0.79 | 0.02 | 0.99 | 0.314 | 0.006 |
| 89-388-5    | 117                 | 83  | 0.71 | 31.390 | 0.938 | 0.72 | 0.02 | 0.98 | 0.313 | 0.006 |
| 89-388-23   | 60                  | 23  | 0.38 | 32.040 | 1.009 | 0.74 | 0.02 | 0.99 | 0.313 | 0.006 |
| 89-388-30   | 234                 | 170 | 0.73 | 30.330 | 0.957 | 0.70 | 0.02 | 0.94 | 0.310 | 0.006 |
| 89-388-27   | 209                 | 153 | 0.73 | 30.350 | 0.686 | 0.71 | 0.02 | 0.99 | 0.305 | 0.006 |
| 89-388-7    | 167                 | 39  | 0.23 | 30.480 | 1.120 | 0.73 | 0.03 | 0.97 | 0.303 | 0.006 |
| 89-388-13   | 624                 | 24  | 0.04 | 25.900 | 0.748 | 0.63 | 0.02 | 0.96 | 0.300 | 0.006 |
| 89-388-31   | 163                 | 76  | 0.47 | 28.060 | 0.752 | 0.69 | 0.02 | 0.98 | 0.291 | 0.006 |
| 89-388-21   | 201                 | 79  | 0.39 | 26.330 | 0.876 | 0.68 | 0.02 | 0.96 | 0.282 | 0.006 |
| 89-388-35   | 68                  | 52  | 0.76 | 25.920 | 1.030 | 0.67 | 0.03 | 0.99 | 0.280 | 0.006 |
| 89-388-33   | 193                 | 77  | 0.40 | 20.120 | 0.706 | 0.59 | 0.02 | 0.97 | 0.245 | 0.005 |
| 89-388-26   | 230                 | 244 | 1.07 | 18.620 | 0.820 | 0.56 | 0.03 | 1.00 | 0.235 | 0.005 |
| 89-388-15   | 187                 | 63  | 0.34 | 19.300 | 0.471 | 0.60 | 0.01 | 0.93 | 0.234 | 0.005 |
| 89-388-12   | 426                 | 38  | 0.09 | 16.020 | 0.825 | 0.52 | 0.02 | 0.95 | 0.227 | 0.006 |
| 89-388-3    | 97                  | 38  | 0.39 | 16.850 | 0.451 | 0.55 | 0.01 | 0.92 | 0.222 | 0.006 |
| 89-388-28   | 139                 | 32  | 0.23 | 17.100 | 1.832 | 0.56 | 0.06 | 1.00 | 0.218 | 0.005 |
| 89-388-4    | 129                 | 57  | 0.44 | 16.500 | 0.542 | 0.56 | 0.02 | 0.82 | 0.216 | 0.006 |
| 89-388-2    | 258                 | 119 | 0.46 | 15.500 | 1.336 | 0.53 | 0.05 | 1.00 | 0.214 | 0.004 |
| 89-388-32   | 512                 | 441 | 0.86 | 16.590 | 0.520 | 0.56 | 0.02 | 1.00 | 0.212 | 0.004 |
| 89-388-11   | 105                 | 5   | 0.05 | 13.470 | 0.450 | 0.47 | 0.02 | 0.97 | 0.208 | 0.004 |
| 89-388-8    | 63                  | 81  | 1.28 | 15.610 | 0.615 | 0.56 | 0.02 | 0.99 | 0.203 | 0.004 |
| 89-388-19   | 46                  | 71  | 1.54 | 15.680 | 0.485 | 0.55 | 0.02 | 0.98 | 0.203 | 0.004 |
| 89-388-24   | 39                  | 41  | 1.05 | 15.720 | 0.414 | 0.56 | 0.01 | 0.94 | 0.202 | 0.004 |
### Stages in evolution of Earth's crust recorded by the Huliaipole block of the West Azov area (4.0-2.0 Ga)

| Isotopic age, Ma | 208\(^{\text{Pb}}\)/232\(^{\text{Th}}\) | 2σ | 207\(^{\text{Pb}}\)/235\(^{\text{U}}\) | 2σ | 206\(^{\text{Pb}}\)/238\(^{\text{U}}\) | 2σ | 208\(^{\text{Pb}}\)/232\(^{\text{Th}}\) | 2σ | 207\(^{\text{Pb}}\)/206\(^{\text{Pb}}\) | 2σ |
|-----------------|----------------|-----|----------------|-----|----------------|-----|----------------|-----|----------------|-----|
| 0.213           | 0.006          | 3986| 49              | 3940| 100            | 3897| 78             | 3997| 25             |
| 0.198           | 0.006          | 3831| 20              | 3739| 59             | 3644| 84             | 3865| 4              |
| 0.211           | 0.006          | 3863| 25              | 3832| 66             | 3866| 81             | 3862| 7              |
| 0.212           | 0.007          | 3704| 21              | 3662| 56             | 3888| 92             | 3734| 5              |
| 0.215           | 0.005          | 3695| 15              | 3637| 36             | 3940| 50             | 3733| 4              |
| 0.192           | 0.006          | 3695| 17              | 3609| 47             | 3551| 72             | 3726| 4              |
| 0.209           | 0.006          | 3740| 22              | 3748| 58             | 3831| 79             | 3722| 5              |
| 0.217           | 0.019          | 3667| 62              | 3620| 170            | 4050| 340            | 3705| 9              |
| 0.229           | 0.011          | 3677| 17              | 3575| 43             | 4160| 170            | 3704| 6              |
| 0.169           | 0.014          | 3601| 22              | 3464| 66             | 3150| 240            | 3656| 7              |
| 0.209           | 0.010          | 3531| 17              | 3411| 50             | 3830| 150            | 3611| 15             |
| 0.218           | 0.008          | 3611| 21              | 3749| 59             | 3980| 120            | 3539| 8              |
| 0.197           | 0.008          | 3526| 22              | 3510| 62             | 3630| 110            | 3538| 6              |
| 0.201           | 0.006          | 3520| 18              | 3501| 48             | 3707| 65             | 3537| 3              |
| 0.188           | 0.008          | 3551| 24              | 3551| 66             | 3490| 130            | 3534| 7              |
| 0.187           | 0.005          | 3496| 24              | 3432| 62             | 3471| 65             | 3520| 10             |
| 0.185           | 0.004          | 3498| 10              | 3462| 33             | 3436| 33             | 3498| 3              |
| 0.198           | 0.006          | 3500| 30              | 3513| 88             | 3654| 71             | 3486| 11             |
| 0.197           | 0.007          | 3342| 20              | 3141| 53             | 3635| 89             | 3471| 5              |
| 0.183           | 0.005          | 3421| 18              | 3394| 51             | 3395| 59             | 3423| 5              |
| 0.177           | 0.005          | 3358| 27              | 3323| 57             | 3298| 67             | 3375| 8              |
| 0.182           | 0.009          | 3341| 34              | 3310| 100            | 3370| 150            | 3363| 7              |
| 0.159           | 0.004          | 3096| 29              | 2999| 77             | 2976| 50             | 3152| 15             |
| 0.119           | 0.023          | 3019| 39              | 2902| 95             | 2250| 420            | 3086| 4              |
| 0.182           | 0.005          | 3056| 14              | 3031| 35             | 3371| 64             | 3078| 7              |
| 0.153           | 0.006          | 2885| 43              | 2712| 64             | 2884| 99             | 3029| 26             |
| 0.206           | 0.010          | 2926| 17              | 2837| 33             | 3790| 150            | 2993| 27             |
| 0.166           | 0.013          | 2920| 110             | 2860| 240            | 3100| 220            | 2962| 12             |
| 0.121           | 0.005          | 2905| 25              | 2864| 60             | 2308| 78             | 2953| 28             |
| 0.060           | 0.009          | 2838| 72              | 2720| 180            | 1170| 170            | 2936| 6              |
| 0.153           | 0.005          | 2910| 24              | 2875| 58             | 2879| 75             | 2920| 3              |
| 0.067           | 0.013          | 2712| 26              | 2511| 41             | 1320| 250            | 2892| 11             |
| 0.163           | 0.006          | 2851| 33              | 2860| 76             | 3058| 79             | 2848| 7              |
| 0.150           | 0.004          | 2856| 23              | 2839| 52             | 2826| 58             | 2852| 9              |
| 0.152           | 0.004          | 2860| 16              | 2878| 38             | 2864| 44             | 2840| 13             |
Conclusions. The Huliaipole Block of the Azov Domain of the Ukrainian Shield carries evidence for a protracted geological evolution from the Hadean to the Palaeoproterozoic. The Azov Domain indicates existence of the cratonic nucleus formed from 3.97 to 3.3 Ga ago. In the Mesoproterozoic (3.2-3.0 Ga), the Huliaipole Block was a part of the Middle-Dnieper-Azov-Kursk granite-greenstone terrane. Felsic and intermediate volcanic rocks of the Huliaipole Suite could have formed due to the melting of the sialic continental crust, including components of the Hadean and Archean age, as a result of the underplating by mafic magmas during the formation of Neoarchean-Paleoproterozoic extension-related rift structures.

REFERENCES
1. Bibikova, E. V. & Williams, I. S. (1990). Ion microprobe U-Th-Pb isotopic studies of zircons from three Early Precambrian areas in the USSR. Precambrian Res., 48, pp. 203-221.
2. Claesson, S., Bibikova, E., Shumlyanskyy, L., Dhuime, B. & Hawkesworth, C. (2015). The oldest crust in the Ukrainian Shield — Eoarchean U-Pb ages and Hf-Nd constraints from enderbites and metasediments in: Van Kranendonk, N.M.W., Parman, S., Shirey, S. & Clift, P.D. (Eds.). Continent Formation Through Time (pp. 227-259). Geological Society, London, Special Publications, 389.
3. Shumlyanskyy, L., Wilde, S. A., Nemchin, A. A., Claesson, S., Billström, K. & Bagiński, B. (2020). Eoarchean rock association in the Dniester-Bouh Domain of the Ukrainian shield: a suite of LILE-depleted enderbites and mafic granulites. Precam. Res., 106001.
4. Bibikova, E. V., Claesson, S., Fedotova, A. A., Artemenko, G. V. & Ilyinsky, L. (2010). Terrigenous zircon of the Archean greenstone belts - a source of information about the early crust of the Earth: Azov and Dnieper regions, Ukrainian Shield. Geochemistry, No. 9, pp. 899-916 (in Russian).
5. Nozhkin, A. D. & Krestin, E. M. (1984). Radioactive elements in the rocks of the Early Precambrian (at the example of KMA). Moscow: Nauka (in Russian).
6. Glevasskiy, E. B., Bosaya, N. I. & Polunovskiy, R. M. (1985). The Huliaipole Suite. Stratigraphic sections of the Precambrian of the Ukrainian Shield (pp. 137-142). Kiev: Naukova Dumka (in Russian).
7. Berzenin, B. Z. (1990). The study of the composition, ore bearing and correlation of the sections of the Osi-penko, Huliaipole, Sachki and Kosivtseve strata of the Azov Block of the Ukrainian Shield. Novomoskovsk GEE, “Yuzhukrgeologiya”, Dnepropetrovsk (in Russian).
8. Zhukov, G. V., Andrushchenko, I. L. & Krivonos, V. P. (1978). The Huliaipole area. Ferrous-siliceous formations of the Ukrainian Shield: In 2 vol. Vol. 1 (pp. 299-304). Kyiv: Naukova Dumka (in Russian).
9. Tatarinova, E. A., Artemenko, G. V. & Dovbush, T. I. (2001). The age of detrital and metamorphic zircon in the rocks of the Huliaipole suite. Mineral. Zhurn., 23, No. 2/3, pp. 61-63 (in Russian).
10. Bobrov, A. B., Malyuk, B. I. & Shpylchak, V. A. (1991). Metamorphosed komatiites of the Azov geoblock of the Ukrainian Shield. Geol. Zhurn., No. 1, pp. 92-100 (in Russian).
11. Artemenko, G. V., Shvaika, I. A., Tatarinova, E. A. & Kalinin, V. I. (2008). Geochemistry of granitoids and volcanic rocks of the Huliaipole block (the Azov Domain of the Ukrainian Shield). Theoretical and applied aspects of geoinformatics (pp. 175-188). Kyiv (in Russian).
12. Stepanyuk, L. M., Bobrov, O. B., Shpylchak, V. O., Stefanishin, O. B. & Sergov, S. A. & Lepukhina, O. M. (2007). New data on the radiological age of granitoids of the Dobropillya massif (the West Azov area). Article 3. Results of the radiological dating. Collection of scientific work of UkrDGRI, pp. 83-89 (in Ukrainian).
13. Demedyuk, V. V. (2010). Isotope age of post-collisional vein of granites in the Ternuvatka structure (the Azov Domain of the Ukrainian Shield). Theoretical and applied aspects of geoinformatics: Collection of scientific papers (pp. 142-146). Kyiv (in Russian).
14. Shcherbak, N. P., Artemenko, G. V., Bartnitsky, E. N. & Shpylchak, V. A. (2000). The age of granitoids of the Huliaipole block. Dopov. Nac. akad. nauk Ukr., No. 5, pp. 139-144 (in Russian).
15. Lobach-Zhuchenko, S. B., Kaulina, A. T., Baltybaev, S. K., Balaganskii, V. V., Egorova, Yu. S., Lokhov, K. I., Skublov, S. G., Sukach, V. V., Bogomolov, E. S., Stepanyuk, L. M., Galankina, O. L., Berezhnaya, N. G., Kapitonov, I. N., Antonova, A. V. & Sergeev, S. A. (2016). The long (3.7-2.1 Ga) and multistage evolution of the Bug granulite gneiss complex, Ukrainian shield, based on the SIMS UePb ages and geochemistry of...
Stages in evolution of Earth’s crust recorded by the Huliaipole block of the West Azov area (4.0–2.0 Ga)

16. Bibikova, E. V., Claesson, S., Fedotova, A. A., Stepanyuk, L. M., Shumlyanskyy, L. V., Kirnozova, T. I., Fugzan, M. M. & Ilinsky, L. S. (2013). Isotope geochronological (U-Th-Pb, Lu-Hf) study of zircons from the Archean magmatic and metasedimentary rocks of the Podolia Domain, Ukrainian shield. Geochem. Int., 51, pp. 87-108.

17. Shumlyanskyy, L., Hawkesworth, C., Dhuime, B., Billström, K., Claesson, S. & Storey, C. (2015). 207Pb/206Pb ages and Hf isotope composition of zircons from sedimentary rocks of the Ukrainian shield: crustal growth of the south-western part of East European craton from Archaean to Neoproterozoic. Precam. Res., 260, pp. 39-54.

18. Stepanyuk, L. M., Shumlyanskyy, L. V., Hoffman, A., Hoffman, M., Kovalik, A. & Becker, A. (2020). On the Mesoarchean age of detrital zircon from metaterrigenous formations of the Skelyuvatka and Saksagan suites of the Kryviy Rih structure (according to the U-Pb dating). Mineral. Zhurn., 42, No. 2, pp. 46-62 (in Ukrainian).

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ЕТАПИ ФОРМУВАННЯ ЗЕМНОЇ КОРИ НА ПРИКЛАДІ ГУЛЯЙПІЛЬСЬКОГО БЛОКА ЗАХІДНОГО ПРИАЗОВ’Я (4,0–2,0 млрд років)

Методом LA-ICP-MS визначено U-Pb вік популяцій циркону з метадацитів гуляйпільської світі — 3085–2850 і 3700–3360 млн років. Крім того, виявлено два кристали циркону віком понад 3800 млн років. Згідно з геологічними і геохронологічними даними, Гуляйпільський блок, який має розміри 30 × 50 км, складений породами і їх реліктами гадейського, архейського і палеопротерозойського еонів. Найдавнішим фундаментом Приазовського мегаблока є ймовірно, породи нуклеарної структури, яка формувалася від 3,97 до 3,3 млрд років. У мезоархеї (3,2–3,0 млрд років) вона стала частиною Середньопридніпровсько-Приазовсько-Курського граніт-зеленокам’яного терейну. Вулканіти кислого і середнього складу гуляйпільської світі могли утворитися внаслідок плавлення порід сіалічної кори, що включала породи гадейського і архейського віку, в результаті андерплейтингу базитових розплавів під час формування неоархей-палеопротерозойських рифтогенних структур.

Ключові слова: Західне Приазов’я, Гуляйпільський блок, гадей, архей, палеопротерозой, Український щит, U-Pb вік.