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Hercynian folded structures in the valley of the Mokra Volnovaha River as the basis of a Geological park at the border of the Donbas and the Ukrainian Shield

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Abstract. The basin of the Mokra Volnovaha River, from the Mykolaivka village to the place where it flows into the Kalmius River, exposes an extremely informative geological cross-section of the conjunction of the Pryazov block of the Ukrainian Shield (US) with the complexly located Donetsk Hercynian structure. The results of the survey of this area

are presented and the perspectives for creation of the MafHaia Geological Park named after the important paleo-volcanic structure are substantiated. The most significant events related to the geological studies of the regions from the academic expeditions of Pierre Guillaume Frédéric Le Play, P. S. Pallas to nowadays are considered in historic sequence. The structural-tectonic position of the territories, mineral-petrographic peculiarities of the rocks of the prospective geopark were studied and great geodiversity important for the development of the geotourism as an important component of functioning of geopark was determined. We followed sequential change in the geological cross-section from the association of Maksymivski granodiorites of the Middle Archean East-Pryazovska Structural-Formation Zones of the Ukrainian Shield in Mykolaivka village, terrigenous and volcanic formations of the Devonian system which are embedded on them and belong to the Eifelian, Givetian, Frasnian and Famennian stages, to terrigenous carbon-bearing deposits of Carboniferous system which form large rock outcrops on the Left Bank of the Styła water reservoir and outcrops in the quarries for extraction of flux limes and dolomites. It is proposed to consider as highly relevant the principally new “Balanced structural-geologic map of the Southern Donbass” proposed by V. V. Yudin, based on fracture-block tectonics, thrust faults which caused pre-fault mélanges and duplexes. The most characteristic peculiarities of the geological structure of the Rozdolne Geological Reserve as the main location of the future geopark were determined. As the one of the main attractions of geotourism itineraries, we evaluated the unique Devonian flora of global significance in the Velyka Karakuba (Rozdolne) village, particularly *Archaeopteris archaetypus* Schm., *Archaeopteris fissilis* Schm., *Lepidodendron karakubense* Schm., *Demerpteris fasciculate* Schm. and others, first in history discovered in 1894 by I. O. Shmal’gauzen. An important peculiarity of the zone of the junction of the US and the folded Donbas is its attractiveness for collecting minerals, including crystals and druse amethyst, smoky quartz, druses of pyrite, pseudomorph on corals, chalcedony, pseudo stalactites with marcasite, small agates, pink quartz, sanjuanite, fulgurite and others.

Key words: geopark, Devonian system, geotourism, *Archaeopteris*, Mokra Volnovaha, paleovolcano, mélange, geodiversity

Герцинські складчасті споруди долини річки Мокрої Волновахи, як основа геологічного парку на межі Донбасу і Українського щита

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Анотація. Басейн річки Мокрої Волновахи від села Миколаївка до її впадіння в річку Кальміус розкриває надзвичайно інформативний геологічний розріз зони зчленування Приазовського блоку Українського щита (УЩ) із складно дислокованою Донецькою герцинською спорудою. Наведені результати дослідження цієї території та доведені перспективи створення геологічного парку «Маф Хая» за назвою великої палеовулканічної споруди. Розглядаються у історичній послідовності найважливіші події, пов’язані з геологічним дослідженням району від часів академічних експедицій П’єра Гійома Фредеріка Ле Пле та П.С. Палласа до наших часів. Досліджено структурно-тектонічне положення території, мінерально-петрографічні особливості порід перспективного геопарку та встановлене велике георізноманіття, важливе для розвитку геотуризму, як необхідної складовою функціонування геопарку. Простежено послідовну зміну геологічного розрізу від асоціації максимівських гранодіоритів середнього архею Східноприазовської СФЗ УЩ в селі Миколаївка, теригенних та вулканогенних утворень девонської системи, які на них залягають і належать ейфельському, живетському, франському і фаменському ярусам до теригенно-карбонатних відкладів кам’яновугільної системи, які утворюють великі скельні виходи по лівому берегу Стильського водосховища та відслонюються в кар’єрах з видобутку флюсових вапняків та доломітів. Пропонується вважати

цілком актуальною принципово нову «Збалансовану структурно-геологічну карту Південного Донбасу», запропоновану В.В. Юдіним, в основі якої не розломно-блокова тектоніка, а насунві пошарові зриви, дією яких створені природзривні меланжі і дуплекси. Визначені найбільш характерні особливості геологічної будови Роздольненського геологічного заказника, як головного осередка майбутнього геопарку. Оцінена як одна з головних атракцій геотуристичних маршрутів перша в історії людства знахідка у 1894 р. І.О. Шмальгаузену унікальної девонської флори світового значення в с. Велика Каракуба (Роздольному), а саме *Archaeopteris archaetypus* Schm., *Archaeopteris Fissilis* Schm., *Lepidodendron karakubense* Schm., *Demerpteris fasciculate* Schm. та інші. Важливою особливістю зони зчленування УЩ із складчастим Донбасом є її привабливість для колекціонування мінералів, серед яких кристали і друзи аметисту, димчастого кварцу, гірського кришталю, щітки піриту, псевдоморфози по коралах, халцедон, псевдосталактити з марказитом, дрібні агати, рожевий кварц, санхуаніт, фульгурит та інші.

Ключові слова: геопарк, девон, геотуризм, *Archaeopteris*, Мокра Волноваха, палеовулкан, меланж, георізноманіття

Introduction. The picturesque steppe river the Mokra Volnovaha, one of the right bank tributaries of the Kalmius River, cuts the area of conjunction of the Priazovia Block of the Ukrainian Shield (US) with the Donetsk Hercynian folded structure and exposes an extremely informative geological cross-section of these structures. Murray Gray, theorist of contemporary usage of the word “geodiversity”, would commend the suitability of using this term regarding this territory. From the Eastern border of Mykolaivka and Novohnativka villages, between which the Mokra Volnovaha River flows, for a length of 45 km, there are fragmented outcrops of rocks of the Pre-Cambrian granitoids to carbonate-terrigenous and volcanogenic formations of Devonian and thick carbonate layers of the Carboniferous system. Ukraine does not belong to the list of countries where geoparks have been created, but the problem of selection of promising objects for organizing future geoparks and evaluating their scientific and touristic attractiveness has been considered by the Ukrainian representatives practically since the moment of establishing the first 4 geoparks in Europe (Grytsenko, 2004; Kravchuk, Zinko, Homyn & Shevchuk, 2012; Manyuk V., 2006, 2007, 2008; Zinko, Shevchuk, 2011; Shevchuk, 2010). From the perspective of geological attractiveness, high level of geodiversity, the area of the conjunction of the US and the Donetsk folded structure obviously corresponds to the criteria of the selection of the objects of both the European and international geopark network.

A Brief History of Geological Research. But first a little bit of history. Its description could be started from the far off year 1721, when Mykyta Vepreisky and Semen Chyrkov organized the extraction of coal in the Bakhmutsky Uyezd. However, we are more interested in the past of the territory, the geological content of which is attractive and scientifically valuable, and therefore entirely suitable for establishment one of the geoparks of Ukraine in the nearest future. First reports on geology of the area are related to visits of S. G. Gmelin (1768-1769), J. A. Guldenstadt (1791) and P. S. Pallas (1794) to the Donbas, while travelling across Russia (Trypilska, 1958) (Fig.1).

The earliest data on designation and stratification of the deposits of the Devonian and Carboniferous systems of the Donbas were given in the studies of the founder of coal petrography Ivanytskyi A. B. (Ivanytskyi, 1833). He wrote “For scientist and miner, this Land is especially interesting regarding diversity of minerals which form its soil” (Ivanytskyi, 1833). Another important study was the one by Pierre Guillaume Frédéric Le Play, famous co-author of the 4-volume study with tables, geological maps and illustrations, published to present the scientific results of the expedition of A. M. Demidov (Le-Play, 1842); Roderick Impey Murchison, another eminent scientist, whose study on the Donbas, according to the contemporaries, determined “the epoch in the manuscripts of geology” (Murchison, 1845); Klemm M. Y., who was first to conduct substantiated studies in the basin in the Mokra Volnovaha River (Klemm, 1874, 1877); Morozevich Y. A., who in his studies between Mykolaivka and Styła distinguished amphibole andesites, feldspar basalts near the Buzynova ravine and for the first time determined and distinguished 8 types of mariupolites of Pryazovia, and others. It is impossible not to recollect also Valerian Domger, who not only discovered the deposits of manganese ores in Nikopol Oblast, the unique location of the fossil fauna of the Upper Eocene in the layers which later received the name Mandrykovski, but also provided a systematic analysis of geological study of the Donbas and reports on the Pryazovia part of the Ukrainian Shield (Domger, 1881). In 1956, Ormont N. P. studied pyroxenes of basalt rocks of the basin of the Mokra Volnovaha River and for the first time offered their chemical analysis and identified them to titan-augite (Ormont, 1956). Information about the geology of the territory of the conjunction of the Ukrainian Shield and the Donetsk folded structure was given in the studies by Luchynsky V. I., Bernadska L. H., Usenko I. S., Meffert B. F., Rotai A. P., Trypilska M. I., Makukhina H. O., Lahutina P. K., Buturlinova N. V., Honshakova N. P., Alokhin V. I. and others.

Geological setting. In the structural-tectonic aspect, the conditionally distinguished territory of the pro-

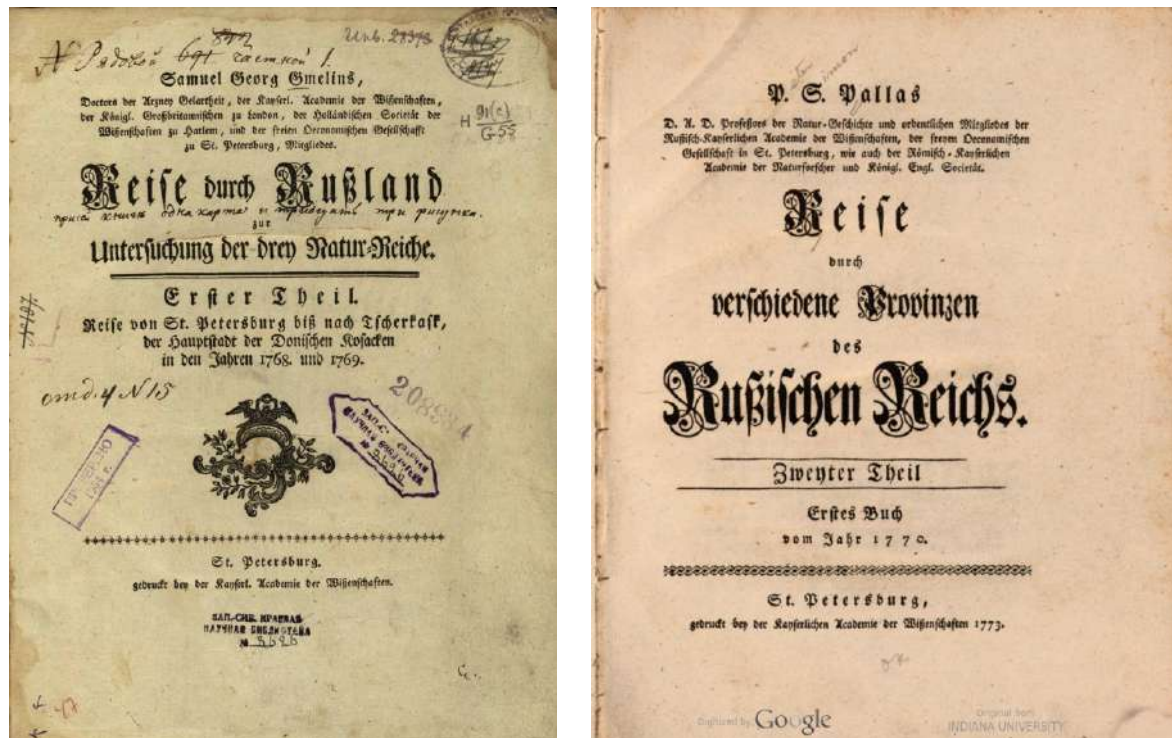


Fig.1 First editions of books by S. G. Gmelin (1774) and P. S.Pallas (1809)

spective geopark with the working name Maf-Haia is characterized first of all by the conjunction in the system of faults between the Ukrainian Shield and the folded Donbas. The main faults in this system are the Voikivsky and Vasylivsky (19, 20 in Fig. 1). Vasylivsky (Pivdenovolnovasky) fault which is the component of the South Donbas zone of faults has the strike close to sublatitudinal, separates Hercynian rocks of the folded Donbas from the Pryazovia block of the US, according to the morphological features it is a dip-slip fault, fissure of which is inclined towards the Shield (in the southern rhumb lines) at the angle of 75-80°, vertical amplitude of shift of up to 600-1,000 m.

The determining role in the folded geological structure of the region belongs to terrigenous-volcanogenic complexes earlier known as components of Paleo basalt cover (Makukhina, 1961), including Haina-Chohrasky, Mokro-Volnovasky, Komyshevsky and Tsyhanka. In modern terminology, it is a volcanogenic-sedimentary structural-formational complex of the folded Donbas, formed during the Bretonian phase of the Hercynian folding of the platform stage of the development of the East European Platform.

There are other views on the complex tectonic zone of the conjunction of the US and the folded Donbas. The noted proponent of ideas of neomobility V. V. Yudin points out the significant controversy surrounding previous theories and ideas. He has created a principally new “Balanced structural-geologic

map of the Southern Donbas” based not on the fault-block tectonics, but the overthrust (flats and detachments), activity of which formed pre-fault mélanges and duplexes). He considers the Stylsky and Volnovasky culminations of the Pre-Cambrian basement as analogues of the Yelanchytsky culmination of the Pre-Cambrian Donetsk ridge, whereas earlier they were considered grabens with downthrow blocks (Yudin, 2006). Detailed studies conducted by V. V. Yudin in the Southern Donbas allowed him to determine principally new structures, including the Donetsk collision structure, series of overlaps, nappes, décollements, and therefore substantiate the folded overthrust, and then nappe structures of the region (Yudin, Artemenko, 1996; Yudin, 2004, 2006).

Practically all the mélanges were substantially designated by V. V. Yudin on the basis of a large amount of actual material and those which distinctively characterize the structure of the zone of the conjunction of the US and the Donetsk ridge, cross the valley of the Mokra Volnovaha and Kalmius rivers and should become the most important components of the geotouristic route, particularly Stylsky, Komyshevsky, South-Dokuchaievsky, Rodnykivsky, South-Stulsky and Dalni mélanges, fragments of which were exposed by erosional activity of the abovementioned rivers and the quarries for the extraction of flux limes and dolomites.

On the basis of the fact that the proposed itineraries follows the valley of the Mokra Volnovaha

and Kalmius, step-by-step exposing the peculiarities of geological structure of the territory in numerous outcrops and quarries, we shall try to gradually describe the geological attractions along this route which should convince those travelling there that it is worth it.

The itinerary begins from the east outskirts of Mykolaivka village, where in the pre-mouth part of the first small unnamed ravine from the village, on the left bank of the Mokra Volnovaha, there are outcrops of grey-pink biotite-amphibole granodiorites. They belong to the association of the Maksymivski granodiorites of the East Pryazovia Structural-Formation Zones ($\gamma\delta AR_2$ mks). The rocks are significantly weathered, in some places to grass, cataclized, contain xenoliths of darker colour, with features of chloritization and epidotization on the surface (Fig. 2).



Fig. 2 Outcrops of weathered and dislocated granodiorites in the zone of conjunction of the folded Donbas (a – general view; b – interveins and veins of aplitic granite)

In the system of randomly orientated fractures, are well developed light pink leucocratic aplitic granites of 2-5 cm thickness and only in the eastern part of the outcrops do they form a larger block, perhaps a fragment of the vein (Fig. 2).

Further, on the right bank of the Anton-Tarama ravine, in its pre-mouth part, there is a small outcrop of terrigenous Devonian formations. There is an outcrop of grayish-yellow quartz arkose sandstone, from average and large-grained to gravellite, thick, quartz-like, ferruginized, highly kaolinized due to weathering of feldspars, with notable thin horizontal lamination. According to the geological mapping, it belongs to the Lower subsuite of the Mykolaivska suite of the Eifelian Stage (“white Devonian”) (D_2mk). East of this outcrop are small outcrops of finer-grained pink sandstone with almost vertical dip of the layers, whereas the first outcrop had the dip angle of 10° , and dip azimuth of 70° (Fig.3).

500 m east of the mouth of the Anton-Tarama ravine, the zone of distribution of volcanogenic formations begins. According to the recent stratigraphic scheme, they belong to the Antonivska suite of middle-upper Devonian period ($D_{2,3an}$), represented there by the alternation of lava and pyroclastic formations. Earlier, this strip of volcanites’ spreading was considered as “Paleo-basalt cover”, including picrite basalts, basalts, andesite-basalts, andesites, spilites, keratophyres, which interlay with tuff-breccias and tuff (Makukhina, 1961; *Geologichne dovyvchennja*, 2007). Makuhina G. O. mentions that within the area of spreading of volcanic cover, according to the data of boring, up to 7 lava flows are present, divided by units of tuff-breccias, tuff conglomerates and tuff which interlay with normal sedimentary rocks of the Frasnian stage. Also, she reports spilite with characteristic globular jointing in the mouth of the Vasyl-Tarama ravine (Makukhina, 1961). According to the modern views, the effusive rocks are represented by alkaline ultra-basic and subalkaline basic types. The first type has subordinate distribution and is represented by augites, limburgites and subalkaline picrites (*Geologichne dovyvchennja*, 2007; Radzyvyl, A., Radzyvyl V., Tokovenko, 1986). Sub-alkaline volcanic rocks are represented by trachybasalts and to a lower extent trachyandesibasalts. Volcanoclastic rocks are represented by clastic lavas, breccias lavas and pyroclastic rocks. By the size of fragments, in numerous outcrops, one can see tuff-breccias with lapilli and volcanic bombs, tuff gravellites, tuff aleurolites and tuff argillites (Fig. 4,5,6,7)

Among the lava facies, trachybasalts dominate, the outcrops of which are characterized by quite notable columnar jointing. Of course, it is not so classic as in the Ivano-Dolynske quarry of basalts, but it is a



Fig. 3. Outcrops of polymictic sandstones of the middle Devonian Mykolaivska suite on the left slope of the Mokra Volnovaha river.

unique phenomenon for the folded Donbas. Massive cryptocrystalline and porphyritic types are common, rarer almond-shaped. Less distributed are augites and limburgites form lava flows of observable thickness of 1-22 m, which interlay with the currents of subal-

kaline effusive rocks. Quite often, one can see globular jointing of basalts with the diameter of separate globes of up to 0.5 m (Fig. 6). The conditions of the embedding of the effusive rocks and peculiarities of their relations with other rocks of the cross-section



Fig. 4. Volcanic bomb from the layer of pyroclastic rocks



Fig. 5. Tuff gravellite (Antonivska suite)



Fig. 6 Tuff argillite (Antonivska suite)



Fig. 7 Globular jointing of the basalts of the Antonivska suite

of the subsuite indicate the simultaneity of their formation and horizon of tuff sedimentary (complex) breccia, limestones and their breccia, sandstones, argillites. Alternation of volcanic rocks and sedimentary rocks in the cross section of volcanic rocks, their variability, domination of ferrous iron over ferric iron indicates the formation of volcanites of the subsuite in the underwater conditions. An important evidence of this is the development of ferrous-chlorite oolites with concentrated ash content in tuff or breccias of similar compound.

Besides the covering basalts in the basin of the Mokra Volnovaha, dyke basalts are distributed, which by the compound are close to the covering basalts, but differ by better level of crystallization (Alokhin, Korchemagin, 2008). They are represented by fine-grained dolerites which earlier belonged to anamesites. Shatalov M. M. identifies them to the Anton-Taramsky dyke belt (Shatalov, 2015).

The area of the distribution of the Antonivska suite (from the indicated border with the Mykolaivska suite to the western border of the Styla water reservoir, where it borders with the rocks of the Dovhynska suite of the Upper Devonian rocks) is considered by V. V. Yudin as the largest *mélange* in Donbas – the Rozdolensky *mélange* (Fig. 8). He thinks that by the content of the clastolites it is a magmatogenic mixtite related to the detachment (decollement of the layers on the surface of the sedimentary dome) of northern sloping dip. The *mélange* pattern of the chaotic complex is indicated by the tectonic pattern of its border and hydrothermal ore manifestations in the matrix (Yudin, 2006).

Downstream, according to the data of geological mapping, the valley of the Mokra Volnovaha crosses a narrow strip of the distribution of the Dovhunska suite of the Frasnian stage of the Upper Devonian

period (D_3dw), but terrigenous deposits of the suite in this area of the valley are overlaid and have small outcrops only in the area of the Rozdolne village. Moreover, its cross section represented by alternation of alevrolites, argillites, conglomerates and gravelites is exposed and studied layer by layer in the Dalny quarry below the place where the Mokra Volnovaha flows into its right tributary the Komyshevaha.

Near the place where the Mokra Volnovaha flows into the Havaleis-Tarama (Buzynova) ravine, on the left bank of the Styla water reservoir there is a low rocky hill Maf Haia (or Chorna mountain according to the more recent sources) of volcanic origin. Together with cross section of carbonate limestones located near, it is a geological relic of nature of national significance, taken under protection in 1975 (Alokhin, Volkova, 2011). On the slopes and in adjacent ravines, there are outcrops of terrigenous-effusive layer of the Rozdolnenska suite of the Famennian stage of the Upper Devonian period and terrigenous-carbonate formations of the Novotroitska suite of the Upper Devonian period. The Rozdolnenska suite is represented by green and brown polymictic sandstones, which interlay with argillites and aleurolites and contain high amount of pyroclastic material. East of the Maf Haia hill in the Havaleis-Tarama gully, 20–25 m below the top of the deposits of the Rozdolnenska suite, there are outcrops of green jasper-like shists with numerous plant remains of *Lepidodendropsis* flora (*Lepidodendropsis hirmieri*, *L. cyclostigmatoides*, *L. vandergrachtii*). (Flora i fauna, 2020). (Fig. 9).

Higher in the ravine, arkosic sandstones with layers of argillites, aleurolites and low-lime sandstones are exposed. In the head of the gully and further along the Mokra Volnovaha River, there were found fine-grained light gray limestones of the upper part of the Novotroitska suite of the Up-

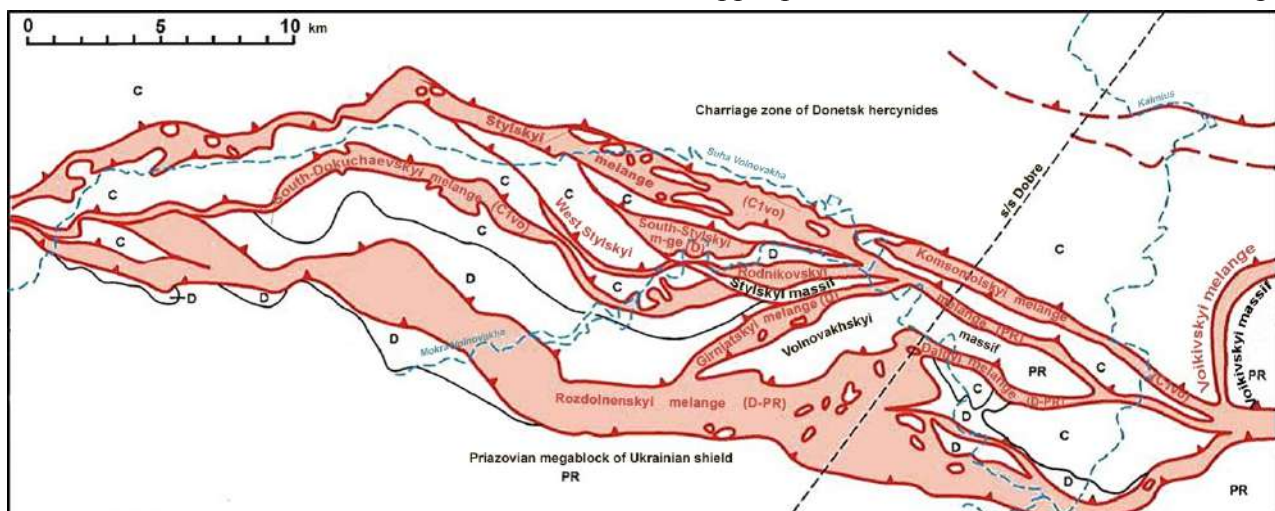


Fig. 8. Tectonic scheme of the Northern Donbas (Yudin, 2006).



Fig. 9. Green jasper-like shists of the Upper Devonian period with imprints of ancient flora and particularly *Lepidodendropsis* found near the MafHaia volcano (<https://www.ammonit.ru/user/Ostrzew.htm>)

per Devonian period with a layer containing numerous colonies of stromatopora *Rosenellalis sitzini* Vass. Above the light grey limestone, there is embedded a layer of yellow-grey semi down flowed limestone with numerous *Camarotoechia kalmiussi* Rot. and scattered *Plicatifera exgr. kalmiussi* Lis. (“plate with *Camarotoechia*”). Higher, a thin latered light-grey limestone of 6 m thickness is embedded, having an interlayer of brown ore in the foot, and being dolomitized in the upper part of the layer. To the upper part of this layer, a layer with numerous *Bisphaera sp.* is confined, and the border between the Devonian and Carboniferous periods runs across the foot of this lay-

er (Flora i fauna, 2020; Ishhenko, 1961).

The best and the largest in size outcrop with notable signs of column jointing of basalts is located right after the mouth part of the Havaleis-Tarama ravine, on the left slope of the valley of the Mokra Volnovaha River (Fig. 10).

Deposits of the Carboniferous system are represented in a small outcrop of the left slope of the valley of the Mokra Volnovaha River, where the carbonate layer forms a promontory opposite the Havaleis-Tarama ravine. Here, in the form of rocky ridges, there is exposure of the complex of rocks with horizontal layering represented by composition of layers of lime-



Fig. 10 Columnar jointing of basalts in the valley of the Mokra Volnovaha River

stones, dolomitized limestones and dolomites (Fig. 10). They belong to the Volnovaska series on the divided Tournaisian and Visean stages. Often, remains of the fossil fauna are found, including *Productus corrugatus* M'Coy, *Spirifer medius* Leb., *Ortotetesarachoides* Phill., *Eomphalus pentangulatus* Sow. and others (Geologicheskaja karta, 1961).

V. V. Yudin considers the strip of the distribution of the rocks of the Mokrovolhovaska series of the Tournaisian and Visean stages of carbon from the contact with Devonian rocks to Styła village as separate parts in the series of duplexes of Northern

manifestations of the pre-overthrust dislocations and clastoliths rocks in the mouth of the Havaleis-Tarama ravine (Fig. 12, 13).

Therefore, this allows the author to draw a conclusion that by geological-structural data, the normal cross section or large masses of undisturbed rocks of the Mokrovolnovaska series of the Lower Carbon were not observed there in any way (Yudin, 2006).

The next attractive and informative object of the geological heritage is the Styła quarry which has not operated for about 9 years and is accessible for visits (Fig. 14).



Fig. 11. Exposure of limestones and dolomites of the Volnovaska suite of the Devonian period (Tournaisian-Visean stages) on the left slope of the Styła reservoir.

Donbas (Fig. 7) and that it constitutes the continuation of the North-Dokuchaievsk mélangé in the area of the Buzynova ravine and further to Styła village. The outcrops contain fractured and alkaline shists of the Visean stage with boulders- clastolith rocks below the limestones of the Visean stage and with fragments of the pre-overthrust folds. This is evidenced in the

During the revision monitoring of geological relics in 2003 it could not be visited, and therefore we present some its peculiarities from the study by Victor Yudin, which today is the most comprehensive. In the west wall of the quarry, one can see the tectonic type of the Styła mélangé and its contact in the lower part of the wall with almost non-affected limestones of



Fig. 12. Pre-overthrust fault dislocations with signs of disintegration and ferruginization in the Havaleis-Tarama ravine (Yudin, 2006)



Fig. 13. Clastoliths of limestones of the Visean stage (C_1v) in the ferruginized matrix of the North-Dokuchaievsk mélangé (mouth of the Havaleis-Tarama ravine) (Yudin, 2006).

the Lower Carboniferous. In the boulders among the schistosity matrix, limestones and dolomites of the Visean stage are present. A distinctive peculiarity of the quarry is the subvertical dyke of trachyandesites, in the contact zones of which increased amounts of pyrite, marcasite and chalcopryrite were determined, which made the quarry well known among collectors of minerals. Apart from druses of pyrites, in different years, druses of dolomite, minerals of sanjuanite, fulgurite, almandine, quartz, etc have been found in the quarry. Very interesting are small cavities in the Tournaisian limestones and dolomites, filled with entire incrustated formations and pseudo-stalactites of hydrothermal pyrite. The photos show findings in the rocks of the Styła quarry by Evhen Naumenko (Fig. 15).

Therefore, in the Styła quarry, one can not only enjoy the geological attraction, but, if lucky, add to one's collection. In carbonate layers, processes of the development of karst are seen and even quite large karst springs in one of the walls of the quarry (Yudin, 2006).

In the outcrops north of Styła village, a stratotype of the Styłska suite of the Lower Carbon period was determined. However, V. V. Yudin thinks that actually there is a lower, smaller part of the suite section. The rocks are disintegrated to jasper, highly ferruginized with formation of ferruginized boulders, with

interveins of chalcedony, small druses of quartz.

The area of the valley of the Mokra Volnovaha from the Styła village to the Rozdolne village remains so far unsurveyed by us due to lack of time during inventorisation of the geological heritage of Ukraine. Nonetheless, it is not less attractive or informative from the perspective of presence of natural and artificial outcrops on the route around the Kypucha, Krynytsia and Rodnykove villages and downstream. Below the place where the Komyshevaha flows into the Mokra Volnovaha, on the right slope of the valley, the Dalny quarry is located, which was closed in 2014 and flooded. It is currently a great place for recreation and geological tourism (Fig. 16).

The real pearl of the geotouristic iteanary is the Rozdolensky Geological Reserve of National significance established in 1974 by the decision of the Council of Ministers of the Ukrainian SSR, covering an area of 100 ha. The main object of the Reserve is the Devonian volcanic structure, which is an elongated hill above the right bank of the Mokra Volnovaha River near the place where it falls into the Kalmius River and near Rozdolne village (Fig. 17).

In the northern part of the hill, the tectonic contact of granites and migmatites of the Antonivska suite of the Devonian period was determined. The latter is an extremely complicated complex of the layers of pyroclastic rocks, volcanic (lava) and sedimentary



Fig. 14. The Styla quarry for extraction of flux limestones and dolomites

terrigenous rocks. Among them, one can find volcanomictous gravellites, sandstones and aleurolites; picrite, basalt and andesibasalt porphyritic rocks, light-green albitophyre, almond rocky basalts; limestones, clayey dense shists, etc. Particularly in the latter rocks, in far off 1894 I. O. Shmal'gauzen for the first time determined the unique Devonian flora of global significance in Velyka Karakuba village (Rozdolne). The village was founded in 1779 by the settlers from

Greece in accordance with the Treaty of Kuchuk-Kainarji. The flora determined by I. O. Shmal'gauzen included *Archaeopteris archaetypus* Schm., *Archaeopteris Fissilis* Schm., *Lepidodendron karakubense* Schm., *Demeripteris fasciculate* Schm. Therefore, this discovery of trees from the most ancient times of the Earth could alone be sufficient reason for the recognition of the Rozdolensky Reserve as an object of global significance. The famous discovery of



Rhinestone



Quartz



Pyrite

Fig. 15. Minerals of the Styla quarry from the collection of Naumenko Y. (<https://webmineral.ru/deposits/item.php?id=274>)



Fig. 16 Flooded Dalny quarry (<https://webmineral.ru/deposits/item.php?id=2343>)



Fig. 17. Picturesque landscape near the place where the Mokra Volnovaha falls into the Kalmius River

the Earth's oldest known forest in Cairo (New York, USA) is at least of the same age, or even younger. The absolute age of the *Archaeopteris* in Cairo, according to the data of the *Current Biology Journal*, 386 M years, is the Givetian stage, when the formation of the volcanic-sedimentary layer of the Rozdolensky volcano took place (Uchjonye nashli, 2020). Fragments of fossil trees which even today could be found on the slopes of the volcano are not that representative as in New York, but the fact of their discovery is extremely important (Trypilska, 1958).

Conclusions. The data about the geological component of the itinerary in the valley of the Mokra Volnovaha River are not determined entirely, insufficient, and also obviously require further studies. Furthermore, the significance of this territory of distribution of Devonian and Carboniferous deposits in the basin of the Volnovaha and Kalmius is increased because of the numerous rare and collectable minerals, fossil fauna and flora. Selection of samples must obviously be regulated, limited, and for some of them completely restricted, as in any protected territories. In different years, in the outcrops and quarries of this territory, findings have included crystals and druses of amethyst, smoky quartz, quartz, druses of pyrite, pseudomorphoses on corals, chalcedony, pseudo-stalactites with marcasite, small agates, pink quartz, sanjuanite, fulgurite and others. Regarding the perspective of creating a geopark, the considerable geodiversity of the territory could be well supported by the large biodiversity. In the valleys of the rivers and adjoining slopes of the Volnovaha, Kalmius and their tributaries, there are well preserved picturesque

steppe landscapes with large number of rare and endangered species of plants and animals. The territory adjacent to the future geopark has possibilities for the development of the cultural-educational, religious and pilgrimage tourisms. For example, in Nikolske village, the Ukraine's largest monastery with a large temple complex is located.

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