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EXOTIC METAMORPHIC SCHIST FRAGMENTS IN THE OLIGOCENE DEPOSITS OF THE SILESIAN NAPPE (UKRAINIAN CARPATHIANS)

(Представлено членом редакційної колегії д-ром геол. наук, доц. С. Є. Шнюковим)

The study aims at analyzing the petrographic composition of exotic metamorphic schist clasts in the Oligocene deposits filling the Silesian Nappe in the south-western part of the Ukrainian Carpathians and reconstructing their possible source area. The methodology includes petrographic, sedimentological and comparative geological methods.

To achieve this goal, field research was carried out along the first right tributary of the Hysnyi Stream (the village of Uzhok, Velykoberezhnianskyi district, Transcarpathian region) and petrographic analysis of the selected samples of the exotic metamorphic schist clasts included in the Oligocene debris-flow deposits was performed.

The results of microscopic studies showed that these exotic rocks are represented by mica-quartz schist and garnet-muscovite-biotite-plagioclase-quartz schist with a low content of chlorite, carbonate and epidote. Mineral composition and structure/texture features suggest the rocks were metamorphosed under green schist and epidote-amphibolite facies. Similar exotic rock fragments were identified by Polish scientists in the south-eastern part of the Polish Carpathians in the Silesian Nappe, where possible source area of the exotic rocks is related to the Bukowiec Paleo-Ridge, which had been located between the Dukla and Silesian basins of the Carpathian sedimentary realm.

Scientific novelty. For the first time, the petrographic composition and textural and structural features of the exotic schists fragments included in the Oligocene deposits of the Silesian Nappe in the Ukrainian Carpathians (area of the village of Uzhok, Ukrainian Carpathians) are described. These schists are similar to the exotic rocks included in the Oligocene deposits of the Silesian Nappe in the Polish Carpathians, which may indicate the same source area.

Keywords: exotic rocks, metamorphic schists, Silesian Nappe, Ukrainian Carpathians.

Introduction. Exotic rocks (or simply "exotics") are the remnants of now buried under the Carpathian nappes source areas. They are a part of the clasts in the Carpathian sediments. The research of these rocks helps to solve the problems of paleogeographic and paleotectonic reconstructions, in particular, to outline the ancient submarine and overwater paleo-uplifts in the Carpathian Basin (so-called "cordilleras") which could have supplied the exotic debris (Danysh, 1973; Vyalov et al., 1981; Oszczypko, 2006; Cieszkowski et al., 2009; Golonka, 2011; Golonka et al., 2019; Gawęda et al., 2019 et al.). In the Ukrainian Carpathians, some of the most significant components of exotic formations are fragments of metamorphic schists (Fedushchak, 1962; Linetska, 1963; Vyalov et al., 1981; Tsar, 2018).

Exotic rocks have been recorded for a long time within the Silesian Nappe of the Ukrainian Carpathians. They are best developed in the Uzh river basin near village of Uzhok (Transcarpathian region), where Oligocene flysch deposits contain the clasts of the metamorphic schist, quartzite, marble, bioclastic limestone and other exotic rocks. The composition and origin of these rocks still remains unclear (Slaczka, 1961; Danysh, 1973; Gabinet et al., 1976; Kulchytskyi, 1977; Vyalov et al., 1981; Hnylko, 2000, 2011 et al.). Metamorphic schists can be the products of the mentioned paleo-uplifts denudation, and their petrographic analysis combined with a sedimentological study of the sediments containing exotics help to understand the nature of these source areas. It is an actual scientific problem.

History of the research. The stratigraphic and geological position of the layers with exotics in the sediments of the Silesian Nappe in the Ukrainian Carpathians was presented by Vacek (1881), Wójcik (1905), Łozyniak and Temnyuk (1971), Kulchytskyi et al. (1977), Gruzman and Smirnov (1985), Hnylko (2000) and others. Sedimentological features of the flysch deposits containing the exotic rock fragments were described by Slaczka (1961) and Hnylko (2000, 2011).

According to Slaczka (1961), deposits with exotics near the village of Bukowiec (Poland) form the sedimentary lens which continue in the Ukrainian Carpathians and are exposed near the village of Uzhok. The researcher believes that the

exotic rocks from these areas are similar and could have been deposited due to the activity of submarine gravitational landslides. Danysh (1973) also compares the exotic-bearing sediments located near the village of Uzhok with the similar sediments developed near the village of Bukowiec. According to Danysh, the presence of exotic rocks should be related to denudation of the ancient Fore-Dukla island ridge.

The purpose of the study is to petrographically analyze the metamorphic schists that make up the clasts in the Oligocene deposits developed in the south-western part of the Ukrainian Carpathians in the Silesian Nappe and to reconstruct their possible source area.

Methods. Petrographic, sedimentological and comparative-geological methods are used in the work. We performed a petrographic analysis of the representative samples of metamorphic schists selected from the clasts distributed in the Oligocene deposits exposed along the Little Polonyinka Stream – the first right tributary of the Hysnyi Stream flowing into the Uzh River near the village of Uzhok (Velykoberezhnianskyi district, Transcarpathian region). The sedimentological features of these exotic-bearing deposits were studied during field work in 2018–2019. The obtained results were compared with the published results of the study of the exotic rocks distributed in the Polish Carpathians (Slaczka, 1961; Slaczka, Wieser, 1962; Mochnacka, Tokarski, 1972; Tokarski, 1975; Bak et al., 2001; Ziemiński, Wolska, 2014 et al.).

Geological setting. The study area is located in the southwestern part of the Ukrainian Carpathians in the Silesian Nappe (see Fig. 1,A). The Oligocene deposits developed here are represented by the Krosno Formation (Kuzovenko, 2003 et al.) – the various bedded gray flysch represented mainly by turbidites. Clasts of the metamorphic schists and other exotic rocks are included into the debris-flow deposits which form the lens-shaped sedimentary layer with a thickness up to 40–60 m developed locally near the village of Uzhok among the Krosno turbidites. Exotic clasts are chaotically scattered among the clay-sand matrix. This chaotic layer was attributed to the Uzhok Olistostrome accumulated by series of the debris flows (Hnylko et al., 2021).

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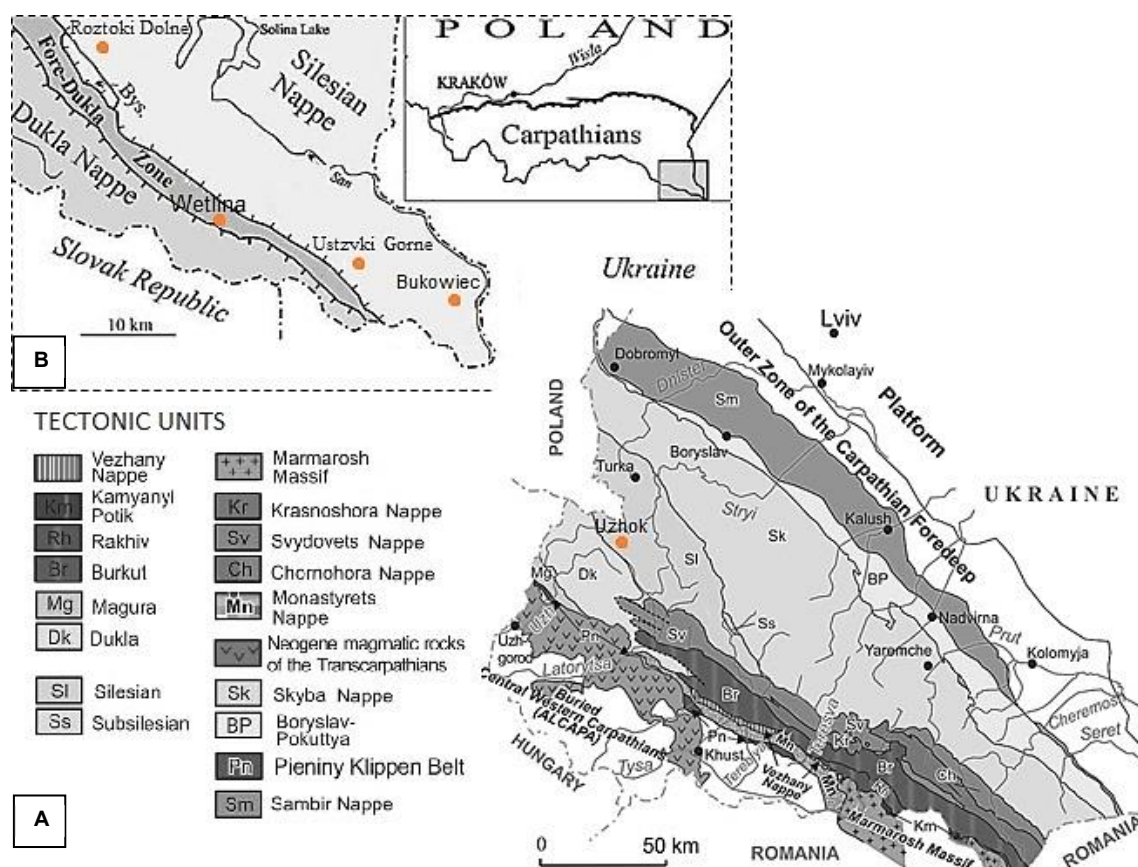


Fig. 1. A – tectonic scheme of the Ukrainian Carpathians according to (Hnylko, 2012, 2016) with the designation of the study area; B – localization of outcrops with fragments of exotic rocks in the Silesian Nappe of the Polish Carpathians on the tectonic scheme according to (Bak *et al.*, 2001)

Similar deposits occur in the Silesian Unit (Nappe) of the Polish Carpathians (see Fig. 1,B) (Wójcik, 1905; Slaczka, 1961; Slaczka, Wieser, 1962; Mochacka, Tokarski, 1972).

Results. Fragments of exotic metamorphic schists found along the Little Polonynka Stream (the right tributary of the Hysnyi Stream near the village of Uzhok) differ in size, rounding and composition (see Fig. 2). Most schist clasts are sub-angular, partly rounded, and somewhere angular ones with the corners sharp. Well-rounded clasts were rarely found. The color of the studied rocks is brown-gray and gray-green. The size is up to 25 cm.

Exotic clasts are included into the matrix represented by gray, dark gray, weakly cemented clay and clay-sandy deposits. The chaotic distribution of the exotic clasts in the matrix, lack of sorting and matrix-supported textures suggest the accumulation of the exotic-bearing deposits by the debris flows as it had been proposed previously by Hnylko (2000).

Fragments of metamorphic rocks were weathered and altered. We microscopically describe only two relatively unaltered samples of metamorphic rocks. Macroscopically, these rocks look like metamorphic crystalline schists and gneiss-like crystalline schist with garnet (see Fig. 2, 3 A, B).

Microscopically in the thin sections, the most representative metamorphic rock samples are identified as mica-quartz schist and garnet-muscovite-biotite-plagioclase-quartz schist with a small content of chlorite, carbonate and epidote (see Fig. 3, A-F).

Mica-quartz schist is characterized by a green-gray color with a brown shade. It has a schistose foliated texture. The structure is generally lepidoblastic.

The mineral composition of the rock is represented by quartz, mica minerals (biotite, sericite, muscovite) and

calcite. Recrystallization blasts of quartz represented by clusters of several grains/subgrains are clearly visible. Quartz blasts show characteristic undulatory extinction, which suggests deformation of their structure. (Fig. 3, C, E). Biotite was recorded in small quantities. The sample has aggregate formations of pelitomorphic-fine-crystalline calcite, as well as its branched veins up to 1 – 1.5 mm thick.

Most crystal grains are of the size not more than 0.05 mm and less common up to 0.1 mm. There are dissolution structures at the grain contacts (including microstylolites) which suggest increased pressure during the metamorphic processes.

Schistose texture is visible macroscopically as well as observed in optical microscopic study due to the developed mica-dominated and quartz-dominated irregular thin layers with the parallel arrangement of the micaceous minerals (Fig. 3, A-E). Such mineral orientation is developed as a result of the metamorphism under directed pressure. Presence of the mica-dominated and quartz-dominated layers suggests that a metamorphic change has taken place in terms of mineral distribution (see Fossen, 2016).

Mineral composition and structure/texture features suggest that mica-quartz schist had been metamorphosed in conditions of green schist facies under directed pressure.

Another sample represents porphyroblastic **garnet-muscovite-biotite-plagioclase-quartz schist** with a rare presence of chlorite, carbonate and epidote. The color of the schist is dark gray with a brownish shade.

The schistose foliated texture is visible macroscopically. The general porphyroblastic structure is caused by the garnet grain (up to 1–3 mm) included in the uniform small-medium-crystalline mass (see Fig. 3, D, F).



Fig. 2. Fragments of exotic metamorphic schists found in the sediments of the Krosno Formation exposed along the right tributary of the Hysnyi Stream (Silesian Nappe of the Ukrainian Carpathians).
A, B – mica-quartz schists; C – gneiss-like garnet-muscovite-biotite-plagioclase-quartz schists

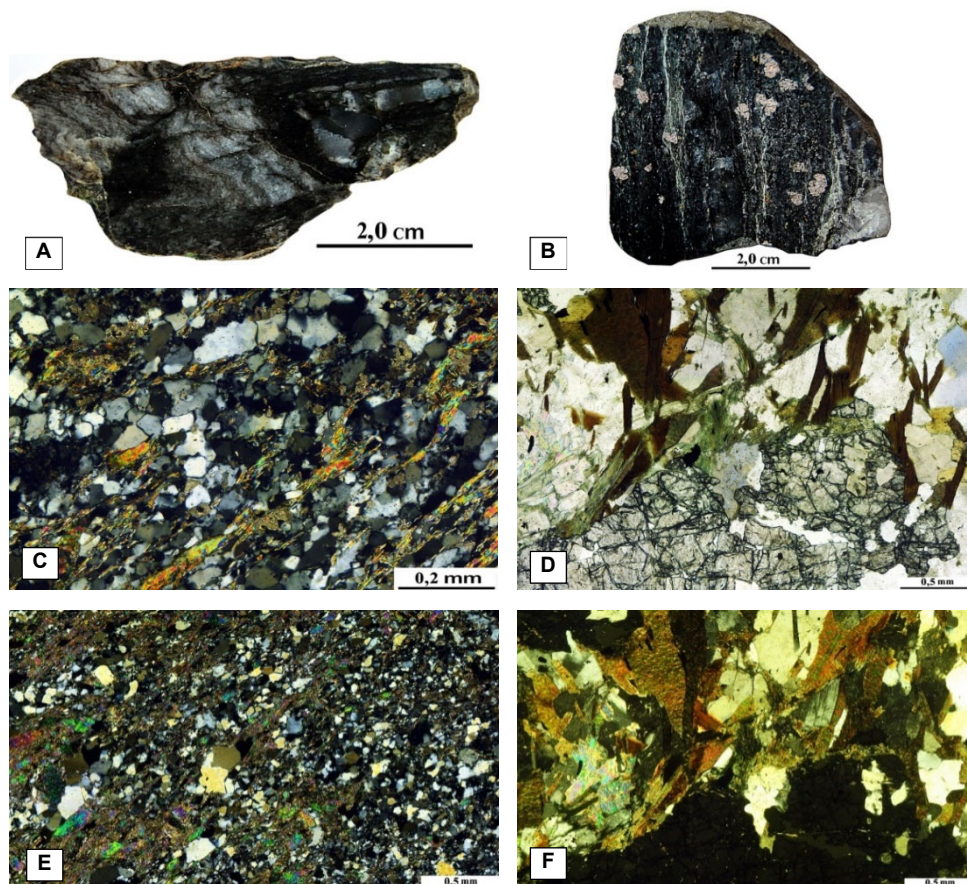


Fig. 3. Macro- and microphotographs of the exotic metamorphic schist filling the clasts in the Oligocene deposits of the Silesian Nappe (Ukrainian Carpathians, right tributary of the Hysnyi Stream flowing into the Uzh River, village of Uzhok).
A, C, E – mica-quartz schist. Nicole X; B, D, F – garnet-muscovite-biotite-plagioclase-quartz schist. D – Nicole II. F – Nicole X

The foliation and mineral orientated texture is not visible in optical microscopic study.

The main association of rock-forming minerals is the light mica (muscovite), quartz, biotite, garnet and albite. Planar minerals are represented by the ferrous biotite chloritized partly and muscovite with greenish shade and weak pseudoabsorption.

Clear features indicating deformation are not found in the rock. Mica is mostly not deformed and not split into individual fragments quartz does not show cracking and undulatory extinction.

The association of the main rock-forming minerals, in particular, the presence of garnet, may indicate that the rock was metamorphosed under conditions of higher greenschist facies up to the epidote-amphibolite facies.

The described crystalline schists are similar to exotic rocks found within the Silesian Nappe in the Polish Carpathians. For comparison, the published data of Polish scientists on exotic metamorphic rocks studied in the vicinity of Baligrod, Ustrzyki Górne, Bukowiec and Wetlina (Polish Outer Carpathians) are taken (see the table).

Table

Comparative table of the exotic metamorphic rock fragments in the deposits of the Silesian Nappe

Location	Baligrod, Roztoki Dolne (Poland) (according to <i>Ślaczka, 1961; Ślaczka, Wieser, 1962</i>)	Wetlina (the Bieszczady Mts, Poland) (according to <i>Bak et al., 2001</i>)	Ustrzyki Górne (Poland) (according to <i>Mochacka, Tokarski, 1972</i>)	Bukowiec (Poland) (according to <i>Ślaczka, 1961</i>)	Uzhok (Ukraine) (own data)
The age of the stratum containing the exotic rocks	Oligocene	Oligocene	Oligocene	Oligocene	Oligocene
The composition of metamorphic exotics	phyllites, albites, amphibolites and quartzites	crystalline schist (quartz-chlorite-muscovite-orthoclase schist with tourmaline and garnet)	chlorite-muscovite schists with garnet	dark green mica schists, rarely gray and white marbles and quartzites	schists, gneiss-like schists with garnet, gravelites, quartzites, marbles, quartz pebbles
The composition of the matrix	unstratified gray calcareous siltstones	light and dark gray clay partly sandy calcareous sediments	–	–	gray and dark gray clay-sand sediments
Probable source area	paleoislands between the Dukla and Silesian subbasins, which were probably a north-western continuation of the Marmarosh Massif	Paleo-uplift between the Dukla and Silesian subbasins	north-western continuation of the Marmarosh Massif between the Dukla and Silesian subbasins	Continuation of the Marmarosh Massif	Bukowiec Ridge, which supplied material for the part of the Silesian Basin (<i>Ślaczka, Golonka, 2006</i>)
Type of metamorphism	Progressive metamorphism in the conditions of epidote-amphibolite facies and regressive metamorphism associated with tectonic activity	a products of two types of metamorphism: progressive, medium-level and retrogressive, low-level	metamorphosed under conditions of greenschist facies	products of regional metamorphism	metamorphosed in the conditions of greenschist facies and epidote-amphibolite facies

Exotic crystalline schists (quartz – chlorite – muscovite – orthoclase schist with tourmaline and garnet) were identified near the village of Wetlina (Bieszczady Mountains) among Oligocene flysch deposits.

Petrographic analysis of these rocks showed that they are the product of two types of metamorphism: progressive, medium-level and retrogressive, low-level (*Bak et al., 2001*).

Also, a fragment of chlorite-muscovite schist with garnet was found in the Krosno deposits near the village of Ustrzyki Górne. This exotic schist was formed as a result of regional metamorphism, probably of the greenschist facies of the quartz-albite-epidote-almandine subfacies (*Mochacka, Tokarski, 1972*).

Exotic rocks in the Baligrod area were studied in detail by *Ślaczka and Wieser (Ślaczka, Wieser, 1962)*. There, the exotic fragments in Oligocene sediments are represented by metamorphic schists, quartzites, marbles, and amphibolites (*Ślaczka, 1961*). Microscopic studies have shown that crystalline exotics of this region can be classified as phyllites, albites and amphibolites. These rocks are the products of regional metamorphism of mainly pelitic sedimentary rocks (*Ślaczka, Wieser, 1962*).

Similar exotic rocks were also found in the area of the village Bukowiec (*Ślaczka, 1961*), where clasts of

metamorphic rocks, rarely gray-white marbles and limestones are among the Oligocene Krosno deposits. Fragments of metamorphic rocks are represented by "green-gray phyllites, albite-calcite gneiss phyllites, garnet phyllites, epidote-albite amphibolites, quartzites and whitish marbles" (*Ślaczka, Golonka, 2006*). *Ślaczka and Golonka (2006)* suggest that the source area for the exotic fragments was the Bukowiec Ridge located between the Dukla and the Silesian sedimentary basins. Bukowiec Ridge supplied exotics during Late Cretaceous – Oligocene time. These authors believed that the Bukowiec Ridge was composed of metamorphic rocks with a sedimentary cover.

You can see that the exotic metamorphic rocks filling the clasts in the Oligocene sediments of the Silesian Nappe of both the Polish and Ukrainian Carpathians are generally similar to each other in composition, textural and structural features and the metamorphic conditions. It suggests the single source area for these exotics.

Conclusions. In the south-western part of the Ukrainian Carpathians, the Oligocene flysch-type mainly turbidite deposits (Krosno Formation) of the Silesian Nappe contain a stratum (40–60 m in thick) of the debris-flow exotics-bearing deposits located near the village of Uzhok (Transcarpathian region). The debris-flow deposits are

composed of clay-sandy matrix and clasts of the exotic rocks including metamorphic schists, quartzites, marbles, bioclastic limestones.

Petrographic study showed that the most representative samples of the metamorphic schists of this stratum are: 1) mica-quartz schist and 2) garnet-muscovite-biotite-plagioclase-quartz schist.

The first sample (mica-quartz schist) is characterized by a schistose foliated texture and generally lepidoblastic structure. The main minerals are quartz, biotite, sericite, muscovite and calcite. Quartz blasts show characteristic undulatory extinction, which suggests deformation of their structure. Presence of the parallel arrangement of the micaceous minerals as well as the mica-dominated and quartz-dominated layers suggests that a metamorphic change and mineral distribution has taken place under directed pressure.

The second sample (garnet-muscovite-biotite-plagioclase-quartz schist) is characterized by a schistose foliated texture and porphyroblastic structure caused by the garnet grain. The main association of rock-forming minerals is light mica (muscovite), quartz, biotite, garnet, and albite. Clear features indicating deformation are not found in the rock.

Mineral composition and structure/texture features suggest the green schist metamorphic facies for the rocks of the first sample and the epidote-amphibolite facies for the ones of the second sample.

The results of the petrographic analysis of the exotic metamorphic rocks from the clasts included in the Krosno Formation of the Silesian Nappe both in the Ukrainian Carpathians (near village of Uzhok) and in the Polish Carpathians (Baligrod, Ustrzyki Górne, Bukowiec and Wetlina) suggest that these rocks have the single source area.

We believe following Ślaczka and Golonka (2006) that the source area for the exotic fragments was the Bukowiec Ridge located between the Dukla and the Silesian sedimentary basins. This paleo-ridge was likely to be a source of the exotic schists for the Oligocene sediment not only of the Polish Carpathians, but also of the Ukrainian Carpathians.

Prospects for further research are related to the reconstruction of the geological position, petrographic analysis and determining the absolute age of the metamorphic exotic rocks in the Ukrainian Carpathians. It is also necessary to continue the comparison of similar exotic fragments in the deposits of the Polish, Slovak and Romanian Carpathians. Comprehensive research will help to understand certain problems of paleogeographic and paleotectonic reconstructions of this region and contribute to the forecasting of deep buried mineral deposits.

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УЛАМКИ ЕКЗОТИЧНИХ МЕТАМОРФІЧНИХ СЛАНЦІВ В ОЛІГОЦЕНОВИХ ВІДКЛАДАХ СІЛЕЗЬКОГО ПОКРИВУ (УКРАЇНСЬКІ КАРПАТИ)

Метою дослідження є аналіз петрографічного складу уламків екзотичних метаморфічних сланців в олігоценічних відкладах південно-західної частини Сілезького покриву Українських Карпат та реконструкція їх можливого джерела живлення. Методологія включає петрографічний, седиментологічний та порівняльно-геологічний методи.

Для досягнення цієї мети проведено польові дослідження в районі першої правої притоки потоку Гусний (с. Ужок, Великоберезнянський р-н, Закарпатська обл.) і виконано петрографічний аналіз відібраних зразків екзотичних метаморфічних сланців, які входять до складу олігоценічних уламкових відкладів.

Результати мікроскопічних досліджень показали, що екзотичні породи представлені слюдисто-кварцовим сланцем і гранат-мусковіт-біотит-плагіоклаз-кварцовим сланцем з незначним вмістом хлориту, карбонату та епідоту. Мінеральний склад та особливості структури/текстури дозволяють припустити, що ці гірські породи метаморфізовані в умовах зеленосланцевої та епідот-амфіболітової фацій. Подібні екзотичні уламки порід були зафіксовані польськими вченими в південно-східній частині Сілезького покриву Польських Карпат, де їхнє можливе джерело живлення пов'язують із палеохребтом Буковець, який був розташований між Дуклянським та Сілезьким басейнами Карпатського седиментаційного регіону.

Наукова новизна. Вперше описано петрографічний склад і текстурно-структурні особливості уламків екзотичних сланців, що входять до складу олігоценічних відкладів Сілезького покриву Українських Карпат (район с. Ужок, Українські Карпати). Зроблено висновок про схожість цих порід з екзотичними породами, які включені в олігоценічні відклади Сілезького покриву Польських Карпат, що може свідчити про єдине джерело живлення.

Ключові слова: екзотичні породи, метаморфічні сланці, Сілезький покрив, Українські Карпати.