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Prospects for the use in the stone-working industry of gemstone raw materials from manganese ore occurrences in the Folded Carpathians

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Abstract. Scientific schools have been formed in Ukraine that are actively researching new types of gemstone raw materials, studying their decorative, technological properties, and economic feasibility of extraction and use. Ukraine has significant resources of these minerals and these can provide substantial revenues to the country's budget in market conditions. Today, gemstone raw materials are gaining popularity, being represented by red-striped jaspilites, sodalite mariupolites, graphic pegmatites, rhodonites, rhodochrosites, etc. The purpose of this work is a detailed gemological analysis of stone material from manifestations and deposits of manganese silicate-carbonate rocks in the Folded Carpathians of Ukraine, establishing their decorative properties to determine the prospects for their use as a gemstone raw material. We have studied about 70 samples of rhodonite-rhodochrosite from various locations in Transcarpathia, which are stored in museums and collections in Ukraine. As is known, rhodonite and rhodochrosite are common minerals of manganese ore occurrences of the Rakhiv and Chyvchyn massifs. Analytical studies included experimental work on processing and determining the technological properties of silicate-carbonate raw materials of manganese ore occurrences. Studies have shown that silicate-carbonate manganese ore occurrence in the Folded Carpathians promises raw materials for the country's stone-working industry. Rhodonite and rhodochrosite within the occurrence form common mineral associations that create a specific textural pattern; the samples have high decorative properties and can be used to produce jewellery and souvenir products. Considering the previous marketing analysis, it can be predicted that products made of rhodonite-rhodochrosite will occupy a prominent place both on the domestic market and in the European one. To organize the extraction of this raw material, we consider it practical to involve the mining experience in developing precious stones in the difficult-to-reach mountainous terrain of the northeastern part of the Marmaros Massif.

Keywords: gemological characteristics, decorative properties, rhodonite-rhodochrosite, coloured stone raw materials, Rakhiv and Chyvchyn massifs, Folded Carpathians of Ukraine.

Перспективи використання каменесамоцвітної сировини манганових проявів Складчастих Карпат для каменеобробної галузі

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Анотація. В Україні сформувалися наукові школи, які активно досліджують нові види каменесамоцвітної сировини, вивчають їх декоративні, технологічні властивості, економічну доцільність видобутку і використання. Україна володіє значними ресурсами цих корисних копалин і в ринкових умовах вони можуть давати суттєві надходження до бюджету країни. На сьогодні набувають популярності самоцвітна сировина, яка презентована червоно-смугастими джеспілітами, содалітовими маріуполітами, графічними пегматитами, родонітами, родохрозитами тощо. Метою даної роботи є детальний гемологічний аналіз кам'яного матеріалу з проявів і родовищ манганових силікатно-карбонатних порід Складчастих Карпат України, встановлення їх декоративних властивостей для визначення перспектив використання у якості каменебарвної сировини. Нами було досліджено близько 70 зразків родоніт-родохрозиту з різних локацій Закарпаття, що зберігаються у музеях і колекціях України. Як відомо, родоніт і родохрозит є поширеними мінералами манганових проявів Рахівського і Чивчинського масивів. Аналітичні дослідження включали експериментальні роботи з обробки та визначення технологічних властивостей силікатно-карбонатної сировини манганових проявів. Дослідження показали, що силікатно-карбонатні манганові прояви Складчастих Карпат є перспективною сировиною для каменеобробної галузі країни. Родоніт і родохрозит в межах проявів формують спільні мінеральні асоціації, які створюють специфічний текстурний малюнок, зразки мають високі декоративні властивості і можуть використовуватися для виробництва ювелірної та сувенірної продукції. Враховуючі попередній маркетинговий аналіз можна передбачити, що вироби з родоніт-родохрозиту займуть чільне місце як на внутрішньому ринку так і на європейському. Для організації видобутку даної сировини вважаємо ефективним залучення старательського досвіду розробки коштовного каміння в складно доступній гірській місцевості північно-східної частини Мармароського масиву.

Ключові слова: гемологічні характеристики, декоративні властивості, родоніт-родохрозит, каменебарвна сировина, Рахівський і Чивчинський масив, Складчасті Карпати України.

Introduction

Precious stones of Ukraine are well represented on the world market by a small group of gems. Popular varieties include black and smoky quartz, beryl, topaz, and different types of amber. However, in the fashion and jewellery industry, there is a growing trend towards expanding the range of precious stones, searching for new, unusual colours, exclusive structural patterns, shades or lustres. New types of gem-quality raw materials are offered to meet this demand, even if they don't always conform to the widely accepted world practice «standards». In addition to the renowned brands that feature traditional gemstones like diamonds, emeralds, rubies, and sapphires, jewellery houses are increasingly showcasing polychrome, landscape and often opaque stones. Among the stones gaining popularity in Ukraine are red-striped jaspilites, sodalite mariupolites, graphic pegmatites, epidosites, unakites, petrified wood, coloured flint, iridescent labradorites, etc. These stones are commonly used in jewellery, accessories, souvenirs, glyptics, and mosaics. They are also gladly ordered by craftsmen, collectors and jewellers from the European Union countries.

Scientific schools have already been established in Ukraine that are actively researching new types of gemstone raw materials. They are examining the decorative and technological properties of these materials, as well as the economic feasibility of their extraction and use (Nesterovskyi et al., 2023 (a,b); Shumlyanskyy et al., 2014; Shevchenko, 2023; Belichenko et al., 2015, etc.). Their works have demonstrated that Ukraine has significant resources of these minerals, and under market conditions, they can provide significant revenues to the country's budget without significant costs for exploration and prospecting (Shumlyanskyy et al., 2014; Shevchenko, 2023; and others).

Due to the Russian-Ukrainian war, a significant portion of these resources remains in the occupied territory and has not entered the market. Specifically, these are deposits and occurrences of sodalite mariupolite, opal and beryl in the Azov region; petrified wood, rock crystal, jasper on the Donetsk Ridge; and jet, unique varieties of jasper (chernomorite, lilac, heliotrope, trout, brocade), attractively coloured carnelian and agate, mandelstein, and landscape marbled limestones in the Mountainous Crimea. Additionally, opal petrified wood and rare collectible minerals are found on the Kerch Peninsula.

These significant losses have significantly reduced the variety of raw gemstone materials on the Ukrainian domestic market, and the demand for some positions of precious stones has exceeded the supply. It is essential for us to respond promptly and seek new opportunities to replenish the country's mineral raw material base (RMB) of coloured stones. In our opinion, one of the promising sources of such raw materials may be the manganese silicate-carbonate rocks of the Carpathian region. These rocks were previously mined for manganese ore, but the occurrences of rhodonite and rhodochrosite rocks in the Ivano-Frankivsk region were considered and studied precisely as gemstone materials. Currently, the Preluky rhodonite deposit is listed in the State Balance of Ukraine, holding manganese reserves categorized as C2 at 419 tons (according to Tretyakov Yu.I. in «Mineral Resources of Ukraine», 2019). The ores in this deposit have a polymineral composition, but three minerals – rhodonite, rhodochrosite, and pyroxmangite – are of particular gemological interest. The estimated reserves of these minerals in the deposit are estimated at 3200 tons.

This study aims to provide a comprehensive gemological analysis of the stone material from various occurrences and deposits of manganese silicate-carbonate rocks of the Folded Carpathians. We will assess their decorative properties and explore their potential for use as coloured stone raw materials.

Research methodology

For this study, we utilized samples of rhodonite-rhodochrosite rocks from the collections of the Geological Department of the National Museum of Natural History of the National Academy of Sciences of Ukraine, the Geological Museum of Taras Shevchenko National University of Kyiv, the Mineralogical Museums of the Ukrainian State Geological Institute, the Ivan Franko National University of Lviv, M.P. Semenenko Institute of Geochemistry, Mineralogy and Ore Formation of the National Academy of Sciences of Ukraine, the State Institution of the Museum of Precious and Decorative Stones (Khoroshiv), and the Gemological Center of the Ministry of Finance of Ukraine. In total, approximately 70 samples from different locations in Transcarpathia were studied. The analytical studies were conducted in the laboratories of Taras Shevchenko National University of Kyiv and M.P. Semenenko Institute of Geochemistry, Mineralogy and Ore Formation of the National Academy of Sciences of Ukraine. Additionally, we carried out experimental work to process and determine the technological properties of silicate-carbonate mineral aggregates.

Research history

Silicate-carbonate manganese ores located in the Folded Carpathians have been recognized since the 1930s; however, their geological position, formation processes, and potential for future use continue to be subjects of debate. Research on these ores is documented in studies by Romanian, German, Slovak, and Polish scientists, including Tokarski J. et al. (1934).

During the Second World War, Germany attempted to exploit these ores. Today, remnants of abandoned mining operations can still be found on the watersheds of the Chyvchyn and Hryniav mountains, atop Mount Lostun, and along the southeastern slopes of the Preluchny ridge within the Perkalab tract.

The next research phase took place during the 1950s-1970s when mineralogical and geochemical studies of rhodonite-rhodochrosite ores in Ukraine intensified. Geological, geochemical, and mineralogical studies of this territory in the 20th century were published in the works of famous Polish and Ukrainian scientists, in particular, Panchenko V.I., Lazarenko E., Matkovsky O., Pavlyshyn V., Hryhorchuk L. and others. (Lazarenko et al., 1962; Lazarenko et al., 1963; Matkovskyy, 2011, etc.).

At the beginning of the 21st century, the Folded Carpathians became the object of comprehensive geological and mineralogical-geochemical research in connection with the State Geological Survey on a scale of 1:200,000, covering the Carpathian series, specifically the sheets M-34-XXXVI (Khust), L-34-VI (Baia Mare), M-35-XXXI (Nadvirna), L-35-I (Viseu-De-Sus) and the search for various minerals (Tsikhon, 2004; Kril, 2015; Marusyak, 2021). Recent comprehensive studies of rhodonite-rhodochrosite mineral aggregates conducted from 2022 to 2024 were prompted by the search for new occurrences of precious stones in Ukraine. This search was influenced by the occupation of eastern territories and the appropriation of the mineral resources of this region (Nesterovskyi et al., 2023 (a,b)).

Geological and geomorphological features of the structure of the territory of rhodonite-rhodochrosite occurrences of the Eastern Carpathians

As is known, manganese occurrences in the Eastern Carpathians are primarily found in the northeastern marginal part of the Marmaros Crystalline Massif (Shniukov et al., 1993). Within the Ukrainian Carpathians, the Marmaros Massif is represented by its northeastern fragments, as with the Rakhiv and Chyvchyn massifs in terms of relief (see Fig. 1). These massifs are characterized by a block structure, featuring significant variations in relative height and canyon-like valleys. Rhodonite and rhodochrosite are common minerals of manganese manifestations of the Rakhiv and Chyvchyn massifs.

The Chyvchyn Massif is complexly constructed, elongated in the northwest direction, and slightly inclined toward the northwest anticlinorium. Its central part consists of ancient gneisses and chlorite-micaceous schists, while the periphery is composed of younger quartzites and limestones. The geological situation of the Chyvchyn territories is illustrated in the accompanying figure.

The Rakhiv Massif has a different structure compared to the Chyvchyn Massif, featuring a brachyform nature of the folds and the presence of sub-latitudinal and sub-meridional dislocations. It consists of Triassic–Jurassic terrigenous carbonate rocks, a Cretaceous–Paleogene flysch complex, and, in the deeply incised river valleys, Upper and Lower Paleozoic metamorphic rocks (Hlushko & Kruglov, 1971).

Located between the Chornyi Cheremosh valley and the border with Romania is the Gryna-va-Losova mountain group, which is a continuation of the Chornohirsky Massif (Palienko et al., 2004). The Preluky rhodonite deposit is located within the Preluchny ridge in the border zone with Romania, between the Chornyi and Bilyi Cheremosh rivers. This area is characterized by difficult accessibility and is dominated by extremely steep slopes ranging from 20 to 35 degrees. The valleys of the streams appear like gorges or canyons (Palienko et al., 2005). This territory is part of the Verkhovyna National Nature Park and the Cheremosh Regional Landscape Park.

Below, we provide a concise overview of rhodonite found in the rhodonite-rhodochrosite ore deposits in the Ukrainian Carpathians. The analysis is based on the publications of prominent Ukrainian geologists and mineralogists who studied the geology and mineralogy of manganese ores during the mid-20th to the 21st centuries (Sinytsia, 1957; Lazarenko et al., 1962; Lazarenko et al., 1963; Shniukov et al., 1993; Matkovskyy, 2011; Shumlyanskyy et al., 2014; Panchenko &Yakovleva, 2015; Nesterovskyi et al., 2023 (a,b) and others).

Rhodonite deposits and ore occurrences of the Folded Carpathians

According to the Law «*On State Regulation of the Extraction, Production and Use of Precious Metals and Precious Stones and Control over Operations with Them*», gemstones are defined as stones of suitable quality used for jewellery, jewellery-production and production stones of appropriate quality, used for the production of various jewellery, decorative and artistic products, in addition to serving scientific, socio-cultural and investment purposes (Zakon «Pro derzhavne…», 1997; Mineral Resources, 2003, Panchenko & Yakovleva, 2015).

Rhodonite deposits are classified (according to (Hursky, 2008)) as category G, i.e. deposits that are insufficiently studied and not yet developed in Ukraine but may become strategically important in the future due to the demands of other industries This category of mineral resources comprises various production and collection stones. Under the right conditions, natural gemstones have the potential to become highly profitable minerals in the market, and certain types can yield significant profits with minimal exploration and development costs (Shumlyanskyy et al., 2014; Shevchenko, 2023).

Rakhiv Massif

The most significant occurrence of the Rakhiv Massif, known as Rudarnya Glimeya, is situated in the upper part of the Kamiany stream, approximately 850 m from the top of Kamin Klyovka Mountain. This location is structurally part of the connection area between the Rakhiv part of the Marmaros Massif and the flysch complex. The primary ore minerals found here include rhodonite, rhodochrosite, siderite, pyrite, and galena. The ore body is a lens of carbonaceous quartzites, measuring up to 130 m long and 8.5-9.0 m thick. The areas enriched with rhodonite have an irregular shape, often mirroring the configuration of rhodochrosite spots. The sizes of these rhodonite-rich areas range from 10-15 cm up to 60-75 cm. Preliminary estimates suggest that the reserves of rhodonite-rhodochrosite rocks in this occurrence are about 16,000 tons, with approximately 668 tons of conditioned raw materials.

The rhodonite-rhodochrosite aggregate found in the Rakhiv Massif exhibits a colour range from pink or grey-pink to dark grey. It is commonly associated with garnet, amphiboles, and secondary products of primary manganese ores. In this area, rhodonite-rhodochrosite is frequently replaced by manganese oxides and hydroxides, which fill in cracks created at the surface.

Below, we provide a brief description of the occurrence of rhodonite-rhodochrosite within the Rakhiv Massif.

The Rudarnya occurrence is located on the southern slope of Mount Golyi Verkh, at a relative elevation of 1,062 m, approximately 350 m below the summit. The ore body consists of a small lens of carbonaceous quartzites, measuring up to 48-50 m in length and 2 m in thickness. The primary ore minerals include rhodochrosite and siderite (Shramko P.P., 1959; Voloshin A.A. et al., 1971). Additionally, rhodonite occurs in small grains or aggregates, forming distinct bands adjacent to rhodochrosite. Small relics of rhodonite can be found among the host rocks, along with oxides and hydroxides of manganese (Matkovskyy 2011).

The Seretplai occurrence is located on the watershed of the Bily and Dovgoruny streams, 400 m southwest of an altitude of 1297 m. This site features several lenses of iron-manganese quartzites. Notable ore minerals here include pyrolusite, psilomelane, and goethite; however, rhodonite and rhodochrosite were not identified (Luginin M.A., 1947).

The Velikobanskyi occurrence is situated on the left slope of the Velikobanskyi stream valley, 1.8 km from its mouth. The ore body is represented by a vein of carbonaceous quartzites that extend up to 550 m in length, lying adjacent to the crystalline schists that contain them. The main ore minerals found in this occurrence include rhodonite, rhodochrosite, siderite, sphalerite, and pyrite. The thickness of the ore body can reach up to 2.45 m (Shramko P.P., 1959; Golovan V.S. et al., 1975).

The Malobanskyi occurrence is located on the watershed between the Velikobanskyi and Malobanskyi streams, 250 m below the height of 782.1 m. The ore lens in this occurrence is composed of rhodochrosite, sphalerite, pyrite, and rhodonite (Voloshin A.A. et al., 1971).

The Svinsky occurrence can be found on the right slope of the Svinsky stream valley, 700 meters from the summit, which stands at an elevation of 1041.5 meters. This occurrence features a lens of carbonaceous quartzites, which are surrounded by the host rocks. Ore minerals are represented by rhodonite, rhodochrosite, siderite, and pyrite (Voloshin A.A. et al., 1971).

Yaseniv-I occurrence is located on the right slope of the Yaseniv stream, approximately 900 m from its mouth. The mineralization is associated with lenticular quartzite bodies, that can reach thicknesses of up to 7 m and extend up to 300 m. The primary ore components include goethite, pyrolusite, pyrite, sphalerite, and rhodochrosite. The host rocks in this area are chlorite-sericite schists (Kuryachiy L.K. et al., 1963; Voloshin A.A. et al., 1971).

The Kuzynsky occurrence is situated on the right slope of the Kuzya stream valley, 850 m from its mouth. Its mineral composition includes siderite, rhodochrosite, and sphalerite (Kuryachiy A.K. et al., 1963).

Chivchinsky Massif

The Preluky rhodonite deposit is located above carbonaceous black quartzites, which are underlain by sericite-chlorite-quartz schists and are partially covered by massive or schistose porphyry-like rocks. The quartzites are brecciated and often fragmented into separate blocks (Hurskyi et al., 2005; Shniukov et al., 1993).

Various studies (Lazarenko et al., 1962; Lazarenko et al., 1963; Matkovskyy, 1971, etc.) indicate that the primary ore minerals in the deposit are rhodonite and rhodochrosite, along with additional occurrences of quartz, chalcedony, siderite, and sulfides. Rhodonite is characterized by its pink or dark pink colour set against a the grey-pink, massive fine-grained rhodochrosite matrix. The mineral grains typically exhibit an isometric or partially elongated shape, and idiomorphic tabular crystals may occasionally be observed. Furthermore, rhodonite is commonly found in association with quartz, pyroxmangite, danemorite, spessartine, and other minerals, forming veined and lenticular inclusions of varying thickness (Matkovskyy, 2011; Nesterovskyi et al., 2023 (a,b)).

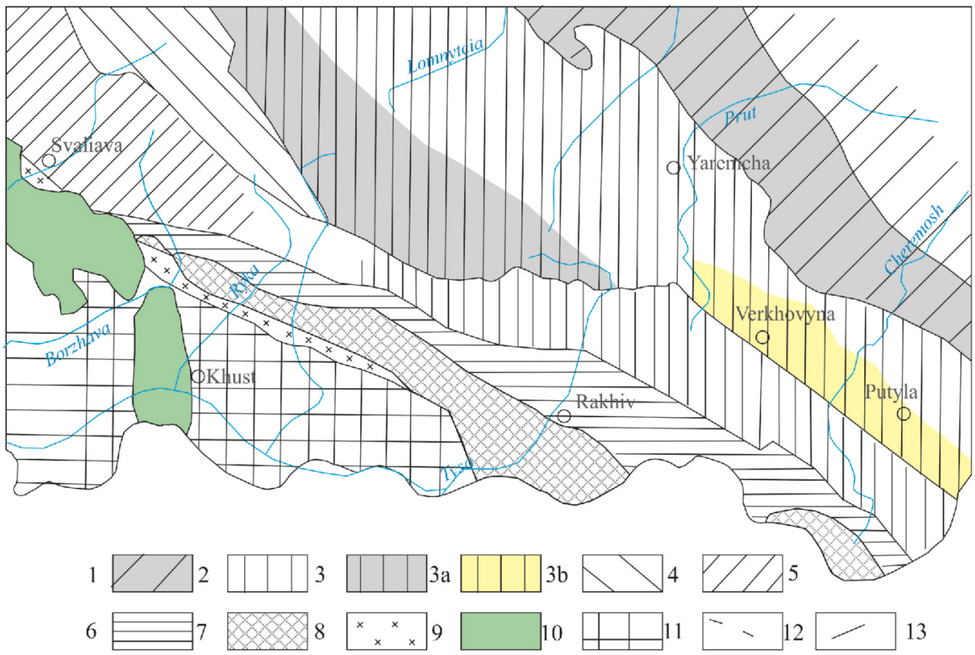

Fig. 1. Position of the Marmaros zone within the framework of tectonic zoning in the southeastern part of the Ukrainian Carpathians (modified from Matkovsky O.I., 1971, Glushko V.V., Kulchytsky Ya.O., Shakyna V.A., 1965). Precarpathian marginal depression: 1 – External zone, 2 – Internal zone. Folded part of the Carpathians: 3 – Skyby zone, 3a – Gorgan Folds, 3b – Verkhovyna Depression 4 – Subsilesia zone; 5 – Silesia zone; 6 – Duklja zone; 7 – Rakhiv zone; 8 – Marmaros zone; 9 – Pieniny zone. Transcarpathian internal depression: 10 – an area of Neogene effusive; 11 – an area of Miocene molasses; 12 – thrusts; 13 – rupture faults.

Gemological Characteristics of Rhodonite-Rhodochrosite Rocks

Gemological studies of rhodonite-rhodochrosite have focused on analyzing their decorative, technological, and consumer characteristics.

The decorative properties of rhodonite-rhodochrosite rocks from the Folded Carpathians should be considered alongside the two primary minerals: rhodonite and rhodochrosite. These minerals form complex aggregates in varying ratios, contributing to their distinctive structural patterns and colours. The aesthetic appeal of these rocks is further enhanced by secondary and hypergenic minerals, such as manganese oxides and hydroxides, which are associated with the oxidation zone.

Rhodochrosite forms granular and finely dispersed mineral aggregates that fill cracks in quartz-carbonate rocks. Upon oxidation, it transforms into manganite and pyrolusite, producing pseudomorphs on calcite and dolomite. Most of the rhodochrosite found in the samples consists of heterogeneous aggregates that measure up to 0.25-0.30 mm and exhibit colours ranging from light grey and grey to shades of olive or pink. Notably, a more pronounced pink colour is typically observed only in grains larger than 0.25 mm.

In thin sections, rhodochrosite is easily identifiable due to the radial and globular structure of its aggregates. Some grains of rhodochrosite show thin veins intersected by a network of cracks filled with pyroxmangite $(Mn, Fe)_7[Si_7O_{21}]$, manganese-calcite, or quartz. Genetically, rhodochrosite forms prior to rhodonite, and its occurrences are associated with zones of fracturing and the secondary alteration of terrigenous-carbonate rocks during the later stages of lithogenesis (Matkovskyy, 2011). The morphology of rhodochrosite inclusions is varied, displaying patterns that can be spotted, striped, veined, or spherical.

Rhodonite occurs in fine-grained aggregates and clusters that develop on rhodochrosite. It fills cracks and leaching areas, increasing the peripheral zones of rhodochrosite inclusions. The main mass of rhodonite inclusions is characterized by various shades of pink-red (Fig. 2). In the examined samples, the shape of rhodonite aggregates lacks clearly defined geometric features, resembling blurred spots with curvilinear outlines. These aggregates range in size from microscopic to 4-7 cm in cross-section and sometimes form wavy stripes, often in association with quartz (Matkovskyy, 2011). In thin sections, rhodonite grains exhibit an isometric or partially elongated shape, and idiomorphic tabular crystals can occasionally be found within them. In areas of fracture, rhodonite is frequently replaced by oxides and hydroxides of manganese.

The decorative properties of rhodonite-rhodochrosite aggregates were evaluated using polished plates. The assessment included studying the colour, lustre, transparency, textural pattern, and size of the elements that contribute to the overall texture.

Three varieties are distinguished by colour and textural pattern: 1) pink, homogeneous, evenly coloured, sometimes with dendrites of manganese oxides and hydroxides (up to 3%), as well as veins and spots (composition mainly rhodonite); 2) rich pink, with various shades of grey and light brown colour, spotted with thin veins of rhodochrosite, lenses and veins of quartz, dendrites of manganese oxides and hydroxides up to 25% (composition rhodonite-rhodochrosite); 3) slightly pink to brown, unevenly coloured, spotted, striped, with dendrites of manganese oxides up to 15% (the composition is mainly rhodochrosite).

All studied rhodonite-rhodochrosite samples are opaque, even when viewed in thin sections. The lustre of the granular aggregates of rhodonite composition and areas of combined composition is glassy in areas with a fine-grained structure – weakly glassy and oily. Individual areas that have a rhodochrosite composition exhibit a pearlescent sheen.

The textural pattern of rhodonite-rhodochrosite is formed due to the combination of multicoloured mineral components, including rhodonite, rhodochrosite, pyroxmangite, manganese oxides and quartz. Numerous varieties can be formed depending on the quantitative and colouristic ratio of these components (see Fig. 2).

Technological properties (hardness, blockiness, processing ability). Rhodonite-rhodochrosite rocks exhibit variable hardness, ranging from 4-4.5 to 6-6.5 on the Mohs scale. The hardest sections typically contain rhodonite with quartz impurities, while the softer areas consist of rhodonite with carbonate and sulfide impurities. The presence of a significant amount of manganese oxides in these samples tends to reduce hardness and increase the fragility of the mineral aggregates.

These rocks are often fractured to varying degrees, which can lead to unpredictable splitting into fragments of different sizes. Consequently, the initial blockiness is relatively low, not exceeding dimensions of 20x30x20 cm.

Rhodonite-rhodochrosite can be effectively processed using with diamond tools for cutting, grinding, drilling, polishing. Plates up to 3-4 mm thick can be cut from the rock mass. After polishing, the treated rock acquires a smooth, shiny surface. However, it is important to be mindful of the varying hardness within the mineral aggregates to avoid the formation of irregularities on the final surface.

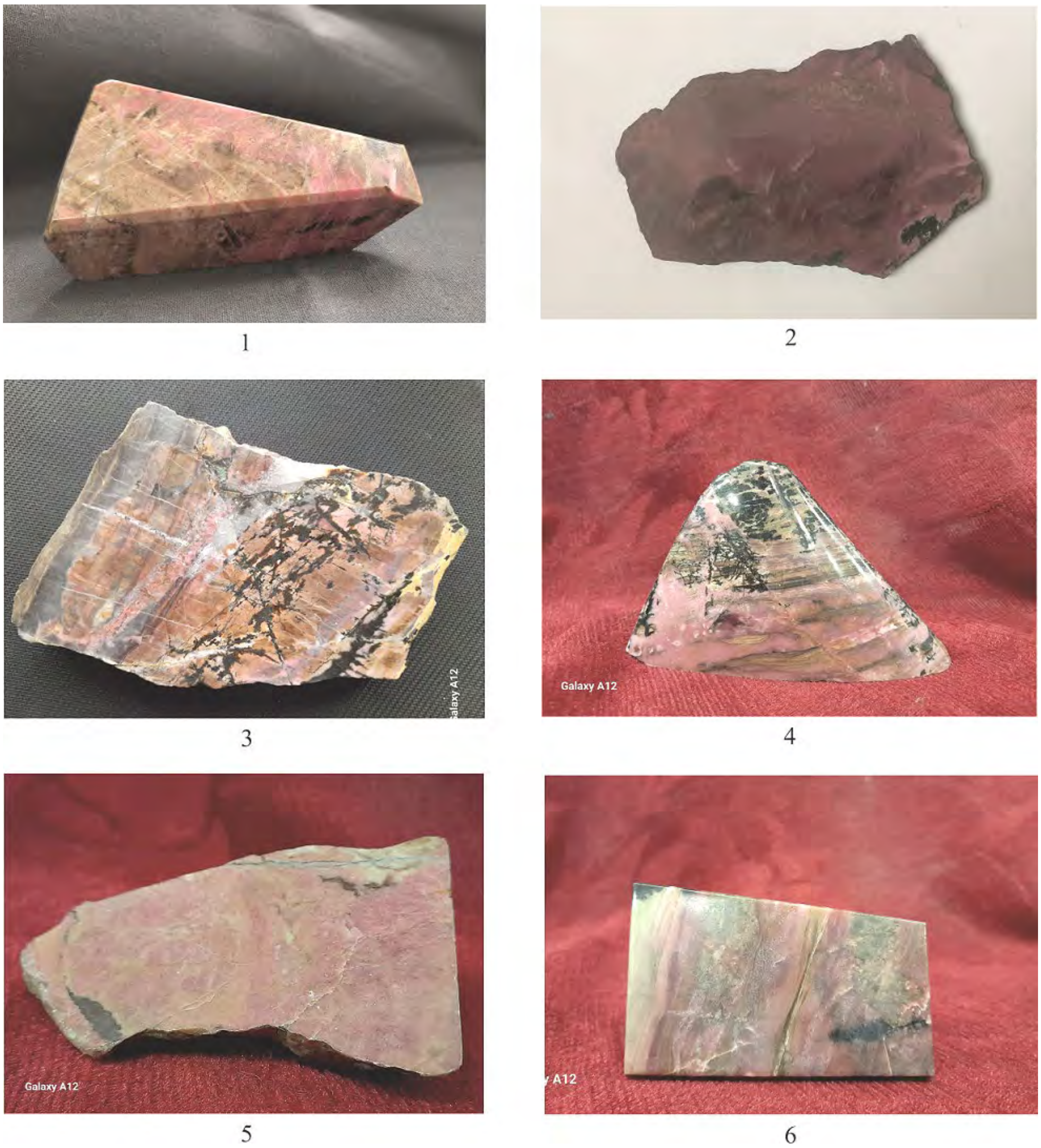

Fig. 2. Variety of structural patterns of Transcarpathian occurrences rhodonite-rhodochrosite.
1, 3, 4 – rich pink, with different shades of grey and light brown colour, spotted with veins of rhodochrosite and quartz, with dendrites of manganese hydroxides up to 25% in cracks;
2 – pink, dark pink homogeneous, evenly coloured, with dendrites of manganese oxides and hydroxides up to 3%;
5, 6 – faintly pink to brown, unevenly coloured, spotted, striped, with dendrites of manganese oxides up to 15%.

Consumer characteristics. Rhodonite is widely used in jewellery as well as in decorative and applied arts (Fig. 3). Experimental work has demonstrated that it is possible to produce from rhodonite-rhodochrosite of the Ukrainian Carpathians cabochons and inserts in jewellery (earrings, brooches, bracelets, rings, pendants), necklaces, mosaics, figures of rotation (vases, balls) and souvenir products of small sizes (writing instruments, napkin holders, boxes, seals, etc.). Some samples featuring polychrome, mosaic, or landscape-like textures can even be used to create «paintings» (Fig. 3.2.).

The radiation background of rhodonite-rhodochrosite rocks is within permissible norms, and its use does not threaten human health. This characteristic makes them safe for use in jewellery and decorative spheres. However, a notable drawback of these mineral aggregates is their low blockiness and varying colours, which limit the possibility of producing large items and hinder the creation of matching jewellery inserts and sets with uniform colour saturation and monochrome tones.

To enhance the this gemstone`s market appeal, we suggest assigning the natural stone from the rhodonite-rhodochrosite occurrences of the Eastern Carpathians the trade name – «rhodonitochrosite». This name emphasizes its unique decorative properties.

Fig. 3. Decorative items from rhodonite-rhodochrosite.
1 – 2 – from the funds of the Department of Geology of the National Museum of Natural History of the National Academy of Sciences of Ukraine; 3 – 4 – from the collection of the Geological Museum of the Taras Shevchenko National University of Kyiv.

Conclusions

The scientific studies conducted on the gemological properties of the rhodonite-rhodochrosite mineral aggregate lead to several conclusions:

1. The silicate-carbonate manganese occurrences in the Folded Carpathians present a valuable raw material for the Ukraine's stone-working industry. The rhodonite-rhodochrosite occurrences represent the main gemological interest.
2. Rhodonite and rhodochrosite commonly occur together, forming unique mineral associations that create distinct textural patterns, setting them apart from the well-known deposits of rhodonite and rhodochrosite found elsewhere.
3. The studied samples exhibit high decorative qualities and can be effectively utilized for producing small jewellery, haberdashery items, and souvenir products despite lacking monochrome colours.
4. Based on the colouration of these rocks and preliminary market analysis, it can is anticipated that products made of rhodonite-rhodochrosite will gain a prominent position both the domestic and the European markets. The proposed trade name for this gemstone raw material, «rhodonitochrosite», will contribute to its promotion on the global market.
5. To facilitate the extraction of this raw material, utilizing the prospecting expertise gleaned from developing precious stones in the difficult-to-reach mountainous area of the north-eastern part of the Marmaros Massif will be beneficial.

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