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Raw material base of crushed stone and rubble stone in Khmelnytskyi Region

Myroslav Syvyi [1]
DSc (Geography), Professor of the Department of Geography and Methods of its Teaching,
[1] Volodymyr Hnatiuk Ternopil National Pedagogical University, Ternopil, Ukraine,
e-mail: syvyi@ukr.net, https://orcid.org/0000-0002-3150-4848;
Petro Demyanchuk [1]
PhD (Geography), Associate Professor at the Department of Geography and Methods of its Teaching,
e-mail: dempetrom@gmail.com, https://orcid.org/0000-0003-4860-7808;
Igor Kholoshyn [2]
PhD (Geology and Mineralogy), Associate Professor, Head of the Department of Geography and Methods of its Teaching, [2] Kryvyi Rih State Pedagogical University, Kryvyi Rih, Ukraine,
e-mail: k_egeography@kdpu.edu.ua, https://orcid.org/0000-0002-2174-5605;
Natalia Panteleeva [2]
Assistant Lecturer, Department of Geography and Methods of its Teaching,
e-mail: panteleeva4y@kdpu.edu.ua, https://orcid.org/0000-0001-6787-2266

ABSTRACT

Problem Statement. Analysis of the "Geoinform" archival materials indicates that the reserve of explored raw material deposits for crushed stone and rubble stone in Khmelnytskyi Region (that are suitable for operation based on the magnitude of reserves, environmental conditions, logistical requirements, etc.) is practically exhausted. Exploration work is not being conducted, the capacities of operating mining enterprises are far from fully utilized, and predominantly small-volume deposits are available for development. Therefore, there is an urgent need for a critical analysis of the current state of the raw material base for rubble and crushed stone in the Khmelnytskyi Region. This is especially crucial given that in the post-war period, the demand for increasing their production volumes will sharply rise for restoring housing and destroyed infrastructure.

Presentation of the Main Material. The article analyzes the current state of research into deposits of raw materials for crushed stone and rubble production in the Khmelnytskyi Region. It shows the correlation of deposits with specific stratigraphic subdivisions and clarifies the general patterns of placement for various types of building stone deposits across the region. The degree of exploration of building stone deposits and their level of industrial development are analyzed. The territorial density (saturation of the territory) and the provision of explored reserves to the population of territorial units are calculated. The dynamics of raw material extraction in recent years are shown, and proposals for increasing extraction volumes in the region are presented.

The areas occupied by active quarries under productive lands, unproductive lands, and forest areas have been identified. It's concluded that the placement of a significant number of explored raw material reserves in the region on unproductive lands creates favorable prospects for their future development.

Analysis of raw material extraction volumes at state and commercial enterprises in the region, the assortment of their products, and the long-terms of provision with reliable reserves allowed us to conclude that overall, the volumes of raw material extraction in the region are satisfactory, even compared to pre-war years. However, there is insufficient provision of reliable reserves for some active quarries, extraction is concentrated in just a few territorial communities, and many enterprises are insufficiently utilized compared to their design capacities.

Conclusions. The article establishes patterns in the location of various types of crushed stone and rubble raw materials across the region. Calculations were made for the territorial density of explored reserves, their provision to individual administrative units, and the placement of explored deposits on productive, unproductive, and forest lands. Current volumes of raw material extraction and the provision of reliable reserves for active quarries have been determined, and possibilities for genuinely increasing raw material extraction in the region have been recommended.

Keywords: *Khmelnytskyi Region, building stone, deposits, igneous rocks, sedimentary rocks, raw materials, territorial communities, territorial density, resource provision, extraction.*

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Problem Statement. Podillia region generally, and the Khmelnytskyi Region specifically, are characterized by a relatively good supply of raw materials for producing construction materials, including building stone. These are primarily sedimentary and magmatic rocks, mainly used for crushed stone production and, to a lesser extent, dimension stone. In recent years, exploration for these raw materials has virtually halted, largely due to a lack of centralized funding. Now, exploration relies entirely on private investors. The reserve fund of thoroughly explored and officially registered deposits, as accounted for by the State Balance of Resources, is dwindling. There are hardly any large-volume, explored deposits remaining. Most of the available deposits are small and economically unviable to develop. On the

other hand, the design capacities of active mining enterprises (quarries) are far from fully utilized, and the operational lifetimes of others are nearing their end. Civil and military infrastructure damages caused by the Russian-Ukrainian war, along with the inevitable need for extensive post-war restoration works, dictate the necessity of increasing the extraction volumes of construction raw materials, including building stone – a natural resource for crushed stone production. In view of the above, it is necessary to analyze the existing raw material base for building stones in the Khmelnytskyi Region, determine the needs of individual administrative units (districts, territorial communities) for various types of construction raw materials, and study the possibilities for expanding its extraction and rational (efficient) use.

Analysis of Publications on the Topic of the Article. Specialized publications that extensively cover the issue at hand are practically absent. The general overview of the region's valuable minerals can be found in the monograph edited by K. Herenchuk titled "Nature of Khmelnytskyi Region", published back in 1980 [18]. A more detailed review of the region's mineral resource potential can be found in monographs by M. Syvyj, "Mineral Resources of Podillia" [23], and by M. Syvyi, B. Havryshok, P. Demyanchuk, "Mineral Raw Material Potential of Khmelnytskyi Region: Current State of Development and Prospects" [24], along with articles [30, 31]. The availability of raw materials for the production of building stones in specific regions of Ukraine in different years, to a certain extent, has also been discussed in publications by V. Burka [2], V. Mykhailov [12], K. Kilinska, V. Kostashchuk [9], V. Petruk et al. [17], and H. Rudko et al. [21, 22] and others. Methodological Issues of Studying Mineral and Raw Material Resources and Complexes of Ukrainian Regions have been addressed in works by V. Mishchenko [14, 15], L. Rudenko et al. [19, 20], H. Rudko, Ye. Yakovliev [22], and H. Rudko, Ye. Ivanov, I. Kovalchuk [21]. Regional features of mineral resource complexes of Ukraine with varying degrees of detail and emphasis on economic-geographical, geo-environmental, economic, and other aspects are covered in the works of A. Vasylenko [3, 4], K. Kilinska, V. Kostashchuk [9], V. Petruk et al. [17], M. Syvyi, B. Havryshko, P. Demyanchuk [24] and others.

The provision of **raw materials for building stones** in certain regions of Ukraine over different years has also been highlighted in publications by V. Burka [2], O. Heleta [6], M. Korzhniev, M. Kurylo [10], V. Kostashchuk [11], and others.

In publications by foreign authors such as T. Elyoufut, F. Alkhomaidat [27], Ch. Myriounisa et al. [28], K. Szamalek, K. Zglinicki, S. Mazurek [32], Schrenk S. [29] and others, research on this issue predominantly focuses on purely applied directions. For instance, detailed studies of the quality characteristics of building stone to determine its application areas, microscopic studies of the structure of various types of building stone, investigations into the impact and interaction of natural stone with the environment, examples of the efficiency and range of natural stone use in different regions and countries worldwide, and more.

Aims and Objectives. The following objectives were planned for the study: 1) to provide a brief description of the rocks suitable for use as building stone in Khmelnytskyi Region; 2) to characterize the degree of exploration and the territorial distribution of building stone deposits; 3) to calculate the resource security of individual administrative units (districts, territorial communities) with the reserves of the explored raw materials; 4) to draw conclusions regarding the opportunities for expanding the extraction and efficient utilization of building stone in the Khmelnytskyi Region.

The study aimed to address the following objectives: 1) To provide a concise characteristic of rocks suitable for use as building stone in Podillia and specifically in Khmelnytskyi Region; 2) To characterize the degree of exploration and territorial distribution of building stone deposits; 3) Calculate the provision of this type of raw material to the administrative units of the region; 4) To analyze the departmental affiliation of developed deposits and their provision with explored raw material reserves; 5) To draw conclusions about the possibilities of expanding extraction and efficient use of building stone in the region.

The main **research materials** were primarily data drawn from various sources of the State Scientific and Production Enterprise "Geoinform of Ukraine" [7, 13], including from the "Balance" database as of 01.01.2022 (Khmelnytskyi Region) [26], interactive maps of mineral deposits, archival materials from geological exploration organizations, and others, which were available for public use only until 2022. For these reasons, the article's conclusions about the state of the raw material base for building stone in the region cover only the pre-war period. The work utilized traditional methods of analytical processing of statistical information and construction of cartographic models: historical-geographical approach, comparison, systematic analysis, cartographic, statistical, sociological, field observations, etc.

Results and Discussion. Building materials enterprises (quarries, plants) produce products in the form of artificial and crushed stone. Artificial stone refers to products of a specific shape processed by splitting, dressing, and cutting natural stone (facing,

wall, curb stones, slabs, paving stones, facing tiles).

Rubble stone consists of irregularly shaped fragments generated from blasting operations, as well as waste material from processing blocks and slabs. When crushed, rubble stone yields crushed stone, grits, and manufactured sand.

The quality of building stone is primarily determined by its physical and mechanical characteristics, including compressive strength in dry and water-saturated conditions, granularity, abrasion resistance, viscosity, frost resistance, volume and bulk density, and water absorption.

There is a range of requirements [25] for rock types used as rubble stone. Rubble stone is utilized for laying foundation walls, constructing building blind areas, reinforcing earth slopes, road works, and as an aggregate in rubble concrete.

However, the main bulk of building stone is actually used for crushed stone production, which serves as an aggregate in concrete and for road construction needs. The suitability of various rock types for producing crushed stone of different purposes is regulated by a series of state standards [16].

The quality of crushed stone is determined by indicators such as grain and petrographic composition, strength, frost resistance, content of weak rock grains, and impurities of dusty, clayey, and silty particles.

The highest quality raw materials for crushed stone production are uniformly grained igneous rocks like gabbro, basalts, granites, granodiorites, andesites, etc. They yield a small amount of waste and are strong and frost-resistant. Metamorphic rocks, widely developed in Podillia – gneisses and migmatites – are somewhat inferior in quality, mainly due to the presence of subparallel banded orientation of dark-colored minerals, which leads to increased waste.

Sandstones are often layered, which reduces their resistance to weathering and, consequently, lowers the quality of gravel; they produce a lot of waste and require washing. Limestones are susceptible to dissolution, leading to the formation of karst voids and cavities with reduced hardness. These voids are often filled with clay, which negatively affects the quality of gravel. Shell limestones generally do not meet the requirements for rubble stone raw material and are suitable, at best, for low-strength gravel or ballast materials.

Currently, in Ukraine, approximately 95% of extracted building stone is processed into rubble. As of January 1, 2022, the State Balance of Mineral Resources of Ukraine includes 946 deposits, out of which 428 are being exploited by the industry. Building stone deposits comprise more than 40 types, including granites, migmatites, gneisses, limestones, sandstones, pegmatites, quartzites, gypsum, andesite, diorites, basalts, etc. [10]. In 2020, the majority of building stone was extracted in the Zhytomyr Region – 21.73%, Khmelnytskyi Region – 13.90%, and Rivne Region – 12.58%. Compared to 2019, raw material extraction increased in all regions except Donetsk and Lviv regions. The most significant increase in extraction volumes compared to 2019 occurred in the Khmelnytskyi and Luhansk regions – nearly 5 times in both regions [7, 13].

Magmatic and metamorphic rocks of the Archean and Proterozoic eras are associated with the Ukrainian Shield. Sandstones are located on the northern and southeast edges of the shield, while western and southern slopes consist of Paleogene and Neogene limestone formations.

The leading consumer of gravel is the industry producing commercial concrete. Pro-Consulting analysts conducted a study of the gravel market in Ukraine [1].

After the crisis observed in 2014–2016, enterprises involved in the production (extraction) of crushed stone have been gradually updating their technological equipment and improving the quality of crushed stone (specifically cuboid-shaped), which is in high demand in modern construction. Ukraine possesses high potential for the production and export of crushed stone. Given continued state and international support for road construction and repair, the crushed stone market is expected to continue its development. The production of crushed stone and its prices are constantly rising, indicating positive development prospects and opportunities for expanding production and sales in the domestic market [1].

In the Podillia region, natural stone building materials consist of crystalline Precambrian rocks of the platform foundation, such as granites, granodiorites, charnockites, migmatites, gneisses, and sedimentary rocks of the cover, including limestones, dolomites, and sandstones.

Crystalline Precambrian rocks are widespread in the territory of Vinnytsia and the northeastern part of Khmelnytskyi Regions. Their western boundary of development roughly passes through Shepetivka – Hrytsiv – Starokostyantyniv – Medzhybizh – Derazhnia – Vovkovyntsi [23].

The rocks are exposed in river valleys and ravines, forming various outcrops, dome-shaped elevations, or sometimes continuous extensive formations (up to 1 km or more). In Khmelnytskyi Region, they lie directly beneath a small thickness of Quaternary and partially Neogene deposits.

Gneisses are found in only two deposits in the Khmelnytskyi Region (Klymentovytske and Hrytsivske). They are often encountered as xenoliths and lenses among younger crystalline rocks. These

rocks are dark gray to black in color, fine-grained, often with a schistose texture, significantly reducing their physical and mechanical properties [24].

Silurian limestones are widespread exclusively in the southeastern areas of Ternopil and southwestern areas of Khmelnytskyi Regions, exposed in the valleys of the Dniester, Seret, Nichlava, Zbruch, Zhvanchyk, Smotrych, Studenytsia, and Ushytsia rivers. The depth of limestone occurrence varies from 0 to 80 m, with a total thickness of 50–60 m. Limestones are mostly gray, dark gray, dense, fissured, often platy, and granular. Fine-grained and hidden-crystalline varieties of limestones, which exhibit sufficiently high compressive strength in an air-dry state, are used as raw materials for producing rubble stone and crushed stone for road and residential construction.

Miocene limestones are known in the southwestern part of Vinnytsia Region, in the central, southern, and southwestern parts of Khmelnytskyi Region, as well as within the Tovtry Ridge in Ternopil Region. They are represented by light-gray, light-yellow, chertaceous, serpulid, detrital, or oolitic varieties, often with strong recrystallization, and sometimes softer variants, relatively pure in chemical composition. These rocks are typically found at depths of 0–15 meters, with thickness ranging from 3 to 20 meters, and up to 100 meters or more within the Tovtry Ridge. The softer varieties are primarily used as carving stone and for lime production, while the dense recrystallized ones are used for producing rubble stone and gravel.

Devonian dolomites are found in the Slobidka-Rykhtivske deposit in the Kamianets-Podilskyi district of Khmelnytskyi Region. Although the reserves of the Slobidka-Rykhtivske deposit are limited, the dolomites are suitable for producing rubble stone and gravel for construction works, as ballast layers for road foundations, and as fillers for road concretes. However, this deposit is not being exploited [24].

In Khmelnytskyi Region, there are also 5 previously explored deposits of granitoids and limestones, with reserves estimated in categories $C_1 + C_2$ and considered insignificant. In general, there are only 4 large deposits of building stone known in Podillia (with reserves exceeding 30 million cubic meters): one of them (Polonske) is located in Khmelnytskyi Region. There are 14 deposits with medium-sized reserves (15–30 million cubic meters), all of which are situated in Khmelnytskyi and Vinnytsia Regions. All other building stone deposits in Podillia are considered small (reserves less than 15 million cubic meters).

Figure 1 illustrates the distribution of building stone deposits in Khmelnytskyi Region. The diagram clearly highlights the areas of concentration of deposits of magmatic and metamorphic rocks – the southwestern slope of the Ukrainian Shield and, correspondingly, the northeastern territories of the region.

The strip of Neogene-age limestone deposits is generally oriented in a southeast-northwest direction. It can be traced in the Kamianets-Podilskyi district (Nova Ushytsia, Dunaivtsi, Smotrych, Slobidka-Kulchiyevetska, Kamianets-Podilskyi, Humentsi, Horodok, Sataniv territorial communities) and continues within the Tovtry Ridge. Only in the southwestern territorial communities of the Ternopil Region is there a rather significant concentration of Silurian-age limestone deposits.

In the region, 48 deposits of raw materials for rubble stone and crushed stone production have been extensively explored and included in the balance with total reserves exceeding 337 million cubic meters. Out of these, 24 deposits with reserves exceeding 213 million cubic meters are currently being exploited [26]. The raw materials come from deposits of granitoids, limestones, dolomites, and sandstones. The majority of the reserves are concentrated in granitoid deposits (over 72%), mainly consisting of granites, as well as charnockites, gneisses, granodiorites, and migmatites.

There are slightly more limestone deposits in the region than granitoids (27 and 21, respectively), but their combined reserves are significantly lower (about 27% of the total). Eleven limestone deposits and thirteen granitoid deposits are currently being exploited. The only detailed explored dolomite deposit in the region (Slobidsko-Rykhtivske in Zhvanets territorial community) has limited reserves and is not currently being developed.

Additionally, there are 5 previously explored deposits in the region with minor reserves (about 3.5 million cubic meters), two of which are under exploitation. In the Chemerivtsi territorial community, one deposit is being exploited with unexplored reserves.

One granitoid deposit (Polonske) with reserves exceeding 30 million tons is classified as large, and six are considered medium-sized (Kamianets-Podilskyi (part Pudlivtsi), Malo-Novoselytske, Klymentovytske, Konotopske, Rudnia-Novenske, and Rudnia-Novenske-1) with reserves ranging from 15 to 30 million tons. Most of them are located in the northeastern territorial communities of the region.

Figure 2, which demonstrates the availability of raw materials for the administrative units of the region and their distribution density, clearly reveals the concentration of the main building stone bases in the northeastern and southwestern areas of the region.

The highest provision with raw materials is observed in territorial communities (TCs) such as Mykhailiuchka, Medzhybizh, and Polonne (respectively, 5680, 3080, and 2770 cubic meters per person), with slightly lower figures in Letychiv (2520 cubic meters per person) and Slobidka-Kulchieve-

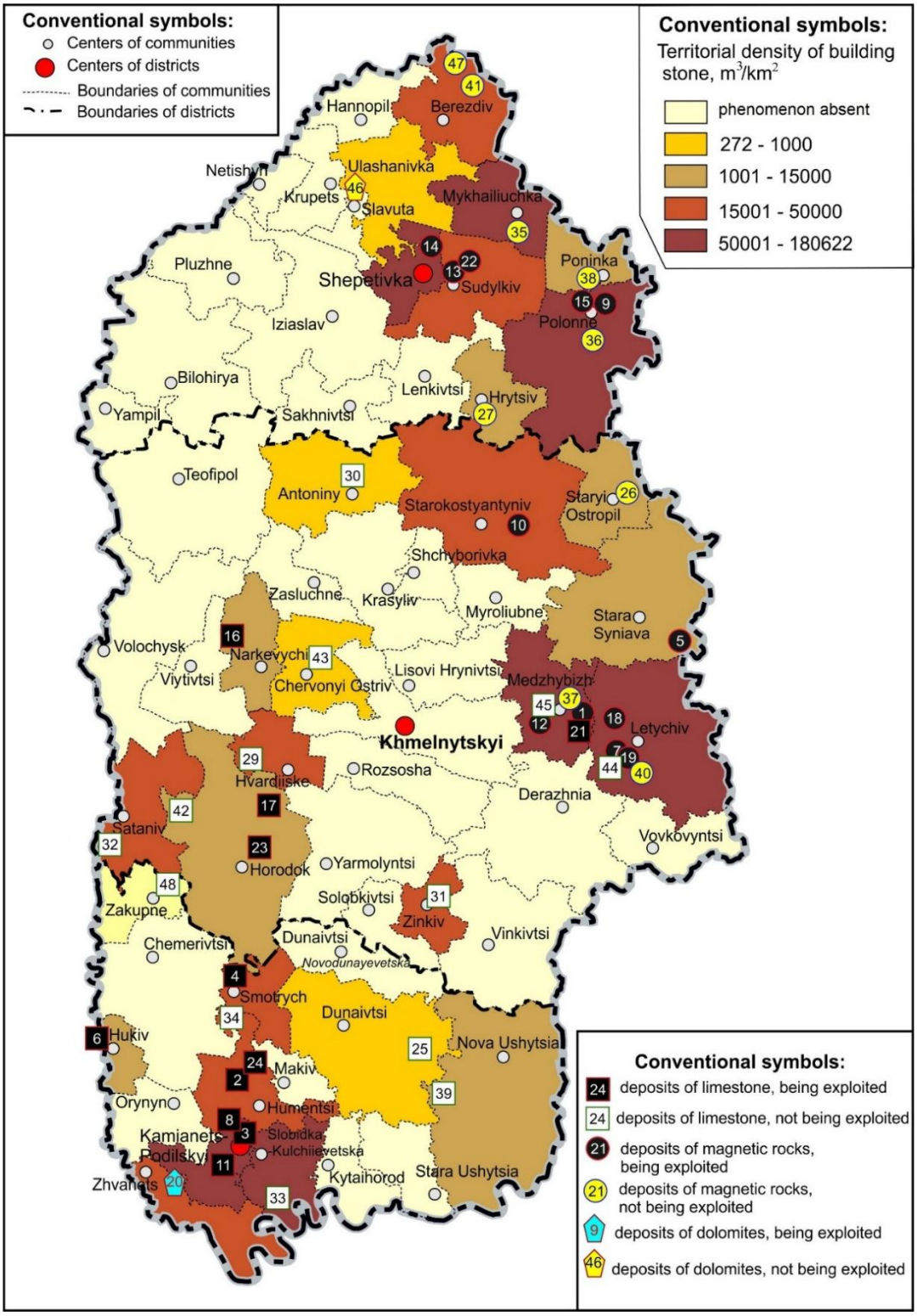

Fig. 1. Location of building stone deposits on the lands of territorial communities in Khmelnytskyi Region (compiled by the authors)

Exploited deposits: *1 – Holovchynetske, 2 – Kyselivske, 3 – Kamianets-Podilskyi, 4 – Smotrytske, 5 – Novosyniavske, 6 – Dolynivske, 7 – Rudnia-Novenske 1, 8 – Kamianets-Podilskyi (Pudlivetske), 9 – Polonske, 10 – Krasnosilkivske, 11 – Kubachivske, 12 – Rusanivetske, 13 – Sudylkivske, 14 – Klymentovytske, 15 – Polonske 2, 16 – Bubnivske, 17 – Kovalivske, 18 – Markivetske, 19 – Rudnia-Novenske, 20 – Slobidsko-Rykhtivske, 21 – Holovchynetske (part 1), 22 – Sudylkivske 1, 23 – Matviykivetske, 24 – Nihynsko-Verbetske.*

Untapped deposits: *25 – Katerynivske, 26 – Ostopilske, 27 – Hrytsivske, 28 – Demkivetske, 29 – Zhuchkovetske, 30 – Zakrynychanske, 31 – Zinkivetske, 32 – Ivankivetske, 33 - Kamianets-Podilskyi (Ustivske), 34 – Karachkivetske, 35 – Konotopske, 36 – Malo-Novoselivske, 37 – Medzhybiske, 38 – Poninkivske, 39 – Tymkivske, 40 – Trebukhovetske, 41 – Trostianetske, 42 – Turchynetske, 43 – Antonivske, 44 – Terlivske, 45 – Stavnytske, 46 – Ulashanivske, 47 – Mukharivske, 48 – Pivdenno-Zakupnianske.*

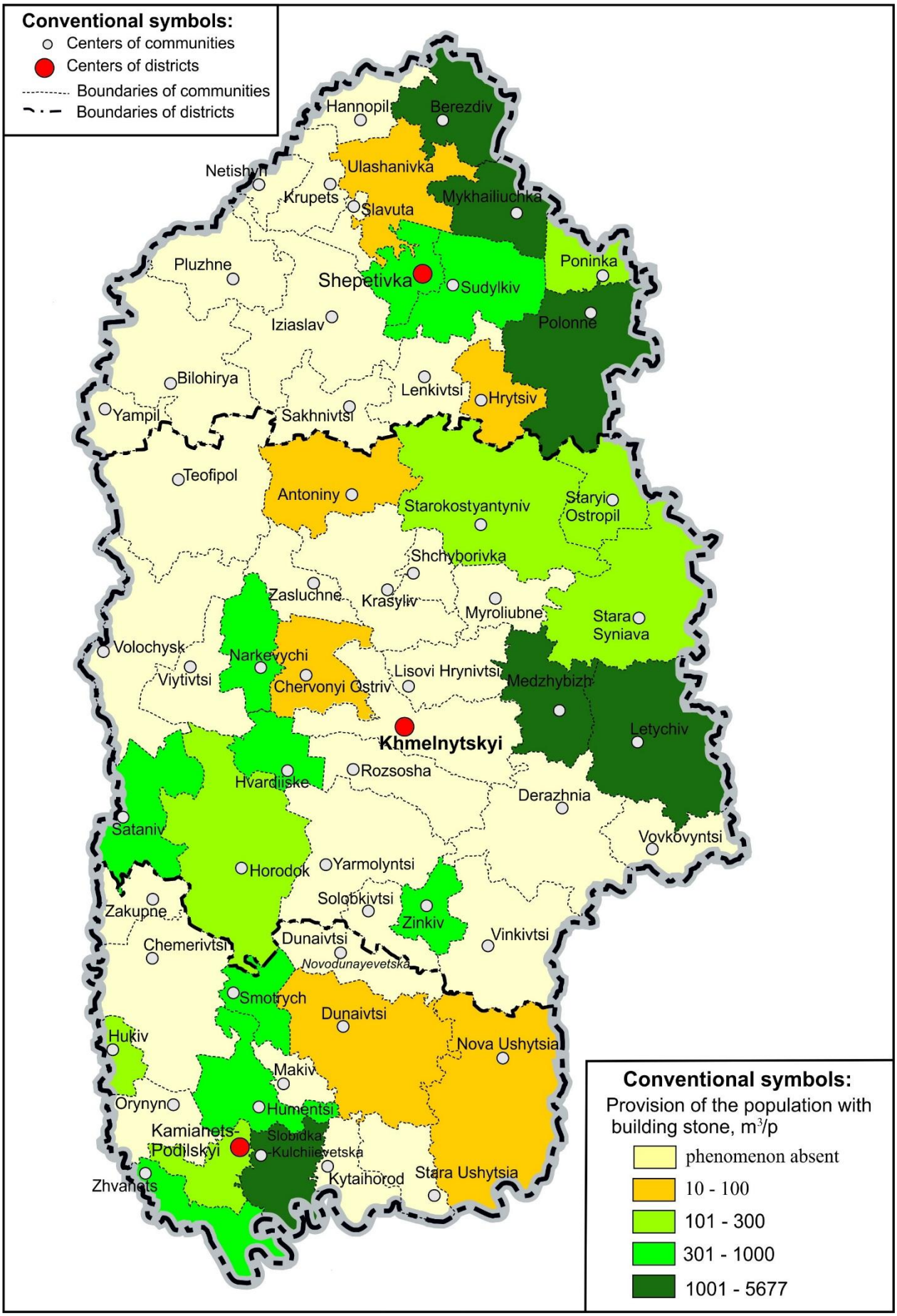

Fig. 2. Provision of territorial communities of Khmelnytskyi Region with building stone reserves (compiled by the authors)

tska TC (2260 cubic meters per person). In Smotrych, Humentsi, Sudylkiv, Zinkiv, Sataniv, Shepetivka, Hvardiyske, Narkevychi, and Kamianets-Podilskyi TCs, the provision ranges approximately from 300 to 800 cubic meters per person. All other TCs are either not provided or almost not provided with this type of raw material.

A similar pattern is demonstrated in the density of raw material distribution across the region: the highest figures are characteristic of Kamianets-Podilskyi and Polonne territorial communities (TCs) (180,620 and 146,210 cubic meters per square kilometer, respectively). In Letychiv, Slobidka-Kulchievetska, Mykhailiuchka, Shepetivka, Medzhybizh, Smotrych, and Humentsi TCs, the density ranges from 30,000 to 110,000 cubic meters per square kilometer. In Starokostantyniv, Sataniv, Berezdiv, Sudylkiv, Hvardiyske, Zinkiv, and Narkevychi TCs, the density is between 10,000 and 30,000 cubic meters per square kilometer, while in other communities, this figure is lower than 10,000 cubic meters per square kilometer.

The total area of building stone deposits located on productive arable land in the region is 156 hectares, accounting for about 16% of the total deposits. The area of currently exploited deposits is 66 hectares. Most of the building stone reserves in the region are located on low-productivity non-arable land, occupying over 748 hectares, which constitutes more than 76% of the reserves [23]. Half of these deposits are currently being exploited, which can be considered a favorable circumstance. Additionally, about 8% of the reserves are situated in deposits under forest cover, covering approximately 125 hectares. Only a small portion of these deposits is currently being exploited. The majority of raw material reserves on productive land are located in Polonne, Kamianets-Podilskyi, and Letychiv TCs. Deposits situated in unsuitable or forested areas are found in Shepetivka, Slavuta, Starokonstantyniv, Horodok, and some other TCs. Overall, the presence of significant explored raw material reserves in non-productive lands in the region creates favorable prospects for their development in the future.

As of now, the exploitation of building stone deposits in Khmelnytskyi Region is carried out by several ministries and agencies, including OJSC State Joint Stock Company “Automobile Roads of Ukraine”, Ukragroprombud, State Corporation “Ukravtodor” (State Road Agency of Ukraine), as well as commercial entities such as LLC Shepetivskyy Hranitnyy Karyer “Proneks” (Shepetivka Granite Quarry “Pronex”), LLC Kamianets-Podilskyi Kombinat Budivelnykh Materialiv (Kamianets-Podilskyi Building Materials Plant), LLC Polonskyy Shchebenevyy Karyer (Polonne Crushed Stone Quarry), PJSC Podilski Tovtry and others [26].

The majority of building stone reserves in the region are under the balance of OJSC State Joint Stock Company “Automobile Roads of Ukraine”, which extracts granite from the Rusanivetske deposit and limestone from the Pudlivetske and Kubachivske deposits. State Corporation “Ukravtodor” exploits the Krasnosilske granite deposit in Starokostantyniv territorial community. Ukragroprombud, a cooperative-state corporation, extracts limestone from the Kyselivske deposit. A large deposit of gneiss and granodiorite, the Klymentovytske deposit in Shepetivka territorial community, falls under the jurisdiction of the Department for the Execution of Criminal Punishments under the Ministry of Justice of Ukraine. The reserves of these quarries are estimated to last for over 100 years. The significant Polonske granite and migmatite deposit is exploited by LLC Polonskyy Shchebenyevyy Karyer. The Rudnia-Novenske deposits, which are medium in terms of reserves, are developed by LLC Shepetivskyy Hranitnyy Karyer. Other smaller building stone deposits in the region are exploited by commercial entities.

Enterprises produce crushed stone for construction purposes. In 2021, Polonne plant produced 624,000 cubic meters of crushed stone, out of a planned capacity of 700,000 cubic meters, indicating a utilization rate of 90%. The Starokostiantyniv Special Quarry exceeded its planned production with 418,000 cubic meters of actual output compared to the planned capacity of 400,000 cubic meters. The quarries are supplied with explored reserves for over 30 years.

The highest extraction rates were recorded at the Holovchynetske (466,000 cubic meters), Krasnosilkivske (418,000 cubic meters), Polonske (204,000 cubic meters), and Polonske 2 (418,000 cubic meters) granite deposits. Extraction in smaller quantities also took place at the Smotrytske, Rusanivetske, Nihynsko-Verbetske, and other deposits.

At the Rusanivtsi Special Quarry, 138,000 cubic meters of raw materials were extracted. The product is construction crushed stone. The quarries are supplied with reserves for long-term operation.

Kyiv-based LLC “Kontur” won an auction for the sale of a special permit to use the Trostianetske granite deposit located in the Shepetivka district. The contract value amounts to 5.18 million hryvnias [24]. The maximum available area for deposit development is 30 hectares. Geological surveys covered an area of 12 hectares. The deposit is located in the Berezdiv territorial community.

In total, 2,192 thousand cubic meters of raw materials for crushed stone and rubble stone were extracted in the region in 2021. For comparison, in 1992, 2,828 thousand cubic meters of raw materials were extracted from explored balance reserves in the

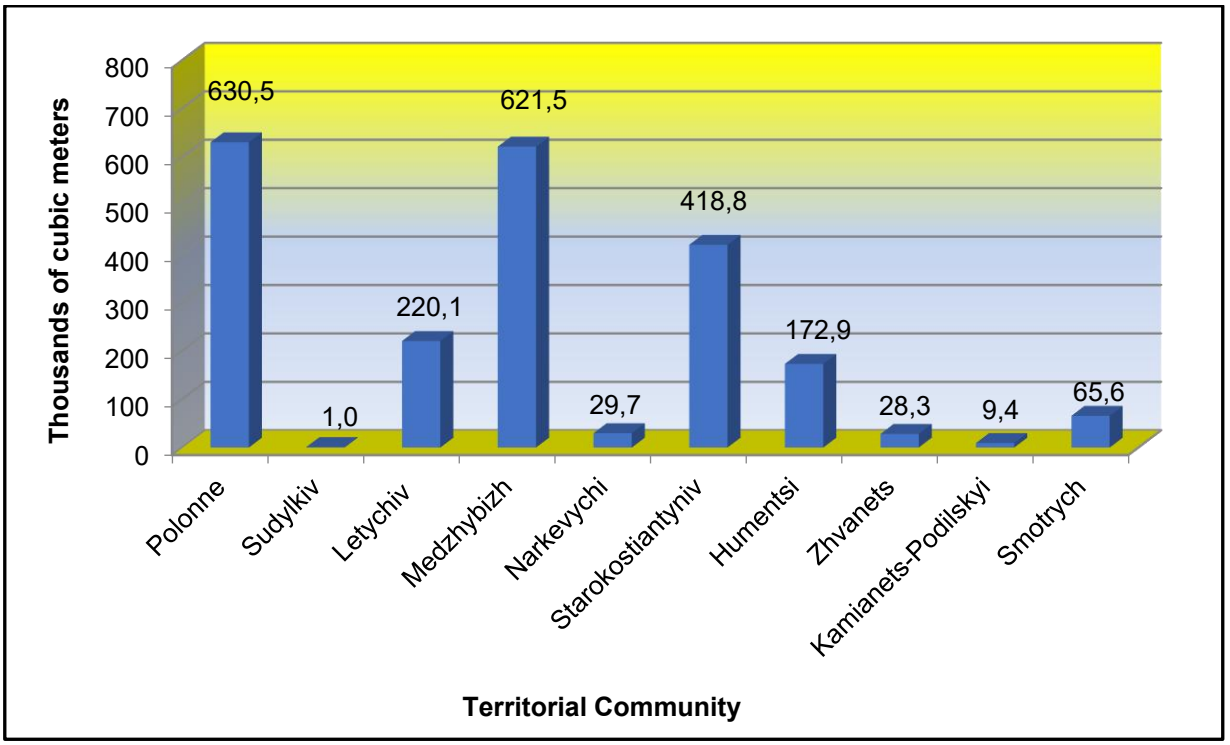

Fig. 3. Dynamics of building stone extraction by territorial communities in 2021 (compiled by the authors)

region, indicating a slight decrease in extraction. As seen in Figure 3, the main volumes of building stone extraction are concentrated in practically three territorial communities: Polonne, Medzhybizh, Starokostiantyniv, and partially in Letychiv and Humentsi, where deposits with significant reserves are exploited. In five other communities, the volumes of crushed stone raw material extraction are insignificant.

In the regions of the region where reserves have been explored, the volumes of raw material extraction have remained generally satisfactory in recent years. For example, in Shepetivka district, the extraction amounted to only 626 thousand cubic meters of raw materials out of the total projected capacity of quarries, which is 980 thousand cubic meters; in Khmelnytskyi – 1,244 thousand cubic meters, and in Kamianets-Podilskyi – 276 thousand cubic meters. However, many western and central territorial communities lack explored reserves of this type of building material and, consequently, do not carry out its extraction.

Expanding the extraction of building stone in the region can be achieved either by increasing the volumes in existing quarries in Shepetivka, Polonne, Letychiv, and some other territorial communities or by putting into operation the reserve explored deposits, of which there are 24 in the region. These include the large Ustivske, Malo-Novoselytske, and Konotopske deposits, the medium-sized Medzhybiske deposit, and smaller ones located in non-agricultural areas in close proximity to transportation routes (highways and railways).

According to expert forecasts, the granite market volume in Ukraine will continue to increase in the medium term. In the western regions of the country, granite is used more for construction and reconstruction of architectural structures and interior decoration, while in the east, it is used in the segment of ritual services and building cladding. The increasing demand will be met by domestic production while maintaining the current minimal level of imports. The price of domestic granite is also showing an upward trend due to inflation and rising wages [1].

As noted by D. Vasilyev [5], mitigating the shortage of building materials in the post-war period can be achieved by creating favorable conditions for the construction of new or restoration of damaged construction plants. For example, providing plots for free use for the first 2–3 years. Moreover, new plants can be exempted from community taxes for the initial period, receive preferential terms for utility connections, etc. Logistic needs can be partially addressed by creating attractive conditions for Western investors. If plants for the production of building materials appear in Ukraine, logistic routes will shorten, as well as logistic costs.

Conclusions

1. In the Khmelnytskyi Region, the natural stone building material base consists of crystalline Precambrian rocks of the platform foundation, including granites, granodiorites, charnockites, migmatites, and gneisses (a total of 21 deposits with total balance reserves of 236.48 million cubic meters), as well as sedimentary cover rocks such as

limestones, dolomites and sandstones (27 deposits with total balance reserves of 94,41 million cubic meters). Granitoids of the Ukrainian Shield are characterized by the largest explored reserves. The granitoids of the Ukrainian Shield are characterized by the largest explored reserves. Limestone deposits are mainly small, except for a few medium-sized ones concerning explored reserves (Pudlivetske, Ustivske, Kovalivske).

2. The main concentrations of magmatic and metamorphic rock deposits are located on the western slope of the Ukrainian Shield, falling within the boundaries of the northeastern territorial communities (TCs) of the region (Shepetivka, Mikhayliuchka, Sudylkiv, Polonne, Starokostiantyniv, and Letychiv). Conversely, limestone deposits are primarily concentrated in the southwestern part of the region within Sataniv, Horodok, Dunayivtsi, Humentsi, Kamianets-Podilskyi, Slobidka-Kulchiyevetska, and other TCs, and are associated with Silurian, Devonian, and Miocene deposits, particularly the Sarmatian formations of the Tovtry Ridge.

3. The territorial communities of Mikhailiuchka, Polonne, Shepetivka, Letychiv, and Kamianets-Podilskyi stand out significantly in terms of the explored industrial reserves of various raw materials for crushed stone production. Simultaneously, thirty territorial communities in the region completely lack explored deposits of these raw materials. In several other communities (Hrytsiv, Ulashanivka, Antoniny, Hvardiiske, Staryi Ostropil, Chornyi Ostriv, Hukiv, Zhvanets), only one small deposit has been explored, with reserves ranging from 100,000 to 400,000 cubic meters.

4. The availability of raw materials per capita and the density of their distribution clearly show the concentration of the main building stone bases in the northeastern and southwestern regions of the region. For instance, TCs such as Berezdiv, Mykhailiuchka, Polonne, Medzhybizh, Letychiv, and Slobid-ka-Kulchievetska have the best provision of explored building stone reserves (1,000–5,000 cubic meters per person). Shepetivka, Sudylkiv, Sataniv, Humentsi, Dunaivtsi, and Zhvanets TCs are slightly less provided (300–1,000 cubic meters per person). Other territorial communities in the region are either poorly provided or not provided at all.

5. Only 16% of the total explored reserves (156 hectares) are located on productive arable lands. The majority of building stone reserves (>76%) are situated on unproductive non-arable lands (approximately 748 hectares). The placement of a significant number of explored raw material reserves in unproductive lands creates favorable prospects for their future development, as it minimizes conflict with agricultural interests. The largest reserves of raw material on productive lands are located in Polonne, Kamianets-Podilskyi, and Letychiv territorial communities. Deposits located in unsuitable or forested areas are found in Shepetivka, Slavuta, Starokostiantyniv, Horodok, and some other territorial communities. Overall, the placement of a significant number of explored raw material reserves in unproductive lands in the region creates favorable prospects for their development in the future.

6. The exploitation of building stone deposits in the Khmelnytskyi Region is currently carried out by several ministries and agencies, as well as commercial entities. In total, 2,192,000 cubic meters of raw materials for crushed stone and rubble stone production were extracted in the region in 2021.

In the administrative units of the region endowed with explored reserves, the volumes of raw material extraction have remained generally satisfactory in recent years. However, many western and central territorial communities lack explored reserves of this type of building raw material and, consequently, do not engage in its extraction. The capacities of many active mining and extraction enterprises are used extremely unsatisfactorily, typically constituting a few percent. This situation is clearly explained by the current state of the building stones market, both in the region and in the country as a whole. Additionally, quarries often remain ownerless due to the complexity of obtaining licenses for opening new mining and extraction enterprises. The situation may change with a shift in the market conditions in the near future and the much-needed simplification of documentation for obtaining licenses. It can also be noted that the active quarries are supplied with explored reserves of raw materials for long-term periods.

7. Increasing the volumes of raw material extraction in the region can be achieved by maximizing design capacities at existing quarries in Shepetivka, Polonne, Letychiv, and other TCs, and by bringing into operation the 24 reserve explored deposits. These reserve deposits include large ones (Ustivske, Malo-Novoselytske, Konotopske), medium ones (Medzhybiske), and smaller ones located near major transportation routes on non-arable lands.

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Сировинна база щебеню та бутового каміння Хмельницької області

Мирослав Сивий [1]
д. геогр. н., професор кафедри географії та методики її навчання,
[1] Тернопільський національний педагогічний університет
імені Володимира Гнатюка, Тернопіль, Україна;
Петро Дем'янчук [1]
к. геогр. н., доцент кафедри географії та методики її навчання;
Ігор Холошин [2]
к. геол.-мінер. н., доцент, зав. кафедри географії та методики її навчання,
[2] Криворізький державний педагогічний університет, Кривий Ріг, Україна;
Наталя Пантелєєва [2]
асист. кафедри географії та методики її навчання

В статті проаналізовано сучасний стан вивченості родовищ сировини для щебеневої й бутової продукції у Хмельницькій області. Показано приуроченість родовищ до певних стратиграфічних підрозділів, з'ясовано загальні закономірності розміщення покладів різних видів будівельного каміння в межах районів, територіальних громад). Визначено ступінь розвіданості родовищ будівельного каміння та рівень їхнього промислового освоєння. Розраховано територіальну щільність та забезпеченість розвіданими запасами населення територіальних одиниць, показано динаміку видобування сировини за останні роки й подано пропозиції щодо нарощування обсягів видобування. Виявлено приуроченість основних баз будівельного каміння до північно-східних та південно-західних теренів області. При цьому в північно-східних територіальних громадах (ТГ) розвідані й експлуатуються в основному поклади магматичних і метаморфічних порід (гранітоїди), в південно-західних – осадових (вапняків). Максимально забезпечені сировиною такі ТГ як Михайлюцька, Березdівська та Полонська Ше-

петівського району (понад 1000 м^3/особу). Високі показники забезпеченості громад у Летичівській та Меджибізькій ТГ Хмельницького району (понад 2000 м^3/особу). У більшості ТГ області з розвіданими запасами будівельного каміння показники забезпеченості становлять 100-600 м^3/особу. Подібну картину демонструє щільність розподілу сировини по території області. Найвищі показники характерні для північно-східних та східних ТГ, а також крайніх південно-західних територій ТГ Кам'янець-Подільського. району В інших ТГ цей показник нижчий за 10000 м^3/км^2. Повністю позбавлені розвіданих запасів західні ТГ Шепетівського та центральні ТГ Хмельницького районів. Аналіз обсягів видобування сировини на державних та комерційних підприємствах регіону, асортименту їхньої продукції та термінів забезпеченості розвіданими запасами дозволив констатувати, про загалом задовільні обсяги видобування сировини в області, навіть порівняно з довоєнними роками, недостатню забезпеченість достовірними запасами окремих діючих кар'єрів, зосередженість видобування в декількох ТГ, а також недостатню завантаженість багатьох підприємств, порівняно з проєктними потужностями. Нарощування видобутку сировини в регіоні при потребі може бути досягнуте за рахунок введення в експлуатацію великих резервних родовищ (Устівське, Конотопське та ін.), розміщених на неугіддях, а також при виведені на проєктні потужності низки родовищ у Шепетівському та Хмельницькому районах.

***Ключові слова**: Хмельницька область, будівельне каміння, родовища, магматичні породи, осадові породи, сировина, територіальні громади, територіальна щільність, забезпеченість, видобування.*

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