EDUCATION AND SCIENCE IN UKRAINE IN THE PERIOD OF TODAY'S GLOBAL CHALLENGES

COLLECTIVE MONOGRAPH

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CEMENT RAW MATERIALS IN KHMELNYTSKYI REGION: GEOSPATIAL CHARACTERISTICS OF RESERVE DISTRIBUTION, CURRENT STATUS, AND UTILIZATION PROSPECTS

Cements are classified as binding materials and are widely used in construction practice. The primary raw materials for producing Portland cement are calcareous-carbonate rocks (limestone, chalk, marl) and clay materials (mainly low-melting clays, clay shales, loams, loesses, and argillites), which are combined in specific proportions in the so-called raw mix. Typically, a mix of 2–3 parts limestone or chalk and one part clay is used. An exception is natural marls, where the clay and carbonate components are naturally in proportions optimal for the raw mix, which is then fired to produce cement clinker.

In addition to the main components, the raw mix includes active mineral additives such as opoka, tripoli, diatomite, volcanic tuffs, pumice, trass, pozzolans, quartz sand, and iron ore – mostly rocks containing free silica. Other active mineral additives can include blast furnace slags, coal ash, and pyrite cinders, among others. These additives enhance the durability of concrete when used in moist environments or underwater. They are added to the cement mixture in quantities of 10–15 %.

To control the setting time of the cement, gypsum is also added to the mix. The amount of gypsum varies depending on the composition of the clinker and the type of cement – for Portland cement, it is typically around 5% of the total product weight.

When the mix of primary components is fired, clinker minerals are formed (silicates, ferrites, calcium aluminates). To produce these, the raw minerals must predominantly contain calcium oxide, silica, alumina, and iron oxides. Limestone, chalk, and marl provide the necessary calcium oxide, while clay materials supply alumina, silica, and iron oxides.

In cement production, carbonate rocks are considered suitable if they contain at least 45 % CaO and require an addition of clay components. Additionally, carbonate rocks should contain (in %): MgO no more than 8.7, SO_3 no more than 1.3, K_2O+Na_2O no more than 1.0, and P_2O_5 no more than 0.44. Harmful components for cement production include magnesium oxide, phosphorus, alkalis, and sulfur (especially if bound in gypsum). Siliceous inclusions, dolomitization, and extensive development of clay-filled karst cavities are also undesirable, as they complicate grinding.

The most suitable materials for cement production are marly and porous limestones with a relatively low compressive strength limit (100–200 kg/cm^2). These materials are easy to crush and do not require high firing temperatures[1].

The clay component must also be uniform in structure, free of large quartz grains and coarse fragments. The fraction of particles larger than 0.2 mm should not exceed 10 %, and those larger than 0.08 mm should be no more than 20 %.

In Ternopil and Khmelnytskyi regions, Silurian limestones and argillites, Upper Cretaceous marls, limestones, chalk, Neogene limestones, clays, Quaternary clays, and loams have been studied as raw materials for cement production. Silurian deposits are widely distributed in the Dniester area, from the village of Molodove (Khmelnytskyi region) to Ustechko (Ternopil region), and are well exposed in the Dniester valley and its left tributaries. The lithological varieties of Silurian rocks mainly include limestones, argillites, marls, and dolomites. The visible thickness of limestones interbedded with argillites and marls ranges from a few meters up to 80 meters, although the total thickness of Silurian deposits reaches 800–900 meters[2]. Their depth of occurrence does not exceed several tens of meters. The CaO content in limestones is 46–49 %, and MgO ranges from 1 to 18 %[3].

A disadvantage of using these materials as cement raw material is the frequent dolomitization and the associated high MgO content. On the other

1 Сивий М. Сировинна база цементної промисловості України : сучасний стан, перспективи // *Вчені записки Таврійського нац. ун-ту ім. В. Вернадського*. Ч. 3. Географія. 2011. Т. 24. № 2. С. 185–191.

2 Лазаренко Є. К., Сребродольський Б. І. Мінералогія Поділля. Львів : Вид-во Львів. ун-ту, 1969. 344 с.

3 Сивий М. Я. Мінеральні ресурси Поділля: конструктивно-географічний аналіз і синтез. Тернопіль : Підручники і посібники, 2004. 656 с.

hand, the reserves of carbonate rocks in the Podolian Dniester region are vast and largely unexplored, leaving the possibility of discovering pure limestone varieties in the future that would meet the quality standards required for cement production.

In the Upper Badenian, two facies may be of practical interest: the so-called «tess» or «sawable» limestone facies and the reef limestone facies. The tess limestone facies consists of organogenic-detrital, lithothamnion, and rarely oolitic limestones with sand and clay interlayers, 10–20 meters thick. Lithothamnion limestones are composed of calcite grains and lumps with inclusions of foraminifera and lithothamnion in the form of rounded nodules, along with numerous mollusk shells and shell fragments. Organogenic-detrital limestones consist of fragments of lithothamnion, bryozoans, echinoderms, pelecypods, and other organisms in a carbonate pelitomorphic cement. These limestones are quarried as building stone and contain up to 53 % CaO.

Reef limestones are associated with the development of the Podolian Cliffs. Their thickness is variable, ranging from 1–2 meters to over 100 meters. They are predominantly composed of lithothamnion varieties. A significant feature of these limestones is the considerable heterogeneity of their physical and mechanical properties: soft detrital varieties can alternate with strong recrystallized limestones, whose mechanical strength can reach 800–900 kg/cm^2. Limestones of this type typically contain the following average percentages: CaO up to 52.5; SiO_2 0.88; MgO up to 2.0; CO_2 up to 43; and P_2O_5 0.69[4]. Deposits of such limestones are usually small in area, with a typical length of 2–3 km and a width of 600–800 meters.

Certain varieties of Neogene limestones are entirely suitable for use as a carbonate component in cement production. The most promising area for establishing raw material bases for the cement industry is the Tovtra Ridge, particularly its southeastern part (Khmelnytskyi region). In this regard, Neogene limestone deposits should be developed in a comprehensive manner: as raw material for the cement industry, for lime burning, as valuable wall material, and as raw material for the sugar industry. However, it is essential to consider that extensive quarrying operations could cause irreparable damage to the unique nature of the Podolian Cliffs.

In Khmelnytskyi region, five cement raw material deposits have been thoroughly explored and put on record (Kryvynske, Humenetske, Kamianets-

4 Міщенко В. С. Економічні пріоритети розвитку й освоєння мінеральносировинної бази України. Київ : Наукова думка, 2007. 360 с.

Podilskyi, Smotrytske, and Kryvynske-1). Additionally, five more deposits (Mizhirsk-Kashchenske, Dunayevetske, Zelenchanske, Loshnyvetske, and Teremkivske) have been preliminarily explored, with reserves assessed according to categories C_1+C_2 (see Table 1).

The majority of deposits are located within the Dunayevetska amalgamated territorial community (3 deposits), which includes one carbonate raw material deposit, one complex deposit, and one clay raw material deposit. There is one complex deposit each in the Humenetska and Staroushytska communities, while two clay deposits are found in the Netishyn community, one in the Bilohirsk community, and two in the Kamianets-Podilskyi community. Thus, the reserves of cement raw materials in the region are concentrated within six territorial communities across two administrative districts (Shepetivskyi and Kamianets-Podilskyi).

In the accounted deposits, the carbonate raw materials (limestones + marls) are estimated at 87,768 thousand tons according to categories A+B+C_1, while the clay raw materials (clays + silty clays) amount to 75,105 thousand tons in categories A+B+C_1, and over 39,879 thousand tons in category C_2 [5].

Table 1

The structure of explored reserves of cement raw materials in the Khmelnytskyi region (calculated by the authors based on the data of the DNVP «Geoinform of Ukraine»[6])

Rayon, territorial community (TC), field, plot	Useful fossil	Stocks in detail of explored fields, accounted for in the balance sheetby category (thousand tons)		Reserves of previously exploredand surveyed fields(thousand tons)	Raw material production in2021 (thousand tons)
		A+B+C_1	C_2	C_1+C_2	
1	2	3	4	5	6
Shepetivskyi **district**					
Netishyn *TC*					
Kryvynske	Clay	1351	28174	-	-
Kryvinske-1	Clay	3298	11705		-
Beloghirsk TC					
1. Mizhhirsko-Kashchenske	Clay	-	-	4000	-

5 Сивий М., Гавришок Б., Дем'янчук П. Мінерально-сировинний потенціал Хмельниччини : монографія. Тернопіль : ТНПУ ім. В. Гнатюка, 2023. 332 с.

6 Ibid.

Continuation of table 1

1	2	3	4	5	6
Kamianets-Podilskyi district *Dunaivtsi TC*					
1. Dunayevetske	Limestone	-	-	10920	-
2. Zelenchanske	Limestone	-	-	72800	-
	Clays	-	-	59800	-
3. Loshkivetske	Clay	-	-	16700	-
Humentsi TC					
1. Humenetske					
Plots:					
а) Humenetska	Limestone	58369	-	-	2949
б) Kolubayevska	Marl	29399	-	-	521
	Clay	25018	136261	-	187
	Loam	2235	-	-	-
в) Pudliwetska	Clay	19686	-	-	-
г) Kolubayevska-2	Loam Clay	2863 -	- -	- -	- -
Stara Ushytsia TC 1. Teremtsivske	Limestone	-	-	81600	-
	Tripoli	-	-	25800	-
Kamianets-Podilskyi TC					
Kamianets-Podilskyi (Dobrovilska section) Smotrytske	Loam Clay Loam	4542 2121 1835	- - -	- -	- 75 103
Total in the region	Limestone	58369	-	263600	2949
	Clays	63640	39879	116500	262
	Marls Loam Tripoli	29399 11475 -	- - -	- - 25800	521 103 -

In the preliminarily evaluated deposits, there are 263,600 thousand tons of carbonate raw materials, 116,500 thousand tons of clay raw materials, and 25,800 thousand tons of hydraulic additives.

All assessed deposits are classified as large, with reserves exceeding 10 million tons. Currently, four sections of the Humenetske deposit are being exploited: Humenetska (limestones), Kolubayevska (clays), Pudlovetska (clays), and Kol-

ubayevska 2 (clays and silty clays). The Kryvynske deposit is dedicated to clay, while the Kamianets-Podilskyi deposit (Dobrovil'ska section) extracts silty clays, and the Smotrytske deposit is focused on clays and silty clays.

The Humenetske deposit has been developed since 1970 by the Kamianets-Podilskyi Cement Plant (now PAO Podilskyi Cement). In 2021, the deposit yielded 2,957 thousand tons of limestone, 187 thousand tons of clay, and 521 thousand tons of marl. Limestone from the quarry is transported by road to the crushing department, located 2.5 km away, and then conveyed by a 4 km long conveyor belt to the plant. Clay is transported by road to the slurry preparation department, 1.5 km away, and then through a 4 km long slurry pipeline to the plant.

Based on the current extraction volumes (for comparison, in 1992, 3,853 thousand tons of limestone, 1,197 thousand tons of clay, and 166 thousand tons of silty clay were extracted), the supply period for the plant's limestone reserves will last nearly 19 years, for clay – 239 years, and for marl – 56 years.

The plant primarily produces Portland cement of grades 400 and 500, with consumers mainly being enterprises across Ukraine. The average consumption of raw materials and additives (in tons) for the production of 1 ton of clinker is as follows: limestone – 1.37 tons, clay – 0.54 tons, iron-containing additives – 0.02 tons, slags – 0.13 tons, ashes and ash-slag wastes from thermal power plants – 0.02 tons, and gypsum – 0.07 tons.

Another assessed deposit in the region is the Kryvynske deposit, located in the Netishyn community, which is being developed by commercial entities and PJSC «Dikergoff Cement Ukraine». Clay from the quarry is transported to the plant by rail over a distance of 40 km. No extraction data were reported for 2021. With assessed reserves (categories $A+B+C_1$) of 13,516 thousand tons and category C_2 reserves of 28,174 thousand tons, and a current extraction rate of approximately 100 thousand tons per year, the plant has enough clay for 135 years. However, if considering the plant's designed capacity of 700 thousand tons, the clay reserves would last only 19 years.

The increase in cement raw material reserves in the region can occur through the following measures:

a) **Conversion of reserves:** By upgrading the reserves classified as category C_2 at the Kryvynske deposit to industrial categories.
b) **Exploitation of the Kryvynske-2 deposit:** This deposit has assessed clay reserves of 3,298 thousand tons, with additional C_2 reserves of 11,705 thousand tons.

c) **Detailed geological exploration:** Conducting detailed geological exploration in previously explored or prospectively identified deposits, such as the Mizhhirsko-Kashchensky (clay), Dunayevetsky (limestone), Zelentsyansky (limestone, clay), Loshnyvetsky (clay), and Teremkovsky (tuff) deposits.

Additionally, no prospective areas for gypsum have been identified near the cement plant. Therefore, it may be possible to consider the transportation of gypsum from the Shishkivetske deposit in the Ternopil region, located about 40 km away. Furthermore, it is entirely feasible to utilize waste from the processing of limestones for the sugar industry at neighboring deposits, such as the Nygynsko-Verbetsky and Verbetsky deposits, especially since some estimates suggest that the amount of this waste could reach approximately 14 million tons upon complete exploitation of the deposits.

Here is a brief characterization of the explored cement raw material deposits in the region:

Mizhhirsko-Kashchensky Deposit

- **Location:** 8 km northwest of the town of Bilogirya on arable land.
- **Useful Mineral:** Sarmatian clays with an average thickness of 6.0 m.
- **Overburden Thickness:** 14.8 m.
- **Characteristics:** The clays are dense, viscous, fatty, and come in greenish-gray and ash-gray colors, exhibiting variable lithological and chemical compositions. They can be used as a clay component in cement mixtures due to their composition and modulus size.
- **Reserves:** Estimated at 40,000 thousand tons under category C_1, with prospects for reserve increase.

Dunayevetsky Deposit

- **Location:** Near the eastern outskirts of the town of Dunayevtsi on arable land.
- **Useful Minerals:** Oolitic limestone with a thickness of up to 11 m and clay with a thickness of 3 m.
- Overburden Thickness: 3–3.5 m.
- **Characteristics:** The limestone belongs to the Sarmatian stage, is gray, and consists of fine and coarse oolites with interlayers of recrystallized limestone. The clay, also from the Sarmatian stage, is dark green, calcareous, and c**ontains detritus and gravel.**
- **Calcium Carbonate Content:** Ranges from 81–98 % in the limestone.

- **Reserves:** The limestone reserves are estimated at 109,200 thousand tons under category C_1. Clay reserves have not been assessed yet.

Zelenchansky Deposit

- **Location:** 12 km northwest of the town of Dunayevtsi, near the village of Zelencha, on low-yield agricultural lands.
- **Useful Minerals:** Loam, clay, and limestone.
- **Loam Characteristics:** Quaternary age, dark brown, yellowish-brown, porous, clumpy, with an average thickness of 1.6 m.
- **Clay Characteristics:** Sarmatian stage, yellowish-gray, sandy, greenish-gray, marly, light gray, and gray marls with an average thickness of up to 28 m.
- L**imestone Characteristics:** Sarmatian stage, clayey, detrital, and shell-detrital, with an average thickness of 3.8 m.
- **Reserves:** Clay reserves estimated at 59,800 thousand tons under category C_1, and limestone reserves at 72,800 thousand tons under category C_2. There is potential for increasing both clay and limestone reserves, including on low-yield lands. After detailed exploration, this deposit could serve as a base for the Kamyanets-Podilsky cement plant.

Loshkivetsky Deposit

- **Location:** 2 km northwest of the town of Dunayevtsi on arable land.
- **Useful Mineral:** Clay with an average thickness of 12 m.
- **Overburden Thickness:** 12 m.
- **Clay Characteristics:** Sarmatian stage, red-brown and gray, bluish-gray with carbonate inclusions.
- **Potential:** The loam from the overburden may also be identified as a useful mineral for use as a clay component in cement mixtures after additional studies.
- **Reserves:** Estimated clay reserves at 16,700 thousand tons under category C_1.

Humenecky Deposit

- **Composition:** This deposit consists of four sections: Humenecky, Kolubaivsky, Pudlivetsky, and Kolubaivsky-2. Specific characteristics and reserve estimates for these sections would typically detail the types of useful minerals found, their thicknesses, and any relevant data regarding exploration and exploitation.

Humenetska Site. The Humenetska site is located 9 km northeast of Kamianets-Podilskyi on arable land. The useful mineral is limestone with a total thickness of 85 m. The limestones belong to the Sarmatian stage and are

characterized as serpulid-algal and lithotamnium-detrital. The overburden thickness is 4.6 m. The limestones are distinguished by the uniformity of their chemical composition and a high content of calcium oxide. When mixed with Sarmatian clays in a ratio of 3:1, they yield a practically identical mineralogical composition when incorporating waste materials up to 1–1.5 %. The clinker exhibits a low silicate modulus (1.93 – 2.0) alongside a high alumina modulus (1.7 – 2.0). This site is being developed by PJSC Podilsky Cement. As of January 1, 2022, the remaining reserves amounted to $A+B+C_1$ – over 58 million tons. Any potential increase in reserves is only possible within the boundaries of the Tovtriv Ridge.

Kolubaivska Site. The Kolubaivska site is located 3.5 km east of the cement plant near the village of Kolubaivtsi on arable land. The useful minerals are clay, marls, and loams. The overburden thickness is 0.6 m. The loam is of Quaternary age, yellowish-brown with carbonate inclusions, cloddy, with an average thickness of 1.9 m. The Quaternary clay is brown, yellowish-brown, sandy, with an average thickness of 1.4 m. The Sarmatian clay is light gray, dark green, carbonate, dense, and plastic, with an average thickness of 11.9 m. The Sarmatian-age marl is clayey, dark gray, finely layered, dense, with an average thickness of 14.1 m. The marls of this site, when mixed with iron additives, can be used as an aluminosilicate component in the production of Portland cement clinker. As of January 1, 2022, the reserves of loams and clays amounted to 2,235 and 25,018 thousand tons ($A+B+C_1$), respectively, and marls amounted to 29,399 thousand tons.

Pudlivetska Site. The Pudlivetska site is located near the village of Pudlivtsi, 5 km west of the cement plant on arable land. The useful minerals are loam and clays, which are found in the overburden above the limestones being exploited for the production of cold asphalt concrete. The loam is of Quaternary age, brown, sandy with carbonate inclusions, with an average thickness of 2.4 m. The Quaternary clay is brown and greenish-brown, dense with carbonate inclusions, with an average thickness of 1.9 m. The Sarmatian clay is greenish-gray, dense, plastic, and layered, with an average thickness of 14.5 m. The reserves of clays and loams amount to 19,686 thousand tons. This site is listed as a reserve for the cement plant. An increase in reserves is possible.

Teremtsi Deposit. The Teremtsi deposit is located 40 km southeast of the Kamianets-Podilskyi cement plant near the village of Teremtsi on low-productive and non-arable land. The useful mineral is tripolite with an average thickness of

11.5 m. The associated useful mineral includes reef limestones, organic, and detrital, with a thickness of 31.5 m. The quality of the tripolite meets the standard DST 21-9-74 «Active Mineral Additives for Binding Agents». The reserves classified as category C_2 are: tripolite – 25.8 million tons, limestones – 81.6 million tons.

Kryvynske Deposit. The Kryvynske deposit is located near the village of Stary Kryvin, 38 km from the town of Zdolbuniv on arable land. The useful mineral is clay with an average thickness of 10 m. The overburden is 2.4 m. The clay belongs to the Sarmatian stage, is variegated in color, black, and coal-bearing. This clay is suitable for producing Portland cement of grades 400–500 in a mixture with loam and chalk from the Zdolbuniv deposit. The mixture ratio of the clay component is: clay – 1.36 parts, loam – 1 part. The reserves of clay in industrial categories as of January 1, 2020, amounted to 13,516 thousand tons, with reserves in category C_2 totaling 28,174 thousand tons. The clay is utilized by commercial structures and PJSC «Dickerhoff Cement Ukraine». Currently, there is no data on extraction, and production capacities have been used at 18–20 % in recent years. An increase in reserves is possible.

In the early 1990s, an expedition from Ukrgeolbud conducted a re-evaluation of the clays from the upper part of the variegated thickness as expanded clay aggregate raw materials at two sites located near the cement plant's quarry. Laboratory and pilot tests established the suitability of the clays from the Southern area, as well as from both the Southern and Northern areas, in a 1:1 ratio with the addition of 0.7 % organic fuel for producing expanded clay gravel. The reserves of clay for expanded clay gravel were approved in categories $B+C_1$ – 2,547 thousand m^3.