УДК 551.438; DOI 10.30970/gpc.2019.2.3066

THE MODERN MORPHODYNAMICS IN THE QUARRIES OF LVIV AND ITS SUBURBS

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Abstract. The seven big quarries have been explored in and around Lviv. All quarries are sandy and most of them are inactive now. There are 3 quarries located directly in the city: two – within the Znesinnia Regional Landscape Park (western and eastern) and Kryvchytskyi. The four quarries are located in the southeastern outskirt of Lviv within the Davydivskyi Chain near the villages of Davydiv (3 quarries) and Vynnychky.

The processes of water erosion (sheet, rill and gully erosion), suffosion, falls, scree formation processes, slides, physical and chemical weathering are widespread in the explored quarries. The specific azonal processes such as aeolian processes (deflation and accumulation of sandy material) and formation of takyrs are also common.

The most common are water erosion processes (sheet, rill and gully erosion). They are present in almost all quarries (except of Western Znesinskyi and Kryvchytskyi Quarries). These processes occur in the lower parts of quarry benches and on the slopes of dumps. They are represented by small and medium-sized erosive pre-rills and rills (width 5–30 cm, depth up to 45 cm), small gullies (depth up to 2.2 m), debris cones, deluvial cones. The sheet, rill and gully erosions mainly occur together.

The suffosion processes develop in the sandy-loam deposits with low density (the Davydivskyi Quarry № 2, the Vynnychkivskyi Quarry). The result of these processes is the formation of suffosion sinkholes (35–60 cm in diameter) and suffosion “wells”.

The processes of rockfalls are locally widespread on steep denudation benches of quarries, where beds of limestone or sandstone are cropped out (the Davydivskyi Quarry № 1, № 3). The scree formation processes are also common in gravitational processes and mainly occur in sandy deposits and are represented by scree cones. Slides occur rarely having small main bodies and are located on the quarry walls and dump slopes. A special type of processes in the studied quarries is the formation of takyrs, which occurs in closed watered areas of the pit floors. After the takyrs dry up, the so-called "desert papyrus" is created.

Key words: modern morphodynamics, quarry, water erosion processes, falls, scree formation processes, Lviv.

СУЧАСНА МОРФОДИНАМІКА У КАР’ЄРАХ МІСТА ЛЬВОВА ТА ЙОГО ОКОЛИЦЬ

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Анотація. На території міста Львова та його околиць досліджено 7 великих кар’єрів. Усі кар’єри піщані, більшість з них на наш час недіючі. Безпосередньо на території міста розташовані 3 кар’єри: два на Знесінні (західний і східний) та Кривчицький. Чотири кар’єри розміщені на південно-східній околиці Львова у межах Давидівського пасма біля сіл Давидів (3 кар’єри) і Виннички.

У досліджених кар’єрах поширені процеси водної ерозії (лінійна і площинна ерозія), суфозія, обвально-осипні процеси, зсуви, фізичне і хімічне звітрювання. До специфічних азональних процесів належать еолові процеси (дефляція та акумуляція піщаного

матеріалу) і такироутворення.

Найбільш поширеними є процеси водної ерозії (лінійна і площинна ерозія). Вони присутні майже у всіх кар'єрах (крім західного Знесіньського і Кривчицького). Ці процеси розвиваються у нижніх частинах уступів кар'єру та на схилах відвалів. Представлені дрібними і середніми ерозійними борознами і вимоїнами (ширина 5–30 см, глибина до 45 см), невеликими ярами (глибиною до 2,2 м), конусами винесення, делювіальними шлейфами. Лінійна і площинна ерозія переважно відбуваються спільно.

Суфозійні процеси розвиваються в неущільнених піщано-суглинистих відкладах насипів (Давидівський №2, Винничківський кар'єри). Результатом дії процесу є утворення суфозійних просадок (діаметром 35–60 см) та суфозійних колодязів.

Обвальні процеси локально поширені на крутих денудаційних уступах кар'єрів, на яких відслонюються шари вапняків або пісковиків (Давидівські кар'єри №1, № 3). Більш поширеними серед гравітаційних процесів є осипища, які переважно відбуваються у піщаних відкладах і представлені осипними конусами і шлейфами. Зсувні процеси трапляються рідко, представлені невеликими зсувними тілами та розміщені на стінках кар'єрів і схилах відвалів.

Особливим видом процесів у досліджених кар'єрах є такироутворення, яке виникає на замкнутих обводнених ділянках днищ кар'єрів і призводить до утворення після їх висихання т. зв. "пустельного папірусу".

Ключові слова: сучасна морфодинаміка, кар'єр, процеси водної ерозії, обвально-осипні процеси, Львів.

Introduction. The quarries in and around Lviv have existed for a long time. In the nineteenth century, there were three major types of quarries in Lviv: clay, sand and limestone. Quarries were located in the southern (especially south-eastern) and western part of the city, which almost exclusively corresponds to the geomorphological area of the Lviv Plateau (Pryroda…, 1972, Lviv…, 2012). At that time, it was suburb territory. In the twentieth century, the relief of Lviv underwent greate changes. The quarrying was developed in different parts of the city, mainly in the south, south-east and northwest. It was an important indicator of industrial development of the city and a source of raw materials for various industries. In the second half of the twentieth century, the quarries in Lviv were gradually closed and the existing quarries remained only in the suburbs.

The modern morphodynamics (modern geomorphological processes) is part of geomorphological studies of quarries as anthropogenic forms of relief. Such studies also involve the study of morphology, genesis and age of these forms, their classification, mapping, etc. (Zaitsev, Rubyna, 1987; Firsenkova, 1987; Horishnyy, Aleksiuk 2004, Dávid, 2008, 2012, Horishnyy, 2010, 2016, 2018; Koltun, Kovalchuk, 2012, Mossa J., and James L.A., 2013, Boengiu S., Ionuş O., Marinescu E., 2016, Urban…, 2018, Horishnyj, Pavelchuk, 2019, etc.). In addition to geomorphology, the landscape science and constructive geography also includes studying the quarry technoforms (Fedotov V., Fedotov S., 2004, Ivanov, 2007, 2017, etc.).

The biggest contribution to the development of scientific thought about the morphodynamics of mining territories was made by V. M. Firsenkova (1987). She suggested a wide range of forms created by different geomorphological processes (water-erosion, landslide, eolian processes, etc.), pointed out the main stages of intensity of landslide and erosion processes and for the first time she constructed morphodynamic maps of quarry-dump complexes in large scales (1:5 000).

The processes in quarries can be divided into two groups: anthropogenic and nature-anthropogenic (Gorshkov, 1982). The anthropogenic processes are considered as direct human activities aimed at changing the relief. These processes include anthropogenic denudation, anthropogenic accumulation, terracing. The nature-anthropogenic processes occur on anthropogenic elements of relief, but operate under the laws of self-development of relief. They are divided by genesis into gravitational, water-erosion, suffosion, landslide, aeolian, abrasive, etc.

The goal of the work is to find out the localization, morphology and morphometry of the forms created by different nature-anthropogenic processes on the basis of our own field and remote researches, and also the peculiarities of their combination in the quarries of Lviv city and its suburbs.

Research methodology. A number of general geographic (remote) and geomorphological (morphometric, morphographic, morphodynamic) methods are used in the article. The general geographical is the remote method, which includes the analysis of cosmographic images of anthropogenic relief of high resolution. It is used for identification, orientation (replacing the basic materials related to mining works) and general characterization of individual quarries. The morphographic method provides a description of the external structure of elements and forms of quarry relief, morphometric – their quantitative parameters (field and laboratory methods). The morphodynamic method aims to identify and characterize the forms created by a particular process (or combination of processes) in the field. In general, field geomorphological research methods were the main ones.

The features of processes in quarries. The modern morphodynamics in quarries is more active than in adjacent natural areas. The main reasons for that are the next:

1) The formed anthropogenic relief is very dissected with great relative heights and steepness of the surface, and therefore has considerable "energy" of the surface. With the development of quarries, the vertical dissection increases. Due to the processes (primarily water-erosion), the horizontal dissection of the relief also sharply increases.

2) During the quarry works, the soil and vegetation layer is destroyed, also, the bedrock and heterogeneous sedimentary rocks are cropped out. Such exposure of rocks creates favorable conditions for the active development of processes, in particular, those that are impossible or almost impossible in natural conditions: gravitational, in particular, falls (within the plain terrain are very rare), weathering processes, formation of takyrs, etc.;

3) The heaped relief contributes to the development of gravitational, water-erosion and other processes due to a low density of rocks, the absence of soil-vegetation layer and due to its morphology (steep walls of sheating dumps).

The geomorphological mapping of modern morphodynamics. All modern processes in quarries are nature-anthropogenic processes, occurring on anthropogenic elements of relief, but act as natural and are subject to the law of self-development of relief. In our opinion, the anthropogenic processes, which are direct cause of the formation of elements and forms of quarry relief, do not need a separate designation on geomorphological maps, because they are considered as purely technological processes.

The exogenic processes are recorded on a cartographic basis directly in the field, using standard designations (as for natural relief). From our own research experience

(Horishnyy, Aleksiuk, 2004, Horishnyj 2016, 2018, etc.), the most common processes in quarries are falls, scree formation processes, rill, sheet and gully erosion, slides, suffosion, etc. In reality, we do not see processes, but the forms created by the process: debris of falls, crown cracks, scree, deluvial and proluvial cones, subsidence sinkholes formed by suffosion, erosional pre-rills, rills, gullies, fault scarps of slides, main body of slides, etc.

The field mapping includes the designation of all (up to the smallest) forms created by the processes, which is explained by the large scale of research. These forms are characterized by morphography (shape by profile and plan, placement in relief) and morphometry (length, width, height (depth), steepness, area, volume, etc.). These characteristics are the basis for dividing forms by size, which can be reflected in the legend of the map. The activity and intensity of processes (for example, the activity of quarry walls, the intensity of surface runoff) can also be indicated on the maps.

The location of quarries. The seven large quarries' forms are located within the city of Lviv and its suburbs. Other quarries have smaller area or are very modified, also many of which have disappeared as a result of human activity (heaped, planned, built up).

There are three big quarries located directly in the city (on the Lysohirska upland), two of them – within the Znesinnia Regional Landscape Park (RLP) and one – in Kryvchytsia locality (Horishnyy, 2010). These quarries have been inactive for over 40 years.

The general characteristics of quarries. The western and eastern quarries are located in the central part of Znesinnia RLP to the east of Mytropolyt Lypkivskyi street. *The Western Quarry* is 530 m long, 260 m wide, with a complex elongated shape with benches 10–15 m high. The quarry's pit floor consists of three parts, almost separated from each other. The lowest (northern) part of the quarry is partially watered, gradually moving to the planned section of dump.

The Eastern Quarry in Znesinnia RLP is 510 m long, 330 m wide, with a complex isometric form. The pit floor is complicated by the two anthropogenic buttes, which often divide it into two parts: northeast and southwest. The height of benches reaches 15–27 m, which is the highest score within Lviv quarries. Both quarries are located on the slopes, occupying the northern slopes of Lysohirska upland, and therefore the height of benches usually decreases to the north.

The Kryvchytsia Quarry is located approximately 1.5 km east of the quarries in Znesinnia RLP, bounded on the south and east by the railway line. This quarry is the most modified and cultivated. Its length is 400 m, width 220 m, depth 10–20 m. The pit floor is divided by a heap into two parts: the western (larger) and the eastern (smaller). This is the only one of the explored quarries in which marls are cropped out, due to its low hypsometric position.

Davydivskyi Quarry № 1 (the quarry of LLC "Lvivske") is located southeast of the Kiltseva Road, approximately 500 m east of the intersection of Kiltseva Road and motorway leading to Bibrka city. The quarry has a complex shape by plan and is elongated from northwest to southeast. The quarry walls are up to 30 m high. The dimensions of quarry are the next: length 540 m, width 300 m.

The geological structure of the quarry walls is the following: loess-like loams lay down on a top, with a capacity of up to 3 m, limestones and sandstones lay down below in several beds with the sand between them (capacity is up to 20 m).

The pit floor has numerous old inner dumps, as well as young, newly created, which are composed of fragments of limestone and sandy-loam deposits. In the south, dumps are heaped up on the quarry wall. The height of the dumps reaches up to 3–7 m. The dumps are usually in the form of separate hills or their combinations. The pit floor is partially covered with woody vegetation. The steepness of dump slope is 21–22º, the shape is concave. There are complex terraced heaps with separate downgrades up to 10–12 m in height. To the east is the old flat dump. The crown cracks are widespread. The quarry has at least 30 years of continuous operation. During this time, its development was mainly in the eastern direction.

The Davydivskyi Quarry № 2 (the Northwest quarry in Davydiv village). In the profile, the geological structure of quarry is similar to the above mentioned Davydivskyi Quarry № 1: the lower bed is composed of fine-grained sands, the middle – by sandstone, and the upper – by loess-like loams.

The length of quarry is about 600 m, the maximum width is 500 m, the height of the walls is 15–25 m.

The pit floor is uneven, with separate heaped hills. It is completely covered with vegetation, except of the road leading to the quarry. The northwestern part of pit floor is surrounded on both sides by walls of east and south exposition. The pit floor is relatively flat with differences in heights of 1–2 m and is covered with thick, high grassy vegetation. There are fragments of limestone at the pit floor. The quarry wall of the eastern exposition is partially covered with vegetation. It is composed on the top of loess-like loams. There are processes of sheet, rill and gully erosion and partially the scree formation processes. Its height is 12–15 m. The wall of southern exposition is almost completely covered with vegetation and has a height of up to 8 m. The upper part is built with an external sheating dump about 4 m high.

The quarry has not been active for about 10 years. At the pit floor of quarry and on its western walls, new dumps (a total of 5) have been created, which are filled by deposits of the overburden stratum from the neighboring Davydivskyi Quarry № 3.

The Davydivskyi Quarry № 3 is located at a distance of 1.5 km to the northeast of the Lviv – Bibrka motorway. The quarry form by plan is a polygon. It has the following morphometric characteristics: length 500 m, width 350–400, depth 20 m.

The sediments are dominated by loess-like loams of light brown and fawn color (Pleistocene), light gray sands (thickness – 18 m; cross-bedding; horizontal irregularities) and limestones (Miocene).

The lowest part of pit floor is flat, with a slight decrease to the middle. There are small pre-rills. Also, there is an elevation decrease of the pit floor to the north, as well as from east to west. The inner dumps of loams of conical form up to 5–6 m in height are available.

The southern wall (bench) of quarry is concave.

The bench surface of the overburden strata (the western part of quarry) is 5–7 m wide (gradually decreasing towards the south). Height is 4–5 m. It is composed of loam. The sands bed has a visible incline toward the south. The bench of overburden strata of the northern wall is composed of loess-like loams of light brown color. The overall height is 5 m. The horizontal bedding is clearly visible in the middle part of the bench. The external sheating dumps, which are located above the surface of bench, have a shape of elongated embankments. Approximate length 50 m, height 4 m, width

6 m. The external sheating dumps, behind the east wall, have a shape of elongated embankments, up to 5–7 m in height. They are covered with vegetation.

The last explored quarry is near Vynnychky village. *The Vynnychky Quarry* has a big size. Its length is 570 m, its width is approximately 200–300 m without clear boundaries in the northeast. It is located at the top part of bench. The quarry extends parallel to the North-Podilskyi bench from northwest to southeast. In the northwestern part of the quarry, the pit floor is planned, fully accumulative and covered with heaps. The heaps are flat, in the part adjacent to the northwest wall – in the form of heaped hills with limestone blocks (up to 1.5 m long) and sand with loam. The hills are up to 1.5 m high. The walls are up to 15–20 m high, to the south-east it increases up to 25 m. The lower part of the slope (approximately 2/3) is composed of scree and deluvial material and individual limestone blocks. On the highest wall of the quarry, beneath the modern soil, lies more or less powerful strata of loess-like loams. At the top of the wall there are beds of low capacity (3–4 m), then (probably) under the sands there quite thick bed of limestone (about 7–8 m). They are separated by sand.

The pit floor at its lowest part has a flat shape, composed of small material, partially covered with water and has a takyr surface. The maximum wall height is up to 30 m. Sandstones and limestones are visibly layered.

The old pit floor is located to the southeast, which operation ended in 2012. This part of the pit floor is separated by a wall from the previous part, which we described. The pit floor length is up to 320 m, width 150 – 200 m. The highest wall of the quarry is in the northern part of pit floor. This part of quarry is being exploited. The height of the wall is up to 30 m. The clay and loam with clear layers of iron and buried soils lie on top (beneath the soil). The limestone bed (up to 1.5 m) lies below. Down to the pit floor of quarry lies a thick sand bed (20 m). The sands are layered, fine-grained, mostly white, yellowish at the lower part of exposure of rocks.

In the extreme southeastern part of quarry, the height of walls is greatly reduced and ranges from 7–8 to 12 m. The walls are concave and partially covered with vegetation. The lower part of walls is accumulative, composed of scree and deluvial material. The pit floor is mostly hilly, composed of separate small heaped hills with fragments of limestone. They are up to 1.5–2 m in height. There is also a separate heap, located at the pit floor, composed of material taken from the active part of quarry. The height of heap walls is 40º or more.

At present, the exploitation of quarry has been stopped.

The modern morphodynamics. The processes of water erosion (sheet, rill and gully erosion), suffosion, falls, scree formation processes, slides, physical and chemical weathering are widespread in the explored quarries. The specific azonal processes such as aeolian processes (deflation and accumulation of sandy material) and formation of takyrs are also common.

The water erosion processes are represented by sheet, rill and gully erosion. The water erosion processes in the quarries of Znesinnia RLP are currently not widely spread. Over the past 30 years, the intensity of erosion processes has decreased significantly. In the early 1990s, most of the walls in the upper parts were cropped out, especially in the Western Quarry. The field studies conducted in 2019 showed that there were few sites left (quarry walls and slopes of anthropogenic hills are almost completely covered with vegetation). One of them is located in the Eastern Quarry on the slope of western (southwest) exposition about 8 m long in the crown part of slope.

This is the area where the processes of sheet erosion and insignificant scree formation processes are being developed. Further to the south, at the junction of the slope of anthropogenic hill and the quarry bench, a small gully developed with an active erosion at its top. The meandering gully form by plan provoked the formation of a small slide. The anthropogenic digression by recreants also causes a sheet erosion, although there are measures to limit it.

A similar situation with erosion monitoring processes is in *the Kryvchytskyi Quarry*. These processs have almost completely disappeared in the last 15 years. In the mid-2000s, erosive pre-rills were observed on the walls in the southern and southeastern parts of quarry on the steep slopes (36–44°).

In the *Davydivskyi Quarry № 1*, erosion processes occur on the denudation (excavated) and accumulative slopes. On the quarry walls (southwest, west and north walls), erosive pre-rills are common, which in general have the following dimensions: width 2–7 cm, depth 2–10 cm.

Much more intensive are the erosion processes on the dumps, which are located at the pit floor and on the lodged dump against the wall in the eastern part of quarry. The erosion on the bench of overburden strata is also being intensively developed. Width of erosion forms is up to 9–15 cm, depth 15–17 cm. The largest erosion forms in this quarry are recorded on the slopes of a small dump at the pit floor. Despite the poor vegetation, single erosive pre-rills here reached depths of 50 cm and widths up to 35 cm. The pre-rills are characterized by different length and meandering.

The erosion processes are almost absent on the east and northeast walls.

According to the field studies in 2019, the development of erosion processes (along with other exogenous processes) is in the southern part of quarry in the upper parts of slopes, on benches of the overburden strata, and on the surface of berms, which are covered by loamy deposits. This is where erosion processes occur with the meandering of water flow in the heaped sediments. On the wall of the north-eastern exposition, the results of passage of a broad stream of loamy masses on the sandy slope are clearly visible.

The Davydivskyi Quarry № 2 was characterized in the past by the intense development of rill erosion, small gully erosion, which occurred in the dumps' sandy-loam deposits with the low density and in the lower accumulative parts of walls, covered by the deluvial cone.

In the northeastern part of quarry, the slopes of dump are dissected by numerous small erosive pre-rills that form, at the base, deluvial cones (photo). This is an example of the joint action of both rill and sheet erosion. One of the erosion forms on this dump has the following parameters: maximum width 30–40 cm, depth 40–50 cm. The shape of erosion rill by plan is meandering, by profile – V-shaped, and it actively crashes into the underlying rocks. The steepness of slope on which it occurs is 31º.

The density of erosive pre-rills in this quarry is different. On the slopes of older dumps that are partially covered with vegetation, there are erosion rills with a depth of up to 2 m. There are hollows of waterfall type up to 3 m deep in the rills.

The erosive pre-rills are present even in the place where scree formation processes are dominant - on scree cones (up to 7 cm deep and up to 70 cm long). The dominance of rills and gully erosion processes on the northern exposition wall is explained by its not coverage with vegetation and steepness of 33–35 °. The rills are 9 cm deep and 5–6 cm wide and up to 10 m long.

On the slope of dump of the southwestern exposition there is a small gully in the heaped sediments. Its length is 15–20 m. It has a stepped longitudinal profile and flat pit floor. The upper part has considerable steepness, sometimes reaching an upright position. Width is 40–60 cm (maximum 90 cm), depth 70 cm. On the slope of gully, we can see the stratification of heaped sediments, which are represented by sand (Fig. 1).

Currently, the quarry is not functioning and is almost completely covered with vegetation. The active processes occur only on the slopes of new, different level dumps located in the western part of quarry (at the pit floor, on the walls and close to the quarry). The system of relatively parallel erosion pre-rills is located in the upper and lower parts of the dump. Their morphometric characteristics fluctuate in the following ranges: width 4–14 cm, depth 10–22 cm. The pre-rills are connected and diverged. The angle of inclination of the dump slope is 37º.

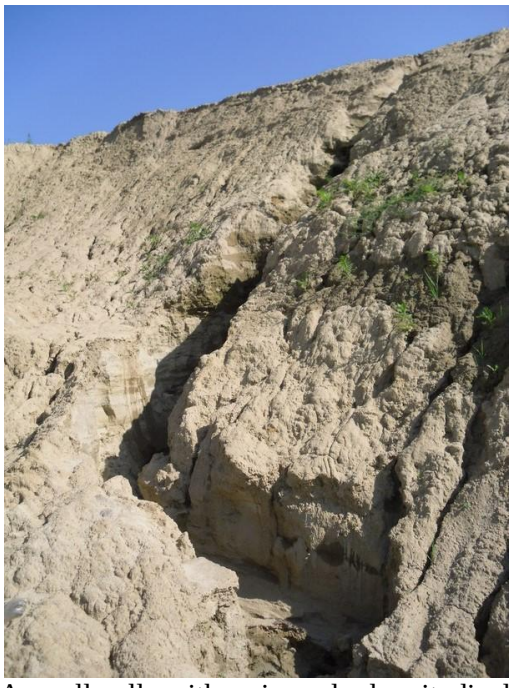

Fig. 1. A small gully with an irregular longitudinal profile
(the Davydivskyi Quarry № 2)

In *the Davydivskyi Quarry № 3*, the sheet, rill and gully erosion processes are being actively developed. They are common on the benches in the eastern and southern parts, on the benches of overburden strata in the western and northern parts, on the slopes of dumps and on the surface of berm, which coincides with the bed of sandy deposits. Also, small pre-rills are visible in the lower part of pit floor.

The benches are completely or partially covered by deluvial and scree deposits, sometimes they are heaped. An example of the intensive development of erosion processes is the south excavated-heaped quarry wall, which has a concave shape. There is a dense network of smaller and larger pre-rills on the deluvial-scree slope (Fig. 2). There are also rills and gullies that sometimes occupy the whole slope.

On the berm surface, in the sandy deposits, there is a small gully with lateral branches (Fig. 3). His mouth goes to the quarry wall. It extends in parallel to the bench. The length of main gully is 15 m, the depth is 2 m. The upper wall is upright, the lower one is a scree (corresponds to the angle of free fall). The width between the crowns is 2–3 m. The gully narrows to the top. The activity of process is explained by the lack of a protective effect of vegetation.

The water erosion processes also develop in the inactive *Vynnychkivskyi Quarry*. In the middle and lower part of its highest wall, rill and gully processes are common. The same water-erosion processes are common at the pit floor and are developed in sandy-loam deposits. The 5 erosive pre-rills and one small gully in the northwestern part of quarry are surveyed. On the slope of dump near the crown of bench is a well-defined erosive pre-rill № 1. Its width is 12–70 cm, depth 30–55 cm.

Fig. 2. Pre-rill erosion (the Davydivskyi Quarry № 3)

Fig. 3. A small gully in sand deposits (the Davydivskyi Quarry № 3)

The next two pre-rills (№ 2 and № 3) extend in parallel to each other. The erosive pre-rill № 2 has a width of 17–25 cm, depth 20–25 cm. The depth of pre-rill increases to the top of slope. The longitudinal profile is stepped, the form of cross section is gutter-like. Closer to the bench is a slightly larger erosion form № 3, which has a width at the mouth of 80 cm. It is flat and trapezoidal. The bottom width is 55 cm, depth 55 cm. There are irregularities in the longitudinal profile.

The erosive pre-rill № 4 is located on the denudation-accumulative slope, 20–22 cm wide, and 65 cm deep. Parallel to it are other erosive pre-rills that are connected with each other.

The gully is located on the dump slope of southern exposition. Its debris cone is composed mainly of coarse sediments (up to 35 cm in diameter), as well as loam and

sand (Fig. 4). The width of the cone is 2.5 m, the length is 3.3 m. The shape of the cross profile is V-shaped, the longitudinal profile is unevenly stepped. The sides of gully are not covered with vegetation. The average width of pit floor at the lower part is 52 cm, the depth of gully is 1–2.2 m. The width of pit floor at the upper part is 70–75 cm, and the depth reaches 3 m. The upper part changes the direction of extension. There are differences in heights in the pit floor. The erosive pre-rills are located on the left side of gully. The angle of incidence of the sides is more than 50º. There is a change in the direction of extension of the stream bed from 220º to 250º.

Fig. 4. The lower part of gully and the debris cone on the slope of dump (the Vynnychkivskyi Quarry)

The erosive pre-rill № 5 is located 6 m to the left of the gully. The width of it in the lower part is 40–50 cm, the depth 35–45 cm. The width of pre-rill in the middle part is 25 cm, depth 35 cm. The acacia 5–6 m high grew in the upper part of gully. The approximate age of the tree is 10 years. Above the acacia is the bench in the pit floor.

In most of the explored quarries, a clear deluvial cone is observed at the foot of the board, which indicates the intensity of sheet erosion processes and puts them in the same row with other nature-anthropogenic processes. Often, the sheet erosion processes operate simultaneously with the scree processes. Deluvial and scree deposits are mixed.

Suffosion develops in the dumps composed of sandy-loam deposits with the low density (Davydivskyi № 2, Vynnychkivskyi Quarry). The result of this process is the formation of suffosion sinkholes and “wells”. In the Vynnychkivskyi Quarry, they are

represented by circular sinkholes (Fig. 5). One of the forms has a shape with diameter of 35 cm, the other has a size of 60 × 50 cm. The depth of both sinkholes ranges within 30 cm. The suffosion sinkholes and "wells" in the Davydivskyi Quarry, located at the

Fig. 5. Suffosion forms in heaped deposits (the Vynnychkivskyi Quarry)

Fig. 6. Linear erosion with the formation of subsidence suffosion forms 2 – 3 m deep (the Davydivskyi Quarry № 2

foot of dumps in loamy deposits, are explored in the mid-2000s. The suffosion processes develop in conjunction with rill and gully erosion processes (Fig. 6).

The gravitational processes in the study area are represented by falls, scree formation processes and slides. Falls processes are locally widespread on steep denudational benches of quarries, where beds of limestone or sandstone are cropped out (Davydivskyi Quarry № 1, 3). More common among gravitational processes are scree formation processes, which mainly occur in sandy deposits and are represented by scree cones. Slides occur rarely having small main bodies and are located on the quarry walls and dump slopes.

Falls and scree formation processes. Minor scree formation processes occur in *the Eastern Quarry Znesinnia* in the loamy deposits of crown part of the western exposition bench.

Falls and scree formation processes are common in *the Davydivskyi Quarry № 1*. In the quarry, there are two sandstone beds located at different hypsometric levels. The blocks of sandstone, losing resistance, come off, sliding down. Under the sandstone bed lies sand, which is periodically subject to scree formation processes. Falls are

monitored in the upper part of slope, where the bed of sandstones is located. Nowadays, falls are less common.

Scree formation processes are well tracked on the southwestern wall of quarry (Fig. 7). The intensity of these processes on the working wall is probably increased after the excavation of sand. A formed vertical wall begins to crumble rapidly (fine-grained, layered, light gray sands). This is also facilitated by aeolian processes (Fig. 8). There are scree cones of different sizes. The scree cones are up to 8 m wide and up to 3–5 m high. The rock usually shattered from the top of wall.

Fig. 7. Scree formation and water-erosion processes
in the Davydivskyi Quarry № 1

The scree formation processes are spread further to the west, beyond the active wall. Here, scree cones are composed of fragments of sandstone and sands. These slopes are partially forested.

During the exploitation of *Davydivskyi Quarry № 2* (until 2008), the falls and scree formation processes actively occurred in the sands and sandstones. The cemented sand blocks with the sizes of 1.5 × 1.5 m are very interesting.

At present, the scree formation processes occur only on the slopes of new dumps in the western and central parts of quarry. The mixed deposits are transported on the two dumps by freight vehicles from neighboring quarries and in the dry state they roll down the slope. Sediments are formed by modern soil, loam, sand, construction waste (fragments of concrete and bricks of various sizes, etc.). The angle of incidence is 36°. The coarse sediments accumulate at the foot of slope. Thus they fill the quarry up.

The most active gravitational processes (mainly scree formation) occur in *the Davydivskyi Quarry № 3*. The sandy (sandy-loamy) deposits and coarse sediments (limestone fragments) are crumbled. The landslides in sands occur mainly on the extraction benches of southern exposition as well as on the inactive bench of eastern exposition.

Fig. 8. The combination of scree formation and aeolian processes (the Davydivskyi Quarry № 1)

The coarse sediments crumble and partially collapse on the wall of western exposition in the eastern part of quarry. Above the sands lies a bed of limestone, which due to mining operations, processes of water erosion and weathering, breaks away from the main mass of rocks and rolls down the slope, forming at the foot scree cones with coarse sediments. Scree formation also occurs on the southern wall (mainly loamy deposits of the overburden strata). The mixed deluvial-scree cones are formed there (Fig. 9).

Slides. In *the Eastern Quarry Znesinnia*, near the top of gully, is a small slide in loess sediments.

In *the Davydivskyi Quarry № 1*, slide processes vary in size and intensity. In the eastern part of quarry, we observe a fault scarp, where slide processes occur, reaching a width of 60 m and a height of up to 35 m.

On the southwestern wall of quarry, which today is covered with vegetation, there are old sites of slides, resulting in the following shapes: at the top – slide cirques, at the bottom – clusters of main bodies. Numerous cracks on the dump surface are observed in the deposits of overburden strata, which can lead to slides.

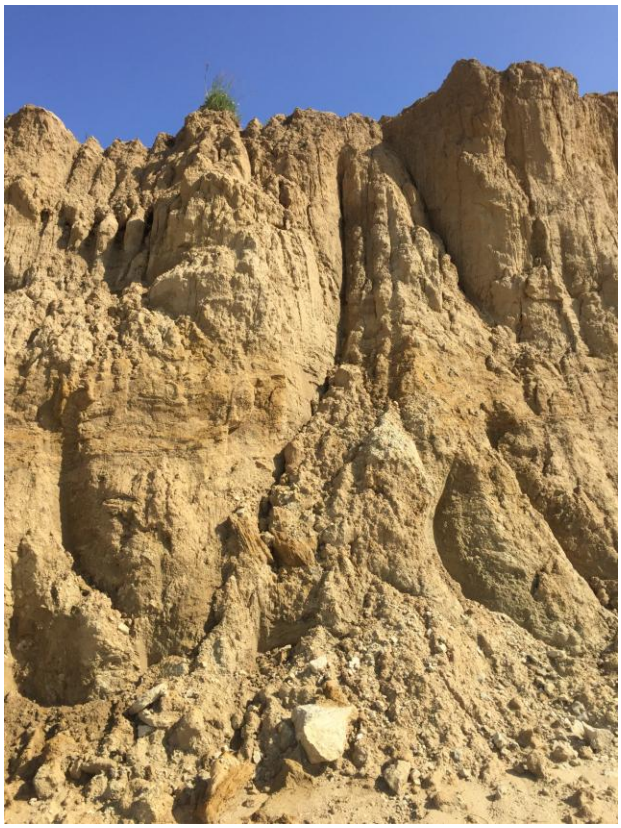

Fig. 9. Scree formation processes in the Davydivskyi Quarry № 3

The Davydivskyi Quarry № 2 was characterized by many main bodies of slides (mostly small size) during its operation. At present (2019) slides are possible only on the slopes of young dumps in the western part of quarry. The long cracks extend along the crown on the dump surface, which can cause slides.

The largest number of modern slides among all the explored quarries is in *the Davydivskyi Quarry № 3*. The slides are mostly recorded in the southeast of quarry, to the west and east of the road which leads to its pit floor. The small blocks with vegetation on very steep (over 50 °) excavated slopes move down. The slide processes work together with the processes of scree formation and water erosion.

The slides' fault scarps of arched form are observed on the wall of southeastern exposition of *the Vynnychkivskyi Quarry* (mostly heaped) (Fig. 10). Above the crown, on the surface there are crown cracks, which fix the initial stage of slide processes. The height of fault scarp is 5–6 m. The capacity of individual blocks is up to 1.8 m. In the eastern part of quarry, there is a small slide on the wall of the northwestern exposition. Its length is 5 m, width 1.5 m.

Weathering in the explored quarries occurs mainly in bedrock (sandstones, limestones, marls), and partly in loess-like loams. It leads to cracking, peeling (like desquamation in desert areas), splitting into separate blocks. This process mainly

Fig. 10. Slides in heaped deposits of the Vynnychkivskyi Quarry

occurs in sandstone and limestone as a result of anthropogenic denudation and gravitational processes (in Kryvchytskyi Quarry – in marls). The limestone blocks are also subjected to chemical weathering. In general, these processes do not play an important role in changing the quarry relief.

Aeolian processes are absolutely atypical for the studied region. These processes occur in quarries almost exclusively on the working benches composed of fine-grained quartz sands, which are the main mining rock (the Davydivskyi Quarries № 1, 3, partly Vynnychkivskyi Quarry) and consist of deflation (blowing), transport and accumulation of sand deposits. The accumulation of sand deposits occurs at the foot of slopes. The aeolian processes are one of the reasons for the crumbling of sand deposits. An interesting form of aeolian relief is the wind ripples that occur on the flat-wavy surface of berm (sandy deposits bed) in Davydivskyi Quarry № 3.

***Other processes*.** Interesting azonal processes are the formation of takyr surface and "desert papyrus". They are recorded in the Davydivskyi Quarry № 3 (Fig. 11) and Vynnychkivskyi Quarry. The process of "takyr formation" occurs on the closed flat watered areas of pit floors and leads to the formation of polygonal structure with a depth of cracks up to 12–15 cm after their drying and cracking. The final stage of the process is the twisting of the takyr surface into tubes (the formation of a "desert papyrus"). These processes were common in the Davydivskyi Quarry № 2 (northwest and east part of the quarry) during its exploitation.

Conclusions. The water erosion (sheet, rill and gully erosion) and gravitational (mostly scree formation) processes are the most common nature-anthropogenic

processes in the quarries of Lviv and its suburbs. Suffosion, slides, falls, aeolian processes are less common processes. The specific (extrazonal) process for this

Fig. 11. The formation of a "desert papyrus" at the pit floor of the Davydivskyi Quarry № 3

territory is the formation of "takyr surface" and "desert papyrus", which are characteristic of arid regions. The interesting forms of aeolian processes are wind ripples that occur on the surface of berm composed of sands in the Davydivskyi Quarry № 3. The geomorphological processes often coexist (for example, sheet, rill and gully erosion, slides, scree formation, deluvial and scree cones, etc.) or one process causes another (the aeolian processes are one of the causes of crumbling of the sand deposits). The most active processes are observed in the Davydivskyi Quarries № 1 and № 3. The modern processes are almost completely absent in the quarries of Lviv city.

REFERENCES

Horishnyy P., Aleksiuk A. (2004). Heomorfolohia i suchasni ekzohenni procesy Yasnyskoho karyeru. [Geomorphology and contemporary exogene processes of the Yasnyska quarry]. In *Scientific notes Ternopil State Pedagogical University. Series Geography*. *№2 (Issue 1*), 69–72 (In Ukranian).

Horishnyy P. (2010). Morfolohiya karyernykh tekhnoform (na prykladi Lvivskoi oblasti). [The morphology of quarry technoforms (on the example of Lviv region)]. In *Physical geography and geomorphology,* 1(58), 164–170 (In Ukranian).

Horishnyy P. (2016). Heomorfolohichne kartohrafuvannia karyeriv. [Geomorphological mapping of quarries]. In *Visnyk of Lviv Univ. Series Geography,* 50, 119–130 (In Ukranian).

Horishnyy P. (2016). Heomofolohichna budova Rozvadivskoho karyeru (Lvivska oblast). [Geomorphological structure of Rozvadiv quarry (Lviv region)]. In *Problems of geomorphology and paleogeography of the Ukrainian Carpathians and adjacent areas,* 1(6), 66–75 (In Ukranian).

Horishnyj P. (2018). Klasyfikatsiia relyefu karyeriv. [Classification of quarries relief]. In *Problems of geomorphology and paleogeography of the Ukrainian Carpathians and adjacent areas,* 1(8),160–170 (In Ukranian).

Horishnyj P., Pavelchuk A. (2019). Relief karieriv Serednioho Pobuzhzhia (na prykladi Sabarivskoho karieru). [Relief of the quarries of the Middle Pobuzhzhia (on the

example Sabariv quarry)]. In *Problems of geomorphology and paleogeography of the Ukrainian Carpathians and adjacent areas,* 1(9),101–116. DOI 10.30970/gpc.2019.1.2805 (In Ukranian).

Gorshkov S. P. (1982). *Ekzodinamicheskie protsessy osvoiennykh territorii.* [Exodynamic processes of developed territories]. Moscow, Nedra, 286 pp. (In Russian).

Zaytsev G. A., Rubina E. A. (1987). Geomorfologicheskoie kartografirovaniie territorii otkrytykh razrabotok. [Geomorphological mapping of the surface mining territories]. In *Geomorphological mapping for economic purposes*. Moscow, Moscow University Publ., 115–123 (In Russian).

Ivanov Ye. A. (2007). *Landshafty hirnychopromyslovykh terytorii*. [Landscapes of mining territories]. Lviv, Publishing centre of Ivan Franko National University of Lviv, 334 pp. (In Ukranian).

Ivanov Ye. A. (2017). *Pryrodno-hospodarski systemy hirnychopromyslovykh terytorii zakhodu Ukrainy: funktsionuvannia, modeliuvannia, optymizatsia.* [Natural and economic systems of mining areas in Western Ukraine: functioning, modeling, optimization]. The thesis for the degree of Doctor of Geographical Sciences, specialty 11.00.11 Kyiv, 578 pp. (In Ukranian).

Koltun O. V., Kovalchuk I. P. (2012). *Antropohenna heomorfolohia.* [Anthropogenic geomorphology]. Lviv, Publishing centre of Ivan Franko National University of Lviv, 194 pp. (In Ukranian).

Shabliy O. I. (Eds.). (2012). *Lviv: kompleksnyi atlas*. [Lviv: comlex atlas]. Kyiv, Kartography, 192 pp. (In Ukranian).

Herenchuk K. I. (Eds.). (1972). *Pryroda Lvivskoi oblasti.* [Nature of the Lviv region]. Lviv, Lviv University Publ., 156 pp. (In Ukranian).

Fedotov V. I., Fedotov S. V. (2004). Tekhnogenez i tekhnogennyi relief tsentra Russkoi ravniny. [Technogenesis and technogenic relief of centre of Russian Plain] // In *Vestnik Voronezh Univ. Series Geography and Geoecology*, 1, 99–105 (In Russian).

Firsenkova V. M. (1987). *Morfodinamika antropogennogo reliefa*. [Morphodynamic of the anthropogenic relief]. Moscow, Institute of geography of the Academy of Sciences of USSR (In Russian).

Lóránt Dávid (2008). Quarrying: an anthropogenic geomorphological approach // Acta Montanistica Slovaca Ročník 13, číslo 1, 66–74.

Lóránt Dávid (2012). *Introduction to Anthropogenic Geomorphology, Studies on Environmental and Applied Geomorphology*, Dr. Tommaso Piacentini (Ed.), ISBN: 978-953-51-0361-5, InTech

Mossa J., and James L.A. (2013). Impacts of Mining on Geomorphic Systems. John F. Shroder (ed.) In *Treatise on Geomorphology*, 13, 74–95. San Diego: Academic Press.

Sandu Boengiu, Oana Ionuş, Emil Marinescu (2016). Man-made changes of the relief due to the mining activities within Husnicioara open pit (Mehedinți County, Romania). In *Procedia Environmental Sciences*, 32, 256–263.

Thornbush M. J., Allen C. D. (Eds.). (2018). *Urban geomorphology: Landforms and Processes in Cities*. Amsterdam, Elsevier. ISBN: 978-0-12-811951-8