# An Overview of Sustainable Mining Practices for Ecological Rehabilitation of Degraded Lands in the Rovinari Mining Basin (Romania). Case Study: North Peșteana Interior Dump

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*Abstract*

*Open-pit mining, regardless of the nature of deposit and the exploitation type (continuous or discontinuous), produces long-term negative effects on the environment. The immediately visible effects are related to the changes in the morphological configuration and the landscape: the disappearance of the plant cover and topsoil on the entire surface of the mining perimeter, the development of deep open-pits, the appearance of waste dumps, the construction of premises and technological roads, etc. The uncovering of a deposit is carried out by removing the vegetation and excavating the soil, followed by the excavation of the sterile material from the deposit's roof, and is a destructive action with consequences for the local habitat and fauna on long term and sometimes, unfortunately, the effects can be hardly reversible or even irreversible. The environmental component that suffers the most as a result of mining is the soil and with it the entire ecosystem in the area. Soil is a resource that is very difficult to regenerate. Natural soil formation takes a long time, tens and hundreds of years. Therefore, it is important to find and apply solutions to maintain or improve its quality whenever possible or to support the pedogenesis process by applying sustainable practices in order to accelerate it. Some of these practices can be applied even during mining activities. The purpose of this research is to find and recommend the best solutions that can be applied in different stages of the lifecycle of a mine and which, applied together, have a synergistic role and a remarkable effect on the pedogenesis process and on its duration. That is why it is very important to design the mining activity from opening to closing, taking into account the decommissioning of buildings, the rehabilitation and revegetation of degraded lands for the subsequent inclusion in the landscape and the resumption of its functions.*

**Keywords:** *degraded lands, sustainable mining, sustainable practices, anthropogenic soil, pedogenesis, industrial ecology*

## 1. Introduction

The high level of resource consumption and its continuous growth is amplified by the demographic explosion produced since the middle of the 21st century, registering a tripling of the number of inhabitants of the planet (Wilmoth et al., 2022; Haiwen, 2019). Today, more than 8 billion people live and this number is expected to reach 9 billion by the year 2040. With the demographic explosion and the intensification of industrial processes, the negative impact on the environment has been amplified. As long as only economic development is pursued, without considering the impact on the environment and society, unintended consequences may arise, many of which are irreversible. The intense exploitation of non-renewable resources accentuates the tendency of their exhaustion.

Topsoil (or vegetal soil) is an extremely valuable resource having an essential role in supporting life. The quality and quantity of the soil is affected by human actions carried out day by day, and even more by mining operations.

Instead of natural topsoils, in the mining perimeters and on the related aste dumps, very diverse lithological materials are encountered from a physical, chemical and especially pedological point of view, materials that constitute anthropogenic protosoils. These types of soils lack the essential feature specific to an evolved soil: fertility (Howard, 2017; Zanella et al., 2018; Schaetzl and Anderson, 2005).

Anthropogenic protosoils called anthrisoils are formed on the waste dumps related to the open-pit mining and fall into the class (IX) of undeveloped soils according to (Florea and Munteanu, 2012).

The fact that this resource is difficult to regenerate and that these actions cannot be prevented or removed, requires the finding of appropriate management and exploitation solutions in harmony with the environment. The purpose of the work is to look for sustainable solutions that can be applied from the first stages of the life cycle of a mine and which can ensure the maintenance of soil quality or support the acceleration of the pedogenesis process on waste dumps, but also the quality of the environment in general.

According to the definition of sustainable development, mining activity, which represents the engine of a society's

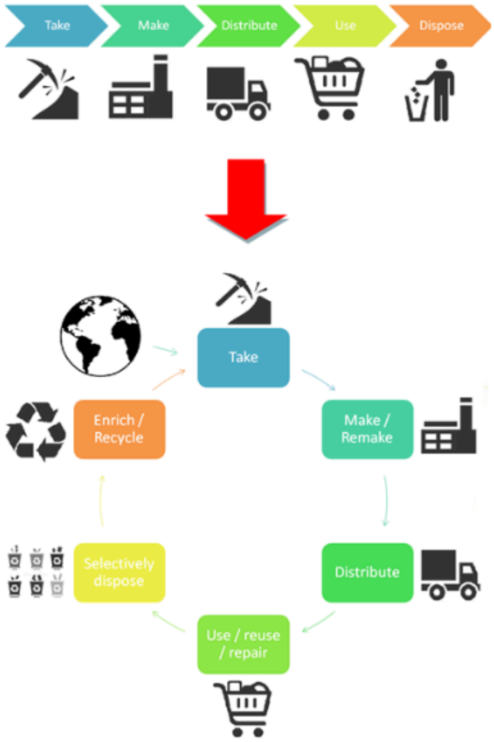


Fig. 1. Linear economy model versus circular economy model
Rys. 1. Model gospodarki liniowej a model gospodarki o obiegu zamkniętym

development, is not a sustainable activity, which is why it is necessary to extrapolate this concept. There is no definition of sustainability that is universally adopted by the mining industry. There are many discussions on this topic, but there are difficulties in applying sustainable development strategies in the mining context, the reasons cited being the multitude of interpretations of this concept of sustainable development.

Applying sustainable practices in the mining industry may sound like an oxymoron. Although the two terms are seemingly incompatible, as long as we do not put an end to the consumption of resources, mining will never end. Sustainable development in the mining sector means that such projects must be financially profitable, technically appropriate, environmentally reasonable and socially responsible (Melan, 2021; Aznar-Sánchez et al., 2019, Hebda 2023). Thus, the best way for the mining industry to coexist with the environment for the purpose of a sustainable development of society from all points of view, is to establish and implement the best sustainable practices applied in conditions of maximum safety and which focus on obtaining favorable results from the point of view of the economy, the environment and the community (Hilson and Murck, 2000; Lazăr, 2010; Miranda et al., 2005; Bastida and Aguado, 2008). At the same time, mining must be in harmony with community expectations, which recognize that the business has a shared responsibility with government and wider society to help facilitate the development of strong and sustainable communities (UNDP, 2018).

The need to redefine the concept of "sustainable development" so as to include the mining industry is even bigger since it is clear to us that ceasing any mining activity is not a feasible choice, given that humanity has and will continue to need mineral raw materials.

Some solutions can be identified by exploring more carefully the concept of industrial ecology, which is relatively recent but still developing. It involves multidisciplinary research combining aspects of engineering, economics, sociology, toxicology, and natural sciences and aims to quantify and document the flow of matter and industrial processes in modern society, focusing on the impact of industrial activities on the environment, taking into account the use and exploitation of natural resources, manufacturing and processing and, crucially, issues involving the storage and/or disposal of waste (Bruel et al., 2018; Cecchin et al., 2020; Walker et el., 2021).

Industrial ecology seeks to understand how industrial activities interact with natural ecosystems. In this context, the idea is promoted that natural systems never leave waste, thus inspiring a sustainable model, where "nothing is lost, nothing is created, everything is transformed" – Antoine Lavoisier.

Industrial ecology looks over the transition from a linear industrial and consumption process (extraction, manufacture, consumption, waste) to a circular one (extraction, manufacture, consumption, recycling or reuse – the concept of circular economy; fig. 1) system in which waste can become resources for new processes, thus minimizing the extraction and consumption of resources. Therefore, the concept of industrial ecology is closely related to that of circular economy (Pont et al., 2019; Sariatli, 2017; Brian, 2004)

Integrating into the process of sustainable industrial development of the main objective of industrial ecology (establishing sustainable practices and responsible methodologies), can lead to an increased level of sustainability of the mining activities.

## 2. Sustainable solutions and practices in mining industry

For increased efficiency, sustainable practices must be established and applied for each stage of the mining activity. Life cycle analysis identifies those particular aspects that have

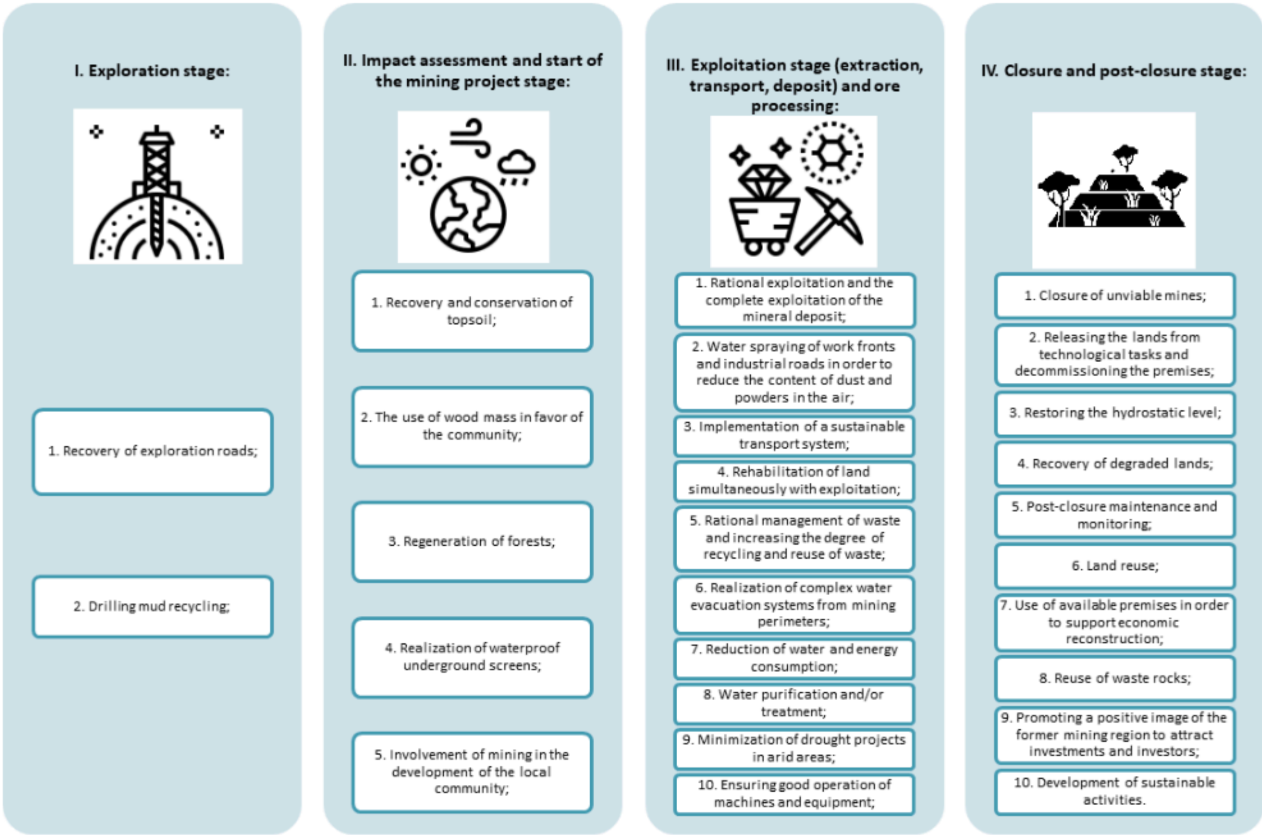


Fig. 2. Sustainable mining practices depending on the main stages of a mining project
Rys. 2. Praktyki zrównoważonego górnictwa w głównych etapach projektu górniczego

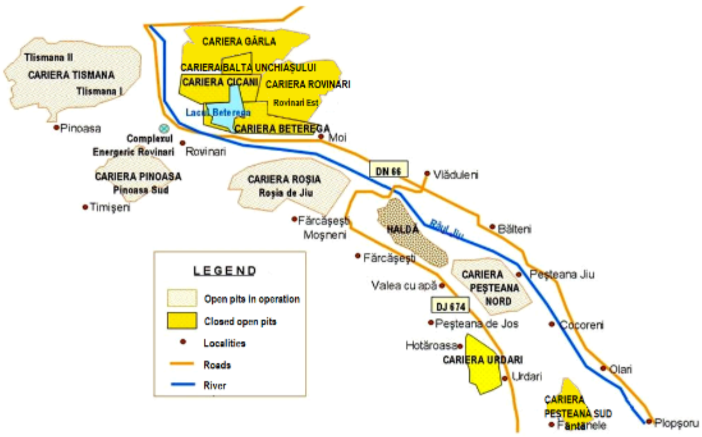


Fig. 3. Rovinari Mining Basin situation plan (***, CEO, 2019–2023)
Rys. 3. Plan sytuacyjny Zagłębia Górniczego Rovinari (***, CEO, 2019–2023)

a significant impact on the environment. Thus, the emphasis is placed on the essential aspects involving the reduction of the impact of mining on the environment in the main stages of the life cycle of a mine (Bastida, 2004).

Following the documentation and research carried out (Nyari, 2016; Fodor and Lazăr, 2006; Hilson and Murck, 2000; Lazăr, 2010; Miranda et al., 2005; Bastida and Aguado, 2008; ***, 2006; ***, 2011), several solutions and practices have been identified that can ensure a sustainable development of the mining sector depending to the main stages of a mining project (fig. 2):

In order to intensify the development of mining while improving the ecological, economic, and social sustainability of the mining sector, emphasis must be placed on the application of sustainable practices in all stages of a mining project, from exploration to closure and post-closure, practices that involve reducing the consumption of mineral resources, increasing the degree of resource conservation, recycling and reusing waste and minimizing the impact on the environment.

## 3. Mining and mining degraded lands in Rovinari Basin - Romania

The Rovinari Mining Basin is located in Gorj county (Romania), in the Rovinari town area. The component mining perimeters (fig. 3) were located on both sides of the Jiu River, in the river meadow area, but also in the hilly areas of the region.

Fig. 1. Linear economy model versus circular economy model
Rys. 1. Model gospodarki liniowej a model gospodarki o obiegu zamkniętym

| Mining perimeter | Mining perimeter surface (ha) | Waste dump surface (ha)* |
|---|---|---|
| North Peșteana | 1176.2 | ≈ 500 |
| Roșia de Jiu | 1738.8 | ≈ 800 |
| Pinoasa | 1581.4 | ≈ 1000 |
| Tismana I+II | 1712.2 | ≈ 1000 |
| **Total** | **6208.6** | **≈ 3300** |

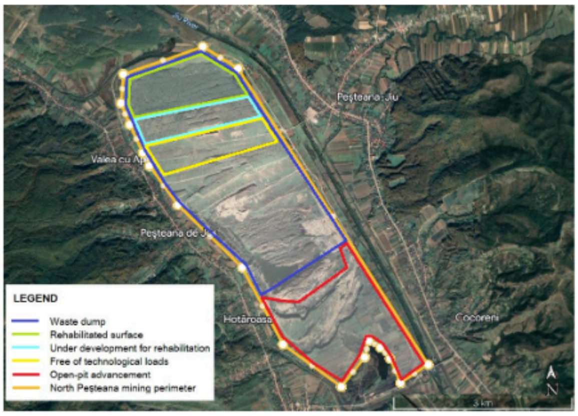


Fig. 4. North Peșteana mining perimeter (***, CEO, 2019–2023)
Rys. 4. Wyrobisko North Peșteana (***, CEO, 2019–2023)

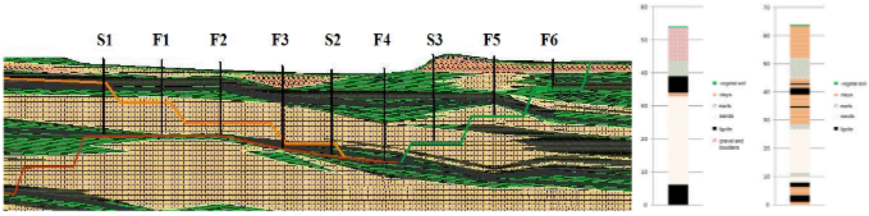


Fig. 5. Location of boreholes and sections and representation of two stratigraphic columns from the Peșteana Nord mining perimeter (Apostu, 2021)
Rys. 5. Lokalizacja otworów i przekrojów oraz przedstawienie dwóch kolumn stratygraficznych z obwodu górniczego Peșteana Nord (Apostu, 2021)

Over time, 12 opne-pits have been put into operation in the Rovinari Mining Basin. Currently, only 5 open-pits are still operational, being united in 4 open-pit mining units (U.M.C.): U.M.C. Tismana (Tismana I + II), U.M.C. Pinoasa, U.M.C. Rosia, and U.M.C. North Peșteana. The other open-pits, Cicani, Balta Unchiașului, Beterega, Urdari, Peșteana Sud, Gârla, and Rovinari Est, ceased their activity as a result of the exhaustion of reserves or the fact that exploitation was no longer technically and economically efficient. Among the closed open-pits, some are used as storage for slag and ash from the Rovinari thermal power plant, others have been returned to the forestry or productive circuit or have reintegrated into the landscape naturally.

Table 1 shows the total surfaces of the active mining perimeters in the Rovinari Mining Basin.

The area of the mining perimeter represents the total area of degraded mining lands (open-pits, dumps, access/technological roads, and other areas occupied by buildings and premises). Of the total area of the 4 active quarry mining units (6208.6 ha), approx. 50% are areas occupied by internal and external waste dumps (***, CEO, 2019–2023).

Considering the size of the Rovinari Mining Basin, but also the lithological constitution of the region, the physical, chemical, and pedological characteristics of the sterile rocks, the mining/dumping methods similar throughout the basin, it was chosen to conduct a case study on the North Peșteana mining perimeter regarding the sustainable practices that can be implemented in order to support and accelerate the pedogenesis process on the waste dumps, considering that the results obtained can be easily extrapolated at least at the level of this basin.

### *3.1 Case study: North Peșteana mining perimeter*

The opening of the North Peșteana open-pit began in 1980s and it is estimated that the exploitation of lignite in this perimeter will cease in 2024 as a result of the exhaustion of the reserve in the license perimeter (***, CEO, 2019–2023; ***, ICSITPML, 2012; ***, ME, 2016).

From an administrative point of view, the perimeter of the North Peșteana open-pit falls within Gorj county, being located within the territory of the Urdari and Bâlteni communes.

From a morphological point of view, the exploitation perimeter of the North Peșteana open-pit is located entirely in the Jiu river meadow area. The minimum altitudes are found in the eastern part of the perimeter, on the old bed of the Jiu river, where the elevation of the land has values between 132 - 136 m. On the western frame, the altitudes have values of 148–150 m. The maximum altitude is 333 m in Bran hill. (Smeu, 2012)

Currently, the excavation activity in the North Peșteana open-pit (fig. 4) is carried out in four excavation steps.

Figure 5 shows the geological profile in longitudinal section of the North Peșteana open-pit and the representative lithology in which sandy, clayey, marly rocks, gravels and boulders predominate, layers between which the exploitable

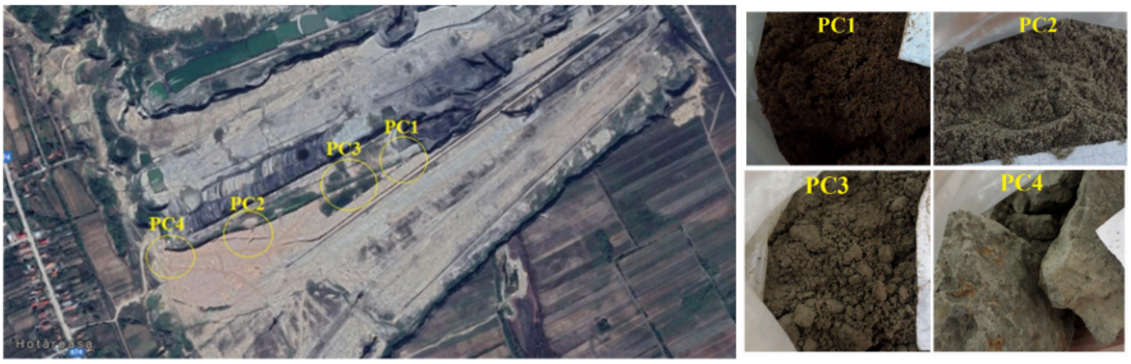


Fig. 6. Sampling points – in-situ slopes
Rys. 6. Punkty poboru próbek – uskoki in-situ


Fig. 7. Sampling points – waste dump
Rys. 7. Punkty poboru próbek – składowisko odpadów

lignite layers are intersposed.

The exploitable layers in the North Peșteana area are layers V–VIII. Excavation is done in parallel blocks, with a width of 40÷45 m. Excavation is carried out with 4 excavators with bucket-wheel excavators. The extracted material is dumped on the front lanes (conveyor belts). Their direction of operation is from west to east, with the distribution equipment located at their end, positioned to discharge either on one of the conveyors in the sterile transport circuits, or on the conveyor in the lignite transport circuit, depending on the excavated rock, respectively sterile or useful.

The sterile rocks from the North Peșteana open-pit are deposited in the internal waste dump with 2 dumping machine. The lignite is stored in the Cocoreni coal deposit located on the right bank of the Jiu River, from where it is delivered to consumers.

### *3.2 Physical, machanical and podologycal characteristics of sterile rocks*

The quality of the topsoil in the mining perimeters is negatively modified by the direct and related activities of lignite exploitation.

In the North Peșteana perimeter, as in the entire basin, the soil is selectively extracted, but it is not enough for revegetation, so it is necessary to analyze the rocks in the intercalations from the point of view of their capacity to represent, under certain conditions, soil substitutes.

To determine the values of the physical characteristics of the rocks from the slopes of the North Peșteana perimeter, 14 samples were taken, 4 samples from the in-situ slopes (PC1 ÷ PC4) and 10 samples from the internal dump (PH1 ÷ PH10) (fig. 6-7; Apostu, 2021).

The physical characteristics of the rocks, resulting from the tests, are shown in table 2 (Apostu, 2021). The rock samples taken were described based on the results as follows: PC1 – Sand (predominantly medium); PC2 – Sand (mainly fine); PC3 – Clayey dusty sand; PC4 – Sandy clay; PH1 – Sandy clay; PH2 – Dusty sand; PH3 – Sand with gravel elements; PH4 – Clay dust; PH5 – Dust; PH6 – Sand (mainly fine) with rare elements of gravel; PH7 – Sand with elements of clay and gravel; PH8 – Sand with elements of clay and gravel; PH9 – Carboniferous rock in dusty clay mass; PH10 – Sand (mainly coarse) with elements of gravel.

According to some research carried out within North Peșteana mining perimeter (Nanu, 2015), the results of the chemical and pedological analyzes carried out on sterile material from the in-situ slopes (P1), the internal dump (P2), and the external dump (P3) show that, according to (Dumitru et al., 2011), they fall into normal load classes (tab. 3) in terms of the content of heavy metals, fluorine, cyanides, phenols, sulfates and hydrocarbons. From a pedological point of view, the waste material is moist to dry (but this characteristic also depends on the weather-climatic conditions), almost totally devoid of humus, generally has a low content in macronutrients (according to DOA, 1997 and Malek et al., 2006 results in a very low N content, low to very low P and moderately to high K) and a moderately acidic pH reaction. The results indicate a reduced cation exchange capacity, the

Tab. 2. Physical characteristics of the waste rocks (Apostu, 2021)

Tab. 2. Charakterystyka fizyczna skały płonnej (Apostu, 2021)

| Sample no. | Provenance | Particle size composition, [%] | | | | INDICES OF THE NATURAL STATE | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Laboratory tests | | | Calculated | | | | Laboratory tests | | Calculated | | |
| | | Clay | Dust | Sand | Gravel | Volumetric weight, $\gamma_a$ [kN/m$^3$] | Specific weight, $\gamma_s$ [kN/m$^3$] | Natural humidity, w [%] | Porozity, n [%] | Pores index, ε | Saturation humidity, $w_{sat}$ [%] | Saturation coefficient, S | Flow limit, $W_c$ [%] | Plastic limit, $W_{pl}$ [%] | Plasticity index, $I_p$ | Consistency index, $I_c$ | Consistency index in saturated state, $I_{csat}$ |
| PH1 | interior dump | 24 | 28 | 42 | 6 | 19.52 | 26.30 | 21.68 | 39.00 | 0.64 | 24.33 | 0.89 | 36 | 16.74 | 19.26 | 0.74 | 0.61 |
| PH2 | | - | 38.5 | 61.5 | - | 20.56 | 26.67 | 23.27 | 38.38 | 0.62 | 23.27 | 1.00 | - | - | - | - | - |
| PH3 | | - | - | 91 | 9 | 20.69 | 26.67 | 22.87 | 37.99 | 0.61 | 22.87 | 1.00 | - | - | - | - | - |
| PH4 | | 20 | 43 | 27 | 10 | 20.21 | 26.26 | 22.47 | 37.17 | 0.59 | 22.47 | 1.00 | 37 | 16.23 | 20.77 | 0.70 | 0.70 |
| PH5 | | 10 | 55 | 33.5 | 1.5 | 17.77 | 25.97 | 20.58 | 43.24 | 0.76 | 29.26 | 0.89 | 44 | 22.73 | 21.27 | 1.1 | 0.67 |
| PH6 | | - | - | 99.5 | 0.5 | 15.99 | 26.64 | 5.65 | 43.19 | 0.76 | 28.53 | 0.2 | - | - | - | - | - |
| PH7 | | - | - | 73 | 27 | 17.59 | 26.72 | 15.19 | 42.85 | 0.75 | 28.07 | 0.54 | - | - | - | - | - |
| PH8 | | - | - | 78 | 22 | 18.82 | 26.48 | 18.59 | 40.07 | 0.67 | 25.30 | 0.73 | 37.8 | 22.64 | 15.16 | 1.27 | 0.82 |
| PH9 | | 41 | 52 | 7 | - | 17.40 | 26.22 | 27.97 | 48.14 | 0.93 | 35.47 | 0.79 | 53.8 | 24.71 | 28.09 | 0.89 | 0.63 |
| PH10 | | - | - | 89.5 | 10.5 | 17.71 | 26.46 | 7.24 | 37.59 | 0.6 | 22.68 | 0.32 | - | - | - | - | - |
| Average | | 23.75 | 43.3 | 60.2 | 10.8125 | 18.626 | 26.439 | 18.551 | 40.762 | 0.693 | 26.225 | 0.736 | - | - | - | - | - |
| PC1 | intercalations (in-situ slopes) | - | - | 100 | - | 16.10 | 26.61 | 7.49 | 43.71 | 0.78 | 29.31 | 0.255 | - | - | - | - | - |
| PC2 | | - | - | 100 | - | 15.72 | 26.64 | 3.65 | 43.07 | 0.76 | 28.53 | 0.13 | - | - | - | - | - |
| PC3 | | 7.5 | 27.5 | 65 | - | 19.70 | 27.11 | 23.53 | 41.17 | 0.7 | 25.82 | 0.91 | - | - | - | - | - |
| PC4 | | 33 | 17 | 50 | - | 20.03 | 26.32 | 8.44 | 29.82 | 0.42 | 15.96 | 0.53 | 47.2 | 34.95 | 12.25 | 3.16 | 2.55 |

analyzed samples being prone to acidification (which explains their moderately acidic reaction and low nutrient content).

Tab. 3. Analysis bulletin – sterile material from the North Peșteana perimeter (Nanu, 2015). P1 – in-situ slopes, P2 – interior dump, P3 – external dump

From the process of lignite exploitation through open-pit mining works, there are no emissions of heavy metals that pollute the soil or water (surface or groundwater). The waste resulting from the production process of the lignite extraction units through open-pit mining works – waste dumps – fall into the category of inert-non-hazardous waste deposits. The waste will not undergo any significant disintegration or dissolution or any other significant change that may cause an adverse effect on the environment or harm human health (***, ICSITPML, 2012).

## 4. Implementation of sustainable practices for ecological rehabilitation of degraded lands on North Peșteana interior dump

### *4.1 Mining opening stage*

In the opening stage of a mining project, numerous changes take place at the level of the local ecosystem, and some of the steps that minimize the impact on the environment and recover a valuable resource are represented by the extraction of topsoil and the regeneration of forests by recovering and planting saplings of trees and shrubs from the lands in the advance areas of the open-pit.

#### *4.1.1 Recovery and conservation of topsoil*

Soil management is an important step in the mining activity. Being essential for the development of plants, but difficult to regenerate, it is required to extract it from the lands to be discovered in order to exploit mineral resources, transport and store it in specially spaces, under optimal conditions, or extract it and deposit it immediately on degreaded lands undergoing rehabilitation.

The extraction of topsoil can be done before the discovery of the deposit or simultaneously with the discovery. The most important aspect to check is the thickness of the topsoil layer, according to which the extraction technology is established. Determining the thickness of the topsoil, in order to establish the procedure for removing it, is done manually (pits or trenches). The method of excavating the soil depends on its thickness and is carried out either with bulldozers and scrapers when the soil thickness does not exceed 1 m, or with mechanical shovel excavators or bucket-wheel excavators, when the soil thickness is greater than 1 m. Transport of the topsoil is done by road or rail means or by means of conveyor belts.

Based on the geotechnical boreholes (F1–F6; ***, ICSITPML, 2012) and the sections (S1, S2, S3; Apostu, 2021) drawn in the areas of interest, the stratigraphic columns were made (see fig. 5). The thickness of the topsoil varies between 0.4 and 0.8 m, and the determinations of the physical, chemical and pedological characteristics indicate a good quality and the opportunity to recover the topsoil from on the site studied. Based on this information, it is recommended to take into account the importance of recovering this extremely useful resource by applying the method of extracting the topsoil simultaneously with the discovery with the help of the bulldozer in independent flow (fig. 8).

Tab. 3. Analysis bulletin – sterile material from the North Peșteana perimeter (Nanu, 2015). P1 – in-situ slopes, P2 – interior dump, P3 – external dump
Tab. 3. Wyniki analiz – materiał z North Peșteana (Nanu, 2015)

| Chemical analysis | | | | | | | Pedologycal analysis | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | UM | Limit | | Determined value | | | Parameter | UM | Determined value | | | Observations |
| | | Alert | Intervention | P1 | P2 | P3 | | | P1 | P2 | P3 | |
| Total cadmium | mg/kg | 5 | 10 | 0.65 | 3.0 | 1.8 | pH | unit. pH | 5.4 | 5.6 | 5.5 | moderately acidic |
| Total lead | mg/kg | 250 | 1000 | 1.20 | 3.4 | 3.2 | Combustible parts | % | 7.1 | 7.6 | 5.6 | traces of lignite |
| Fluorine | mg/kg | 500 | 1000 | 0 | 0 | 0 | Moisture | % | 35 | 51 | 48 | wet to dry |
| Free cyanides | mg/kg | 10 | 20 | 0 | 0 | 0 | Humus | % | 0 | 0 | 2.3 | very low to total absence |
| Phenols | mg/kg | 10 | 40 | 3 | 2 | 0 | Bases of exchange | me/ 100 g | 2.62 | 5.85 | 2.87 | reduced |
| Tone | mg/kg | 5000 | 50000 | - | 0 | - | Exchange cations | me / 100 g | 2.15 | 7.21 | 3.65 | reduced |
| Polycyclic aromatic hydrocarbons | mg/kg | 25 | 150 | 2 | 0 | 0 | Total exchange capacity | me / 100 g | 4.77 | 13.06 | 6.52 | reduced |
| Petroleum hydrocarbons | mg/kg | 1000 | 2000 | 75 | 0 | 0 | assimilable N | % | 0.05 | 0.15 | 0.10 | very low |
| Copper | mg/kg | 250 | 500 | 1.10 | 8.2 | 6.5 | assimilable P | mg % | 0.8 | 1.9 | 1.2 | low to very low |
| Nickel | mg/kg | 200 | 500 | 0.35 | 2.5 | 2.1 | assimilable K | mg % | 4.5 | 6.3 | 7.2 | moderate to high |
| Zinc | mg/kg | 700 | 1500 | 8.3 | 8.6 | 9.3 | - | - | - | - | - | - |
| Manganese | mg/kg | 2000 | 4000 | 6.5 | 10.5 | 14.6 | - | - | - | - | - | - |
| Chromium | mg/kg | 300 | 600 | 0.35 | 1.40 | 1.35 | - | - | - | - | - | - |

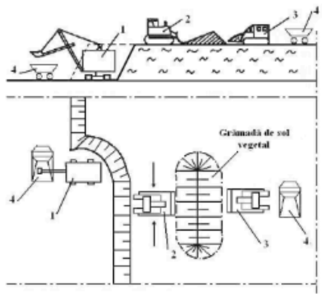


Fig. 8. Extraction of topsoil using the bulldozer in independent flow (Lazăr, 2010): 1 – mechanical shovel excavator; 2 – bulldozer; 3 – bucket loader; 4 – dumping machine
Rys. 8. Zdejmowanie wierzchniej warstwy gleby za pomocą spychacza (Lazăr, 2010)

According to (***, CEO, 2019-2023), as a result of the non-uniformity of the land and the reduced thickness of the topsoil layer, a volume of approximately 500,000 m³ of topsoil was recovered from an area of 137.34 ha.

*4.1.1 Regeneration of forests through the recovery of saplings of trees and shrubs*

The intensification of the forest regeneration process is possible by starting some projects that involve the afforestation of land areas at least equal to the deforested area for mining. The recovery of saplings of trees and shrubs and their replanting to expand the area of the forest fund by afforestation of lands without forest vegetation, which have no other assigned uses, is a sustainable and cheap solution.

Through forest regeneration activity, the aim is to ensure the integrity and permanence of forests, so as to reduce the current trend of uncontrolled deforestation, depletion of woody mass and/or loss of forests, giving them continuity in terms of production and protection functions.

Such programs existed in the entire Oltenia coal basin (of which Rovinari is also a part). Until 1989s–1990s, the mining operator proceeded to afforest equivalent (even larger) areas, through so-called compensatory afforestation actions, throughout the country (especially in the Moldova area).

***4.2 Exploitation stage***

*4.2.1 Rehabilitation of degraded land simultaneously with the continuation of exploitation*

The lignite exploitation activity must ensure the return of the productivity of the affected land as quickly as possible (Ghose, 1989; Ghose, 2005).

The rehabilitation process must start, as far as possible, immediately after the release of the areas of technological burdens, and the opening of the deposit is done progressively, on relatively small areas, enough to ensure the necessary space and allow exploitation to advance to a new front (fig. 9).

In the North Peșteana open-pit, rehabilitation works were carried out on the degraded lands as a result of the construction of the dumps, but in a small percentage. Out of a total area proposed for greening of 637.17 ha (internal dump + external dump), only 90 ha were greened (plantation establishment on the external dump located in the northern part of the perimeter), representing 14.1%. Currently, an area of 65 ha is unde development for rehabilitaion, and another of 73.5 ha is an area free of technological loads, which will also be greened (see fig. 1; ***, CEO, 2019–2023).

The main advantage is that of saving time in favor of the environment, the closure being done immediately after the end of the exploitation of a work front and its release, thus reducing the size of the degreaded land surface, the degree of pollution of environmental factors, and implicitly, the impact on the environment.


Fig. 9. Scheme for the rehabilitation of degraded land simultaneously with the continuation of exploitation (Feng et al., 2019)
Rys. 9. Schemat rekultywacji terenów zdegradowanych przy jednoczesnej kontynuacji eksploatacji (Feng et al., 2019)

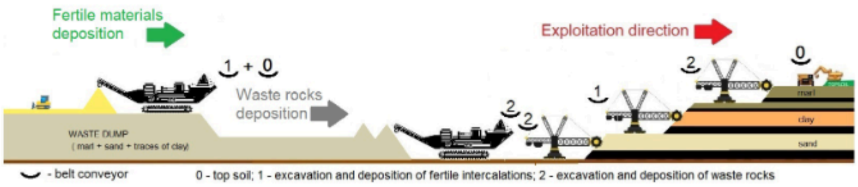


Fig. 10. Scheme of selective exploitation and directed deposition of waste rocks depending to its quality
Rys. 10. Schemat selektywnej eksploatacji i ukierunkowanego składowania skały płonnej w zależności od jej jakości

The rehabilitation of the land also involves leveling, compaction, modeling, revegetation, but also works to restore the hydrostatic level so that the effects of the dewatering are not felt on the reclaimed land surfaces nor in the areas adjacent to the mining perimeter.

*4.2.2 Reuse of sterile rocks*

In the idea of sustainable development, it is essential to increase the degree of recovery and reuse of waste. Recovery means the extraction of resources from waste that can be reused. Recovery can be done through recycling, reuse, regeneration or any other process of extracting auxiliary raw materials, through which either the material part or the energetic part can be recovered. When it no longer presents any possibility of valorization, it is necessary to dispose of the waste. This process must be done by methods that are not harmful to the environment and do not endanger human health.

*4.2.3 Directions for accelerating the restoration of the fertile potential of the lands on the waste dumps*

An increasingly studied variant is the use of waste in the pedogenesis process, inert clay and clay-sandy rocks constituting a good base of inorganic matter for the reconstitution of topsoil when it is mixed with biodegradable organic matter and enriched with nutrients necessary for plant growth and life support. Starting from this idea, it is recommended to establish technologies for the selective exploitation of sterile rock layers according to their characteristics, so that the rocks with better physical, chemical and pedological characteristics are deposited at the upper part of the slopes and berms of the final steps of the dump, and those with weaker characteristics are deposited in lower parts.

Analyzing the specialized literature (Scorţariu et al., 2011), it was identified the possibility of combining clays (identified as richer in phosphorus than Romanian soils) with sands, coal dust and coal fragments, all from the same exploitation perimeter, in certain proportions, in order to obtain anthropogenic soils with really good properties.

In Ist and IInd steps of the North Peşteana open-pit, clayey and marly rocks predominate, while in IIIrd and IVth steps sandy and clayey rocks predominate.

From a qualitative point of view, coal fragments and coal dust contain free humic acids, which can also be contained in clay rocks, especially in those from the layers immediately adjacent to the lignite layers. In general, clays with a carbon content and implicitly humic acids have a series of valuable properties: the formation of structural soil aggregates, contributing to their loosening which allows its aeration and moistening; hygroscopic retention of water due to humic acids; decomposition of humic substances (Scorţariu et al., 2011).

Depending on the clay particle size, mixtures can be made, or not, including with sandy rocks.

Quantitatively, the clays can be excavated directly from the working slopes and deposited directly on the dumps, areas free of technological load (Scorţariu et al., 2011), leveled and properly compacted, being used as anthropogenic soils on which plant species tolerant to poorer conditions or with minimal nutrient requirements will develop, subsequently enriching the anthropogenic soil with organic material, which will increase its biological diversity. In addition, it is recommended to use compost, manure and organic fertilizers to accelerate the pedogenesis process.

In the North Peșteana open-pit, lignite mining is carried out in continuous flow, using bucket wheel excavators in combination with belt conveyors and dumping machine. The large thickness of the clay layers (generally over 6 m), allows selective exploitation and its direction on lands free of technological loads, leveled and compacted. After depositing the material in deposition cones, it is pushed with the bulldozer and leveled in a layer of 20-30 cm, which is sufficient for the first stage of the pedogenesis process (fig. 10).

Thus, the selective exploitation and directed deposition of the waste rock depending its quality can support the acceleration of the pedogenesis process that begins immediately after the final storage of the waste into the dump, but which naturally requires long periods of time of the order of tens and hundreds of years (Sheoran et. al, 2010).

On anthropogenic soils in the early stages of their formation as fertile soil, in order to support the growth and development of vegetation, it is necessary to apply some amendments (chemical fertilizers, compost, sludge from water treatment plants, manure, wood waste, etc.). Subsequently, the establishment of so-called green cultures is recommended. There are a number of plants recommended as green manures, such as clover, grass, alfalfa, peas, etc. Due to their specificity, these types of crops capture atmospheric nitrogen and retain it in their body, later transferring it, through decomposition, to the soil (Davidescu and Davidescu, 1999). Among their main characteristics are: high installation speed; high degree of germination; fixing nitrogen in the soil (through symbiosis with nitrogen-fixing microorganisms); the production of a plant mass as rich as possible (high productivity); high thread density; low sensitivity; resistance to drought, to low or high temperatures, etc.; increased regeneration capacity after cutting/mowing (case of clover, alfalfa and grass); the vegetation period (of the order of months) that allows the analysis and observations necessary for the proposed research; the sowing and germination period; efficiency on soils poor in organic matter; improving and/or improving the physico-chemical properties of the soil.

**5. Final conclusions and recommendations**

Lignite represented for a long period of time one of the major sources for the production of energy, so in Romania, as in the whole world, this resource was exploited on a large scale, especially through open mining. The mining of lignite meant and still means the occupation and degradation of large areas of land, which are removed from the natural and/or economic circuit. Closing a quarry involves freeing the working fronts from technological tasks, decommissioning the premises, if they cannot be used for another purpose or if they present insecurity from the point of view of the structure's stability, the rehabilitation of the affected lands, their improvement and revegetation.

In order to facilitate the development and rehabilitation of degraded lands, it is very important that the mining project is planned from the beginning, taking into account the protection of the environment at each stage of its life cycle.

The impact produced by lignite exploitation activities on the soil refers to disturbing the physical-chemical and pedological balance of the geological environment, with significant, unavoidable and irreversible effects, the destruction of the soil on the land surfaces from which it cannot be recovered for various reasons, the degradation of the soils and the decrease of their fertility class on large areas, by changing the initial destination of the agricultural or forestry lands and the organization of exploitation-related activities. This impact can be limited in time and space, but it generates changes and imbalances of all environmental components for a period of several decades, which corresponds to the life cycle of a mining operation (exploration, exploitation, closure and post-closure). What remains behind is a degraded land, morphologically modified, with a lunar aspect and completely devoid of productive function.

The soil is the environmental component that suffers a lot, being affected both qualitatively and quantitatively. Knowing the importance of topsoil as a resource in developing ecosystems and sustaining productivity and life on earth, it is easy to understand why efforts are being made to find solutions for its conservation and correct management or to support the pedogenesis process in the case of lands degraded by various anthropogenic activities.

In order to minimize the impact of mining on the land and, implicitly, on the soil, several solutions and sustainable mining practices were proposed in the paper (considering in particular techniques of selective excavation and directing the sterile material with fertile potential in the upper part of the dumps), which can be applied from the start of the mining works and actual exploitation, practices that support the acceleration of the pedogenesis process and ensure the integration of the degraded land into the landscape and taking over the ecological function it's as early as possible. Due to the similar characteristics of the rocks within the Rovinari mining basin (physical, chemical, pedological characteristics), the research results can be extrapolated, the proposed sustainable practices being valid for the entire basin (with possible adjustments, if necessary) or for other similar mining perimeters.

In the context of sustainable development, the closure of a mining activity does not mean the socio-economic collapse of the affected area, but an opportunity for the development of other businesses. The new activities must have the capacity to ensure: the protection of the environment, the protection of the community and the socio-economic development of the area. Such an activity must fulfill at least two functions: the ecological function and the productive function, aiming to achieve results beyond expectations.

After the recovery of degraded lands, they can be subject to a program to promote the area, depending on the natural, cultural, traditional, touristic objectives that characterize them, so as to attract investors willing to contribute to the socio-economic and ecological reconstruction of the affected localities, in order to develop their own businesses and transform these areas into development poles, by providing jobs that bring benefits to the local communities, taking into account, at the same time, the importance of protecting the environment.

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## *Przegląd zrównoważonych praktyk górniczych w zakresie ekologicznej rekultywacji obszarów zdegradowanych terenów górniczych w Zagłębiu Górniczym Rovinari (Rumunia). Studium przypadku: wewnętrzne składowisko w Północnej Peşteanie*

*Górnictwo odkrywkowe, niezależnie od charakteru złoża i rodzaju eksploatacji (ciągła lub nieciągła), powoduje długotrwałe negatywne skutki dla środowiska. Natychmiast widoczne efekty są związane ze zmianami morfologii i krajobrazu: zanik szaty roślinnej i wierzchniej warstwy gleby na całej powierzchni wyrobiska, rozwój głębokich odkrywek, pojawienie się składowisk odpadów, budowa obiektów, dróg technologicznych itp. Prowadzone jest odsłanianie złoża poprzez usunięcie roślinności i usunięcie gleby, a następnie wydobycie materiału ze stropu złoża, jest to działanie destrukcyjne mające negatywne konsekwencje dla środowiska w tym lokalnych siedlisk fauny. W dłuższej perspektywie, skutki mogą być trudno odwracalne lub nieodwracalne. Elementem środowiska, który ucierpi najbardziej górnictwa jest gleba, a wraz z nią cały ekosystem na tym obszarze. Gleba jest zasobem, który jest bardzo trudny do regeneracji. Naturalne tworzenie się gleby zajmuje dużo czasu, dziesiątki i setki lat. Dlatego ważne jest znalezienie i zastosowanie rozwiązań pozwalających na utrzymanie lub poprawę jego jakości gleby, wspieranie procesu pedogenezy poprzez stosowanie zrównoważonych praktyk. Niektóre z tych praktyk można stosować już podczas działalności wydobywczej. Celem przedstawionych badań jest znalezienie i zarekomendowanie najlepszych rozwiązań możliwych do zastosowania różnych etapach cyklu życia kopalni, które stosowane łącznie pełnią rolę synergistyczną oraz niezwykły wpływ na proces pedogenezy i czas jego trwania. Dlatego bardzo ważne jest zaprojektowanie działalności wydobywczej od otwarcia do zamknięcia, biorąc pod uwagę likwidację budynków, rekultywację i ponowne zazielenienie terenów zdegradowanych.*

**Słowa kluczowe:** *tereny zdegradowane, zrównoważone górnictwo, zrównoważone praktyki, gleba antropogeniczna, pedogeneza, ekologia przemysłowa*