Management of mining waste at Valea Arsului dump, Romania
Csaba R. Lorinț, Maria Lazăr, Adrian Florea

Mining Engineering Faculty - University of Petroșani, Hunedoara, Romania.
Corresponding author: C. R. Lorinț, csabigeo@yahoo.com

Abstract. Vulcan is one of the few active remaining collieries from Jiu Valley, in the Meridional Carpathian Mountains. The Valea Arsului heap stockpiles the tailings from the underground workings from Vulcan colliery. European legislation stipulates the necessity of a waste management plan. The location area of Valea Arsului heap is affected by the subsidence phenomenon due to underground coal extraction. In the paper is presented the stages involved in order to provide the landfill capacity in respect to the subsidence, stability, and environmental issues.

Key Words: Jiu Valley colliery, mining waste management, waste dump stability, environmental issues, slide prevention, subsidence modeling.

General context. In accordance with the objectives of Community policy on the environment (EUR-Lex 2014), it is necessary to lay down and apply minimum requirements in order to prevent or reduce as far as possible any adverse effects on the environment or on human health which are brought about as a result of the management of waste from the extractive industries, such as tailings, waste rock and overburden and topsoil provided that they constitute waste.

Regional settings. Vulcan is one of the few active remaining collieries from Jiu Valley, a hard coal mining basin located in south west of Romania (Buia & Lorinț 2010), (Figure 1), in the Meridional Carpathians Mountains.

The Vulcan colliery is located in the central part of Jiu Valley hard coal mining basin (Figure 2). Currently, the mining activities in the Jiu Valley are carried out under the
coordination of National Society of Mining Decommissioning Jiu Valley within the perimeters of the mining sectors Petrita, Paroșeni and Uricani and under the coordination of the entity known as Energy Complex Hunedoara (CEH). CEH was created by the unification of several commercial entities, namely “Electrocentrala Deva S.A.”, “Electrocentrala Paroșeni S.A.” and “Societatea Națională a Huilei S.A.”; with purpose of electricity production using hard coal sourced from the mining perimeters Lonea, Livezeni, Vulcan and Lupeni, Figure 2 (CEH Portal 2014; Lorin et al 2013; Buia et al 2014). The Valea Arsului landfill location is in the valley of the Arsului creek, in the northern side of Vulcan town. The inclination of eastern and western slopes of the valley in cross section is between 7 and 18°. The inclination of the valley bottom in the heap area is about 5° (Lorin et al 2013).

Figure 2. Location of Vulcan colliery in Jiu Valley hard coal basin; Spatial distribution and status of mining perimeters in the Jiu Valley.

Waste dump description. The Valea Arsului heap was created for storage of sterile rocks resulting from underground coal exploitation to Vulcan colliery. The location of the heap is in the valley of the Arsului creek and is formed by transport with trucks and dump with bulldozers of the sterile rocks. In hydrographical terms, the heap area is affected by the Arsului creek and by the torrents that forms on the slopes during periods with heavy rainfall or melting snow. After deposition of the sterile rocks in the valley, the creek bed was deviated and formed a lake downstream, due to land sinking due to underground mining activity, with natural drainage possibilities (Figure 3).

Figure 3. Valea Arsului creek and his downstream formed lake.
The presence of the lake is an unfavorable factor in terms of stability, whereas the water saturated the rocks at the base of the heap and modifies their physical-mechanical properties. In addition, it can lead to the formation of hydrostatic pressure that alters the balance of active and passive forces in the heap. During periods with heavy rainfall are present erosion and accumulation of water in the southern part of the heap. The rocks from the heap consist of rocks that occur in the productive horizon (Petrescu et al 1987; Pop 1993), i.e. clay, marl, sandstone, argillaceous sandstone and carbonaceous shale with different degree of granulometry (from millimeters to tens of centimeters) and alteration (Lorint et al 2013; Lazar et al 2014).

The used technology leads to construction of a heap in several benches, whose geometrical parameters are dependent on the morphology of the terrain and on the geotechnical characteristics of the sterile (Figure 4). The heap has an uneven geometry and consists of three benches, which in this study were numbered 1, 2 and 3 from upstream to downstream (Figure 4). The berm between the slopes 1 and 2 has a length of about 180 m, and an inclination of 2.9°, the berm between the slopes 2 and 3 has a length of about 57 m and an inclination of 3° to slope 2 and lower berm has a length of about 65 m and is almost horizontal.

The slopes height is variable and dependent on the land surface altitude and on the amount of deposited material and ranges from 5 m at the bottom and top of the heap and 7–10 m in the middle. Slope angles have values between 11–37°, higher values being found in particular in cases of the eastern and western slopes. The heap has a length of about 420 m and a width of about 210 m at the top, and narrows to 80 m in the lower area (Lorint et al 2013; Lazar et al 2014).

Considerations on the geotechnical characteristics of the rock. The sterile rocks from the Valea Arsului heap are a heterogeneous material in terms of grain size and lithology. In terms of particle size predominates gravel (Φ = 2–20 mm) and sand (Φ = 0.05–2 mm). The bulk density (γb) of the sterile rocks varies widely due to the mineralogic-petrographical heterogeneity and due to the different humidity. The stability analysis was considered the maximum values of the volumetric weight, which correspond to the worst situation. Shear strength characteristics are influenced by mineralogic-petrographic composition of the sterile rocks and by their humidity. Technical conditions of the heap and the limits of variation of mechanical characteristics lead to adopting the average values of cohesion and internal friction angle for the stability analysis. The samples of topsoil and clay material from the directly foundation of the heap have a moderate to high compressibility, which corresponds to a low degree of consolidation. The bearing capacity is lower than the sterile rocks from heaps and there is the risk of plastic deformation under stress. The values of cohesion for topsoil and for heap ground are higher than the mixture of rock. The determined mechanical characteristics are superior to those determined for the topsoil but lower than the heap ground, so it is
possible to transmit the failure surface on the contact surface between topsoil and basic heap ground.

**Stability analysis of the waste dump.** Geotechnical mapping of land, nature of the deposited rocks, geomorphology of the terrain on which is build the heap and previous studies conducted for other heaps in the Jiu Valley, showed that the most likely failure surfaces have a circular shape and is transmitted through the heap body (Rotunjanu 2005). Also, the failure surface may have a polygonal shape, in the case of the heaps formed on the ground surface with variable inclination. Consequently, the stability analysis of the heap was based on these assumptions.

**Circular failure surfaces.** Stability analysis aimed four sections drawn in the areas where the slope geometry is less favorable: one longitudinal section and three cross-sections. The values of the strength properties for sterile rocks and topsoil considered in stability analyzes are the result of statistical processing of the values obtained in 2005, (Lazăr et al 2005) and 2013 (Lorin et al 2013; Lazar et al 2014). Analyzing the results of stability tests in the cases of the circular failure surfaces can be found the following: for the longitudinal section, the stability coefficient show a sufficient stability reserve in all analyzed cases and in the cross sections the heap is stable in all analyzed cases for all used analysis methods or is at the limit of stability for the few extremes values especially of the eastern slope. The critical failure surface is transmitted through the ground base of the heap in the case of high values of cohesion and angle of internal friction of the sterile rocks and topsoil, and only trough the body heap in the case of low values of these parameters. It also notes that any failure slip will be a deep failure, involving large volumes of waste material. It is noted that the slopes that are unstable or is at the limit of stability are inclinations higher as 30°. A possible failure of the eastern slope leads to blocking of the riverbed, causing more problems related to water regime and management. A failure of the western slope would lead to blocking of the access road and, under certain conditions, can affect the electrical network pillars.

**Polygonal failure surfaces.** To analyze the stability over the polygonal failure surfaces are taken into account of one longitudinal section and two cross-sections, where the heap ground has inclinations that could favor the slide. Were analyzed three variants for the transmission of the failure surface: trough the sterile rocks, trough the topsoil and on contact surface between topsoil and the clay layer. For all analyzed sections, the critical failure surface is transmitted through the sterile rocks from heap. In these cases, the failure probability is almost zero, because the stability coefficients have values above 1.3 and in the calculations was used the worst value of the rock strength characteristics. It was also taken into account the rate of seismicity of the area.

**Interaction between sterile rocks heap and underground activity.** The Valea Arsului heap has relatively small size and contains a volume of ca. 185000 m³. The underground works for coal exploitation currently runs at a depth of about 300 m from the ground surface elevation. Given these data, it is acceptable that the heap represent a load on the land, which can cause compaction of directly foundation, but this is unlikely to influence the underground activities. To support this assertion, were made calculations to determine the specific pressure exerted on the ground heap and the critical pressure that supports the ground heap. The average specific pressure exerted from the heap on the land was calculated for a heap surface of 29500 m² and heap volume of 185000 m³ (for a volumetric weight of 18.05 kN/m³) and has a value of 1.132 daN/cm². The maximal specific pressure calculated for a maximal height of the heap (17 m in the section T₂), has a value of 3.068 daN/cm². The critical pressure what can be supported from the land was calculated on the basis of the national standards (NP 2005), using the equation:

\[
P_{cr} = \gamma^* \cdot B \cdot N_y \cdot \lambda_{\gamma} + q \cdot N_q \cdot \lambda_q + c^* \cdot N_c \cdot \lambda_c \quad \text{kPa}
\]

Where:
γ* – volumetric weight of the rock layers under the heap, kN/m³;  
B' – reduced width of the heap base, m;  
N_y, N_q, N_c – dimensionless coefficients of the bearing capacity that depend on the angle of internal friction φ* of the rock layers under the heap;  
q – calculated overload acting on the side at level of the heap foundation, kPa;  
c* – cohesion of the rocks layer under heap base, kPa;  
λ_y, λ_q, λ_c – shape coefficients of the heap base, depending on the reduced width and reduced length of the heap base.

The reduced width and reduced length of the heap base (B', L') is calculated taking into account the eccentricities in the longitudinal and transversal plan of the calculation point. In the case of the Valea Arsului heap, the critical pressure was determined for the section T2-2, where the height value is maximal and the effective specific pressure is 3.068 daN/cm². On the basis of the geometrical and geotechnical characteristics and taking into account that overload q is null (because the heap is built directly on the land) have considered the following calculation values:

\[
\gamma^* = 18 \text{ kN/m}^3; \quad c^* = 34.5 \text{ kPa}; \quad \phi^* = 17^\circ; \quad B' = 40 \text{ m}; \quad L' = 260 \text{ m}
\]

In these circumstances, was determined the critical pressure \( P_{cr} = 605.8 \text{ kPa} \), respectively 6.05 daN/cm², a value that is higher than the actual pressure exerted by the heap in the calculation point, respectively \( P_{ef} = 3.06 \text{ daN/cm}^2 \). Instead, the underground activity have a high enough influence on the heap due to the directing of the mining pressure trough total collapse and generating subsidence phenomena. This lead to changes of the morphology of the land and also to change of the structure and resistance of the rock layers under the heap, but also to the change of the state of effort and tension in the heap body.

**Subsidence phenomenon and assessment.** First studies on subsidence phenomenon occurred in Valea Arsului was conduct in 1981 and it can be seen the Arsului creek water accumulation in the subsidence trough. After the occurrence of water accumulation in Valea Arsului, this small lake migrated to the south along the valley axes, following the subsidence phenomenon due to underground coal extraction, with an average rate of approx. 10 m/year. Modeling was necessary because the subsidence phenomenon was not monitored and the actual shape and position of base terrain was unknown. The shape and size of trough diving were assessed using analytical methods (Dima et al 1996), according to the geological particularities of the coal deposit (dip and dept of coal seam). In case of horizontal or low dip seam deposit ( \( \alpha \leq 25^\circ \) ) the maximum sinking is represented by a symmetrical curve but in the case of average or large dip seam deposit ( \( \alpha > 25^\circ \) ) the sinking curve is an asymmetric one (Figure 5).

![Figure 5. The trough diving generated at extraction of a dip seam deposit.](image-url)
Displacement $q$ from symmetry can be calculated using the equation:

$$
q = \frac{H}{\tan(90^\circ - 0.15 \cdot \alpha)}
$$

where:

- $H = \frac{H_1 + H_2}{2}$ is the average depth between the minimum and maximum depth of exploitation and $\alpha$ is the dip angle of exploited seam.

In this case $H_1 = 294$ m; $H_2 = 41$ m; $\alpha = 39^\circ$.

For the Valea Arsului condition we have the average depth of exploitation $H = 167.5$ m and the displacement from symmetry $q = 17.16$ m. The value of the maximum sinking can be calculated using the equation:

$$
S_0 = a \cdot m \cdot f \cdot z
$$

where:

- $a$ – is the sinking factor (for pressure routing methods through total collapse $a = 0.85$);
- $m$ – seam thickness;
- $f$ – superficiality factor;
- $z$ – time factor (if the movement not yet stopped $z = 1$).

For the Valea Arsului condition we have the maximum sinking value $S_0 = 23.8$ m and the location of maximum sinking point at middle distance between pillar 15 and 16 of electric power grid. The lateral limits of the subsidence trough are visible on the eastern and western slope that borders the heap (Figure 6) (Florea et al 2014).

Based on subsidence phenomenon assessment, we proceeded to current land surface modeling under the heap Valea Arsului.

**Surface modeling, resizing and design of the geometric elements of the heap.** As starting point we had an aerial survey from 1981 which was made before landfill process started and the sinking phenomenon was in an early stage. In the first stage, we digitized the level curves from this aerial survey (Figure 7-left). In the second stage, we applied correction to this level curves, taking into account the results of the sinking assessment and then we generate the digital terrain model (Figure 7-right).

Given the stability analysis results and the consequences of a possible landslide, it is necessary to resize the geometric elements of the heap, so to have a minimum 30% stability reserve, even under the most unfavorable geotechnical conditions. To establish the geometric elements of the heap under slope stability conditions, can be used different graphic-analytical methods as E. Hoek, which proved its validity in many cases, including for the many heaps in the Jiu Valley (Băncilă 1981; Florea 1979).

The method use a graphic to find the adequately value for the slope angle, depending on the slope height and on the geo-mechanical characteristics of the rocks. The obtained results of calculations are presented in Table 1.
Figure 7. Digitized level curves from aerial survey made in 1981 in Valea Arsului (left) and Digital terrain model of Valea Arsului with sinking phenomenon (right).

Table 1

<table>
<thead>
<tr>
<th>$H, [m]$</th>
<th>$\varphi, [\text{grads}]$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$S = 1.3$</td>
</tr>
<tr>
<td>5</td>
<td>56</td>
</tr>
<tr>
<td>10</td>
<td>41.5</td>
</tr>
<tr>
<td>15</td>
<td>34</td>
</tr>
<tr>
<td>20</td>
<td>30.5</td>
</tr>
<tr>
<td>25</td>
<td>28</td>
</tr>
<tr>
<td>30</td>
<td>26.5</td>
</tr>
</tbody>
</table>

After resizing calculation results that to have a geometry that satisfies the requirements of stability, even in the presence of water in the heap body and/or in the case of the occurrence of seismic shocks, it is preferable to construct and maintain the height of the slope of 10 m and a maximum slope angle of 30°.

For a total heap height of 30 m, the general slope angle is recommended to be 22°. Therefore, it is proposed to construct the heap in three benches by providing a protective berm of 5 m by Valea Arsului side (Figure 8). Heap geometry control, subsidence and displacements caused by direct ground land deformations will be done through the monitoring with topographic landmarks. Landmarks position, number and distance between them are determined by the geologist and surveyor from field observations.

Figure 8. Final geometry of the waste dump.
The development of dumping works and land monitoring. Considering these geometric elements the heap is suggested to be built on three benches ensuring a 5 m protective berm towards the Valea Arsului river bed. The lower bench of 10 m maximum height should be built from ground level up to +641 m altitude, the median bench of 10 m maximum height should be built up to +651 m altitude while the upper bench of 7 m maximum height should be built up to +658 m altitude. This kind of heap development within the current land perimeter allows the storage of an additional quantity of 65000 m$^3$ compared to the already stored quantity (Figure 9).

The land sinking phenomenon generated by underground exploitation of coal seam no.3 lead to a water accumulation on the southern part of the heaping area. For its removal is recommended to deposit in this area about 10000 m$^3$ of sterile in order to counterbalance the sinking phenomenon and the expansion of the land perimeter towards south, both in the 4800 m$^2$ area which is already affected by sinking and in the area which will be further affected by this phenomenon. Therefore the heap lower bench could be expanded which will allow the storage in the Valea Arsului heap of an additional quantity of 120000 m$^3$ compared to the already stored quantity (Figure 9).

![Figure 9. Final geometry of the heap with the expanded perimeter towards south (blue body).](image)

According to the project data, the final geometry of the heap will be done in four development stages:
- stage I: heaping works in the southern part, to counterbalance the sinking phenomenon and to eliminate the water accumulation;
- stage II: further heaping works in the southern part and leveling the heap material until it reaches the altitude +641, ensuring the slope angle of $30^\circ$;
- stage III: heaping works in the median area and leveling the heap material until it reaches the altitude +651, ensuring the slope angle of $30^\circ$;
- stage IV: heaping works in the upper area and leveling the heap material until it reaches the altitude +658, ensuring the slope angle of $30^\circ$.

The development width of the heap body is conditioned by the land geometry. Therefore the berm from +658 ground level will have the final width 61 m and the length 70 m, measured along the longitudinal heaping axis. The berm from +651 ground level will have the final width between 81 m (the upstream area) and 17 m (the downstream area) and the length 103 m, measured along the longitudinal heaping axis. The berm from +641 ground level will have the final width between 45 m (the upstream area) down to 4 m (the downstream area) and the length 400 m, measured along the longitudinal heaping axis.

According to the data above, currently in Valea Arsului heap are deposited 185000 m$^3$ of sterile rocks, compared to the 427577 m$^3$ value, provided by other studies. Also, the sterile quantity estimated to be generated during the validity period of the exploitation license (until 2024) is 203000 m$^3$. Using the described methods, it will be possible to store in the Valea Arsului heap of an additional quantity of 120000 m$^3$. 
compared to the already stored quantity. This quantity ensures, at present rate of dumping, the possibility of sterile storage until 2019, providing the stability conditions of the Valea Arsului heap. Above this quantity, the storage can be done by: expanding the land perimeter to the west, by moving the road and the electric line or identifying a new heaping placement.

Heap geometry control will be done by landmarks which will indicate the expansion areas of benches, the berm arrangement levels and their width.

Also, by tool measurements on the landmarks, fixed on the base terrain and on the berms which separate the benches, there will be followed the settlings and displacements caused by the deposit strains or by the direct foundation.

The registration of strains is a signal to carefully observe the area in order to predict the possibility of landslides.

The landmarks position, number and distance between them are established by the geologist and the surveyor after field observation.

The strain measurement is done from time to time, the intervals being established depending on the strain speed and the sinking phenomenon amplitude.

**Heap ecologic rehabilitation measures.** Considering the natural elements which characterize the Valea Arsului heap area, but also its stability problems, for the ecologic rehabilitation it is suggested the natural recovery method.

Within this recovery type, the natural shape of the terrain and of the landscape affected by the exploitation is recreated. It represents a recovery method suitable for mountain area lands and is used for heaps placed on wooded slopes or along water streams (Lorint et al 2013).

The natural recovery includes all the operations resulting in greening, resturaution or natural creation of water bodies/surface, mainly land improvement, leveling and revegetation, without further human interfering.

For this purpose, naturalistic engineering techniques can use seeds for flat surfaces sowing, roots and seedlings together with inert or biodegradable artificial materials (natural fiber fabrics from coconuts, hay, straw or wool) or with non biodegradable materials (galvanized grids, geogrids, geonetworks, geotextiles) to counter the erosion and ensure the slopes stability. Multiple plant categories are recommended to be used:

- local species, characteristic to the environment (birch, beech, eventually sylvan pine and/or black pine);
- ecosystem compatible species, which do not harm other natural area species (seabuckthorn);
- pioneer species, with sterile land colonization and resistance capacity;
- specific biotechnic properties species (tensile roots, frost resistant).

The biotechnic characteristics of used plants need to meet the following requirements:

- quick land coverage capacity and erosion protection;
- root capacity of improving the ground geotechnic parameters (cohesion, internal friction angle, shear strength);
- capacity of reducing the superficial drainage speed and water engaging force;
- capacity of adjusting the ground hidrologic balance (i.e. the evapotranspiration).

Following the natural engineering techniques lead to the generation of lands with vegetation close to the local environment characteristics, using for this purpose materials available in the area and minimum heavy installations. They represent a simple and cheap method for solving local environmental problems and can be associated to the traditional engineering techniques, such as embankment or concrete structures.

**Conclusions.** The Valea Arsului heap was created for storage of sterile rocks resulting from underground coal exploitation to Vulcan colliery. The sterile rocks are a heterogeneous material in terms of grain size and lithology, a mixture of rocks from productive horizon, consisting of clay, marl, sandstone and shale coal. After deposition of
the sterile rocks in the valley, the creek bed was deviated and formed a lake downstream, because of land sinking due to underground mining activity, with natural drainage possibilities. The presence of the lake is an unfavorable factor in terms of stability, whereas the water saturated the rocks at the base of the heap and modifies their physical-mechanical properties. The used technology leads to construction of a heap in one or more benches, whose geometrical parameters are dependent on the morphology of the terrain and on the geotechnical characteristics of the sterile. The Valea Arsului heap has an uneven geometry and consists of three benches. The stability studies show that the Valea Arsului heap is generally stable, and for the most sets of values of geomechanical characteristics the stability reserve is adequate, exceeding the reference value of 30%. The failure probability exists only for the few extremes values, especially of the eastern slope.

Based on the literature, on the field studies and not least on our research experience, we recommend the following measures to ensure stability of the heap.

- reducing of the negative influence of water on the strength characteristics of the rocks. It requires works that does not allow water infiltrations inside the heap bodies or to their base from various sources like rainfall, snowmelt, streams and water accumulation. Thus, it is recommended a permanent leveling of the berms, providing a terrain inclination for water drainage from the existing heap and the drainage of the lake downstream of the heap by depositing of the sterile rocks in the lake;

- compliance of the designed geometry and technology of the heap. It is necessary the construction of benches with a height of 10 m and a slope angle of 30° for every bench. The general slope angle should not exceed the value of 22°;

- permanent leveling and compaction of the heaping zones under lateral expansion of the heap. It is recommended that further expansion of the heap toward south and east in order to drainage of the existing lake;

- monitoring of the land base and heap deformations;

- ensuring of the final geometry for the definitive slopes for the forestation and grassing works, being known that vegetation are a factor of stability and consolidation of the heaps, trough the land reinforcement effect of the roots and trough the effect of preventing the growth of cracks. This eliminates the quickly infiltration of rainfall into the heap body and formation of potential sliding surfaces.

Finally, considering the natural elements which characterize the Valea Arsului heap area, but also its stability problems, for the ecologic rehabilitation it is suggested the natural recovery method.

References


CEH Portal, 2014 Available at: http://www.cenh-d.ro/.

Dima N., Padure I., Herbei O., 1996 [Mining surveying], Corvin Publishing House, Deva [in Romanian].


Rotunjanu I., 2005 [The stability of slopes and embankments], INFOMIN Publishing House, Deva. [in Romanian].