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Deliverable 2.1

Closed extractive coal waste facilities information

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EXECUTIVE SUMMARY

Deliverable 2.1 of the CRMsDataSpace project presents the first consolidated dataset on selected closed or transitioning extractive coal waste facilities in Europe, with the purpose of supporting the recovery of critical raw materials (CRMs) from legacy mining waste.

The document is part of Work Package 2 and focuses on five case studies: Petrila (Romania), Janina/Libiąż (Poland), Waleska (Poland), San Nicolás (Spain), and the Ibbenbüren mine water sludge tailing ponds (Germany). Its core objective is to gather georeferenced site information, conduct sampling, and establish the geological, geochemical, environmental, and operational baselines required for subsequent mineralogical characterisation, metallurgical testing, resource estimation, and integration into a shared European data space.

The report shows that these facilities differ significantly in origin, material composition, environmental condition, and redevelopment potential, but all represent important secondary raw material targets.

Petrila is a rehabilitated Romanian mine waste dump now under the Jiu Valley Energy Complex. The study documents its geometry using LiDAR, confirms a large footprint, and notes that the site is generally stable under natural moisture conditions but may become unstable on some slopes when saturated. This makes Petrila a relevant case where both resource potential and geotechnical constraints must be considered together. The site has already undergone stabilisation, regrading, grassing, and afforestation, illustrating how legacy facilities can combine environmental rehabilitation with renewed resource assessment.

The Janina waste facility in Libiąż is part of a larger Polish coal-waste accumulation with a long history of mining-waste deposition, which ceased in 2016 after the disposal capacity was reached. The report identifies Janina as environmentally significant because the weathering of pyrite-rich waste is producing acid drainage symptoms, including iron-rich seepages and sulfate salt efflorescence. At the same time, the site has already become a testbed for experimental reclamation using anthropogenic substrates and vegetation-based restoration. This makes Janina a particularly important demonstration site for balancing risk mitigation, closure management, and the possible future valorisation of stored waste.

The Waleska dump, also in Poland, is presented as a reclaimed facility with strong evidence of post-operational stabilisation and land-use transition. Created from coal-mining waste and associated sludges, it operated from 1994 to 2007 and is now designated for protective, green, and landscape-recreational functions. Compared with Janina, Waleska appears more advanced in its reclamation trajectory, but it remains

relevant because its material composition, disposal history, and archived environmental data may still support CRM screening and future resource evaluation. In strategic terms, Waleska demonstrates that closed and rehabilitated facilities should not be excluded from raw-material assessment simply because their primary closure phase has ended.

The Spanish case study, San Nicolás, is especially significant because it connects mining heritage, landscape integration, and the very recent dynamics of closure. The dump is linked to HUNOSA's operations in Asturias and remained in use until the closure of the mine on 31 December 2024. The report describes the site as a visible and symbolic legacy of regional coal mining, but also as a technically relevant deposit containing both black and red waste materials with variable physical and chemical properties. Sampling has progressed through drilling, with seven boreholes completed due to field conditions, although analytical results are still pending. San Nicolás, therefore, stands out as a site where the baseline characterisation is in progress and where the resource and environmental interpretation will strengthen as the new data become available.

The German case, Ibbenbüren, broadens the project beyond conventional waste dumps by examining sludge tailing ponds generated from mine-water treatment after the closure of one of Germany's last hard coal mines. These ponds contain fine-grained iron-rich precipitates that may also concentrate trace metals and rare earth elements, making them especially promising for CRM recovery. The report emphasises that the site is part of Germany's long-term post-mining water-management obligations and that the sludge ponds represent both an environmental management asset and a secondary resource opportunity. This case is strategically important because it shows that CRM potential may exist not only in coarse mine waste, but also in treatment residues created decades after mine closure.

Overall, Deliverable 2.1 establishes a strong foundation for the next stages of the CRMsDataSpace project. Its main value lies in converting diverse legacy coal-waste sites into structured, comparable datasets that combine location, geometry, waste characteristics, environmental condition, ownership, sampling, and historical context.

The document also makes clear that these facilities are not uniform: some are stabilised and reclaimed, some remain environmentally sensitive, and some are still transitioning from closure to long-term management.

1 INTRODUCTION

Work Package 2 addresses the data acquisition from closed facilities, with the following objectives:

- Gather general information and undergo a georeferenced geochemical sampling of the selected closed extractive coal waste facilities.
- Develop a chemical and mineralogical characterisation of the samples.
- Identify and develop potential approaches for the mineralurgical concentration of the targeted critical raw materials.
- Identify and develop potential approaches for the hydrometallurgical concentration of the targeted critical raw materials.
- Undergo multi-hole exploration drilling or equivalent techniques in selected closed facilities.
- Undergo mineral resource estimation of the targeted critical raw materials using mineral resource planning software.
- Introduce the obtained information into the data space.

Within this Work Package, Task 2.1 Information gathering and geochemical sampling will gather the information and collect the samples from two closed extractive coal waste facilities in Poland, a Spanish facility, a Romanian facility, and a German facility.

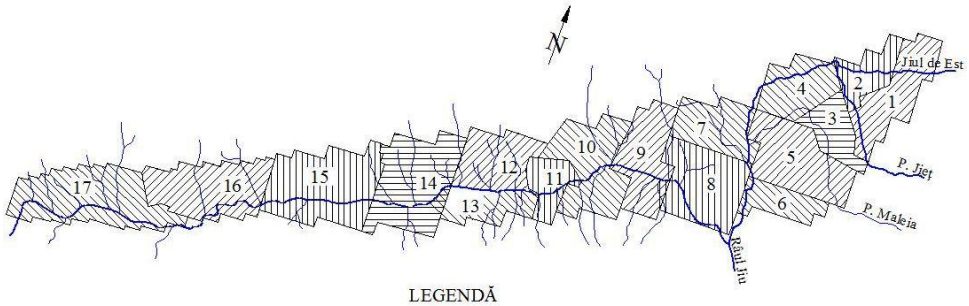
The task will include gathering background information about the study areas, including spatial coordinates, history, nearby populations, geological characteristics, geometry, 3D representation, digital elevation model, waste volume (or estimation), photographs, operator, former operator or legal successor, administrative status, characterisation of the mining and environmental surroundings, type of mining and beneficiation process (extraction, crushing, grinding, separation and concentration) of the deposit, mining legacy data of interest and original mineral deposit information.

Georeferenced geochemical samplings will also be collected in each facility. The samples will be selected and distributed according to the facility's area. Data acquisition will be made at closed extractive coal waste facilities of coal mining companies with which the partners has a strong cooperation record. In case of some difficulties, abandoned facilities will be selected.

2 PETRILA MINE WASTE DUMP (Romania)

2.1 Facility identification

Jiu Valley coal field is located in the southern part of Hunedoara county and in the southwest of Transylvania, in the Southern Carpathian depression called Petroşani depression or ”Valea Jiului” depression. The coal field comprises 17 mining perimeters, as presented in Figure 2-1.



LEGENDĂ

1 - Lonea;	7 - Dâlja;	13 - Lupeni Sud;
2 - Lonea Pilier;	8 - Iscroni;	14 - Bărbăteni;
3 - Petrila Sud;	9 - Aninoasa;	15 - Uricani;
4 - Petrila;	10 - Vulcan;	16 - Valea de Brazi;
5 - Livezeni;	11 - Paroşeni;	17 - Câmpu lui Neag.
6 - Sălătruc;	12 - Lupeni;	

Figure 2-1. Jiu Valley mining perimeters

The utilities and administrative/industrial facilities serving the underground mining operations and the processing of the coal extracted at the Petrila mining unit (closed mine unit) were located within the following mining area (sites):

- Main area
- Jupâneasa Filtration and Chlorination Satation area
- Jupâneasa Water Intake area
- Waste Dump Area

Petrila Mine operated under various organizational structures until its closure in 2015, at which time it was managed by the National Company for Mine Closure Jiu Valley (SNIMVJ). SNIMVJ continued its activity for several more years, completing the closure and environmental rehabilitation of the three mines under its administration (Petrila, Uricani, and Paroșeni).

In 2023, SNIMVJ was reorganized into the Jiu Valley Energy Complex (CEVJ), state-owned company, which currently operates the last four active mines in the Jiu Valley (Lonea, Livezeni, Vulcan, and Lupeni). Part of SNIMVJ’s assets was transferred to CEVJ, including the land on which the closed waste dump of the former Petrila Mine was located.

Petrila mine waste dump is classified as rehabilitated, as active stabilization and landscape rehabilitation measures have been implemented following the cessation of mining operations, in accordance with the approved rehabilitation documentation and technical plans.

2.2 Location and extent

The Petrila mine waste dump is located in Romania, Hunedoara County, within the administrative territory of Petrila. The facility is spatially defined as a polygon in the WGS84 coordinate reference system (Figure 2-2).

From an administrative standpoint, the Petrila mining area belongs to the town of Petrila, where the headquarters of the Petrila Mine is also located, at the following address: Minei Street, No. 2, Hunedoara County.

The Petrila mining area is situated in the eastern part of the Jiu Valley coal basin and is bordered to the east by the Lonea Development–Exploitation Area and the Livezeni Development–Exploitation Area, to the south.

Access to the region is ensured via the Filiași–Târgu Jiu–Livezeni–Simeria railway and via the European Road E79 (Târgu Jiu–Petroșani–Simeria–Oradea), corresponding to the DN 66 route, following the East Jiu River.

The Waste Dump perimeter (Figure 2-2) is located at approximately 2500 m from the East Jiu River and about 1000 m from the inhabited area (https://maps.app.goo.gl/QXe77CPzj6RHKQUK8 / 45.431864, 23.393718).



Figure 2-2. Waste Dump perimeter (comprising branch 4 and branch 5) – topographic number

The geographic coordinates of the polygon vertices are provided in Table 2-1.

Table 2-1. Petrila mine waste dump – geographic coordinates

No.	Latitude	Longitude
1	45°25'57.522"N	23°24'12.298"E
2	45°25'57.853"N	23°24'11.797"E
3	45°25'58.022"N	23°24'11.311"E
4	45°25'58.048"N	23°24'10.562"E
5	45°25'57.850"N	23°24'7.819"E
6	45°25'57.853"N	23°23'56.144"E
7	45°25'57.857"N	23°23'44.470"E
8	45°25'54.693"N	23°23'16.037"E
9	45°25'54.685"N	23°23'15.979"E
10	45°25'53.260"N	23°23'3.160"E
11	45°25'53.260"N	23°23'3.156"E
12	45°25'52.965"N	23°23'0.517"E
13	45°25'51.928"N	23°23'1.594"E
14	45°25'50.769"N	23°22'59.340"E
15	45°25'50.851"N	23°23'1.893"E
16	45°25'51.276"N	23°23'9.542"E
17	45°25'51.485"N	23°23'16.580"E
18	45°25'51.488"N	23°23'24.752"E
19	45°25'51.906"N	23°23'25.832"E
20	45°25'51.406"N	23°23'27.344"E
21	45°25'51.308"N	23°23'45.686"E
22	45°25'51.287"N	23°23'48.437"E
23	45°25'50.880"N	23°24'1.588"E
24	45°25'52.050"N	23°24'5.015"E
25	45°25'52.903"N	23°24'4.666"E
26	45°25'54.649"N	23°24'6.873"E
27	45°25'55.150"N	23°24'8.222"E
28	45°25'55.157"N	23°24'11.182"E
29	45°25'55.319"N	23°24'11.707"E
30	45°25'55.452"N	23°24'12.236"E
31	45°25'55.636"N	23°24'12.776"E
32	45°25'55.916"N	23°24'12.997"E
33	45°25'55.913"N	23°24'12.888"E
34	45°25'55.884"N	23°24'10.879"E
35	45°25'55.988"N	23°24'10.876"E
36	45°25'55.985"N	23°24'10.645"E
37	45°25'57.083"N	23°24'10.613"E
38	45°25'57.115"N	23°24'12.849"E
39	45°25'57.522"N	23°24'12.298"E

The land is located within the built-up area and is classified as non-productive. It covers a total surface area of 225,201 m².

This surface area is presented in the topographic and cadastral documents and is identified in most documents as Branch 5; however, the perimeter of the waste dump includes both direction 4 and direction 5, as shown in Figure 2-10.

The detailed plan and the general layout plan are presented in

Figure 2-3 and Figure 2-4.

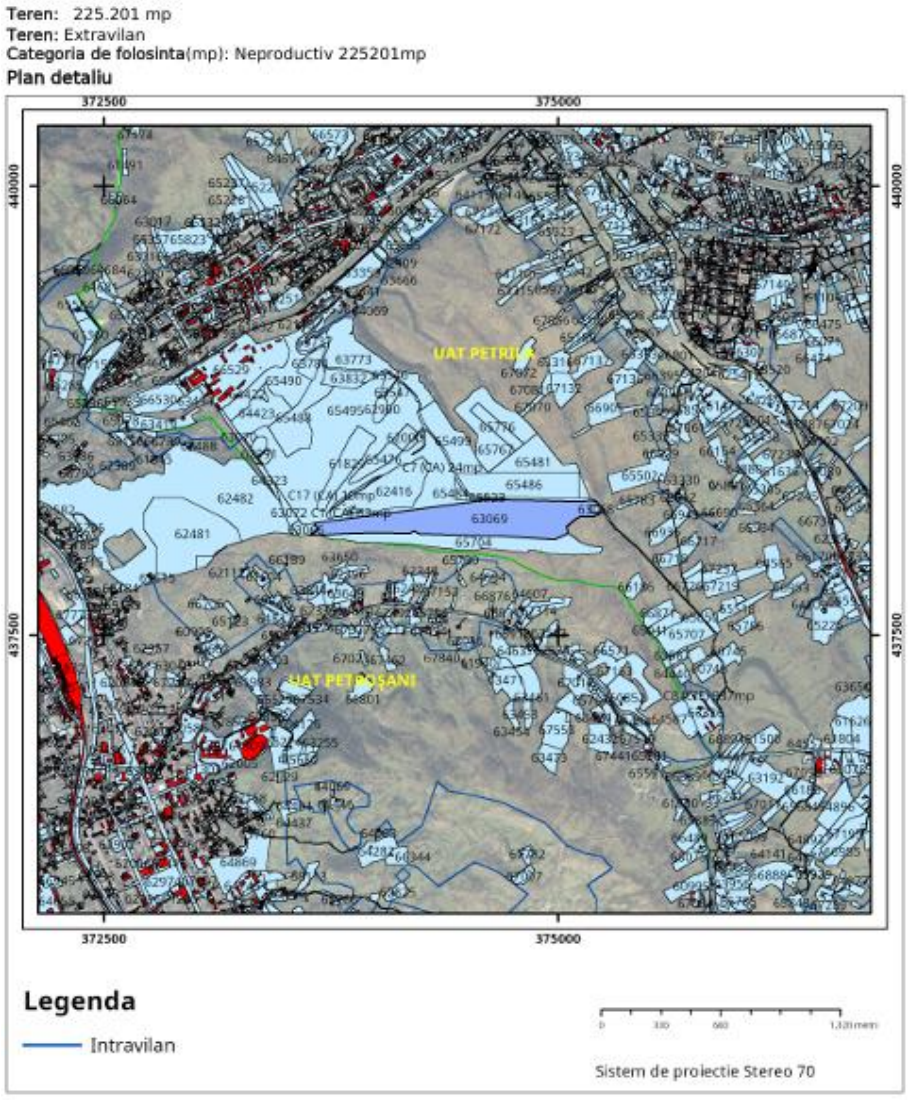


Figure 2-3. Detailed plan

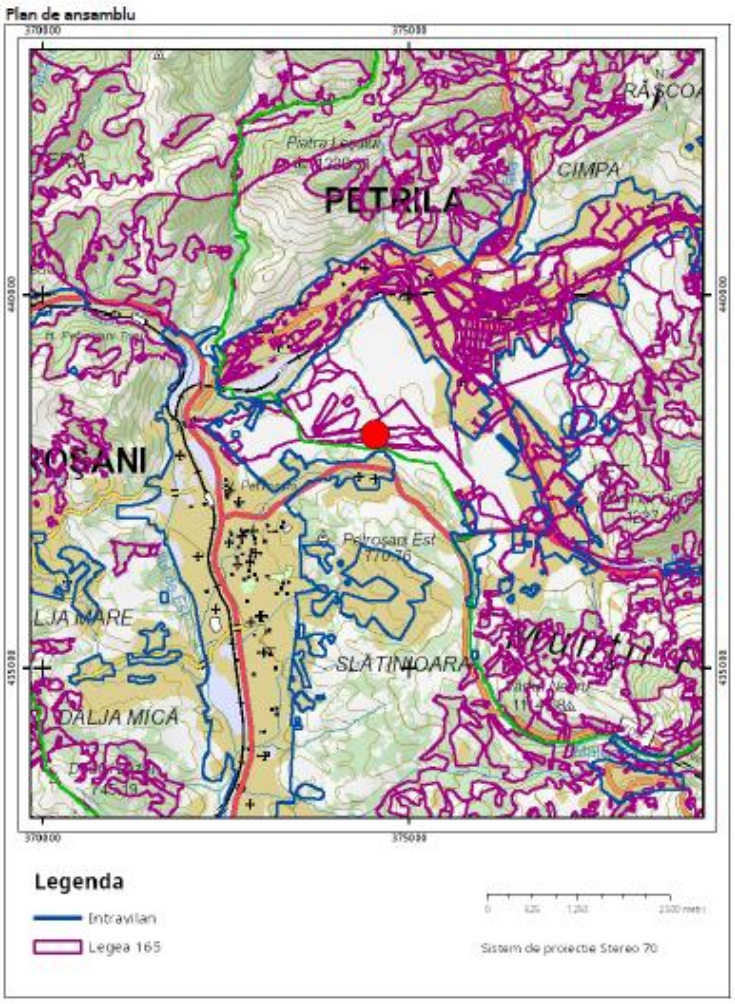


Figure 2-4. General layout

Petrila mine waste dump perimeter, in the topographical and cadastral documents has an area of S = 225,201 m². Branch 5 of Petrila mine waste dump presets the following particularities:

- Designed capacity: 3,348,000 m³
- Available capacity: 775,828 m³ at a maximum height of 25 m
- Total waste rock deposited: 5,686,060 tonnes (2,600,984 m³)

2.2.1 Determination of the geometric characteristics of the waste dump

For the present study, Branch 4 of the Petrila Mining Exploitation waste dump was taken into consideration. The determination of the geometric shape of this branch was carried out by means of LiDAR scanning using a DJI Matrice 350 RTK drone (Figure 2-5), equipped with a DJI Zenmuse L2 LiDAR sensor.



Figure 2-5. The DJI Matrice 350 RTK drone, equipped with a DJI Zenmuse L2 LiDAR sensor

The point cloud processing was carried out using the application specific to the drone type, namely DJI Terra. The coordinate system used was WGS 84 (World Geodetic System 1984), which is also employed by the Google Maps application. The coordinates of the control point are as follows:

Check Point Latitude (Y/N)	Check Point Longitude (X/E)	Check Point Altitude (Z/U)
45.4317566°	23.388586°	734 m

The slopes of Branch 4 of the waste dump are covered with vegetation, as can be observed from the resulting 3D point cloud model obtained through scanning (Figure 2-6).

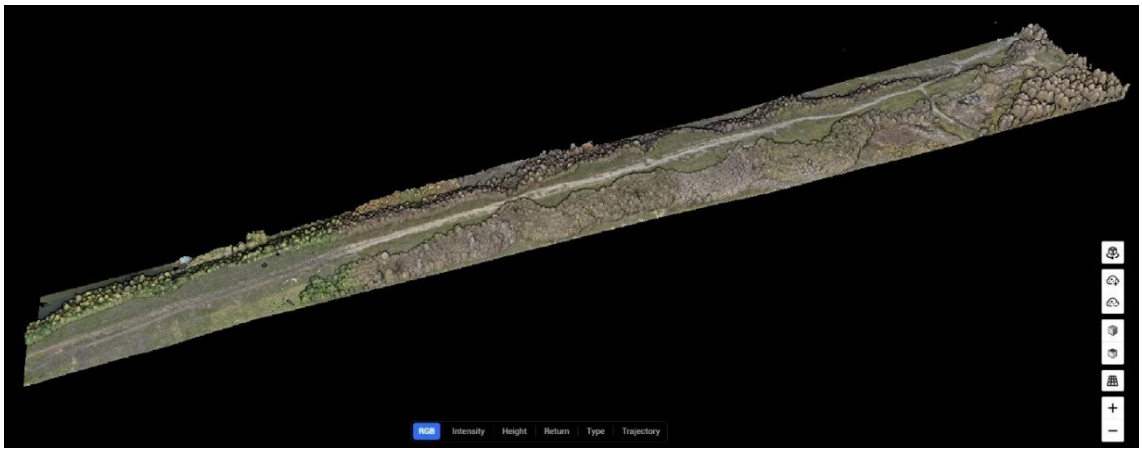


Figure 2-6. The point cloud of Branch 4 of the waste dump (RGB)

By removing the vegetation and applying elevation-based color contours, the image shown in Figure 2-7 was obtained.

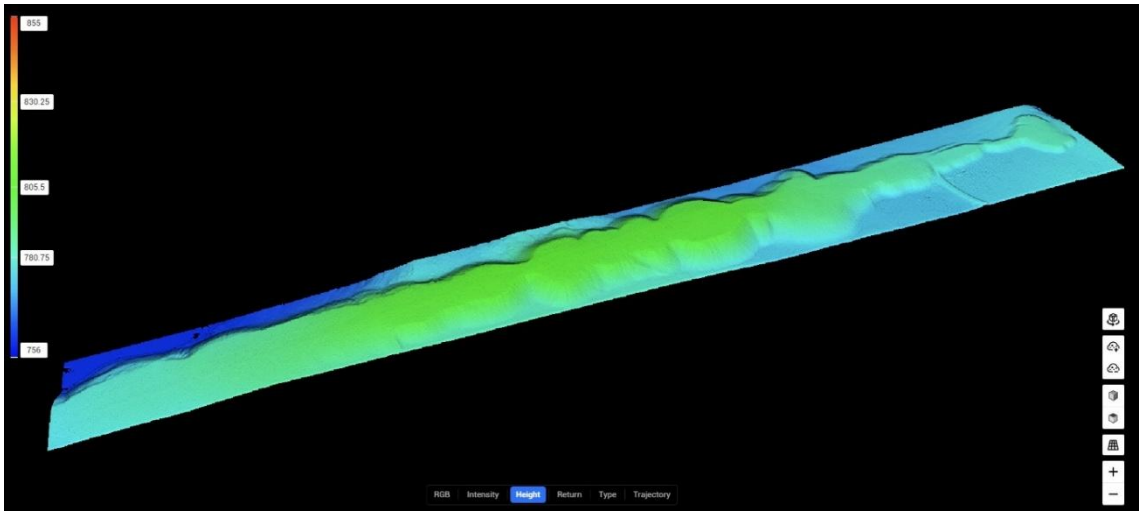


Figure 2-7. Point cloud of Branch 4 of the waste dump (Height, without vegetation)

The length of Branch 4 of the waste dump, according to the point cloud data, is 1,231.55 m, with the dump branch reaching a maximum width of 99.3 m in its widest area (Figure 2-8).

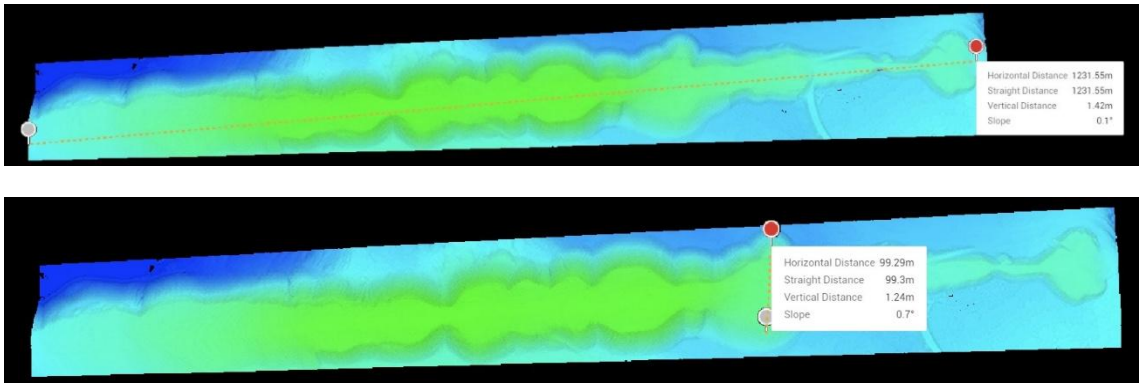


Figure 2-8. Length and width of Branch 4 of the waste dump

Along its length, this branch of the waste dump extends between the coordinate points Y/N: 45.43136331; X/E: 23.38769169; Z/U: 781.104 m to the west and Y/N: 45.43235025; X/E: 23.40333911; Z/U: 782.828 m to the east. Along its width, Branch 4 of the waste dump is located between the coordinate points Y/N: 45.43267778; X/E: 23.39850945; Z/U: 776.474 m to the north and Y/N: 45.43121469; X/E: 23.38768619; Z/U: 780.108 m to the south.

Branch 4 of the Petrila Mining Exploitation waste dump occupies a projected area on the horizontal plane of 108,107.46 m² (Figure 2-9).

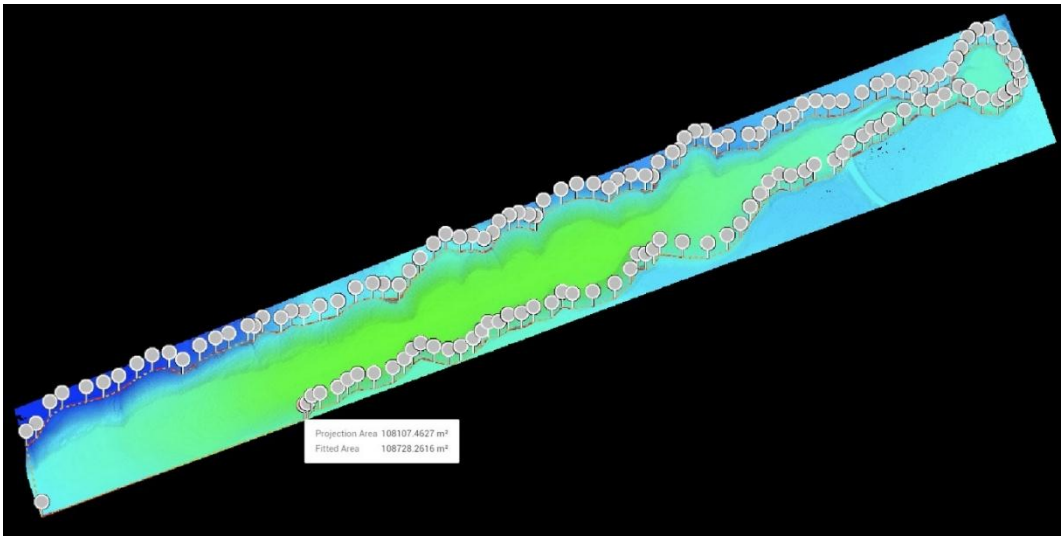


Figure 2-9. Projected surface area of Branch 4 of the waste dump

2.3 Operator information

The Petrila mining unit operated under different organizational structures throughout its activity period.

At the time of closure (2015), the mine was managed by the National Company for Mine Closure Jiu Valley (SNIMVJ).

Following the cessation of mining operations, SNIMVJ continued the closure and environmental rehabilitation works for the Petrila mining unit.

In 2023, SNIMVJ was reorganized into the Jiu Valley Energy Complex (CEVJ).

Part of SNIMVJ's assets, including the land hosting the closed waste dump of the former Petrila Mine, were transferred to CEVJ.

The land on which the waste dump is located is the property of CEVJ, and no access restrictions are currently in place.

2.4 Characteristics of waste

The waste dump from Petrila mine was formed gradually, in parallel with the development of the mining operation. The waste material originates both from the excavation of underground mining works and from the activity of the Preparation Plant, which generated a significant volume of fine material resulting from coal separation.

The geometric configuration of the waste dump exhibits a structure developed along five deposition directions and a stepped growth pattern, with areas that were successively filled depending on land availability and the routes used for waste transport.

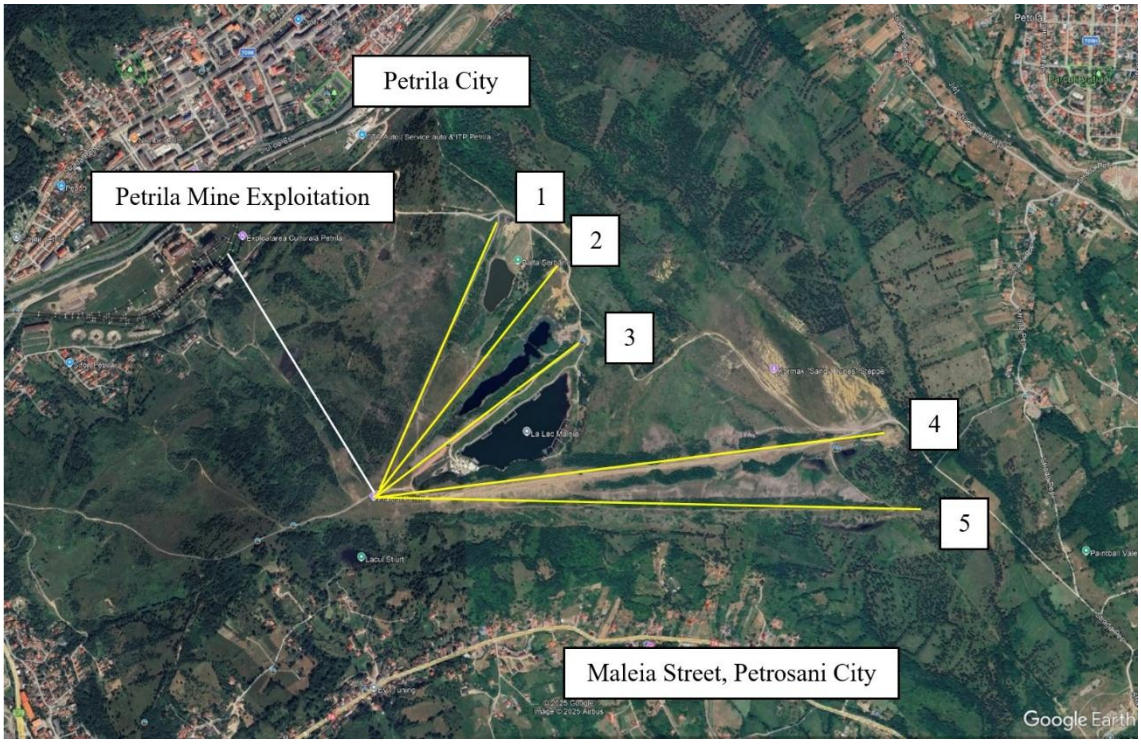


Figure 2-10. The five deposition directions of the Petrila mine waste dump

Over time, the transport of waste material to the Petrila dump was carried out by:

- Aerial cableway, used mainly for deposition in hard-to-access areas;
- Conveyor belt transport, used for preparation waste and deposition in the vicinity of the plant;
- Road transport, during periods of reduced activity.

The conveyor belts and aerial cableways were dismantled prior to the closure of the Petrila Mining Exploitation.

The waste rock resulting from mine opening and development works was brought to the surface and discharged by tipping (overturning/dumping the mine cart using the tippler) onto a conveyor, then loaded into buckets and transported to the waste dump by cableway.

Petrila mine Waste Dump is classified as presented in

Table 2-2.

Table 2-2. Waste dump classification

Classification Criteria		Classification group
		Characterisation
According to the nature of the rocks and the deposited materials	Content in useful substances	Waste dump
	Rock strength	Dump formed of hard and soft rocks
	Flammability	Dump containing combustible materials (coal, carbonaceous shales)
	Degree of radioactivity	Dump without radioactivity
According to the geometry of the dump	Number of steps	Single-step dumps
	Height	Low-height dumps (< 30 m)
	Surface relief	Dump on sloping ground with 20° ≤ a
According to the potential for environmental pollution	Influence of wind-borne dust	Dump with some potential for atmospheric dusting
	Influence of water	Normal dumps, meaning without water at the base or in the direct foundation
Dump formation technology	Dry transport	Dry dump formed by aerial ropeway transport

The geotechnical characteristics of the dumped rocks are presented in Table 2-3 and

Table 2-4.

Table 2-3. Particle size distribution and physico-mechanical properties of the dumped rock mixture

No.	Specification	Unit	Variation limits
1	Particle size composition		
	Clay (< 0.005 mm)	%	—
	Dust (0.005 ÷ 0.05 mm)	%	2.3 ÷ 6.8
	Sand (0.05 ÷ 2.0 mm)	%	13.2 ÷ 39.3
	Grave (2.00 ÷ 20.0 mm)	%	23.3 ÷ 55.5
	Boulders (> 20 mm)	%	6.5 ÷ 59.7
2	Absolute specific gravity	cN / cm^3	2.46 ÷ 2.69
3	Bulk density	cN / cm^3	1.79 ÷ 2.10
4	Natural moisture content	%	7.85 ÷ 17.56
5	Porosity	%	23.0 ÷ 42.88
6	Void ratio	-	0.29 ÷ 0.75
7	Degree of saturation	-	0.46 ÷ 0.96
8	Compressibility coefficient	10^{-2} cm^2 / daN	0.4 ÷ 1.07
9	Compressibility modulus	daN / cm^2	80.0 ÷ 166.0
10	Specific settlement	cm / m	1.11 ÷ 3.80

Table 2-4. Shear strength of the dumped rock mixture

Operational moisture content W, %	Degree of saturation S	Cohession C, daN / cm²	Internal friction angle φ,°
7.85 ÷ 10.00	0.45 ÷ 0.76	0.32 ÷ 0.46	26 ÷ 33
12.49 ÷ 18.52	0.85 ÷ 0.96	0.26 ÷ 0.42	23 ÷ 31
15.18 ÷ 19.09	1.0	0.20 ÷ 0.38	26 ÷ 27

The foundation of the dump consists of topsoil and slope deluvium, underlain by microconglomerates and sandstones, with the direct foundation being eroded or affected by local landslides in certain areas.

During the period in which the mine was in operation, when selecting the location of the waste dump, no criteria were considered other than minimizing the affected land area, using terrain with rugged morphology and low productivity (reduced vegetation), which would allow the deposition of a large volume of waste rock.

The nature of the dumped rocks does not allow the recovery of the stored waste. The deposits formed within the mining perimeter of the site do not contain harmful elements that would require neutralization.

2.5 Original deposit info

2.5.1 Geological structure

Jiu Valley coal field is located in the southern part of Hunedoara County and in the southwest of Transylvania, in the Southern Carpathian depression called Petroşani depression or ”Valea Jiului” (EN: Jiu Valley) depression.

Petroșani Basin is part of the generation of post-Laramic sedimentary basins in the Southern Carpathians. The foundation of the basin is of a metamorphic type and involves rocks affected by different degrees of metamorphism, belonging to both the Danubian and the Getic units.

The basin presents itself as an asymmetric syncline with a WSW-ENE orientation. Starting from the area of Aninoasa where the sedimentation basin widens, its structure bifurcates into two synclinal folds, as presented in Figure 2-11.

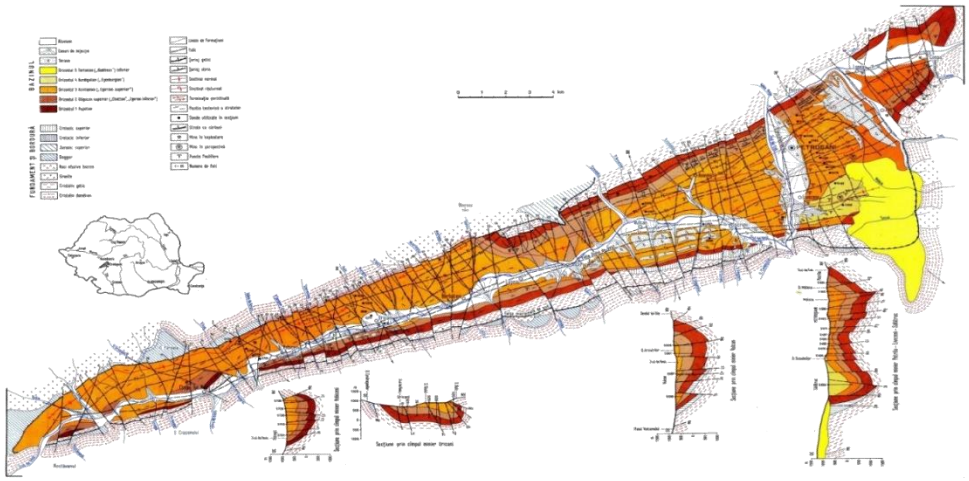


Figure 2-11. Jiu Valley tectonics

a) the Nordic syncline oriented WSW-ENE affecting the Dâlja, Petrila, Lonea, Răscoala mining perimeters;
b) the southern syncline oriented W-E and then ESE in the perimeter of Iscroni and Sălătruc-Livezeni.

In the northern part of the Iscroni perimeter and in the Livezeni perimeter, an anticlinal zone with an approximate direction SW-ENE can be observed.

The foundation of this mining field is formed by the crystalline schists of the Getic Domain. The oldest formations that constitute the stratigraphic succession of the Petrila mining field belong to the Lower Conglomeratic Level.

Above the base formed by the Getic-type crystalline schists lies, in a discordant and transgressive manner, the Lower Conglomeratic Level, also known as the bedding formation.

Above the deposits of this level lies the productive formation, whose thickness reaches approximately 500 m.

The succession of sedimentary deposits ends here, unlike in the Lonea area, with the Upper Conglomeratic Level, composed predominantly of conglomerates and sandstones.

Structurally, the sedimentary formations represent the northern flank of a syncline that actually develops farther to the south, known as the Petrila–Maleia syncline.

A system of longitudinal and transverse faults divides the mining field into separate blocks.

2.5.2 Hydrogeological conditions

Geomorphologically, the Petrila mining perimeter displays a hilly landscape shaped by the erosive action of watercourses and torrents flowing along the flanks of the syncline. The surface of the mining field is crossed by numerous torrents that carry water only temporarily, following atmospheric precipitation.

The rehabilitation measures provide a certain degree of sealing of the dump surfaces in order to limit the infiltration of precipitation water into the dump body.

It should be noted that stability analyses performed did not take pore water pressure into account, because the material is granular and has a high permeability, allowing the possibility of rapid gravitational drainage of water from the dump body.

Based on the above, it can be concluded that the Waste Dump is stable when the deposited waste material is at natural moisture content and may become unstable when moisture increases to the saturation limit. However, this is considered unlikely given the high water-draining capacity of the dumped rock.

2.5.3 History and status

Mining operations began in 1840 (the earliest in the Petroșani Basin), intensified in 1859, and experienced further development after 1870.

Between the Lonea mining field, located to the east, and the Petroșani–Dâlja mining field to the west, the Petrila operation extends over a length of approximately 3 km. This mining field, which appears to be one of the oldest in the Petroșani Basin, is crossed by the Transylvanian (Eastern) Jiu River and its tributaries: the Rău, Fântânii, Rusalin, Francisc, and Ferro streams on the left side, and the Bănița stream on the right side.

In the Petrila mining field, 16 seams were identified, of which seams 3, 4, 5, 6, 7, 8, 9, 12, 13 and 14 are exploited. The remaining seams, consisting of shaly material, are not workable.

Seam No. 3 is considered the main seam. Its thickness ranges between 2 and 40 m. It consists of several intercalations of coal and clay shales, and sometimes lenses of spherosiderites, either intercalated within the clays or within the coal seam.

Seam No. 4 was not exploited up to Level IX, since it reached a thickness of only 1 to 1.1 m starting from Level X.

Seam No. 5 has a thickness ranging between 2 and 4.5 m and represents the second main seam.

The mine operated under various organizational structures until its closure in 2015. The waste dump currently forms part of the assets transferred to CEVJ (Jiu Valley Energy Complex)

2.5.4 Geo-mechanical characterization of the rocks in the Jiu Valley

Geo-mechanical characteristics of the rocks in the Jiu Valley are summarised in Table 2-5.

Table 2-5. Geomechanical characterization

No.	Nam of the rock	Clay material, %	Carbonate material, %	Sandstone material, %
1	Clay-sandy marl	23.2	48	28.8
2	Marly-clay sandstone	11.7	29	59.3
3	Clay-sandy marl	33.2	44	22.8
4	Calcareous sandstone	9.2	31.2	59.6
5	Clay with marly nodules	61.4	28.4	10.2
6	Weakly coarse clayey marl	34.1	46.3	19.6
7	Clay-ferruginous sandstone	33.6	-	66.4
8	Calcareous-clay sandstone	14.5	29	56.6
9	Weakly gritty marly clay	58.2	30.2	11.6
10	Weak limestone-clay sandstone	12.4	15.6	72
11	Clay-sandy marl	34.5	42.3	23.2
12	Coarse clay	65.3	-	34.7

2.5.5 Characteristics of coals

The sedimentary deposits in which the coal beds are buried are made up of alternations of rocks such as: clays, marls, gritty clays, gritty marls, sandstones and less microconglomerates. The weight of these rocks is different, depending on the level in which they are located.

Petrographic characteristics

Macroscopically, the Valea Jiului coal has a black colour, tar gloss or semi-matte, and frequently presents stratification due to the alternation of glossy, semi-glossy bands or impure intercalations.

Physico-chemical characteristics

The physico-chemical properties of coals are quite varied, both from one layer to another and within the same layer.

The inhibition humidity has an average value of 3.55%, and the hygroscopic humidity of 2.47%.

Ash represents the inorganic mass of coal, namely: clay substances, carbonates, sulphates, quartz, etc.

The average value of clay ash, compared to the initial sample, is 25.80%, and the combustible mass represents 38.02%.

Volatile substances represent an average percentage of 34.80%, compared to the initial sample, and 47.03% for the fuel mass, belonging to the group of oils with a high index of volatile substances.

Combustible sulphur, present in coals in the form of pyrite, has an average value of 2.83% compared to the initial sample and 4.02% compared to the fuel mass.

The lower calorific value depends on the ash content and the moisture content of the coals, the average value related to the fuel mass being 7596kcal/kg.

Industrial characteristics

Industrial characteristics of coal in Jiu Valley are summarised in Table 2-6.

Table 2-6. Coal industrial characteristics

Rock	Apparent specific gravity, γ_a, 10^4 N/m^3	Compressive strength, σ_c, Mpa	Strength coefficient, F
Shale hard coal	1.37	20.7 – 33.7	2 – 3.37
Compact hard coal	1.36	3.8 – 22.6	0.38 – 2.26
Friable hard coal	1.33	2.7 – 22.6	0.27 – 2.26
Siderite hard coal	1.38	8.1 – 15.4	0.81 – 1.54
Fractured hard coal	1.23 – 1.35	8.4 – 10	0.84 – 1
Slightly fractured hard coal	1.34	1.7 – 27.5	0.17 – 2.75

2.6 Environmental & access considerations

The region is characterized by a temperate-continental subalpine climate, with abrupt temperature variations, influenced mainly by Mediterranean air currents and, more rarely, by northern currents.

The transportation routes serving the Petrila and Lonea mines pass through the town of Petrila.

Between the Lonea mining field, located to the east, and the Petroșani–Dâlja mining field to the west, the Petrila operation extends over a length of approximately 3 km.

According to the data collected during the 2011 census, the Town of Petrila had a population of 22,692 inhabitants. However, over the past 10 years, the number of residents has decreased by 3,092 persons, representing a 13.63% decline compared to the 2011 census. This significant demographic decrease reflects, among other factors, the profound decline of mining activity in the area. Consequently, based on the information obtained in 2022, the population of the town of Petrila is estimated at 19,600 inhabitants.

2.6.1 Location and access to the mining perimeter

From an administrative standpoint, the Petrila mining area belongs to the town of Petrila, where the headquarters of the Petrila Mine is also located, at the following address: Minei Street, No. 2, Hunedoara County.

The Petrila mining area is situated in the eastern part of the Jiu Valley coal basin and is bordered to the east by the Lonea Development–Exploitation Area and the Livezeni Development–Exploitation Area, to the south.

The useful mineral substance exploited within the area was energetic hard coal, with weak agglutinating and coking properties.

2.6.2 Geometrization works for Branch 5 waste dump

The morphological reshaping works were carried out with the purpose of increasing the stability of the slope and consisted of operations aimed at reducing the slope angle as much as possible.

The dump was grassed, and the slopes were afforested in order to improve their stability.

A portion of the waste material needed for backfilling the voids and foundations remaining after the demolition of buildings was taken from this dump.

For the revegetation of the waste dump through grassing and afforestation, the following operations were planned:

- Leveling works and slope reduction;
- Clearing works for removing oversized materials;
- Afforestation with acacia forest seedlings planted in 30×30×30 cm pits filled with borrowed topsoil;

- Maintenance and revision works for the plantations, including gap filling.

2.6.3 Leveling, stabilization, consolidation

The environmental rehabilitation works planned for the waste dump were:

- cleaning of the land;
- regrading of the dump to increase stability;
- land levelling;
- scarification;
- application of fertilizing substances;
- grassing;
- planting of deciduous seedlings on the slopes.

2.6.4 Preparatory works for returning the dump to the forestry land use

The installation of woody or herbaceous vegetation was preceded by works consisting of the removal of foreign bodies from the land, shaping (leveling) and consolidation of the slopes, and securing the planting material.

For waste dumps, the horizontal surfaces (platforms) require, as applicable, the removal of foreign bodies, leveling works, and scarification before placing a 20 cm thick layer of topsoil, which is subsequently seeded with perennial grasses. The leveling and scarification works are carried out after the prior removal of foreign bodies (various debris and waste) and large stones.

More difficult issues are posed by the stabilization of the dump slope and the prevention of runoff and erosion on steep slopes (25–30°). These objectives can be achieved by manually terracing the slope into narrow terraces of 0.7–1.0 m, spaced at approximately 3 m.

The main factors for characterizing and classifying the site conditions on waste dumps, which determine the selection of woody species, are the grain size composition of the deposit (rock fragments, boulders, stones, fine gravel), the petrographic nature of the fragments, and their pH. In general, since these are deposits of raw waste composed of hard, consolidated rocks, the dumps are completely lacking in the two components essential for plant life: nutrients (N, P, K, humus) and the water required for physiological processes such as transpiration and growth, which is not retained in sufficient quantities due to the grain size distribution.

These conditions require the selection of species with very low nutrient demands, more xerophytic in relation to soil water requirements, and the mandatory use of borrowed topsoil in planting pits or during seeding, in order to ensure a minimal nutrient stock.

2.6.5 Revegetation of the waste dump surface

For the environmental rehabilitation of the land previously occupied by mining activities and its return to forestry use, grassing and afforestation were chosen as the technical solution.

The Petrila waste dump was arranged in order to limit the pollution generated by the deposited materials.

For the waste dump, afforestation and grassing works were planned as follows:

- the dump platforms were grassed;
- the dump slopes were grassed and afforested.

The slope consolidation works on the waste dump were preparatory operations for afforestation and for controlling deflation (wind erosion) and, in particular, water-induced erosion.

For restoring the forest land on the areas occupied by the waste dumps within the Petrila mining perimeter, landscape rehabilitation works through grassing were planned.

The total area occupied by the waste dump, around 26 hectares, was subjected to revegetation works through grassing and afforestation, of which:

- platform area: 18.2 ha;
- slope area: 7.8 ha.

Waste dump grassing

For the restoration of the landscape through grassing, the following stages were planned:

- harrowing of the land;
- covering the areas with a 20 cm layer of topsoil;
- procurement and transport of topsoil to the site;
- seeding of the areas with perennial grasses;
- application of fertilizers;
- watering of the areas.

Afforestation works for landscape restoration

The slope of the waste dump, with a surface area of 7.8 hectares, was also subjected to revegetation works through afforestation.

The restoration of the landscape through afforestation involved the following stages:

- manual digging of 0.3 × 0.3 × 0.3 m pits

- planting of seedlings
- application of organic fertilizers (manure compost)
- application of organic fertilizers (farmyard manure)
- soil loosening around the seedlings
- watering of the areas with a hose, 0.02 m^3 per pit, in 3 cycles

After planting, during the following spring, supplementary planting works were planned to replace missing seedlings (those that dried out or did not take root) in a proportion of 30%, due to the difficult vegetation conditions, particularly the lack of nutrients in the substrate in which planting is carried out and, in some cases (in the hilly area), the moisture deficit.

As maintenance works, six soil loosenings around the planted seedlings and six inspections of the seedlings are carried out over a period of four years, starting from the year of planting.

The total surface of the dump landscaped through grassing (platforms) is 18.2 ha. The surface of the slopes landscaped through afforestation is 7.8 ha.

According to the available technical and administrative documentation, there is no information indicating that the waste facility has been classified as presenting major accident hazards within the meaning of Directive 2006/21/EC on the management of waste from extractive industries.

2.7 Other information

2.7.1 Stability study of the Waste Dump - Branch 5 at the Petrila mining unit

Taking into account the geometric configuration of the dump and the shape of the foundation ground, the stability analysis was performed after the mine closure and for returning the dump to its natural state, considering that sliding may occur along surfaces with a cylindrical–circular outline.

The stability analysis of the Branch 5 waste dump from Petrila was carried out using input data from the site plan, the longitudinal section L1–L1, and four cross sections: T1–T1, T2–T2, T3–T3, and T4–T4.

The positions of the cross sections were selected so as to define the sensitive areas of Branch 5 from a stability perspective, specifically the areas where the toe of the slope comes into contact with the two lakes located on the northern side, as well as the areas with maximum dump height and inclination.

The values of the mechanical strength characteristics of the dumped material used in the stability analysis for the two cases, material at natural moisture content and material at saturation moisture content, are presented in Table 2-7.

Table 2-7. Physico-mechanical characteristics used in the stability analysis

Rock type	Natural moisture			Saturation moisture		
	Bulk density γ_{nat}, kgf/m^3	Cohesion c, kgf/cm^2	Internal friction angle ϕ, degrees	Bulk density γ_{sat}, kgf/m^3	Cohesion c, kgf/cm^2	Internal friction angle ϕ, degrees
Waste dump material	1780	0.40	16	1930	0.18	15
Topsoil	1810	0.3	23	1930	0.21	18
Waste dump material / Topsoil	-	0.29	24	-	0.05	24

For the purpose of determining the stability reserve of the slopes, the stability factor was calculated for each slope considered. In each case, 52 potential slip surfaces passing through the dump body were generated, and the most probable slip surface and the minimum stability coefficient were determined. The results of the analyses are presented in Table 2-8, and the critical slip surfaces can be viewed in Figure 2-12 to Figure 2-21.

It should be noted that the stability analyses did not take pore water pressure into account, because the material is granular and has a high permeability, allowing the possibility of rapid gravitational drainage of water from the dump body.

Therefore, in order to assess the behaviour of the dump under precipitation conditions, the physical and mechanical parameters of the dumped waste were determined and calculated for different moisture conditions, and the design values were selected following the processing of the data.

Table 2-8. Cylindrical–circular slip surfaces

Section	Slope	H, m	α, grade	Natural moisture			Saturation moisture		
				Fellenius	Janbu	Bishop	Fellenius	Janbu	Bishop
$T_1 – T_1$	northern	16.50	33.46	1.77	1.83	1.79	1.02	1.06	1.05
$T_2 – T_2$	northern	16.41	30.33	2.28	2.39	2.30	1.38	1.42	1.40
$T_3 – T_3$	northern	19.40	25.15	1.69	1.75	1.81	1.10	1.15	1.20
$T_3 – T_3$	southern	15.10	50.05	1.36	1.55	1.38	0.78	0.85	0.82
$T_4 – T_4$	northern	25.08	33.1	1.29	1.34	1.33	0.82	0.86	0.86
$T_4 – T_4$	southern	16.94	30.72	1.61	1.69	1.69	1.00	1.05	1.08

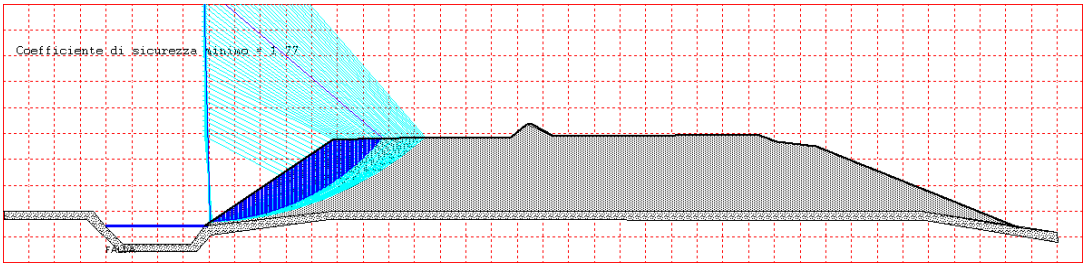


Figure 2-12. $T_1 – T_1$ section, northern slope, natural moisture

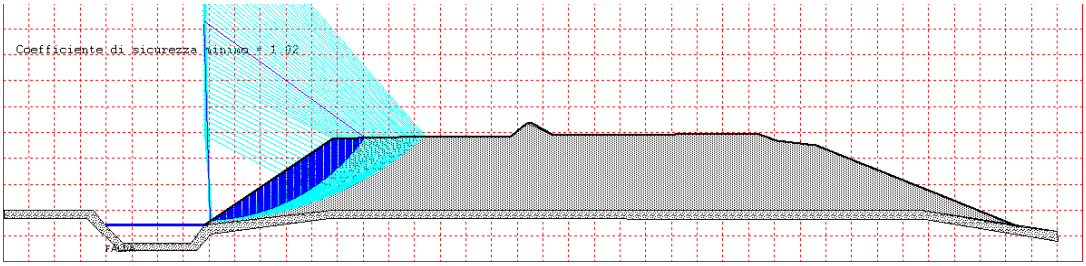


Figure 2-13. $T_1 – T_1$ section, northern slope, saturation moisture

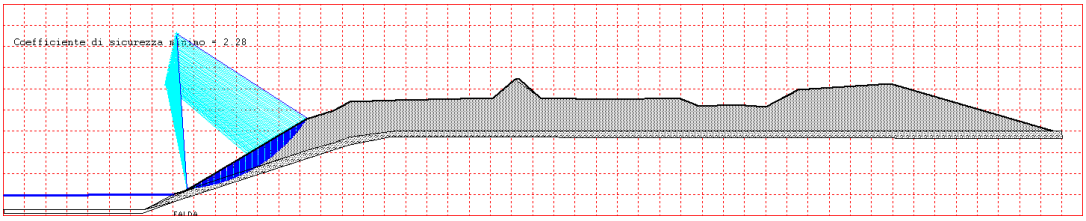


Figure 2-14. T_2 – T_2 section, northern slope, natural moisture

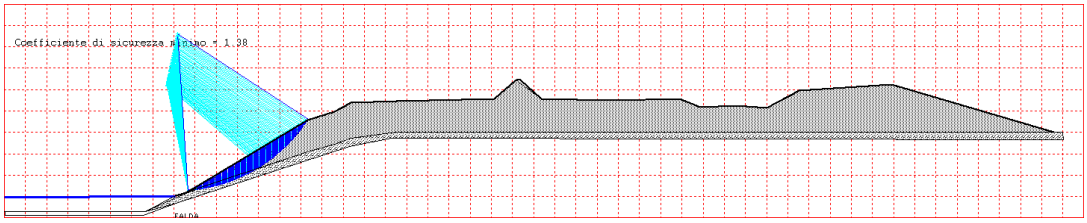


Figure 2-15. T_2 – T_2 section, northern slope, saturation moisture

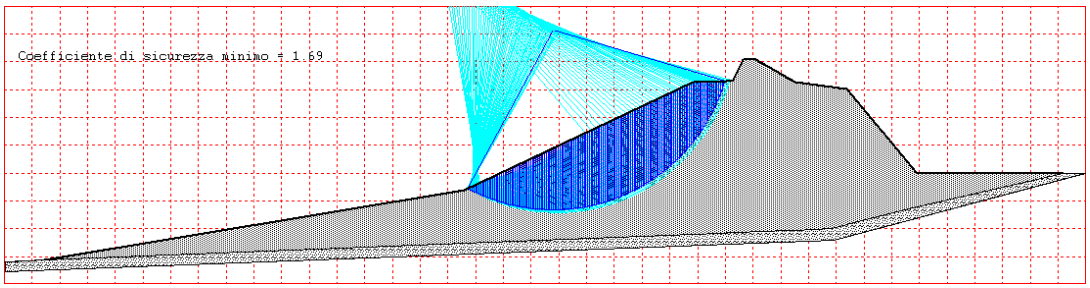


Figure 2-16. T_3 – T_3 section, northern slope, natural moisture

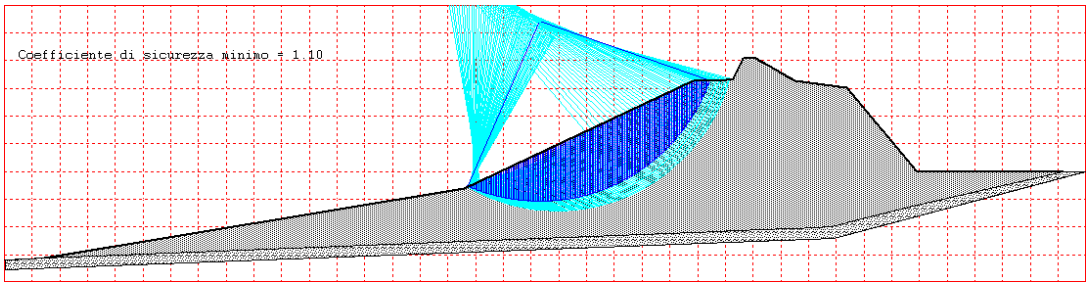


Figure 2-17. T_3 – T_3 section, northern slope, saturation moisture

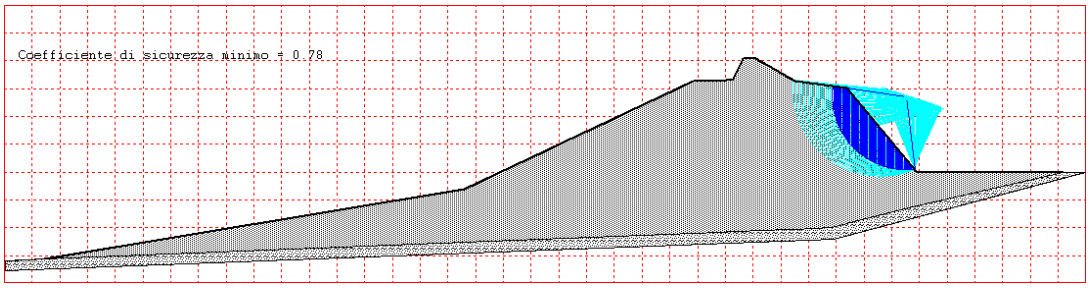


Figure 2-18. T_3 – T_3 section, southern slope, saturation moisture

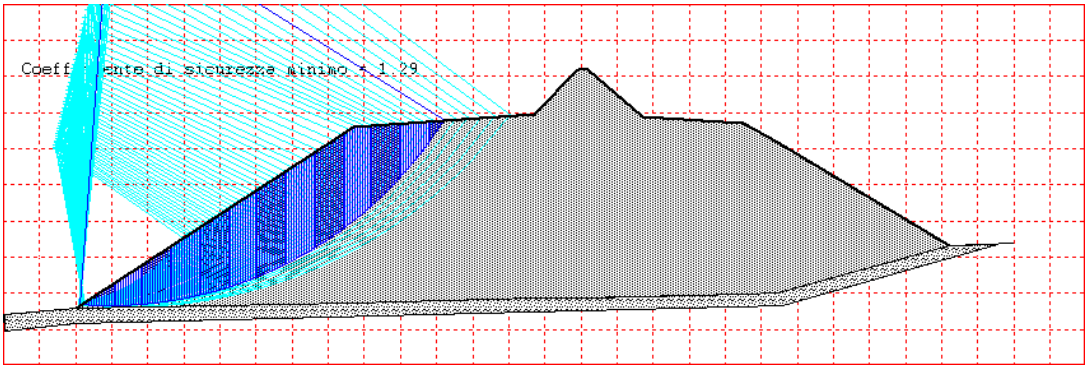


Figure 2-19. $T_4 – T_4$ section, northern slope, natural moisture

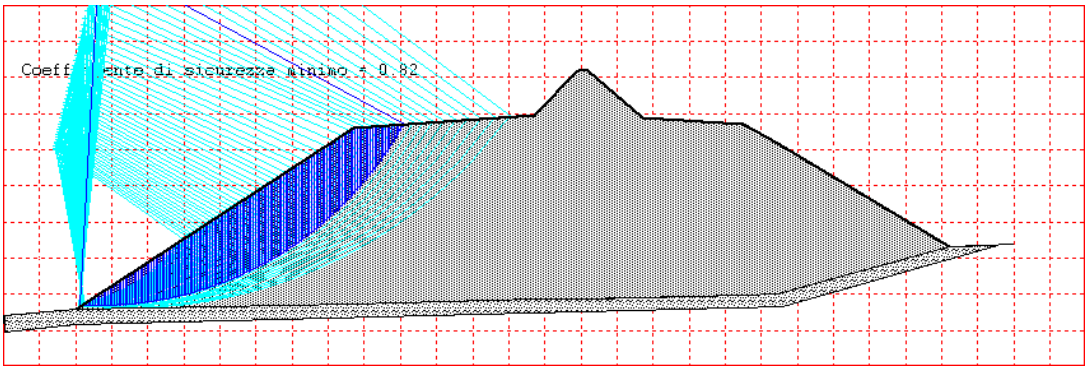


Figure 2-20. $T_4 – T_4$ section, northern slope, saturation moisture

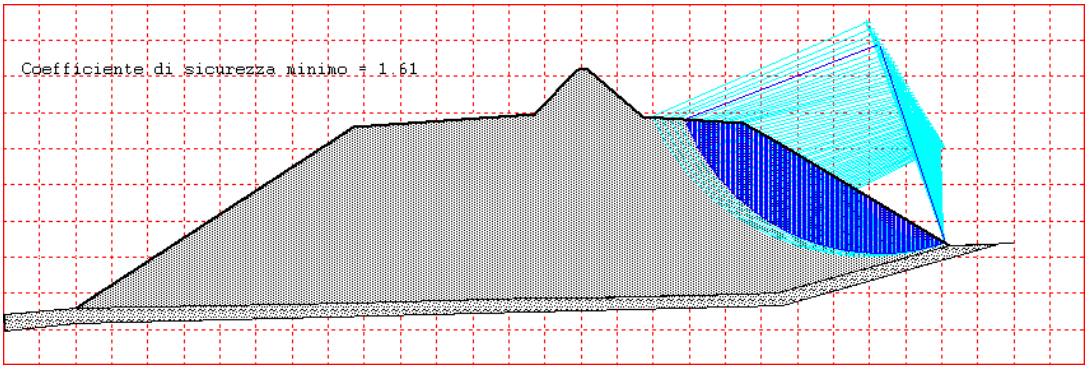


Figure 2-21. $T_4 – T_4$, section southern slope, natural moisture

Based on the results obtained from the stability analyses, there can be concluded:

- The stability analysis concerned slopes with heights between 15.1 m and 25.08 m and slope angles between 25.15° and 50.05°, located on both the northern and southern flanks.
- The cross sections used as the basis for the stability analysis were carried out as follows:

- ✓ Section T1–T1 between pillars P1 and P2, covering the contact area with the first lake
- ✓ Section T2–T2 between pillars P3 and P4, covering the contact area with the second lake
- ✓ Section T3–T3 near pillar P6, where a zone with a steep southern slope (approximately 50°) was identified
- ✓ Section T4–T4 between pillars P7 and P8, where the maximum dump height (25.08 m) was identified on the northern flank, corresponding to a slope angle of 33.1°

- For all analysed sections, when using the physico-mechanical characteristics of the material at natural moisture content, the obtained stability factor values were greater than 1.0 and even exceeded the value of 1.3 recommended by the Technical Specifications for the design, construction and conservation of waste dumps.
- Under conditions where the material is at saturation moisture content, only the northern slope in section T2–T2 has a stability reserve greater than 1.3. For the other slopes, the stability factors indicate a limit equilibrium condition or instability;
- At the limit of stability are the northern slope in section T1–T1 (s = 1.02 according to Fellenius), the northern slope in section T3–T3 (s = 1.10 according to Fellenius), and the southern slope in section T4–T4 (s = 1.00 according to Fellenius);
- The slopes that become unstable when the material reaches saturation moisture content are the southern slope in section T3–T3 (s = 0.78 according to Fellenius), where the potential failure is caused by the high slope angle, and the northern slope in section T4–T4 (s = 0.82 according to Fellenius), which has the greatest height (25 m) at a slope inclination of 33°;
- By analysing the shape and position of the potential slip surfaces, it can be observed that, in the case of material with high moisture content, the critical slip surface is located closer to the slope, has a shorter length, and mobilises a smaller sliding mass.

2.8 Sample collection

For the geochemical analysis of the material deposited on Branch 4 of the Petrila waste dump, 12 samples were collected from four different locations: three locations situated on the upper plateau of the waste dump and one location outside the perimeter of the dump, the latter serving for the collection of control samples (Figure 2-22).



Figure 2-22. Sample collection locations

From each location, three samples were collected at different depths, namely 30 cm, 50 cm, and 70 cm below the ground surface, Figure 2-23,as follows:

Depth	Samples
30 cm	P1, P4, P7, P10
50 cm	P2, P5, P8, P11
70 cm	P3, P6, P9, P12

The coordinates of the four locations are presented in Table 2-9:

Table 2-9. Sample location coordinates

Location	Sample	Latitude (Y/N)	Longitude (X/E)
L1	P1, P2 ,P3	45.4317566	23.388586
L2	P4, P5, P6	45.4320459	23.3940802
L3	P7, P8, P9	45.4323699	23.40113664
L4	P10, P11, P12	45.4300583	23.4070503



Figure 2-23. Sampling depth of 70 cm at Location 3

2.9 References and metadata

Florea, C. (2018). Petrila Mine – Sacred Underground. In Belaj, J., Belaj, M., Krznar, S., Sekelj Ivančan, T. & Tkalčec, T. (eds.), *Sacralization of Landscape and Sacred Places.* Zbornik Instituta za arheologiju 10, 375–381. Zagreb: Institute of Archaeology.

Halda Steril Petrila – Ecologizare (n.d.). Plan tehnic DWG (in English: Petrila Waste Dump – Rehabilitation Plan).

Halda Steril Petrila – Situație existentă (n.d.). Plan tehnic DWG (in English: Petrila Waste Dump – Existing Situation Plan).

Jujan, C. & Svoboda, T. (2009). *Mina Petrila – 150 ani de activitate în mineritul industrial* (in English: Petrila Mine – 150 Years of Industrial Mining Activity). Deva: Cetate.

Oficiul de Cadastru şi Publicitate Imobiliară Hunedoara – Biroul de Cadastru şi Publicitate Imobiliară Petroșani (2025). *Extras plan cadastral pentru imobilul cu IE 63069, UAT Petrila / Hunedoara* (in English: Cadastral Plan Extract for Property IE 63069, Petrila Administrative Unit, Hunedoara County).

Onica, I. (2016). *Contribuții la modelarea și analiza stabilității terenurilor aflate sub*

influența excavațiilor miniere subterane și perfecționarea sistemelor de exploatare a zăcămintelor de substanțe minerale utile (in English: Contributions to the Modelling and Stability Analysis of Land under the Influence of Underground Mining Excavations and Improvement of Mineral Deposit Exploitation Systems). Teză de abilitare. Universitatea din Petroșani.

Point Zero – Ideogram Studio – Arheco Arhitectura Economică (2024). *Elaborarea Planului Urbanistic pentru Zone Construite Protejate și a Regulamentului Local de Urbanism aferent Zona Mina Petrila. Etapa 1: Elaborarea studiilor de fundamentare. Studiu peisagistic* (in English: Preparation of the Urban Plan for Protected Built Areas and Related Local Urban Regulation – Petrila Mine Area. Stage 1: Baseline Studies. Landscape Study). Contract nr. 9769/22.04.2024. Beneficiar: Consiliul Județean Hunedoara.

Svoboda, T. (2009). *Cărbunele și drumurile sale de fier* (in English: Coal and Its Iron Roads). Caietele Petro-Aqua 7. Petroșani: Grafica Plus.

3 COAL WASTE DUMP in LIBIĄŻ (Poland)

3.1 Facility identification

The coal waste dump constitutes an anthropogenic accumulation of waste generated by coal mining and processing at the ZG Janina Coal Mine.

3.2 Location and extent

The mining waste disposal facility of ZG Janina is in Libiąż town, southern Poland (50°04' 46.7" N, 19° 18' 16.0" E) (Figure 3-1).

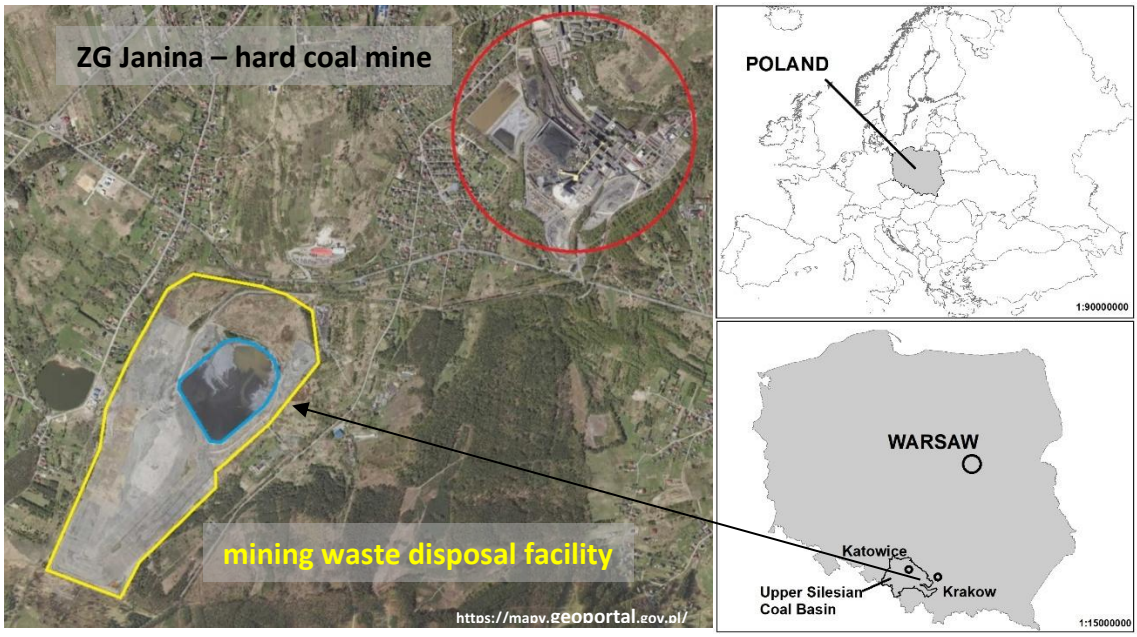


Figure 3-1. Location of ZG Jania mining waste disposal facility in Libiąż town

The facility is in an area designated as an industrial waste disposal site (SOP) in the local development plan for the city of Libiąż. This area is a heavily anthropogenic wasteland. On the western side, the facility is separated from single-family housing by a natural green belt. On the eastern side, it borders the Janina Mining Plant's construction facility, the "West" ventilation shaft, and its adjacent infrastructure.

3.2.1 Determination of the geometric characteristics of the waste dump

The area of the OUOW is 33.51 ha, and its capacity is 5,767,653 m^3 (9.8 million Mg). The mining waste heap was formed as an above-ground object with a relative height of up to 52 m. The elevation of the object's top is 278-279 m above sea level. The slope of the

slopes is uniform and amounts to 1:3.5. Views of the entire spoil heap and selected slopes are presented on the figures Figure 3-2 - Figure 3-6.



Figure 3-2. 3D view of ZG Jania mining waste disposal facility in Libiąż



Figure 3-3. View of the western escarpment of ZG Jania mining waste disposal facility in Libiąż



Figure 3-4. Western slope of the Solid Mining Waste Storage Facility in Libiąż



Figure 3-5. The top of the Solid Mining Waste Outfall in Libiąż



Figure 3-6. Northern slope of the Solid Mining Waste Storage Facility in Libiąż

3.3 Operator information

Południowy Koncern Węglowy S.A. (Southern Coal Concern S.A.), in Jaworzno,Poland

The mining waste disposal facility of ZG Janina in Libiąż town (Poland) belongs to Southern Coal Concern S.A. and, until January 2016, was used for the deposition of mining waste from coal extraction and processing.
Southern Coal Concern S.A. is one of the leading producers of thermal coal in Poland, playing a key role in the national energy sector. The company manages three mining facilities located in western Małopolska and the eastern part of the Silesian Voivodeship: the Sobieski Mining Plant in Jaworzno, the Brzeszcze Mining Plant in Brzeszcze, and the Janina Mining Plant in Libiąż.

Coal extracted from these facilities is mainly supplied to the energy sector, district heating systems, and households.

The origins of Southern Coal Concern date back to 2005, when, following the merger of the Sobieski Jaworzno III Mining and Energy Plant and the Janina mine in Libiąż, a company was established that would later become the foundation of today's concern.

In recent years, the company has achieved an annual production level of approximately 4.6 million tonnes of coal, and its operations are supported by nearly 6,200 employees.

Zakład Górniczy Janina (Janina Mining Plant) in Libiąż, Poland

The mine was built by French investors. In 1906, the company was officially registered under the name *Compagnie Galicienne des Mines* (Galician Mining Company), with its headquarters in Paris. The share capital amounted to 5.5 million French francs.

The Janina Mining Plant conducts its production activities within a mining area covering 81.13 km². It is a typical single-operation facility, where the extraction and processing activities are concentrated in the "Janina" shafts. To the southwest of the "Janina" shafts is the "Western" shaft, which serves as a ventilation shaft.

Mining operations are currently carried out in seam 207. Extraction is conducted in two mining areas and includes exploitation of seam 207 in the eastern and central parts of each area.

Taking into account the size of the balance reserves of hard coal at ZG Janina—constituting about one-third of Poland's resources—the geological conditions of the deposit, its level of exploration, the extensive network of tectonic discontinuities, surface development, and economic factors, it is estimated that the current access and expansion of the 800 m level will enable the plant to operate stably at the planned extraction level for up to approximately 60 years.

3.4 Characteristics of waste

Mining waste deposited at the mining waste disposal facility (OUOW) originates from:

- preparatory and access works: shafts, crosscuts and roadways driven in coal seams with roof or floor cutting (waste code 01 01 02 – wastes from the extraction of minerals other than metal ores),
- the coal preparation plant, as wastes from coal sorting and beneficiation processes (01 04 12 – wastes from washing and cleaning of minerals other than those mentioned in 01 04 07 and 01 04 11).

Wastes with code 01 01 02 originating from preparatory mining works are characterized by high variability in petrographic composition; the proportions of claystones, sandstones, siltstones and partings vary and depend on the access works being carried out. The grain-size distribution of this material usually ranges from 0 to 300 mm.

In the petrographic composition of wastes 01 01 02, dark grey claystones dominate (over 90%). The remaining 10% consists of siltstones and sandstones. The mineralogical composition of the waste is as follows:

- quartz: 55–56%,
- potassium feldspar: 21–23%,
- kaolinite: 4–6%,
- illite and muscovite: 3–5%,
- chlorite: <1%
- amorphous material: 12–13%.

Wastes with code 01 04 12 originating from the Coal Mechanical Processing Plant differ in grain size depending on the process in which they are generated; therefore, this group of wastes includes:

- coarse-grained washer rejects (from heavy-liquid beneficiation) with a particle size of 20–200 mm,
- medium-grained wastes from jigs with a particle size of 2–200 mm,
- fine-grained wastes from spirals with a particle size of 0.5–2.0 mm.

In terms of petrographic composition, preparation wastes are characterized by a relatively uniform composition (clay rocks, siltstones, sandstones) containing coal partings. Their mineralogical composition includes:

- quartz: 30–31%,
- kaolinite: 20–22%,

- illite and muscovite: 9–11%,
- feldspars: 2–4%,
- chlorite: 1–3%,
- mixed-layer structures, probably illite–smectite: 1–3%
- halite: <1–2%,
- amorphous material: 29–30%,
- siderite and pyrite occur in trace amounts.

Preparation wastes also include slurry (mud) wastes. These wastes originate from the chamber and belt filter presses. They are very fine-grained materials, with particle sizes from 0.0 mm to 0.5 mm. In terms of petrographic composition, in addition to claystone grains, they also contain a certain amount of coal.

It is estimated that within the OUOW body, wastes from preparatory and access works (01 01 02) account for approximately 14%, while the remaining part, about 86%, consists of preparation wastes (01 04 12).

To assess the physicochemical properties of wastes deposited at the OUOW, in 2020, as part of the study *"Analysis of the chemical stability of mining waste disposal facilities of TAURON Wydobycie S.A. – Janina Mining Plant in Libiąż"*, samples of wastes accumulated at the OUOW were collected for testing. A total of four waste samples were collected, each composed of five subsamples. Two samples (K1/1 and K2/1) represented wastes from the near-surface layer (0.0–0.1 m below ground level), and two samples (K1/2 and K2/2) represented wastes from the deeper layer (0.5–1.0 m below ground level). The collected samples were weathered, seasoned wastes exposed to atmospheric conditions for approximately 3 years.

For the collected samples, determinations were made of oxide chemical composition, total metal and non-metal contents, and the chemical composition of aqueous extracts. The results of chemical analyses of the wastes are summarized in the tables below.

Table 3-1. Chemical composition waste from the Janina Mining Plant

Oxides	K 1/1	K 1/2	K 2/1	K 2/2	Average
	% wag.				
SiO_2	48.01	42.46	53.24	50.12	**48.46**
Al_2O_3	18.25	16.95	17.62	18.13	**17.74**
Fe_2O_3	2.94	3.91	4.85	3.76	**3.87**
CaO	0.07	0.16	0.25	0.81	**0.32**
MgO	0.53	0.48	0.63	0.94	**0.65**
Na_2O	0.01	0.01	0.04	0.07	**0.03**
K_2O	1.94	1.86	2.39	2.36	**2.14**
SO_3	0.08	0.23	0.27	0.64	**0.31**
TiO_2	0.70	0.69	0.75	0.76	**0.73**
P_2O_5	0.04	0.03	0.02	0.02	**0.03**
Loss on ignition	26.93	32.69	19.45	21.92	**25.25**

Source: Bauerek et al., 2020. Analysis of the Chemical Stability of Mining aste Disposal Facilities of TAURON Wydobycie S.A. – ZG Janina in Libiąż

Table 3-2. Content of metals and metalloids in waste samples from the Janina Mining Plant

Metal/ metalloid	K 1/1	K 1/2	K 2/1	K 2/2	Average
	mg/kg				
As	5.9 ± 3.1	8.4 ± 4.5	8.7 ± 4.6	7.7 ± 4.1	7.7
Ba	230 ± 100	740 ± 330	300 ± 130	310 ± 140	395
Cd	<1	1.0 ± 0.4	1.0 ± 0.4	<1	1
Co	4.1 ± 2.2	21 ± 9	5.1 ± 2.7	6.9 ± 3.7	9
Cr	69 ± 31	65 ± 29	60 ± 27	63 ± 28	64
Cu	40 ± 18	64 ± 29	74 ± 33	72 ± 33	63
Hg	0.08 ± 0.04	0.24 ± 0.12	0.31 ± 0.16	0.19 ± 0.10	0.21
Mo	1.4 ± 0.7	3.2 ± 1.7	1.8 ± 0.9	1.3 ± 0.7	1.9
Ni	28 ± 13	57 ± 26	46 ± 21	30 ± 14	40
Pb	32 ± 14	22 ± 10	73 ± 33	88 ± 40	54
Sn	4.7 ± 2.5	<1	3.5 ± 1.8	3.4 ± 1.8	3.9
Zn	47 ± 21	139 ± 63	171 ± 77	193 ± 87	138

Source: Bauerek et al., 2020. Analysis of the Chemical Stability of Mining Waste Disposal Facilities of TAURON Wydobycie S.A. – ZG Janina in Libiąż

Table 3-3. Composition of water extracts from waste deposited at the Janina Mining Plant

Component	K 1/1	K 1/2	K 2/1	K2/2
pH	2,9	2,9	3,2	6,6
mg/l				
Antimony	< 0.005	< 0.005	< 0.005	< 0.005
Arsenic	< 0.005	< 0.005	< 0.005	< 0.005
Barium	0.31	0.027	0.026	0.027
Chromium	0.018	0.034	< 0.003	< 0.003
Zinc	0.72	1.60	0.47	0.0050
Cadmium	0.0032	0.0065	0.0017	< 0.0005
Magnesium	13.8	32.4	6.42	5.16
Manganese	0.51	1.20	0.37	0.0062
Copper	0.20	0.31	0.13	< 0.005
Nickel	0.12	0.22	0.033	< 0.005
Lead	< 0.005	0.054	0.011	< 0.005
Potassium	0.58	0.68	0.43	5.98
Mercury	< 0.001	< 0.001	< 0.001	< 0.001
Selenium	0.0067	0.0054	< 0.005	0.0066
Sodium	2.37	2.85	2.17	57.0
Vanadium	< 0.003	< 0.003	< 0.003	< 0.003
Calcium	37.3	102	27.1	13.5
Iron	6.30	12.0	2.3	< 0.005
Chlorides	< 5	< 5	< 5	31
Sulphates	305	696	138	85

Source: Bauerek et al., 2020 Analysis of the Chemical Stability of Mining Waste Disposal Facilities of TAURON Wydobycie S.A. – ZG Janina in Libiąż

3.5 Original deposit info

3.5.1 Geological structure

Libiąż is in the eastern part of the Upper Silesian Coal Basin (USCB). The USCB is the largest hard coal mining region in Poland, covering approximately 5,400–5,600 km². It is situated in the foreland of the Moravian-Silesian fold zone (Figure 3-7).

The USCB is characterized by the occurrence of over 200 industrial seams of thermal and coking coal, making it a key source of energy resources in Poland and the only source of coking coal in Europe.

Approximately 1,800 km² of the area is developed for mining, with around 20 active mines.

Above the Carboniferous coal-bearing strata lie deposits of the Triassic, Neogene, and Quaternary periods.

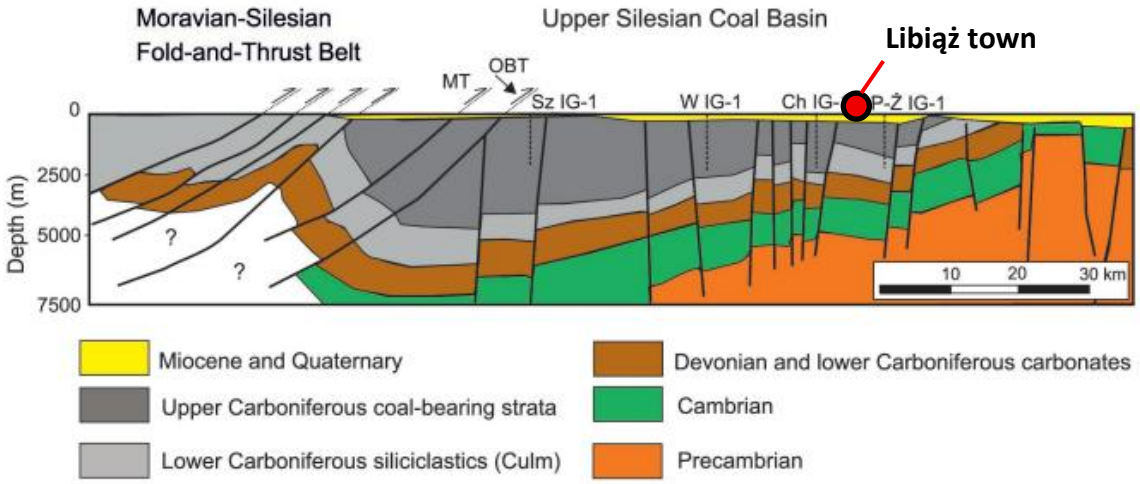


Figure 3-7. ***Libiąż location on the E–W cross-section of the Upper Silesian Coal Basin***

The geological structure around the mining waste disposal facilities was characterized based on data from exploratory boreholes drilled for the documentation of the hard coal deposit, as well as information derived from the Detailed Geological Map of Poland – Chrzanów sheet. Near the disposal site, the rock mass is composed of Carboniferous formations overlain by overburden consisting of Triassic, Tertiary and Quaternary deposits (Figure 3-8).

Carboniferous

In the upper part, the Carboniferous is represented by the Łaziska and Libiąż beds. In the geological profile of the Łaziska beds, thick-bedded sandstones dominate, with grain sizes ranging from fine- to coarse-grained. The thickness of individual sandstone beds ranges from several to several tens of metres. Between the sandstone beds occur claystone layers, locally sandy, with thicknesses of up to several metres, most often associated with numerous coal seams: 201/1, 201/2, 203/1, 203/2, 203/3, 203/4, 203/5, 204, 205/1, 205/2–3, 205/4, 205/5, 206/1, 206/2, 207, 207/2. The thickness of these seams varies from several tens of centimetres to several metres.

Overlying the Łaziska beds, the Libiąż beds, with a total thickness exceeding 200 m, are also built mainly of fine- and medium-grained sandstones, locally coarse-grained, sometimes with conglomerate intercalations. The Libiąż sandstones are characterized by medium to low cohesion and are sometimes friable. The thickness of individual sandstone beds ranges from several to several tens of metres. Between the sandstone

beds occur claystones with thicknesses from several tens of centimetres to several metres, locally sandy, most often associated with coal seams 116/1, 116/2, 117, 118, 119/1 and 119/2.

In the upper part of the Libiąż beds, several tens of centimetres thick layers of shale also occur. The predominance of sandstone layers means that aquifers developed in the sandstones of the Łaziska and Libiąż beds form a single, common Carboniferous aquifer. As a result of the draining effect of underground hard coal mining, the original groundwater table of the Carboniferous aquifer, which stabilized at a depth of several metres, has been lowered in the mining area to the level of mine workings in seams 116 and 118.

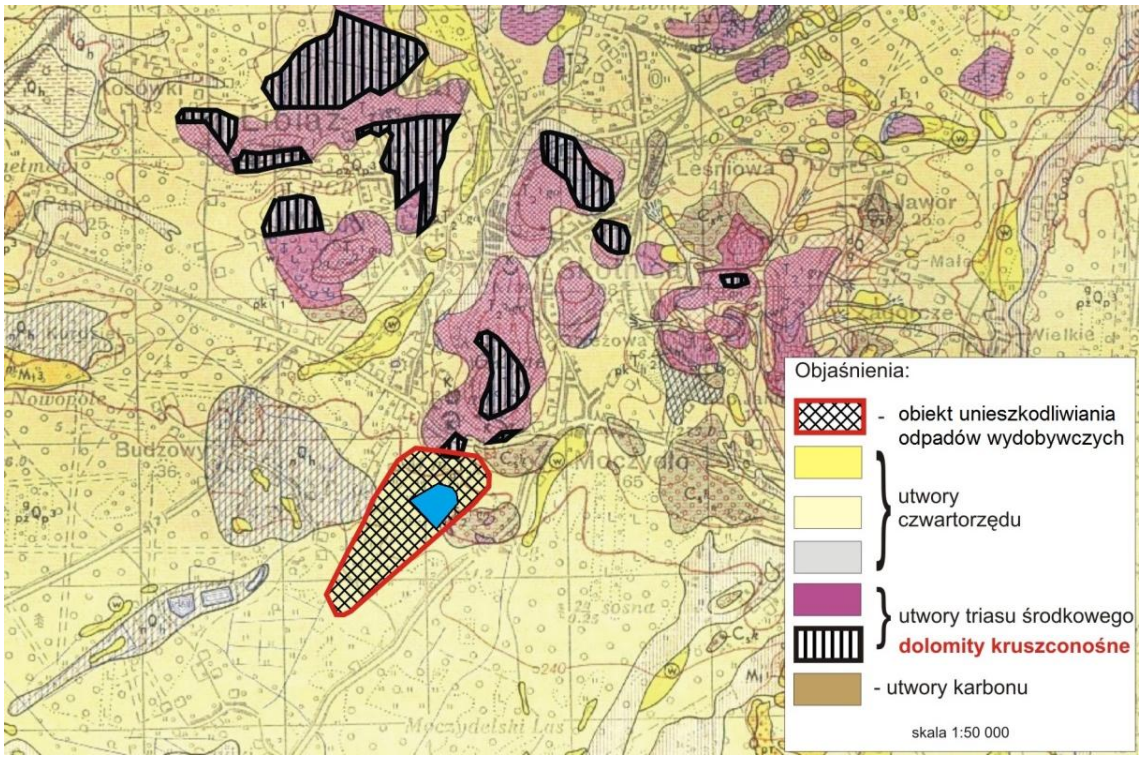


Figure 3-8. Mining waste disposal facility against the background of geological structure
Source: Polish Geological Institute – National Research Institute, 1956.
Detailed Geological Map of Poland. Sheet: Chrzanów

Triassic

Triassic deposits, lying unconformably on the Carboniferous formations, are developed mainly as a complex of diversified carbonate rocks belonging to the Lower Triassic (Buntsandstein) and the Middle Triassic (Muschelkalk). Lithologically, carbonate rocks such as marls and dolomites (less commonly limestones) dominate in the profile of the Triassic deposits. At present, these formations are covered by a layer of weathered clays. Outcrops of Triassic formations are located north of the mining waste disposal facility (Góra Lipie, Góra Karpiówka) and in the Janina Mining Plant facilities, forming the highest elevations exceeding 300 m a.s.l.

Tertiary

The Tertiary, with a variable thickness of 10 to 56 m, is composed mainly of Miocene clays and clay shales, partly sandy. Clay shales and sandstones occur primarily in the lower part of the Tertiary deposits. Miocene clays in the upper part, at the boundary with the water-bearing Quaternary, most often exhibit a plastic state, while at greater depths they occur in a semi-compact to compact state.

Quaternary

The Quaternary, with a thickness of several to several tens of metres, is developed primarily as fine- and medium-grained sands of glacial accumulation, less commonly as gravels with a thickness of approximately 1.0 to 2.0 m, resting directly on the Tertiary. The lower sections of local watercourses are filled with fluvial deposits, including clays up to 3.0 m thick and peats and soils up to approximately 1.0 m thick.

3.5.2 Hydrogeological conditions

Due to the diverse geological structure, the hydrogeological conditions in the area under consideration vary. Near the OUOW, where isolating Neogene formations (mainly clays) occur, the Quaternary aquifer is isolated from the underlying Carboniferous or Triassic aquifers. In contrast, in the northern and eastern parts of the catchment there are no continuous isolating layers separating individual aquifers, which therefore remain in hydraulic connection. Groundwater in the area under discussion occurs in Quaternary, Triassic, and Carboniferous formations.

Quaternary aquifer

Quaternary formations are saturated with groundwater practically throughout their entire extent. The Quaternary aquifer is absent within the range of Triassic uplands. The area located south of the OUOW lies within the extent of the usable groundwater level UPWP QII of the Mała Wisła region.

Quaternary deposits are generally composed of variably graded sands with interbeds of gravels, tills, and clays of glacial (Pleistocene) and fluvial (Holocene) origin. The thickness of the Quaternary is variable and reaches its greatest values in the valleys of the Vistula River. At the same time, in the area of Triassic uplands, it is small, or the Quaternary cover is absent.

Groundwater flow generally occurs from north to south, as the Vistula River constitutes the main drainage base of the Quaternary aquifer. In areas where the Quaternary aquifer is not isolated from the underlying Triassic and Carboniferous levels, groundwater is also drained by the Janina Mining Plant. Recharge of the Quaternary aquifer takes place directly through atmospheric precipitation.

Triassic aquifer

In the OUOW area of the Janina Mining Plant, Triassic formations create local morphological uplands associated with permanent or periodic springs in the Libiąż Hills. Hydrogeological windows (where Triassic formations crop out at the surface) serve as recharge zones for deeper aquifers.

Within the boundaries of the Janina mining area, Triassic formations generally form a hydraulically connected aquifer complex with the underlying Carboniferous sandstones, and together they have been drained by mine dewatering. Therefore, groundwater associated with the fissured–karst carbonate rock complex occurring north of the OUOW is of marginal importance.

Carboniferous aquifer system

The Carboniferous aquifer in the area under discussion is primarily associated with the sandstone beds of the Libiąż and Łaziska formations.

The Carboniferous aquifer system is multi-level in nature, with fissure–pore groundwater flow. The aquifer within Carboniferous formations is recharged by infiltrating waters from the overlying Triassic and Quaternary formations in areas devoid of Neogene clay deposits (isolating layers). Maximum recharge occurs through strongly water-bearing Quaternary deposits filling the valleys of modern and fossil rivers, as well as through hydrogeological windows.

Drainage of the aquifer levels results from the dewatering of mine workings at the Janina Mining Plant. The drainage base has been lowered to depths of as much as 300–500 m. This results in drying of the rock mass and a lowering of the Quaternary groundwater table in areas where isolating Neogene formations are absent.

3.5.3 History and status

The mining waste disposal facility (OUOW) – solid mining waste – has been in operation since the 1970s. During its operation, the facility's waste collection capacity was 5,000 Mg/day. In January 2016, the facility's total capacity was reached, and since then, the Janina Mine has not stored mining waste there.

The Janina Mining Plant in Libiąż, part of Południowy Koncern Węglowy S.A., operates the mining waste disposal facility (OUOW) – solid mining waste, based on the decision of the Marshal of the Małopolska Voivodeship, reference number SR.III.7244.1.1.2012.MW, dated April 2, 2012, granting Południowy Koncern Węglowy S.A. permission to operate a mining waste disposal facility.

The operating instructions for the mining waste disposal facility – solid mining waste – were approved by the decision of the Marshal of the Małopolska Voivodeship of June 10, 2010, reference number SW.III.JP. 7654–18/10.

In January 2016, TAURON Wydobycie S.A. ZG Janina ceased storing mining waste at the facility because the facility's target shape had been achieved and its available capacity had been exhausted. Despite the cessation of storage, the tailings storage facility is still formally in operation.

3.6 Environmental & access considerations

3.6.1 Weathering processes occurring on the surface of the waste management facility

The surface of the waste visually consists of a mixture of mineral fragments (claystones, sandstone fragments, quartz pebbles) of various grain sizes, grey in colour, with black coal fragments. Pyrite fragments at various stages of weathering occur in large numbers (Figure 3-9).

Clay minerals, whose total content ranges from 20 to 36%, and amorphous material (mainly coal) with contents from 21.1 to 24% determine the susceptibility of wastes deposited under hypergenic conditions to weathering processes. From an environmental point of view, the most important factor is the presence of weathering-susceptible pyrite, whose content in the waste ranges from 1 to 2%, as well as the high total sulfur content of 2.14 to 4.22% (on average 2.47%) (Bauerek et al., 2017).



Figure 3-9. Surface of waste deposited at the OUOW of the Janina Mining Plant

In mining wastes stored in the Upper Silesian Coal Basin, sulfur occurs predominantly in inorganic compounds, including sulfur bound in pyrite (FeS_2), which accounts for 85–95% of total sulfur (Szczepańska & Twardowska, 1999). Therefore, at the present stage of research, it can be assumed that the high sulphur contents in the surface layer of the waste are associated with the presence of pyrite (FeS_2). As a result of hypergenic processes such as leaching and/or wind removal of lighter mineral grains (quartz ~2.65 g/cm³, kaolinite ~2.6 g/cm³, feldspars ~2.65 g/cm³), pyrite grains, as a mineral with a relatively high specific density (approximately 5.0 g/cm³), tend to concentrate at the site of occurrence.

The relatively short half-life of pyrite present in post-mining wastes, estimated at 150 to 260 days (Twardowska et al., 2004), further enhances the potential for negative environmental impacts of these wastes.

In the mineral composition of the investigated wastes, the dolomite content reaches up to 2%, with a very uneven distribution of this mineral phase. The very low content of carbonate phases in the wastes forming the surface layer of the Janina Mining Plant disposal site, or their complete absence, indicates that these wastes have a very limited capacity to neutralize H^+ ions generated during pyrite oxidation in the presence of atmospheric oxygen and water, according to reaction (1) (Lattermoser, 2010):

$$FeS_2(s) + 3.5\ O_2 + H_2O \rightarrow Fe^{2+} + 2\ SO_4^{2-} + 2\ H^+ \qquad (1)$$

As a result of processes related to pyrite weathering on the embankments, manifestations of acid drainage are visible, such as seepages of rust-red, iron-enriched waters (Figure 3-10) and efflorescences of white and yellow sulfate salts (Figure 3-11).



Figure 3-10. Seepages of iron-enriched waters on the embankment of the Janina Mining Plant OUOW



Figure 3-11. Crystallization of sulfate salts on the embankment of the Janina Mining Plant

3.6.2 Actions to limit the environmental impact of the ZG Janina waste management facility

As part of the international research project RECOVERY – Restoration of degraded and transformed ecosystems in post-mining areas, financed by the Coal and Steel Research Fund, a vegetation experimental plot with an area of 4,000 m² was constructed in 2020 at the Mining Waste Disposal Facility (OUOW) (**¡Error! No se encuentra el origen de la referencia.**).

The method developed by specialists from the Central Mining Institute is ultimately intended to enable the initiation of diversified natural habitats (xerothermic grasslands, flower meadows, shrub communities and wet habitats) with a high potential to perform ecological, recreational and economic functions. The practical knowledge obtained will make it possible to develop appropriate methods for initiating plant communities in degraded areas.

Experimental reclamation is carried out by constructing so-called anthropogenic substrates from by-products of coal mining and combustion, as well as biomass.



Figure 3-12. Construction of the experimental vegetation plot in 2020

The year 2021 was the first growing season on the research plot; however, observation results indicate that the experimental reclamation using the designed soil substitutes will be successful. A dense cover of meadow vegetation was obtained (Figure 3-13, Figure 3-14).



Figure 3-13. Research site from the east



Figure 3-14. Dense herbaceous vegetation cover in the meadow part of the research site

Południowy Koncern Węglowy S.A. – Janina Mining Plant in Libiąż is currently implementing the decision of the Marshal of the Małopolskie Voivodeship, ref. no. SR-III.7241.3.1.2022.MW of 15 June 2022, which granted consent for the closure of the Mining Waste Disposal Facility (OUOW) for permanent post-mining wastes and approved the closure and reclamation plan for this facility.

As part of the works currently being carried out, the slopes of the OUOW for permanent post-mining wastes are being successively covered with mineral material and will be vegetated in the future. It should be noted that the reclaimed OUOW for permanent post-mining wastes and the OUOW mine-water settling pond form a single body. Therefore, the reclamation works aim to reduce the environmental pressure from mining waste deposited along Krakowska Street in Libiąż. The current stage of the reclamation works is shown in Figure 3-15 and Figure 3-16.



Figure 3-15. Reclamation of the OUOW for permanent post-mining wastes at the Janina Mining Plant in Libiąż



Figure 3-16. Reclamation of the OUOW for permanent post-mining wastes at the Janina Mining Plant in Libiąż

3.7 Sample collection

Three locations were selected for sample collection (Table 3-4, Figure 3-17). Samples were collected from the following depth intervals: 0–0.5 m; 0–5 m; 5–10 m; 10–15 m in an amount of at least 30 kg each sample.

Table 3-4. Sample collection coordinates

Point	Coordinates	
	N	E
PL-J/1/S	50° 05’ 02,7”	19° 18’ 19,4”
PL-J/2/S	50° 04’ 59”	19° 18’ 17,7”
PL-J/3/S	05° 04’ 56,6”	19° 18’ 14,5”



Figure 3-17. Sample collection locations



Figure 2-18. Sample collection

3.8 References and metadata

Bauerek A., Frączek R., Paw K., Kasperkiewicz K., (2017) - Geological Review. Variability of the chemical composition of acidic surface runoff waters from an active mining waste dump representing sediments of the Kraków sandstone series of the Upper Silesian Coal Basin., 67/7, 450-458

Bauerek, A. et al. (2020) Analysis of the Chemical Stability of Mining Waste Disposal Facilities of TAURON Wydobycie S.A. – ZG Janina in Libiąż, Central Mining Institute, Katowice.

Lattermoser B. G. (2010). Mine Wastes. Characterization, treatment and environmental impacts. Berlin, Springer-Verlag.

Szczepańska J. & Twardowska I. (1999). Distribution and environmental impact of coal-mining wastes in Upper Silesia, Poland. Environmental Geology 38 (3): 249-258.

Twardowska I., Allen H. E., Kettrup A. F. & Lacy J. L. (2004). Solid Waste: Assessment, Monitoring and Remediation, Elsevier.

Polish Geological Institute – National Research Institute (1956). Detailed Geological Map of Poland at a scale of 1:50,000. Sheet: Chrzanów. Warsaw: PGI–NRI.

4 "WALESKA" WASTE DUMP (Poland)

4.1 Facility identification

Closed coal mining waste dump "Waleska" was associated with hard coal extraction of KWK Bolesław Śmiały coal mine (Poland).

4.2 Location and extent

The mining waste disposal facility of KWK Bolesław Śmiały mine is in Łaziska Górne town, southern Poland (50° 08' 31.1" N, 18° 52' 49.4") (Figure 4-1).
The reclaimed Waleska mining waste dump. An area of irregular shape, covered with unmanaged (natural) vegetation, with no buildings. It is in the vicinity of green areas, industrial and warehouse facilities, residential and service developments, and allotment gardens.

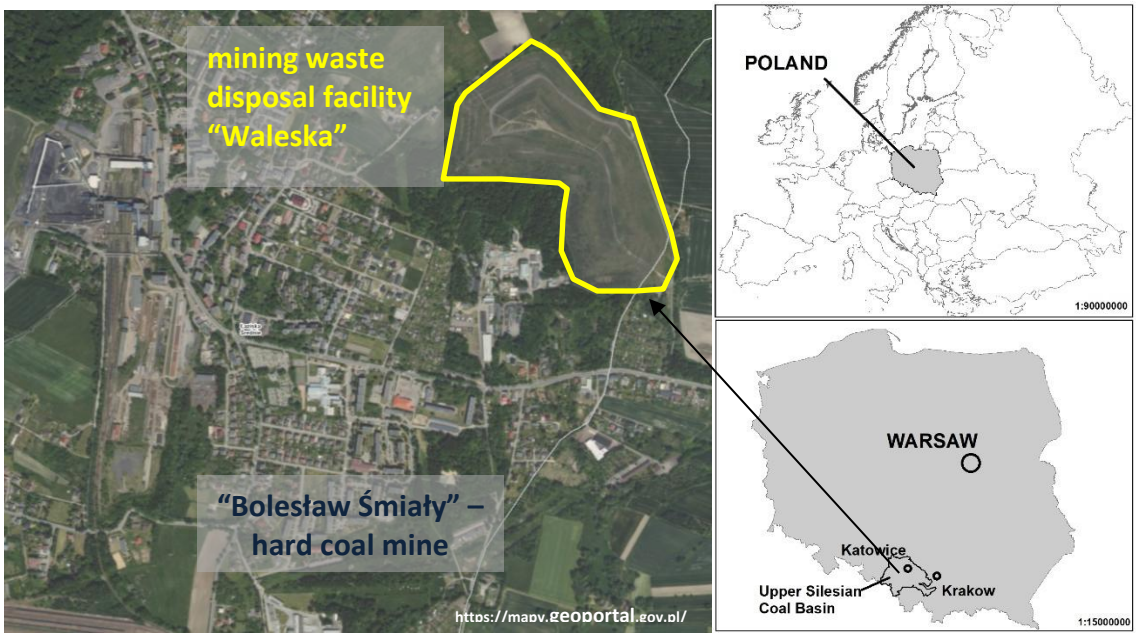


Figure 4-1. Location of closed mining waste disposal facility of KWK Bolesław Śmiały mine in Łaziska Górne town

4.2.1 Determination of the geometric characteristics of the waste dump

The area of the OUOW is 18.2 ha, and its capacity is 3.5 million m^3 (5.9 million Mg). The mining waste heap was formed as an above-ground object with a relative height of up to 40 m. The elevation of the object's top is 340 m above sea level. The slope of the slopes is uniform and amounts to 1:2.5.

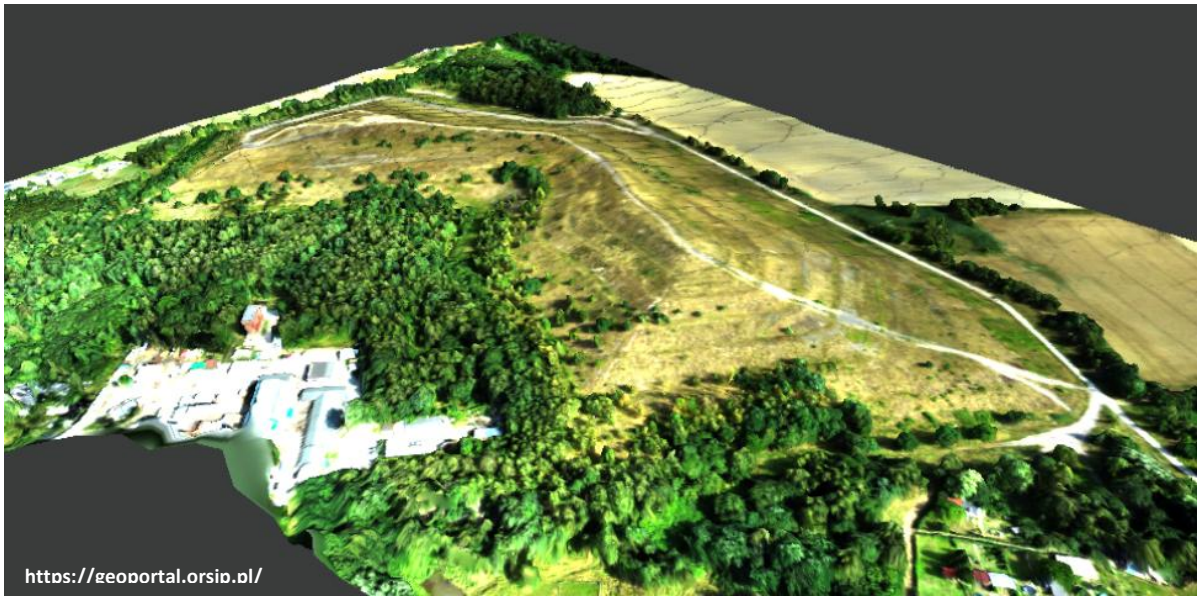


Figure 4-2. "Waleska" spoil heap – 3D view from south



Figure 4-3 "Waleska" spoil heap – view on northern slope and main plateu



Figure 4-4. Aerial photo from "Waleska" spoil heap plateau to the north



Figure 4-5. Aerial photo from "Waleska" spoil heap plateau to the south

4.3 Operator information

POLSKA GRUPA GÓRNICZA S.A. (Polish Mining Group S.A.)in Katowice, Poland

Polska Grupa Górnicza S.A. is a Polish commercial capital company (joint-stock company) headquartered in Katowice. It is the largest mining enterprise in Europe and the largest producer of hard coal in the European Union.

The company was established as a special purpose entity on January 16, 2015 (under the name Polska Grupa Górnicza sp. z o.o.), to take over the assets and liabilities of the bankrupt Kompania Węglowa.

Oddział KWK Bolesław Śmiały (Bolesław Śmiały Coal Mine) in Łaziska Górne, Poland

The Bolesław Śmiały Coal Mine (KWK Bolesław Śmiały) in Łaziska Górne is one of the oldest mines in Poland, as well as the oldest and largest industrial facility in the city of Łaziska Górne.

The beginnings of organized coal extraction in the Łaziska area date back to 1779, when the "Szczęście Henryka" mine was established. Since then, numerous mines were developed in the region. As a result of their consolidation, the "Zjednoczona Aleksander" mine was formed, which has operated under the name "Bolesław Śmiały" since 1945.

In the following years, the mine continued to develop through successive modernizations. Since 2016, the "Bolesław Śmiały" Mine has been operating within the structures of Polska Grupa Górnicza S.A., the largest producer of hard coal in the European Union.

4.4 Characteristics of waste

The "Waleska" spoil heap received coal-mining waste from the "Bolesław Śmiały" coal mine as well as decarbonisation sludges from the water-treatment process at a power plant (used as a protective and sealing material for the landfill). According to the applicable waste catalogue, the landfill contains wastes classified into the following groups:

- 01 01 02 – wastes from the extraction of minerals other than metal ores,
- 01 04 12 – wastes generated from washing and cleaning of minerals other than those mentioned in 01 04 07 and 01 04 11,
- 19 09 03 – sludges from water decarbonisation.

Among the coal-mining wastes from the KWK "Bolesław Śmiały" coal mine, the majority consist of processing wastes. Until 1999, coal-mining wastes of the following composition were deposited at the landfill annually:

- wastes from development works: approx. 1.7%,
- processing wastes from the coal preparation plant: approx. 84.4%,
- fine coal sludges from filter presses: approx. 13.9%.

The results of investigations into the physical and chemical properties of the wastes are presented in Table 4-1.

Table 4-1 Characteristics of Waste Deposited at the "Waleska" spoil heap

Parameter	Unit	Development works waste	Coal preparation plant waste	Sludge waste
Ash content (Aa)	%	97.37	72.05	38.10
Total sulphur content (Sta)	%	0.37	1.60	1.79
Combustible sulphur content (Sc)	%	0.34	1.45	1.37
Pyritic sulphur content (Spir)	%	0.36	1.30	1.24
Ash sulphur content (SA)	%	0.03	0.15	0.40
Dissolved substances	%	38.51	86.53	79.79
Sulphates	mg/dm³	9.25	18.30	12.76
Chlorides	mg/dm³	3.19	12.76	3.90

Source: Central Mining Institute, 1998. Technical Design for the Reclamation of the Coal Mining Waste Disposal Site at the "Skalny" Shaft of the Bolesław Śmiały Coal Mine)

Since 2000, following the commissioning of the Energy Coal Fines Beneficiation and Desulphurisation Plant (ZWiOME), dewatered wastes (after filter presses) from this facility have also been disposed of at the landfill. In the years 2000–2002, they accounted for approximately 60% of the total amount of waste deposited at the site. Table 4-2 presents the results of analyses of waste from the ZWiOME facility disposed

of at the landfill in recent years, carried out as part of the environmental audit of the landfill in 2002.

Table 4-2 Characteristics of Waste deposited at the "Waleska" spoil heap since 2000

Type of analysis	Parameter	Unit	Dewatered coal fines wastes	Fine-grained surface waste	Coarse-grained surface waste
Sieve analysis	>4 mm	%	51.4	36.6	54.9
	4–2 mm	%	6.4	6.5	6.9
	2–1 mm	%	11.2	7.6	9.7
	1–0.5 mm	%	9.4	12.2	10.0
	0.5–0.25 mm	%	10.3	12.5	8.4
	0.25–0.125 mm	%	9.5	18.4	5.0
	0.125–0.063 mm	%	1.3	5.8	3.4
	<0.063 mm	%	0.5	0.4	1.7
	Total	%	100.0	100.0	100.0
Loss on ignition	815 °C	%	36.17	41.75	41.66
Total sulphur (Eschka)		%	1.41	1.15	1.68
pH		-	7.22	8.24	8.40
Water extract	Electrical conductivity	µS/cm	5208	1534	1207

Source: ROT Recycling Waste Technologies, 2002.

4.4.1 Waste disposal technology

The "Waleska" coal waste landfill has been operated since 1994 in accordance with the technology developed in a design prepared by GPSiPG Kraków. Waste deposition was carried out in lifts approximately 6 metres high, each terminated by a bench about 2 m wide.

In accordance with the design technology, the first stage involved forming an embankment along the perimeter of the landfill, 6 m in height, with external slopes inclined at a ratio of 1:2.5. These slopes were shaped and compacted on an ongoing basis and were successively subjected to reclamation treatments by covering them with soil and seeding with grass. After the embankments were formed, the space inside them was filled.

Waste was deposited in layers approximately 0.5 m thick, with interlayers of material preventing spontaneous combustion in the landfill (decarbonisation lime from the power plant water treatment process) with a thickness of about 0.1 m (Figure 4-6).

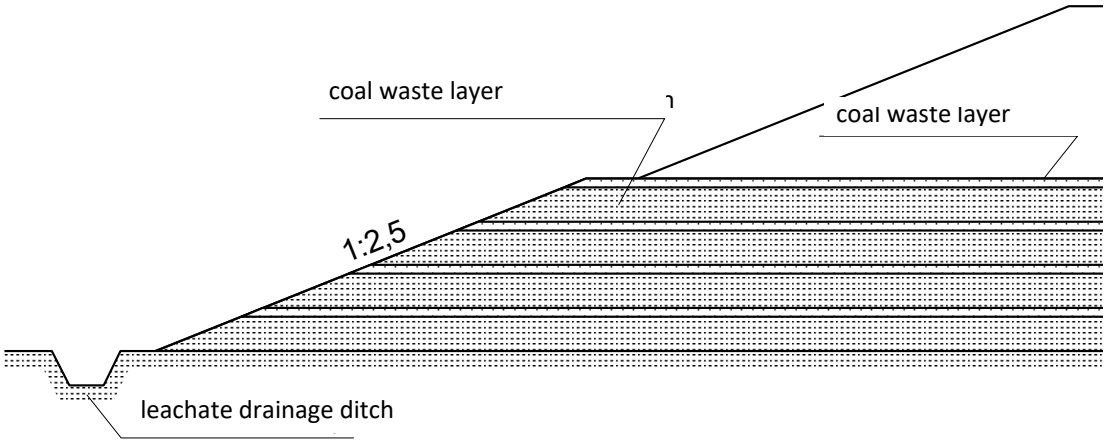


Figure 4-6 Waste disposal technology (Source: ROT Recycling Waste Technologies, 2002)

4.5 Original deposit info

4.5.1 Geological structure

The area of Łaziska Górne is in the central part of the Upper Silesian Coal Basin.

Carboniferous

The productive formation of the basin is represented by the two lower stages of the Upper Carboniferous: the Namurian and the Westphalian. Their deposits are divided into three groups: the Marginal, Anticlinal, and Synclinal Groups. The spoil heap area lies within one of the four levels of the Synclinal Group—the Łaziska Beds. The dominant lithologies of the Łaziska Beds are sandstones and conglomerates with interbeds of shales and hard coal seams. The thickness of the productive Carboniferous in the Łaziska Górne area reaches up to 2,000 m. Coal seams vary in thickness from 1 to 5.5 m.

Within the administrative boundaries of Łaziska Górne, Upper Carboniferous rocks (sandstones, conglomerates, shales, and hard coal) crop out directly at the surface, occupying more than 70% of the central and northern parts of the city (Figure 4-7).

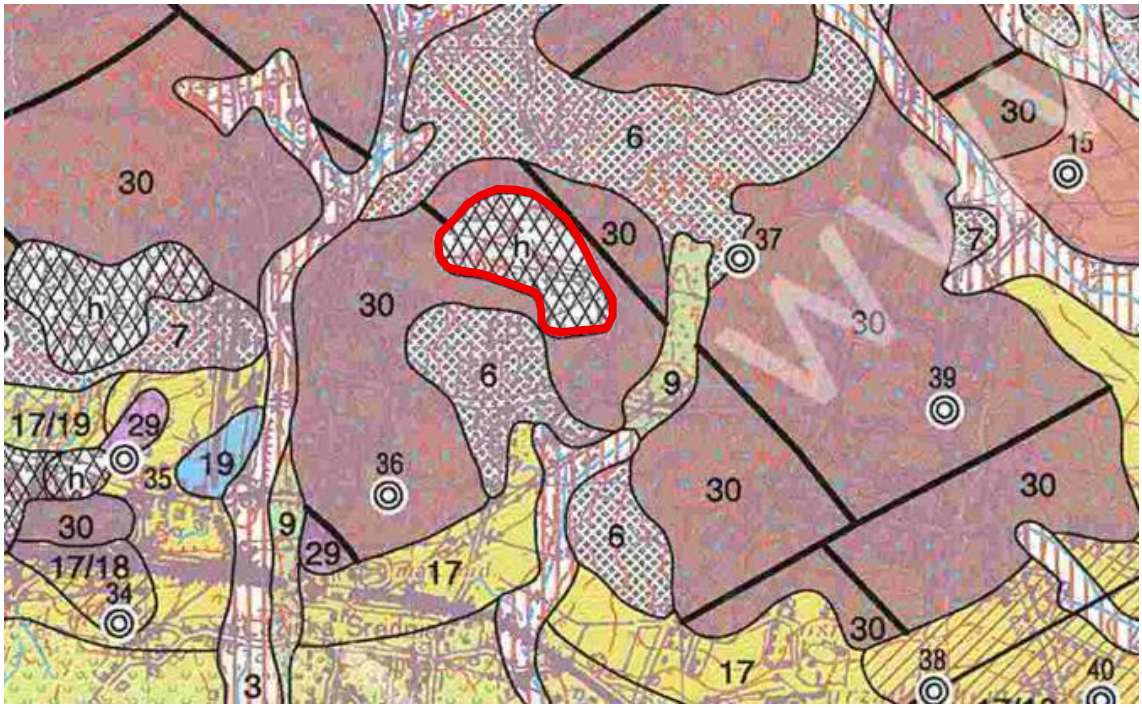


Figure 4-7 Mining waste disposal facility "Waleska" against the background of geological structure

Legend: **Holocene:** 6 – deluvial sands and clays; 7 – deluvial clays; **Pleistocene:** 17- fluvioglacial sands and gravels; 19: glaciolacustrine clays and silts; **Triassic:** 29 - limestones, marls, and dolomites; **Carboniferous** 30 - sandstones, conglomeratic sandstones, and conglomerates with interbedded claystones and siltstones, containing coal seams; **Anthropogenic landforms:** h – spoil heaps. Source: Polish Geological Institute – National Research Institute, 2000, Detailed Geological Map of Poland. Sheet: Chrzanów

Triassic

Triassic rocks are represented by the Bunter Sandstone and Rhaetian formations, occurring as fine-grained sandstones, clays, marls, and dolomites. In Łaziska Górne, the Triassic is represented by limestones, marls, and dolomites of the Botnickie and Gogolin Beds, corresponding to the lower part of the Muschelkalk. The Triassic strata are several metres thick, and their extensive outcrops occur between the conical "Bolesław Śmiały" mine, spoil heap and road No. 81.

Tertiary

Surface deposits within the city also include Cenozoic rocks, consisting of clays, sands, and silts with thicknesses ranging from several to several tens of metres. These deposits cover the eastern and south-western parts of the city.

Quaternary

Pleistocene deposits are also present in Łaziska Górne. Till from the Middle Polish Glaciation, up to 6 m thick, occurs over a small area (0.5 km²) in the northern part of the city. In the southern parts of the municipality, fluvio-glacial outwash from the ice-sheet margin led to the deposition of sands and gravels in the form of alluvial fans (lower reach of the Brada stream) and sandur plains. Remnants of this period also include isolated Scandinavian erratic boulders found in many locations across the municipality. In the floors of larger valleys, Holocene organic-mineral deposits have accumulated because of sedimentation from slope wash. These processes were intensified by deforestation. The youngest deposits are anthropogenic sediments, which occupy significant areas of the Łaziska Górne municipality.

4.5.2 Hydrogeological conditions

The main usable aquifer consists of Upper Carboniferous deposits (sandstones, siltstones, and claystones), which in the Katowice subregion are characterized by relatively low groundwater productivity. The Carboniferous aquifer has the greatest influence on the hydrogeological conditions of the municipality, with groundwater occurring at depths ranging from 20 to 120 m. Within the Carboniferous aquifer, two distinct hydrogeological complexes are identified, associated with the Łaziska Beds and the Orzesze Beds. The Łaziska Beds are characterized by high permeability and significant water-bearing capacity, resulting from the coarse-grained and porous nature of the Carboniferous deposits as well as the numerous fractures within the rock mass. The second complex—the Orzesze Beds—cannot store large quantities of groundwater, as it is dominated by shale-rich facies with low water-bearing capacity.

Recharge of the Carboniferous aquifer occurs through the infiltration of atmospheric precipitation directly on outcrops or through a permeable overburden. Recharge may also take place via dynamic resources, i.e. drainage from higher aquifers supplied by rainfall. A secondary aquifer is formed by Quaternary sands (in the northern part of the municipality) and by sands and gravels in the remaining areas, occurring to a depth of up to 10 m. Due to its shallow occurrence, the Quaternary aquifer is vulnerable to the migration of surface-derived contaminants. There is hydraulic connectivity between groundwater in the Quaternary and Carboniferous deposits, which may also result in contamination of groundwater in deeper aquifers.

The remaining aquifers—the Tertiary and Triassic ones—are very poorly recognized and of marginal importance. The Carboniferous aquifer is intensively drained because of the operation of the "Bolesław Śmiały" coal mine, leading to significant transformations of the groundwater regime. A cone of depression has developed, causing the disappearance of upper reaches of streams and a reduction in stream discharge. Because of the draining role of the Carboniferous horizons, the Quaternary aquifer has also undergone a significant decline in groundwater levels.

4.5.3 History and status

The "Waleska" spoil heap is one of the largest coal waste dumps in the Silesian Voivodeship and was created in association with the KWK "Bolesław Śmiały" coal mine. Between 1994 and 2007, various types of coal-related waste were deposited there, mainly waste rock, processing residues, and filter-press sludges.

At present, the "Waleska" spoil heap is a reclaimed site, and its designated land use in the Local Spatial Development Plan of the City of Łaziska Górne is defined as "protective (buffer) green areas and landscape/recreational functions."

4.6 Sample collection

Three locations were selected for sample collection. Samples were collected from the 0–0.5 m depth intervals in an amount of at least 30 kg each sample.

Table 4-3. Sample collection coordinates

Point	Coordinates	
	N	E
PL-W/1/S	50°08’19,9”	18°52’58,1”
PL-W/2/S	50°08’32,1”	18°52’35,7”
PL-W/3/S	50°08’32,1”	18°52’41,8”



Figure 4-8. Sample collection locations



Figure 4-9. Sample collection

4.7 References and metadata

Bauerek A., Frączek R., Paw K., Kasperkiewicz K., (2017) - Geological Review. Variability of the chemical composition of acidic surface runoff waters from an active mining waste dump representing sediments of the Kraków sandstone series of the Upper Silesian Coal Basin., 67/7, 450-458

Central Mining Institute (1998) Technical Design for the Reclamation of the Coal Mining Waste Disposal Site at the "Skalny" Shaft of the Bolesław Śmiały Coal Mine. Katowice.

Gogola, K., Bajerski, A., et al. (2003). Technology for the elimination of thermal phenomena on the southern slope of the "Waleska" coal waste landfill of the Bolesław Śmiały Coal Mine. Documentation of the Central Mining Institute, Katowice.

Polish Geological Institute – National Research Institute (2000). Detailed Geological Map of Poland at a scale of 1:50,000. Sheet: Tychy. Warsaw: PGI–NRI.

Conference ROT Recycling Wastes Technologies (2002), Environmental Review Report of the Coal Waste Disposal Site of the "Bolesław Śmiały" Coal Mine at the "Waleska" Shaft in Łaziska Górne –Gliwice.

5 SAN NICOLÁS DUMP (Spain)

5.1 Facility Identification

The San Nicolás dump is a key geographical and landscape feature of the mining industrial heritage of Asturias, Spain. It represents decades of mining activity at the San Nicolás coal mine, part of the state-owned company HUNOSA. Unlike other dump that have been completely dismantled, the San Nicolás heap has been the subject of several environmental restoration and landscape integration plans. It is visible from the A-66 motorway (Autovía de la Plata) and serves as a visual re-minder of the region's economic history.

This report will analyze the characteristics of the materials present in the study area and that have been deposited in the San Nicolás landfill.

5.1.1 Montsacro and San Nicolás Mines (Sueros Area)

The Sueros Area comprises the Montsacro and San Nicolás mines (Figure 5-1). The Montsacro Mine (Morcín-Riosa) began operations in 1955 and closed in 2014, while the San Nicolás Mine (Mieres) began operations in 1952 and ceased coal extraction on December 31, 2024, being the last HUNOSA mine to close.



Figure 5-1. Montsacro Well (left) and San Nicolás Well (right)

5.1.2 Materials

The materials that make up the stratigraphic series of the study area are detailed below:

Shales and Siltstones (Slates)

The term "slate" is a mining term, but metamorphism has been minimal, and they are found in varying degrees of stratification. Therefore, they can be defined as more or less sandy shales. Within this group, there are diverse types, corresponding to the different environments in which they were deposited and the composition of their materials;

thus, there are micaceous, calcareous, sandy, and bituminous slates. Slates from marine deposits frequently include fossils that reflect the environment in which they were laid down. They tend to have a massive macroscopic appearance, more defined than continental slates, losing their gray color on the surface to become ochre-colored, displaying erosional forms with concentric structures. Continental slates almost always show a better-stratified appearance and are generally finer.

Sandstones

Within this group we distinguish between quartzitic, calcareous, clayey and micropudding sandstones.

The quartzitic sandstones exhibit grains welded together, forming mosaic textures, in which the growth of newly formed quartz can sometimes be observed. They are grouped in thin beds, typically located in the upper part of the lower half of the sequence, and in some cases, they support vegetation just below a coal seam.

Calcareous and clayey sandstones have a detrital fraction composed mainly of quartz grains, some feldspars and muscovite, showing a cement that binds all the intermediate grains between the carbonate and clayey ones.

The micropuddingstones include grains of varying composition such as quartz, microquartzite fragments, siliceous rocks, various types of more or less altered slates, feldspars, and micas, all embedded in a calcareous or clayey matrix, which may be abundant or scarce. These sandstones form the thickest beds in the series, exhibiting lenticular stratification characteristic of their sedimentary nature, and sometimes form very continuous layers that have often served as guides.

Conglomerates

These are formed almost exclusively of rounded quartzite pebbles, with sizes varying between a few millimetres and several centimetres, in a sandy matrix. There may be some layers of sandstone or shale among them.

Limestones

These are notably represented in the Central Basin, not only at its base but also in the lower layers of the productive sequence. Above the Alba (Griotte) Formation and the Montaña limestone, there are numerous limestone beds, which become less frequent and thinner as we ascend the stratigraphic sequence.

5.1.3 Nature and origin of coal

Coal is a sedimentary rock used as a fossil fuel; it is black in color and very rich in carbon. It is usually found under a layer of shale and above another of sand and clay.

It began forming millions of years ago from existing vegetation. Large coal de-posits began to form during the Carboniferous period (approximately 350-280 million years ago). This coal formation process continued during the Permian period (approximately 280-225 million years ago) and more recently in the Cretaceous period (about 100 million years ago). There are also younger coals formed in the Tertiary period (a few tens of millions of years ago).

The ferns and giant trees that existed in those times, as they died, were deposited in layers and transformed into coal by the action of fungi and bacteria. Through an anaerobic (oxygen-poor) process at moderate temperatures (250°C) and high pressure, the organic matter was formed into coal, a process known as carbonization.

In the process of coal formation, the disappearance of moisture from the sediments and compaction have made it possible for the content of carbon and other com-pounds present in it to gradually increase.

Although coal seams contain certain inorganic minerals, they are largely com-posed of macerals, which are plant compounds ranging from Woody plants to resins. The three general categories of macerals are vitrinite, liptinite, and inertinite. Maceral data reflect the basic composition of coal, which is important for determining its origin and provenance.

Carbon (primarily), hydrogen, and oxygen are the main components of coal, although it also contains sulfur, nitrogen, and other elements. Due to its composition, coal is combustible (that is, it combines with oxygen to release heat).

Depending on its age, formation conditions, and carbon and volatile matter content, there are different types of coal, with varying textures and calorific values. For commercial purposes, coal quality is typically measured by the percentage of fixed carbon, volatile matter, moisture, sulfur, hydrogen, and by its calorific value (which is determined by the aforementioned parameters). Generally, the higher the carbon content and the older the coal, the higher its quality and, consequently, the greater its capacity to produce heat during combustion.

5.2 Location and extent

The San Nicolás landfill is located in the vicinity of Ablaña, in an area known as Lleros de Abajo, within the municipality of Mieres and adjacent to the San Nicolás well of HUNOSA (Figure 5-2).



Figure 5-2. Situation of the San Nicolás dump

The geographical coordinates of the San Nicolás dump are those that are shown in Table 5-1.

Table 5-1. Coordinates of the San Nicolás dump

System	Coordinates
Decimal (WGS84)	43.2381° N, -5.7905° W
DMS	43°14'17.2"N 5°47'25.8"W
UTM (Zone 30N)	X: 273,250 / Y: 4,791,010

It has an area of 5.18 Ha, measuring approximately 590 m long and 110 m wide (Figure 5-3) and has an average variable height of 40 m from the Nicolasa river to the top surface of the heap, generating a volume of 700,000 m³ of waste from the old Nicolasa Mine and the San Nicolás Mine.

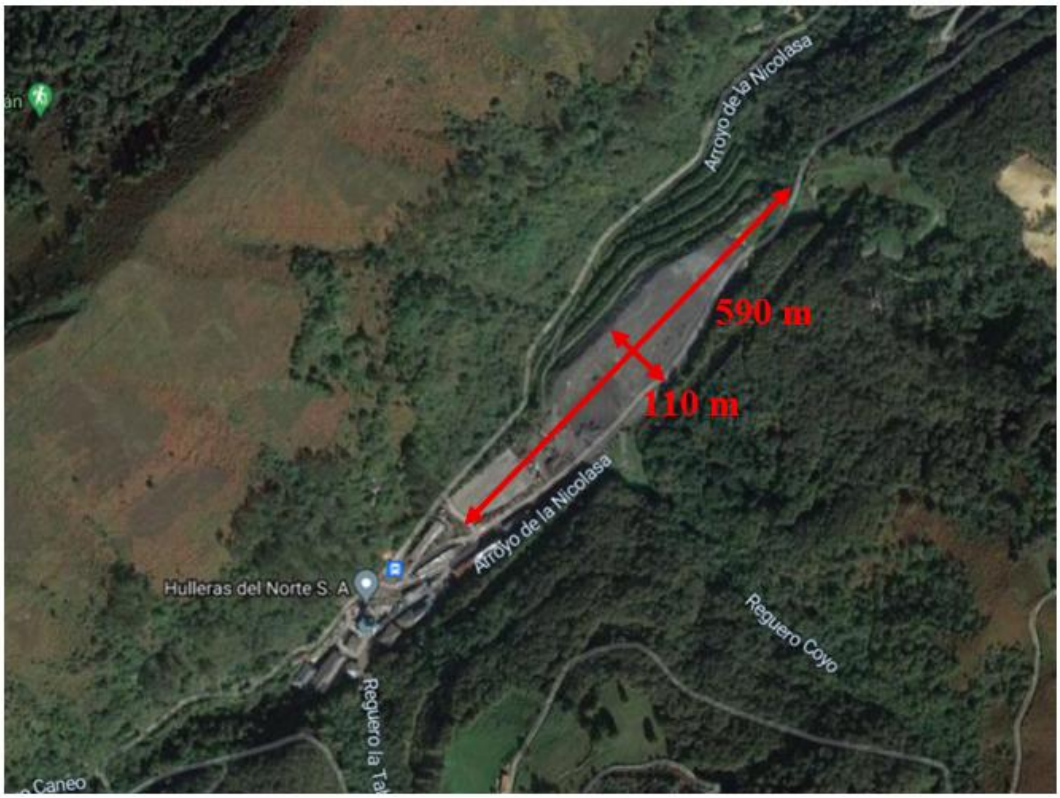


Figure 5-3. Measurements of the San Nicolás dump

5.3 Operator Information

HUNOSA (Hulleras del Norte S.A.) is a Spanish state-owned company established in 1967 with the aim of managing and modernising coal mining in the northern coalfields of the country, particularly in Asturias, where it has played a key role in economic, social and industrial development for decades. It is currently part of the SEPI business group, which reinforces its strategic role within the public sector. Its historical activity focused on coal extraction through underground mining, becoming one of the region's main economic drivers and generating thousands of direct and indirect jobs, as well as a significant mining culture that has profoundly shaped Asturian identity. However, due to the gradual decline of coal as an energy source, driven by economic, environmental and regulatory factors, HUNOSA has undergone a profound transformation in recent decades, gradually moving away from traditional mining and shifting towards new areas of activity linked to sustainability and the energy transition. In this regard, the company has diversified its operations into the management of industrial infrastructure, the development of renewable energy projects and the provision of energy services, with a particular focus on geothermal energy, utilising water accumulated in former mining sites to generate thermal energy efficiently and in an environmentally friendly manner.

5.4 Characteristics of waste

5.4.1 Coal waste

Coal waste refers to the residue from the separation of coal from the surrounding rock. It originates from the mining of bituminous coal and anthracite mines and pits, as well as from coal washing processes. It is generally stored in spoil heaps. There are three types:

- Mine waste: consists of host rocks of the coal seams, mainly slate and sandstone.
- Washing wastes: represent 90% of the total waste production and are obtained as a residue from the coal washing operation, obtained from bituminous coal and anthracite once separated by flotation and dense liquids.
- Waste rock dumps: These are the residues resulting from the storage of the two previous types in a waste rock dump. 90% of the material stockpiled in waste rock dumps is coal washing residue, and 10% is typically mine waste. They are characterized by a particle size that varies depending on the original waste rock types. This type can be subdivided into (Figure 5-4):
    - Black waste that is the residue from coal mining itself.
    - Red waste, which is the material resulting from the self-combustion of the coal contained in the black waste. It has a characteristic reddish color and greater strength because it is fused together.



Figure 5-4. Types of coal waste: washing wastes (left) and red wastes (right)

5.4.2 Physical properties of sterile materials

In general, coal waste consists of fragments of various rocks, with a variable grain size, from 0 to 200 mm. The average specific gravity of coal waste in Spain ranges between 23.5 and 28.5 kN/m³. Plasticity is usually medium-low to non-existent.

Mine waste is characterized by having a more irregular granulometry, not being degraded and generally not containing coal.

The waste rock from the coal washing plant has a very regular particle size distribution and mineralogical and chemical composition and is generally not degraded. Its carbon content varies depending on the different processes used in the washing plant. It is gray in color and contains a certain percentage of flakes. It is usually classified as coarse (>150 mm), grains (150-10 mm), and fine (10-1 mm), while the content of the fines is 2.2 t/m³. Fine particles (<1 mm). The specific gravity of the grains and small particles is 2.5 t/m³.

The waste rock from the spoil heap has variable granulometries and significant percentages of particles larger than 50 mm (Table 5-2).

Table 5-2. Properties of waste with particles larger than 50 mm

Property	Sterile red	Sterile black
Sizes	Decimetric to metric	Decimetric to metric
Granulometry	Variable <300 mm	Variable From 0.1-1 mm to 34-40 mm
Percentage of fines (%)	<10	2-75
Apparent density (t/m³)		1.26-1.80
Plasticity	No plastic	LL:18-30; IP:3-10
Modified Proctor: Maximum density (t/m³) Optimum humidity (%)	 1.8 11	 1.50-2.02 8-12
CBR: Normal Proctor density Modified Proctor density	 40	 9-16 11-29

For particles smaller than 50 mm, the main properties are reflected in the following Table 5-3:

Table 5-3. Properties of spoil heaps with particles smaller than 50 mm

Property	Sterile red	Sterile black
Granulometry	Contínue <5% inf. 0.08 mm	Contínue <5% inf. 0.08 mm
Density (t/m^3)	2.70-2.73	2.74
Absorption (%)	5.6-5.8	
Shape: Slab Index Shape: Needle Index	36-42 46-51	
Los Angeles test	36-39 granulometría B 31-46 granulometría A 21-25 arenisca	31-36
Sand equivalent	30-51	38
Plasticity	No plastic	LL:26-29; LP:19-20; LP:7-9
Modified Proctor: Maximum density (t/m^3) Optimum humidity (%)	 >1.9 10.2-15.5	 1.99-2.09 7-10
CBR	>50	<20

The petrography of coal tailings exhibits considerable variation due to the geological diversity and complexity. These are sedimentary rocks with highly variable quartz-to-clay ratios. Sandstones predominate in mine tailings, while shales are more common in washing tailings, although small amounts of ferruginous and carbonaceous rocks are also present.

In relation to mineralogical composition, waste rock consists of mixtures of different components that can vary significantly, although with predominance of from clay rocks such as illite, kaolinite, chlorite, … The percentages in quartz range between 20 and 50%. Other minerals present are pyrite, carbonates, etc.

Table 5-4 presents the unconfined compressive strength values of the materials in the study area calculated according to measurements in the mine with the Schmidt hammer.

Table 5-4. Unconfined compressive strength of materials

Material	Description	Density, kn/m³	Simple compressive strength, kg/cm²	Simple Compressive strength, Mpa
Pudding stone	Quartzite stones	26.26	2551	250.10
	Silica matrix	25.38	698	68.43
Quartzite	Quartzite	25.87	1531	150.10
	Quartzite with threads and grains of coal	25.87	2245	220.10
Sandstone	Quartzitic sandstone.	25.38	1939	190.10
Shale 3	Very sandy shale with roots	24.00	602 - 1385	59.02-135.78
	Very sandy shale with carbonate nodules	24.00	388	38.04
Shale 2	Sandy shale	23.00	627	61.47
	Sandy shale with roots satin	23.00	428	41.96
	Sandy shale with roots	23.00	236	23.14
Shale 1	Broken shale	21.00	283	27.75
	Carbonaceous shale	21.00	271	26.57
	Carbonaceous shale satin	21.00	153	15.00
	Carbonaceous and sulfurous shale satin	21.00	283	27.75
	Satin shale with roots	21.00	163	15.98
	Shale with roots	22.00	398	39.02
Coal	Hard and vitrinitic coal	16.46	163-221	15.98-21.67
	Coal and satin carbonaceous shale	16.46	178	17.45
	Coal and interbedded carbonaceous shale	16.46	132	12.94

5.4.3 Chemical properties of sterile materials

The sterile ones (Table 5-5) have a high percentage of SiO2 (40-70%) and of Al_2O_3 (10-25%). The following table shows the average chemical composition of coal waste:

Table 5-5. Chemical composition of coal waste

SiO_2	Al_2O_3	Fe_2O_3	K_2O	MgO	TiO_2	CaO	S_{total}
43-49	22-24	5-7	2.9-3.2	1.2-1.5	1.1-1.2	1.1-2.0	0.6-1.4

5.4.4 Mineralogical composition of rock materials

The mineralogical composition of sedimentary materials, such as those found in the stratigraphic sequence of the Hunosa mines, is a fundamental physical property, since it allows the petrographer to determine the specific classification of the studied sample. The presence of sandstones, shales, siltstones, conglomerates, and limestones has already been mentioned. In general, the mineralogical composition includes the following factors:

- Lithology of the source area.
- The resistance of minerals to weathering
- The time and distance of transport of the fragments
- The mineral's resistance to abrasion
- The conditions of the depositional environment in which the fragments are deposited.

Major minerals are those with an abundance greater than 2% and can be divided into stable (quartz) and semistable (feldspars).

- Quartz: It is the major detrital constituent of 35-50% of the terrigenous fraction of sedimentary rocks. It is the most durable mineral due to its hardness, strength, and lack of cleavage. Ultrastable under almost all surface conditions, very little quartz dissolves through weathering.
- Quartz in sandstones can occur in three forms (Figure 5-5):
    - Monocrystalline Quartz: a single cristal
    - Polycrystalline Quartz: aggregate of crystals
    - Microcrystalline Quartz: aggregate of crystals, but very fine (flint)



Figure 5-5. Images of quartz crystals in thin section

- Feldspar: It is a very important mineral in detrital rocks. It constitutes 8.5 to 12% and is very abundant in modern sands of diverse origins. Some sandstones do not contain feldspar, but others can contain more than 90%. River sands appear to be more feldspar-rich than dunes or beach sands. Its abundance is due to:

    - composition of the parent rock
    - chemical weathering at the place of origin
    - solution during diagenesis

    The Feldspar classes are (Figure 5-6): orthoclase, sanidine, microcline, anorthoclase, plagioclase, and perthite.

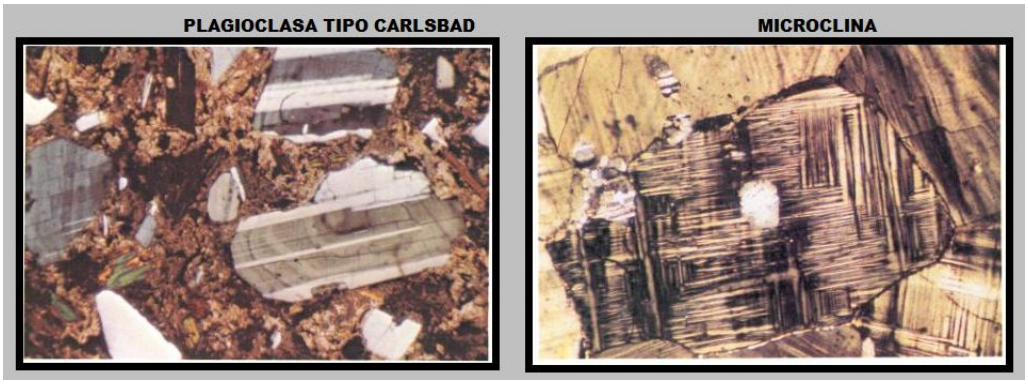


Figure 5-6. Images of feldspar crystals in thin section

- Micas and clays: Its are considered a single group due to their chemical composition (hydrated aluminosilicate) and crystalline structure (lamellar). Sandstones (Figure 5-7) contain large grains of muscovite, biotite, and chlorite. They rarely make up more than 2% of the rock and less than 0.5% of the terrigenous fraction. This is a very durable mineral, extremely difficult to round and almost impossible to fracture.

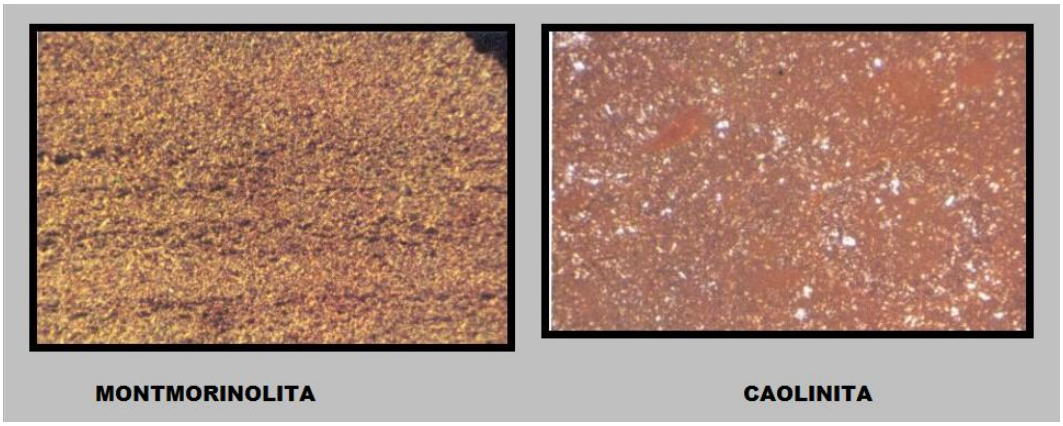


Figure 5-7. Images of mica and clay crystals in thin section

- Fragments of sedimentary rocks: Common in conglomerates, although many sands contain grains of mudstone, shale, limestone, and fine sandstone (Figure 5-8). They are generally not resistant to abrasion; therefore, if present in large quantities, they indicate short-distance transport.

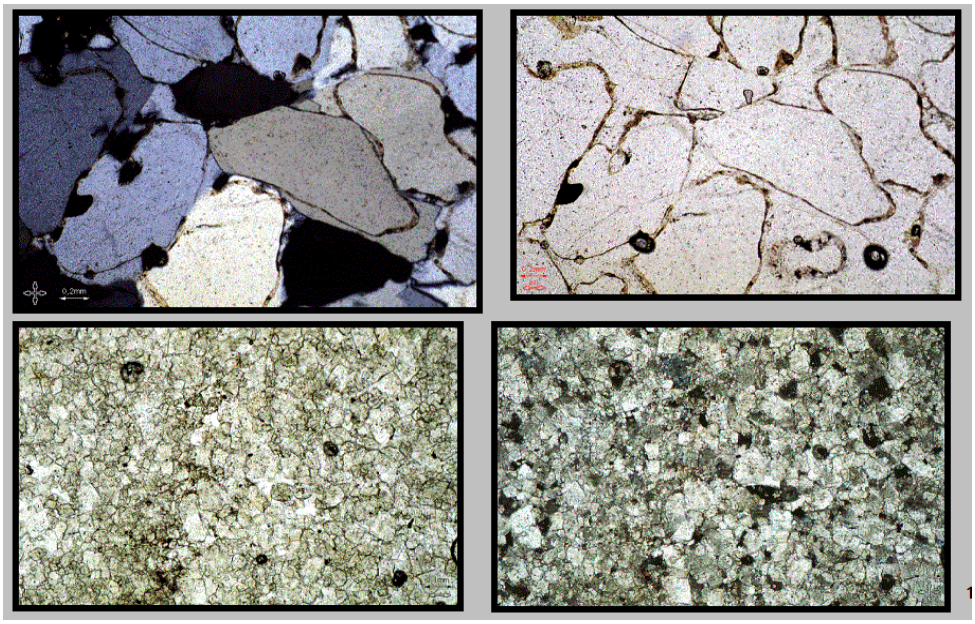


Figure 5-8. Images of sedimentary rock fragments in thin section. The top two of sandstones and the two lower ones of limestone.

5.5 Original deposit info

5.5.1 Geological structure

The overall structure of the deposit exploited by HUNOSA is situated on a large scale within the Cantabrian Zone of the great Spanish Hercynian Massif, also known as the Iberian or Hesperian Massif (Figure 5-9), which is generally composed of Precambrian and Paleozoic rocks that underwent the intense folding and fracturing of the Hercynian or Variscan orogeny. Within this Massif, the Riosa area is classified within the Cantabrian Zone, according to Lotze (1945), and within the Central Asturian Coal Basin, according to Julivert et al. (1972).

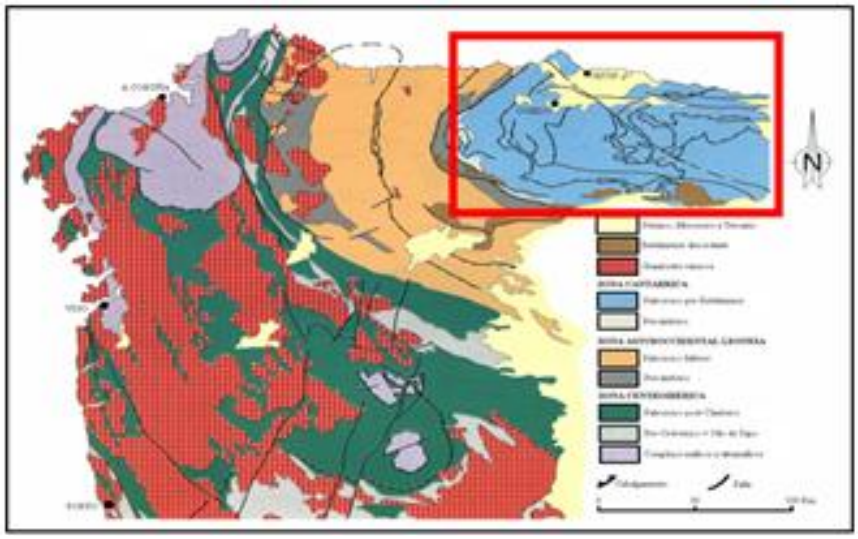


Figure 5-9. Zones of the Lotze Hesperian Massif (Book "Geology of Asturias")

The Central Asturian Coal Basin occupies the innermost concavity of called the Asturian Arch or Knee. The Hercynian orogeny took place precisely at the end of the Carboniferous period and, therefore, with the coal-bearing sediments still in a phase of consolidation. This resulted in a multitude of mining phenomena in which it is difficult to distinguish the sedimentary component from the tectonic one. Even so, the basin was generally spared the metamorphic and magmatic processes that affected other areas of the old Hercynian mountain range, except for specific cases where some coarse schistosity and even some volcanic episodes can be observed (as in the case of the two tonsteins that have been located).

Tectonically, the Riosa Belt is inserted between a large thrust fault to the North (Figure 5-10), which caused enormous limestone masses to fall onto the coalfields, even partially covering them, and another no less spectacular faulted strip to the Southeast, formed by the Peña and Carrera faults, to which are associated the mercury mineralizations exploited since Roman times.

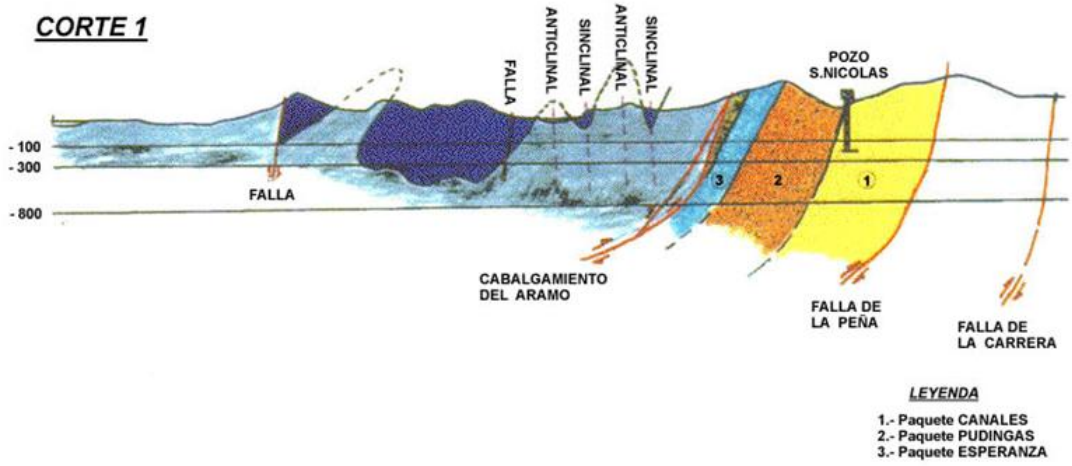


Figure 5-10. Geological cross-section of the Banda de Riosa – El Viso

Of these faults, the one at Peña is interpreted with a spectacular stra-parallelism typographic, along 20 km and therefore folded equally into the layers.

Despite such extraordinary tectonic confinement, the 20 km of thrust of the layers of the Riosa Band are free of longitudinal faults and those that have been interpreted to date are only transverse accommodation faults, sometimes of doubtful continuity as is the case of the so-called Montsacro Fault, known since ancient times and, above all, the faults of the East of Nicolasa, recently reviewed.

Almela and Ríos (1953) point out that the large mass of puddingstone that separates the Canales from the Esperanza package may have acted to give rigidity to the whole, an interpretation that Julivert (1964) supports due to the rigidity with which the layers continue towards the Northeast.

The western zone of the central coal basin, specifically the El Viso-Montsacro Unit or Band, exhibits a monoclinal arrangement in the form of a narrow band comprised of four packages with an average width of 2,000 m, extending for 20 km from the eastern slope of the Sierra del Aramo to the right bank of the Nalón River. This width, however, varies between 1,500 m at Grandiella and 4,000 m at Olloniego, depending on two key phenomena: the extent of the Montsacro-El Padrún thrust fault, which defines the band to the north and west, and the thickening caused by the deposition of the Olloniego polygenic conglomerate.

At this last point, the thrusting of the Mountain Limestone fossilizes the Viso-Montsacro Band until it is almost completely wedged.

If the northern border is marked by such important tectonic problems as well as by spectacular sedimentary phenomena such as the aforementioned Olloniego

Conglomerate, the southern border of the Banda is no less problematic and, according to ENADIMSA, "is marked by a set of important fractures, the Grandiella, Porcio and Merujedo faults, in Riosa, and the La Peña Fault in Nicolasa, Llamas and Olloniego, which separate them from an area with important coal outcrops, but so intensely tectonized that it does not allow for a profitable exploitation to be established there".

Stratigraphy

Stratigraphically, these are five packages that cannot be correlated with those known in the rest of the basin; from bottom to top, they are the following (Figure 5-11):

- Canales, the one that contains the main layers.
- Pudingas, a large accumulation of siliceous pebble conglomerates, exactly like those found in Mieres, Aller, and Langreo, but reaching almost 900 meters in thickness in the Ablaña area. Laterally, they wedge gradually but surprisingly both northeast (towards the Nalón River, past the Olloniego area) and in the opposite direction, towards the Riosa River. Their evolution at depth is not well established, as only three galleries ever passed through them, and only in the Esperanza area.
- Esperanza. Define the two- or three-layer package that occurs between the top of the previous package and a new, less powerful but more continuous pudding-like section. This package seems somewhat similar to the upper section of Canales, specifically layers 1, 2, 3, and 5 of San Nicolás.
- Ablanedo. Define the two or three layer package that is wedged against the thrust of the Mountain Limestone.
- Grandiella. Like the previous package, it defines groups of layers that appear in wedged zones between the Esperanza package and the Montaña Limestone thrust. They were never mined at pit depths.

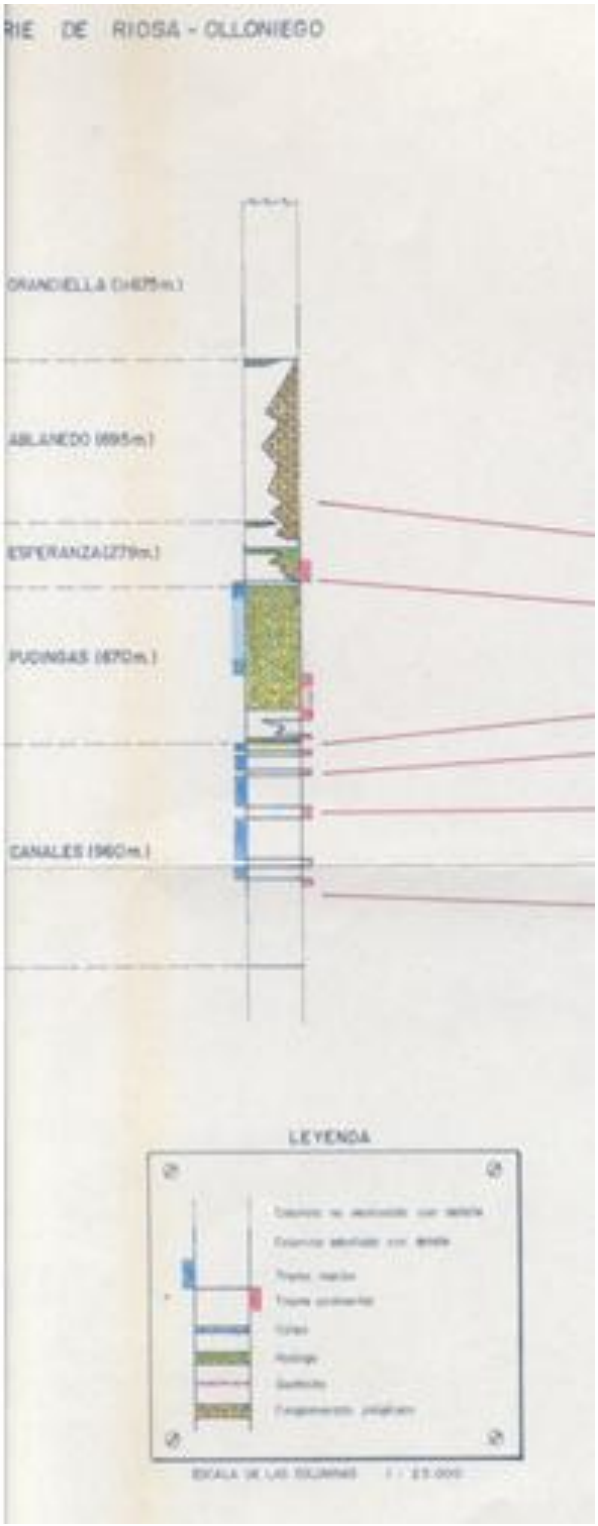


Figure 5-11. Stratigraphic column of the geological packages

Tectonic

Its deposit is located on the Riosa-Olloniego-El Viso unit (Figure 5-12) of the Central Coal Basin.

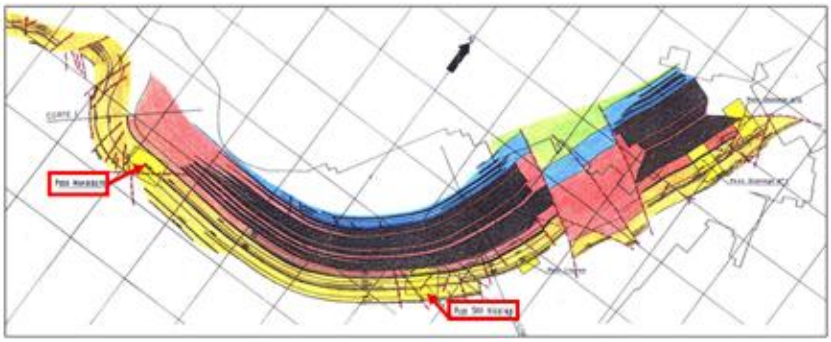


Figure 5-12. The Riosa-Olloniego Unit of the Central Asturian Coalfield

The differences between the Riosa-Olloniego unit and the rest of the central Asturian coal basin are, broadly speaking, reflected in different percentages of conglomeratic materials in the total series.

The stratigraphic sequence of the Sueros Area consists of four packages, named from bottom to top: Canales, Pudingas, Esperanza, and Ablanedo. Currently, only the Canales package is of mining interest. Sometimes the boundary between the Channels and Puddingstone packages is defined by the wall puddingstone or Small Puddingstone, thus including the section between layers 1 and 5 in the Puddingstone package. For operational purposes, it would be more practical to define this section as a subpackage. In fact, the large size of the Channels package suggests doing the same with the sections in which the other layers are grouped. This would allow for a better visualization of tectonic phenomena at the cartographic level.

The Riosa-Olloniego unit arcs from the E-W position in Riosa to the N-40º E in El Viso, passing through the NS in the middle part of its run. Its shape is that of a monocline with uniform dips to the North or West, except to the West of Pozo Montsacro where the strata dip to the South.

The eastern and western zones of the area are separated by the Montsacro fault. In the eastern zone (east of the Montsacro well and the San Nicolás well field), the ore body is relatively calm, trending east-west, in an upright position, and dipping 70-75° to the north. In the western zone (west of Montsacro), the ore bodies form an arc with the concavity directed northward and a steep dip also to the north. Consequently, the ore bodies dip N-30°W on the eastern flank, east-west at the end, and N-62°E on the western flank, always in an inverted position, dipping southward. This arcing produces a series of stepped faults that hinder mining operations. Fifteen ore bodies of the Canales package, one of the Pudingas package, and one of the Esperanza package have been

mined, although currently only ten ore bodies of the Canales package are considered viable.

5.5.2 Hydrogeological conditions

The San Nicolás and Montsacro wells represent the main underground works within the study area and are located in the alluvial plains of the Nicolasa and Riosa rivers.

The strategic location of the Sueros Area mines is the root of the drainage pro-blem, which stems from their history, as they were excavated below the piezometric level (Figure 5-13), which at the time roughly coincided with the river level, in an area of the terrain saturated with moisture. The rivers in the area drain a large catchment basin, primarily of a torrential nature, with abundant rainfall and snowfall.

Furthermore, the area's mining history has been extensive throughout this century. With few exceptions, mining has taken place entirely above valley level, meaning the entire area is heavily fissured and affected by subsidence from mountain mining. It can be considered that all the water that infiltrates the area ends up being drained via the Montsacro and San Nicolás wells, which creates a primarily economic problem (energy costs of drainage, loss of working hours due to water in the mining pits, etc.).

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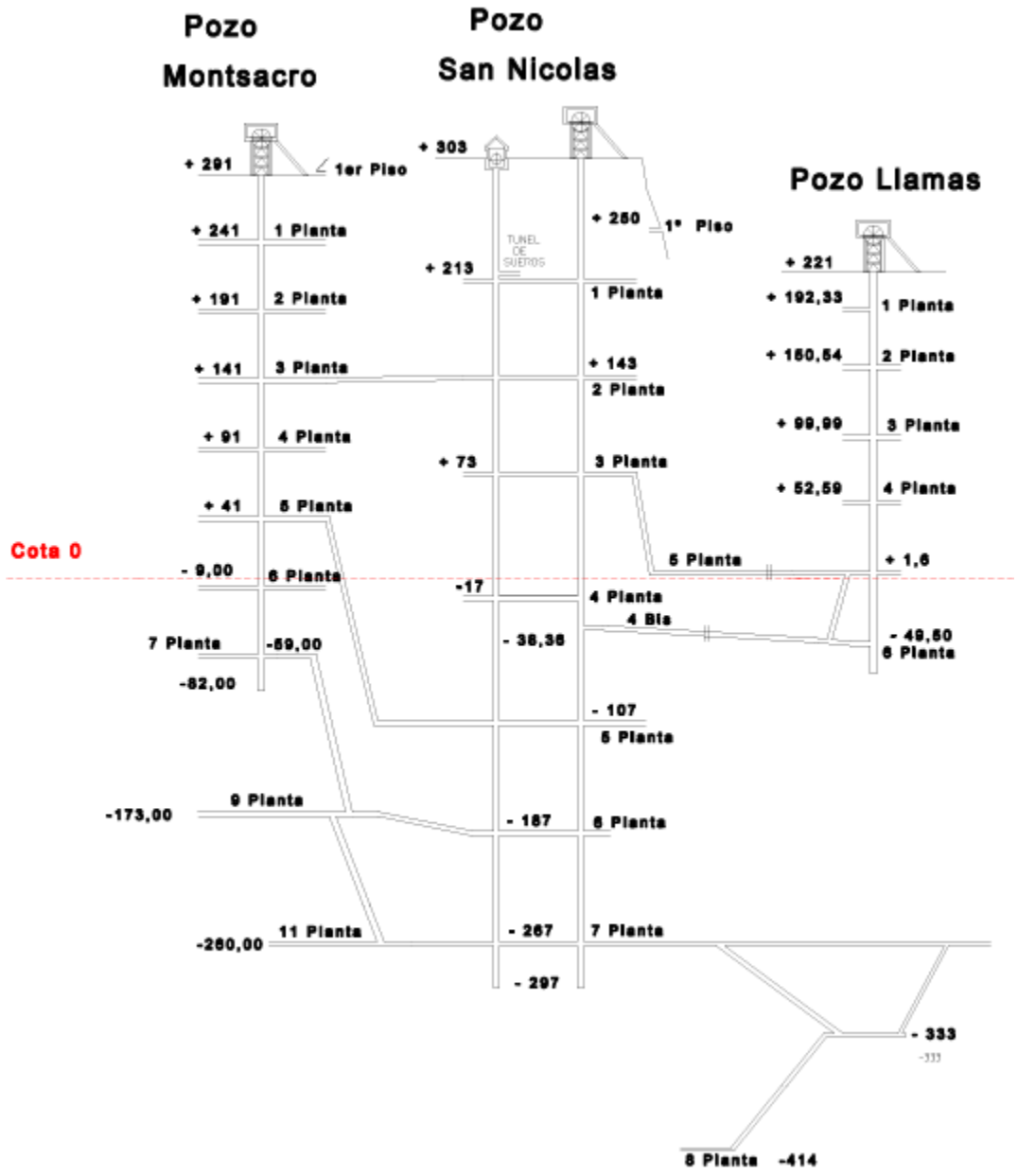


Figure 5-13. Connections between the shafts in the Sueros Area

5.6 Environmental and access considerations

The San Nicolás spoil heap was restored using hydroseeding and has continued to be used as a disposal site until the mine's closure on 31 December 2024.

5.7 Sample collection

Five boreholes have been planned in the San Nicolás dump (Figure 5-14) to take samples for analysis, although the results have not yet been received.



Figure 5-14. Location of the boreholes in the San Nicolás dump

Due to the ground conditions and technical problems encountered during the work, seven vertical boreholes have been drilled, passing through the spoil heap until they reach the natural ground, the characteristics of which are set out in the

Table 5-6.

Table 5-6. Characteristics of the boreholes drilled in the San Nicolás dump

Borehole	Code	Depth (m)	Cordenates
SN-1	20251203102026-UUN	7.00	X: -1191145.911 Y: 15004575.479
SN-1 BIS	20251203102952-UUN	14.00	X: -1191142.779 Y: 15004579.332
SN-2	20260128094324-UUN	13.00	X: -1190872.074 Y: 15004701.836
SN-3	20260128093739-UUN	14.50	X: -1191006.264 Y: 15004623.325
SN-4	20260128093152-UUN	4.00	X: -1190981.220 Y: 15004669.342
SN-4 BIS	20260128092447-UUN	32.00	X: -1190989.888 Y: 15004668.309
SN-5	20251203103353-UUN	10.50	X: -1191128.220 Y: 15004527.915

6 IBBENBÜREN MINE WATER SLUDGE TAILING PONDS (Germany)

6.1 Facility identification

The investigated facility corresponds to the sludge tailing ponds associated with the Gravenhorst mine water treatment plant, located near Hörstel in the former Ibbenbüren hard coal mining district, North Rhine-Westphalia, Germany.

These tailing ponds are used as deposition sites for residual sludge generated during the treatment of mine water originating from the former Ibbenbüren coal mine. The material deposited in these ponds consists primarily of fine-grained iron-rich precipitates and sediments generated during mine water treatment processes.

Following the closure of the Ibbenbüren hard coal mine in 2018, long-term mine water management became part of the perpetual post-mining obligations. The Gravenhorst facility plays a central role in this process, receiving mine water from underground workings and treating it before discharge into the regional river system.

During treatment, dissolved iron and other metals precipitate as hydroxides and oxides. These precipitates are separated from the water and deposited in nearby sludge tailing ponds, forming long-term controlled deposits of fine-grained mineral residues. These deposits represent secondary accumulations of materials potentially enriched in trace elements and critical raw materials (CRMs).

The site is therefore relevant both for environmental monitoring and for evaluating the potential recovery of secondary raw materials from mine water treatment residues.

6.2 Location and extent

The Ibbenbüren sludge tailing ponds are located in the vicinity of the Gravenhorst mine water treatment plant, near the municipality of Hörstel in the district of Steinfurt, North Rhine-Westphalia, Germany. The site is part of the former Ibbenbüren coal mining region, which represents the northernmost extension of the German Carboniferous hard coal basin.

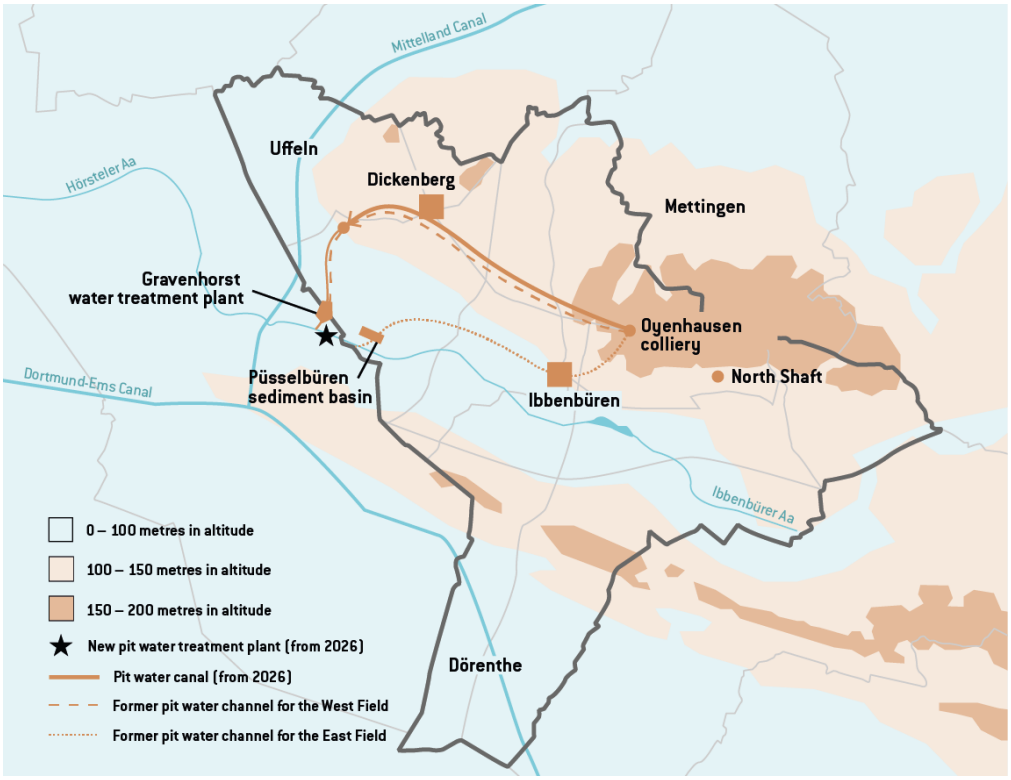


Figure 6-1. Regional overview of the Ibbenbüren coalfield in North Rhine-Westphalia, Germany, showing the location of the Gravenhorst mine water treatment plant and the associated sediment deposition basin. The map also illustrates the main hydrographic features, surrounding municipalities, and the planned pit water canal that will transport mine water from the former underground workings to the treatment facility (Modified from RAG Foundation, 2026)

The sludge deposition facility consists of several tailing ponds constructed to store residual sludge generated during mine water treatment processes. These ponds have been used continuously for sludge deposition since the early 1980s and today represent one of the largest accumulations of mine water treatment residues in Germany.

An orthophoto of the site is shown in Figure 6-2, where the four main tailing ponds used for sludge deposition are delineated. The deposited material consists primarily of iron-rich sludge formed during the precipitation and removal of dissolved metals from mine water prior to discharge into the regional river system.



Figure 6-2. Orthophoto showing the sludge tailing ponds located near the Gravenhorst mine water treatment plant (Ibbenbüren, Germany). The highlighted polygons delineate the main deposition areas where iron-rich sludge produced during mine water treatment is accumulated.

The surface area of each tailing pond was calculated from polygon delineations derived from orthophoto interpretation (Table 6-1). The four ponds together form a sludge deposition complex with a total surface area of approximately 257,000 m^2.

Table 6-1. Surface area of the four sludge tailing ponds located near the Gravenhorst mine water treatment plant (Ibbenbüren, Germany). The areas were calculated from polygon delineations derived from orthophoto interpretation.

Tailing Pond	Area (m^2)
Pond 1	94,802
Pond 2	49,837
Pond 3	56,900
Pond 4	55,817
Total Area	257,357

The sludge deposits accumulated within these basins typically reach depths of approximately 2–4 m, resulting in an estimated total sludge volume ranging between 472,000 and 944,000 m^3.

6.3 Operator information

The Ibbenbüren mine water treatment plant and the associated sludge deposition ponds are operated by RAG Aktiengesellschaft (RAG AG), which is responsible for implementing long-term mine water management measures following the closure of German hard coal mining. These activities form part of the long-term post-mining obligations associated with former underground coal mining operations in Germany (commonly referred to as Ewigkeitsaufgaben) (RAG Aktiengesellschaft, 2026).

The financing of these post-mining obligations is ensured by the RAG Foundation (RAG-Stiftung), which was established to secure long-term funding for environmental and technical responsibilities after the end of German hard coal mining in 2018. The main post-mining obligations include pit water management in former underground mines, pumping of surface water in subsidence areas (polder management), and groundwater purification and monitoring at selected former mining and industrial sites (RAG-Stiftung, 2022).

Within this framework, RAG AG operates and maintains the necessary technical infrastructure, including mine water treatment plants such as the Gravenhorst facility, which manages mine water discharged from the former Ibbenbüren mine.

Following the closure of the Ibbenbüren mine in 2018, RAG AG implemented the mine closure plan approved by the responsible mining authorities in 2020. This plan includes

the long-term management of mine water and the continued operation of treatment facilities required to ensure environmentally safe post-mining water management (RAG-Stiftung, 2026).

The sludge tailing ponds are therefore part of the long-term environmental management system designed to ensure safe treatment and storage of mine water treatment residues.

The ponds contain fine-grained iron-rich sediments derived from decades of mine water treatment operations. These deposits represent long-term accumulations of ferric hydroxides, manganese oxides, gypsum and associated trace metals.

6.4 Characteristics of waste

The material deposited in the Gravenhorst tailing ponds consists of sludge generated during the treatment of mine water originating from the former Ibbenbüren coal mine.

The sludge is produced during chemical and physical treatment processes that remove dissolved metals and suspended particles from mine water prior to discharge into natural water bodies.

The deposited sludge typically consists of:

- ferric hydroxides (FeOOH)
- iron oxides
- manganese oxides
- gypsum ($CaSO_4 \cdot 2H_2O$)
- clay-sized particles
- adsorbed trace metals

These fine-grained precipitates form the reddish to orange sediments characteristic of iron-rich mine water treatment residues (Flores et al., 2024).

Previous studies have indicated that such materials may contain elevated concentrations of metals and trace elements (Reker et al., 2025), including:

- manganese
- aluminium
- nickel
- cobalt
- titanium
- rare earth elements (REEs).

Iron and manganese hydroxides act as important sorption phases for trace metals, potentially concentrating elements of economic interest during precipitation processes.

This makes mine water treatment sludges particularly relevant for secondary raw material assessment and CRM exploration (Reker et al., 2022; Flores et al., 2024).

6.5 Original deposit information

The sludge deposited in the tailing ponds originates from the treatment of mine water draining from the underground workings of the former Ibbenbüren coal mine.

Mine water emerges primarily from the Dickenberger adit (Dickenberger Stollen), which drains the western field of the coal deposit (Rudakov et al., 2014). Since the early 1980s, when underground pumping was reduced and mine water levels began to rise, mine water has been continuously discharged through the Dickenberger adit and treated at the Gravenhorst facility (Hensel et al., 2020). Considering that the western field of the Ibbenbüren coal mine was flooded during this period, the hydrogeochemical signal of the discharged mine water has likely been influenced by a first flush effect, where elevated concentrations of dissolved metals are released during the early stages of mine flooding and drainage stabilization (Younger, 1997).

The discharged mine water contains dissolved metals, sulphates, and other constituents derived from interaction with underground rock formations and mining infrastructure. At the Gravenhorst treatment plant, this water undergoes treatment processes that induce the precipitation of iron and other dissolved metals. These precipitates form the sludge that is subsequently deposited in the tailing ponds (UIT, 2025). Over time, the continuous deposition of these materials has created large accumulations of iron-rich sediments that represent secondary anthropogenic deposits.

6.5.1 Geological structure

The Ibbenbüren coalfield is located within the Tecklenburger Land geological unit, representing the northernmost extension of the Carboniferous coal basin in Germany (RAG-Stiftung, 2026).

The geological sequence consists mainly of Westphalian coal measures of Carboniferous age, composed of alternating sandstone and conglomerate layers with subordinate mudstone horizons containing numerous coal seams (Bedoya-Gonzalez et al., 2021; Bässler, 1970). These formations were deposited in fluvio-deltaic environments during the late Carboniferous period (Bässler, 1970).

The coal extracted from Ibbenbüren was characterized by:

- high coal rank (anthracite)
- high calorific value (up to 30 MJ/kg)
- low volatile content

These properties made the coal particularly suitable for electricity generation and metallurgical applications.

Mining operations reached depths exceeding 1,500 meters, making Ibbenbüren one of the deepest coal mines in Europe.

6.5.2 Hydrogeological conditions

Hydrogeological conditions at the Ibbenbüren site are strongly influenced by the legacy underground mining infrastructure and the current mine water management strategy implemented after mine closure. After the cessation of coal production in 2018, mine water levels began to rise within the underground workings. In the western field of the mine, pumping operations were discontinued and mine water now flows naturally through the Dickenberger adit. Historically, water levels in this sector stabilized at approximately 65 m above sea level, enabling passive drainage through the existing system (Rudakov et al., 2014).

In contrast, the eastern field required continued pumping due to hydrogeological constraints. To address this, a new underground drainage canal is currently under construction to enable passive transport of mine water to the Gravenhorst treatment plant. The canal is designed with an approximate length of 7.4 km, a depth of about 70 m below surface, and a width of approximately 3.6 m. Once completed, this infrastructure will allow mine water from both sectors of the former mine to be conveyed passively to the treatment facility, reducing the need for energy-intensive pumping operations.

6.5.3 History and status

Coal mining at Ibbenbüren has a long history dating back to the 16th century, with industrial-scale underground mining beginning around 1850 (Stemke & Wieber, 2022). The Ibbenbüren mine was one of the last remaining hard coal mines in Germany and remained operational until 2018, when the final German hard coal mines were closed.

Following the cessation of mining operations:

- the closure plan was approved in 2020,
- mine shafts were backfilled in 2021,
- surface facilities were dismantled or repurposed,

The region is currently undergoing structural transformation from mining-based industry to new economic activities. Mine water management remains one of the key long-term responsibilities associated with the former mining operations. The Gravenhorst mine water treatment plant and its associated tailing ponds therefore represent essential infrastructure for ensuring environmentally safe post-mining water management.

6.6 Environmental and access considerations

The tailing ponds are located in a controlled area managed by RAG AG. Access to the site is restricted due to safety and environmental protection considerations.

The deposited sludge material is typically saturated or semi-saturated, creating muddy ground conditions that may limit accessibility for sampling activities.

To prevent the dispersion of fine particles into the surrounding environment, the tailing surfaces are regularly managed and kept partially wet.

Environmental monitoring is conducted to ensure that the treated water discharged from the facility complies with regulatory standards before entering the Hörsteler Aa river and ultimately the Ems river system.

6.7 Other information

The Gravenhorst sludge tailing ponds represent a significant accumulation of mine water treatment residues that may contain elevated concentrations of metals and trace elements.

Recent research initiatives have focused on evaluating the potential recovery of critical raw materials from such deposits.

Studies conducted within the framework of previous projects have demonstrated that iron hydroxide precipitates may act as carriers for trace metals and rare earth elements.

These findings highlight the potential for revalorisation of mine water treatment residues as secondary raw material resources, particularly within the context of European strategies aimed at securing sustainable supplies of critical raw materials.

6.8 Sample collection

Sampling activities are planned within the framework of the CRMsDataSpace project to characterize the geochemical composition of the sludge deposits at the Ibbenbüren facility. The sampling campaign aims to collect approximately 40–50 kg of sludge

material from selected locations within the tailing ponds to support subsequent laboratory analyses.



Figure 6-3. Overview of the sludge tailing pond surface at the Gravenhorst facility (Ibbenbüren, Germany) during a field campaign conducted in 2023. The image illustrates the characteristic iron-rich sediments derived from mine water treatment and the typical surface conditions of the deposit where sediment samples were collected for geochemical characterization (Photography by Hernan Flores).

The collected material will be used for several analytical purposes, including:

- geochemical characterization,
- mineralogical analysis,
- assessment of critical raw material (CRM) potential,
- metallurgical testing.

Sampling locations will be documented using geographic coordinates, site photographs, field descriptions, and a map showing the sampling points. Due to access restrictions and the soft, muddy ground conditions within the ponds, samples will be collected from accessible areas near the margins of the deposits.

7 CONCLUSIONS AND LESSONS LEARNT

Deliverable 2.1 confirms that closed and transitioning coal waste facilities across Europe can be systematically documented as potential secondary sources of critical raw materials, provided that geological, environmental, operational and access-related information is collected in a structured and comparable way.

The deliverable establishes this baseline for five contrasting case studies in Romania, Poland, Spain, and Germany, thereby laying the foundation for the next project stages: detailed mineralogical and geochemical characterisation, metallurgical testing, resource estimation, and integration into the CRMsDataSpace.

A central conclusion of the document is that these facilities cannot be treated as a single category. Their origin, geometry, waste composition, hydrogeological setting, environmental sensitivity, reclamation status and current management conditions differ substantially.

The deliverable also shows that technical characterisation must go beyond simple site identification. Useful baseline knowledge includes accurate geometry, deposit extent, historical development, waste typology, sampling strategy, ownership and legal status, hydrogeological conditions, and environmental constraints.

Another important conclusion is that environmental liability and resource opportunity often coexist. At the same time, the document shows that reclamation and ecological restoration measures are already underway, indicating that environmental management and future valorisation need not be contradictory pathways.

The report further concludes that reclamation should not be interpreted as the end of technical relevance.

Finally, Deliverable 2.1 supports a broader strategic conclusion: Europe's coal-mining legacy should be reframed not only as a post-industrial environmental burden, but also as a potentially valuable stock of secondary raw materials.

However, this potential can only be unlocked through site-specific evaluation, because feasibility will depend on the balance between resource content, geotechnical stability, environmental risk, accessibility, and the status of closure or rehabilitation works.

The lessons learnt from this Deliverable are as follows:

- The first lesson learnt is that site heterogeneity is decisive. Even when facilities originate from the same broad sector, their material properties, environmental behaviour and redevelopment constraints differ markedly. This means that no

uniform methodology based only on desk research or generic assumptions would be sufficient.

- The second lesson is that environmental and geotechnical factors must be addressed from the outset. The document shows that recovery potential cannot be assessed independently from slope stability, water interactions, oxidation processes, and reclamation status.
- A third lesson is that good geometry and sampling design are essential. In other words, reliable resource assessment starts with knowing where the material is, how it is distributed, how thick it is, and how variable it may be both laterally and vertically.
- The fourth lesson is that reclamation and valorisation can be complementary. The practical implication is that closure planning should preserve, whenever possible, the information and access conditions needed for future resource evaluation.
- The fifth lesson is that post-mining residues extend beyond classic spoil heaps. This is significant because it suggests that future inventories of CRM-bearing coal legacies should include fine residues, sludges and treatment by-products, not just traditional waste dumps.
- A final lesson is that this deliverable is a baseline, not an endpoint. Therefore, the main achievement of Deliverable 2.1 is not the final quantification of recoverable CRMs, but the creation of a consistent evidence base that allows the project to move toward mineralogical testing, concentration studies, drilling-based resource definition and digital integration in the common data space.

REFERENCES AND METADATA

Bässler, R. (1970). Hydrogeologische, chemische und Isotopen-Untersuchungen der Grubenwässer im Ibbenbürener Steinkohlenrevier. Zeitschrift der Deutschen Geologischen Gesellschaft, 209–286.

Bedoya-Gonzalez, D., Hilberg, S., Redhammer, G., & Rinder, T. (2021). A petrographic investigation of the Carboniferous sequence from the Ibbenbüren mine: Tracing the origin of the coal mine drainage. Minerals, 11(5), 483. https://doi.org/10.3390/min11050483

Flores, H., Reker, B., Pawlik, M., Haske, B., & Rudolph, T. (2024). Hyperspectral UAS sensing for tailing ponds monitoring: Towards responsible resource repurposing. In B. Kleinmann, J. Skousen & Ch. Wolkersdorfer (Eds.), West Virginia Mine Drainage Task Force Symposium & 15th International Mine Water Association Congress (pp. 196–202). Morgantown, WV, USA: International Mine Water Association.

Hensel, P., Kugel, J., Terwelp, T., & Tuschmann, J. (2020). Long-term management of mine water operations in the German coalfields: An interim evaluation based on operating plans and hydrological permits. Mining Report Glückauf, 156, 97–105.

RAG Aktiengesellschaft (2026). Was sind die Ewigkeitsaufgaben? Available online: https://www.rag.de/loesungen/wasserhaltung/grubenwasser-faq/ (accessed on 05 March 2026).

RAG-Stiftung (2022). The RAG Foundation at a glance. Available online: https://anrep.rag-stiftung.de/2022/the-rag-stiftung-at-a-glance.html (accessed on 05 March 2026).

RAG-Stiftung (2026). Mine water management in Ibbenbüren. Available online: https://www.rag-stiftung.de/ewigkeitsaufgaben/ibbenbueren/ (accessed on 05 March 2026).

Reker, B., Westermann, S., & Melchers, C. (2022). Mine waters as a resource of critical raw materials in Germany. GeoResources, 4(2022), 43–47. https://www.georesources.net/cms.php/de/journals/865/Grubenwaesser-als-Ressource-kritischer-Rohstoffe-in-Deutschland

Reker, B., & Westermann, S. (2025). Re-mining of mine water sludges in Germany: An opportunity? In T. Valente, R. Mühlbauer, A. Ordóñez & Ch. Wolkersdorfer (Eds.), International Mine Water Association Conference – Time to Come (pp. 807–812). Braga: International Mine Water Association.

Rudakov, D. V., Coldewey, W. G., & Goerke-Mallet, P. (2014). Modeling the inflow and discharge from underground structures within the abandoned hard coal mining area of West Field (Ibbenbüren). In W. Sui, Y. Sun & C. Wang (Eds.), An interdisciplinary response to mine water challenges: Proceedings of the 12th International Mine Water Association Congress (pp. 699–705). Xuzhou, China: China University of Mining and Technology.

Stemke, M., & Wieber, G. (2022). Closure of German hard coal mines: Effects and legal aspects of mine flooding. Mine Water and the Environment, 41, 280–291. https://doi.org/10.1007/s10230-021-00842-7

UIT GmbH (2025). Mechanical completion of the mine water treatment plant in Gravenhorst finished: functional tests and commissioning are starting. Available online: https://www.uit-gmbh.de/en/news-and-fairs/news/news-detail/mechanical-completion-of-the-mine-water-treatment-plant-in-gravenhorst-finished (accessed on 05 March 2026).

Younger, P. L. (1997). The longevity of mine water pollution: A basis for decision-making. Science of the Total Environment, 194–195, 457–466. https://doi.org/10.1016/S0048-9697(96)05383-1