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Executive Summary

This deliverable presents the multihole exploration drilling, sampling and laboratory characterisation activities carried out at two coal mining waste facilities within the CRMsDataSpace project: the San Nicolás waste dump in Asturias (Spain) and the Janina facility in Libiąż (Poland).

The main objective was to establish an initial geological and geochemical dataset to assess the presence, concentration and spatial distribution of Critical Raw Materials (CRMs) in these deposits, providing the technical basis for evaluating their potential as secondary raw material sources.

The exploration campaign comprised seven boreholes at San Nicolás, representing approximately 95 m of drilling and 21 representative samples, and three boreholes at Janina, from which 12 samples were reported. We employed different drilling techniques based on each site's characteristics, demonstrating the importance of adapting exploration procedures to the heterogeneous and often unconsolidated nature of mining waste deposits.

Sampling was performed at approximately 5 m depth intervals, consistent with the spatial resolution envisaged for subsequent three-dimensional modelling using RecMin software. Standardised borehole and sample identification procedures, together with geographical and photographic documentation, ensured traceability and facilitated data integration.

We prepared the collected samples and conducted homogenisation and chemical and mineralogical analyses using complementary laboratory techniques.

The results confirmed the presence of several elements of interest for CRM assessment at both facilities, although differences were observed in their concentrations and distribution.

At San Nicolás, we identified significant spatial and vertical variability, including tungsten concentrations reaching approximately 1,785 ppm and copper concentrations up to 390 ppm in selected intervals, along with variations in rare earth elements such as cerium and neodymium.

At Janina, the analysed samples generally showed more consistent concentrations of several rare earth elements, along with gallium and vanadium. These findings provide preliminary evidence of the geochemical characteristics of the investigated materials but cannot be extrapolated to the entire deposits without further spatial analysis.

The investigation has successfully established an initial dataset for the subsequent assessment of CRM distribution and potential recovery from coal mining waste.

However, identifying elements of interest does not necessarily demonstrate their technical or economic recoverability.

Further activities will therefore focus on validating and integrating the analytical results into RecMin to develop three-dimensional geochemical models, completing the mineralogical characterisation and conducting hydrometallurgical leaching tests to determine the recovery potential of the identified elements.

Overall, the results demonstrate the applicability of a systematic exploration methodology combining drilling, representative sampling, laboratory characterisation and digital geological modelling.

The knowledge gained provides a valuable foundation for the next stages of the CRMsDataSpace project and contributes to improving the assessment of coal mining waste facilities as potential secondary sources of Critical Raw Materials, supporting resource efficiency and circular economy objectives.

1 Introduction

This report presents the drilling, sampling, and chemical and mineralogical characterisation carried out at two coal mining waste facilities: the San Nicolás dump in Asturias, Spain, and the ZG Janina waste facility in Libiąż, Poland. The objective is to establish a technical basis for assessing the possible presence, concentration, and distribution of Critical Raw Materials (CRMs) in these materials and, in subsequent stages, to evaluate their potential use as secondary sources.

The San Nicolás campaign comprised seven vertical boreholes, with an approximate cumulative drilled length of 95 m, from which 21 representative samples were obtained.

At Libiąż, three auger boreholes were completed, with a cumulative drilled length of 45 m, and 12 samples were selected. In total, 33 samples from different locations and depth intervals are available. The sampling strategy used approximately 5 m intervals to match the spatial resolution envisaged for RecMin modelling.

The samples were identified, prepared, and analysed using complementary techniques, including ME-MS89L, ME-MS19, PGM-ICP27, FTIR-MIN, FTIR-BAUX, AQ200, and LF200, depending on the required determination. The programme provides data on elements of interest—including rare earth elements and other potentially relevant elements—as well as selected mineral phases and major components. Mechanical preparation, homogenisation, and sample traceability allow analytical results to be linked to the corresponding borehole and depth interval.

The available results support an initial comparative assessment of the two facilities. San Nicolás shows variation between boreholes and depth intervals, with notable values in some intervals for elements such as tungsten, copper, and selected rare earth elements.

In the Janina samples presented, several elements show comparatively consistent values across the three boreholes, including rare earth elements, gallium, and vanadium. These observations are preliminary and must be interpreted in light of the sample numbers, detection limits, analytical methods, and units used in the tables.

This report therefore provides an initial characterisation and organisation of the information required for subsequent evaluation. Spatial integration of the data in **RecMin software**, detailed review of analytical quality and comparability, additional mineralogical characterisation, and hydrometallurgical leaching tests will be needed to assess element distribution, potential recovery, and the potential of the materials as secondary resources.

RecMin is a software tool specialised in managing, visualising, and evaluating geological and mining data. The software integrates and visualises information from boreholes, samples, and laboratory analyses in both two-dimensional views and a three-

dimensional environment. This functionality facilitates interpreting the spatial distribution of geological units and variables of interest throughout the deposit.

RecMin provides tools for the analysis and processing of geological data and for the estimation of variables using geostatistical methods. Integrating sampling data and analytical results into the block model enables the generation of a three-dimensional representation of the deposit and analysis of the spatial distribution of grades and other relevant properties.

One of RecMin's main functions is generating and managing block models, in which the deposit volume is divided into discrete units to which different properties can be assigned, such as lithology, density, or grades of analysed elements. In this work, we incorporate analytical results from borehole samples into the model to provide a spatial representation of the deposit's characteristics (Figure 1-1).

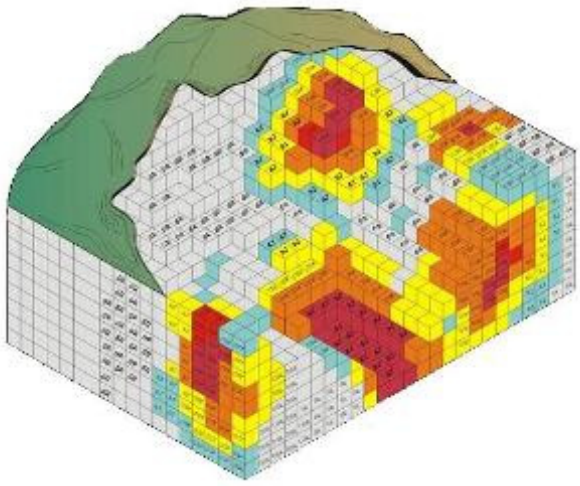


Figure 1-1. Examen of a block model of a deposit generated by RecMin

Thus, the methodology combines systematic borehole sampling, representative sample preparation and selection for chemical analysis, and subsequent integration of the analytical results into RecMin. This approach ensures consistency between the analytical data resolution and the model's spatial scale, providing a basis for characterising and evaluating the mineral resources within the deposit.

The **Caderneta application** was designed to support field data collection and management using an Android Tablet. The application enables the collection of information on sampling points and samples within a predefined fieldwork plan, while also facilitating monitoring of field activities as they are carried out.

Annex I (Caderneta application) provides a detailed description of the application's functionalities, along with examples of its use for recording borehole information and photographic documentation during the San Nicolás drilling campaign.

2 San Nicolás dump in Asturias (Spain).

The San Nicolás dump is a key geographical and landscape feature of Asturias's mining industrial heritage. It represents decades of mining activity at the San Nicolás coal mine, part of the state-owned company HUNOSA. Unlike other dumps that have been completely dismantled, the San Nicolás heap has been the subject of several environmental restoration and landscape integration plans. Figure 2-1 presents the San Nicolás Mine.



Figure 2-1. San Nicolás Mine

The San Nicolás dump is located in the vicinity of Ablaña, in an area known as Lleros de Abajo, within the municipality of Mieres (Figure 2-2) and adjacent to the San Nicolás mine of HUNOSA (Figure 2-3).

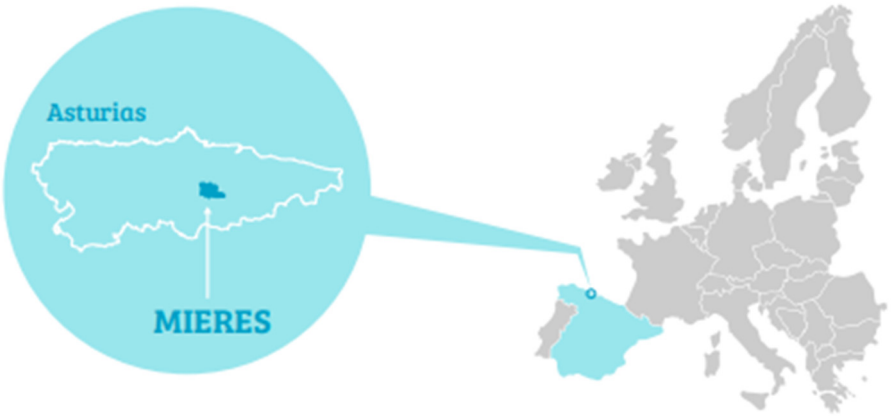


Figure 2-2. General layout



Figure 2-3. Location of San Nicolás dump

The geographical coordinates of the San Nicolás dump are those that are shown in Table 2-1. It covers 5.18 ha, measuring approximately 590 m long and 110 m wide, with an average variable height of 40 m from the Nicolasa River to the top surface of the heap, and contains a volume of 700,000 m³ of waste from the old Nicolasa Mine and the San Nicolás Mine.

Table 2-1. 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

2.1 Borehole characteristics from Spain

The project initially planned five vertical boreholes in the San Nicolás dump to collect samples for analysis and characterise the entire spoil heap. During drilling of Boreholes 1 and 4, technical difficulties caused the drilling equipment to collapse, requiring the rig to be repositioned approximately 2 m from the original locations.

Consequently, seven vertical boreholes were ultimately completed. All boreholes were drilled through the spoil material until the underlying natural ground was encountered, and samples were collected from each borehole at 5-metre intervals.

Figure 2-4 shows the borehole locations in the San Nicolás Mine waste dump.

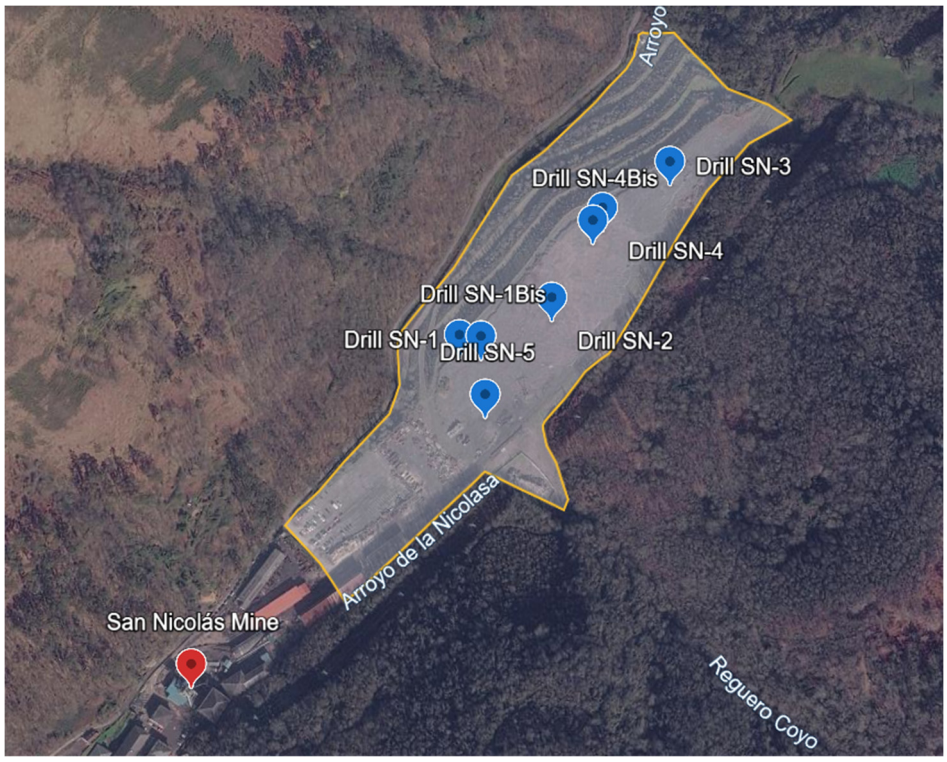


Figure 2-4. Location of the boreholes of San Nicolás dump.

The drilling machine used to drill boreholes (Figure 2-5) is owned by HUNOSA and was used to carry out the drilling operations required for installation. The equipment is a self-propelled drilling unit with a crawler-type undercarriage, allowing it to be transported and positioned within the work areas.



Figure 2-5. San Nicolás dump, drilling rigs.

The main identification characteristics of the equipment are as follows:

- Manufacturer/model: Rotatec RL-400
- Motor: CATERPILLAR mod. C4.4 IND ACERT 96.5 KW (131 CV) at 2,200 r.p.m.
- Mobility system: crawler-type undercarriage.
- Diameter HQ/NQ.

The drilling machine is mounted on a crawler-type undercarriage, which facilitates its movement and positioning at the drilling locations.

This configuration is particularly suitable for operations carried out at mining waste facilities and other sites where access conditions and ground characteristics may require a high degree of manoeuvrability (Figure 2-6).



Figure 2-6. East and west views of the San Nicolás dump

Before the works began, the general condition of the equipment was checked, along with the availability and suitability of the components required to perform the drilling operations. The main characteristics of the completed boreholes are summarised in

Table 2-2.

Table 2-2. Characteristics of the boreholes drilled in the San Nicolás dump

Initial Borehole	Code	Caderneta Code	Depth (m)	UTM ZONE 30 Coordinates (m)	Geographical Coordinates
SN-1	SN 001A 00700	20251203102026	7.00	X: 271504.67 Y: 4793012.57 Z: 293.49	Lat: 43°15'19.03''N Long: 5 °48'53.81''W
SN-1 BIS	SN 001B 01400	20251203102952	14.00	X: 271527.58 Y: 4793027.76 Z: 293.81	Lat: 43°15'19.24''N Long: 5 °48'52.89''W
SN-2	SN 002A 01300	20260128094324	13.00	X: 272390.44 Y: 4792347.29 Z: 293.69	Lat: 43°14'58.46''N Long: 5 °48'13.59''W
SN-3	SN 003A 01450	20260128093739	14.50	X: 271628.93 Y: 4793076.73 Z: 291.03	Lat: 43°15'21.25''N Long: 5 °48'48.40''W
SN-4	SN 004A 00400	20260128093152	4.00	X: 271645.83 Y: 4793128.54 Z: 292.45	Lat: 43°15'22.94''N Long: 5 °48'47.73''W
SN-4 BIS	SN 004B 03200	20260128092447	32.00	X: 271630.00 Y: 4793139.31 Z: 292.26	Lat: 43°15'22.90''N Long: 5 °48'48.01''W
SN-5	SN 005A 01050	20251203103353	10.50	X: 271537.43 Y: 4792964.15 Z: 294.87	Lat: 43°15'17.50''N Long: 5 °48'52.29''W

The table shows, in the first column, the initial designation assigned to each borehole (SN-1, SN-1BIS, SN-2, etc.), together with its depth and UTM and geographic coordinates. The second column provides the standardised code established for the project, which is used consistently to identify the boreholes, samples, and heaps across all participating countries (Figure 2-7).

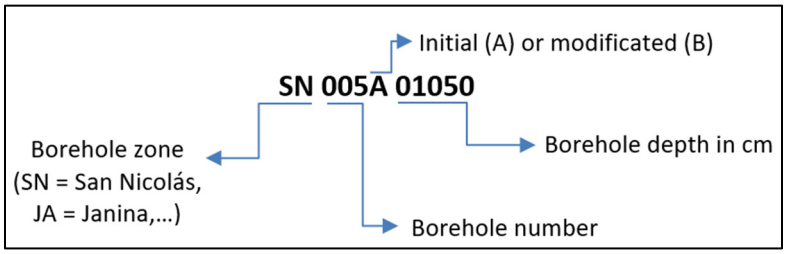


Figure 2-7. Standardised code to identify the boreholes

The third column contains the code generated by the Caderneta application, which was used to register the boreholes, and which corresponds to the WGS84 coordinates.

2.2 Samples from Spain

Samples were selected for analysis from the 7 drill holes completed (95 m), resulting in a total of 21 representative samples. The samples were collected at regular 5 m intervals, using all material from each interval.

The collected material was then size-reduced and homogenised to ensure uniform distribution of its characteristics. From the homogenised material, we obtained an approximately 200 g representative sample by quartering and sent it to the laboratory for chemical analysis.

The selection of 5 m sampling intervals is related to the spatial resolution subsequently used for modelling in RecMin. In this case, a minimum block size of 5 m is used to represent the deposit. Therefore, the sampling interval was set to match the model's spatial discretisation, allowing the analytical results to be linked to the corresponding blocks.

The samples were properly identified, prepared, and submitted to an accredited laboratory, ALS Laboratory Group, S.L., for chemical and mineralogical characterisation. The analyses were performed to determine the concentration of the elements of interest and, in particular, the Critical Raw Materials (CRMs) potentially present in the investigated materials. The hydrometallurgical leaching tests have not yet been carried out.

The samples were named using the same identifier assigned to each drill hole, with the corresponding depth interval added to each sample's drill-hole name (Figure 2-8).

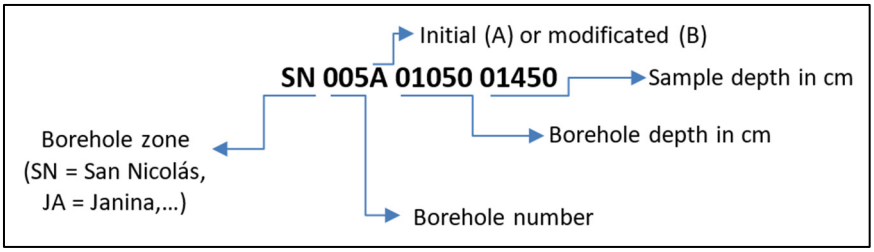


Figure 2-8. Standardised code to identify the samples

This naming convention allows both the source drill hole and the depth at which each sample was collected to be directly identified. The sampling intervals were defined consecutively every 5 m, following the structure 0–5 m, 5–10 m, 10–15 m, and so on, until the investigated depth of each drill hole was reached (**¡Error! La autoreferencia al marcador no es válida.**). This nomenclature facilitates sample traceability and allows the analytical results to be unambiguously related to their position within the corresponding drill hole.

Table 2-3. Characteristics of the boreholes drilled in the San Nicolás dump

Initial Borehole	Borehole Code	Borehole Depth (m)	Sample Code	Description
SN-1	SN 001A 00700	7.00	SN 001A 00700 00500	From 0.00 to 5.00 m
			SN 001A 00700 01000	From 5.00 to 7.00 m
SN-1 BIS	SN 001B 01400	14.00	SN 001B 01400 00500	From 0.00 to 5.00 m
			SN 001B 01400 01000	From 5.00 to 10.00 m
			SN 001B 01400 01400	From 10.00 to 14.00 m
SN-2	SN 002A 01300	13.00	SN 002A 01300 00500	From 0.00 to 5.00 m
			SN 002A 01300 01000	From 5.00 to 10.00 m
			SN 002A 01300 01300	From 10.00 to 13.00 m
SN-3	SN 003A 01450	14.50	SN 003A 01450 00500	From 0.00 to 5.00 m
			SN 003A 01450 01000	From 5.00 to 10.00 m
			SN 003A 01450 01450	From 10.00 to 14.50 m
SN-4	SN 004A 00400	4.00	SN 004A 00400 00400	From 0.00 to 4.00 m
SN-4 BIS	SN 004B 03200	32.00	SN 004B 03200 00500	From 0.00 to 5.00 m
			SN 004B 03200 01000	From 5.00 to 10.00 m
			SN 004B 03200 01500	From 10.00 to 15.00 m
			SN 004B 03200 02000	From 15.00 to 20.00 m
			SN 004B 03200 02500	From 20.00 to 25.00 m
			SN 004B 03200 03000	From 25.00 to 30.00 m
			SN 004B 03200 03200	From 30.00 to 32.00 m
SN-5	SN 005A 01050	10.50	SN 005A 01050 00500	From 0.00 to 5.00 m
			SN 005A 01050 01050	From 5.00 to 10.50 m

2.3 Sample analysis from Spain

The results of the samples taken from the boreholes at the San Nicolás dump are presented below.

Table 2-4, Figure 2-9 and Figure 2-10, show the analysis results for borehole SN001A00700 (SN-1). The CRM elements in the mineral substances are analysed separately due to the significant difference in their concentrations.

Table 2-4. Results of quantitative analysis of the borehole SN001A00700 (SN-1)

METHOD	CRM	SN 001A 00700 00500 (ppm)	SN 001A 00700 01000 (ppm)
ME-MS89L	Sb	0.90	1.00
ME-MS89L	As	15.00	9.00
ME-MS19	Al	10.00	<5.00
ME-MS89L	Ba	374.00	243.00
ME-MS89L	Be	1.90	1.10
ME-MS89L	Bi	0.30	0.20
ME-MS19	B	<10.00	<10.00
ME-MS89L	Co	25.70	9.20
ME-MS89L	Cu	50.00	60.00
ME-MS89L	Ga	16.80	10.40
ME-MS89L	Ge	1.10	1.20
ME-MS89L	Hf	10.00	10.00
ME-MS89L	Sc	10.00	7.00
ME-MS89L	Y	24.30	18.00
ME-MS89L	La	35.80	24.40
ME-MS89L	Ce	0.34	0.02
ME-MS89L	Pr	8.20	5.74
ME-MS89L	Nd	31.20	22.60
ME-MS89L	Sm	5.95	4.19
ME-MS89L	Eu	1.25	0.87
ME-MS89L	Gd	5.18	3.68
ME-MS89L	Tb	0.73	0.55
ME-MS89L	Dy	4.39	3.05
ME-MS89L	Ho	0.88	0.63
ME-MS89L	Er	2.43	1.89
ME-MS89L	Tm	0.36	0.24
ME-MS89L	Yb	2.36	1.43
ME-MS89L	Lu	0.34	0.21
ME-MS89L	Li	77.00	38.00
ME-MS89L	Mg	435.00	344.00
ME-MS89L	Mn	590.00	420.00
ME-MS89L	Ni	40.00	40.00
ME-MS89L	Nb	12.20	9.10
ME-MS19	P	<5.00	<5.00
PGM-ICP27	Pt	<0.01	<0.01
PGM-ICP27	Pd	<0.01	<0.01
PGM-ICP27	Au	<5.00	<5.00
ME-MS19	Si	70.00	20.00
ME-MS89L	Sr	160.00	150.00
ME-MS89L	Ta	0.96	0.45
ME-MS89L	Ti	0.37	0.26
ME-MS89L	W	123.00	200.00
ME-MS89L	V	98.00	58.00
FTIR-MIN	K Feldspar	10,000.00	10,000.00
FTIR-MIN	Plagioclase	30,000.00	30,000.00
FTIR-BAUX	SiO_2	710,000.00	760,000,00
FTIR-BAUX	Al_2O_3	90,000.00	60,000.00
FTIR-BAUX	Al_2O_3avl	<10,000.00	<10,000.00
FTIR-BAUX	Boehmite	<10,000.00	<10,000.00
FTIR-BAUX	Gibbsite	50,000.00	30,000.00

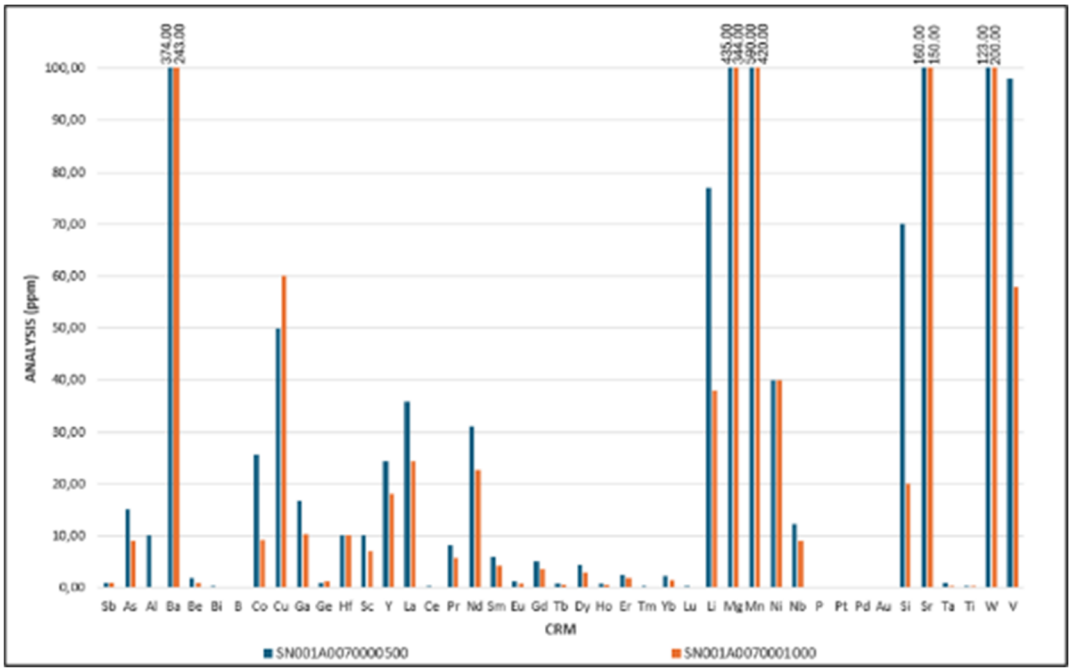


Figure 2-9. Graph of the quantitative analysis of the CRM elements of the borehole SN001A00700 (SN-1)

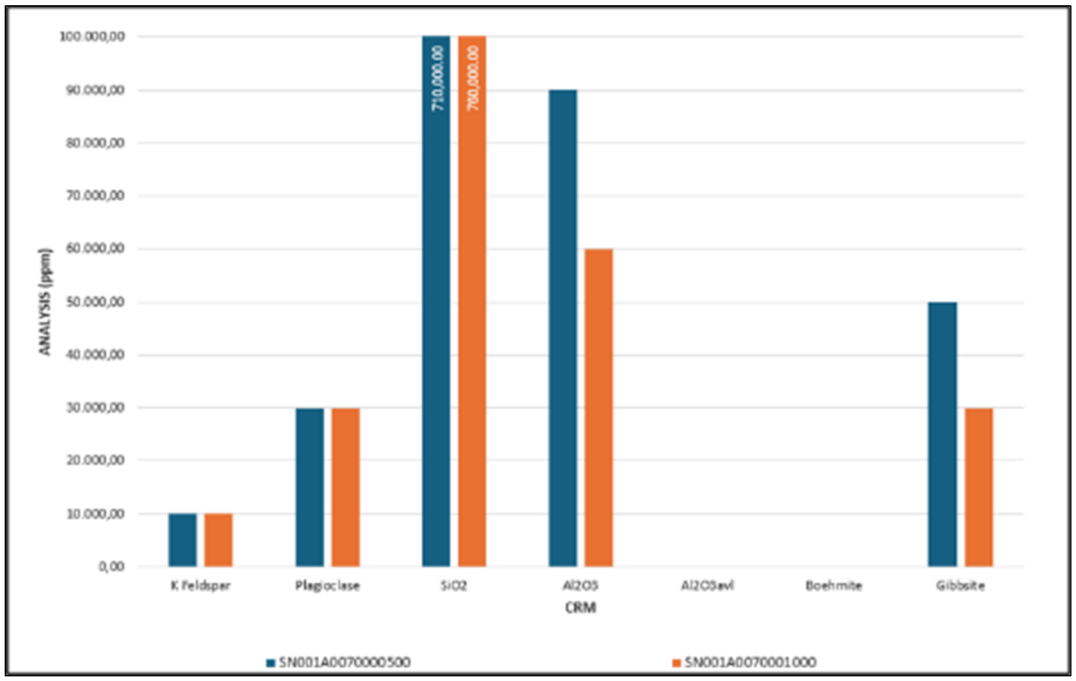


Figure 2-10. Graph of the quantitative analysis of the CRM minerals of the borehole SN001A00700 (SN-1)

Table 2-5, Figure 2-11 and Figure 2-12 show the analysis results for borehole SN001B00400 (SN-1Bis).

Table 2-5. Results of quantitative analysis of the borehole SN001B01400 (SN-1Bis)

METHOD	CRM	SN 001B 01400 00500 (ppm)	SN 001B 01400 01000 (ppm)	SN 001B 01400 01400 (ppm)
ME-MS89L	Sb	1.50	1.40	1.50
ME-MS89L	As	12.00	18.00	13.00
ME-MS19	Al	7.00	215.00	970.00
ME-MS89L	Ba	334.00	338.00	381.00
ME-MS89L	Be	2.10	1.90	2.30
ME-MS89L	Bi	0.30	0.30	0.30
ME-MS19	B	<10.00	<10.00	<10.00
ME-MS89L	Co	13.00	20.50	20.40
ME-MS89L	Cu	90.00	160.00	290.00
ME-MS89L	Ga	17.20	17.50	19.60
ME-MS89L	Ge	1.50	1.40	1.70
ME-MS89L	Hf	10.00	10.00	10.00
ME-MS89L	Sc	12.00	12.00	13.00
ME-MS89L	Y	21.50	22.40	22.90
ME-MS89L	La	32.60	31.80	35.40
ME-MS89L	Ce	63.80	61.60	69.10
ME-MS89L	Pr	7.32	6.86	7.82
ME-MS89L	Nd	29.20	27.70	31.40
ME-MS89L	Sm	5.66	5.32	5.93
ME-MS89L	Eu	1.05	0.95	1.04
ME-MS89L	Gd	4.37	4.50	4.59
ME-MS89L	Tb	0.64	0.67	0.68
ME-MS89L	Dy	3.90	3.98	4.05
ME-MS89L	Ho	0.78	0.81	0.79
ME-MS89L	Er	2.27	2.30	2.40
ME-MS89L	Tm	0.30	0.30	0.30
ME-MS89L	Yb	1.97	1.98	1.96
ME-MS89L	Lu	0.27	0.28	0.30
ME-MS89L	Li	73.00	70.00	74.00
ME-MS89L	Mg	6,600.00	6,200.00	6,400.00
ME-MS89L	Mn	490.00	550.00	580.00
ME-MS89L	Ni	6.10	8.70	27.70
ME-MS89L	Nb	12.40	12.00	13.40
ME-MS19	P	<5.00	<5.00	6.00
PGM-ICP27	Pt	<0.01	<0.01	<0.01
PGM-ICP27	Pd	<0.01	<0.01	<0.01
PGM-ICP27	Au	<0.01	0.01	<0.01
ME-MS19	Si	90.00	240.00	860.00
ME-MS89L	Sr	120.00	120.00	120.00
ME-MS89L	Ta	0.69	0.62	0.74
ME-MS89L	Ti	3,860.00	3,630.00	3,960.00
ME-MS89L	W	353.00	634.00	1,145.00
ME-MS89L	V	97.00	101.00	113.00
FTIR-MIN	K Feldspar	10,000.00	10,000.00	30,000.00
FTIR-MIN	Plagioclase	30,000.00	40,000.00	40,000.00
FTIR-BAUX	SiO_2	770,000.00	730,000.00	730,000.00
FTIR-BAUX	Al_2O_3	100,000.00	110,000.00	110,000.00
FTIR-BAUX	Al_2O_3avl	<10,000.00	<10,000.00	<10,000.00
FTIR-BAUX	Boehmite	<10,000.00	<10,000.00	<10,000.00
FTIR-BAUX	Gibbsite	30,000.00	20,000.00	10,000.00

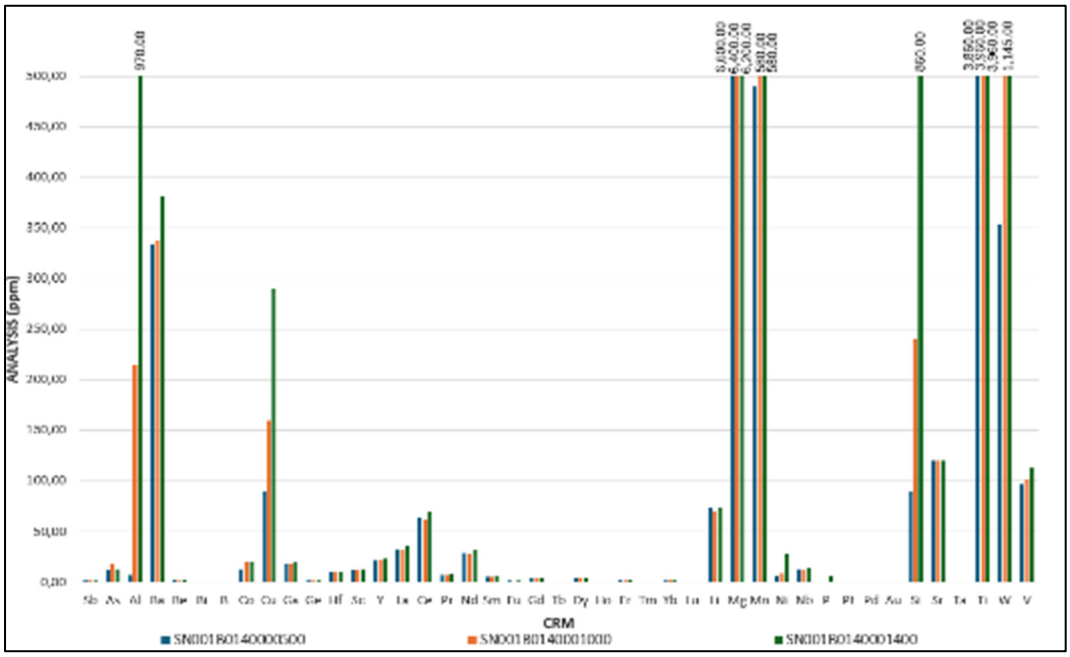


Figure 2-11. Graph of the quantitative analysis of the CRM elements of the borehole SN001B01400 (SN-1Bis)

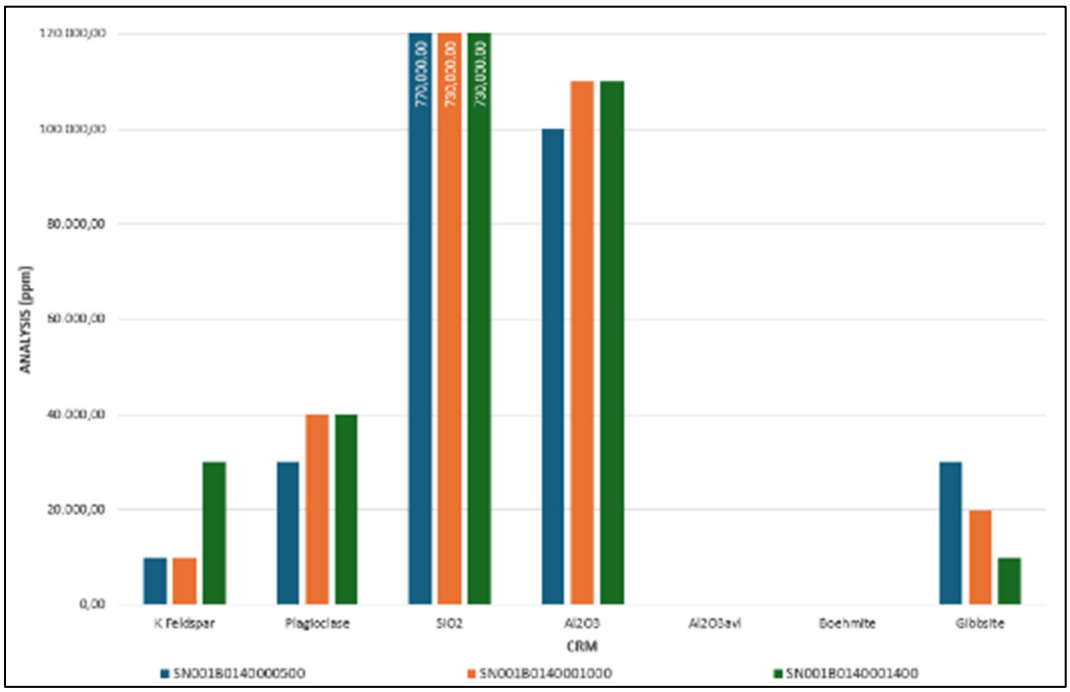


Figure 2-12. Graph of the quantitative analysis of the CRM minerals of the borehole SN001B01400 (SN-1Bis)

Table 2-6, Figure 2-13 and Figure 2-14 show the analysis results for borehole SN002A01300 (SN-2)

Table 2-6. Results of quantitative analysis of the borehole SN002A01300 (SN-2)

METHOD	CRM	SN 002A 01300 00500 (ppm)	SN 002A 01300 01000 (ppm)	SN 002A 01300 01300 (ppm)
ME-MS89L	Sb	2.00	2.50	2.30
ME-MS89L	As	12.00	14.00	14.00
ME-MS19	Al	778.00	923.00	983.00
ME-MS89L	Ba	314.00	348.00	284.00
ME-MS89L	Be	1.80	2.20	1.60
ME-MS89L	Bi	0.30	0.40	0.30
ME-MS19	B	<10.00	<10.00	<10.00
ME-MS89L	Co	11.10	12.80	12.40
ME-MS89L	Cu	60.00	70.00	70.00
ME-MS89L	Ga	16.50	18.60	15.80
ME-MS89L	Ge	1.50	1.60	1.60
ME-MS89L	Hf	10.00	10.00	<10
ME-MS89L	Sc	11.00	14.00	10.00
ME-MS89L	Y	18.00	22.50	17.20
ME-MS89L	La	29.10	31.80	27.00
ME-MS89L	Ce	53.90	63.00	49.10
ME-MS89L	Pr	6.24	7.16	5.60
ME-MS89L	Nd	24.50	28.20	23.00
ME-MS89L	Sm	4.53	5.07	4.37
ME-MS89L	Eu	0.86	0.94	0.79
ME-MS89L	Gd	3.75	4.45	3.28
ME-MS89L	Tb	0.54	0.67	0.52
ME-MS89L	Dy	3.24	3.93	3.02
ME-MS89L	Ho	0.64	0.80	0.59
ME-MS89L	Er	1.78	2.33	1.65
ME-MS89L	Tm	0.25	0.30	0.22
ME-MS89L	Yb	1.56	1.88	1.49
ME-MS89L	Lu	0.23	0.28	0.21
ME-MS89L	Li	66.00	78.00	62.00
ME-MS89L	Mg	4,600.00	5,400.00	4,400.00
ME-MS89L	Mn	490.00	730.00	490.00
ME-MS89L	Ni	40.00	40.00	40.00
ME-MS89L	Nb	12.20	12.90	11.40
ME-MS19	P	88.00	52.00	91.00
PGM-ICP27	Pt	<0.01	<0.01	<0.01
PGM-ICP27	Pd	<0.01	<0.01	<0.01
PGM-ICP27	Au	<0.01	0.01	0.01
ME-MS19	Si	750.00	680.00	750.00
ME-MS89L	Sr	90.00	110.00	90.00
ME-MS89L	Ta	0.69	0.74	0.61
ME-MS89L	Ti	3,510.00	3,840.00	3,280.00
ME-MS89L	W	169.50	247.00	233.00
ME-MS89L	V	95.00	107.00	89.00
FTIR-MIN	K Feldspar	10,000.00	10,000.00	10,000.00
FTIR-MIN	Plagioclase	20,000.00	30,000.00	20,000.00
FTIR-BAUX	SiO_2	710,000.00	710,000.00	760,000.00
FTIR-BAUX	Al_2O_3	100,000.00	110,000.00	90,000.00
FTIR-BAUX	Al_2O_3avl	<10,000.00	<10,000.00	<10,000.00
FTIR-BAUX	Boehmite	<10,000.00	<10,000.00	<10,000.00
FTIR-BAUX	Gibbsite	20,000.00	40,000.00	40,000.00

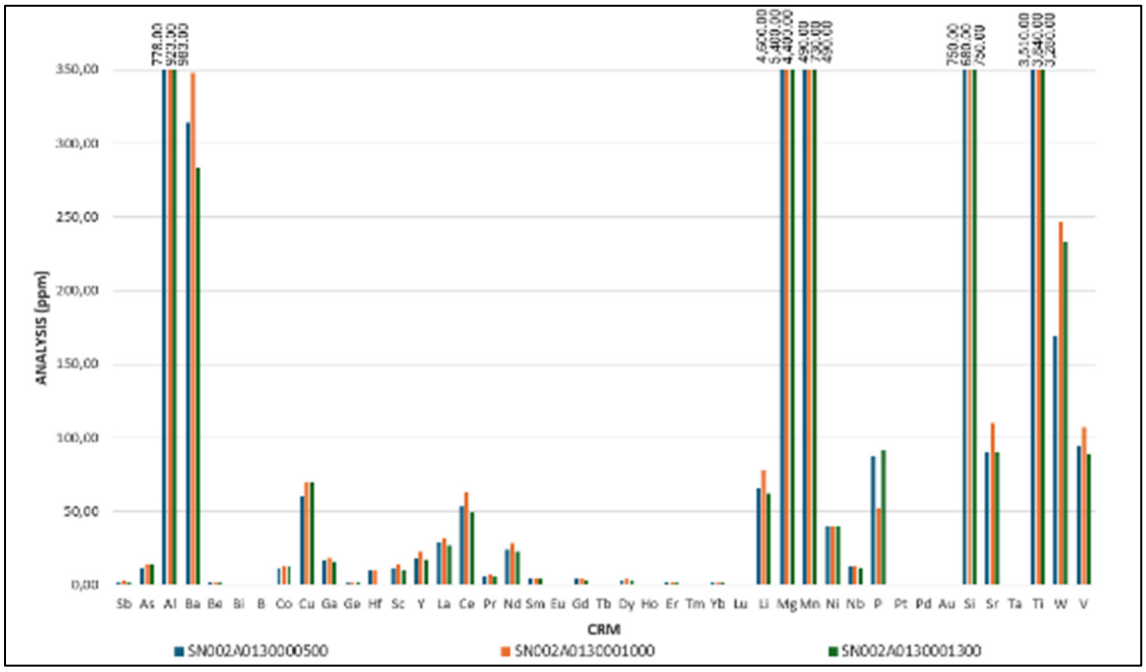


Figure 2-13. Graph of the quantitative analysis of the CRM elements of the borehole SN002A01300 (SN-2)

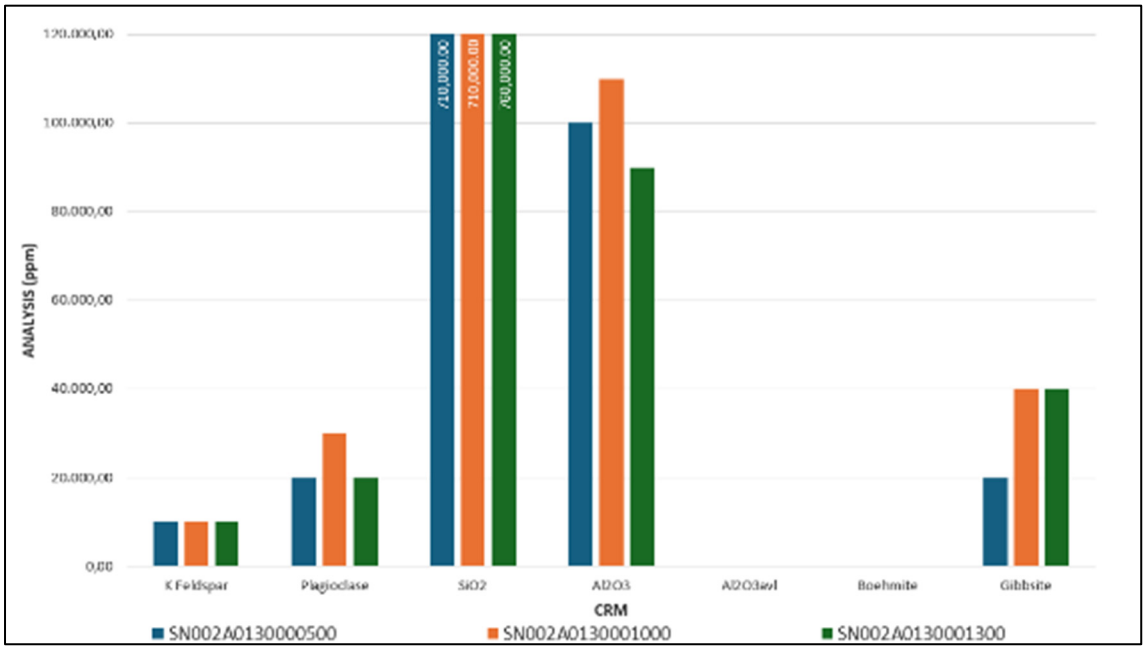


Figure 2-14. Graph of the quantitative analysis of the CRM minerals of the borehole SN002A01300 (SN-2)

Table 2-7, Figure 2-15 and Figure 2-16 show the analysis results for borehole SN003A01450 (SN-3).

Table 2-7. Results of quantitative analysis of the borehole SN003A01450 (SN-3)

METHOD	CRM	SN 003A 01150 00500 (ppm)	SN 003A 01450 01000 (ppm)	SN 003A 01450 01450 (ppm)
ME-MS89L	Sb	2.40	4.90	3.00
ME-MS89L	As	15.00	17.00	16.00
ME-MS19	Al	1,360.00	708.00	963.00
ME-MS89L	Ba	453.00	478.00	370.00
ME-MS89L	Be	2.80	2.90	2.10
ME-MS89L	Bi	0.40	0.40	0.30
ME-MS19	B	<10.00	<10.00	<10.00
ME-MS89L	Co	14.30	16.40	14.80
ME-MS89L	Cu	60.00	80.00	70.00
ME-MS89L	Ga	23.30	24.30	19.20
ME-MS89L	Ge	1.90	2.00	1.80
ME-MS89L	Hf	10.00	10.00	10.00
ME-MS89L	Sc	16.00	17.00	14.00
ME-MS89L	Y	26.70	29.90	25.00
ME-MS89L	La	40.00	43.70	35.40
ME-MS89L	Ce	77.50	88.50	72.60
ME-MS89L	Pr	8.91	10.05	8.22
ME-MS89L	Nd	35.90	39.20	32.20
ME-MS89L	Sm	7.01	7.52	6.21
ME-MS89L	Eu	1.26	1.39	1.25
ME-MS89L	Gd	5.60	5.90	5.14
ME-MS89L	Tb	0.82	0.86	0.75
ME-MS89L	Dy	4.94	5.45	4.57
ME-MS89L	Ho	0.96	1.05	0.89
ME-MS89L	Er	2.71	3.00	2.60
ME-MS89L	Tm	0.34	0.40	0.33
ME-MS89L	Yb	2.26	2.51	2.10
ME-MS89L	Lu	0.32	0.36	0.32
ME-MS89L	Li	94.00	93.00	80.00
ME-MS89L	Mg	7,500.00	8,100.00	6,900.00
ME-MS89L	Mn	650.00	630.00	570.00
ME-MS89L	Ni	50.00	50.00	50.00
ME-MS89L	Nb	15.50	16.40	14.10
ME-MS19	P	43.00	5.00	11.00
PGM-ICP27	Pt	<0.01	<0.01	<0.01
PGM-ICP27	Pd	<0.01	<0.01	<0.01
PGM-ICP27	Au	0.01	0.01	<0.01
ME-MS19	Si	1.160.00	490.00	930.00
ME-MS89L	Sr	150.00	160.00	130.00
ME-MS89L	Ta	0.91	1.02	0.78
ME-MS89L	Ti	4,560.00	4,940.00	4,050.00
ME-MS89L	W	127.00	109.50	161.00
ME-MS89L	V	139.00	140.00	111.00
FTIR-MIN	K Feldspar	20,000.00	10,000.00	10,000.00
FTIR-MIN	Plagioclase	10,000.00	20,000.00	30,000.00
FTIR-BAUX	SiO_2	660,000.00	680,000.00	740,000.00
FTIR-BAUX	Al_2O_3	120,000.00	130,000.00	100,000.00
FTIR-BAUX	Al_2O_3avl	<10,000.00	10,000.00	<10,000.00
FTIR-BAUX	Boehmite	<10,000.00	<10,000.00	<10,000.00
FTIR-BAUX	Gibbsite	30,000.00	30,000.00	10,000.00

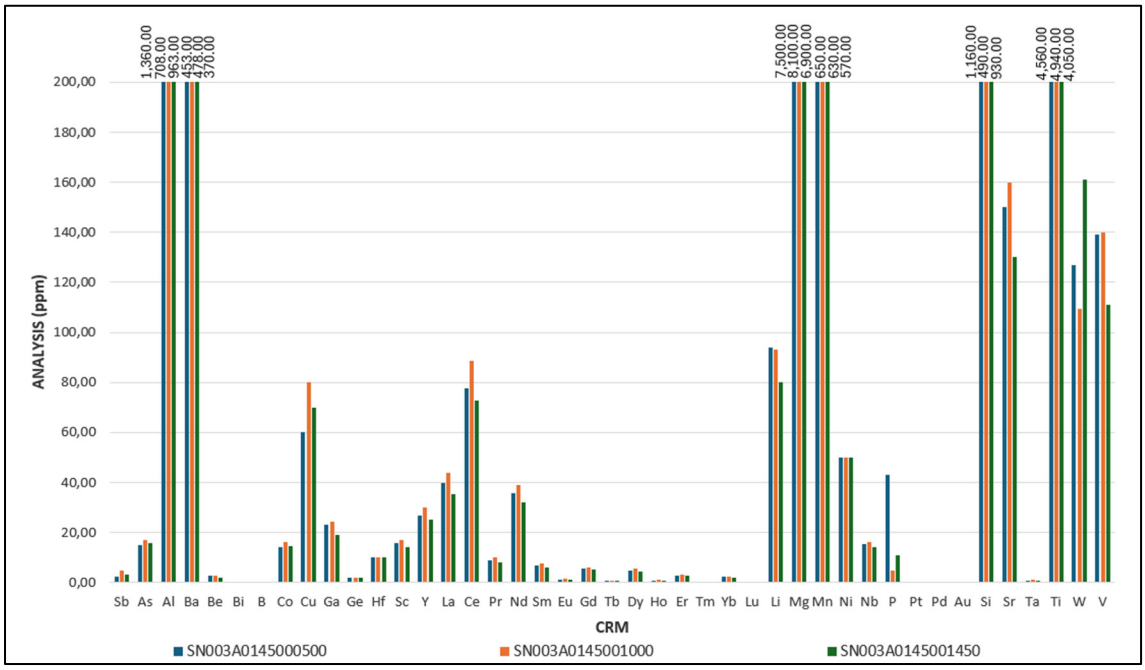


Figure 2-15. Graph of the quantitative analysis of the CRM elements of the borehole SN003A01450 (SN-3)

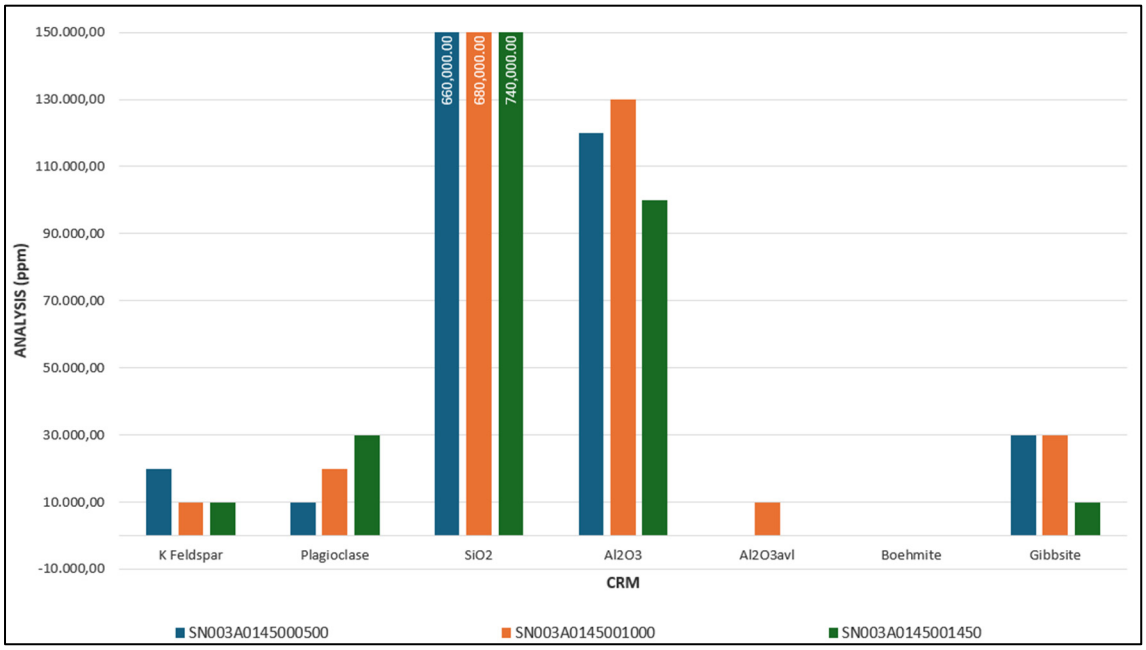


Figure 2-16. Graph of the quantitative analysis of the CRM minerals of the borehole SN003A01450 (SN-3)

Table 2-8, Figure 2-17 and Figure 2-18 show the analysis results for borehole SN004A00400 (SN-4).

Table 2-8. Results of quantitative analysis of the borehole SN004A00400 (SN-4)

METHOD	CRM	SN 004A 00400 00400 (ppm)
ME-MS89L	Sb	1.30
ME-MS89L	As	25.00
ME-MS19	Al	557.00
ME-MS89L	Ba	229.00
ME-MS89L	Be	1.50
ME-MS89L	Bi	0.20
ME-MS19	B	<10
ME-MS89L	Co	11.20
ME-MS89L	Cu	80.00
ME-MS89L	Ga	13.00
ME-MS89L	Ge	1.60
ME-MS89L	Hf	10.00
ME-MS89L	Sc	9.00
ME-MS89L	Y	18.80
ME-MS89L	La	25.40
ME-MS89L	Ce	50.70
ME-MS89L	Pr	5.87
ME-MS89L	Nd	23.20
ME-MS89L	Sm	4.72
ME-MS89L	Eu	0.86
ME-MS89L	Gd	3.90
ME-MS89L	Tb	0.56
ME-MS89L	Dy	3.51
ME-MS89L	Ho	0.66
ME-MS89L	Er	1.88
ME-MS89L	Tm	0.25
ME-MS89L	Yb	1.49
ME-MS89L	Lu	0.23
ME-MS89L	Li	50.00
ME-MS89L	Mg	4,700.00
ME-MS89L	Mn	380.00
ME-MS89L	Ni	50.00
ME-MS89L	Nb	10.20
ME-MS19	P	12.00
PGM-ICP27	Pt	<0.01
PGM-ICP27	Pd	<0.01
PGM-ICP27	Au	<0.01
ME-MS19	Si	460.00
ME-MS89L	Sr	100.00
ME-MS89L	Ta	0.51
ME-MS89L	Ti	2,890.00
ME-MS89L	W	319.00
ME-MS89L	V	72.00
FTIR-MIN	K Feldspar	<10,000.00
FTIR-MIN	Plagioclase	20,000.00
FTIR-BAUX	SiO_2	760,000.00
FTIR-BAUX	Al_2O_3	90,000.00
FTIR-BAUX	Al_2O_3avl	<10,000.00
FTIR-BAUX	Boehmite	<10,000.00
FTIR-BAUX	Gibbsite	30,000.00

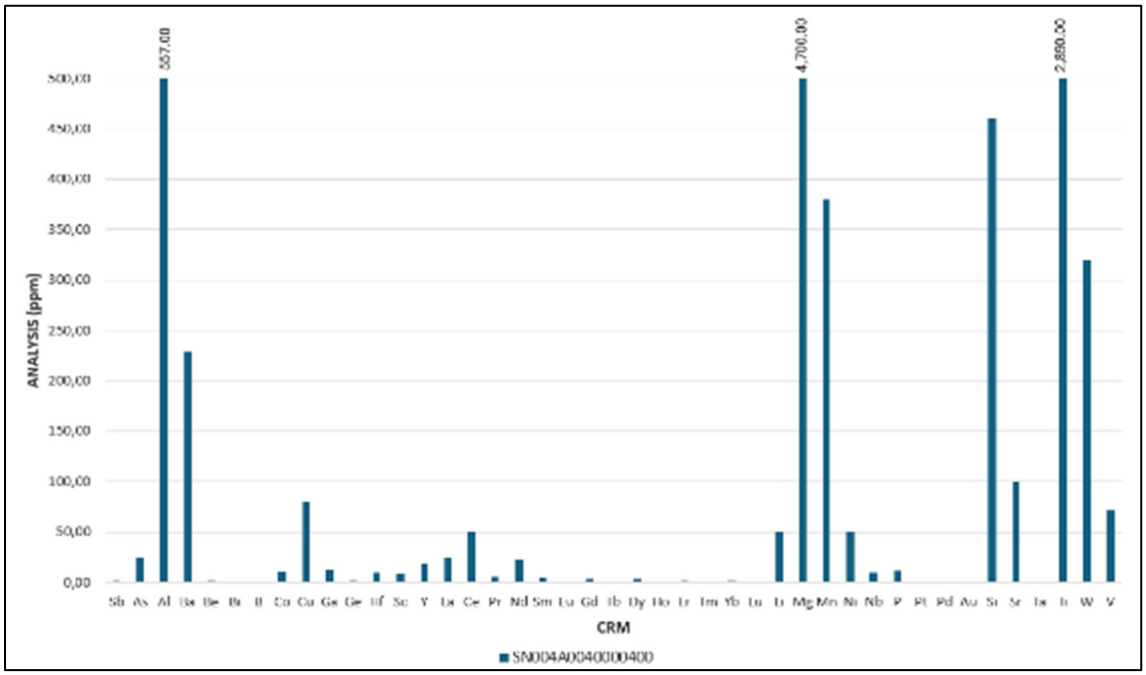


Figure 2-17. Graph of the quantitative analysis of the CRM elements of the borehole SN004A00400 (SN-4)

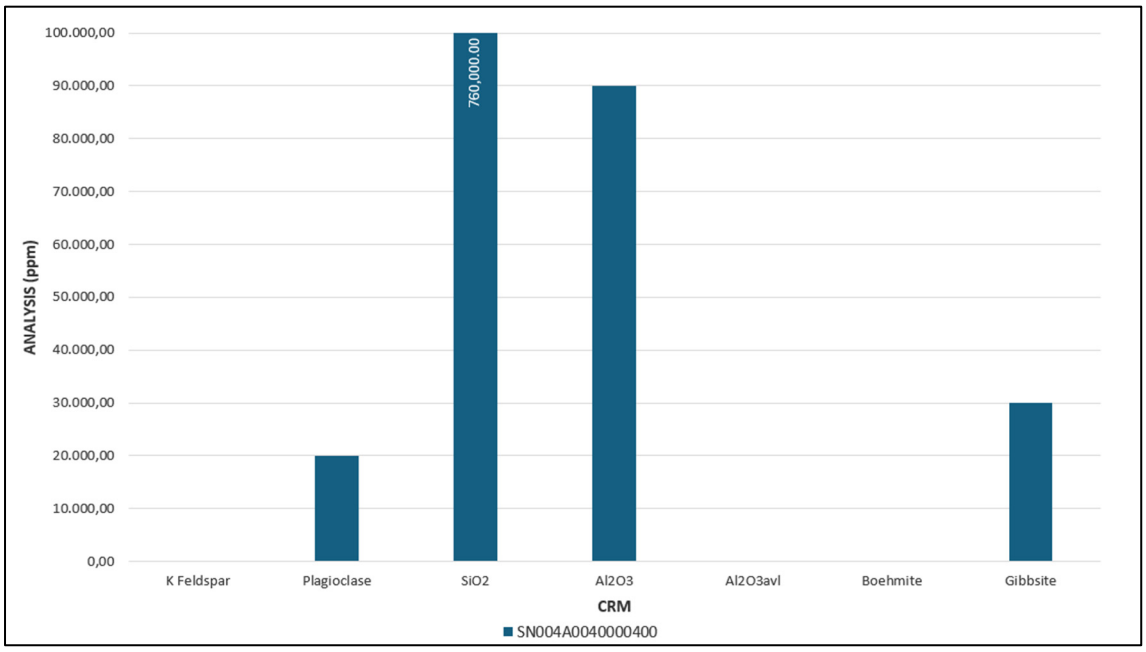


Figure 2-18. Graph of the quantitative analysis of the CRM minerals of the borehole SN004A00400 (SN-4)

Table 2-9, Figure 2-19 and Figure 2-20, show the analysis results for borehole SN004B03200 (SN-4Bis).

Table 2-9. Results of quantitative analysis, in ppm, of the borehole SN004B03200 (SN-4Bis)

METHOD	CRM	SN 004B 03200 00500	SN 004B 03200 01000	SN 004B 03200 01500	SN 004B 03200 02000	SN 004B 03200 02500	SN 004B 03200 03000	SN 004B 03200 03200
ME-MS89L	Sb	2.00	2.40	2.60	2.00	1.60	1.30	0.80
ME-MS89L	As	12.00	20.00	14.00	15.00	13.00	13.00	7.00
ME-MS19	Al	575.00	<5.00	247.00	61.00	17.00	524.00	766.00
ME-MS89L	Ba	414.00	326.00	394.00	353.00	320.00	255.00	123.00
ME-MS89L	Be	2.40	1.80	2.00	2.00	1.80	1.50	0.40
ME-MS89L	Bi	0.40	0.40	0.40	0.40	0.50	0.40	0.30
ME-MS19	B	<10.00	<10.00	<10.00	<10.00	<10.00	<10.00	<10.00
ME-MS89L	Co	14.80	13.60	13.20	16.60	15.20	14.60	7.80
ME-MS89L	Cu	110.00	170.00	80.00	300.00	240.00	390.00	130.00
ME-MS89L	Ga	20.50	16.40	18.60	17.00	15.60	13.00	6.90
ME-MS89L	Ge	1.60	1.70	1.60	1.70	1.30	1.20	1.40
ME-MS89L	Hf	10.00	10.00	10.00	10.00	10.00	10.00	10.00
ME-MS89L	Sc	14.00	11.00	12.00	12.00	11.00	9.00	<5.00
ME-MS89L	Y	22.80	21.60	22.00	23.30	21.60	21.00	11.00
ME-MS89L	La	35.30	29.70	33.30	33.30	30.00	26.60	17.35
ME-MS89L	Ce	68.00	59.70	64.60	66.50	59.30	52.60	33.40
ME-MS89L	Pr	7.79	6.96	7.40	7.61	6.78	5.92	3.78
ME-MS89L	Nd	31.80	27.30	29.60	29.50	27.20	24.10	15.50
ME-MS89L	Sm	6.16	5.40	5.66	5.72	5.43	4.55	2.99
ME-MS89L	Eu	1.11	1.01	1.01	1.01	1.07	0.83	0.55
ME-MS89L	Gd	4.99	4.31	4.48	4.76	4.60	4.09	2.33
ME-MS89L	Tb	0.71	0.64	0.66	0.67	0.66	0.57	0.33
ME-MS89L	Dy	4.21	3.87	3.84	4.06	4.19	3.65	1.92
ME-MS89L	Ho	0.83	0.76	0.78	0.81	0.81	0.75	0.38
ME-MS89L	Er	2.43	2.17	2.14	2.32	2.33	2.20	1.08
ME-MS89L	Tm	0.32	0.29	0.29	0.33	0.31	0.29	0.14
ME-MS89L	Yb	2.03	1.79	1.88	1.99	1.99	1.93	0.86
ME-MS89L	Lu	0.31	0.26	0.27	0.28	0.28	0.26	0.13
ME-MS89L	Li	93.00	68.00	80.00	71.00	64.00	50.00	25.00
ME-MS89L	Mg	6,400.00	6,600.00	6,800.00	7,200.00	6,800.00	5,500.00	2,100.00
ME-MS89L	Mn	480.00	590.00	540.00	600.00	640.00	580.00	380.00
ME-MS89L	Ni	50.00	60.00	50.00	100.00	80.00	110.00	50.00
ME-MS89L	Nb	13.50	12.40	13.90	12.90	12.40	11.00	7.40
ME-MS19	P	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00	51.00
PGM-ICP27	Pt	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
PGM-ICP27	Pd	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
PGM-ICP27	Au	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
ME-MS19	Si	460.00	30.00	200.00	190.00	140.00	380.00	610.00
ME-MS89L	Sr	150.00	150.00	120.00	120.00	110.00	90.00	60.00
ME-MS89L	Ta	0.82	0.70	0.88	0.76	0.71	0.61	0.35
ME-MS89L	Ti	4,040.00	3,470.00	3,870.00	3,810.00	3,600.00	3,200.00	1,900.00
ME-MS89L	W	210.00	595.00	203.00	1.185.00	852.00	1.785.00	478.00
ME-MS89L	V	119.00	93.00	107.00	94.00	91.00	72.00	39.00
FTIR-MIN	K Feldspar	<10,000.00	<10,000.00	<10,000.00	<10,000.00	10,000.00	10,000.00	20,000.00
FTIR-MIN	Plagioclase	60,000.00	20,000.00	30,000.00	40,000.00	30,000.00	20,000.00	10,000.00
FTIR-BAUX	SiO_2	710,000.00	770,000.00	740,000.00	760,000.00	760,000.00	760,000.00	870,000.00
FTIR-BAUX	Al_2O_3	120,000.00	90,000.00	100,000.00	90,000.00	90,000.00	70,000.00	50,000.00
FTIR-BAUX	Al_2O_3avl	<10,000.00	<10,000.00	<10,000.00	<10,000.00	<10,000.00	<10,000.00	<10,000.00
FTIR-BAUX	Boehmite	<10,000.00	<10,000.00	<10,000.00	<10,000.00	<10,000.00	<10,000.00	<10,000.00
FTIR-BAUX	Gibbsite	40,000.00	40,000.00	30,000.00	30,000.00	30,000.00	20,000.00	<10,000.00

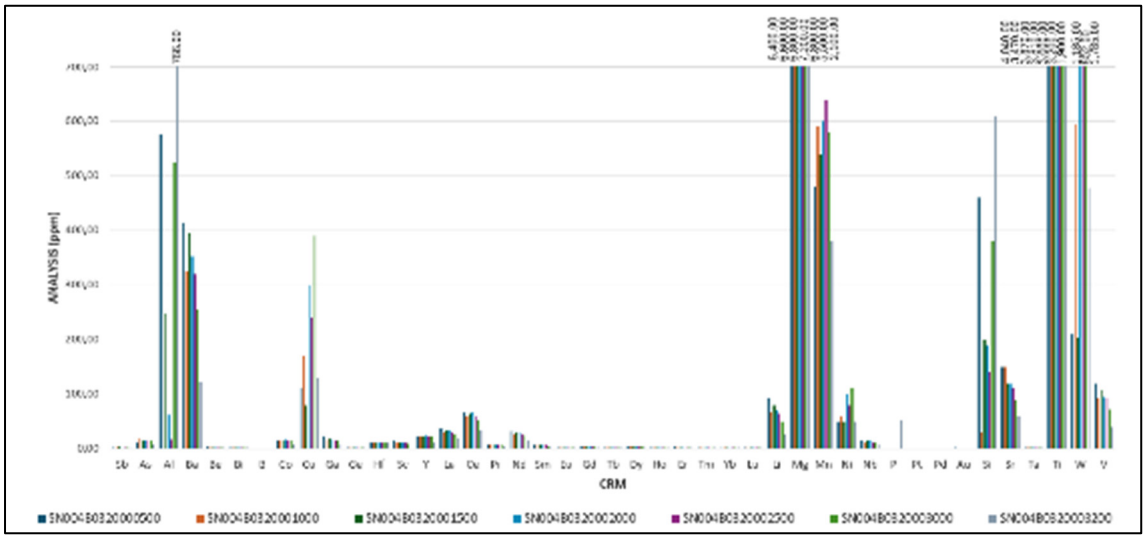


Figure 2-19. Graph of the quantitative analysis of the CRM elements of the borehole SN004B03200 (SN-4Bis)

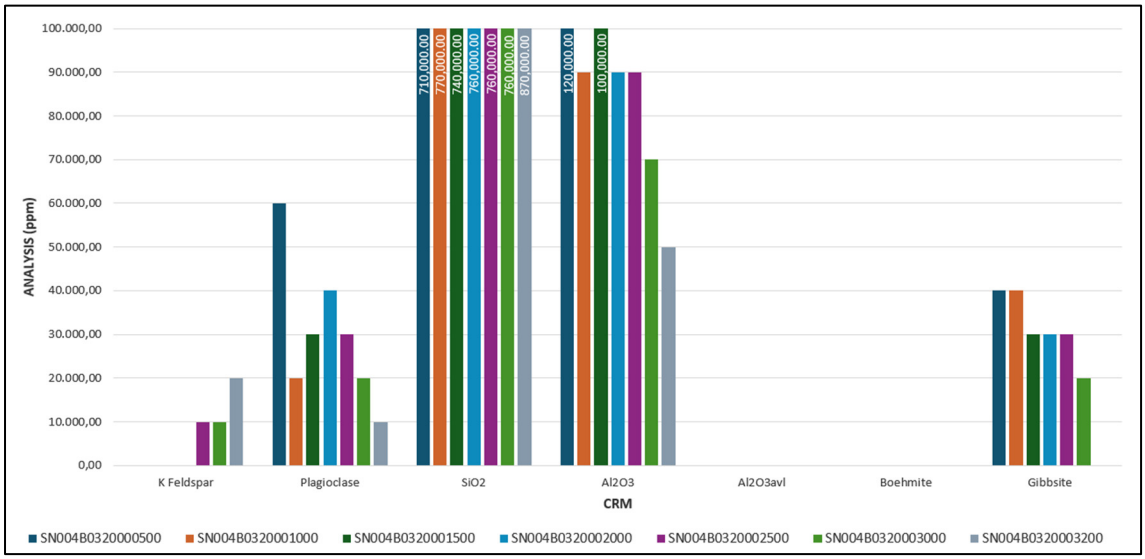


Figure 2-20. Graph of the quantitative analysis of the CRM minerals of the borehole SN004B03200 (SN-4Bis)

Table 2-10, Figure 2-21 and Figure 2-22 show the analysis results for borehole SN005A01050 (SN-5).

Table 2-10. Results of quantitative analysis of the borehole SN005A01050 (SN-5)

METHOD	CRM	SN 005A 01050 00500 (ppm)	SN 005A 01050 01050 (ppm)
ME-MS89L	Sb	1.70	1.60
ME-MS89L	As	14.00	17.00
ME-MS19	Al	826.00	1,165.00
ME-MS89L	Ba	362.00	401.00
ME-MS89L	Be	2.10	2.50
ME-MS89L	Bi	0.40	0.50
ME-MS19	B	<10.00	<10.00
ME-MS89L	Co	16.60	16.10
ME-MS89L	Cu	70.00	90.00
ME-MS89L	Ga	19.20	22.00
ME-MS89L	Ge	2.00	2.10
ME-MS89L	Hf	10.00	10.00
ME-MS89L	Sc	13.00	15.00
ME-MS89L	Y	20.90	24.60
ME-MS89L	La	33.70	37.90
ME-MS89L	Ce	59.30	73.60
ME-MS89L	Pr	6.93	8.30
ME-MS89L	Nd	28.00	33.10
ME-MS89L	Sm	5.37	5.89
ME-MS89L	Eu	0.94	1.12
ME-MS89L	Gd	4.19	4.77
ME-MS89L	Tb	0.60	0.72
ME-MS89L	Dy	3.61	4.33
ME-MS89L	Ho	0.74	0.87
ME-MS89L	Er	2.02	2.55
ME-MS89L	Tm	0.27	0.33
ME-MS89L	Yb	1.72	2.06
ME-MS89L	Lu	0.27	0.32
ME-MS89L	Li	66.00	87.00
ME-MS89L	Mg	5,500.00	5,900.00
ME-MS89L	Mn	400.00	450.00
ME-MS89L	Ni	50.00	50.00
ME-MS89L	Nb	13.50	14.70
ME-MS19	P	67.00	56.00
PGM-ICP27	Pt	<0.01	<0.01
PGM-ICP27	Pd	<0.01	<0.01
PGM-ICP27	Au	<0.01	<0.01
ME-MS19	Si	600.00	760.00
ME-MS89L	Sr	110.00	130.00
ME-MS89L	Ta	0.69	0.93
ME-MS89L	Ti	3,780.00	4,330.00
ME-MS89L	W	205.00	264.00
ME-MS89L	V	112.00	129.00
FTIR-MIN	K Feldspar	30,000.00	50,000.00
FTIR-MIN	Plagioclase	40,000.00	40,000.00
FTIR-BAUX	SiO_2	750,000.00	690,000.00
FTIR-BAUX	Al_2O_3	110,000.00	120,000.00
FTIR-BAUX	Al_2O_3avl	<10,000.00	<10,000.00
FTIR-BAUX	Boehmite	<10,000.00	<10,000.00
FTIR-BAUX	Gibbsite	10,000.00	10,000.00

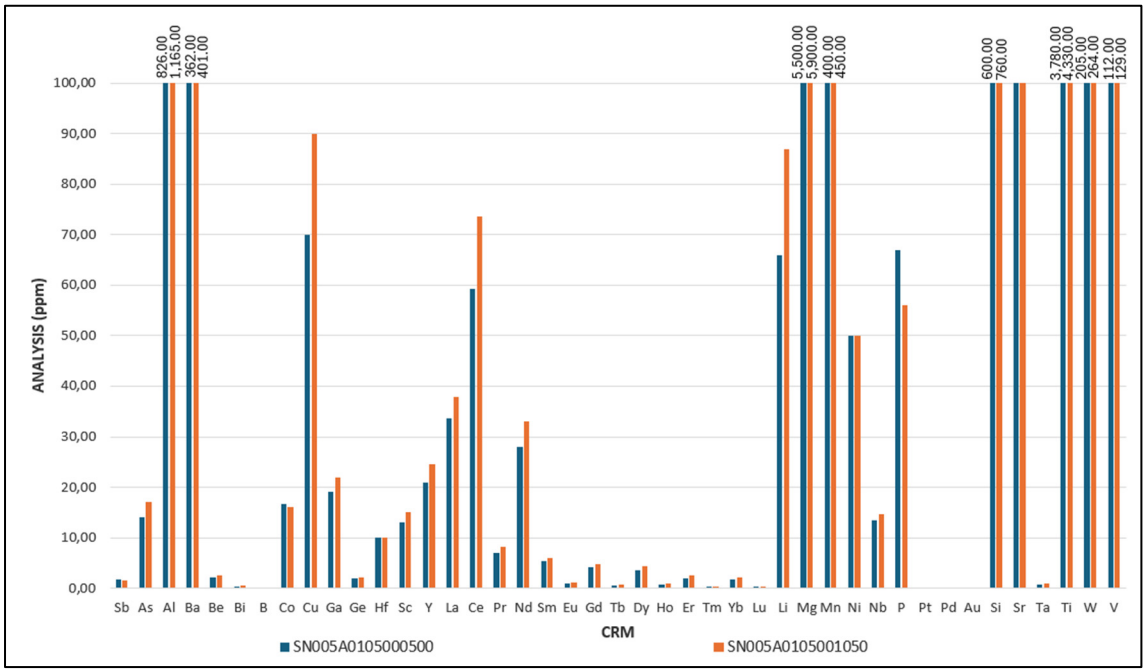


Figure 2-21. Graph of the quantitative analysis of the CRM elements of the borehole SN005A01050 (SN-5)

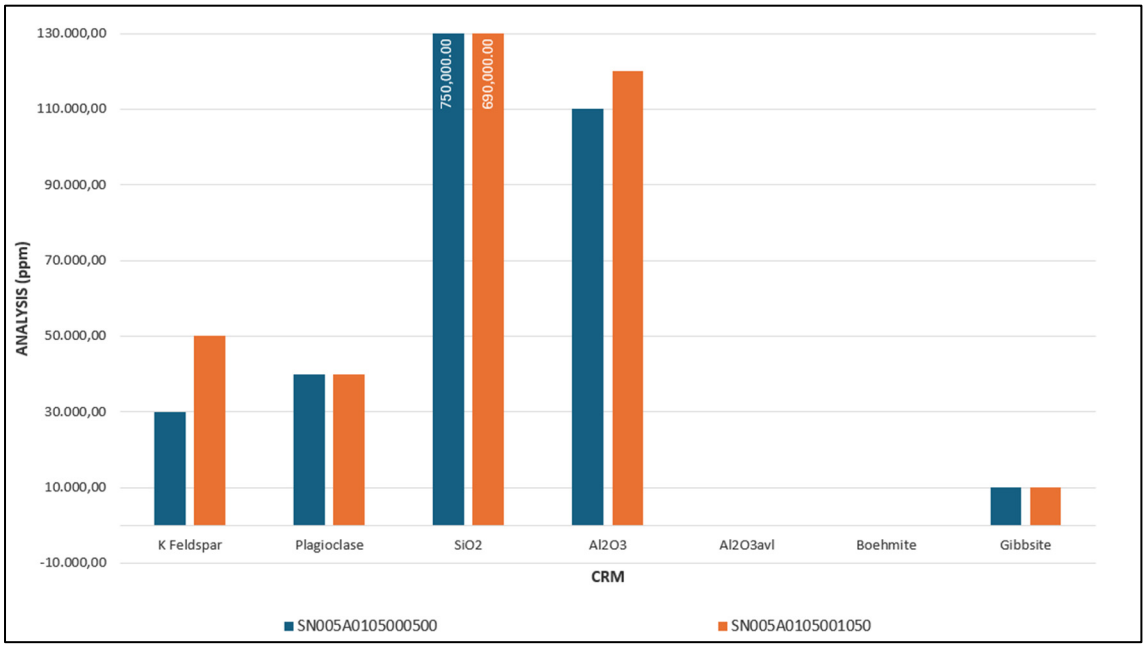


Figure 2-22. Graph of the quantitative analysis of the CRM minerals of the borehole SN005A01050 (SN-5)

3 Janina dump in Libiąż (Poland)

The coal waste dump is an anthropogenic accumulation of waste generated by coal mining and processing at the ZG Janina Coal Mine (Figures 3-1 and 3-2).



Figure 3-1. Janina dump from Libiąż (Poland)



Figure 3-2. Janina dump as seen on geoportal.gov.pl

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 3-3).

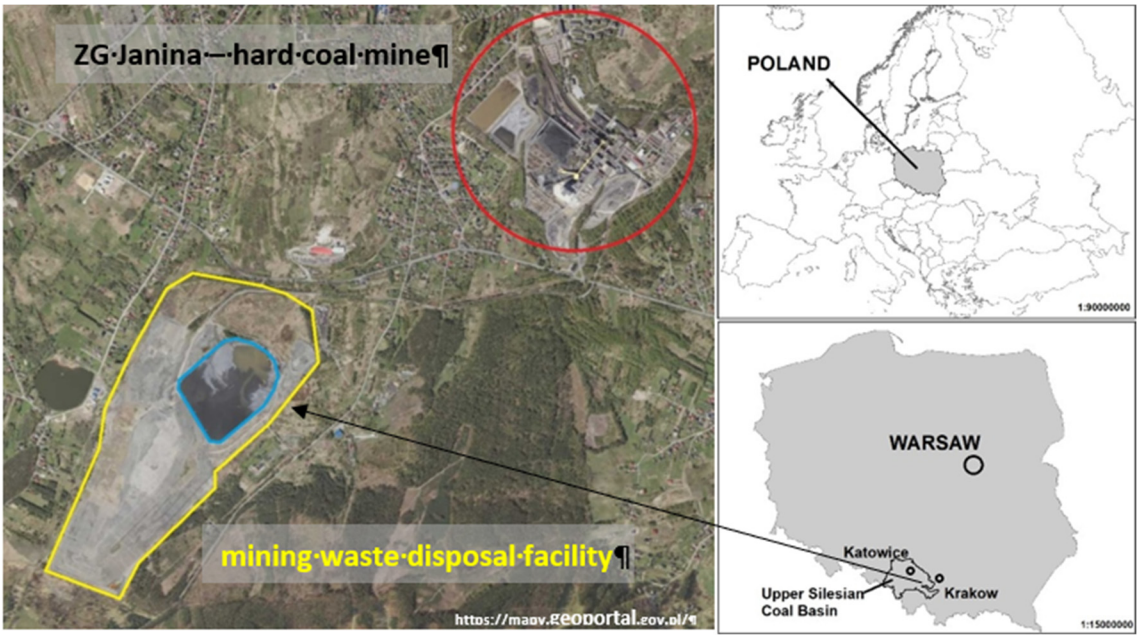


Figure 3-3. Location of ZG Jania mining waste disposal facility in Libiąż town

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, a natural green belt separates the facility from single-family housing. On the eastern side, it borders the Janina Mining Plant's construction facility, the "West" ventilation shaft, and its adjacent infrastructure.

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.

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.

3.1 Sample collection from Poland

Three locations were selected (Figure 3-4) for sample collection (



Figure 3-4. Location of the boreholes of the Janina dump from Libiąż

Table 3-1. Coordinates of the coal waste "Janina" dump

Initial Borehole	Code	Caderneta Code	Depth (m)	UTM ZONE 34N Coordinates (m)	Geographical Coordinates
PL-J/1/S	JA 001A 01000	-	10.00	X: 378,767.23 Y: 5,549,354.80 Z: 258.50	Lat: 50°05'2.7''N Long: 19°18'19.4''E
PL-J/2/S	JA 002A 01500	-	15.00	X: 378,730.85 Y: 5,549,241.30 Z: 261.32	Lat: 50°04'59.0''N Long: 19°18'17.7''E
PL-J/3/S	JA 003A 01500	-	15.00	X: 378,665.58 Y: 5,549,468.62 Z: 260.69	Lat: 50°04'56.6''N Long: 19°18'14.5''E

). Samples were collected from the following depth intervals: 0–5 m, 5–10 m, and 10–15 m, following the sampling intervals required for the subsequent processing and modelling in RecMin. We collected a minimum of 30 kg of material from each sample to

ensure a representative amount was available for sample preparation and subsequent analysis.



Figure 3-4. Location of the boreholes of the Janina dump from Libiąż

Table 3-1. Coordinates of the coal waste "Janina" dump

Initial Borehole	Code	Caderneta Code	Depth (m)	UTM ZONE 34N Coordinates (m)	Geographical Coordinates
PL-J/1/S	JA 001A 01000	-	10.00	X: 378,767.23 Y: 5,549,354.80 Z: 258.50	Lat: 50°05'2.7''N Long: 19°18'19.4''E
PL-J/2/S	JA 002A 01500	-	15.00	X: 378,730.85 Y: 5,549,241.30 Z: 261.32	Lat: 50°04'59.0''N Long: 19°18'17.7''E
PL-J/3/S	JA 003A 01500	-	15.00	X: 378,665.58 Y: 5,549,468.62 Z: 260.69	Lat: 50°04'56.6''N Long: 19°18'14.5''E

The samples were obtained using a drilling machine equipped with an auger-type drilling system (Figure 3-5), in which penetration is achieved through the rotation of a helical

screw. As the auger rotates, the cut material is transported upwards along the flights of the screw and recovered at the surface.



S

Figure 3-5. Sample collection, screw machine

This drilling equipment is particularly suitable for unconsolidated or relatively soft formations, as it enables continuous material recovery and efficient sampling at shallow depths. The auger drilling method also allows relatively rapid advancement and provides sufficient material for subsequent sample preparation and laboratory análisis. In this study, we collected the recovered material according to the predefined depth intervals to ensure consistency between the sampling procedure and subsequent geological and resource modelling.

In this case, the drill holes were not positioned using the field notebook (caderneta); instead, their locations were determined using the available positioning data and subsequently incorporated into the project dataset.

3.2 Samples from Poland

Three drill holes were completed using an auger drilling machine, reaching a total length of 45 m. During the sampling campaign, we collected three surface samples from the 0–0,5 m interval, followed by one sample every 5 m, using the same procedure as at the Spanish waste dump, to use the resulting data in the RecMin software. A total of 12 representative samples were selected for analysis. The samples were properly identified and prepared, then sent to Spain for hydrometallurgical leaching tests. The nomenclature (Table 3-2) facilitates sample traceability and allows unambiguous assignment of analytical results to their position within the corresponding drill hole.

Table 3-2. Names of the samples from each borehole

Initial Borehole	Borehole Code	Borehole Depth (m)	Sample Code	Description
PL-J/1/S	JA 001A 01000	10.00	JA 001A 01000 00500	From 0.00 to 5.00 m
			JA 001A 01000 01000	From 5.00 to 10.00 m
PL-J/2/S	JA 002A 01500	15.00	JA 002A 01500 00500	From 0.00 to 5.00 m
			JA 002A 01500 01000	From 5.00 to 10.00 m
			JA 002A 01500 01500	From 10.00 to 15.00 m
PL-J/3/S	JA 003A 01500	15.00	JA 003A 01500 00500	From 0.00 to 5.00 m
			JA 003A 01500 01000	From 5.00 to 10.00 m
			JA 003A 01500 01500	From 10.00 to 15.00 m

3.3 Sample analysis from Poland

The results of the samples taken from the boreholes at the Janina dump are presented below.

Table 3-3, Figure 3-6 and Figure 3-7 show the analysis results for borehole JA001A01000 (PL-J/1/S). The elements in the mineral substances are analysed separately because their concentrations differ significantly.

Table 3-3. Results of quantitative analysis of the borehole JA001A01000 (PL-J/1/S)

METHOD	CRM	JA 001A 01000 00500 (ppm)	JA 001A 01000 01000 (ppm)
AQ200	Sb	0.40	0.40
AQ200	As	5.60	3.60
LF200	Ba	337.00	346.00
LF200	Be	3.00	4.00
AQ200	Bi	1.00	1.00
LF200	Co	7.50	8.30
AQ200	Cu	53.00	51.40
LF200	Ga	19.90	21.30
LF200	Hf	3.50	3.60
LF200	Sc	13.00	13.00
LF200	Y	16.30	18.00
LF200	La	28.60	30.20
LF200	Ce	57.20	60.90
LF200	Pr	6.74	7.15
LF200	Nd	24.80	26.40
LF200	Sm	4.61	5.08
LF200	Eu	0.91	0.95
LF200	Gd	3.85	4.12
LF200	Tb	0.56	0.63
LF200	Dy	3.26	3.56
LF200	Ho	0.63	0.68
LF200	Er	1.90	2.04
LF200	Tm	0.26	0.30
LF200	Yb	1.82	1.96
LF200	Lu	0.26	0.27
LF200	MnO	200.00	200.00
LF200	Ni	33.00	35.00
LF200	Nb	13.10	14.30
LF200	P_2O_5	400.00	400.00
AQ200	Au	<0.005	<0.005
LF200	Sr	49.10	49.80
LF200	Ta	1.10	1.10
LF200	W	3.30	3.50
LF200	V	101.00	109.00
LF200	MgO	8,500.00	8,400.00
LF200	TiO_2	7,000.00	7,100.00
LF200	K_2O	20,800.00	20,600.00
LF200	SiO_2	455,000.00	460,700.00
LF200	Al_2O_3	171,000.00	177,800.00

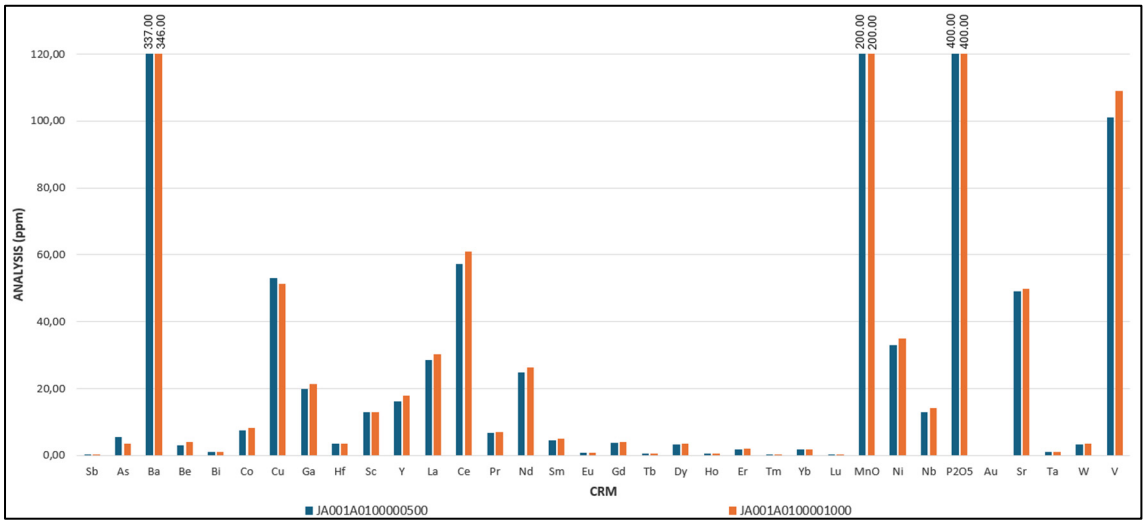


Figure 3-6. Graph of the quantitative analysis of the CRM elements of the borehole JA001A01000 (PL-J/1/S)

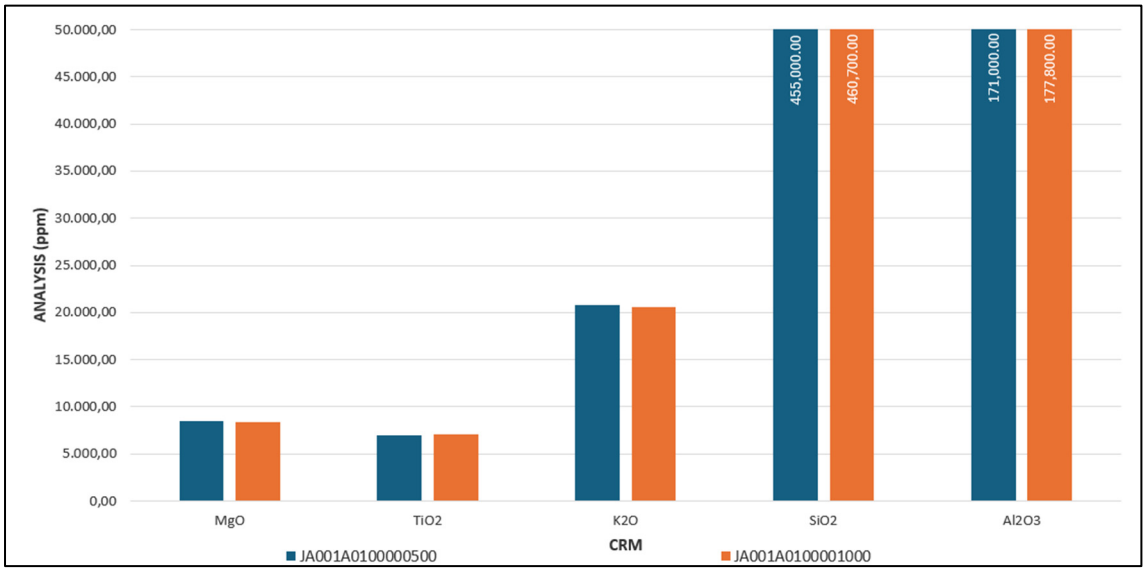


Figure 3-7. Graph of the quantitative analysis of the CRM minerals of the borehole JA001A01000 (PL-J/1/S)

Table 3-4, Figure 3-8 and Figure 3-9 show the analysis results for borehole JA 002A 01500 (PL-J/2/S)

Table 3-4. Results of quantitative analysis of the borehole JA002A01500 (PL-J/2/S)

METHOD	CRM	JA 002A 01500 00500 (ppm)	JA 002A 01500 01000 (ppm)	JA 002A 01500 01500 (ppm)
AQ200	Sb	0.70	0.60	0.60
AQ200	As	5.20	5.50	5.00
LF200	Ba	403.00	458.00	448.00
LF200	Be	5.00	4.00	4.00
AQ200	Bi	0.90	0.80	0.80
LF200	Co	9.40	8.30	8.50
AQ200	Cu	48.00	40.40	42.80
LF200	Ga	20.40	19.60	18.50
LF200	Hf	3.00	3.50	3.30
LF200	Sc	13.00	13.00	12.00
LF200	Y	17.90	16.90	16.30
LF200	La	29.50	29.60	28.90
LF200	Ce	58.30	58.30	56.70
LF200	Pr	6.72	6.77	6.56
LF200	Nd	24.60	24.50	24.10
LF200	Sm	4.87	4.74	4.44
LF200	Eu	0.93	0.92	0.90
LF200	Gd	4.09	3.94	3.74
LF200	Tb	0.59	0.58	0.57
LF200	Dy	3.52	3.29	3.20
LF200	Ho	0.68	0.65	0.64
LF200	Er	2.02	1.92	1.91
LF200	Tm	0.29	0.28	0.28
LF200	Yb	1.91	1.93	1.89
LF200	Lu	0.27	0.27	0.28
LF200	MnO	200.00	200.00	200.00
LF200	Ni	43.00	43.00	37.00
LF200	Nb	11.90	11.50	11.40
LF200	P_2O_5	400.00	400.00	400.00
AQ200	Au	<0.005	<0.005	0.01
LF200	Sr	55.90	61.70	61.50
LF200	Ta	1.00	0.90	0.90
LF200	W	3.60	3.60	2.80
LF200	V	108.00	106.00	104.00
LF200	MgO	7,300.00	7,200.00	6,800.00
LF200	TiO_2	6,500.00	6,300.00	6,000.00
LF200	K_2O	23,200.00	25,800.00	25,100.00
LF200	SiO_2	426,100.00	510,300.00	516,700.00
LF200	Al_2O_3	167,600.00	164,200.00	156,.700.00

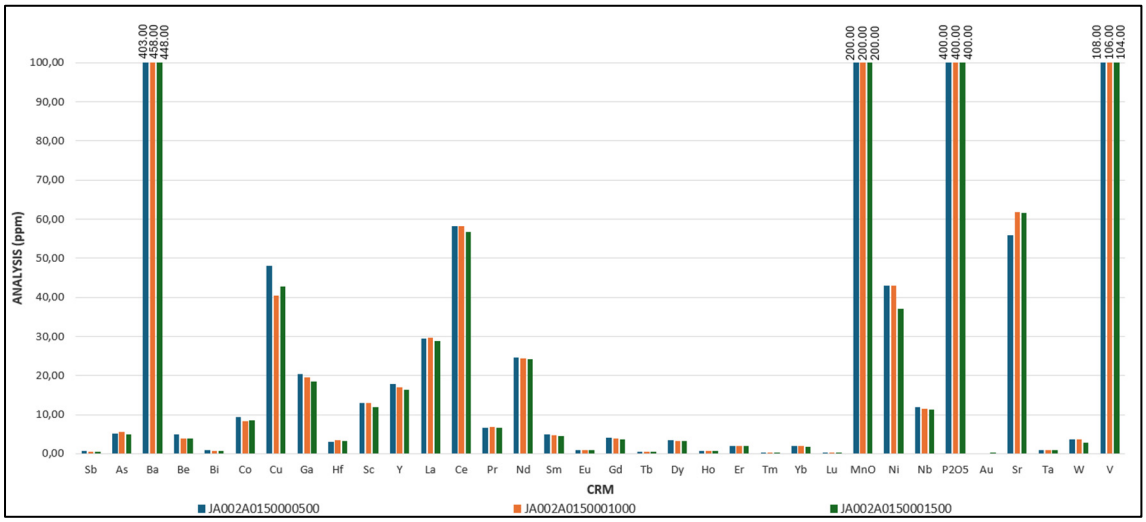


Figure 3-8. Graph of the quantitative analysis of the CRM elements of the borehole JA002A01500 (PL-J/2/S)

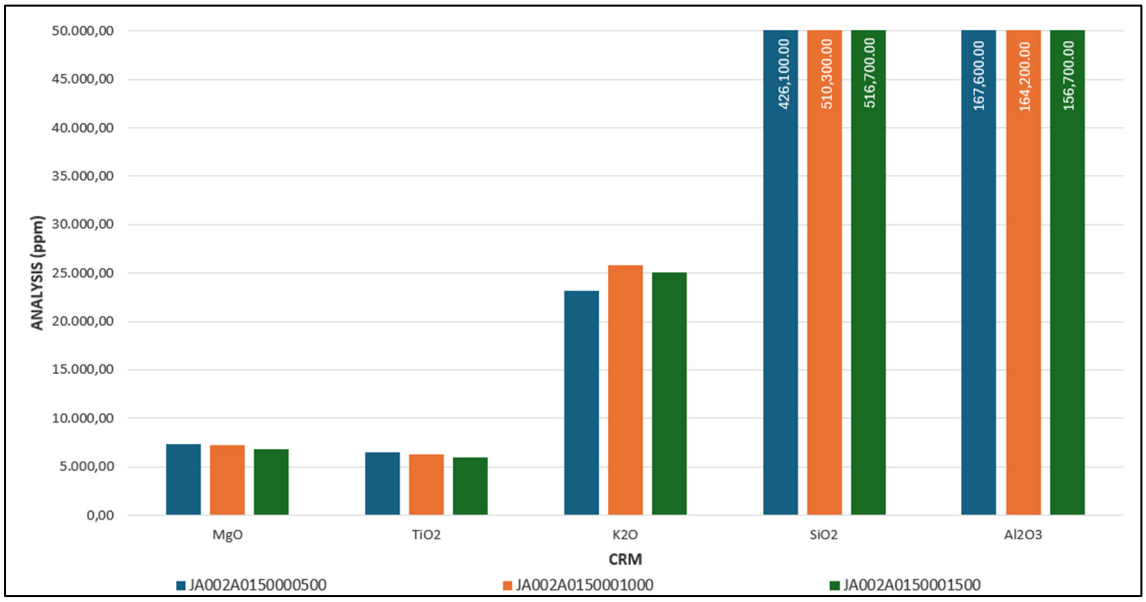


Figure 3-9. Graph of the quantitative analysis of the CRM minerals of the borehole JA002A01500 (PL-J/2/S)

Table 3-5, Figure 3-10 and Figure 3-11 show the analysis results for borehole JA 003A 01500 (PL-J/3/S)

Table 3-5. Results of quantitative analysis of the borehole JA003A01500 (PL-J/3/S)

METHOD	CRM	JA 003A 01500 00500 (ppm)	JA 003A 01500 01000 (ppm)	JA 003A 01500 01500 (ppm)
AQ200	Sb	0.50	0.60	0.40
AQ200	As	4.40	7.30	3.70
LF200	Ba	423.00	485.00	506.00
LF200	Be	5.00	5.00	5.00
AQ200	Bi	0.80	0.80	0.80
LF200	Co	8.70	11.80	8.30
AQ200	Cu	42.50	46.40	41.50
LF200	Ga	20.10	21.40	23.00
LF200	Hf	3.70	3.30	3.80
LF200	Sc	13.00	13.00	14.00
LF200	Y	17.90	18.90	21.30
LF200	La	30.60	31.00	34.60
LF200	Ce	60.10	60.80	69.50
LF200	Pr	7.06	7.01	8.07
LF200	Nd	25.80	26.20	29.40
LF200	Sm	4.99	4.92	5.68
LF200	Eu	0.98	0.99	1.09
LF200	Gd	4.16	4.12	4.62
LF200	Tb	0.60	0.61	0.69
LF200	Dy	3.53	3.61	4.12
LF200	Ho	0.69	0.72	0.77
LF200	Er	2.04	2.10	2.40
LF200	Tm	0.28	0.30	0.34
LF200	Yb	1.91	2.07	2.28
LF200	Lu	0.28	0.30	0.34
LF200	MnO	200.00	200.00	200.00
LF200	Ni	50.00	45.00	36.00
LF200	Nb	11.80	11.70	13.30
LF200	P_2O_5	400.00	500.00	400.00
AQ200	Au	<0.005	<0.005	<0.005
LF200	Sr	57.50	67.70	59.40
LF200	Ta	1.00	0.90	0.80
LF200	W	3.80	3.60	6.70
LF200	V	108.00	111.00	101.00
LF200	MgO	8,000.00	7,600.00	9,100.00
LF200	TiO_2	6,700.00	6,300.00	7,000.00
LF200	K_2O	24,100.00	26,700.00	24,500.00
LF200	SiO_2	498,900.00	507,500.00	498,600.00
LF200	Al_2O_3	168,100.00	167,300.00	177,500.00

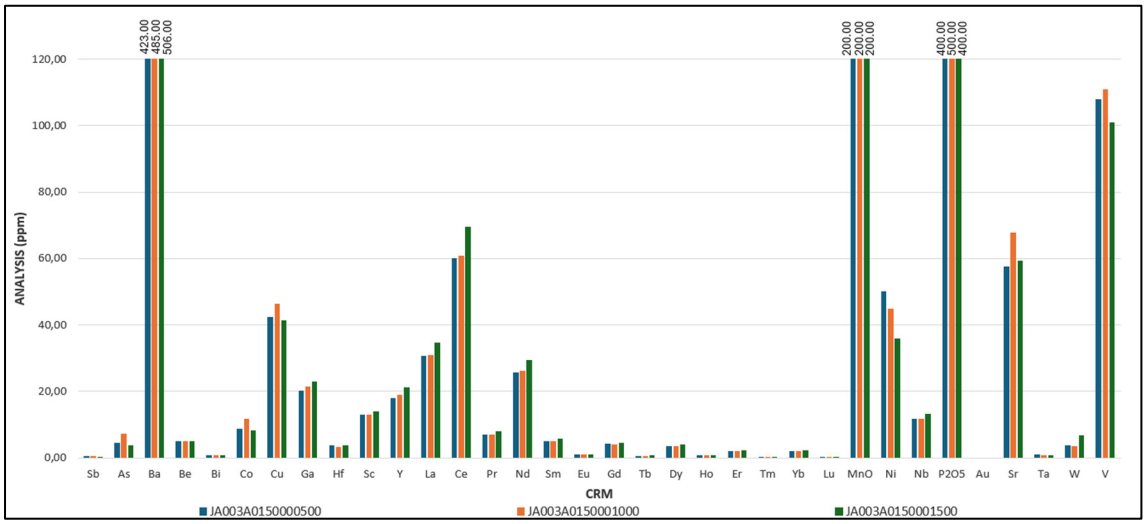


Figure 3-10. Graph of the quantitative analysis of the CRM elements of the borehole JA003A01500 (PL-J/3/S)

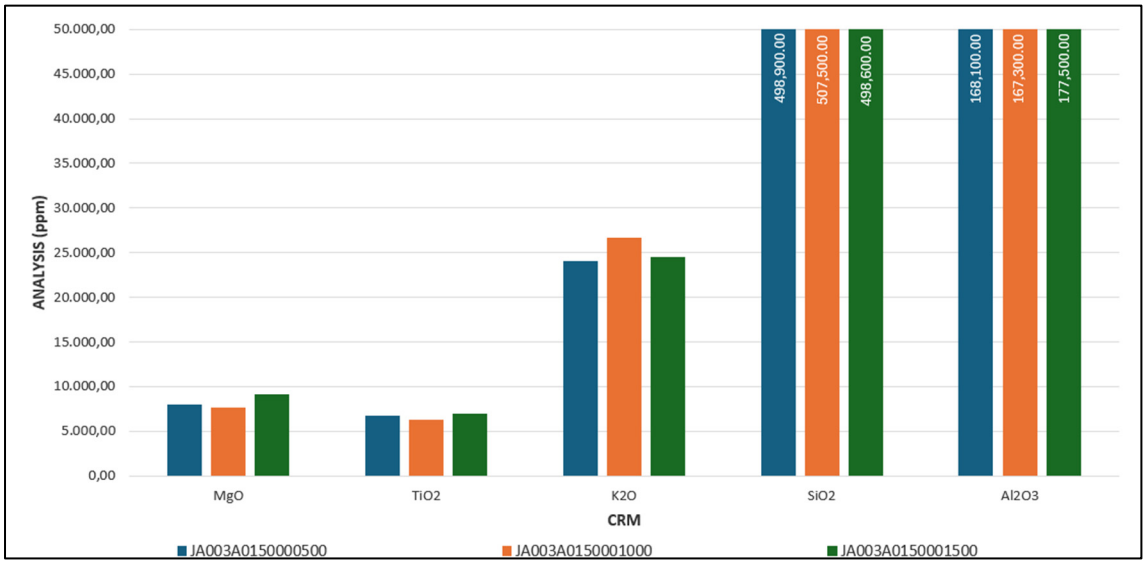


Figure 3-11. Graph of the quantitative analysis of the CRM minerals of the borehole JA003A01500 (PL-J/3/S)

4 Laboratory Analysis and Sample Characterisation

The analytical techniques applied were ME-MS89L, ME-MS19^{TM}, PGM-ICP27, FTIR-MIN and FTIR-BAUX. These methods were selected according to the nature of the samples and the elements and mineral phases targeted for identification and quantification.

Complementary characterisation may include instrumental techniques such as Inductively Coupled Plasma–Atomic Emission Spectrometry (ICP-AES) and X-Ray Fluorescence (XRF), along with other mineralogical characterisation techniques selected based on each sample's specific characteristics.

ME-MS89L (Table 4-1) is a multi-element analytical method based on sodium peroxide fusion followed by ICP-MS analysis. This technique is suitable for determining trace and super-trace elements, particularly in samples containing refractory minerals and elements such as Li. B and rare earth elements.

Table 4-1. Analysis and ranges (ppm) of ME-MS89L technique

ME-MS89L^{TM}: ANALYTES & RANGES (ppm)							
Ag	5-12,500	Er	0.02-25,000	Mn	10-25,000	Sr	20-25,000
As	4-25,000	Eu	0.03-25,000	Mo	2-25,000	Ta	0.04-25,000
B*	8-25,000	Fe	0.01-25%	Nb	0.8-25,000	Tb	0.01-25,000
Ba	2-25,000	Ga	0.5-25,000	Nd	0.07-25,000	Te	0.5-25,000
Be	0.4-25,000	Gd	0.03-25,000	Ni	10-25,000	Th	0.1-25,000
Bi	0.1-25,000	Ge	0.5-25,000	Pb	0.5-25,000	Ti	0.005-25%
Ca	0.1-25%	Ho	0.01-25,000	Pr	0.03-25,000	Tl	0.02-25.000
Cd	0.8-25,000	In	0.3-25,000	Rb	0.5-25,000	Tm	0.01-25,000
Ce	0.2-25,000	K	0.05-25%	Re	0.01-25,000	U	0.2-25,000
Co	0.5-25,000	La	0.08-25,000	Sb	0.3-25,000	V	1-25,000
Cs	0.1-25,000	Li	2-25,000	Se	3-25,000	W	0.3-25,000
Cu	20-25,000	Lu	0.05-25,000	Sm	0.04-25,000	Y	0.2-25,000
Dy	0.03-25,000	Mg	0.01-30%	Sn	3-25,000	Yb	0.02-25,000
						Zn	10-25,000

PGM-ICP27 (Table 4-2) is an ore-grade precious-metal method based on fire assay followed by ICP-AES analysis, used to determine Au, Pt, and Pd.

Table 4-2. Analysis and ranges (ppm) of PGM-ICP27 technique

PGM-ICP27: ANALYTES & RANGES (ppm)	
Pt	0.01-100
Pd	0.01-100
Au	0.01-100

ME-MS19^{TM} (Table 4-3) is an ammonium sulphate leach method developed primarily for exploring rare earth elements associated with ionic clays, allowing determination of REEs adsorbed onto clay surfaces.

Table 4-3. Analysis and ranges (ppm) of ME-MS19^{TM} technique

ME-MS19^{TM}: ANALYTES & RANGES (ppm)							
Al	5-250,000	Fe	5-500,000	Nb	0.005-500	Ta	0.005-500
B	10-10,000	Gd	0.005-1,000	Nd	0.05-10,000	Tb	0.002-1,000
Ba	0.5-10,000	Hf	0.005-500	Ni	0.1-10,000	Th	0.005-10,000
Be	0.01-1,000	Ho	0.002-1,000	P	5-10,000	Ti	5-100,000
Ca	20-250,000	K	20-100,000	Pb	0.05-10,000	Tm	0.002-1,000
Ce	0.005-500	La	0.002-10,000	Pr	0.004-1,000	U	0.005-10,000
Co	0.005-10,000	Li	0.2-10,000	Rb	0.05-10,000	V	0.4-10,000
Cs	0.005-500	Lu	0.002-1,000	Sc	0.005-10,000	W	0.01-10,000
Cu	0.04-10,000	Mg	1-250,000	Si	10-10,000	Y	0.005-500
Dy	0.005-1,000	Mn	0.2-50,000	Sm	0.004-1,000	Yb	0.004-1,000
Er	0.004-1,000	Mo	0.01-10,000	Sn	0.05-500	Zr	0.01-500
Eu	0.004-1,000	Na	50-100,000	Sr	0.03-10,000		

FTIR-MIN (Table 4-4) is an infrared spectroscopic technique used to identify and quantitatively determine major rock-forming and alteration minerals.

Table 4-4. Analytes of FTIR-MIN technique

FTIR-MIN: ANALYTES					
Quartz	Amphibole	Hematite	Chlorite	White Mica	Spodumene
Plagioclase Feldspars	Pyroxene	Calcite	Calcium Sulphates	Kandite-Kaolinite	Ankerite-Dolomite
K-Feldspars	Magnetite	Siderite	Epidote	Alunite	Zeolite
Biotite	Goethite	Talc	Pyrite	Garnet	

Finally. FTIR-BAUX (Table 4-5) is specifically designed for the characterisation of bauxite. providing quantitative information on alumina-bearing phases such as gibbsite and boehmite, as well as reactive silica, iron oxides and other parameters relevant to bauxite processing.

Table 4-5. Analytes of FTIR-BAUX technique

FTIR-BAUX: ANALYTES					
Al_2O_3	SiO_2	Fe_2O_3	Organic C	Sulphate	Boehmite
Al_2O_3avl	RxSiO_2	Oxalate	Carbonate	% Magnetic	Gibbsite

The chemical characterisation included the quantitative determination of a range of elements. The ME-MS89L method reported concentrations in ppm, along with selected elements and their corresponding oxides determined by X-ray fluorescence as weight percentages. In addition, the ME-MS89L analysis specifically included the determination of Hf and Zr to complement the elemental characterisation of the samples.

Before analysis, the samples underwent drying and mechanical preparation (Figure 4-1), including pulverisation to approximately 75 µm. These preparation procedures were performed to ensure sample homogeneity and to obtain material suitable for subsequent chemical and mineralogical analyses. The corresponding procedure for determining the moisture content of the samples was also carried out.



Figure 4-1. San Nicolás, samples 1 and 2

The results to be obtained using the different analytical techniques provide information on the elemental composition of the investigated materials and constitute the basis for assessing the presence, concentration and distribution of the targeted Critical Raw Materials (CRMs).

In addition, further characterisation of the different sample fractions will be carried out in order to determine, in greater detail, the mineralogical composition and the mineral species associated with the identified CRMs (Figure 4-2).



Figure 4-2. San Nicolás, samples 3 and 4

To accurately establish the geochemical potential of the deposit, of the Janina dump in Poland, two complementary analytical procedures were evaluated and applied: AQ200 (partial digestion) and LF200 (total fusion).

The AQ200 technique (Table 4-6) employs a partial chemical digestion using an aqua regia mixture ($HCl:HNO_3$ in a 3:1 ratio), followed by analysis via Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) and/or Inductively Coupled Plasma Mass Spectrometry (ICP-MS) to quantify extractable metals and trace elements, including key Critical Raw Materials (CRMs) such as Cu, Ni, Co, Zn, Pb, Mo and As. While it offers high sensitivity for identifying geochemical anomalies and easily extractable base metals, its main limitation is that it is a partial digestion; it fails to fully dissolve silicate networks and refractory mineral phases, which may underestimate total elemental concentrations.

Table 4-6. Analysis and ranges (ppm) of AQ200 technique

AQ200: ANALYTES & RANGES (ppm)					
Ce	N/A	Ga	1-1,000	Ni	0.1-10,000	V	1-10,000
Co	0.1-2,000	La	1-10,000	Ta	N/A	W	0.1-100
Cu	0.1-10,000	Nd	N/A	U	0.1-2,000	Zr	N/A
Dy	N/A	Nb	N/A				

The LF200 technique (Table 4-7) consists of a whole-rock geochemical characterisation where pulverised samples are fused at high temperatures using a lithium borate flux ($Li_2B_4O_7$), and the resulting molten bead is dissolved in dilute nitric acid (HNO_3) for analysis via ICP-OES (major elements) and ICP-MS (trace and rare earth elements). By integrating the LF100 package for refractory/REE elements (REEs, Nb, Ta, Zr, Hf, Li and W) and the LF302 package for major oxides (with detection limits starting from 0.01%, including Loss on Ignition/LOI testing), its primary objective is to determine total whole-rock chemical composition. Its major advantage is the complete decomposition of refractory minerals and resistant silicates that conventional acid digestion cannot

attack, though its overall elemental coverage and detection limits depend on the specific contracted analytical package.

Table 4-7. Analysis and ranges (ppm) of LF200 technique

LF200: ANALYTES & RANGES (ppm)							
Ce	0.1-50,000	Ga	0.5-10,000	Ni	N/A	V	8-10,000
Co	N/A	La	0.1-50,000	Ta	0.1-1,000	W	0.5-10,000
Cu	N/A	Nd	0.3-10,000	U	0.1-10,000	Zr	0.1-50,000
Dy	0.05-10,000	Nb	0.1-1,000				

Regarding analytical ranges and reference specifications, it is important to note from a methodological standpoint that these ranges reflect the Lower Detection Limit (LDL) and Upper Reporting Limit (URL) expressed in ppm (mg/kg), thus representing strict laboratory instrument analytical boundaries rather than the natural concentration range present within the waste material itself.

5 Conclusions and lessons learned

The multihole exploration drilling campaign within the CRMsDataSpace project has established an initial geological and geochemical dataset to assess the potential of coal mining waste facilities as secondary sources of Critical Raw Materials (CRMs).

Investigations at the San Nicolás waste dump in Asturias (Spain) and the Janina facility in Libiąż (Poland) provided valuable information on the chemical composition and spatial variability of the deposited materials, laying a technical foundation for subsequent resource evaluation.

At the San Nicolás facility, seven boreholes were completed, representing approximately 95 m of drilling and yielding 21 representative samples collected at different depths. At Janina, three boreholes were drilled using auger equipment, providing samples from different depth intervals.

The exploration activities demonstrated the feasibility of obtaining representative material from coal mining waste deposits, although drilling procedures had to be adapted to each site's specific geotechnical characteristics. The technical difficulties encountered at San Nicolás, which required the repositioning of two boreholes, highlight the heterogeneous nature of these anthropogenic deposits and the importance of maintaining operational flexibility during exploration campaigns.

The chemical analyses confirmed the presence of several elements of interest for CRM assessment at both facilities, although differences were observed in their elemental composition and distribution.

At San Nicolás, significant variations were identified between boreholes and sampling intervals, with tungsten concentrations reaching approximately 1,785 ppm and copper concentrations of up to 390 ppm in specific samples. Rare earth element concentrations also varied, particularly for cerium and neodymium. These results suggest that potentially valuable elements are not uniformly distributed throughout the waste deposit and that identifying higher-concentration areas will require detailed spatial modelling.

The Janina samples exhibited a comparatively more consistent geochemical composition for several elements across the investigated boreholes.

The analyses identified rare earth elements, including cerium, lanthanum, and neodymium, along with other elements of interest such as gallium and vanadium. Nevertheless, the available results remain preliminary, and the observed concentrations cannot be extrapolated to the entire waste facility without further investigation and validation of their spatial representativeness.

The combination of systematic drilling, interval-based sampling, sample preparation and complementary laboratory techniques has proved suitable for the preliminary characterisation of coal mining waste deposits.

Standardised borehole and sample identification, together with the geographical and photographic documentation collected during fieldwork, provides an essential basis for integrating the analytical results into the RecMin software. This integration will enable the development of three-dimensional models to investigate the lateral and vertical distribution of the elements of interest and, where sufficient information is available, support preliminary resource estimation.

A key conclusion of this investigation is that identifying potentially valuable elements does not necessarily mean they are technically or economically recoverable.

An element's chemical concentration is only one parameter in evaluating its exploitation potential. Its mineralogical occurrence, association with other minerals, accessibility to extraction processes and achievable recovery efficiency must also be considered.

Consequently, additional mineralogical investigations and the planned hydrometallurgical leaching tests are essential to determine whether the identified elements can be recovered under technically viable conditions.

Overall, the results demonstrate the value of a systematic exploration methodology for investigating the CRM potential of historical coal mining waste facilities. However, the present findings should be regarded as a preliminary characterisation rather than confirmation of economically exploitable resources.

Further validation of the analytical dataset, integration into three-dimensional geological models, and experimental assessment of element recoverability are necessary before drawing conclusions about the resource potential and possible valorisation of the investigated deposits.

The experience gained during the drilling, sampling and analytical activities at San Nicolás and Janina provides several lessons that should be considered when planning and implementing similar exploration campaigns in coal mining waste facilities:

- **Adaptation of drilling techniques to site conditions**. The heterogeneous and frequently unconsolidated nature of mining waste deposits can create technical difficulties during drilling operations. The experience at San Nicolás demonstrated the importance of maintaining flexibility in borehole positioning and drilling procedures, while the auger drilling system used at Janina proved appropriate for recovering material from relatively shallow and unconsolidated

deposits. Future campaigns should incorporate contingency measures to address unexpected ground conditions and minimise operational disruptions.

- **Importance of an appropriate sampling strategy**. Regular depth intervals facilitate comparison of analytical results and their integration into geological models. The approximately 5 m sampling intervals adopted in this investigation were selected to correspond to the spatial resolution envisaged for RecMin modelling. Nevertheless, variability in some elements suggests that more detailed sampling may be needed in selected areas to identify localised concentrations and better characterise heterogeneous materials.

- **Need for representative sample preparation**. Coal mining waste deposits contain materials with different particle sizes, mineralogical compositions and physical characteristics. Consequently, obtaining representative analytical samples requires appropriate procedures for material collection, size reduction, homogenisation and quartering. These operations minimise sampling bias and ensure laboratory results adequately reflect the characteristics of the investigated intervals.

- **Standardisation and traceability of field information**. Implementing a common identification system for boreholes and samples proved particularly valuable for managing the information generated at the two investigation sites. Using the Caderneta application at San Nicolás facilitated recording geographical coordinates, photographs, and field observations. This experience highlights the benefits of standardised digital field documentation and the need to maintain equivalent data structures across all participating countries to support subsequent integration and comparison.

- **Importance of analytical consistency and quality control**. Using different analytical techniques showed the need to consider each method's characteristics and limitations when interpreting laboratory results. In particular, methods based on partial digestion and those involving total fusion may provide different information about elemental concentrations. Detection limits, analytical units, sample preparation procedures and quality-control results must therefore be carefully reviewed before comparing datasets or incorporating them into resource evaluation models.

- **Recognition of spatial variability and sampling limitations**. The differences observed between boreholes and depth intervals, particularly at San Nicolás, confirm that coal mining waste deposits cannot necessarily be treated as chemically homogeneous materials. Consequently, average concentrations derived from a limited number of samples may not adequately represent the overall deposit. Three-dimensional modelling and, where necessary, additional

targeted sampling are required to improve the understanding of elemental distribution and reduce uncertainty in subsequent assessments.

- **Distinction between elemental concentration and recoverability**. Identifying CRMs through chemical analysis is an essential first step, but it does not show that these elements can be extracted economically. Detailed mineralogical characterisation and hydrometallurgical leaching tests are necessary to investigate their modes of occurrence, potential extraction behaviour and achievable recovery efficiencies. These investigations should precede any definitive assessment of the technical or economic feasibility of recovery operations.

- **Value of an integrated and progressive exploration methodology**. The experience gained confirms the importance of combining field investigation, laboratory characterisation, systematic data management and three-dimensional geological modelling within a coordinated workflow. The information obtained at each stage should guide subsequent activities, including selecting areas for additional sampling and identifying representative materials for recovery testing. This progressive approach can help optimise investigation resources and reduce uncertainty before proceeding to more detailed technical, economic and environmental assessments.

Taken together, these lessons provide a methodological basis for improving future exploration campaigns within the CRMsDataSpace project and for supporting the systematic assessment of other coal mining waste facilities as potential secondary sources of Critical Raw Materials.

ANNEX I. Caderneta application

The **Caderneta application (v.1.1.2)** is designed to support field data collection and management using an Android tablet.

The application enables the collection of information on sampling points and samples within a predefined fieldwork plan, while also facilitating monitoring of field activities as they are carried out (Figure A-1).



Figure A-1. Recording the initial SN-1 data in Caderneta

Before fieldwork begins, a reference work plan can be established by importing a **.shp (Shapefile)** containing the planned sampling points.

This reference layer provides the basis for organising field activities and allows field personnel to identify and manage the sampling points included in the work plan.

During fieldwork, Caderneta allows users to record information for both planned and additional sampling points. Relevant information can be collected for each point and, where applicable, associated samples can be registered (Figure A-2).

The application also enables photographs to be captured and linked to the corresponding sampling points and samples. If a sampling point is visited but no sample is collected, the application can also record this.

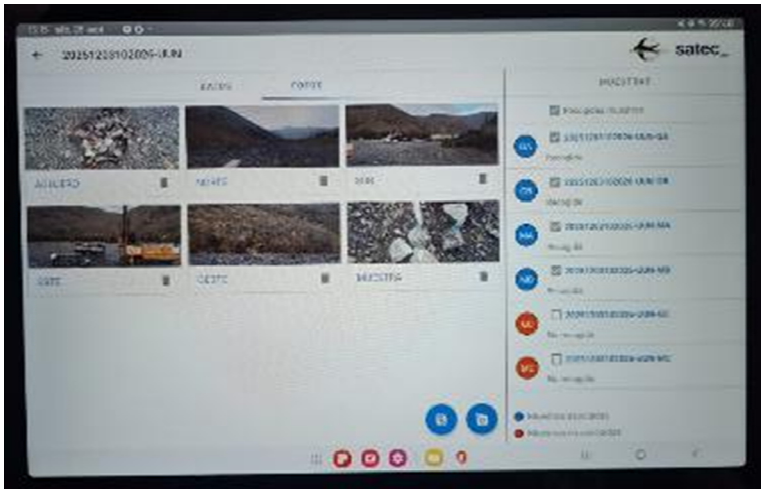


Figure A-2. Recording of the SN-1 photographs in Caderneta



Figure A-3. Photographs of SN-1

BOREHOLE - SN001B01400 (SN-1Bis)

The photographic record corresponding to borehole SN001B01400, obtained using the Caderneta application, comprises six photographs representative of the conditions observed during borehole drilling. These correspond to the **borehole collar, the north, south, east and west orientations, and the recovered samples or drill cores** (Figure A-4)

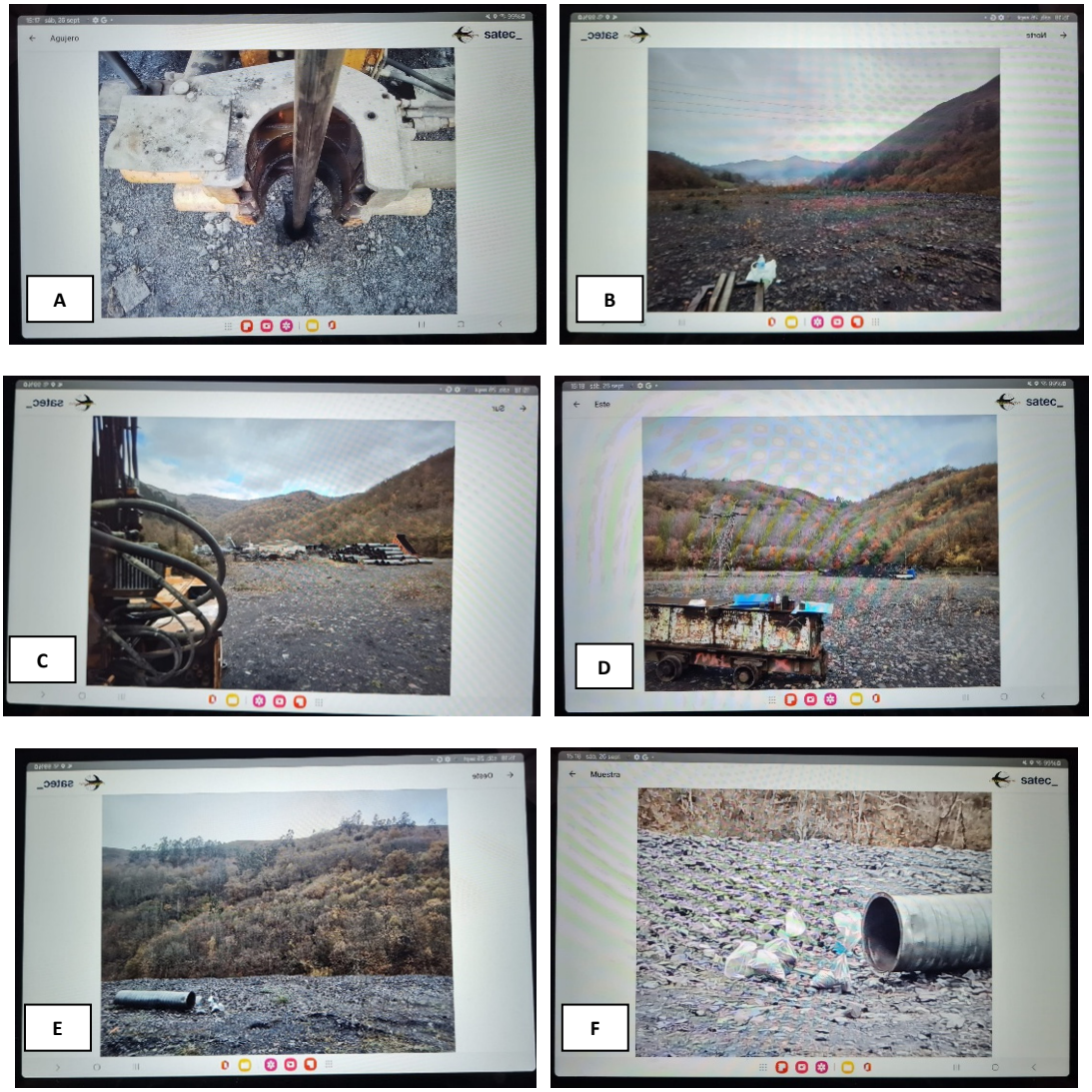


Figure A-4. Photographs of SN-1Bis

BOREHOLE - SN002A01300 (SN-2)

The photographic record corresponding to borehole SN002A01300, obtained using the Caderneta application, comprises six photographs representative of the conditions observed during borehole drilling. These correspond to the **borehole collar, the north, south, east and west orientations, and the recovered samples or drill cores** (Figure A-5).

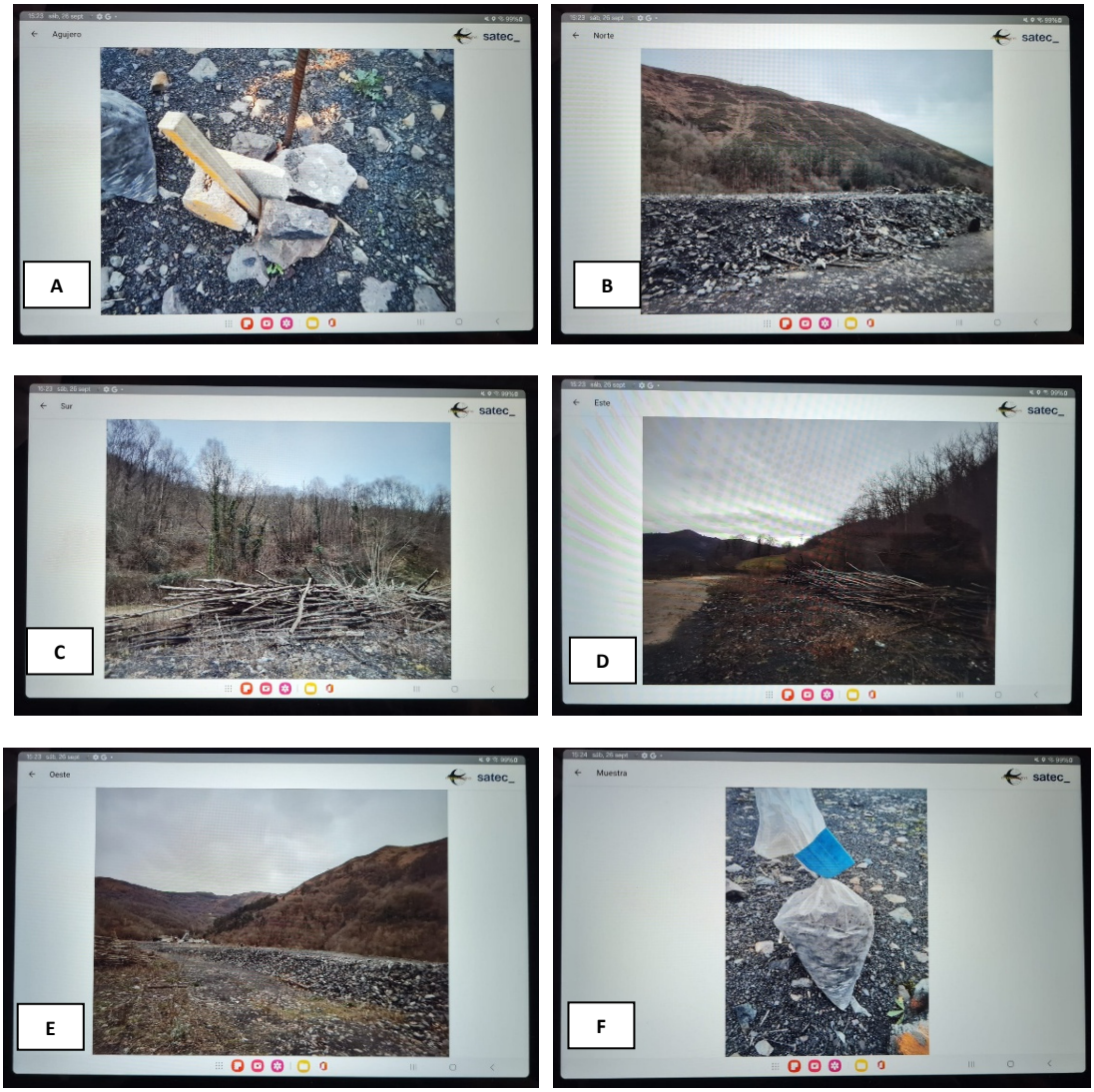


Figure A-5. Photographs of SN-2

BOREHOLE - SN003A01450 (SN-3)

The photographic record corresponding to borehole SN003A01450. obtained using the Caderneta application, comprises six photographs representative of the conditions observed during borehole drilling. These correspond to the **borehole collar, the north, south, east and west orientations, and the recovered samples or drill cores** (Figure A-6).

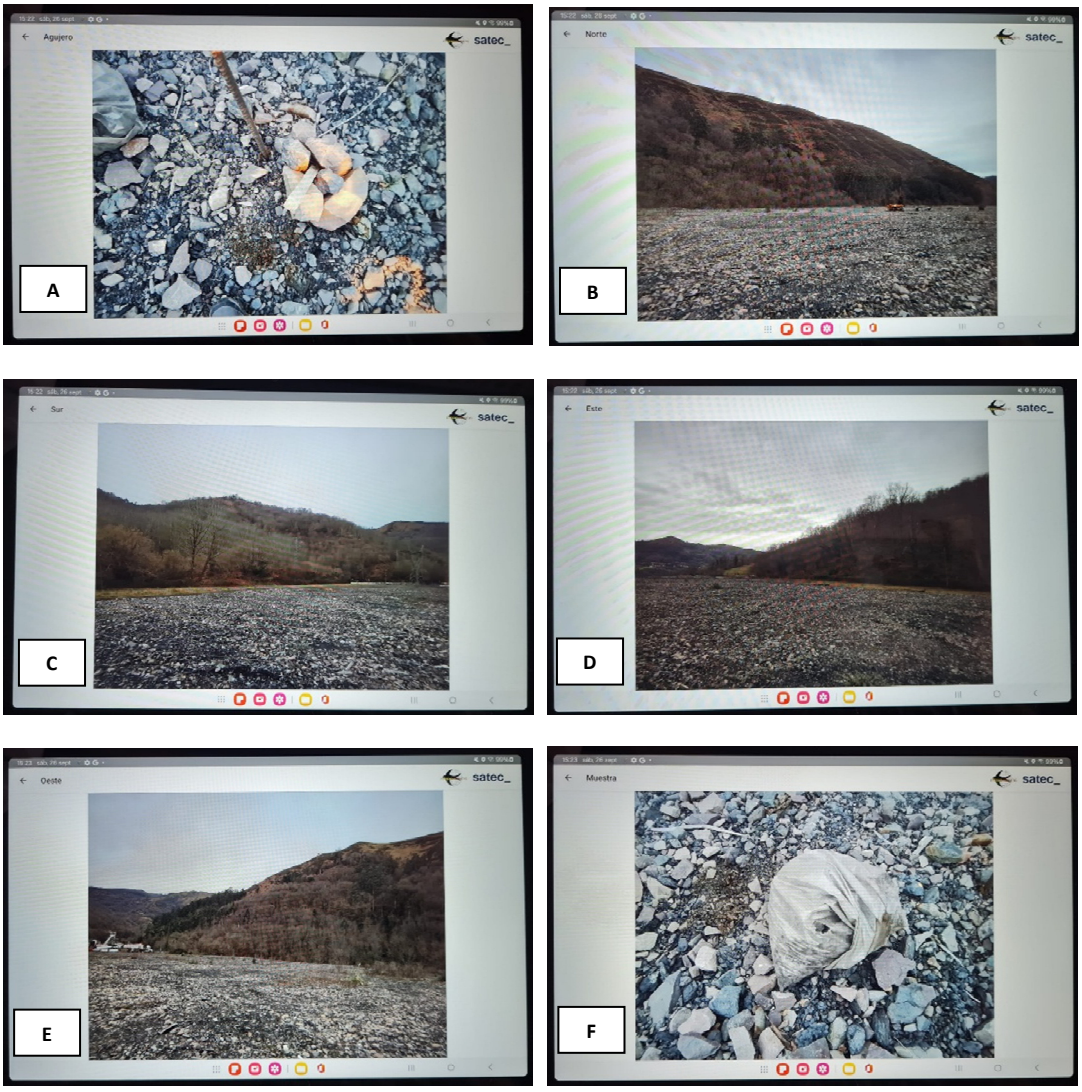


Figure A-6. Photographs of SN-3

BOREHOLE - SN004A00400 (SN-4)

The photographic record corresponding to borehole SN004A00400. obtained using the Caderneta application, comprises six photographs representative of the conditions observed during borehole drilling. These correspond to the **borehole collar, the north, south, east and west orientations, and the recovered samples or drill cores** (Figure A-7).

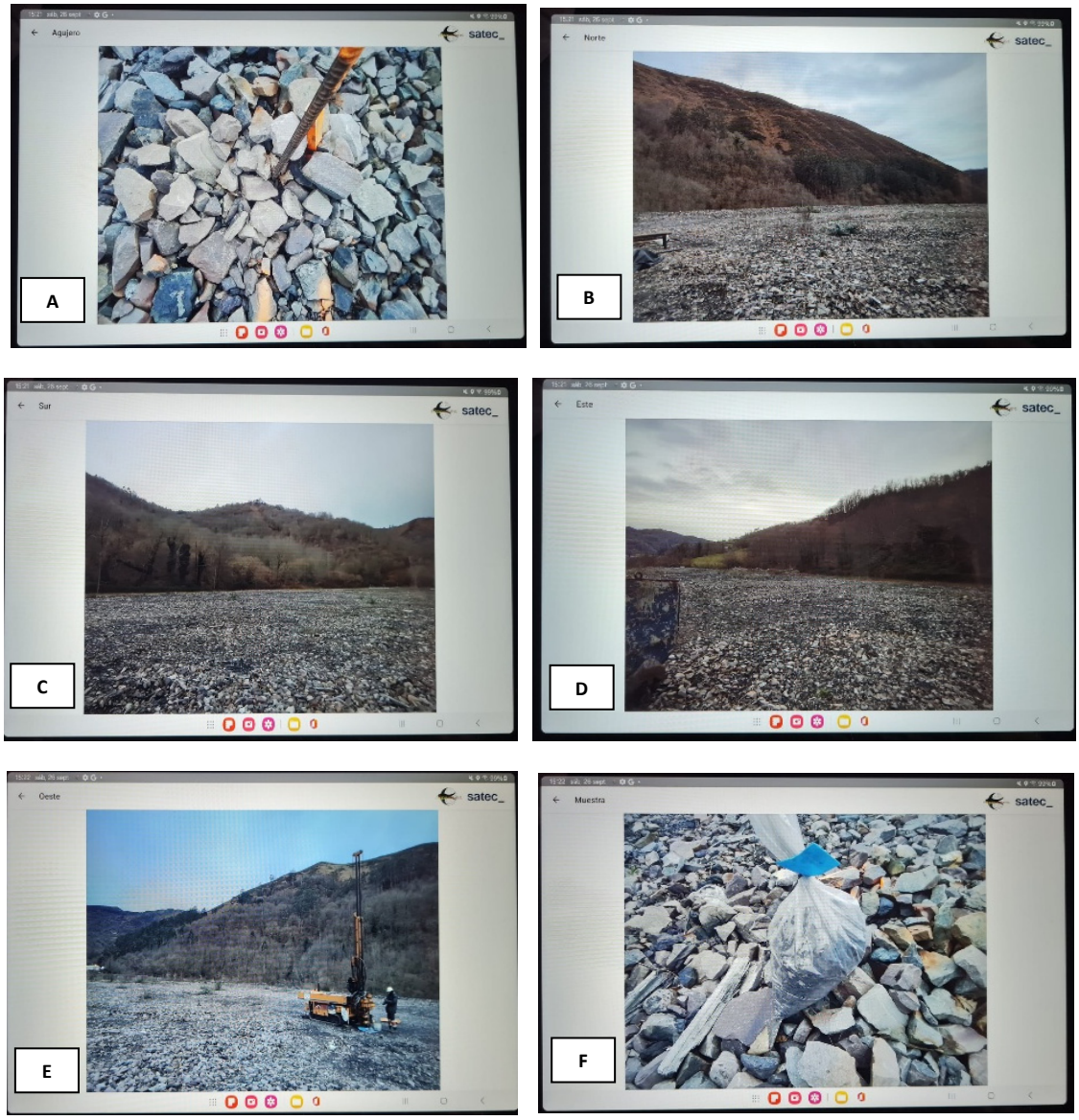


Figure A-7. Photographs of SN-4

BOREHOLE - SN004B03200 (SN-4Bis)

The photographic record corresponding to borehole SN004B03200. obtained using the Caderneta application, comprises six photographs representative of the conditions observed during borehole drilling. These correspond to the **borehole collar, the north, south, east and west orientations, and the recovered samples or drill cores** (Figure A-8).

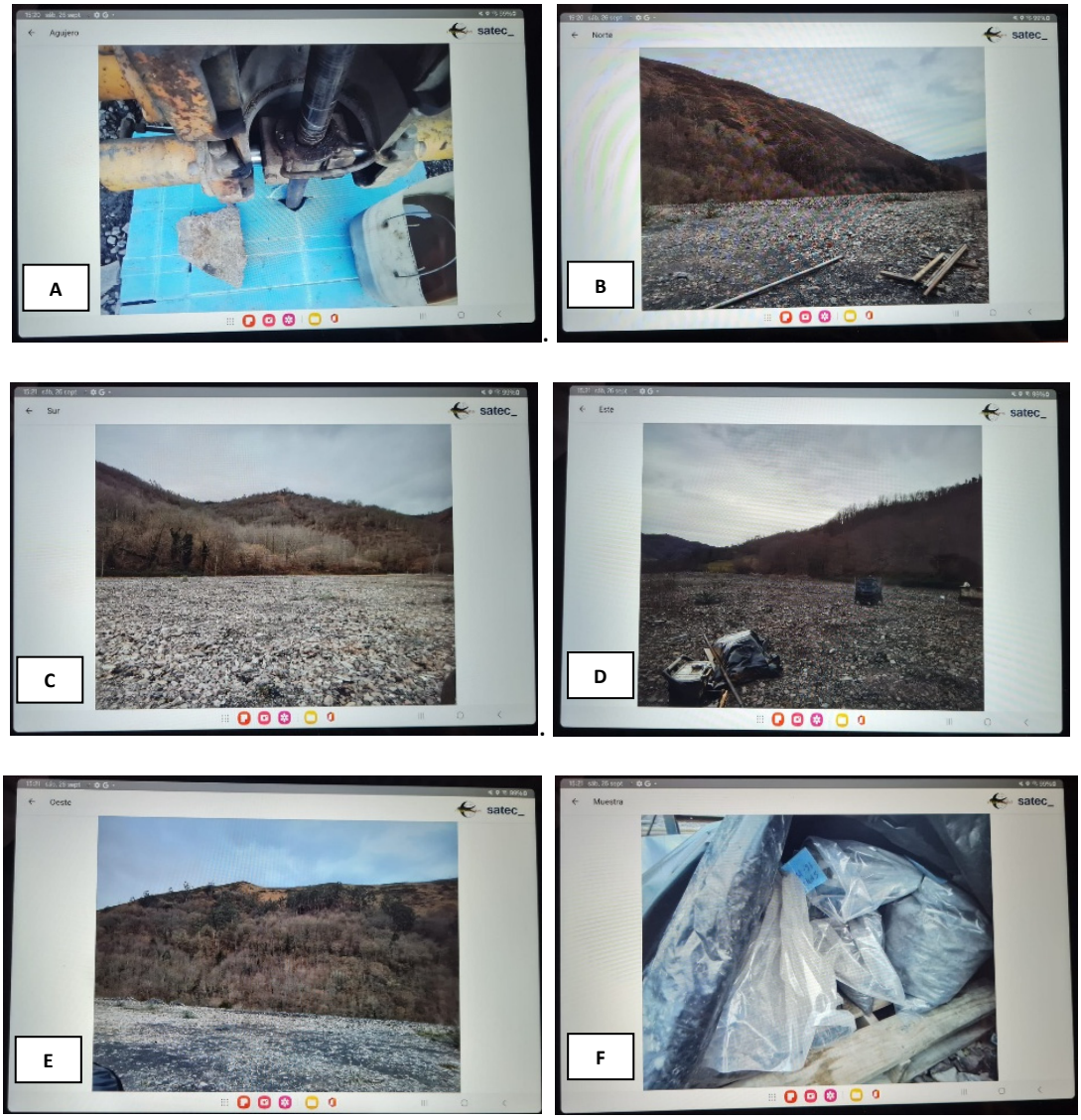


Figure A-8. Photographs of SN-4Bis

BOREHOLE - SN 005A01050 (SN-5)

The photographic record corresponding to borehole SN005A01050. obtained using the Caderneta application, comprises six photographs representative of the conditions observed during borehole drilling. These correspond to the **borehole collar, the north, south, east and west orientations, and the recovered samples or drill cores**. (Figure A-9).

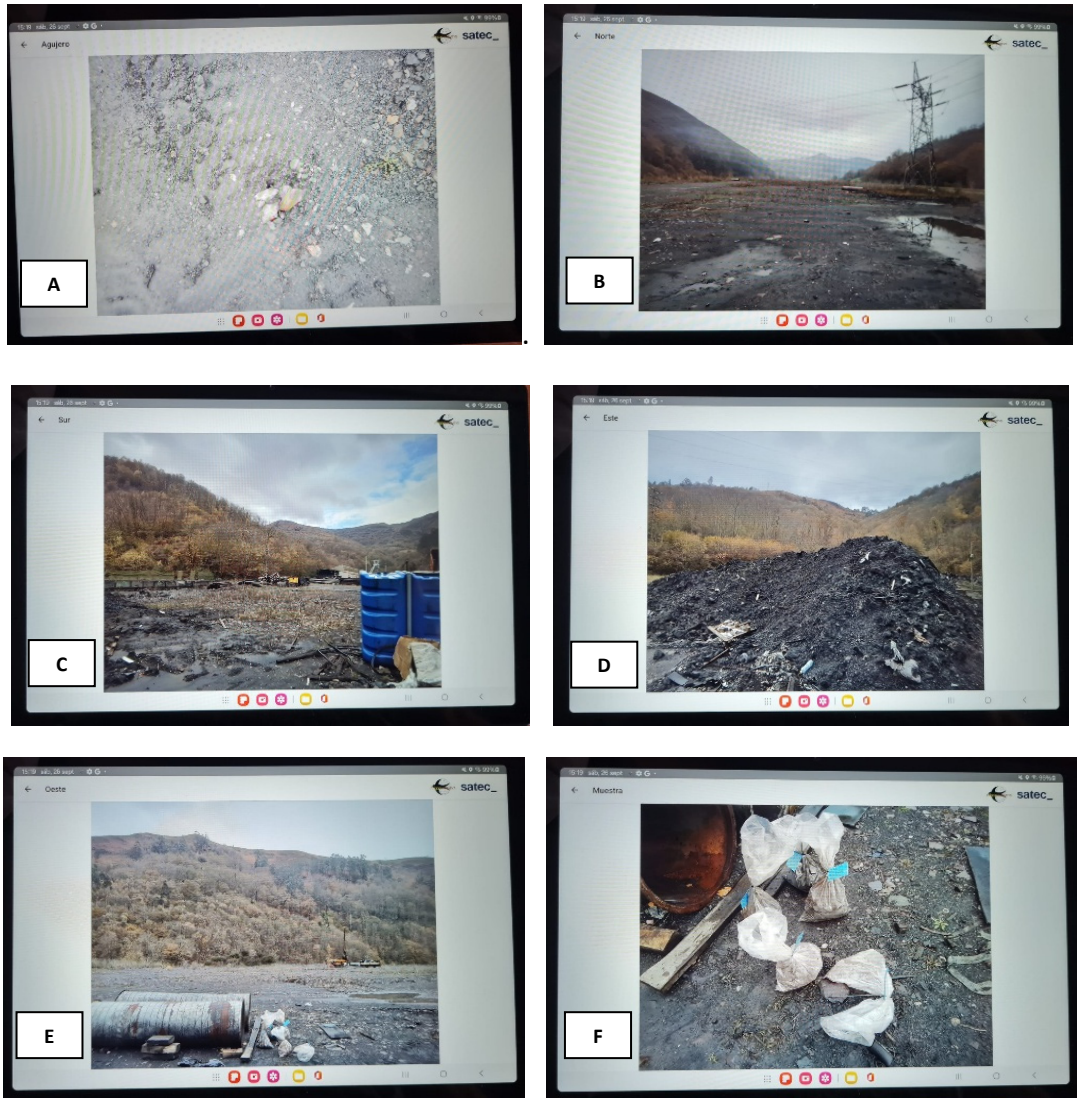


Figure A-9. Photographs of SN-5