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CURVATURE AND RADIUS OF CURVATURE VARIATION IN THE CHARACTERIZATION OF AN AREA AFFECTED BY ANTHROPOGENIC MINING ACTIVITIES

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Abstract: *This study analyzed the curvature and radius of curvature in order to characterize an area affected by anthropogenic coal mining activities. The study took place in an area located in Jiu Valley, Romania. 16 control points were considered (CP1 – CP16), for which the quota values were determined (X,Y,Z system) at the moment of analysis (T1) in relation to a reference moment (T0). The differences in quota were calculated (XYZ) between moments T1 and T0. Curvature (Curv) and radius of curvature (RadC) values were calculated. Strong correlation was recorded between Curv and Z(T1-T0), r = -0.847***, between Curv and Dg (diving the ground), r = 0.847***, and between Curv and Ls (land slope), r = 0.891*** (*** p < 0.001). Weak correlation was recorded between RadC and Y(T1-T0), r = 0.586***. Spline type mathematical models described the variation of curvature, and Radius of curvature in relation to the control points (XYZ values), under conditions for curvature, respectively for radius of curvature. According to the multivariate analysis, the PCA diagram resulted, in which PC1 explained 50.737% of variance, and PC2 explained 49.263% of variance. The cluster analysis generated the dendrogram in which the control point CP16 was positioned separately, and the other control points were grouped in a cluster based on similarity (Coph.corr = 0.998). The ranking of the control points, in relation to the values recorded for the Curv and RadC parameters, was done in the form of Scaling dendrogram.*

Keywords: *Coal mining area; curvature; ecological systems; mathematical models; radius of curvature*

1. Introduction

The settlement of coal mines generated complex effects on the environment, with direct influences on the relief, soil and vegetation [1]. The authors recorded how the subsidence affected the degree of soil coverage with vegetation, the water regime on the soil surface, the vegetation and overall led to a reduction in the quality of environmental factors.

Mining represented a sector of the economy that provided jobs, and provided and continues to provide energy resources and raw materials for society [2], [3]. The authors also communicated how mining, in addition to positive effects, also presented negative effects on the environment.

Underground coal mines have generated cumulative spatio-temporal effects on the environment [2]. Effects of mining have been recorded on the aquifer layer on an extensive scale, as a result of the direct and indirect effects of underground mining operations [4].

The ecology of the land surface has recorded variations in time and space as a result of the impact of coal mine subsidence [5]. The authors of the study evaluated the physical, chemical and hydrophysical properties of the soil based on a number of approximately 3000 soil samples, taken from 60 sampling points.

The underground exploitation of coal generated extensive changes of the geomechanical nature of the rock mass [6]. The authors considered that studying the processes that lead to deformations of the earth's crust,

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associated with mining activities, can ensure the sustainability of mining operations in relation to the environment. The authors studied the parameters of the horizontal deformations of the earth's surface and the comparative analysis of the values of the parameters with objectives of interest (e.g. the positioning of some pipelines). Underground mining has the effect of moving and deforming the land following the extraction of the useful mineral substance [7].

These areas of land affected by underground mining will have to be monitored over time in order to protect the surface and existing constructions on it in order to make forecasts over time of this phenomenon and the sustainable development of these areas, which are generally mono-industrial areas and disadvantaged areas [8].

Determining real forecasts in time can make investments in these areas constantly and with maximum efficiency. Land subsidence under the influence of underground exploitations is monitored over time by determining some parameters that define the phenomenon as well as through the characteristic curves that will be realized following topographical observations carried out in alignments and tracking stations that were placed on the surface covering the underground exploitations [9].

The present study evaluated the curvature and radius of curvature of the land, associated with the phenomenon that affected the surface of the land, as an effect of coal mining in the Jiu Valley area, Romania.

2. Materials and method

In relation to the purpose of the study, changes to the land surface were evaluated in the Jiu Valley area, Romania, figure 1.

The monitoring station for the phenomenon of land subsidence under the influence of underground mining in the case of the Petroșani Mining Basin, covered the perimeter of Livezeni mine, an area in that the phenomenon manifested itself significantly, with implications in the protection of the constructions carried out on the surface and on the constructions planned to be carried out.

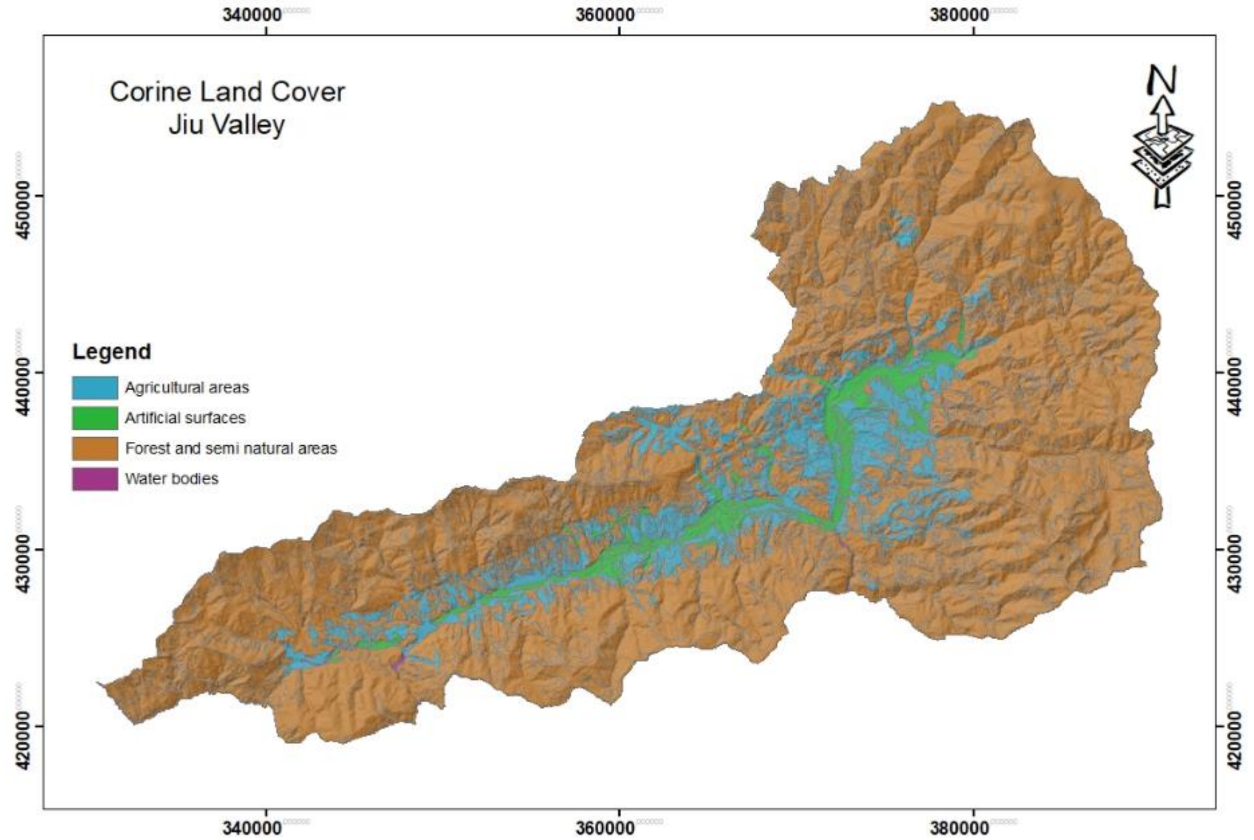

Fig.1. The study area, Jiu Valley, Romania

The area considered for monitoring and study was in Maleia zone in the study area. According to the specialized literature [10], [11], [12], which provided a series of parameters to describe the phenomenon of changing the earth's crust, Radius were selected for the present study of radius of curvature (RadC), equation (1), and Curvature (Curv), equation (2).

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The radius of curvature is determined by the succession of deformations in time, and the curvature of the surface is the inverse of the radius of curvature, and was defined as the inverse of the ratio between the angle of convergence of the tangents in the neighboring points and the distance between them.

$$R_i = \frac{d_{i-1,i+1}}{\frac{s_{i+1}-s_i}{d_{i,i+1}} - \frac{s_i - s_{i-1}}{d_{i-1,i}}} \quad \text{or:} \quad R_i = \frac{d_{i-1,i+1}}{\Delta I_i} \tag{1}$$

$$C_i = \frac{1}{R_i}[km^{-1}] \quad \text{or:} \quad C_i = \frac{\frac{s_{i+1}-s_i}{d_{i,i+1}} - \frac{s_i - s_{i-1}}{d_{i-1,i}}}{d_{i-1,}d_{i+1}} \tag{2}$$

16 control points (CP1 to CP16) were used with XYZ coordinate values at T1 (actual time) and T0 (reference time) presented by [11].

Appropriate software was used to analyze the results and generate some graphic representations [13], [14].

3. Results and discussion

Curvature (Curv) and Radius of curvature (RadC) were calculated in relation to the values of the coordinates of the control points at the moment T1 (current time) and the moment T0 (reference time). The results are the values presented in table 1.

Table 1. Calculated values for the coordinates of the control points, curvature and radius of curvature, area located in Jiu Valley, Romania

Control point	**Different XYZ coordinate values (moments T1 and T0)**			**Curvature**	**Radius of Curvature**
	$\mathbf{X_{(T1-T0)}}$	$\mathbf{Y_{(T1-T0)}}$	$\mathbf{Z_{(T1-T0)}}$	**(Curv)**	**(RadC)**
CP1	0.0031000	-0.0037000	-0.0128000	0	0
CP2	0.0035000	-0.0055000	-0.0181000	0	0
CP3	-0.0027000	-0.0140000	-0.0766000	-0.0006013	-1663.0531385
CP4	0.0007000	-0.0326000	-0.1280000	0.0136276	73.3807045
CP5	0.0026000	-0.0156000	0.9214000	-0.0835935	-11.9626513
CP6	0.0053000	-0.0067000	-0.0365000	0.0530850	18.8377198
FP7	0.0000000	0.0000000	-0.0001000	-0.0087576	-114.1865069
CP8	0.0135000	0.0103000	-0.0737000	0.0037720	265.1104388
CP9	0.0090000	-0.0068000	-0.0659000	-0.0022557	-443.3189514
CP10	-0.0004000	-0.0008000	0.0005000	-0.0000732	-13659.1407419
CP11	0.0056000	-0.0001000	-0.0346000	0.0024905	401.5240584
CP12	0.0065000	-0.0160000	-0.1007000	-0.0009545	-1047.6682898
CP13	-0.0234000	-0.0056000	-0.0288000	-0.0002389	-4185.2018811
CP14	0.0030000	0.0005000	0.0192000	0.0001234	8105.5649623
CP15	-0.0016000	-0.0118000	-0.0298000	0.0002789	3585.5318707
CP16	-0.0051000	0.0214000	-0.0590000	0.0000088	113481.7811205

The correlation analysis was done to evaluate the interdependence between the values of the coordinates (XYZ), curvature (Curv), radius of curvature (RadC) and other parameters that described the land sinking phenomenon communicated in previous studies [11], [15]. The result was the correlation matrix in map format, figure 2.

Curvature (Curv) showed a strong correlation with $Z_{(T1-T0)}$, r = -0.847***, with the Dg parameter, r = 0.847, and with the Ls parameter, r = 0.891***. Radius of curvature (RadC) showed weak correlation with $Y_{(T1-T0)}$, r = 0.586*.

Very strong correlation was recorded between Dg and $Z_{(T1-T0)}$, r = -1***, and between Td and Dd, r = 1***. Moderate correlation was recorded between Ls and $Z_{(T1-T0)}$, r = -0.7**, and respectively between Ls and Dg, r = 0.7**.

The variation of the values of the curvature (Curv) and radius of curvature (RadC) parameters was analyzed in relation to the control points.

The curvature (Curv) variation in relation to the $X_{(T1-T0)}$ values at the 16 control points (CP1 to CP16) was described by a Spline model. The statistical values resulting from the analysis are presented in table 2, and the graphic distribution is presented in figure 3. The errors related to the Spline model were described by equation (3).

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$$\bar{\varepsilon} = \left(\sum_{i=1}^{n} \varepsilon_i\right) / n = \left(\sum_{i=1}^{n} \left|\frac{ys_i - y_i}{y_i}\right|\right) / n \qquad (3)$$

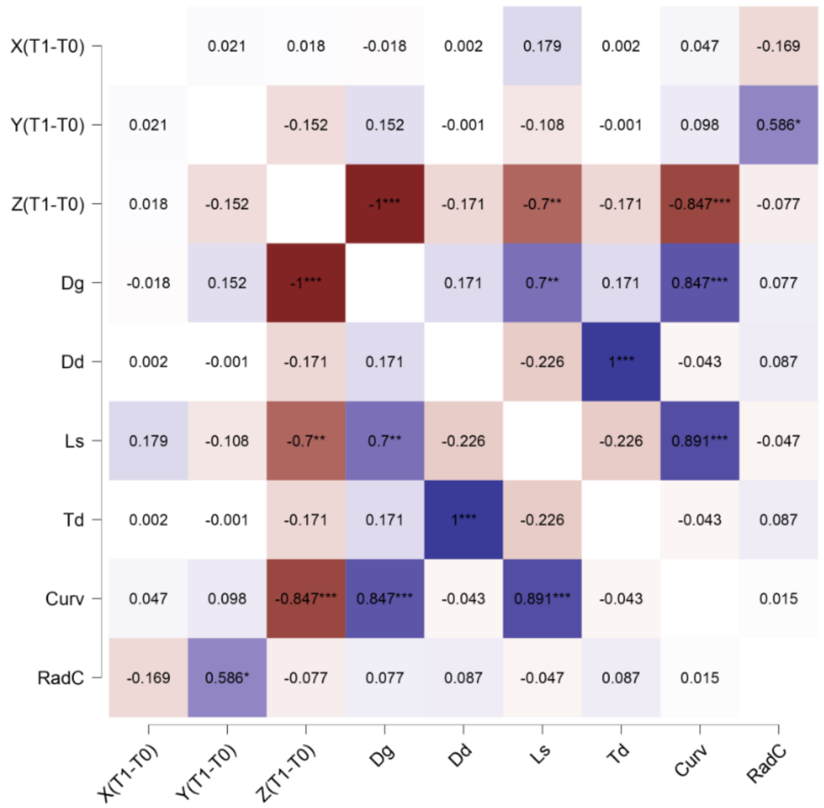

Fig. 2. The matrix of correlations between XYZ coordinates and parameters that described the phenomenon of land subsidence

The variation of Radius of curvature (RadC) in relation to $Y_{(T1-T0)}$ associated with the 16 control points (CP1 to CP16) was described by a Spline model.

The statistical values resulting from the analysis are presented in table 3, and the graphic distribution is presented in figure 4.

Table 2. Statistical values that described the variation of Curvature (Curv) in the study area, located in Jiu Valley, Romania

Trials data		**Curvature (Curv)**			
No	**x_i**	**y_i**	**y_{si}**	**e_i**	**$I_{i/1}$**
PC1	0.00310	0.00000	0.00116	0.00000	1.00000
PC2	0.00350	0.00000	0.00253	0.00000	2.17933
PC3	-2.70E-03	-0.00060	-0.00062	0.02636	-0.53235
PC4	0.00070	0.01363	0.01224	-0.10178	10.55896
FP5	2.60E-03	-0.08359	-0.07936	-0.05065	-68.45510
FP6	5.30E-03	0.05309	0.04957	-0.06625	42.75684
FP7	0.00E+00	-0.00876	-0.00702	-0.19799	-6.05857
FP8	0.01350	0.00377	0.00377	-0.00069	3.25144
PC9	9.00E-03	-0.00226	-0.00222	-0.01379	-1.91892
PC10	-4.00E-04	-0.00007	-0.00099	12.51216	-0.85318
PC11	0.00560	0.00249	0.00622	1.49661	5.36341
PC12	6.50E-03	-0.00095	-0.00159	0.66873	-1.37393
PC13	-2.34E-02	-0.00024	-0.00024	0.00000	-0.20607
PC14	3.00E-03	0.00012	-0.00690	-56.90924	-5.95118
PC15	-1.60E-03	0.00028	0.00037	0.31312	0.31591
PC16	-5.10E-03	0.00001	0.00001	0.06105	0.00805

$\bar{\varepsilon} = -2.64140$

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Table 3. Statistical values that described the variation of Radius of curvature (RadC) in the study area, located in Jiu Valley, Romania

Trials data		**Radius of curvature (RadC)**			
No	x_i	y_i	y_{si}	e_i	$I_{i/1}$
PC1	-0.00370	0.00000	-3150.70000	0.00000	1.00000
PC2	-0.00550	0.00000	-1463.00000	0.00000	0.46434
PC3	-1.40E-02	-1663.10000	-242.94000	-0.85392	0.07711
PC4	-0.03260	73.38100	71.59600	-0.02433	-0.02272
FP5	-1.56E-02	-11.96300	-800.77000	65.93722	0.25416
FP6	-6.70E-03	18.83800	-346.51000	-19.39420	0.10998
FP7	0.00E+00	-114.19000	-356.31000	2.12033	0.11309
FP8	0.01030	265.11000	901.70000	2.40123	-0.28619
PC9	-6.80E-03	-443.32000	-239.38000	-0.46003	0.07598
PC10	-8.00E-04	-13659.00000	-4849.00000	-0.64500	1.53902
PC11	-0.00010	401.52000	-965.16000	-3.40377	0.30633
PC12	-1.60E-02	-1047.70000	-859.36000	-0.17977	0.27275
PC13	-5.60E-03	-4185.20000	-1431.40000	-0.65799	0.45431
PC14	5.00E-04	8105.60000	2666.40000	-0.67104	-0.84629
PC15	-1.18E-02	3585.50000	2566.30000	-0.28426	-0.81452
PC16	2.14E-02	113480.00000	113310.00000	-0.00150	-35.96344

$\bar{\varepsilon} = 2.74269$

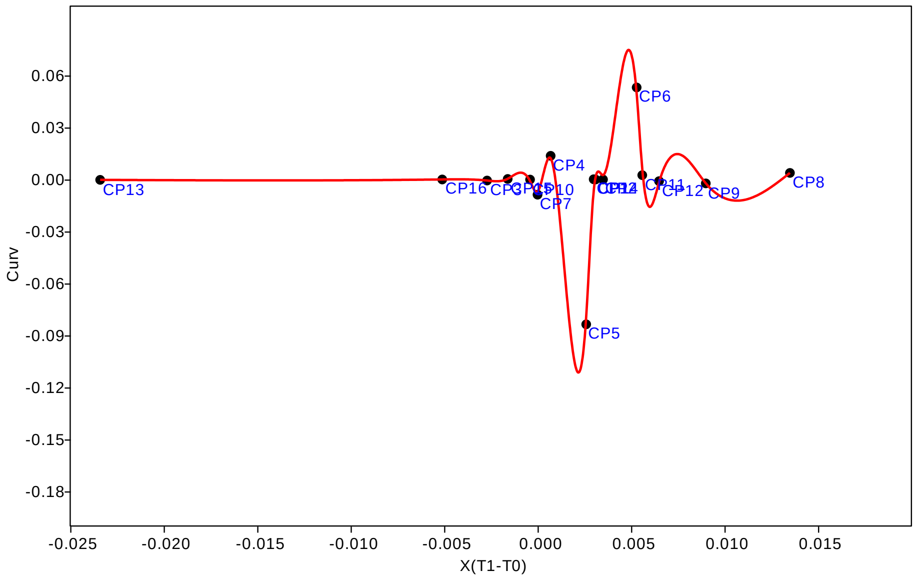

Fig. 3. Graphical distribution of curvature (Curv) for the study area, located in Jiu Valley, Romania

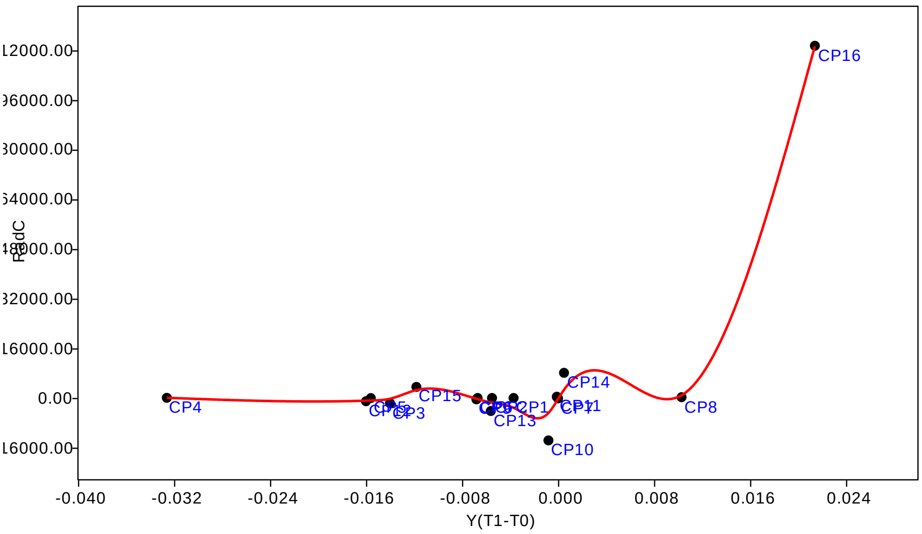

Fig. 4. Graphical distribution of the radius of curvature (RadC) for the study area, located in Jiu Valley, Romania

The multivariate analysis was applied to generate the PCA diagram, to find out the distribution of control points in relation to the two parameters (Curv, RadC), as well as to find out how the main components explained the presence of variance, figure 5.

From the analysis of the distribution of the control points, it was observed the positioning of two points outside the safety zone, 95% confidence (CP5, and CP16). Control point CP5 presented the maximum deviation in the description of curvature (figure 3), and CP 16 presented the maximum deviation in the description of RadC (figure 4).

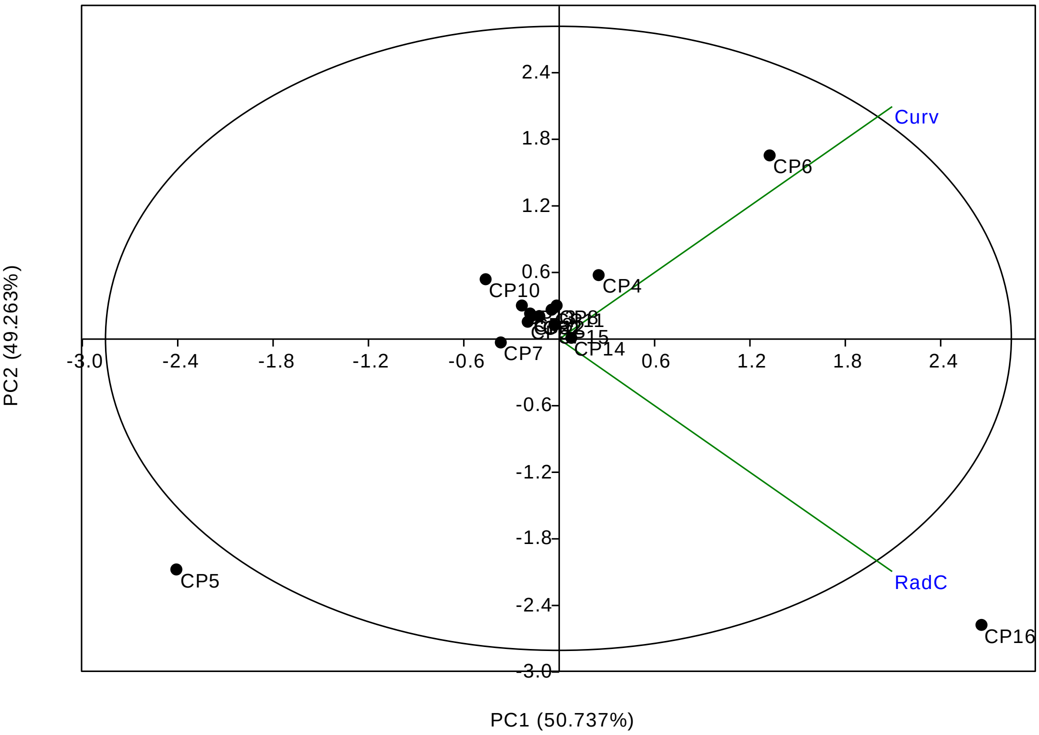

Fig. 5. PCA diagram, for the description of the obtained results

Cluster analysis was used to generate the control point association dendrogram (CP1 to CP16). The result was the dendrogram from figure 6, under statistical safety conditions (Coph.corr. = 0.998). The separate positioning of the control point CP16 was found and the grouping of the other control points within a cluster.

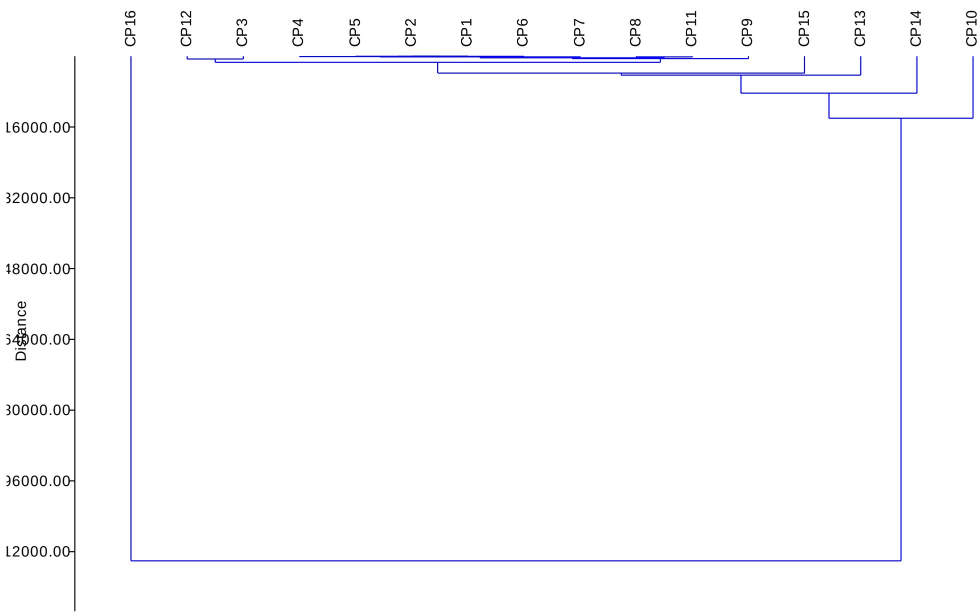

Fig. 6. Dendrogram of association of control points,
in relation to the values generated for Curv and RadC parameters

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The ranking of the control points, in relation to the values recorded for the Curv and RadC parameters, was done. Figure 7 resulted, in which the 16 control points are hierarchically positioned on the y axis (Event). It was established that the control point CP16 is positioned in the middle of the series of control points. The control point CP16 presented an independent position also within the Cluster analysis dendrogram (figure 6).

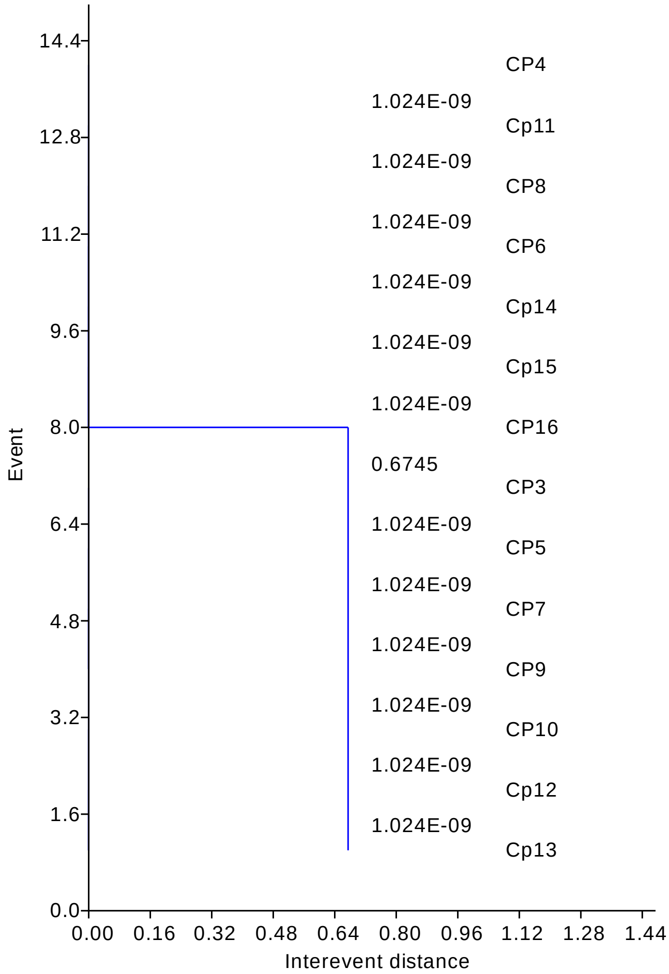

Fig. 7. Scaling dendrogram

The alteration of ecosystems, through the settlement of mines, subsidence zones with variability in time and space, and a series of associated processes regarding the soil and vegetation, requires a differentiated ecosystem management for the recovery of the affected lands [7], [1]. Marian and Onica (2021a) [8] considered it important to permanently monitor these areas, and to make forecasts in real time.

Determining the parameters that define the phenomenon of subsidence and describing the characteristic curves was considered important to characterize the affected areas and for preventive purposes in relation to predictable events [9].

In relation to plant nutrition were considered appropriate [3]. Such practices presuppose the consolidation of the land, and depending on the functionality of the soil, various ameliorative and fertilizing products were considered appropriate for the soil, the cultivation of plants with a good adaptation, such as local populations [16], [17], [3].

Different models have been found useful in describing areas affected by subsidence and predicting associated phenomena [4], [5].

Changes in soil structure, associated with mine settlement processes, represent an important factor in soil productivity in the affected areas [5], [18], [19], [20]. The authors considered important the prompt monitoring and interventions, in good time, of the affected areas (cracks with dimensions up to 6 m), and the selection of appropriate vegetation on the surface of the land, represent useful methods for controlling the affected surfaces.

The present study contributes to the evaluation of the areas affected by mining operations over time, by describing the curvature (Curv) and the radius of curvature (RadC) and finding some Spline models that described these parameters.

4. Conclusions

Curvature parameters (Curv) and radius of curvature (RadC), associated with subsidence phenomena generated by mining operations in the Valea Jiului area, Romania, were described based on 16 control points and the associated XYZ values.

Curvature (Curv) showed a strong correlation with $Z_{(T1-T0)}$, r = -0.847***, with the Dg parameter, r = 0.847, and with the Ls parameter, r = 0.891***. Radius of curvature (RadC) showed weak correlation with $Y_{(T1-T0)}$, r = 0.586*.

Spline models were found that described with high fidelity the variation of curvature (Curv) in relation to the values $X_{(T1-T0)}$ at the 16 control points (CP1 to CP16) , and a radius of curvature (RadC) in relationship with $Y_{(T1-T0)}$ associated with the 16 control points (CP1 to CP16).

Multivariate analysis facilitated the generation of distribution diagrams and association of control points in relation to analyzed parameters (Curv, RadC). The points with independent positioning in relation to the analyzed parameters were identified. The hierarchy of the control points was obtained, in the form of Scaling dendrogram.

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MONITORING DEFORMATIONS IN THE E36 MINING PILLAR AT SALINA OCNA DEJ USING UAV EQUIPMENT

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Abstract: *Monitoring deformations in mining pillars in salt mines is crucial for detecting spalling, cracks, and distortions caused by internal pressures, with the aim of preventing mining accidents and maintaining structural integrity. At Salina Ocna Dej, annual measurements have not utilized drone technology, which was recently introduced in Romania. The measurements conducted with the DJI Phantom 4 Pro Plus drone in 2020 and 2024 provided essential data on changes in the mining pillar. In 2020, difficulties caused by air currents slightly affected the measurements, but by 2024, improved conditions allowed for more accurate results. The horizontal sections taken at various elevations revealed significant spalling and distortions, particularly on the eastern and western sides, with substantial rupture in the northwest corner and displacements on the northern side. Comparing the data from the two measurement sets showed a significant difference in precision, highlighting the need for regular inspections to prevent premature erosion and avoid accidents.*
Keywords: *drone measurements, point cloud, ground control points (GCP), errors, precision, pillar*

1. Introduction

Monitoring mining pillars in salt mines is crucial for detecting exfoliations, cracks, and plastic deformations caused by internal pressures [1]. This monitoring is essential to prevent mining accidents and ensure the structural stability of the entire complex. To effectively address any reductions in pillar overlap due to these issues, measurements should be performed at least semiannually or annually.

At Salina Ocna Dej, however, these measurements have traditionally been carried out only once a year or every two years. The introduction of drone technology for these measurements represents a significant advancement for this mine and is relatively new in Romania [2]. The initial use of drone technology for this purpose was conducted in 2020, followed by a subsequent measurement in 2024. This approach not only enhances the accuracy of the data collected but also improves the ability to monitor changes over time more effectively.

2. Flight plan

The DJI Phantom 4 Pro Plus drone was used, adapted for operation in underground environments where satellite systems and internet access are unavailable [3]. Due to these constraints, measurements cannot be performed as they are on the surface. Predefined flight paths could not be selected due to the small distance between mining pillars and the very low flight altitude, ranging between 4 and 7 meters. During the 2020 measurements, at altitudes between 5 and 7 meters, there was a high intensity of air currents within the mine, complicating the drone's maneuverability and requiring increased caution to avoid collisions that could

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damage the drone. Despite these challenges, there were two incidents where the drone collided with a mining pillar, resulting in damage to the propellers. Although the propellers were rendered unusable, the other components of the drone remained unaffected.

Due to the intense air currents, five batteries were fully utilized, resulting in a total flight time of approximately one and a half hours, with an actual working time underground of about three hours. In 2024, the measurements were much easier to conduct, as the air current intensity was significantly lower than in 2020. At an altitude of 6-7 meters, the drone was successfully maneuvered around the upper edges of the mining pillars without incidents similar to those in the 2020 flight.

Given the reduced air current intensity, the 2024 measurements were carried out using only two batteries, with a flight duration of approximately 35 minutes.

On-site, four square reference markers, established by the institution, were installed to obtain coordinates and altitudes. These markers, positioned over the topographical benchmarks in the mine, were visible in the drone's images and were essential for image post-processing.

Before each use, the drone underwent pre-flight checks and cleaning to ensure the proper functioning of all sensors, preventing operational errors that could endanger nearby personnel. Due to the dim lighting provided by flashlights and LED projectors, only the camera's protective filter was mounted on the drone to capture as much necessary information for subsequent processing. However, some images showed burnt areas when the drone flew toward the light source. This was unavoidable as no option has yet been developed for mounting on the drone to provide diffuse lighting with an intensity of at least 600 lumens, measured 6-8 meters from the drone, to prevent burnt areas in images and ensure proper functioning of proximity sensors.

3. Post-processing of data

The data processing was largely carried out in the same manner as the previous case study. However, the following modifications were made:

During the image alignment stage, a significantly larger number of key points and tie points were selected due to the low lighting conditions and the visible chromatic aberration in the images, as well as pixelation in certain cases (see Fig.1).

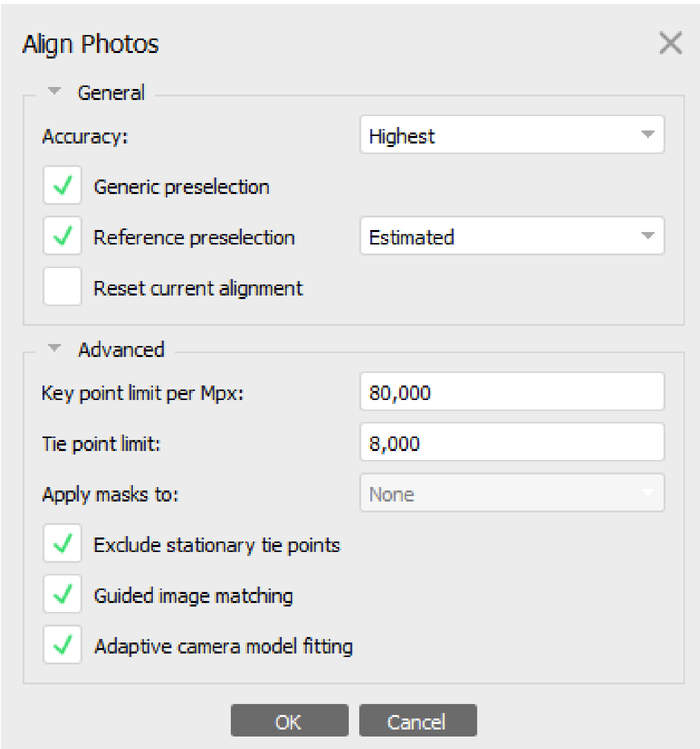

Fig. 1. Image Alignment Settings

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To ensure the accuracy of the 3D model, an error minimization technique using bundle adjustment was employed [4]. This method involves minimizing the differences between observed points and projected points, thereby enhancing the precision of the reconstructed model.

$$E = \sum_{i=1}^{N} [(x_i - \hat{x_i})^2 + (y_i - \hat{y_i})^2] \tag{1}$$

where:

E - is the total error function

(xi,yi) are the observed point coordinates

((x_i) ̂, (y_i) ̂) are the projected point coordinates

This is done using optimization algorithms, such as the Least Squares Method, to adjust projection and rotation parameters. Altitude adjustment was not performed in the altitude adjustment program because, underground, the drone does not have access to satellite systems and, therefore, the program installed on the control remote cannot detect the flying altitude. At best, the altitude in the EXIF data of the captured images only reflects the last known altitude of the drone.

After each adjustment of the GCP positions in the images, image alignment optimization was repeated. This process allowed for the reduction of errors associated with the GCPs and the entire point cloud. Although this process is very detailed, if the project does not require millimeter precision, repeated adjustments are not justified; that is, it is not necessary to adjust each GCP in the relevant images pixel by pixel.

The point cloud was generated through the 3D reconstruction of points from the aligned images. This forms the basis for the 3D model of the studied surface.

$$P = K \cdot R \cdot (X - C) \tag{2}$$

where:

P - represents the set of projected points.

X - represents the set of points in the real-world coordinate system.

C - represents the set of camera coordinates.

At first glance, the generated point clouds contain between 49 and 149 million points, which is enormous, as shown in Figure 2.

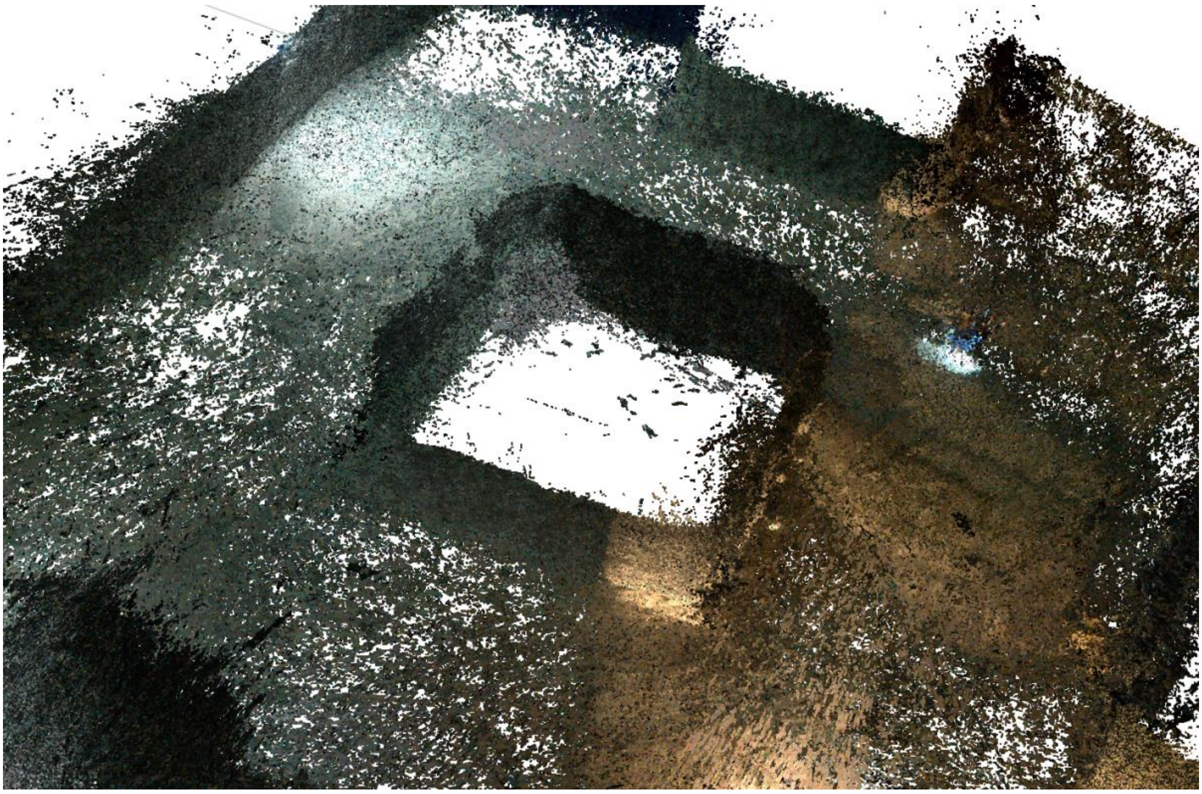

Fig.2. Pointcloud

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Surface modeling and interpolation are performed to create a continuous representation of the studied surface. Interpolation algorithms, such as linear interpolation or kriging, are used to estimate unknown values between the measured points [5].

$$Z(x, y) = \sum_{i=1}^{N} \lambda_i \cdot Z_i \quad (3)$$

where:
Z(x,y) is the interpolated value at the point (x,y)
λi are the interpolation coefficient
Zi are the measured values of the points

During data processing, there were situations where the thickness of the contour of the mining pillar was excessive in some cases. Subsequent analysis revealed that some images had incorrectly placed GCPs (Ground Control Points) on the specified markers, leading to a phenomenon known as "lamination" or "exfoliation" of the point cloud. This phenomenon occurs when the quality of the photos used to generate the point cloud varies significantly. In areas where high-quality images were used, the point cloud was precise and well-defined. Conversely, images that were not correctly aligned for various reasons led to a decrease in the overall accuracy of the point cloud. This caused misalignments, aberrations, and dislocations of points relative to their correct positions in the final point cloud, as the post-processing software failed to correctly identify their positions. These issues required careful review and additional adjustments to ensure optimal accuracy in the final data obtained. (Fig. 3)

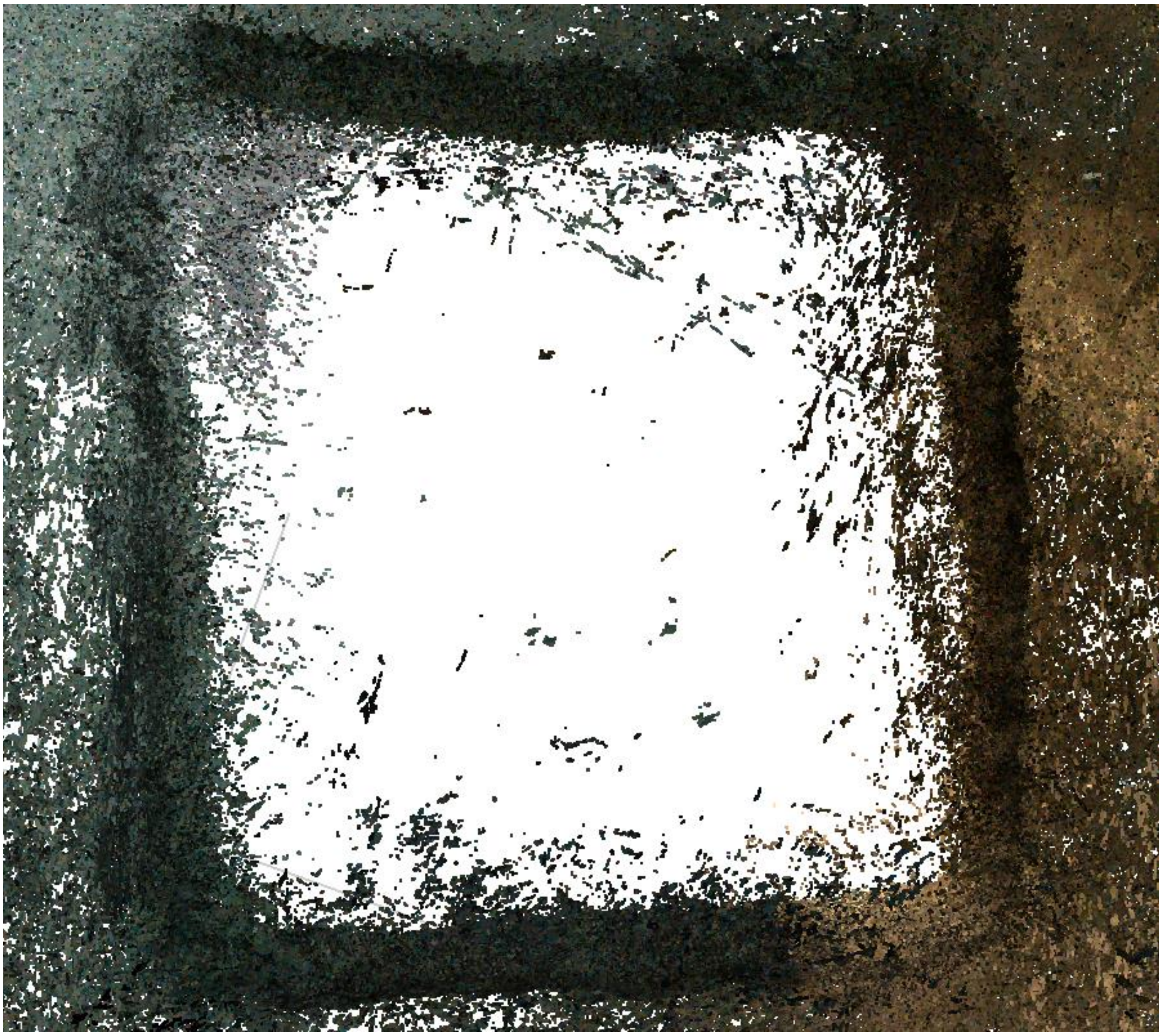

Fig. 3. Exfoliation of points in the unfiltered point cloud

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All irrelevant areas were removed, and the point cloud was cleaned using the filtering function available in the processing software. After applying these filters, the volume of the point cloud decreased significantly, reaching approximately 1.9 to 3.6 million points, with a “thickness” of the mining pillar contour of 5 to 10 mm. The elevation module was activated on the point cloud to verify the height of the mining pillar. Compared to 2020, in 2024, the generated point cloud extends up to the gallery ceiling, due to the reduced fluctuation and intensity of the airflow, which facilitated easier drone flight. (Fig. 4 and Fig. 5)

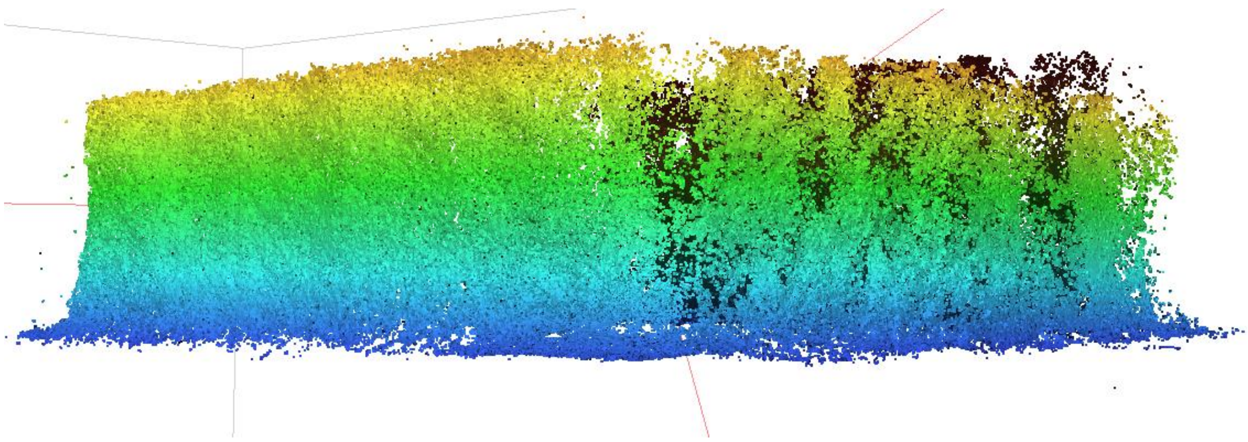

Fig. 4. Filtered point cloud 2020 (S-E corner view)

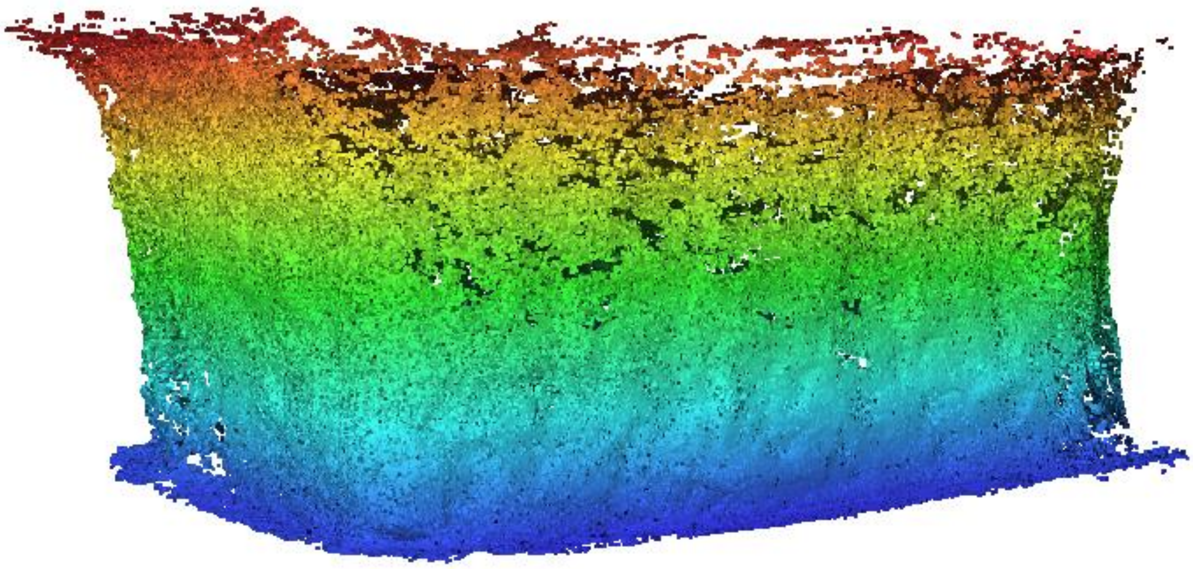

Fig. 5. Filtered point cloud 2024 (S-E corner view)

To verify the conformity and accuracy of the data in Metashape, processing verification reports were generated. These reports contain relevant information such as the camera position on the drone during aerial photography, the required overlap of images for correct point cloud generation, and the evaluation of GCP errors after updating the data according to imposed constraints. In our case, the camera rotation was not a relevant variable since the camera was fixed in a single position.

Based on the camera locations, the propagated errors are zero in both cases, as shown in Figure 6. The image overlap for proper alignment and compliance with the requirements was excellent. The propagated errors on the point cloud and 3D model show a slight difference: the point cloud from 2020 has an error of -2 mm on the top left to bottom right diagonal and +2 mm on the top right to bottom left diagonal (Fig. 7). In 2024, the propagated errors on the point cloud and 3D model are +4.8 µm on the top left to bottom right diagonal and -4.8 µm on the top right to bottom left diagonal (Fig. 8).

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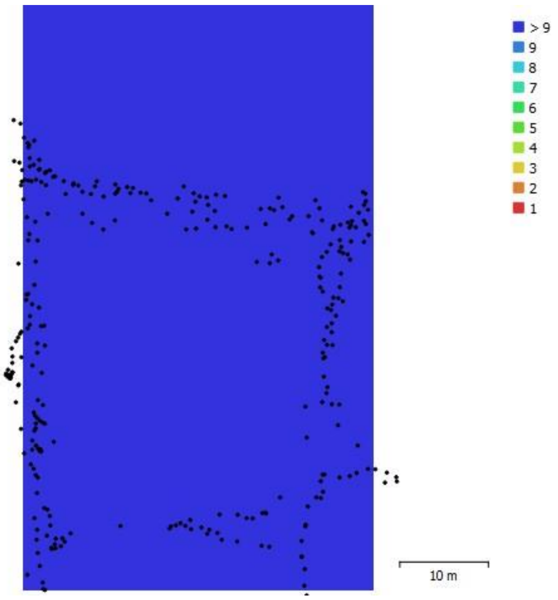

Fig.6. Report with Image Location and Overlap 2024

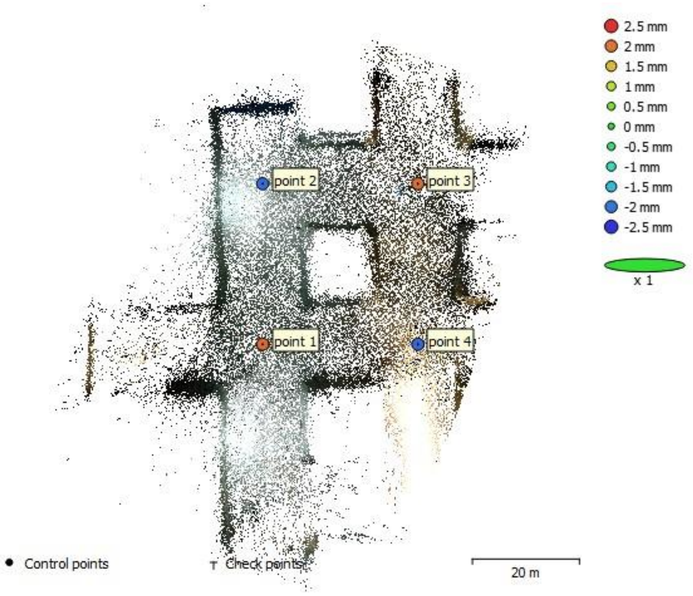

Fig.7. Propagated Errors on the Point Cloud with GCPs 2020

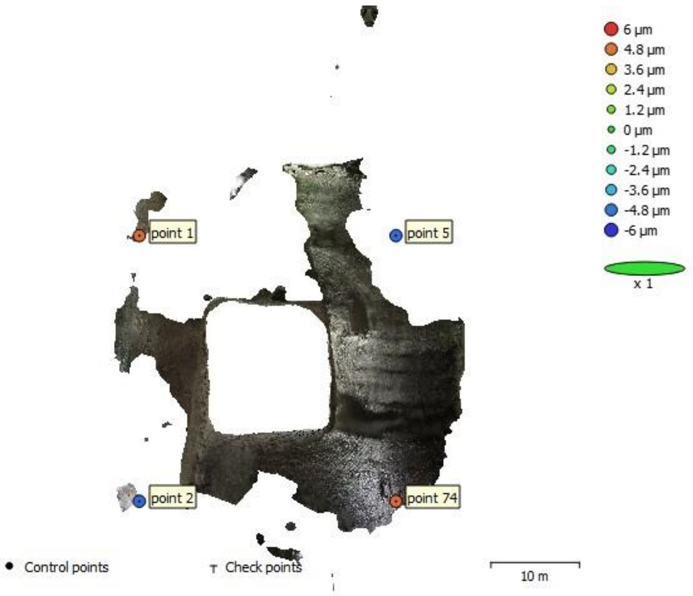

Fig.8. Propagated Errors on the Point Cloud with GCPs 2024

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The data generated based on the reports provide an initial confirmation of the correctness of the process and procedures, and implicitly the results obtained. The difference in precision between the two point clouds, namely ±2 mm in the initial measurements and ±4.8 μm in the 2024 measurements, is significant and cannot be overlooked under these conditions.

After generating and filtering the point clouds, they were exported in the Cloud Optimized LAZ format (.copc.laz) to be uploaded into Autodesk Recap Pro. Within this program, the point clouds were converted from the .copc.laz format to the .rcs format, which is recognized by AutoCAD. This allowed for the effective verification of changes over time to the mining pillar by comparing the data obtained from the two measurement sets.

4. Generating Sections and Data Verification

The point clouds were imported into AutoCAD Civil 3D using the POINTCLOUDATTACH command, with each dataset placed on separate layers [6]. These point clouds were aligned according to the fixed local coordinates specified in the .rcs files.

The process began by creating a horizontal section of the mining pillar using the SECTIONPLANE command. The elevations at which the horizontal section was to be made were established, and the desired section thickness was specified. (Fig.9. and Fig.10.)

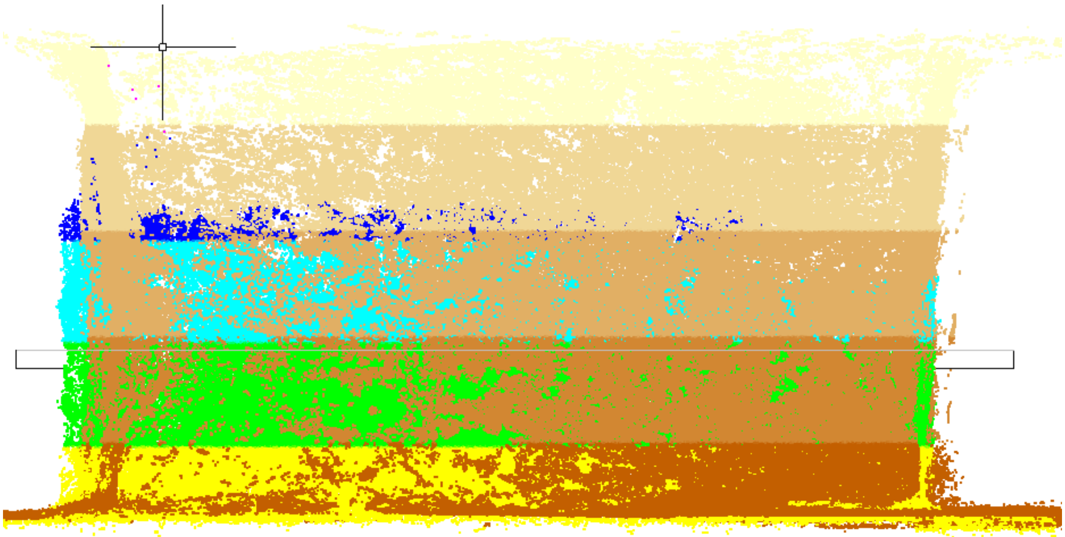

Fig.9. Side View - Point Clouds Where the Section is Made

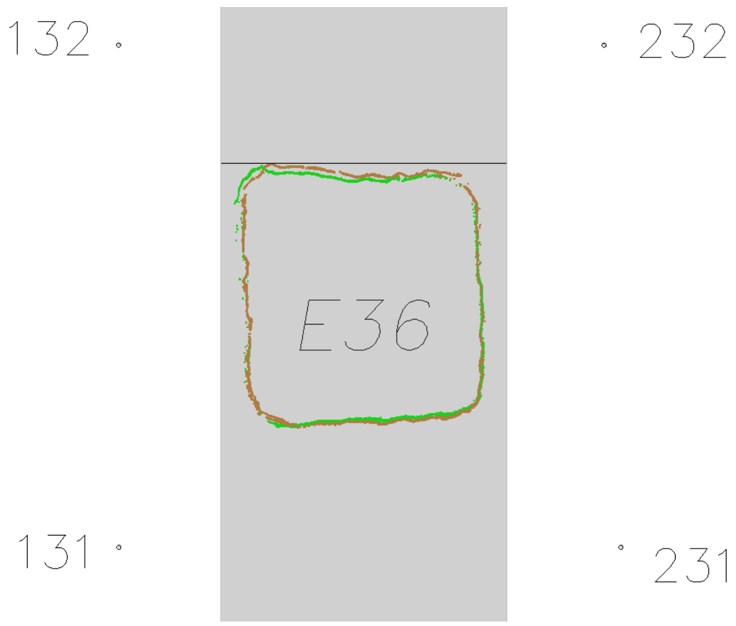

Fig.10. Cross-Section of Point Clouds from 2020 and 2024

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Horizontal sections were created at various elevations: 158m, 159m, 160m, 161m, and 161.5m. Sections above these elevations were not performed because, at two of the sides, the 2020 measurements did not provide sufficient information to generate a complete point cloud up to the gallery ceiling, as mentioned in the introduction of this case study.

Based on the horizontal sections, with a thickness varying between 0.10 and 0.50m, a contour was created using a polyline. This allowed for precise identification of changes over time to the mining pillar.

5. Data interpretation

The sections previously created provided the basis for outlining the interior contours, which allowed for precise visualization of the changes over time [7]. The blue line represents the interior contour of the pillar from the 2020 point cloud, while the red line represents the interior contour of the mining pillar from the 2024 point cloud, as shown in Figure 11.

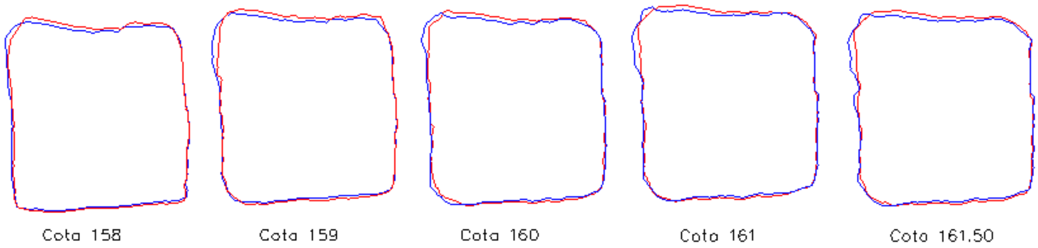

Fig.11. Overlay of Horizontal Section Contours 2020-2024

To verify the pillar's contour and section against the database held by the salt mine, the three contours were overlaid at the 158m elevation: the contour from the mine, obtained using a total station or theodolite, and the two contours derived from drone measurements processed into point clouds.

It is observed that the position of the mining pillar is generally consistent with that in the mine's archive, but there are differences in its shape, reflecting deformations that have occurred over the past four years. The brown line represents the E36 pillar contour according to the coordinates specified by Salina Ocna Dej. This is overlaid on the other two sections based on the 2020 and 2024 measurements, as shown in Figure 12.

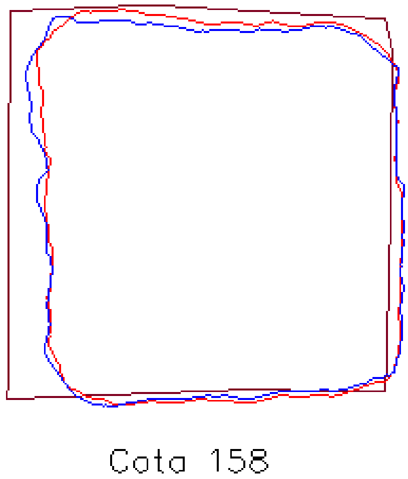

Fig.12. Overlay of Horizontal Section Contours 2020-2024 vs. Mine Archive

6. Conclusions

Based on the above points, the following conclusions can be drawn:

- Enhanced Detail with Drone Measurements: Traditional measurement equipment cannot match the level of detail provided by drone-based measurements and the generated point cloud. The advanced technology of drones offers a more comprehensive and precise depiction of mining pillars.

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- Efficient and Precise Surface Analysis: Differences in the surface area of the mining pillar, as illustrated in tabular form, are detected more quickly, easily, and accurately using drone measurements compared to alternative methods. (See Table 1.)

Table 1. Overlap of Horizontal Section Contours: 2020-2024 vs. Historical Archive

The elevation at which the section was made (m)	**Year of UAV measurements**	
	2020	**2024**
	Measured area per section (m²)	
158.00	199.088	200.872
159.00	198.180	201.454
160.00	198.564	199.796
161.00	201.593	202.754
161.50	200.940	202.330

- Significant Deformations Observed: The measurements indicate substantial exfoliation and degradation on the eastern and western sides of the mining pillar. This highlights the effectiveness of drone technology in detecting such structural changes.
- Notable Damage in the Northwest Corner: A more pronounced rupture was observed in the northwest corner of the pillar, emphasizing the importance of detailed analysis in identifying critical areas of damage.
- Displacement on the Northern Side: The northern side of the pillar shows notable displacement due to cracks that have developed over time, leading to plastic deformation of the structure.
- Need for Regular Inspections: Observations, measurements, and checks underscore the necessity for increased vigilance. Regular inspections, at least annually, are crucial for addressing premature erosion and preventing potential mining accidents [8]. Ensuring ongoing monitoring and maintenance will help maintain the structural integrity of the mining pillars.

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INFLUENCE OF MEASUREMENT ERRORS ON UNDERGROUND TOPOGRAPHIC BASES

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Abstract: *Underground topographic bases are of particular importance in the design and management of underground mining works. They can be dependent on the geodetic and topographic system on the surface, but they can also be independent in relation to a particular reference system. In the case of dependent topographic bases, it is preferable, from the point of view of the precisions required for the drawing of mining works in safe conditions, that they are related to two points known by their x, y (fixed) coordinates. The quantities measured in such situations are angles and distances. Measurement errors are transmitted to the determined quantities and consequently it is necessary to analyze the factors with which such a process can be evaluated. The necessary scientific approach is presented below.*
Keywords: *mining surveying, topographic underground networks, errors, topographic measurements*

1. Content of the paper

It is considered the underground topographic base consisting of a polygonal route supported at the ends (fig. 1) [1].

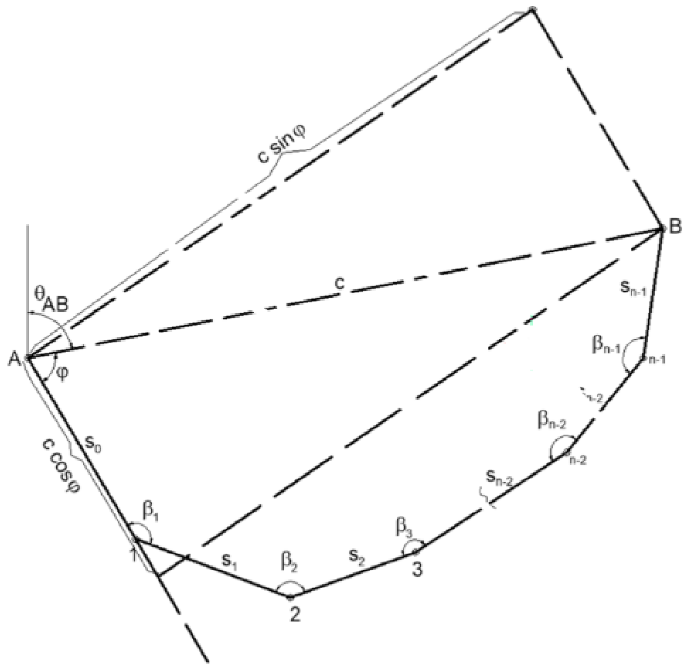

Fig.1. Polygonal route supported at the ends

The topographic base is formed at the level of an open horizon by two vertical wells on which the transmission of coordinates is carried out by the mechanical method [2].

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The resolution of the polygony is carried out using:
The coordinates x_A, y_A, and x_B, y_B of points A and B, as given quantities.

$\beta_1, \beta_2 \dots\dots\dots \beta_{n-1,} s_0, s_1 \dots\dots\dots s_{n-1,}$ as measured quantities

The coordinates of the point $B(x_B', y_B')$ are determined with the equalities:

$$x_B' = x_A + s_0 \cos\theta_1 + s_1 \cos\theta_2 + \cdots s_{n-1} \cos\theta_n \qquad (1)$$
$$y_B' = y_A + s_0 \sin\theta_1 + s_1 \sin\theta_2 + \cdots s_{n-1} \sin\theta_n$$

The orientations of the sides are:

$$\theta_1 = \theta_{AB} + \varphi \qquad \overline{\beta_1} = \beta_1$$
$$\theta_2 = \theta_{AB} + \varphi + \overline{\beta_1} \qquad \overline{\beta_2} = \beta_1 + \beta_2 \qquad (2)$$
……………………………………………………..
$$\theta_n = \theta_{AB} + \varphi + \overline{\beta}_{n-1} \qquad \theta_n = [\beta]$$

The first tie of (1) is developed in the Taylor series and the following are obtained:

$$x_B' = x_B + \frac{\partial x_B'}{\partial x_A} v_{x_A} + \frac{\partial x_B'}{\partial \beta_1} v_{\beta_1} + \frac{\partial x_B'}{\partial \beta_2} v_{\beta_2} + \cdots + \frac{\partial x_B'}{\partial \beta_{n-1}} v_{\beta_{n-1}} + \frac{\partial x_B'}{\partial s_1} v_{s_1} + \qquad (3)$$
$$+ \frac{\partial x_B'}{\partial s_2} v_{s_2} + \cdots + \frac{\partial x_B'}{\partial s_n} v_{s_n}$$

calculated:

$x_B - x_B' = fx$ not closing on x at point B.

but:

$$\frac{\partial x_B'}{\partial x_A} = 0$$

and then:

$$\frac{\partial x_B'}{\partial \beta_1} v_{\beta_1} + \frac{\partial x_B'}{\partial \beta_2} v_{\beta_2} \dots + \frac{\partial x_B'}{\partial \beta_{n-1}} v_{\beta_{n-1}} + \frac{\partial x_B'}{\partial s_1} v_{s_1} + \qquad (4)$$
$$+ \frac{\partial x_B'}{\partial s_2} v_{s_2} + \cdots + \frac{\partial x_B'}{\partial s_n} v_{s_n} + f_x = 0$$

similarly:

$$\frac{\partial y_B'}{\partial \beta_1} v_{\beta_1} + \frac{\partial y_B'}{\partial \beta_2} v_{\beta_2} + \cdots + \frac{\partial y_B'}{\partial s_1} v_{s_1} + \frac{\partial y_B'}{\partial s_2} v_{s_2} + \cdots + f_y = 0 \qquad (5)$$
$$f_y = y_B - y_B'$$

On the other hand, it can be written:

$$\frac{\partial x_B'}{\partial \beta_1} = -s_1 \sin\theta_1 \frac{\partial \theta_1}{\partial \beta_1} - s_2 \sin\theta_2 \frac{\partial \theta_2}{\partial \beta_1} - \cdots - s_n \sin\theta_n \frac{\partial \theta_n}{\partial \beta_1}$$
$$\frac{\partial x_B'}{\partial \beta_2} = -s_1 \sin\theta_1 \frac{\partial \theta_1}{\partial \beta_2} - s_2 \sin\theta_2 \frac{\partial \theta_2}{\partial \beta_2} - \cdots - s_n \sin\theta_n \frac{\partial \theta_n}{\partial \beta_2} \qquad (6)$$
………………………………………………………………
$$\frac{\partial x_B'}{\partial \beta_{n-1}} = -s_1 \sin\theta_1 \frac{\partial \theta_1}{\partial \beta_{n-1}} - s_2 \sin\theta_2 \frac{\partial \theta_2}{\partial \beta_{n-1}} - \cdots - s_n \sin\theta_n \frac{\partial \theta_n}{\partial \beta_{n-1}}$$

But, each orientation also depends on the distances measured, as a result we can write:

$$\frac{\partial x_B'}{\partial s_1} = -s_1 \sin\theta_1 \frac{\partial \theta_1}{\partial s_1} - s_2 \sin\theta_2 \frac{\partial \theta_2}{\partial s_1} - \cdots - s_n \sin\theta_n \frac{\partial \theta_n}{\partial s_1}$$
……………………………………………………………………… (7)
$$\frac{\partial x_B'}{\partial s_n} = -s_1 \sin\theta_1 \frac{\partial \theta_1}{\partial s_n} - s_2 \sin\theta_2 \frac{\partial \theta_2}{\partial s_n} - \cdots - s_n \sin\theta_n \frac{\partial \theta_n}{\partial s_n}$$

The orientation of one side is:

$$\theta = \theta_{AB} + \varphi + \bar{\beta}$$

and then:

$$\frac{\partial\theta}{\partial\beta} = \frac{\partial\theta_{AB}}{\partial\beta} + \frac{\partial\varphi}{\partial\beta} + \frac{\partial\bar{\beta}}{\partial\beta} \quad (8)$$

$$\frac{\partial\theta}{\partial s} = \frac{\partial\theta_{AB}}{\partial s} + \frac{\partial\varphi}{\partial s} + \frac{\partial\bar{\beta}}{\partial s}$$

it is noted that:

$$\frac{\partial\theta_{AB}}{\partial\beta} = \frac{\partial\theta_{AB}}{\partial s} = 0 \quad (9)$$

Because the orientation in the general system does not depend on the angles and distances measured, as a result:

$$\frac{\partial\theta}{\partial\beta} = \frac{\partial\varphi}{\partial\beta} + \frac{\partial\bar{\beta}}{\partial\beta}$$

$$\frac{\partial\theta}{\partial s} = \frac{\partial\varphi}{\partial s} + \frac{\partial\bar{\beta}}{\partial s} \quad (10)$$

also:

$$\frac{\partial\beta}{\partial s} = 0$$

$$\frac{\partial\bar{\beta}}{\partial s} = 1 \quad (11)$$

as a result:

$$\frac{\partial\theta}{\partial\beta} = 1 + \frac{\partial e}{\partial\beta} \quad (12)$$

$$\frac{\partial\theta}{\partial s} = \frac{\partial e}{\partial s}$$

From figure (1) it can be seen that we can write:

$$tg\varphi = \frac{c\sin\varphi}{c\cos\varphi} = \frac{s_1\sin\bar{\beta}_1 - s_2\sin\bar{\beta}_2 + s_3\sin\bar{\beta}_3 \ldots}{s_0 - s_1\cos\bar{\beta}_1 + s_2\cos\bar{\beta}_2 - s_3\cos\bar{\beta}_3 + \cdots} = \frac{N}{n} \quad (13)$$

Differentiate the relationship (13) and obtain:

$$\frac{1}{cos^{\,2}\varphi}d\varphi = \frac{Ndn - ndN}{n^2} = \frac{c\sin\varphi dn - \cos\varphi dN}{c^2 cos^2\varphi}$$

or:

$$cd\varphi = \sin\varphi\, dn - \cos\varphi dN \quad (14)$$

We switch from differential to derivative and obtain:

$$c\frac{\partial f}{\partial\beta} = \sin\varphi\frac{\partial n}{\partial\beta} - \cos\varphi\frac{\partial N}{\partial\beta} \quad (15)$$

but:

$$\frac{\partial n}{\partial\beta} = s_1\sin\bar{\beta}_1 - s_2\sin\bar{\beta}_2 + s_3\sin\bar{\beta}_3 \ldots = R\sin\bar{\beta} \quad (16)$$

and:

$$\frac{\partial N}{\partial\beta} = s_1\cos\bar{\beta}_1 - s_2\cos\bar{\beta}_2 + s_3\cos\bar{\beta}_3 \ldots = R\cos\bar{\beta} \quad (17)$$

as such:

$$c\frac{\partial\varphi}{\partial\beta} = -\mathrm{R}\left(\cos\varphi\cos\bar{\beta} - \sin\varphi\sin\bar{\beta}\right) = -R\cos\left(\varphi + \bar{\beta}\right)$$

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and:

$$\frac{\partial\varphi}{\partial\beta} = -\frac{R\cos(\varphi+\bar{\beta})}{c} = -\frac{R^{'}}{c} \tag{18}$$

Substituting in (12) yields:

$$\frac{\partial\theta}{\partial\beta} = 1 - \frac{R^{'}}{c} \tag{19}$$

By applying all derivatives, it results [3]:

$$\frac{\partial\theta_1}{\partial\beta_1} = \frac{\partial\varphi}{\partial\beta_1} = -\frac{R_1^{'}}{c}$$
$$\frac{\partial\theta_2}{\partial\beta_2} = \frac{\partial\varphi}{\partial\beta_1} + \frac{\partial\bar{\beta}_1}{\partial\beta_1} = 1 - \frac{R_1^{'}}{c} = \frac{\partial\theta_3}{\partial\beta_1} = \frac{\partial\theta_3}{\partial\beta_1} = \cdots = \frac{\partial\theta_n}{\partial\beta_1}$$

$$\frac{\partial\theta_1}{\partial\beta_2} = \frac{\partial\varphi}{\partial\beta_2} = -\frac{R_2^{'}}{c} = \frac{\partial\theta_2}{\partial\beta_2} \tag{20}$$

$$\frac{\partial\theta_3}{\partial\beta_2} = \frac{\partial\varphi}{\partial\beta_2} + \frac{\partial\bar{\beta}_2}{\partial\beta_2} = 1 - \frac{R_2^{'}}{c} = \frac{\partial\theta_4}{\partial\beta_2} = \cdots = \frac{\partial\theta_n}{\partial\beta_2}$$
…………………………………………………..
$$\frac{\partial\theta_n}{\partial\beta_{n-1}} = -\frac{R_{n-1}^{'}}{c} = \frac{\partial\theta_2}{\partial\beta_{n-1}} = \frac{\partial\theta_3}{\partial\beta_{n-1}} = \cdots = \frac{\partial\theta_{n-1}}{\partial\beta_{n-1}}$$

For distances, from (14) by switching to derivatives we have:

$$c\,\frac{\partial\varphi}{\partial s} = \sin\varphi\,\frac{\partial n}{\partial s} - \cos\varphi\,\frac{\partial N}{\partial s} \tag{21}$$

but how:

$$n = s_0 - s_1\cos\bar{\beta}_1 + s_2\cos\bar{\beta}_2 - s_3\cos\bar{\beta}_3 + \cdots$$

it results:

$$\frac{\partial n}{\partial s_0} = 1;\ \frac{\partial n}{\partial s_1} = -\cos\bar{\beta}_1;\ \frac{\partial n}{\partial s_2} = -cos\bar{\beta}_2\ ... \tag{22}$$

The minus sign is due to the belonging of the orientation to different dials.

Also:

$$N = s_1\sin\bar{\beta}_1 - s_2\sin\bar{\beta}_2 - s_3\sin\bar{\beta}_3\ ...$$

and:

$$\frac{\partial N}{\partial s_0} = 0;\ \frac{\partial N}{\partial s_1} = \sin\bar{\beta}_1\,;\ \frac{\partial N}{\partial s_2} = -\sin\bar{\beta}_2\ ... \tag{23}$$

Replacing with (21) yields:

$$c\,\frac{\partial\varphi}{\partial s_0} = \sin\varphi\cdot 1 - \cos\varphi\cdot 0 = \sin\varphi$$

and:

$$\frac{\partial\varphi}{s_0} = \frac{1}{c}\sin\varphi \tag{24}$$
$$c\,\frac{\partial e}{\partial s} = \sin\varphi\cos\bar{\beta} - \cos\varphi\sin\bar{\beta} = \sin(\varphi - \bar{\beta})$$
$$\frac{\partial\varphi}{\partial s} = \frac{1}{c}\sin(\varphi - \bar{\beta}) = \frac{1}{c}\sin\delta \tag{25}$$

δ – is the angle formed by the sides of the line and side "c"

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but:

$$\frac{\partial\theta}{\partial s}=\frac{\partial\varphi}{\partial s}$$

$$\frac{\partial\theta}{\partial s_0}=\frac{\partial\varphi}{\partial s_0}=\frac{1}{c}\sin\varphi \tag{26}$$

and:

$$\begin{aligned}
&\frac{\partial\theta_1}{\partial s_0}=\frac{1}{c}\sin\varphi=\frac{\partial\theta_2}{\partial s_0}=\frac{\partial\theta_3}{\partial s_0}=\dots=\frac{\partial\theta_n}{\partial s_0}\\
&\frac{\partial\theta_1}{\partial s_1}=\frac{1}{c}\sin\delta_1=\frac{\partial\theta_2}{\partial s_1}=\frac{\partial\theta_3}{\partial s_1}=\dots=\frac{\partial\theta_n}{\partial s_1}\\
&\frac{\partial\theta_1}{\partial s_2}=\frac{1}{c}\sin\delta_2=\frac{\partial\theta_2}{\partial s_2}=\frac{\partial\theta_3}{\partial s_2}=\dots=\frac{\partial\theta_n}{\partial s_2}\\
&\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\\
&\frac{\partial\theta_1}{\partial s_{n-1}}=\frac{1}{c}\sin\delta_{n-1}=\frac{\partial\theta_2}{\partial s_{n-1}}=\frac{\partial\theta_3}{\partial s_{n-1}}=\dots=\frac{\partial\theta_n}{\partial s_{n-1}}
\end{aligned} \tag{27}$$

The system of error equations has the form:

$$\begin{aligned}
&\left[s_0\sin\theta_1\frac{R_1'}{c}-s_1\sin\theta_2\frac{R_1'}{c}-\dots-s_{n-1}\sin\theta_n\left(1-\frac{R_1'}{c}\right)\right]v_{\beta_1}+\\
&\left[s_0\sin\theta_1\frac{R_2'}{c}-s_1\sin\theta_2\frac{R_2'}{c}-s_2\sin\theta_3\frac{R_2'}{c}-\dots-s_{n-1}\sin\theta_n\left(1-\frac{R_2'}{c}\right)\right]v_{\beta_2}+\\
&+\dots+\left[s_0\frac{\sin\theta_{n-1}}{c}\right]+s_1\sin\theta_2\frac{\sin\theta_{n-1}}{c}+s_2\sin\theta_3\frac{\sin\theta_{n-1}}{c}+\\
&+\dots+s_{n-1}\sin\theta_n\frac{\sin\theta_{n-1}}{c}\Big]v_{s_{n-1}}+f_x=0
\end{aligned} \tag{28}$$

$$\left[\frac{y_B-y_A}{c}R_1'-(y_B-y_1)\right]v_{\beta_1}+\left[\frac{y_B-y_A}{c}R_2'-(y_3-y_2)\right]v_{\beta_2}\dots+\dots$$

$$\dots+\left[\frac{y_B-y_A}{c}R_{n-1}'-(y_B-y_{n-1})\right]v_{\beta_{n-1}}+\left[\cos\theta_1\frac{\sin\varphi}{c}+(y_B-y_A)\frac{\sin\delta_1}{c}\right]v_{s_0}+\dots$$

$$+\left[\cos\theta_2\frac{\sin\varphi}{c}+(y_B-y_A)\frac{\sin\delta_2}{c}\right]v_{s_1}+\dots+\left[\cos\theta_2\frac{\sin\varphi}{c}+(y_B-y_{n-1})\frac{\sin\delta_{n-1}}{c}\right]v_{s_{n-1}}+f_x=0$$

$$[R_1'\cos\theta_{AB}-(y_B-y_1)]v_{\beta_1}+[R_2'\cos\theta_{AB}-(y_B-y_2)]v_{\beta_2}+\dots+$$

$$\begin{aligned}
&+[R_{n-1}'\cos\theta_{AB}-(y_B-y_{n-1})]v_{\beta_{n-1}}+\frac{1}{c}[\cos\theta_1\ \sin\varphi+(y_B-y_A)\sin\delta_1]v_{s_0}+\\
&+\frac{1}{c}[\cos\theta_2\ \sin\varphi+(y_B-y_2)\sin\delta_1]v_{s_1}+\dots+\\
&+\frac{1}{c}[\cos\theta_n\ \sin\varphi+(y_B-y_{n-1})\sin\delta_{n-1}]v_{s_1}+f_x=0
\end{aligned}$$

It is noted:

$$R_1^y=R_1'\cos\theta_{AB}$$
$$\cos\theta_i=\sin\varphi\cos\theta_i$$

resulting:

$$\begin{aligned}
&[R_1^y-(y_B-y_1)]v_{\beta_1}+[R_2^y-(y_B-y_2)]v_{\beta_2}+\dots+\\
&+[R_{n-1}^y-(y_B-y_{n-1})]v_{\beta_{n-1}}+\frac{1}{c}[(\cos\theta_1+(y_B-y_1)]v_{s_0}+\\
&+[\cos'\theta_2+(y_B-y_2)]v_{s_1}+\dots+[\cos'\theta_n+(y_B-y_{n-1})v_{s_{n-1}}]+f_x=0
\end{aligned}$$

It is similarly applied on the y-axis.

Conclusions

The paper aims to make a complex analysis of the transmission of the errors of the measured quantities on the quantities determined in the independent simple polygonal routes.

The results of the analysis, which can be obtained analytically, but also graphically, pave the way for determining the accuracies after compensation of the determined quantities. For the tracing of underground works, such analyzes lead to safety in the achievement of objectives of major technical and financial importance.

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PROFESSIONAL WEB APPLICATION FOR LIDAR DATA VISUALIZATION AND METRIC INSPECTION

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Abstract: *Lidar data is difficult to access for regular users due to the very large memory volume required and the need to handle it with powerful computers and quite expensive specialized software. The presented web application is offered for free in the LidarTools version and at a low cost in the LidarMap version, which combines shape-type vector data with the Lidar point cloud. The application uses a POTREE structure adapted for rapid visualization functions but enhanced with functions for measuring in the point cloud (distances, areas), visualization functions, profile extraction, statistical functions, semi-automatic vectorization functions of linear objects (power lines), coordinate transformation functions, as well as other functions specific to users of such data. It is also presented here the project for stereo vectoring module in LidarMap application.*
Keywords: *Lidar, change detection, application, cloud points, data visualization*

1. Introduction

The most efficient solutions for developing complex scientific applications with point cloud data are based on the development environment around the open-source web application, POTREE. Following an in-depth analysis of the Potree working environment, a basic program was built on the Potree framework and using its function libraries, where we developed specific applications based on our own algorithms. Potree files are partitioned in an **octree** structure. All octree nodes, both intermediate and branches, contain a subsample of sparse points. The spacing defines the minimum distance between points in the root node. With each level, the distance is halved; for example, if the distance in the root is 1.0, then the distance in its children is 0.5. Rendering at a lower level of smaller nodes is done through a coarse representation of the point cloud.

This hierarchical structure helps manage and efficiently render very large datasets by subdividing the point cloud into a series of nested cubes.

Root Node: The entire point cloud is initially represented by a single root node, which covers the entire spatial extent of the data.

Subdivisions: The root node is recursively subdivided into eight smaller cubes (octants), each representing a smaller portion of the point cloud. This subdivision continues down the hierarchy, creating nodes at various levels of detail.

Leaf Nodes: The octree structure ends at the leaf nodes, which contain the actual point data. Each leaf node holds a subset of the point cloud, and these subsets are smaller and denser compared to nodes at higher levels. The more nodes loaded, the higher the quality. The figure below shows the content of the root and its children, as well as how the level of detail increases when rendered together

This structure is perfectly suited for visualizing large Lidar datasets, but data processing operations such as classification, filtering, and even data selection are difficult or impossible on such structures. Therefore, for manipulating, visualizing, and processing Lidar data, combined data structures should be used, and if we want to develop complex applications, we must be careful to choose programming environments, languages, and function libraries that are adapted to the objectives we aim to achieve. An application that we

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consider extremely useful for Lidar data users is one that allows us to extract 3D linear details useful for infrastructure project designers, for example. 3D mapping from Lidar data is accessible through complex and very expensive programs such as ORBIT GT (Orbit Geospatial Technologies) from Belgium, VisionLidar produced by Geo-Plus from Canada, or the most widespread on the market of applications that work with Lidar data, the set of applications from TerraSolid.

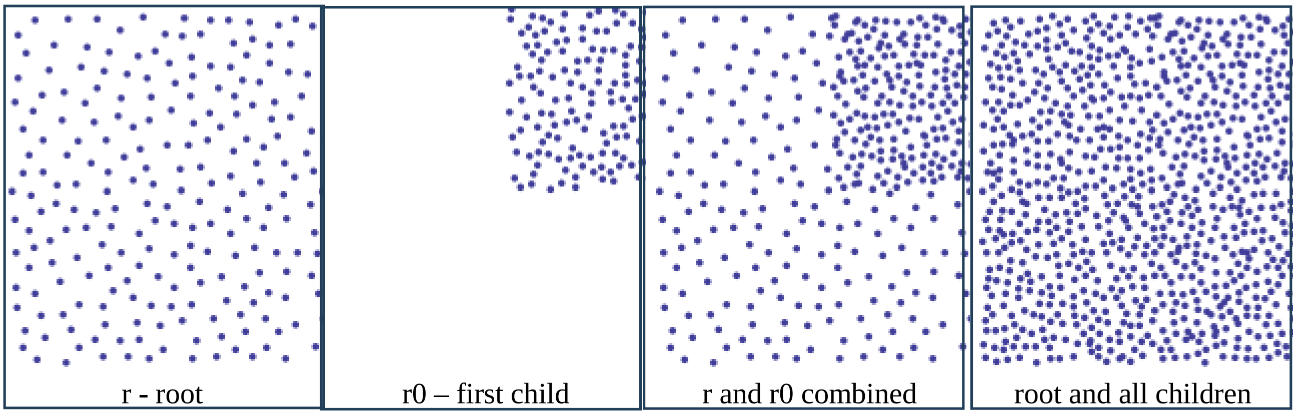

Fig. 1. OCTREE structure

Vectorization on the point cloud in these software tools is conceived as a semi-automatic procedure for drawing lines of slope change, for example, curb corners for sidewalks, or eaves edges for a roof. It involves drawing on a 3D model but viewed on a 2D screen. It should be emphasized that such vectorization cannot be more accurate than vectorization on a pair of stereoscopic images because the likelihood that the Lidar point cloud on which the vectorization is snapped to a point contains points exactly on the roof corner is almost zero. Figure 2 shows how, in a roof corner, the distribution of points is so random that there is no point that falls exactly at the mathematical corner of the roof.

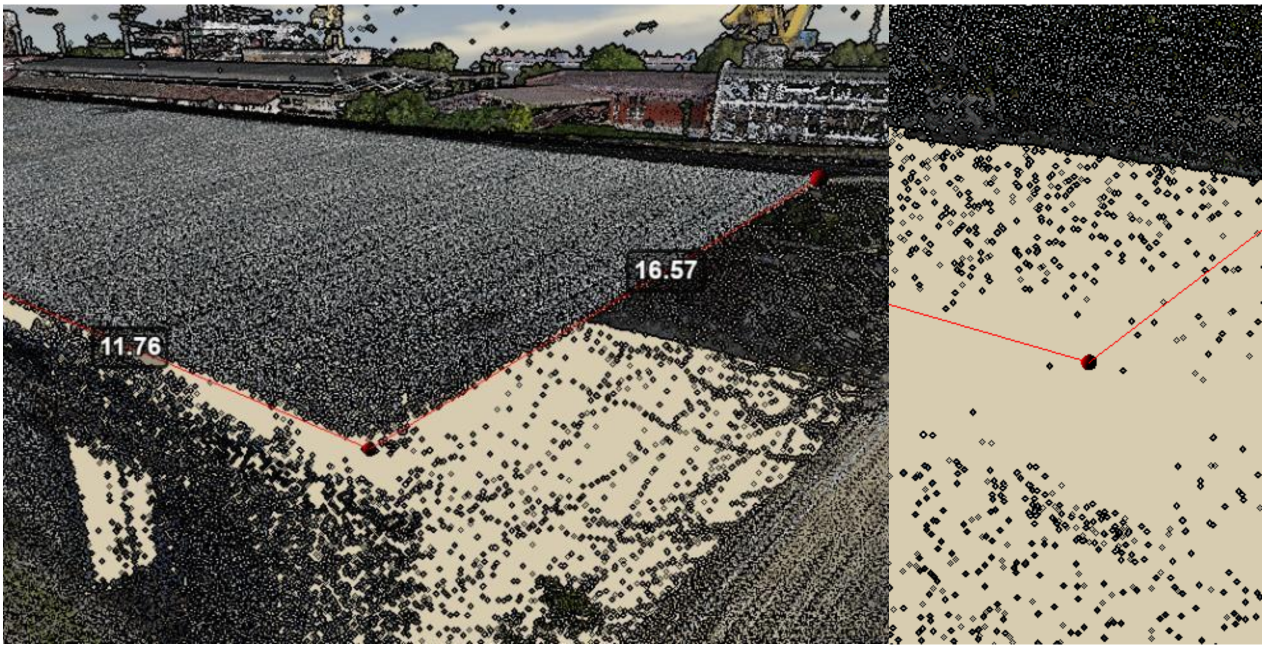

Fig. 2. 3D Vectoring using 2D screen with our LidarTools web application

In our ongoing efforts to extract linear information from Lidar point clouds, we have recurrently encountered a significant challenge: selecting the most optimally positioned point at a corner necessitated the exhaustive rotation of the point cloud in all possible orientations to ascertain the best solution. To mitigate the substantial time investment required for these vectorization processes, we identified the imperative need to develop a straightforward yet effective application, which we have designated as LidarMap. This tool facilitates stereoscopic vectorization within the point cloud, thereby achieving a level of precision commensurate with that of image-based vectorization. Moreover, stereoscopic vectorization within the point cloud affords the capability to dynamically alter the perspective, enabling the identification of the most precise point placement for details, including the building's footprint. This process is markedly more arduous when constrained to images, which are limited to a fixed nadir perspective.

For creating 3D stereo applications, OpenGL and the associated GLUT library is needed. It is assumed that the reader is both familiar with how to create the appropriate eye positions for comfortable stereo viewing and the reader has an OpenGL card and any associated hardware (eg: stereo monitors and associated 3D glasses).

2. Stereo viewing principle

We will explain here the basic principles of stereoscopic vision implemented through OpenGL and the associated libraries that we used in the development of the LidarMap application. It is good to know that the options are diverse and depend on the programming environment and the hardware used, but the principle of approaching stereoscopic vision is largely based on the similarity with human vision.

The most frequently used principle is based on the use of a monitor at least 120Hz frequency and which allows the alternative display of two perspectives corresponding to the 2 eyes at the frequency of 60Hz. Thus, the perspective of the left eye will alternate with the perspective of the right eye, creating the effect of depth, of stereoscopy on the screen for the viewer. This technique is known in OpenGL terminology as Quad Buffering. Another hard implementation is based on the use of a 4K monitor and the alternate display of perspectives on odd and even horizontal lines, the technology being called "interlaced". But the programmer working with OpenGL no longer has to take into account these technological aspects, the OpenGL routines and libraries recognize and apply the specific procedures transparently for the programmer.

The best implementation of the stereo view using OpenGL is the so called **off-axis method**, the correct one as is described by Paul Bourke in [1].

Camera (the eye) is defined by its position, view direction, up vector, eye separation, distance to zero parallax (figure 3) and the near and far cutting planes. Position, eye separation, zero parallax distance, and cutting planes are most conveniently specified in model coordinates, direction and up vector are orthonormal vectors. With regard to parameters for adjusting stereoscopic viewing we would argue that the distance to zero parallax is the most natural, not only does it relate directly to the scale of the model and the relative position of the camera, it also has a direct bearing on the stereoscopic result ... namely that objects at that distance will appear to be at the depth of the screen. In order not to burden the operators with multiple stereo controls one can usually just internally set the eye separation to 1/30 of the zero parallax distance (camera.eyesep = camera.fo / 30), this will give acceptable stereoscopic viewing in almost all situations and is independent of model scale.

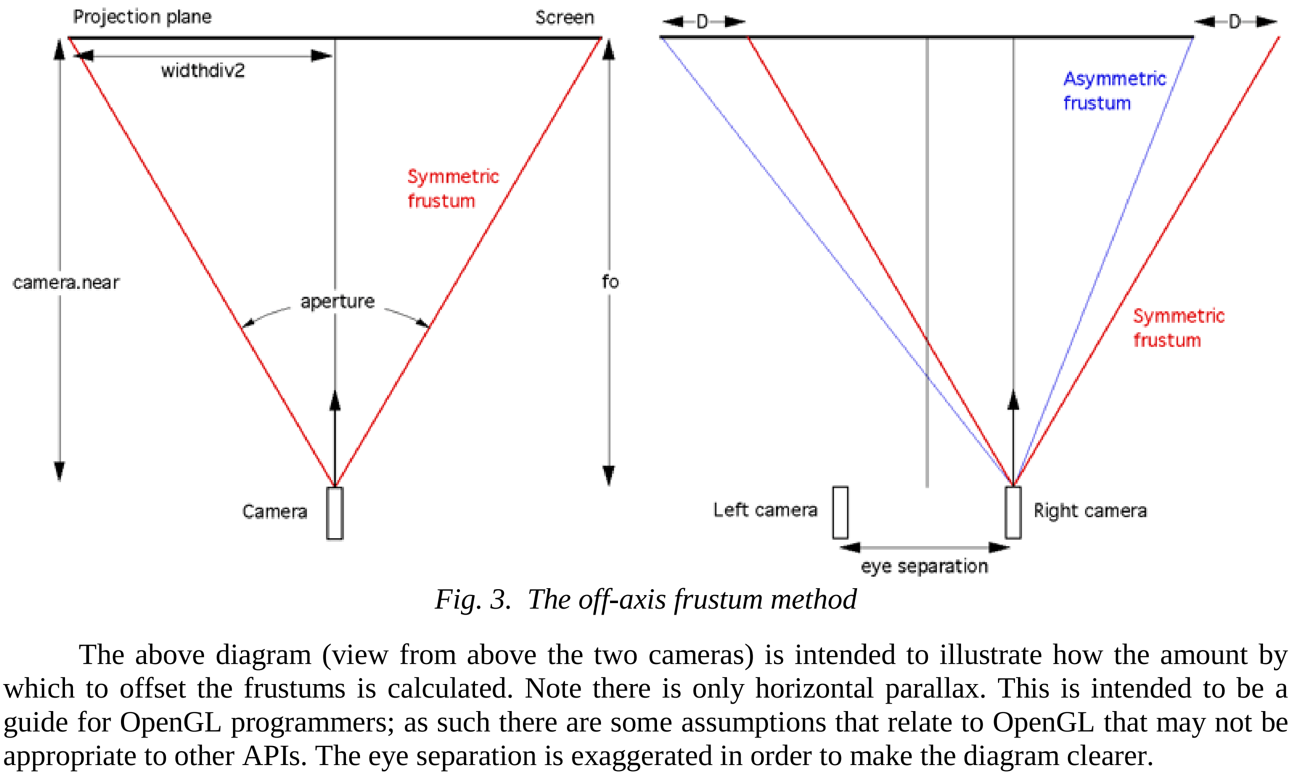

Fig. 3. The off-axis frustum method

The above diagram (view from above the two cameras) is intended to illustrate how the amount by which to offset the frustums is calculated. Note there is only horizontal parallax. This is intended to be a guide for OpenGL programmers; as such there are some assumptions that relate to OpenGL that may not be appropriate to other APIs. The eye separation is exaggerated in order to make the diagram clearer.

Another approach is Toe-in method (figure 4) where the camera has a fixed and symmetric aperture, each camera is pointed at a single focal point. Images created using the "toe-in" method will still appear stereoscopic but the vertical parallax it introduces will cause increased discomfort levels. To implement this, gluPerspective() function is used comparing with off-axis method where glFrustum() is used.

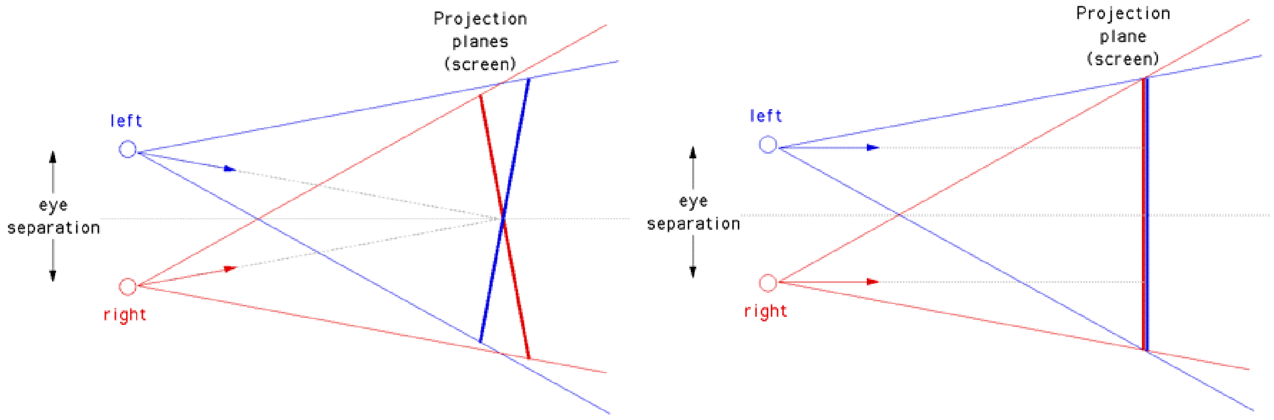

Fig. 4. The Toe-in method (left) versus off-axis frustum method (right)

As it was mentioned, to implement the correct method, glFrustum was used. To understand better the frustum concept, see figure 5, a perspective representation of the frustum which is in fact a truncated pyramid with the top cut off, creating a shape that has six planes: near, far, left, right, top, and bottom. These planes define the boundaries of what will be projected onto the screen from the 3D scene.

In perspective projection, objects further from the viewer appear smaller, mimicking how human vision works. OpenGL uses the frustum to determine which objects or parts of objects should be rendered based on their positions in 3D space.

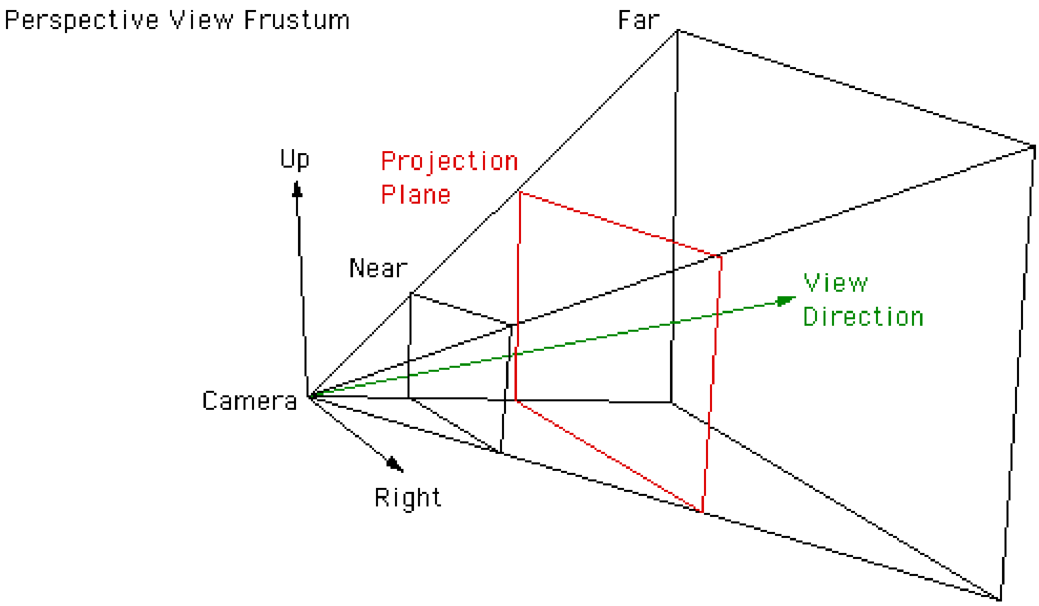

Fig. 5. The Perspective view of the frustum

Parameters of a Frustum

When defining a frustum in OpenGL, the following parameters should be specified:

- **Field of View (FoV):** The angle between the top and bottom planes (vertical FoV).
- **Aspect Ratio:** The ratio of the width to the height of the frustum, often matching the aspect ratio of the display or window.
- **Near Plane Distance:** The distance from the viewer to the near clipping plane.
- **Far Plane Distance:** The distance from the viewer to the far clipping plane.

In OpenGL, is possible to create a perspective frustum using functions like glFrustum (older OpenGL) or more commonly gluPerspective (part of the GLU library), see below:

```
#include <GL/glu.h>
// Set up a perspective projection matrix
void setupPerspective() {
        glMatrixMode(GL_PROJECTION);
        glLoadIdentity();
        gluPerspective(fovY, aspectRatio, nearPlane, farPlane);
        glMatrixMode(GL_MODELVIEW); }
}
```

where:

- **fovY:** Vertical field of view angle in degrees.
- **aspectRatio:** Aspect ratio of the viewport (width/height).
- **nearPlane:** Distance to the near clipping plane.
- **farPlane:** Distance to the far clipping plane.

The near plane is closer to the viewer, and objects between the near and far planes are rendered.
The far plane is further away, and objects beyond this plane are not rendered.
The left, right, top, and bottom planes define the field of view.

The frustum is crucial for determining visibility and culling. Only objects within the frustum are rendered, which improves performance by avoiding the rendering of objects outside the viewer's view.
Understanding and configuring the frustum correctly ensures that scenes are rendered realistically and efficiently, with the appropriate perspective that matches the intended view of the 3D world.

For the moment we succeed to implement these concepts in a test Python application for stereoviewing the cloud points representing Corvin Castle from Hunedoara town.

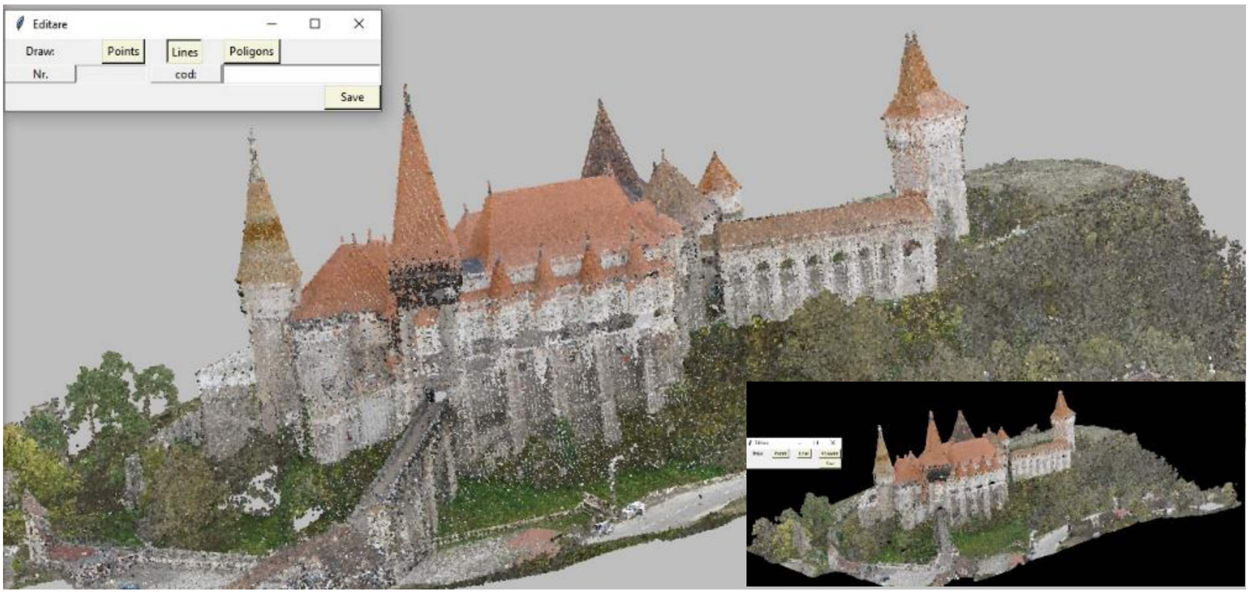

Fig. 6. 3D StereoView using a test Python application

In the image from figure 6, the data contains 20 million points, which Python loads in 4 seconds, then structures according to an octree in another 4 seconds, and subsequently works with only 460 thousand points. Unfortunately, in this this printscreen it is not possible to view both images to understand the stereoscopic view because the images are viewed alternately.

3. Best options for LidarMap development application

In order to create this test we analyze more possibilities to develop the LidarMap application.
First we had to choose the programming language from C++, Python and C#.

C++ is generally faster and offers better memory control compared to Python. And C#. For applications that require handling a large amount of data, such as LAS files with tens or hundreds of millions of points, C++ is a good choice.

C# is a high-level language that offers a balance between performance and ease of use. It provides good performance and better memory management than Python, thanks to its garbage collection mechanism. However, it typically does not match the raw performance and memory control of C++. C# is well-suited for applications that need a compromise between development productivity and performance.

Python is easier to use and offers increased productivity, but it may have lower performance for intensive processing and memory-consuming tasks. However, certain libraries such as Numpy and Pandas can help in this regard.

Looking to these characteristics we choose Python for the test application due to the rapid development but the final product will be developed in C++.

Very important in this development, was the choice for supporting Lidar data libraries. The most important are PCL (Point Cloud Library) and PDAL (Point Data Abstraction Library)

PCL provides a robust implementation of the octree, which is used for various operations such as nearest neighbor search, spatial segmentation, and point cloud compression.

PCL includes functionalities like OctreePointCloudSearch, OctreePointCloudCompression, and OctreePointCloudDensity, which can help to perform various operations on point clouds using the octree structure. Using the integrated structures, PCL offers a high level of trust in the implementation, as well as compatibility with other PCL components. It also saves from the complexity of developing and maintaining your own octree.

PDAL is more used for preprocessing and manipulating point clouds, with a focus on data flows and transformations. Although PDAL does not directly provide octree implementations for search or segmentation operations, PDAL may be used to manipulate and preprocess data before sending it to other libraries such as PCL.

PDAL excels in transformations, pipelines, and interoperability with other libraries and file formats. PDAL may be used to process data and then send it to PCL for octree-based operations.

The research for the best environment and libraries was very time consuming with a lot of tests. Here, below there are some results:

Characteristics	Python	C++	C#
Dev. Environment	Anaconda	Visual Studio	Visual Studio, Unity 3D
Support for OpenGL	pyOpenGL, GLFW	GLFW, GLM	OpenTK, GLFW<
Support for Lidar	PDAL, Laspy, PCL,pyproj, Rasterio, scipy, numpy	PCL, PDAL, VTK	PCL, HDF5, Potree
Performance top	3	1	2
Rapid development top	1	3	2

An important aspect for stereo view is that **PCLVisualizer**, part of the Point Cloud Library (PCL), is based on VTK (Visualization Toolkit), which uses OpenGL for 3D rendering. So, although PCLVisualizer uses OpenGL, options for stereoscopic rendering might be limited or require additional configuration, as most PCL implementations focus on traditional 3D rendering.

Stereoscopic Rendering Capability in PCLVisualizer VTK offers support for stereoscopic rendering, which can be enabled and configured for PCLVisualizer. However, the exact details of stereoscopic rendering may depend on the specific hardware and configuration. Stereoscopic rendering can be also useful for VR (Virtual Reality) or AR (Augmented Reality) applications, as well as for advanced 3D visualizations.

4. Conclusions and future development

In according with all these results we created 2 development environments, one for Python and one for C++. For Python, we use Anaconda and we add pygame and we import GLFW. Also, PDAL and PCL were installed through the commands: pip install pdal and pip install python-pcl or conda install -c sirokujira pcl through anaconda. Their use in Windows is done through the classical import pdal and import pcl commands respectively.

For C++ we installed PDAL and PCL through vcpkg preinstalled in Visual Studio. We used the commands: vcpkg install pdal and vcpkg install pcl. For anyone interested in such approach you have to know that the installation could take several tens of minutes up to hours.

Until now we succeed to test the main functionalities of the application, managing the lidar data, read and view in a decent period of time, the read of LAS file in 4,5 seconds for 20 millions of points and movements of the data like rotation, in real time.

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Next development will be to implement an intelligent 3D mouse cursor for vectoring [2] and to implement the user interface design presented in the figure no 7.

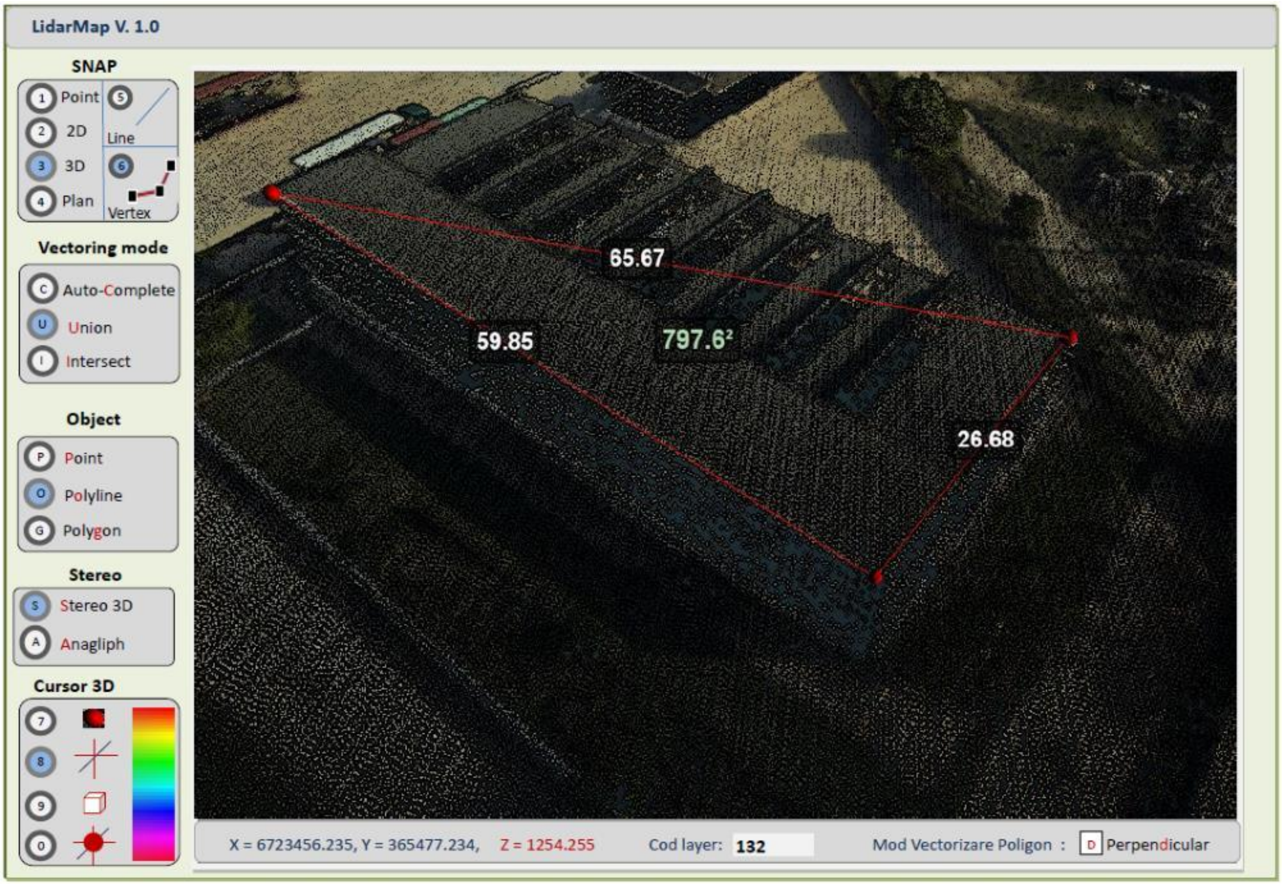

Fig. 7 LidarMap user interface design

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TECHNOLOGIES AND TECHNICAL MEANS FOR ELECTROSORPTION LEACHING OF GOLD FROM FLOTATION TAILINGS OF RESISTING SULFIDE RAW MATERIALS

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Abstract: ***Relevance.*** *The problem of expanding the raw material base of the gold mining industry is becoming more pressing due to the depletion of explored reserves, rising production costs and the costs of minimizing the man-made impact on the environment. With the depletion of oxidized gold-bearing ores, finely disseminated ores are increasingly being involved in processing. An increase in gold production volumes can be achieved by improving the beneficiation process. An alternative to traditional beneficiation technologies is electrotechnologies that use the phenomenon of energy impact on mineral raw materials. Among them, the range of application of the resin-in-pulp electrosorption leaching technology is expanding.*
Objective. *Justification of technologies and technical means for electrosorption leaching of gold from flotation tailings of refractory sulfide raw materials. This will increase metal production and strengthen the mineral resource base of gold mining enterprises and reduce damage to the environment.*
Methodology. *A comprehensive method was applied, including analytical studies using the fundamentals of system analysis and mathematical statistics, technological experimentation using mathematical planning of experiments, economic and mathematical modeling, technical and economic calculations and pilot industrial implementation. Laboratory studies were modeled on the tailings of flotation enrichment of gold from the flotation tailings of refractory sulfide raw materials. The application of electric fields was provided by two parallel electrodes.*
Scientific novelty. *Theoretical and technological experimentation, substantiation of fundamentally new technologies and technical means of electrosorption leaching of gold from flotation tailings of refractory sulfide raw materials.*
Results. *The efficiency of using technogenic resources is achieved by combining traditional enrichment technologies with the capabilities of hydrometallurgy and electrochemistry. Flotation tailings of ores with gold content from 1.0-1.5 g/t are leached according to the scheme: granulation to a size of 15-30 mm with the addition of 1 g/l of cyanide, sulfuric acid removal of metals, alkaline treatment to pH 10-11, cyanidation with an irrigation density of 20 l/m^2 per hour, gold sorption on anion exchanger, anion exchanger regeneration and regenerate electrolysis. Gold leaching from refractory sulfide raw materials is possible after the destruction of sulfides upon reaching an oxidation potential of 1000 mV, it effectively proceeds in a solution of 20-30% sodium chloride upon application of direct electric current with a density of 800-1200 A/m^2, pH of the medium 2.0-4.0 and a temperature of 60-800 C with the extraction of up to 70-80% of gold into the solution with an electric power consumption of 120-220 kW/t. The results of the experiment confirm the efficiency of the technology of electrosorption leaching of gold from gold-bearing pulps. The leaching rate increases by 25-30%, the sorption capacity of the anionite AM-2B increases by 2.5-3 times. An increase in the capacity of the sorbent and a decrease in the amount of gold in the liquid phase shifts the equilibrium of the system towards gold dissolution and intensifies the volume and completeness of its extraction.*

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Implementation. *The technologies of electrosorption and electrochemical leaching of gold from ore flotation tailings have been tested and recommended for industrial development at the Aksu, Bestobe, Zholymbet deposits and implemented in the practice of ABS-Balkhash, Kazakhaltyn JSC (Republic of Kazakhstan) and can be recommended for other developed mining and gold mining countries of the world.*
Keywords: *gold-bearing ores, enrichment, electro-sorption leaching, resin in pulp, ecology, efficiency*

1. Introduction

In the context of continuous increase in production and consumption of metals, the problem of expanding the raw material base of the gold mining industry is of particular importance [1]. Increasing the efficiency of mining production based on the use of waste from the extraction and processing of gold ore raw materials, ensuring environmental safety, taking into account the electrosorption leaching of gold from pulp, improving the beneficiation process, using electrical technology and the phenomenon of energy impact on mineral raw materials, solves important scientific, practical and social problems [2]. The authors have carried out a study and definition of an effective technology for the use of technogenic resources while combining traditional processing with the capabilities of hydrometallurgy and electrochemistry, as well as laboratory and production experiments, physical modeling using standard and new methods of leading specialists from developed mining countries of the world with the participation of the authors [3].

The purpose of the work is to substantiate technologies and technical means for electrosorption leaching of gold from flotation tailings of refractory sulfide raw materials. This will ensure an increase in metal production and strengthening the mineral resource base of gold mining enterprises and reduce damage to the environment. To achieve the set goal, the following tasks are solved:
– analyze the experience of using technologies and technical means for gold mining;
– propose effective technologies and technical means for extracting gold into solution, as well as processing solutions and pulps;
– assess the environmental safety of the proposed nature- and resource-saving technologies and promising areas for further research.

Research methods. The work uses a comprehensive method, including analytical studies using the fundamentals of system analysis and mathematical statistics, technological experimentation using mathematical planning of experiments, economic and mathematical modeling, technical and economic calculations and pilot implementation. Five series of studies were carried out in stages: identification of input parameters; sorption leaching with the imposition of an electric field. Samples were collected according to the scheme: before the start of the experiment, the initial gold content in the solid and liquid phase and the sodium cyanide content were determined in the pulp. The current at a voltage of 36 V increased from experiment to experiment within 20...80 A. Laboratory studies were conducted in a column, the volume of which ensured the possibility of cyanidation of pulp up to 0.5 kg at a solid to liquid ratio of 1:1. Compressed air consumption during the study was 0.5 l / s.

The scientific novelty of the work lies in the theoretical and technological experimentation of the substantiation of fundamentally new technologies and technical means of electrosorption leaching of gold from flotation tailings of refractory sulfide raw materials.

Object of study and its technological audit. The object was the flotation tailings of the Aksu mine (Republic of Kazakhstan). The electric field was created by two parallel stainless steel electrodes with a diameter of 3 mm and a distance between the electrodes of 40 mm (Fig. 1).

A rectangular pulse generator was used as a power source, providing the possibility of varying the signal frequency within 10–20,000 Hz and the duty cycle within 2.5–45.0 μs, a stabilized DC source of the type and an autotransformer. The sample is characterized by a quartz-silicate composition with a small amount of sulfur and carbon dioxide, the presence of arsenic, copper sulfides, iron and carbonates, clay and mica. The results of processing gold-bearing sulfide are systematized, and the variables affecting enrichment are ranked. Using regression analysis in the Maple environment, the proportion of gold recovery into the solution during pulp disintegration is determined depending on the time of exposure to electrical pulses. A rectangular pulse generator was used as a power source, providing the possibility of varying the signal frequency within 10–20,000 Hz and the duty cycle within 2.5–45.0 μs, a stabilized DC source of the type and an autotransformer. The sample is characterized by a quartz-silicate composition with a small amount of sulfur and carbon dioxide, the presence of arsenic, copper sulfides, iron and carbonates, clay and mica. The results of processing gold-bearing sulfide are systematized, and the variables affecting enrichment are ranked. Using regression analysis in the Maple environment, the proportion of gold recovery into the solution during pulp disintegration is determined depending on the time of exposure to electrical pulses.

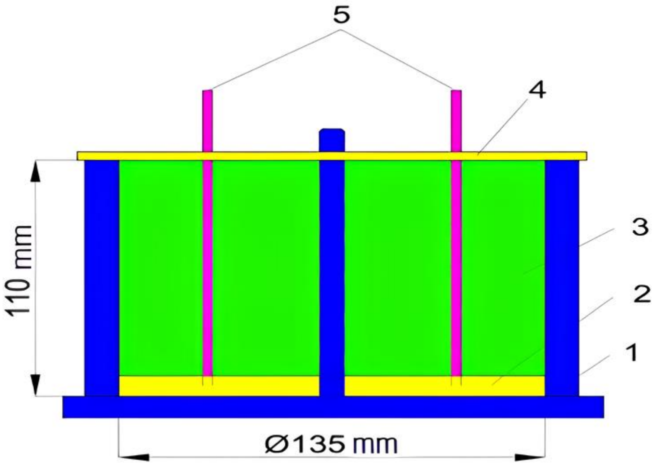

Fig. 1. Potentials of the electric field in the cell: 1-frame; 2-polyurethane foam fixing pad; 3-working container; 4-cover with holes at the nodal points; 5-potential-setting movable electrodes

2. Researching existing solutions to the problem

The urgency of the problem of providing industry with metals is further increasing due to the depletion of reserves suitable for development, the rise in the cost of mining mineral resources and the need to minimize the negative impact of ore beneficiation tailings on the environment [4]. A significant share of reserves is lost during the extraction and beneficiation of raw materials extracted from the subsoil. With the depletion of reserves of oxidized gold-bearing ores, finely disseminated ores are increasingly involved in processing. In the context of changing economic systems, the urgency of finding fundamentally new technologies for gold extraction and processing is increasing [5], [6]. Due to losses from 10 to more than 30% of gold during extraction and beneficiation, its reserves in technogenic deposits reach 2 thousand tons. Using the capabilities of geotechnology, hydrometallurgy and electrochemistry makes it possible to significantly increase the volume of gold production, reduce the number and duration of operations and increase the lifespan of enterprises [7], [8]. The increase in gold production volumes is ensured by activating the beneficiation process under the influence of energy flows [9], [10]. The main methods of ore enrichment are gravity and flotation. Of these, gravity methods are the most common. The capabilities of gravity enrichment and its efficiency depend on the morphometric parameters of gold and the nature of its mineral bonds. The lower limit of grains for effective gravity separation varies in the range from 500 to 40 μm. Centrifugal enrichment of raw materials with fine gold in intergrowths ensures the extraction of 40–70% of gold. Thus, during gravity enrichment of stale tailings with a gold content of 0.6–0.8 g/t in a centrifugal concentrator, gold recovery after three separation stages ranged from 4.8 to 43%. From the current flotation tailings of the enrichment plant, after centrifugal enrichment, 40% of gold was extracted into a gold-bearing product. Gravity methods are promising for the recovery of fine gold using centrifugal concentrators and concentration tables, but in most cases this method does not provide high gold recovery and is only applicable in combination with flotation and hydrometallurgy.

Flotation and gravity-flotation technologies are the most common method of enrichment of non-ferrous and precious metal ores [11], [12]. Their efficiency is affected by the size and degree of grain opening, the presence of coating films, isomorphic impurities and associations with ore and rock minerals. During flotation of sulphide ores, gold recovery does not exceed 60–70%. The least efficient is flotation extraction of gold from finely dispersed tailings. The developed product is resistant to cyanidation due to the fine dissemination of gold in sulphides. Combined gravity-flotation schemes include additional grinding of waste, flotation classification of hydrocyclone discharge and copper flotation of the froth product. When using butyl xanthate, mercaptobenzothiazole and their mixtures as collectors in sulfide concentrate, gold extraction was 56%, and silver extraction was 52% [13], [14]. An alternative to common technologies are electrotechnologies that use the phenomenon of the impact of energy flows on mineral raw materials. Among them, the range of application of the resin-in-pulp electrosorption leaching technology is expanding [15], [16].

3. Research results

Theory of the issue. Electrical action on the system "crushed ore - leaching solution - sorbent" is accompanied by a number of effects that contribute to an increase in the capacity of the sorbent, a more complete dissolution of gold and intensification of mass transfer. Full-scale studies of the distribution of the electric field in the working volume of an industrial column at different distances between the electrodes allow us to draw a conclusion about the acceptable distance between the electrodes with their length corresponding to the total power of the working layer. The effect of electrical treatment is characterized by the value of excess of the sorption capacity parameter relative to the control one at the achieved degree of leaching. The confidence interval is described by a model of the type:

$$\left[\bar{x}-1{,}64\frac{\delta}{\sqrt{n}};\bar{x}+1{,}64\frac{\delta}{\sqrt{n}}\right], \qquad (1)$$

where $\bar{x}$ – average value of the indicator; δ – standard deviation; n – sample size of observations; 1.64 – Student's distribution coefficient.

Laboratory studies. As a result of laboratory work it was established: An electric field intensifies the process of sorption leaching of gold by 25-30%. The sorption capacity of the ion exchanger increases by 2.2 times during electrical treatment. The "resin in pulp" technology includes the preparation of ore pulp, cyanidation, sorption leaching of gold on ion-exchange resin, gold desorption, resin regeneration and electrolysis. The most complete extraction of gold from the liquid phase of the pulp is achieved by ensuring optimal pulp-resin counterflow, pulp viscosity, temperature and intensity of mixing of the resin-pulp mixture. At the gold recovery plant of the Kyzylkumredmetzoloto concern (Republic of Uzbekistan), the technology of sorption leaching of gold is used to process ore from the Muruntau deposit (Republic of Uzbekistan).

Sorption leaching is carried out continuously in a cascade of several sequentially connected devices, observing the counter-current principle. The pulp is fed into the first device (pachuca) and removed from the last pachuca. Fresh anionite is loaded into the next device in the direction of pulp movement, and the gold-saturated resin is removed from the first. The pulp is separated on the pachuca screens. The pulp passes through the screen and enters the next pachuca via a chute. The resin rolls into the same pachuca, and from the two outer screens it enters the resin flow and is removed to the next pachuca. Slide distribution of the resin is carried out upon reaching the equilibrium capacity of the resin at a given stage of sorption [17], [18]. The saturated resin is fed to a drum screen to wash the resin from the pulp and then to a jigging machine to separate it from sand.

After jigging, the resin is pumped to the resin preparation unit, where the resin and chips are separated and the resin is dehydrated on drum screens. After dehydration, the resin is fed for regeneration. The spent pulp is separated from the pulp through drum screens and sent to the tailings storage facility. Disadvantages of the multi-stage resin regeneration scheme: long process duration - more than 300 hours; loss of silver at the cyanide treatment stage; low gold concentration in the regenerate when the solution is saturated with sodium sulfate. At the stage of cyanide purification of the resin from impurities on it, desorption occurs: iron - 43%, copper - 96%, silver - 47%, gold - 10%.

Desorption of nickel, zinc, cobalt at this stage is insignificant. Most of the impurities are removed at the stage of sulfuric acid treatment of the resin. The regenerated sorbent has a residual capacity for gold of 0.08 mg/g and for the sum of impurities less than 0.7 mg/g. The resin sorbs gold from solutions contaminated with impurities of non-ferrous metals and iron, which reduces its sorption-volume capacity for gold. The depressant effect is determined by the nature of the depressants and the ratio between the components of the solution.

The main task of increasing the efficiency of sorption leaching is to prevent the extraction of impurities into the solution during leaching. To intensify the sorption leaching of gold by suppressing impurities, electrical methods of activating gold ions are used, for example, applying an electric current to the process. Electrical methods of intensifying chemical and technological processes for extracting metals from ores are aimed mainly at intensifying the desorption process. Solutions are known for using electric current to intensify the sorption process and intensify leaching. Sorption is carried out with the application of an alternating electric field with a frequency of 5-40 Hz. High frequency does not cause pulsation of the solution in the capillaries due to inertial forces and insufficient polarization. At low frequencies of about 1-2 Hz, the effect is also not great.

White mud from the Pavlodar Aluminum Plant containing zeolites is used as a sorbent. In the process, 1 g of the sorbent is mixed with 1 l of calcium hydroxide solution while passing an electric current of 0.6 A, 35 V, and 16 Hz for 30 min. Calcium sorption from the calcium hydroxide solution increases to 300 versus 58 mg/g without applying current. Sorption on ion exchangers in a constant magnetic field is carried out within the framework of the ion-exchange process in a column with a suspended layer of finely dispersed ion exchangers. The liquid flow rate in this case is 8-10 times higher than the filtration rate. An increase in the sorbent capacity in the "raw material - sorbent - solution" system shifts the equilibrium towards gold dissolution and intensifies its extraction.

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Gold sorption from pulps is a process in which the forces of electrical action between the ions of the solution and the active centers of the crushed ore and sorbent prevail. If the sorbent charge is higher than that of the crushed ore pulp, complex ions settle on the sorbent. The process of gold dissolution in cyanide solutions has an electrochemical nature. The mechanism of action of electric fields is characterized by a number of effects. In external electric fields, layers of hydrated ions are set in motion, attracted by the force of the uncompensated electric charge of the surface. This effect, or electroosmosis, occurs at an electric field strength of about 0.1 V/cm. The destruction of layers of hydrated counterions facilitates the access of complex gold ions to the active centers of the sorbent and solvent ions. White mud from the Pavlodar Aluminum Plant containing zeolites is used as a sorbent. In the process, 1 g of the sorbent is mixed with 1 l of calcium hydroxide solution while passing an electric current of 0.6 A, 35 V, and 16 Hz for 30 min. Calcium sorption from the calcium hydroxide solution increases to 300 versus 58 mg/g without applying current.

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The electrochemical effect is created by the formation of a short-circuited galvanic cell, one of the electrodes of which is a gold particle, and the other is an electrically conductive mineral. The electrochemical nature of gold dissolution is that on the surface of the gold electrode, as a result of gold oxidation, electrons are released, the removal of which is carried out by oxygen. When an electric field is applied, the reactions are activated. The percolation effect occurs when, when an electric current passes through rock particles in the pulp, energy is released in the pores, capillaries and microcracks, in places of their narrowing. The growth of cracks and capillaries facilitates the access of the solvent to gold. At a current density of about 5-10 A / m^2, several hours are enough for the permeability in the rock to change. The effect of sorbent polarization in a constant electric field increases its activity and capacity with different areas of electrodes and the pachuca body.

The system also experiences secondary effects: piezoelectric, magnetostriction, thermal, thermomechanical, etc. The input power of the electric current source is estimated by the activation energy of ions on the ion exchanger. According to research, 4.5 mg of gold is sorbed from the flotation tailings leaching solution per 1 g of AM-2B ion exchanger. Since gold precipitates in the ion exchanger as a complex ion, the calculation is performed for 1 mole of this substance. The weight of 1 mole of the complex gold cyanide ion is 249, including 197 pure gold. This amount of gold is sorbed on 43.8 kg of ion exchanger or on 0.31 m^3 of resin. With a sorption column volume of about 50 m^3, there will be 128 mol of gold in the column. The required amount of energy to activate gold ions will be 4.8x 106 J. Knowing the sorption time (10 h), the specific input power per column will be 133 W.

About 90% of the energy passes between the ion exchanger grains, therefore the power of the current source is taken as 1–3 kW per column. The parameters of the change in the energy characteristics of the electric field for different electrode configurations were determined in a steel cuvette with a diameter of 135 mm and a height of 110 mm. A stainless steel rod with a diameter of 3 mm was used as an electrode. A caustic soda solution with a pH of 9 served as the working medium. A potential of 18 V was applied to the electrodes, and the voltage drop relative to the grounded mass of the cuvette was measured in a section with a step of 1 cm along the x and y axes. A three-electrode power input scheme with a symmetrical arrangement of electrodes relative to the central compressor pipe was used in a cyanidation pachuca with a diameter of 5.6 m and a height of 24 m.

The distance from the electrode to the pachuca wall is 0.7; 0.9; and 1.0 m, to the compressor pipe - from 1.9 to 2.2 m. To increase the representativeness of the experiment, we tested schemes with two, three and four electrodes. Laboratory studies were carried out in a column, the volume of which ensured the possibility of cyanidation of pulp up to 0.5 kg at a solid to liquid ratio of 1: 1. Compressed air consumption during the study was 0.5 l / s. The application of an electric field was ensured by two parallel stainless steel electrodes with a diameter of 3 mm and a distance between the electrodes of 40 mm. A rectangular pulse generator was used as a source of electricity, providing the ability to vary the signal frequency in the range of 10-20000 Hz and the duty cycle in the range of 2.5-45 m / ks, a stabilized DC source of the type and an autotransformer. The sample is characterized by a quartz-silicate composition with a small amount of sulfur and carbon dioxide, the presence of arsenic, copper sulfides, iron and carbonates, clay and mica. The results of experiments with changing the modes (R) of electrical action, sorption capacity for gold and copper concentration on the leaching process are given in Table 1.

Table 1. Modes of electro-impact, sorption capacity for gold and zinc concentrations

Mode	**R_1**	**R_2**	**R_3**	**R_4**	**R_5**	**R_6**	**R_7**	
Modes of electrical action								
Voltage, V	15-18	15-18	15-18	15-18	15-18	15-18	15-18	
Current, A	0.5	0,.	0.5	0.2	0.2	0.2	0.5	
Field frequency, Hz	20000	20	10000	10	10000	20000	10000	
Sorption capacity for gold								
Sorbent capacity, mg/g	4.5	12.8	6.2	11.7	4.9	10.3	11.0	10.4
Zinc concentrations								
Concentration in the process, mg/dm^3	2.9	1.42	2.8	1.33	1.37	2.61	2.61	1.52
Residual concentration, mg/dm^3	0.97	0.09	-	0.73	0.99	0.68	1.37	0.35

One of the pachucas was equipped with a system of electrodes and connected to an electric current generator, the second pachuca was intended for control observations. The duration of the stage was 9 hours. The following were monitored: voltage, frequency and density of electric current, as well as the concentration of gold in the sorbent and solution. The electrosorption leaching operations are characterized by Table 2. The data of chemical analyses and the dynamics of the gold leaching-sorption processes are presented in Table 3 (series 2 at a current of 20-25 A) and (series 5 at a current of about 60-80 A). The specific input power in the last experiments is given as 12 W per 1 m^3 of pulp. Information on the test complex is presented in Table 4.

Table 2. Sequence of the experiment

Name of operations	**Process technology indicators**
The tailings are dried, mixed and placed in a container	–
The sorbent is soaked in distilled water	–
Tailings and sorbent are weighed	200 mg tailings, 5 g sorbent (2.5%)
Sodium cyanide solution is prepared	C=180 mg/dm3 (water, pH adjustment with sodium per 10 l of water - 1 g Na OH and 6 g 30% Na CN)
The compressor is started, equal volumes of tailings and solution are introduced into the column	Cyanidation duration
The compressor is switched off, the tailings are soaked for 15 minutes.	– 2 h
The sorbent is introduced into the column, current is applied to the electrodes, the compressor is started	Sample volume – 5 ml
The compressor and electrodes are switched off, the pulp is settled for 15 minutes	Sorption duration – 1 h
Samples of the solution and sorbent are taken	– 15 ml solution, 1.5 g sorbent
The pulp is neutralized	–

Table 3. Results of experimental work

Time from the beginning of the experiment, h.	**Sorbent capacity, mg/g**	
	electrical processing	**control mode**
Basic Contents	0.08	0.08
Episode 2		
0.5	1.1	0.6
1	2.1	1.1
1.5	2.5	1.4
5	11.5	3.1
9	12.7	4.4
Episode 5		
0.5	2.6	0.9
1	3.9	1.3
1.5	11.5	3.2
5	13.2	4.3
9	14.2	4.7

Table 4. Results of a set of 5 experiments

Duration of leaching, hours	**Gold concentration, mg/dm^3 under the conditions**		**Sorbent capacity, mg/g under the conditions**	
	impact	control	impact	
Initial content	1.28	1.28	0.08	0.08
0.5	0.95	1.10	1.85	0.75
1.0	0.82	0.92	3.0	1.2
1.5	0.70	0.81	7.5	2.3
5.0	0.39	0.52	12.35	3.7
9.0	0.31	0.42	13.45	4.55

4. Efficiency of the research

Technological efficiency. Electrical impact on the process of sorption leaching intensifies the dissolution of gold by sodium cyanide, which at the cyanidation stage increases the concentration of gold in the solution due to the shift of the chemical equilibrium in the "pulp-sorbent" system towards sorption with an increase in the capacity of the anion exchanger for gold [19], [20]. According to research data, the concentration of gold on the sorbent increases, and in the solution it decreases, which leads to a shift in the equilibrium and intensification of the process of sorption leaching of gold. With an increase in the input power, an increase in the concentration of gold was noted, both in the resin and in the leaching solution. The studies substantiated the feasibility of involving gold-containing waste in the processing with an increase in gold production and a decrease in damage to the environment. The efficiency of resource use is achieved by combining traditional enrichment technologies with the capabilities of hydrometallurgy and electrochemistry.

The suitability of enrichment tailings for leaching is determined by a probabilistic recognition algorithm based on a set of attributes, the scope of application is the reaction of profit to the ratio of gold production volumes using new and traditional technologies. Flotation tailings of ores with a gold content of 1.0–1.5 g/t are leached according to the following scheme: granulation to a size of 15–30 mm with the addition of 1 g/l of cyanide, sulfuric acid removal of non-ferrous metals, alkaline treatment to pH 10–11, cyanidation with an irrigation density of 20 l/m^2 per hour, gold sorption on anion exchanger AM–2B, anion exchanger regeneration, and regenerate electrolysis. Gold leaching from refractory sulfide raw materials is possible after the destruction of sulfides upon reaching an oxidation potential of 1000 mV. It proceeds effectively in a 20–30% sodium chloride solution with the application of direct electric current with a density of 800–1200 A/m^2, pH of the medium of 2.0–4.0 and a temperature of 60–800 C with the extraction of up to 70–80% of gold into the solution with an electric power consumption of 120–220 kW/t. The experimental results confirm the efficiency of the technology of electrosorption leaching of gold from gold-bearing pulps [21]. The leaching rate increases by 25–30%, and the sorption capacity of the AM-2B anion exchanger increases by 2.5–3 times. When combining the processes of gold leaching from ores and their processing products and sorption, activated, for example, by the application of electric fields, the reactions are enhanced due to the occurrence of a synergistic effect. An increase in the capacity of the sorbent and a decrease in the amount of gold in the liquid phase shifts the equilibrium of the system towards gold dissolution and intensifies the volume and completeness of its extraction (Fig. 2).

Electrical impact on the process of sorption leaching intensifies the dissolution of gold by sodium cyanide, which at the cyanidation stage increases the concentration of gold in the solution due to the shift of the chemical equilibrium in the "pulp-sorbent" system towards sorption with an increase in the capacity of the anionite for gold.

Economic efficiency. The starting material for the experiment was sulfide-containing raw materials from the Aksu, Bestobe and Zholymbet deposits of Kazakhaltyn JSC. Capital investments in the construction of a pilot industrial complex for electrochemical leaching of gold, thousand dollars: total estimated cost - 830; construction and installation work - 383; equipment - 420; other - 27 thousand dollars. Specific capital investments: per 1 ton of processed raw materials - 16.6 dollars; per 1 gr. gold obtained from raw materials - $ 2.96. Estimated annual operating costs: $ 920 thousand, including electricity - $ 414 thousand - 45%. For 1 g of gold leached from sulfide raw materials containing 7 g / t of gold, the annual productivity of the pilot industrial complex for raw materials is 50 thousand tons, operating costs are $ 3.28. The cost of electrochemical leaching of 1 g of gold from sulfide raw materials is at the level of heap leaching technology from oxidized raw materials. The costs of sorption, desorption and refining (3.28 x 0.85 = $ 2.79 / t). The cost of production of 1 g of gold (in finished products) - ≈ $ 6 /g. With the selling price of 1 gram of gold being $ 12, the profit is $ 6/g.

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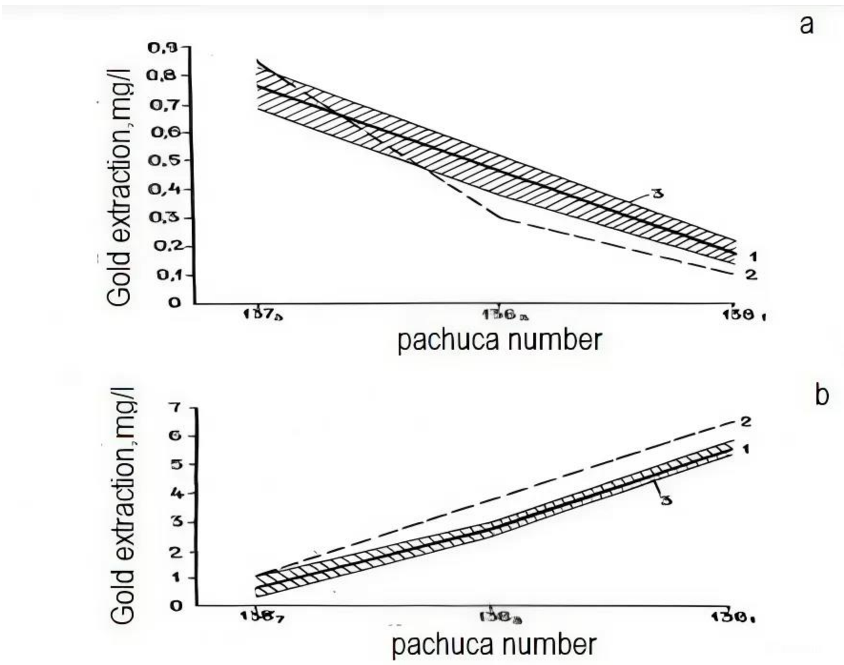

Fig. 2. Change in gold concentration in solution (a) and sorbent (b) during cyanidation:
1 – control mode, 2 – experimental mode, 3 – 90% confidence interval region

The profit from the involvement of substandard useful components and reserves in production due to the increase in production volumes, growth in production and increased return on capital for combined leaching technologies is determined according to a mathematical model of the type [22]:

$$P = \sum_1^n \left[\left(C_{ore}^b - C_{ext}^b - C_{enr}^b - C_{met}^b \right) V^b + \left(C_{ore}^c - C_{ext}^c - C_{enr}^c - C_{met}^c \right) - D_{total} \right] V^c, \qquad (2)$$

where P – annual profit from combining technologies, monetary units; C_{ore}^b, C_{ore}^c– accordingly, the cost of selling metals from balance and combined ore reserves, monetary units/t; C_{ext}^b, C_{enr}^b, C_{met}^b – accordingly, the costs of extraction, enrichment and metallurgical processing of balance ores, monetary units/t; C_{ext}^c, C_{enr}^c, C_{met}^c – accordingly, the costs of extraction, enrichment and metallurgical processing of combined ore reserves, monetary units/t; V^b, V^c – respectively, the volume of selectively mined balance and combined ores, t; n – nomenclature of extractable metals; D_{total} – total damage (economic consequences) caused (–) to the environment or prevented (+) taking into account the costs of storing pollutants and protecting the population living in the area of influence of mountain objects, monetary units.

Implementation of new technologies. In general, the technology of electrosorption leaching of metal from ore flotation tailings allows extracting, for example, gold without their agglomeration, intensifies the leaching process and increases the capacity of the sorbent for the corresponding metal. Theoretical and methodological developments have been used in the practice of scientific research work at JSC CGCC (Stepnogorsk, Republic of Kazakhstan) and the D.A. Kunayev Institute of Mining (Republic of Kazakhstan), the State Company Kyzylkumredmetzoloto (Navoi, Republic of Uzbekistan), JSC SredazNIPI Promtekhnologii (Tashkent, Republic of Uzbekistan), as well as in the educational process of KazNTU named after K.I. Satpayev (Almaty, Republic of Kazakhstan).

Methodological recommendations for heap leaching of gold form the basis for the technological complex developed by JSC SredazNIPIpromtekhnologii (Tashkent, Republic of Uzbekistan) for the Globa-Kazakhstan corporation (Republic of Kazakhstan).

Technologies of electrosorption and electrochemical leaching of gold have been tested at the production base of the Central Scientific Research Laboratory of the Joint-Stock Company "Tselinny Mining and Chemical Combine" (Stepnogorsk, Republic of Kazakhstan) and the hydrometallurgical plant ("Kyzylkumredmetzoloto" (Navoi, Republic of Uzbekistan). They are also recommended for industrial development of gold mining from flotation tailings of ores of the Aksu, Bestobe, Zholymbet deposits and have been introduced into the practice of the ABS-Balkhash company, JSC "Kazakhaltyn" (Republic of Kazakhstan).

5. Perspective research directions

Processing of technogenic waste (ore beneficiation tailings) requires technologies based on the latest achievements of science and technology. Implementation of effective methods for extracting metals from such waste will improve the environmental situation in the areas of their storage and will ensure an increase in the mineral resource base of the mining industry. Involvement in the production of technogenic reserves of ore beneficiation tailings, as well as processing of dumps of ores with substandard content of useful components in modular units helps to obtain additional metal, as well as reduce environmental pollution in developed mining countries [23], [24].

To prevent dust transfer of contaminated material beyond the mining facilities, sanitary protection zones and strips around them should be planted with tall trees, which will restrain the wind speed over the specified facilities. These include mines, waste rock dumps and off-balance, in terms of useful component content, ores, stowage complexes, sites for preliminary concentration and heap leaching of metals from substandard ore raw materials, tailings storage facilities, etc. Dust will settle without entering populated areas. New scientific and methodological foundations, technologies and technical means are needed to improve the efficiency of soil use in industrial zones of mining facilities, as well as to assess their impact on the environment [25], [26].

It is necessary to separately note the need to create protective forest belts along the perimeter of tailings storage facilities, as well as along transport routes (roads, railways, pulp pipelines, etc.). Territories where the maximum permissible concentration (MPC) of pollution is exceeded should be converted to sowing industrial crops, in water bodies - prohibit fishing, swimming and other environmental protection measures [27], [28].

Territories of gold ore mining and processing should be considered taking into account man-made sources of natural radioactivity, as well as environmental pollution with heavy metals and implement appropriate measures to identify uranium and gold ore legacy sites [29].

Also relevant are rehabilitation projects that involve at least partial restoration of landscapes at the site of former uranium production facilities to a socially acceptable level of comfort for the population living in the adjacent territories. For example, during the rehabilitation of the facilities of the Wismut enterprise in Germany, the task was not only to bring the uranium production waste storage sites into a safe condition, close old mines and clean up the territories, but also to almost completely restore all man-made landscapes [30]. Today, this program is almost complete. According to various estimates, € 3-5 billion were invested in it, with a significant share of the funds spent on social payments and restoration of the aesthetics of the environment, harmoniously fitting into the landscape of the adjacent territories (Fig. 3). And also the still rare experience of strengthening radiation and social protection of the population of Zhovti Vody, Ukraine, which is forced (since the 50-s of the last century) to live in the zone of influence of uranium industry facilities. Rehabilitation and social activities are carried out at the expense of the central and local authorities, as well as the enterprise in accordance with the special state "Program of activities for radiation and social protection of the population of the city of Zhovti Vody", Ukraine [1**],** [2], [27]. Mining and technical reclamation of the tailings storage facility in the quarry of brown iron ore presented at (Fig. 4).

Fig. 3. Modern view of the areas where the waste heaps of depleted ores and tailings of the Wismut enterprise were previously located (photographs by Ch.Kunze, Wisutek, Germany)

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Fig. 4. Mining and technical reclamation of the tailings storage facility in the quarry of brown iron ore (photo, Zhovti Vody, Ukraine)

To protect the hydrogeological environment from heavy metal pollution, ensuring increased efficiency of gold mining in the zone of influence of its tailings, the construction of semi-active permeable chemically active barriers (SPACB) and biological technologies is very relevant [31], [32]. In this case, the length of the SPACB should be at least 100 m, the minimum depth 6.0 m. To monitor the efficiency of its operation, it is necessary to construct an observation network of wells monitoring the input and output flows of groundwater into the hydrogeological environment, consisting of three profiles and four wells with a total drilling volume of up to 120 m.

In our opinion, the following new scientific and methodological provisions deserve attention:

Methodological principles for choosing production development options, in particular gold and technologies for its repeated extraction from ore enrichment waste, have been developed. They allow increasing the completeness of the use of natural mineral resources and reducing the negative impact of waste on the environment.

Detailing of the theoretical foundations and methodological base for gold mining from ore enrichment waste has been completed electrosorption leaching. The obtained results of the study can be used in the development of gold-bearing deposits in developed mining countries of the world.

The technologies of electrosorption leaching of gold from ore flotation tailings are recommended, which allows extracting gold without their agglomeration, intensifies the leaching process and increases the capacity of the sorbent for gold. The proposed technology is recommended both for the repeated extraction of gold from ore flotation tailings and for leaching gold from low-grade gold-bearing raw materials.

6. Conclusions

The efficiency indices of gold leaching in the liquid phase have been established, which increase by 11% during cyanidation, and decrease by an average of 15% during electro-treatment during sorption, while the sorption capacity of the resin increases by 11%.

The indices of gold leaching from refractory sulfide raw materials after sulfide destruction upon reaching an oxidation potential of 1000 mV have been substantiated. Gold leaching proceeds effectively in a 20–30% sodium chloride solution upon application of direct electric current with a density of 800–1200 A/m^2, pH of the medium of 2.0–4.0, and a temperature of 60–800 C with extraction of up to 70–80% of gold into the solution at an energy consumption of 120–220 kW/t.

The efficiency of using technogenic resources by combining traditional beneficiation technologies with the capabilities of hydrometallurgy and electrochemistry is demonstrated. In this case, flotation tailings of ores with a gold content of 1.0–1.5 g/t are leached according to the following scheme: granulation to a size of 15–30 mm with the addition of 1 g/l of cyanide, sulfuric acid removal of non-ferrous metals, alkaline treatment to pH 10–11, cyanidation with an irrigation density of 20 l/m^2 per hour, gold sorption on anion exchanger, anion exchanger regeneration, and regenerate electrolysis.

The efficiency of the technology of electrosorption leaching of gold from gold-bearing pulps is confirmed: with an increase in the leaching rate, it increases by 25–30%, and the sorption capacity of the AM-2B anion exchanger increases by 2.5–3 times.

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INCREASING THE EFFICIENCY OF TITANIUM-IRON ORE ENRICHMENT THROUGH USING NEW TYPE SEPARATORS

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Abstract: *The object of the research is technologies and technical means for selective destruction of mineral matrices of complex multicomponent titanium ores of primary deposits and beneficiation of minerals with altered magnetic properties. The aim of the work is to increase the efficiency of enrichment of titanium-iron ores by preliminary high-temperature treatment using new-type separators. This is achieved by substantiating the targeted selective destruction of mineral complexes and changing the magnetic properties of ore minerals as a result of temperature-controlled oxidation reactions. Methods of complex generalization, analysis and evaluation of practical experience and scientific achievements in the field of creation and introduction of new technologies and technical means for increase of efficiency of enrichment of titanium ores on the basis of separators of new type by substantiation of the directed selective destruction of mineral complexes and change of magnetic properties of ore minerals are described. It was found that for ilmenite, the main titanium component of raw materials, a low mass fraction of titanium is typical - no more than 30.0%, and ilmenite has lamellar-thin nano inclusions of hematite - 31.53 vol. %, which are difficult to remove from the ilmenite matrix. It is proved that in titanium-containing ores selective opening of splices occurs due to recrystallization of grains due to previous reduction, strengthening of bonds in hematite-ilmenite contact zones and non-ore inclusions and creation of a network of germinal cracks inside nano splices due to exposure to mineral matrix. C. It is shown that the use of magnetic separation of raw materials after high-temperature treatment reduces the mass fraction of harmful elements such as silicon, aluminum and calcium oxides from 11.89 to 1.2% in the concentrate product and allows to increase the mass fraction of titanium oxide from 32.3 up to 37.6%, and total iron from 33.86 to 42.29%; The technology of complex ore beneficiation has been developed to provide concentrates used for the extraction of titanium slag (mass fraction of titanium oxide - 80-81.84%) and high-purity metallic iron Fe with an average chemical composition of Fe 0.993 Ti 0.006. The results of development and implementation of new generation technologies and separators in the enrichment and processing of titanium ore were obtained in the laboratories of the State Higher Educational Institution (KVUZ) "Kryvyi Rih National University" (Krivoy Rog, Ukraine) and implemented at the Public Joint Stock Company (PJSC) » (Zaporozhye, Ukraine) and the State Institute for the Design of Mining Enterprises SE" Krivbasproekt "(Krivoy Rog, Ukraine). The developed technologies are also the basis for the feasibility study of ore processing technology of the Abu Galaga field (Egypt), in the design of the industrial complex and can be useful for other enterprises in developed mining countries. Research and implementation of new technologies and technical means using dry magnetic separation will allow for the stable production of high-quality concentrates, as well as the reduction of the grinding and enrichment front by at least 15–20% of the original, which will reduce operating and capital costs by more than 30% and will become a powerful technological reserve for the development of mining production.*

Keywords: *technologies, separators, magnetic enrichment, titanium ores, process efficiency*

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1. Introduction

Problem statement. The current state of the mineral resource base and objectively established trends in the development of metallurgical production necessitate the creation and widespread use of technologies for the comprehensive and more complete extraction of useful components in the processing of ore raw materials [1], [2]. The efficiency of the enrichment process depends on how fully the ore preparation has ensured the disclosure of mined minerals with minimal regrinding. This problem is especially relevant for titanium ores, which are distinguished not only by the complexity of their material composition, but also by uneven dissemination and size of useful components, and close mutual intergrowth of valuable and rock-forming minerals [3], [4]. The organization of low-waste technologies for processing mineral raw materials is associated with selective destruction. The titanium industry is no exception, and in its development it is equally important to address issues of not only the comprehensive use of raw materials, but also the expansion of the sphere of influence in the world through the development of technologies for the enrichment of complex titanium ores from primary deposits, both domestic and global [5], [6]. Therefore, increasing the efficiency of titanium-iron ore beneficiation by preliminary high-temperature treatment using new type separators is an urgent scientific, practical and social task that requires an urgent solution [7], [8].

The object of the research is technologies and technical means for selective destruction of mineral matrices of complex multicomponent titanium ores of primary deposits and beneficiation of minerals with altered magnetic properties.

The subject of the research is the processes of targeted selective destruction of intergrowths and changes in the structure, texture of ore and magnetic properties of minerals, as well as the patterns of their separation during beneficiation of complex multicomponent titanium ores of primary deposits.

Research methods - a set of research methods was used in the work, including: generalization of scientific information; X-ray phase and mineral analysis of ore and beneficiation products of raw materials before and after heat treatment; study of magnetic and structural properties of minerals and mineral complexes; thermodynamic calculations and thermodynamic modeling of processes; technological tests in laboratory conditions; methods of experiment planning; methods of statistical processing of research results; regression and factor analysis to establish analytical patterns and substantiate optimal parameters for the process of separating minerals of a polycomponent system.

The aim of the work is to increase the efficiency of enrichment of titanium-iron ores by preliminary high-temperature treatment using new-type separators. This is achieved by substantiating the targeted selective destruction of mineral complexes and changing the magnetic properties of ore minerals as a result of temperature-controlled oxidation reactions.

The following tasks are solved in the work:

– to analyze the chemical composition of hard-to-enrich titanium ore and obtain a thermodynamic model of the effective magnetization of the mineral components of the ore;

– to establish the effect of temperatures in the range of 850–1050°C on the mineral matrix “hematite-ilmenite” and recommend a scheme for a modernized separator for material whose temperature exceeds 150°C;

– to perform a technical and economic calculation of the results of the activities of a new enterprise for the production of titanium products.

2. Researching existing solutions to the problem

Industrial reserves of primary hematite-ilmenite ores are known in Ukraine, China, Canada and Egypt. These ores are characterized by very fine mutual intergrowth of hematite and ilmenite, or rutile. Today, Ukraine is the leading titanium-ore province in the world and occupies a leading position in the extraction of ilmenite concentrates and the production of titanium products. A significant part of the issues of selective destruction of mineral complexes has been studied and developed in the works of Revnivtsev V.I., Olofinsky M.F., Gaponov G.V., Zarogatskogo L.P., Kostin I.M., Finkelshtein G.A., Khopunov E. A., Yashina V.P., Kozina V.Z., Pervukhina A.V., Shatailova Yu.V., Pilov P.I., Mladetskogo I.K., Urvantseva A.I., Chanturii V.A., Chaplygina N.N., Vigdergauz V.E. and others [9], [10].

An analysis of the work revealed the need to improve the energy efficiency of processing difficult-to-dress titanium ores from primary deposits by using the technology of controlled selective destruction of polymineral complexes. This is ensured by exposure to high temperatures, weakening the boundaries of mineral intergrowths, due to the accelerated diffusion of atoms of various minerals in these boundaries. Selective (controlled) destruction is a process of sequential transformation of the original ore structure by targeted formation and development of micro- and macrocracks in its various elements at the corresponding

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structural levels. An analysis of the practice of enrichment of primary titanium ores showed that complex hematite-ilmenite ores are enriched using gravity, electrical and magnetic methods. They are then sent for high-temperature treatment and metallurgical processing [11], [12].

3. Research results

Analysis of the chemical composition of the refractory titanium ore showed that the mass fraction of titanium oxide is 32.3%. A high content of the ore component - polymineral inclusions "hematite-ilmenite" - 58.5% was established. To identify and confirm the features of the polymineral complexes "hematite-ilmenite", microprobe studies were carried out, which were carried out using a scanning electron microscope microanalyzer REMMA-102-02 (Fig. 1).

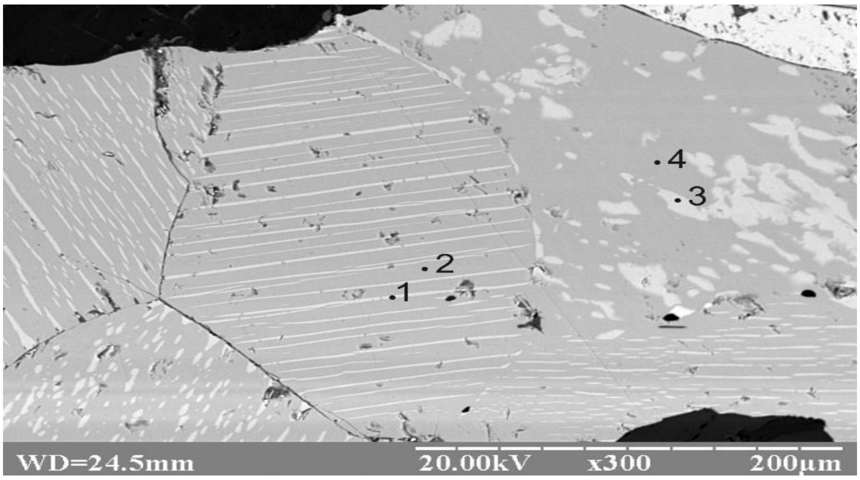

Fig. 1. Ilmenite grains with hematite admixture (photo): 1, 2, 3, 4 – thin section probing points

Points 1, 3 were located in hematite inclusions, points 2, 4 – in the ilmenite field of the matrix. The results of studies of difficult-to-process hematite-ilmenite ore of the primary deposit are given in Table 1. Statistical processing of microprobe analysis data separately for hematite and ilmenite is given in Table 2.

Table 1. Results of microprobe study of polymineral complexes

Element	Dot 1	Element	Dot 2	Element	Dot 3	Element	Dot 4
Mg	0.73	Mg	1.76	Mg	0.60	Mg	1.75
Al	1.03	Al	1.14	Al	0.84	Al	1.18
Ca	1.24	Si	1.31	Si	1.12	Si	1.35
Sc	1.29	Ca	1.23	Ca	1.10	Ca	1.16
Ti	12.64	Sc	1.40	Sc	1.25	Sc	1.36
V	2.05	Ti	34.93	Ti	10.15	Ti	34.79
Cr	1.18	V	2.04	V	2.02	V	1.86
Mn	1.63	Cr	1.13	Cr	1.17	Cr	1.15
Fe	75.78	Mn	1.86	Mn	1.54	Mn	1.86
Au	2.43	Fe	51.23	Fe	77.64	Fe	51.05
Total	100.00	Au	1.97	Au	2.57	Au	2.49
		Total	100.00	Total	100.00	Total	100.00

The analysis revealed the chemical composition features of hematite and ilmenite grains, which have a high mass fraction of titanium (more than 10%). The analysis of the mineral composition showed that ilmenite has lamellar-thin inclusions of hematite (31.53 vol.%), measured in micrometer units. The ore of such polymineral inclusions contains 58.5% of "hematite-ilmenite". The presence of a large number of harmful elements, such as silicon, sulfur, phosphorus, magnesium, chromium, was also established. It was determined that silicates in the sample are presented in the form of olivine, pyroxene and actinolite - 16.4%. The content of plagioclase is 8.2%, and the content of sulfide minerals (pyrite, chalcopyrite, pyrrhotite) is 7.5%.

Analysis of the physical properties of the minerals that make up the raw material showed that their magnetic properties are low-contrast. In addition, some of the non-metallic (silicate) minerals are present as fine inclusions in ore grains, so the non-metallic component can be completely separated from the ore component only after selective disclosure of the non-metallic phase.

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Table 2. Microelement composition of hematite and ilmenite grains of titanium ore

Element	Hematite				Ilmenite			
	Dot 1	Dot 3	Dot 5	average	Dot 2	Dot 4	Dot 6	average
Mg	0.73	0.60	0.71	0.68	1.76	1.75	1.05	1.52
Al	1.03	0.84	0.99	0.95	1.14	1.18	1.31	1.21
Si	-	1.12	1.19	1.16	1.31	1.35	1.34	1.33
S	-	-	0.97	0.97	-	-	0.99	0.99
Ca	1.24	1.10	1.15	1.16	1.23	1.16	1.18	1.19
Sc	1.29	1.25	1.24	1.26	1.40	1.36	1.44	1.40
Ti	12.64	10.15	14.50	12.43	34.93	34.79	32.95	34.22
V	2.05	2.02	2.00	2.02	2.04	1.86	1.89	1.93
Cr	1.18	1.17	1.19	1.18	1.13	1.15	1.01	1.10
Mn	1.63	1.54	1.56	1.58	1.86	1.86	1.89	1.87
Fe	75,78	77.64	67.17	73.53	51.23	51.05	48.16	50.15
Co	-	-	1.58	0.53	-	-	1.54	0.51
Ni	-	-	1.31	0.44	-	-	1.26	0.42
Cu	-	-	1.48	0.49	-	-	1.36	0.45
Au	2.43	2.57	2.96	2.65	1.97	2.49	2.63	2.36
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

The data from studying the mineral and chemical composition of the ore characterize it as a difficult-to-brine and hard-to-recover raw material, i.e. it is problematic to obtain monofragments of ilmenite and hematite in the process of mechanical destruction. Most of the ilmenite fragments will be “contaminated” by hematite inclusions even at very small sizes [13], [14].

As a result of magnetic enrichment of the original ore with a mass fraction of titanium oxide of 32.3%, a “rough” concentrate with a mass fraction of TiO^2 of 34.8% was obtained. It is represented mainly by polymineral intergrowths of “hematite-ilmenite” (76.67%). Non-metallic minerals that contaminate the concentrate are olivines and pyroxene (13.81%), sulfides (2.53%), as well as plagioclases and actinolite, which together make up 1.87%. Other minerals account for 5.13%. The release of minerals by mechanical disintegration methods is ineffective. This is confirmed by the results of magnetic separation of the original ore.

The efficiency of separation of ore minerals according to Hancock-Luycken is 15.76%, non-metallic - 22.66%. It is practically impossible to release "hematite-ilmenite" intergrowths with a size of lamellar hematite impregnation at the level of 0.00065 mm by mechanical methods [15], [16]. When analyzing the results of derivatographic studies of the oxidation of synthetic ilmenite, it was found that ilmenite begins to oxidize at a noticeable rate at temperatures of about 400 °C. At temperatures of ≃1000 °C, the degree of oxidation is close to 100%. Oxidation was carried out in air by heating to 1100 °C at a rate of 10 deg / min., holding the ore sample for 10, 20, 30, 40, 60 minutes. The results of studies of changes in ore mass during high-temperature processing (HTP) are shown in Fig. 2.

The increase in the mass of the sample is determined not only by the oxidation of the iron present in ilmenite from Fe^{2}+ до Fe^{3}+, but also the oxidation of magnetite to hematite, which is accompanied by a noticeable release of heat: $2Fe_3O_4 + 1/2O_2 = 3Fe_2O_3 + 231$ МДж.

The decrease in the sample mass is caused by the removal of sulfur and oxidation of pyrite. The amount of magnetite, depending on the holding time in the furnace, fluctuates from 8.2 to 10.03% in sample 1, and from 4.18 to 4.75% in sample 2. The authors suggest that in the presence of oxygen in the temperature range of 850-1050° C, the following oxidation reactions of pyrite occur:

$FeS_2 + 4O_2 = FeS_2O_8$; $2FeS_2O_8 \leftrightarrow Fe_2O_3 + SO_2 + SO_3 + O_2$; $10Fe_2O_3 + FeS = 7Fe_3O_4 + SO_2$;

$FeS_2 + 3O_2 = FeSO_4 + SO_2$; $5FeSO_4 + FeS = 2Fe_3O_4 + 6SO_2$;

$4FeS_2 + 11O_2 = 2Fe_2O_3 + 8SO_2$; $3FeS_2 + 8O_2 = Fe_3O_4 + 6SO_2$.

In this case, the decomposition of pyrite can, on the one hand, promote the formation of predominantly hematite rims (peripheral zones), and on the other hand, lead to the formation of titanium-enriched magnetite in the central parts of ore inclusions. Due to the oxidation of sulfides during high-temperature processing of material samples, the amount of sulfur in the ore is reduced to a minimum (from 0.32 to 0.000008%).

In addition to the formation of magnetite in the altered samples, an increase in the amount of silicates is noted in them. In sample 1 - by 6.75-10.53%, in sample 2 - by 3.99-4.69%. This occurs due to the diffusion of iron cations at high temperatures: $2FeO + SiO_2 = Fe_2SiO_4$. The absence of actinolite in the samples is explained by the fact that actinolite thermally decomposes at temperatures above 850°C.

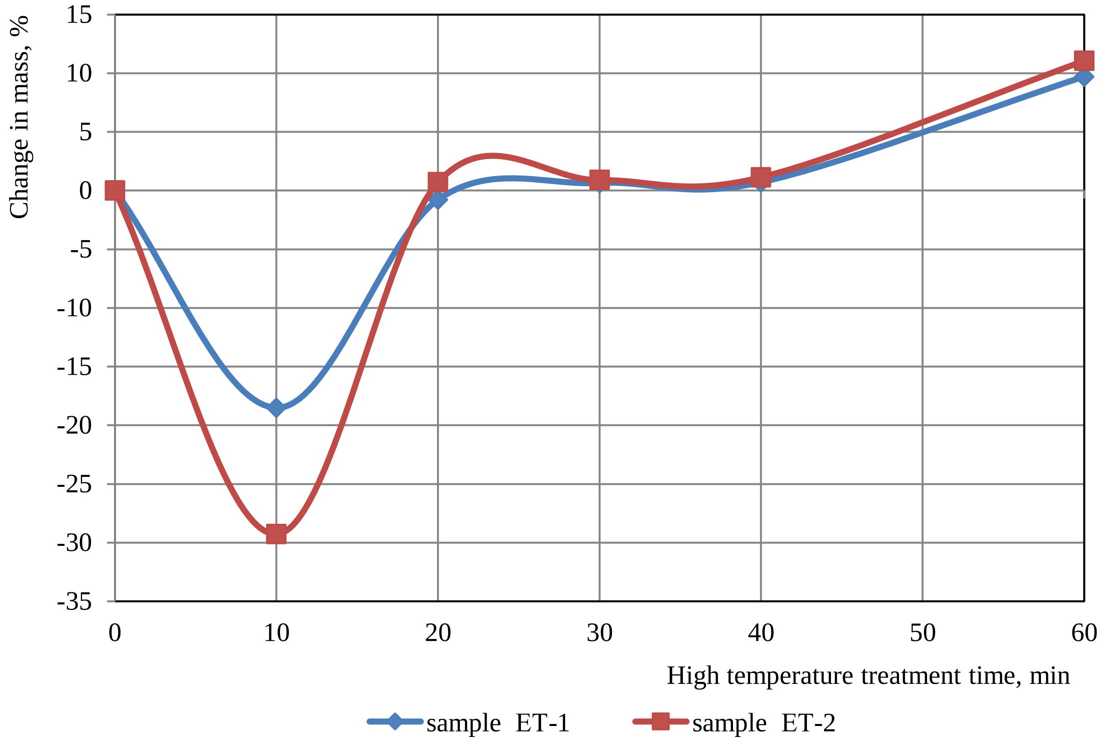

Fig. 2. Change in ore mass during high-temperature processing

We have established that as a result of the effect of temperatures in the range of 850-1050°C on the mineral matrix "hematite-ilmenite", a change in the texture of the ore occurs. The creation of a network of embryonic cracks inside the intergrowths and the occurrence of decription rims of hematite allows, during further destruction, to increase the selectivity of the opening of intergrowths by an order of magnitude and to reduce the time of ore grinding by 7.8 times [17], [18].

Elevated temperatures (above 800°C) lead to the irreversible entry of ferric iron into the ilmenite lattice. This process is possible based on the replacement of titanium and ferrous iron with oxidizing iron. When assessing the results of selective destruction of mineral matrices, it was established that the central parts of ore grains are prone to cracking. Ore inclusions look homogeneous; as an exception, they contain rare relict remains of hematite.

Next, experiments were conducted to open up newly formed mineral intergrowths (Fig. 3). The figure shows the dependences of the degree of opening of minerals before (opening of grains) and after (opening of plagioclase, ore grains, silicates and magnetite) high-temperature treatment (HTT) on the grinding time. The analysis of the experimental results showed that: with increasing grinding time, the degree of mineral disclosure increases from 12-22% (depending on the mineral) to 92-99% (with a grinding time of 40 minutes). Further grinding of the products is impractical, since it leads to the formation of a large amount of sludge. Regardless of the grinding mode, preliminary softening of the ore provides an increase in the efficiency of magnetic enrichment of ore minerals compared to the enrichment of the original ore by 16.57-17.42%. For the selective destruction of mineral intergrowths, high-temperature treatment of hematite-ilmenite ore is necessary, which causes accelerated diffusion of atoms of various minerals to the planes of intergrowths.

The actual composition of hematite-ilmenite grains after high-temperature treatment can be described by the resulting equation of the result of oxide reactions in a furnace at high temperatures:

$$0{,}69\ (Fe, Mg, Mn)\underline{TiO_3} + 0{,}31(Fe, V, Al, Cr)_2O_3 + (Co, Ni)_xO_y \rightarrow$$

$$\rightarrow 0{,}53\ (Fe,Mg,Mn)TiO_3 + 0{,}16\ (Fe,Mg)_2TiO_5 + 0{,}16\ (Fe,Mg, Ni)(Fe, V, Al, Cr, Mn, Co)_2O_4.$$

From the analysis of the above reaction, it can be concluded that as a result of exposure to high temperatures, altered ilmenite is formed, which will be the main mineral phase. The average empirical formula of altered ilmenite is $(Fe_{1,080}\ Mg_{0,129}\ Mn_{0,004}\ Cr_{0,002}\ V_{0,002})\ Ti_{0,890}\ O_3$ determined by chemical analysis. Magnetite, which is formed within the mineral matrices "ilmenite-hematite" has the empirical formula $(Fe_{0,968}Cr_{0,010}Ti_{0,007}Mg_{0,004}V_{0,003}Al_{0,003}Ni_{0,002})_3O_4$. After high-temperature processing of the sample material, hematite grains can be described by the formula: $(Fe_{0,791}Ti_{0,135}Mg_{0,024}V_{0,005}Cr_{0,004}Al_{0,0035}Mn_{0,001})_2O_3$.

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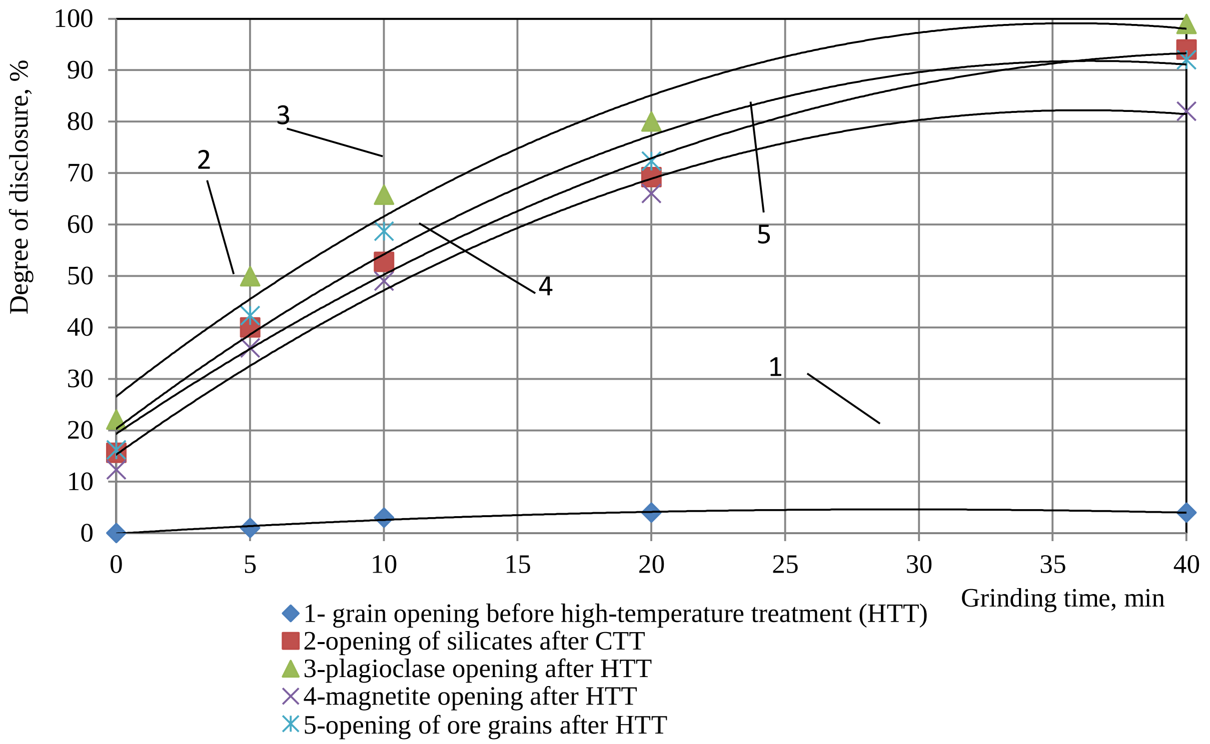

Fig. 3. Kinetics of mineral release before and after WTO treatment

After high-temperature softening of the ore, the product was subjected to magnetic separation in a weak and strong magnetic field. Analysis of the mineral composition of the products of magnetic separation of the altered open ore showed that weakly magnetic minerals enter the magnetic product obtained at 0.2 T. Non-metallic minerals (pyroxene + olivine, plagioclase, etc.) enter the non-magnetic product. The authors were the first to establish that at a temperature of 850-1050 °C, the ore structure changes due to the homogenization of the original ore inclusions and the formation of new mineral phases (hematite, magnetite, ilmenite, fayalite, etc.). They are distinguished by magnetic properties, which allows, when using magnetic separation of raw materials after high-temperature processing, to reduce the mass fraction of harmful elements in the concentrate: silicon, aluminum and calcium oxides from 11.89 to 1.2% and to increase the mass fraction of titanium oxide from 32.3 to 37.6%, and total iron from 33.86 to 42.29%;

The recommended technology for obtaining titanium slag was used by the Institute of State Enterprise "GPI Titan" (Zaporozhye, Ukraine). As a result, titanium slag with the average chemical formula was obtained: Fe0.197Mg0.271Mn0.004) (Ti1.094Al0.041V0.0075Cr0.0025)2O5. The slag also contains tiny balls of high-purity metallic iron Fe with the average chemical composition Fe0.993Ti0.006 [19], [20]. The idea of selective separation of refractory titanium ores of primary deposits at high temperatures is implemented in the design of an improved magnetic-gravity separator with air or water flow cooling (Fig. 4). The essence of the proposed changes lies in the possibility of high-quality separation of heated material. This ensures maximum contrast of the magnetic properties of its components.

Modernized magnetic separator. It consists of a non-magnetic inclined body 1 (see Fig. 4), onto the upper part of which material 2 (its temperature exceeds 150°C) is fed uniformly across the entire width by means of a device for its distribution 5. The separator has a divider (gate) for separation products 3 (concentrate 7, middlings 8 and tails 9), a magnetic system 4, which consists of a movable surface 6 (magnetic circuit), on which permanent magnets 10 are installed, as well as a bath with a heated water outlet branch pipe 11 of a magnet irrigation system 12 with nozzles 13 (see Fig. 4, a) or a system for removing hot air from the magnetic system 14 (see Fig. 4, b).

The separator operates as follows. The material to be separated 2 enters the housing 1 from the hopper 5 and is distributed in a uniform layer. Under the action of gravity, the material particles roll down and enter the magnetic field of the system of magnets 4, fixed on the movable surface 6. The magnetic particles are concentrated in places of the greatest field gradient opposite the magnets 10. The movable magnets 4 allow the magnetic particles to enter the concentrate hopper 7, and the weakly magnetic aggregates - into the hopper 8. Non-magnetic particles roll into the hopper 9 with the help of dampers 3. The liquid for cooling the magnets enters through the branch pipe 12 into the nozzles 13 and is discharged through the branch pipe 11

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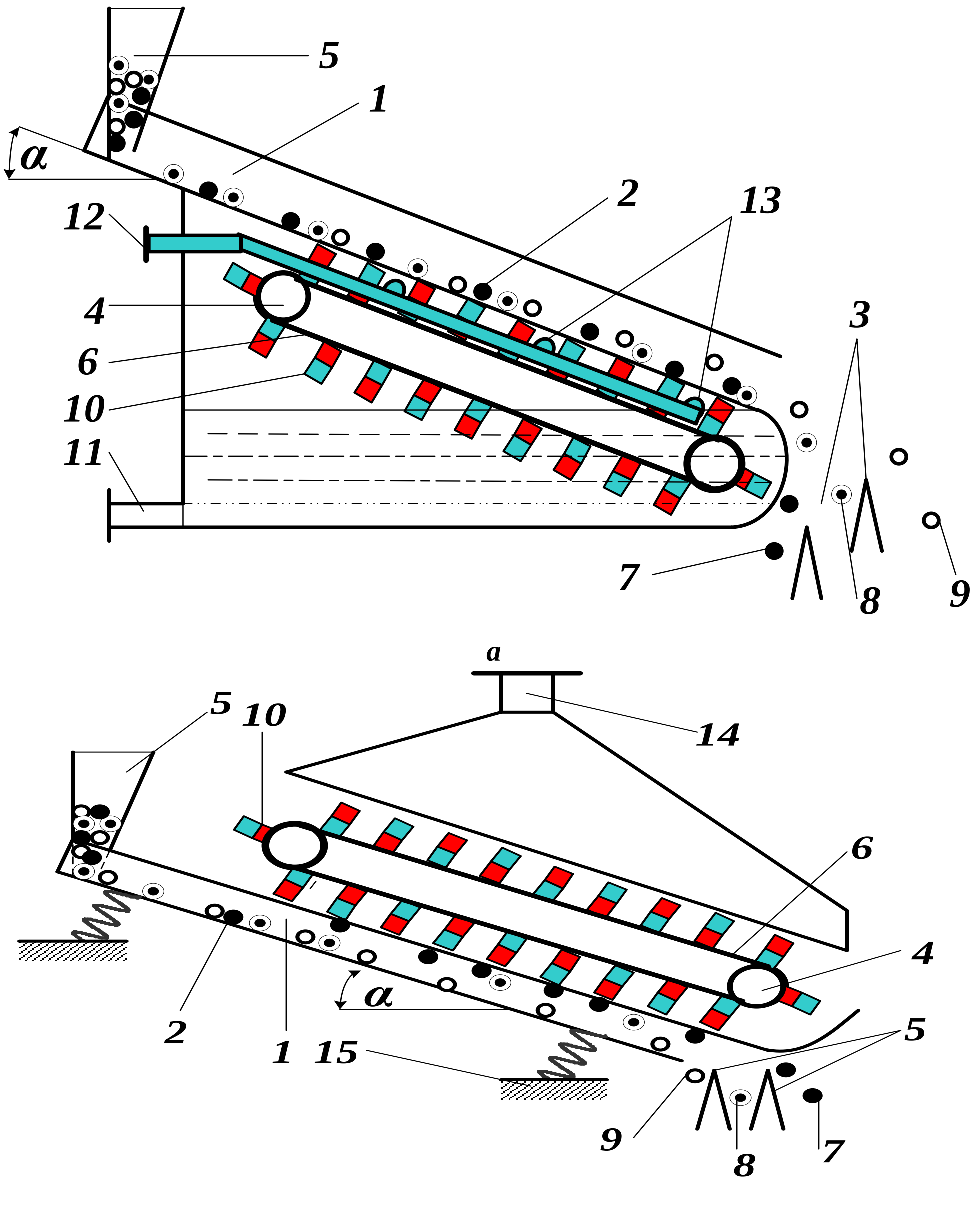
in an amount ensuring immersion of part of the magnets of the system 4 into it. Vibration of the housing 1 reduces the contact of the particles with the non-magnetic material and also prevents heating of the magnets. Cooling of the magnetic system 4 by an air flow is performed in the same way [21], [22].



b

Fig. 4. Schematic diagram of the modernized separator for hot material with water (a) and air cooling of magnets (b): 1 - inclined body, 2 - separated hot material, 3 - separator (damper), 4 - magnetic system, 5 - device for separating material, 6 - magnetic circuit, 7 - concentrate bin, 8 - bin for middlings, 9 - bin for non-magnetic product, 10 - permanent magnets, 11 - heated water outlet pipe, 12 - magnet irrigation system, 13 - nozzles, 14 - system for removing hot air from the magnetic system, 15 - shock absorbers

4. Efficiency of the research

Technological efficiency. The authors obtained a thermodynamic model of the effective magnetization of the mineral components of the ore, in which, unlike those previously proposed for simulating the magnetic order in minerals, average molecular fields are used, approximated by the Hamiltonian function, or the operator of the total energy of the system. This allows, during high-temperature processing, to justify the possibility of changing the magnetic properties of ilmenite and the optimal composition of the feedstock, which is characterized as a composite system with a hematite content range from 15% to 60% [23], [24]. As a result of laboratory studies of the technology of selective destruction of mineral complexes and magnetic separation of hematite-ilmenite ores, a concentrate with a mass fraction of titanium oxide of 34.8% was obtained, which is represented mainly by polymineral inclusions of "hematite-ilmenite" (76.67%). The non-metallic minerals that contaminate the concentrate are olivines and pyroxene (13.81%), sulfides (2.53), as well as plagioclases and actinolite, which together make up 1.87%. The share of other minerals is 5.13%. Due to the fact that the contrast of the properties of minerals: structural, elastic and strength characteristics, is insufficient to create a stress concentration gradient in the corresponding zones, the disclosure of minerals by mechanical disintegration methods is ineffective, which is confirmed by the results of magnetic separation of the original ore. The efficiency of separation of ore minerals according to Hancock-Luycken is 15.76%, non-metallic - 22.66%. It is practically impossible to disclose the solid substance "hematite-ilmenite", with lamellar impregnation of hematite at the level of 0.00065 mm, by mechanical methods [25], [26].

A technology for selective destruction of minerals of complex polycomponent titanium ores of primary deposits is recommended, due to the targeted change in the mechanism of crack formation. The idea of selective separation of new mineral types of ores is implemented in the design of an improved magnetic separator. Measures have been developed to increase the efficiency of magnetic enrichment of complex polycomponent titanium ores by 16.57-17.42%. A technology for complex ore processing has been proposed, ensuring the production of concentrates used for the extraction of titanium slag (weight fraction of titanium oxide - 81-84%) and high-purity metallic iron with an average chemical composition of Fe0.993Ti0.006. The developed technologies are the basis for the feasibility study of the ore processing technology of the Abu Galago deposit (Egypt), when designing the industrial complex of the State Enterprise "GPI Institute of Titanium", Zaporozhye, Ukraine [27], [28].

Economic efficiency. The technical and economic calculation confirmed the positive results of the new enterprise, namely: the payback period of capital investments in terms of net profit is 2.71 years, the profitability of products in terms of net profit is 37.83%, the expected annual economic effect from the implementation of the enrichment technology of hematite-ilmenite ores of primary deposits is 159,042 thousand UAH, the average annual discounted flow value NPV is 7,070,000 UAH or 328.98 thousand USD, the average annual discounted economic effect is 4,466 thousand UAH or 207.7 thousand US dollars.

Environmental safety (efficiency). The developed technology for the enrichment of hematite-ilmenite ores using new separators allows obtaining concentrates without the use of flotation and chemical methods, thereby ensuring the environmental safety of the environment.

5. Perspective research directions

The authors have developed new generation magnetic separators at the invention and patent level (utility model patents: Centrifugal magnetic separator UA No. 51638 U; Device for magnetic cleaning of liquids and gases UA No. 67185 U; Multi-product magnetic separator UA No. 68638 U) for enrichment of iron and titanium ores and dust collection during their processing. They have been implemented at mining and processing plants in Kryvbas (Ukraine) and make it possible to reduce dustiness of the air in workplaces and emissions into the atmosphere, as well as to increase the economic efficiency and environmental safety of the processes of processing rock mass and enrichment of ore raw materials, including titanium-containing ones [29], [30].

In addition, the design of the triboelectrostatic separator (utility model patents UA No. 91469 and UA No. 91470), in which more intensive charging of particles and selective separation of positively charged particles occurs (Fig. 5).

It has been established that the apparatus for the effective separation of oxidized iron ore minerals requires several charging and separation systems. After passing several stages of charging and separation, the separated flow is completely cleared of positively charged particles. The maximum concentration of particles per unit volume of gas (with an increase in this concentration, the efficiency of the apparatus will decrease) is calculated, which is equal to 2.74·106 m-3, which corresponds to the maximum permissible concentration of material in the carrier air equal to 41.3 g/m^3, which ensures the normal operation of the separator.

Research and implementation of new technologies and technical means using dry magnetic separation will allow for the stable production of high-quality concentrates, as well as the reduction of the grinding and enrichment front by at least 15–20% of the original, which will reduce operating and capital costs by more than 30% and will become a powerful technological reserve for the development of mining production [31].

In our opinion, the following new scientific and methodological provisions deserve attention:

1. An increase in the coefficient of disclosure of ore and non-metallic minerals is substantiated by reducing the strengthening of bonds in the contact zones of grains due to the accelerated diffusion of atoms of various minerals to the planes of fusion and the boundaries of concentrations of local defects and the creation of a network of embryonic cracks inside nanosprouts and, as a consequence, the recrystallization of individuals.

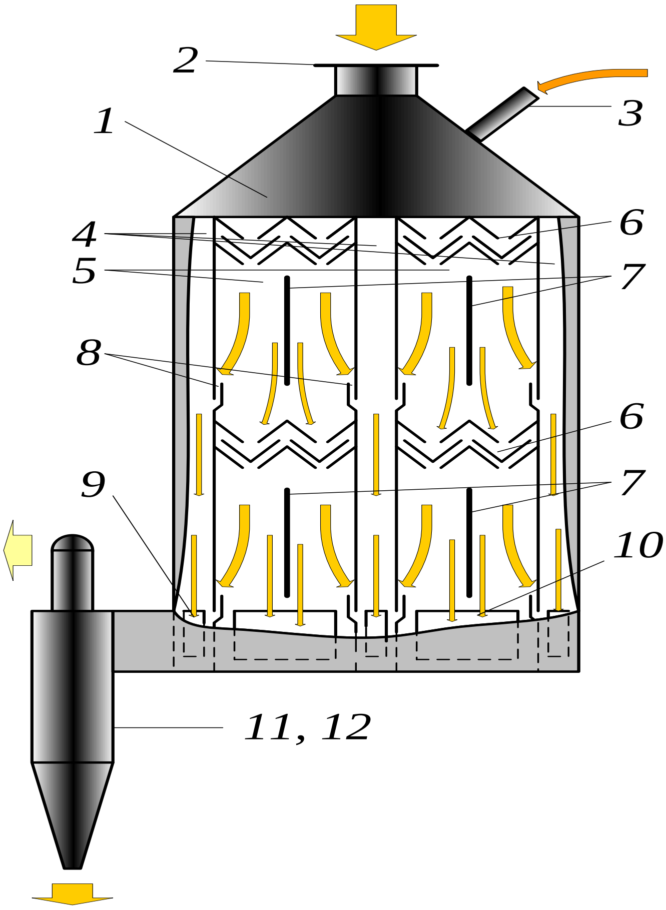


Fig. 5. Triboelectrostatic separator (diagram): 1 - working chamber; 2 - separation product feed pipe; 3 - additional loading pipe; 4 - negative deflection electrodes; 5 - separator sections; 6 - particle charging devices; 7 - positive deflection electrodes; 8 - horizontal slots; 9, 10 - collectors; 11, 12 - cyclones.

2. An increase in the difference in the contrast of magnetic properties of hematite-ilmenite ore minerals during their high-temperature processing was established due to the formation of new homogeneous ore and non-ore minerals with a minimum content of impurities that have different magnetic favorability, which makes it possible to increase the efficiency of raw material enrichment in absolute terms by 16.57%.
3. A thermodynamic model of the effective magnetization of the mineral constituents of the ore was obtained, in which, unlike those previously proposed, to simulate the magnetic order in minerals, average molecular fields are used, which are approximated by the Hamiltonian function (Hamiltonian), or the operator of the total energy of the system, which allows us to substantiate the possibility of changing magnetic properties of ilmenite and the optimal composition of the raw material, which is characterized as a composite system with a range of hematite content from 15% to 60%.

6. Conclusions

Based on many years of research and the results obtained, a modernized separator scheme for material with a temperature exceeding 150 °C is recommended for the new enterprise; the authors have made the following conclusions.

It is shown that the enrichment technology for hard-to-enrich hematite-ilmenite ores of the primary deposit involves a combination of a highly efficient magnetic separation process and ore softening under the influence of temperatures within 1000-1050 °C.

According to this technology, using modernized magnetic separators, titanium concentrate was obtained from ore with a content of Fetotal -37%, TiO2 - 32.7% and V2O5 -0.3%. Titanium slag with a mass fraction of titanium oxide of 80-81.84% and high-purity metallic iron with an average chemical composition of Fe0.993Ti0.006 were obtained in the metallurgical process. It was established that as a result of magnetic enrichment on modernized separators of crushed ore with a mass fraction of titanium oxide of 32.3% (after high-temperature treatment - HTT), a "rough" concentrate with a mass fraction of titanium oxide of 37.6%, total iron - 42.29% was obtained in laboratory conditions.

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At the same time, the mass fraction of harmful elements: silicon, aluminum and calcium oxides in total amounted to 1.2%. The efficiency of separation of ore minerals according to Hancock-Luiken using the proposed technology was 17.42% against 15.76% using the technology without preliminary HTT, and non-metallic minerals - 45% against 22.66%.

It has been determined that as a result of the impact of temperatures in the range of 850-1050 ° C on the mineral matrix "hematite-ilmenite", the texture of the ore changes through the creation of a network of embryonic cracks inside nano-growths and the emergence of decrepitation rims of hematite, the thickness of which increases with the lengthening of time around the ore grains of ilmenite. This allows, with further destruction, to increase the selectivity of the opening of the intergrowths by an order of magnitude and reduce the time of ore grinding by 7.8 times.

The positive results of the new enterprise's activities have been confirmed by technical and economic calculations, namely: the payback period for capital investments in terms of net profit is 2.71 years, the profitability of products in terms of net profit is 37.83%, the expected annual economic effect from the implementation of the enrichment technology for hematite-ilmenite ores from primary deposits is 159,042 thousand UAH, the average annual discounted flow value NPV is 7,070,000 UAH or 328.98 thousand USD, the average annual discounted economic effect is 4,466 thousand UAH or 207.7 thousand USD.

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MAKING SENSE OF SENSEMAKING IN SAFETY CULTURE DEVELOPMENT: A ROMANIAN COMPANY EXPERIENCE

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Abstract: *Safety culture is a topic that has been debated for too little time in Romania. Especially in multinational companies, there are numerous programs implemented in order to develop the safety culture among employees. Since in Romania a framework, a culture, which favors the full understanding of the concept of safety at work is not developed, still, in most companies, the term safety at work is assimilated to the set of cumbersome laws and government decisions, instructions and procedures, inspections, helmet and boots. Romania is at the bottom of the list of countries in terms of the number of occupational accidents with incapacity for work, but it is at the top of the list of countries with the most fatal accidents. A paradox, a reality concealed by economic operators by not reporting work accidents with work incapacity, which means that an investigation of the root causes is not carried out, thus leading to accidents that result in death. Accident reporting shows the maturity of the safety culture. The following article discusses the steps taken by Port Operator CHIMPEX to make the transition from a company based on indicators, systems and profit to a company based on people, in this case during implementing and developing an organizational culture based on leadership.*

Keywords: *safety culture, sensemaking, Bradley curve, leadership, life-saving rules, occupational injury*

1. Introduction

Sensemaking' is an extremely influential approach with a substantial following among management and organization scholars interested in how people appropriate and enact their 'realities' [1], [2], [3].

The theory of sensemaking was developed to explain the way in which organizations create their worldviews [4], [5], [6]. Sensemaking in organizations is the process by which they make sense of their environments through a process of intervention [7], [8].

"Safety Culture" was born for the first time in 1986 in the report of the International Atomic Energy Agency, following the Chernobyl disaster [9]. In the same year, after another major accident, the explosion of the space shuttle Challenger immediately after liftoff, the analysis reported the lack of a safety culture. The two catastrophes were cataloged as the result of a gradual accumulation of failures within the organization that had weakened all the protective barriers, one after the other [10]. This was the beginning, since then, most major accident investigations have placed safety culture at the center of attention [11]. The existence of a positive safety culture is now considered a cornerstone on which occupational health and safety performance is built. In companies with a low incident rate, the advantages are considerable: the company is seen as an attractive workplace, people have good morale, and organizational performance is high. [12].

Safety culture is a topic debated for too little time in Romania [13]. Especially in multinational companies, there are numerous programs implemented in order to develop the safety culture among employees. Overall, the safety culture includes two terms that are quite difficult to understand by all participants in the work process, in this case management, workers, contractors, subcontractors. "Culture", a term that, unfortunately, only large companies integrate into the common vocabulary, is essentially based on behaviors and values. "Safety" translates into trust, comfort, both physically and psychologically [14].

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Since in Romania a framework, a culture, which favors the full understanding of the concept of safety at work is not developed, still, in most companies, the term safety at work is assimilated to the set of cumbersome laws and government decisions, instructions and procedures, inspections, helmet and boots. Safety culture, as the literature defines it, is a collection of beliefs, perceptions and values that people share in relation to risks within an organization, a community, including at home. In other words, safety culture means mutual care, responsibility, assumption, personal example, understanding, communication, dialogue [15], [16].

H. W. Heinrich, an employee of the Traveler's Insurance Company, in the 1930s published a number of innovative theories on occupational health and safety. Heinrich, who laid the foundations of Heinrich's Law, in this case the Safety Pyramid, sometimes called the safety triangle, indicates a relationship between major injuries, minor injuries and near misses. It states that 88% of all injuries and incidents are caused by a human decision to perform an unsafe act [17]. Heinrich concluded that by increasing the number of unsafe actions/conditions and near-misses reported/analyzed and rectified, companies could reduce the total number of major accidents (fig. 1).

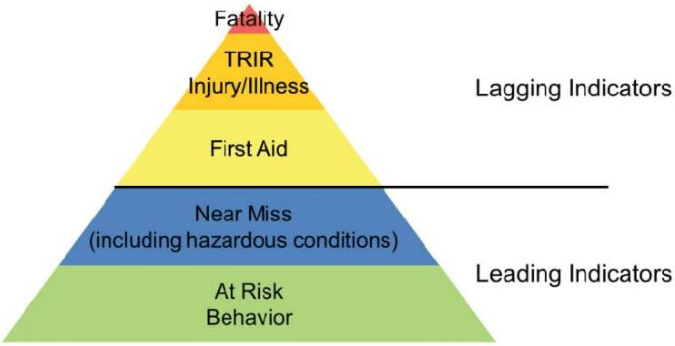

Fig. 1. The Heinrich / Bird safety pyramid

Contrary to Heinrich's studies, Romania is on the last place in the list of countries in terms of the number of work accidents with incapacity for work, but it is in the top of the countries with the most fatal accidents. A paradox, a reality concealed by economic operators by not reporting work accidents with work incapacity, which means that an investigation of the root causes is not carried out, thus leading to accidents that result in death. Accident reporting shows the maturity of the safety culture.

According to the data provided by the Labor Inspectorate, centralized in table 1, the number of occupational accidents resulting in death has decreased in recent years, while the number of accidents with temporary incapacity for work has remained constant. We can appreciate that this decrease is due to the fact that more and more companies have addressed awareness campaigns and programs, to develop an organizational culture based on safety [18].

Table 1. The evolution of work injuries in the last 10 years in Romania

Indicator/Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Fatalities (FTL)	185	183	163	172	167	182	143	153	99	54
Lost Time Injuries (LTI)	3419	4117	4408	4632	5045	4963	4232	4603	4414	3961

The following article discusses the steps taken by the Port Operator CHIMPEX to make the transition from a company based on indicators, systems and profit to a people, in this case an organizational culture based on leadership.

2. Description of the investigated company: CHIMPEX, part of the AMEROPA group

Founded in 1948, Ameropa is a Swiss company with private capital, with international exposure on the agricultural market. AMEROPA is one of the largest companies of agricultural raw materials and fertilizers in Europe, based in Switzerland, business of the Zivy family, started immediately after the Second World War. Headquartered near Basel, AMEROPA today conducts business in 26 countries on five continents (figure 2). In Europe, the Swiss company is the fifth player on the grain trade market, having businesses in Austria, France, Italy, Germany, Spain, Serbia, Croatia and Romania. In Romania, AMEROPA is present through five subsidiary companies: Azomureș, AMEROPA Grains. Promat, Agroind and CHIMPEX, which form an integrated, modern and efficient production and distribution chain, starting from the farm gates and extending to external export markets (figure 3). Due to its activities, size, investments, it contributes to the success and competitiveness of Romanian agriculture, including the logistics infrastructure [19].

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Fig.2. Global distribution of AMEROPA

The company is dedicated to supporting innovative agriculture on the agricultural market in Romania, through optimal and sustainable intervention in increasing production, a high-performance logistics system, with collection points at national level, silos and agricultural bases, but above all through the assumed values: strong connection, agility, responsibility and expertise. Involvement in the local community, in education and in the (re)discovery of values is part of the same growth vision applied in all specific policies and processes.

Fig. 3. National distribution of AMEROPA

By Order of the Minister of Chemical Industry no. 1655 of April 1, 1971, "CHIMPEX" Constanța became the legal and sole representative of all foreign trade companies and companies providing export duties in relations with the port authorities and companies competing in the export-import of products belonging to the Ministry of Chemical Industry, being also the sole representative in the commission for coordinating the port activity in Constanța, Galaţi and Brăila. CHIMPEX, the port terminal of the Group in Constanța, manages all exports of grain and oilseeds of AMEROPA Grains, as well as imports of raw materials, such as be the phosphate rock required for the production of complex fertilizers of the Azomureș Company [20].

It also deals with managing the fertilizer imports of AMEROPA Grains as well as other distributors. Currently, CHIMPEX is a leader in the operation of agricultural products from the port of Constanța and a hub in the fertilizer trade (figure 4).

Characteristics:

- 360,000 square meters. operating area; 10 operating berths (with a total length of the quay of 2.26 km).
- water depth of up to 13.5 m; 10 railways and access for road transport up to 80 tons.
- average quantities that can be received/day 33,000 Mt
- total storage capacity of over 600,000 Mt.
- 290 employees; over 150 permanent contractors daily.
- daily average of ~500 trucks in/out.

Services:

- Handling of goods, loading/unloading from wagons/barges/trucks/ships, storage, weighing.
- Barge transport, barge handling and cleaning.
- Rail transport, wagon handling.
- Packaging/palletizing, product conditioning (segregation, aeration), shipping, loading/unloading 20 FT containers.

Fig. 4. Overview, characteristics and services of the Port Operator

The new ultramodern grain terminal (fig. 5) has a storage capacity of 200,000 tons, distributed in 20 vertical cells, it can receive goods both on barges (1 x 400 tons per hour), cars (2 x 400 tons per hour), as well as by rail (1 x 400 tons per hour) and has a ship loading capacity of 2 x 800 tons per hour. The investment of over 42 million euros is part of the company's continuous commitment to provide high-quality services to its customers, to protect the environment, but also to ensure a safe working environment for its employees.

Equipments:

- Quay cranes (Mt): 2x6.3 & 5x20.
- Portal type cranes (Mt): 1x25.
- Liebherr mobile port cranes (Mt): 2x64. &1x84; Mobile cranes (Mt): 1x25 & 1x50.
- Forklifts (Mt): 16; Front loaders (Volvo): 16; Excavators (Hitachi): 4.
- Mini loaders (Bobcat and Volvo): 5.
- Mobile conveyor belts: 15.
- Scales for trucks: 7 and for wagons: 5
- Cereal ship loader (Mt/h): 1x400.
- Platform trailer trucks (MAN): 5.
- Floating crane: 2x16 & 1x10.
- Packaging machines: 4 x 1000 Mt/z.

Fig. 5. Overview and operational facilities of the Cereal Terminal

CHIMPEX is a major risk SEVESO operator, as it can store up to 20,000 tons of ammonium nitrate and NPK (hazardous grades). The average number of employees is 290 workers. Starting from the abbreviation of the values C.A.R.E. (Connection, Agility, Responsibility and Expertise), which denotes care and belonging, the company has developed countless campaigns under this motto: C.A.R.E. for Safety; Safety Leadership Training; Celebration of the international day of OSH; Safety themed contests; Safety Seminar; Personalization of personal protective equipment with this slogan; WHICH. for Environment; WHICH. for Education, Community and People [20].

In 2014, the number of work accidents in the premises of the Chimpex Port Operator reached a worrying level. The figures in table 2 refer both to work accidents involving our own employees and those involving contractors. Out of the total of 25 work accidents, 13 of them involved contractors, including all fatalities occurred among contractors.

The causes of work accidents with serious consequences are mainly due to: alcohol consumption, falling into water as a result of resorting to improvisations, not using protective devices for working at height, not following the rules for using work equipment, etc. Also, all work accidents highlighted gaps in the management system. From experience and statistics, most accidents that have occurred in Chimpex are caused by unsafe actions, not unsafe conditions or equipment. People make mistakes, take risks, but not because they want to get hurt, but because they want to help. This is where the challenge of the company began, how do we do it, what do we do, when do we do it, how much do we do it, so that people no longer take unnecessary risks, and if they do, the colleagues next to them correct the unsafe behaviors, address the risks, without there is also the famous line: "*it's none of my business*".

Table 2. The evolution of work accidents in the last 10 years within Chimpex

Indicator/Year	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
Fatalities (FTL)	1	0	1	1	0	1	0	0	0	0
Lost Time Injuries (LTI)	8	5	2	1	1	0	1	1	1	1
Lost Time Injuriy Rate (LTIR)	10.69	6.42	1.59	0.83	0.80	0.88	0.93	0.84	0.84	0.84
Total Rate of Injuries at Work (TRIR)	12.02	6.42	2.38	1.66	0.80	0.88	0.93	0.84	0.84	0.84

3. Implementation of proactive safety culture: paths and targets achieved

3.1. Safety culture. Landmarks of structure and content

To improve safety performance, coherent action is needed in 3 areas: technical aspects, safety management and human and organizational factors. These different "*pillars*" all influence safety culture. It should be emphasized that in any company safety priorities have gone through several phases of chronological development, each new area of concern being added to the previous one to improve safety performance:

- phase focused on technical actions (installation design, equipment quality, redundancy, fault sensors, automatic protection systems, etc.);
- followed by the development of safety management systems (formalization of all processes, procedures and rules implemented to promote safety);
- and finally, more recently, the recognition of the importance of human and organizational factors, or in other words the identification and integration of the factors necessary for a human activity to be carried out efficiently and safely.

In many companies, this area of concern of human and organizational factors remains the one with the most significant possibilities for progress. The three "pillars of safety" (figure 6) - namely the technical, system and people aspects - are of course not independent of each other: well-designed and well-maintained facilities together with clear and enforceable rules contribute to people's safety. In this three-pillar representation, "safety culture" falls under the category of "human and organizational factors", focusing the approach on the behaviors of individuals. But the culture of an organization is also directly influenced by technical aspects and safety management.

Fig. 6. Safety culture and safety pillars

In fact, there is a two-way relationship between safety culture and these three "*pillars of safety*":

- The safey culture results from the organization's technical safety practices and management systems: faulty technical systems and difficult-to-enforce rules and procedures will be perceived as signs that the organization places little importance on safety and will contribute to a decrease in the interest of all involved.
- The safety culture of the organization influences the decisions that are made regarding the technical design and the formulation of the rules: for example, if the company has a *participative culture*, the operational staff is involved in the process of designing the facility and in developing the procedures.

It is impossible to change the safety culture without changing the signals the organization sends through the higher or lower quality of what it provides in terms of technical design, safety management systems and the integration of human and organizational factors. Because they address fundamental aspects of the organization, safety culture actions have positive effects on overall company performance. The safety culture approach is a lever for ensuring the longevity of the company, whose survival can be jeopardized by the worst accidents. It can also have benefits that extend beyond improved risk management. It is an opportunity to carry out a strategic assessment of the organization's strengths and weaknesses and its ability to cope with a changing environment.

3.2. The results of the safety culture audit in the investigated company

In the middle of 2015, the company's management decided to conclude a collaboration contract with an external company to carry out an audit regarding the evaluation of the safety culture in Chimpex. The audit was structured in five parts and took place over three months:

1. Viewing existing documents;
2. Interviews with the management team and employees;
3. Surveys regarding safety perception and risk appetite;
4. Field visits;
5. Defining the action plan.

The conclusions of the audit can be systematized as follows:

i. Compliance with the minimum legal requirements will not guarantee fewer accidents, additional efforts are needed.
ii. Safety is a minor part of the integrated management system policy.
iii. A structured safety audit program will enhance management's role model.
iv. There is no strategic plan for improving safety outcomes and systems.
v. Many safety-related activities are still considered a task for safety specialists.
vi. No training materials are used, except for existing procedures and laws, on paper.
vii. Employee feedback is not used in a structured way to improve working conditions.

The audit was based on the Bradley Curve (figure 7), created by Berlin Bradley, a DuPont employee, indicating the relationship between workplace accidents and how the company's safety culture affects the occurrence of safety incidents. By plotting the number of incidents against their severity, the Bradley Curve provides a clear picture of an organization's safety performance over time [21]. This information can then be used to identify areas where improvement is needed. Based on this external assessment, ***Chimpex ranks 2 out of 5 in terms of safety culture***.

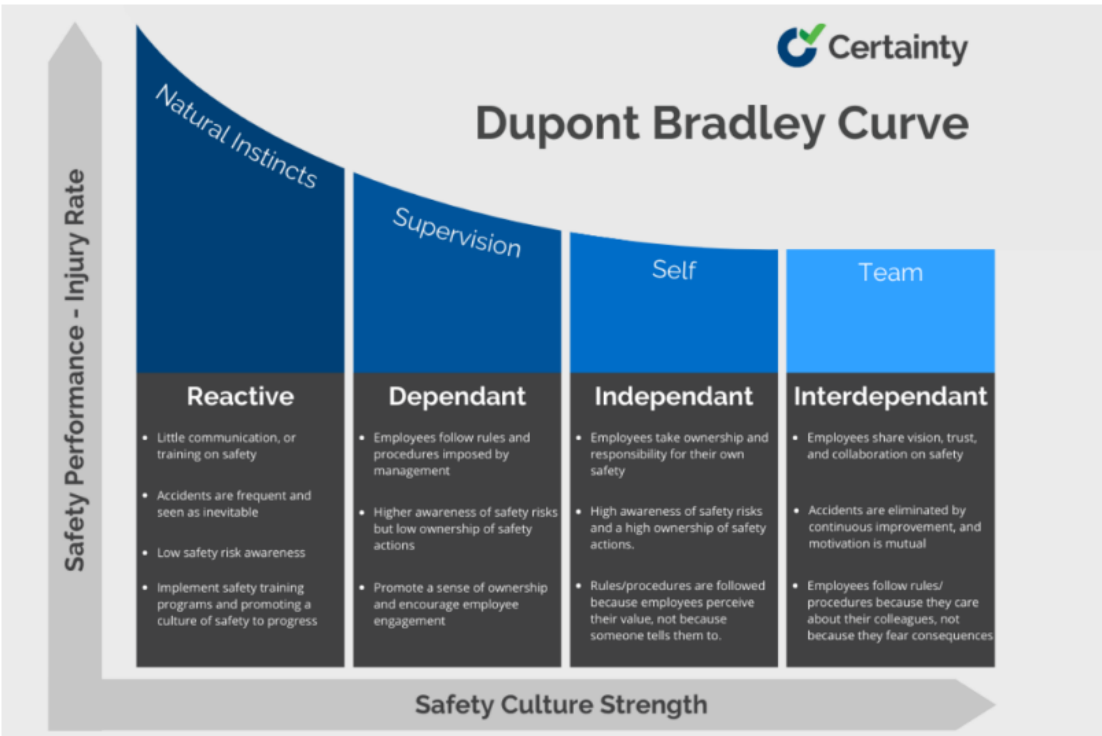

Fig. 7. Dupont Bradley Curve [21]

Assessment results are not an objective measurement that everyone should accept as true. It is an intermediate goal that must be communicated to all involved, discussed, adjusted and modified to arrive at a widely shared diagnosis that will serve as a starting point for a change process. Too many companies conduct safety culture assessments and fail to implement appropriate, concrete actions based on the findings. Chimpex management is committed to improving the safety culture. With the audit report as a starting point, the company's safety culture development journey continued internally.

3.3. The safety team

Until 2015, the safety team was represented by two people. Simultaneously with the safety culture assessment audit, the company strengthened the safety team. From 2016 until now, the same team has been providing management support in the process of growing the safety culture. In pursuit of organizational excellence and commitment to the safety of people and the environment, the QHSE Department was established, in which seven people work. Comprising dedicated professionals with a shared vision for a safe, healthy and sustainable future, the team plays an essential role. Each team member has well-defined responsibilities. Whether it's developing and implementing safety protocols, ensuring product quality, or leading environmental initiatives, team members are dedicated to their specific roles while collaborating to achieve overall goals.

The team is dedicated to continuous improvement, leveraging state-of-the-art technologies and methodologies to continually improve processes. Recognizing that continuous training is the cornerstone of a QHSE specialist, it invests in dedicated training programs. For example, one week of the year, for more than 5 years, is dedicated to the National HSE Seminar, where all Ameropa Romania QHSE Specialists meet and debate issues common to all companies.

3.4. Safety Audit/ Behavioral audit

In 2015, Chimpex implemented the Safety Audit Program. The purpose of safety audits is to proactively measure occupational safety and incident prevention performance by targeting staff awareness and improving behavior while performing work tasks. The safety audit consists exclusively of observations and dialogues, being focused on actions (safe and unsafe) and less on recording unsafe conditions. This type of audit does not combine or replace other activities: inspections, internal/external audits, current surveillance activity, etc. Auditors are the managers who go to the field in mixed teams, from different departments, on a monthly basis, and who audit departments other than the ones in which they work. The goals of this audit are dialogue and observations and not blaming anyone. The behavioral safety audit does not hunt for mistakes: it goes straight to the spot, explaining why and how!

The benefits of this type of audit include:

- Focuses on safety.
- Shows how well it is understood and applied.
- Shows where systems are going well.
- Helps identify weaknesses in systems.
- Helps clarify standards.
- Identify areas where risks are assumed.
- Prevents accidents.

Through this program, Management Commitment in the field of Safety and Health at Work is supported, demonstrated primarily through visibility in the field and personal example. Direct discussions between management and employees are the best way to promote and understand workplace safety issues.

3.5. Implementation of the program "Your idea matters for us - proposals and referrals "

"*Your idea matters to us - proposals and referrals*" is a program created and implemented to encourage initiative and creativity and also to increase safety culture and awareness through motivation. Any worker, employee or contractor, has at his disposal a form that he can fill in with unsafe actions and/or unsafe conditions observed, proposals for improvement, as well as cases in which an activity is stopped, in this case the "*Stop Work Policy*" is applied. This form is required to identify all occupational health and safety (OHS) actions/unsafe conditions/suggestions, immediate actions and remedial proposals.

Special boxes are installed in all workplaces to collect ideas / suggestions / complaints. Ideas / proposals / complaints are reviewed by a designated team and the best ideas/proposals are rewarded monthly. Later, the program was updated with the online version. In addition to the printed forms found next to all collection boxes, a QR code has been generated and posted on all boxes. The QR code can be easily scanned by any

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phone camera and will redirect the user to the online platform. The implementation of this program led to the collection of an impressive number of improvement proposals, which were later put into practice.

3.6. The training matrix

To ensure that all employees benefit from training programs sufficient to carry out activities in safe conditions, a training matrix was created, used and maintained by Safety and HR managers. The tool supports the planning, tracking and management of the employee training process. The matrix includes details about each employee, such as their name, role, department, and manager, as well as all training programs that employees complete and information about their progress in each program. The matrix includes all work instructions, procedures and policies. Through the Training Matrix, progress is monitored, training gaps are identified and specific training opportunities are offered. The first step in creating the matrix was to identify all mandatory trainings, starting from the legal requirements.

Subsequently, the information from the professional development plans of the employees was used to identify the areas in which the employees need to improve, in order to offer them the appropriate courses. Using another internal tool, the performance appraisal, the matrix was completed with the training programs that the employees requested. Even if the implementation of such a tool involves the allocation of additional resources, time and people, the benefits are numerous, especially in a multi-risk work environment where people need to have up-to-date information about the risks they are exposed to, the activities carried out.

3.7. Life-saving rules

A set of life-saving rules has been implemented within Chimpex. These rules cover the most dangerous activities that can be encountered inside the terminal. Periodically, specialized training is carried out internally for each rule, both theoretical and practical, and annually, specialized external companies provide training that includes practical demonstrations for: *Working at heights* (fig. 8), *Closed spaces* (fig. 9), *Energy sources* and *Barge work* (fig. 10).

Fig. 8. Rescue from height

Fig. 9. Practical training session regarding working and rescuing from closed spaces

Fig. 10. Practical training session regarding working on barges

How these rules are promoted:

- Boards containing the rules were made and displayed at all workplaces.
- These rules apply to TV monitors at workplaces.
- They are the subject of training sessions;
- During safety audits, they are constantly reminded.
- Annually, the description of each rule is revised. Basically, the life-saving rules are correlated with incidents that took place in Ameropa companies, where these rules were not followed;
- A safety calendar is drawn up every year. Each tab in the calendar contains a rule, so that even those who spend more time in the office do not forget them.
- On computer monitors, a rule runs each month.
- Video materials were made with each of these rules, including a message from Top Management regarding the importance of respecting them.

3.8. The "Stop Unsafe Work" policy

Starting from 2022, at the level of the companies within the Ameropa Group in Romania, a Safety Steering Committee was established, coordinated by the CEO of the Ameropa Group. The mission of this working group is to involve and hold Management accountable in shaping the safety culture and to encourage and support employees/contractors in all safety related activities. Thus, one of the first initiatives of this working group was the setting of a Policy whereby any employee, contractor, subcontractor, collaborator, visitor, pupil/student/trainee, etc., has the responsibility and obligation to stop immediately any unsafe activity as soon as it is noticed and ensure that all aspects of Occupational Health and Safety are observed before resuming the activity.

The implementation of the "*Stop Unsafe Work*" Policy was achieved through numerous training campaigns, advertising materials and office products inscribed in this sense, written and video messages of the top management, permanent encouragement regarding the application of this policy during safety visits, inclusion in job descriptions, internal regulations, conventions, etc. It also promotes responsibility among employees, who are responsible for their own safety and that of their colleagues. The results of the implementation of this policy were not slow to appear. The downward trend in the number of occupational accidents and the involvement of a very large number of workers in the application of this policy, denotes that the authority to stop a dangerous activity is a fundamental principle of safety management.

This assumed policy allows people to manage occupational safety issues in real time in all unsafe or dangerous work situations with high accident risk. It is a practical approach, without discussions, without waiting, without repercussions on the person applying it, and with immediate measures.

***Challenges in applying this policy**:*

- Human nature, the level of education and the specifics of the organizational culture are important factors influencing the decision to exercise responsibility and the obligation to stop work/activity when there is an imminent risk of injury. This means that the implementation imagined in the office does not match the reality in the field.
- Managerial pressure causes people to take risks to meet an operating objective.
- The observer unconsciously and irrationally puts productivity and machinery above their own safety.
- Peer pressure not to speak is a practice accepted and encouraged by the group.
- Risky behaviors are evaluated subjectively, because the observer has worked in a similar manner before without being injured.
- The bystander may feel that they do not have the authority to intervene in that particular situation when it is a superior or contractor worker, even if they are at risk of injury.
- The observer may not perceive the situation or action as dangerous because he does not have the necessary expertise and skills.
- When people are in groups of three or more, they may feel less responsibility to get involved. When the observer is unsure of the situation, he looks around to see what others are doing. When no one takes any action, he may assume that others may have already done so, or that the situation probably does not warrant any action on his part.
- Even though stopping work can have negative consequences on productivity, the observer is not always sure that his managers will interpret the situation in the same way and not apply sanctions.

Studies show that most people do not want to initiate action to stop the activity/work when they observe unsafe situations. The main reason reported is fear/fear: fear of trying something new, fear of reprisal, fear of making a mistake. This fear causes them to decide to wait for someone else to take action. Recognizing and rewarding workers who implement this policy helps increase the number of those who will exercise this responsibility.

3.9. Investments in safety

We can associate Chimpex with a vehicle and the workforce is the driver; its health, safety and well-being is represented by lubrication, which prevents the vehicle from breaking down. You checked your oil before a long trip, right? Thus, the company always takes care to ensure the necessary lubrication for our journey in ensuring safe workplaces. Like this, through sustainable investments. Annually, a budget of ~6,000,000 EUR is allocated to investments, and a similar amount to maintenance operations. The main investments refer to:

i. ***The new horizontal storage warehouse*** of 25,000 mt of bulk cargo: the warehouse is equipped with a fire detection system and an underground tank that provides fire-fighting water for the entire terminal.
ii. ***Grain Terminal***: Completed in 2017 with a storage capacity of 200,000 tons. The construction work took place over a period of two years and involved the presence of 290 workers on average. Despite the fact that construction work was carried out in the middle of an operational port facility, the project was successfully completed, totaling 760,000 accident-free hours.
iii. ***Working at height***: with a sheet of paper and a pen in front, the "*lifeline*" type devices (fig. 11) were sketched for working at height in safe conditions for personnel working on wagons / trucks / tanks. These devices were specially designed for the terminal configuration, being at the same time also mobile, they can be transported with the forklift. The concept belongs to Chimpex, and for the implementation and calculation of the structure, a company active in the field of safety devices was called upon. Later, after a short use, it proved necessary to complete these devices with folding access ladders, so that when changing the position of the wagons, the workers do not have to go down after them. The devices were immediately accepted by all the staff, right from the moment of their presentation, but especially from the moment of the first practical training. Both the practical training and the thorough checking of these devices are carried out annually by a specialized company.

Fig. 11. Lifeline systems

Subsequently, many other devices for the protection of workers at height were installed, such as:

- ***devices for working at height***, for situations in which workers have to go down or up from/on the ship to the barge/ship, taking into account heights of at least 4 m.; these anti-fall devices are mounted together with pilot ladder, making climbing/descending safe.
- ***port hoppers for loading wagons***, have been equipped with retractable devices that slide with the user, practically monitoring him throughout the operations.
- ***the ship-loaders*** (automatic installations for loading ships with grain, part of the Grain Silo) are provided with vertical lifeline systems, along the access stairs.
- staff supervising the loading of trucks from a distance, at the same level as the truck bed, use ***safe platforms*** that ensure good visibility and can be transported by forklift.

To service these devices, high-quality harness-type safety belts, accompanied by certificates of conformity, were purchased. All these devices have been accompanied by specific training with all personnel with responsibilities in these areas.

iv. ***LOTO (Lock-Out / Tag-Out)***: in order to ensure the safety of maintenance activities, within the Grain Silo of Chimpex, the LOTO project was implemented a few years ago. All production equipment has been audited and equipped with the necessary LOTO equipment.

v. ***System for detecting pedestrians in the vicinity of machinery and work areas with a risk of collision***: At the same time, on a normal working day, 450 people can be present in the terminal premises. At the same time, the total number of mobile work equipment, in this case machines such as forklifts, front-end loaders and cranes that can move in the Terminal, is 86. In order to prevent possible collisions of workers, as well as to avoid collisions with stationary objects, have installed anti-collision systems. These systems detect pedestrians and obstacles that appear during the machine's reverse maneuver, with a sound signal and a "*pedestrian attention*" or "*attention*" symbol in the upper left corner of the display in the driver's cabin. The obstacle detection area has been set up to approx. 3 meters and the pedestrian detection area has been set up to approx. 6 meters.

vi. ***Consolidation of the Phosphate Silo***: for a period of two years, with a multitude of circular scaffolds, heights of over 40 meters, numerous contractors, the consolidation and modernization of the Phosphate Silo was carried out (fig.12).

Fig. 12. The evolution of the consolidation of the phosphate silo

vii. ***Restoration of crane tracks and railway tracks.***

viii. ***New changing rooms***: The building is equipped with a state-of-the-art HVAC system that uses heat pumps to transfer heat between the fresh and exhaust air flow. It also includes a dual hot water system that uses both eco-friendly heat pumps and solar thermal panels.

Forklift trucks and front loaders are replaced annually, and starting this year, an extensive project to replace quay cranes begins.

3.10. Synergy Life by DNV (digital solutions and software applications)

The beginning of 2023 is also the beginning of the company's journey towards an effective management of all aspects of QHSE through the digitization of this area. Through this software we collect the right information, process and analyze data, communicate, improve risk management.

Specifically, all QHSE non-conformities, incidents, risks, audits, inspections, suggestions for improvement are managed. In parallel, also with the support of DNV, the implementation of SCAT - Systematic cause analysis technique, the revision of the entire incident management process and the process of learning from incidents, which at this moment are an integrated part of Synergi Life, began. SCAT is a simple tool that helps us investigate the causes of accidents and quickly identify the root causes and determine the corrective actions needed to prevent similar events in the future.

3.11. Safety Leadership Training- C.A.R.E. FOR SAFETY

The multi-year training program "*Safety Leadership Training- C.A.R.E. FOR SAFETY*", was launched in 2022, and is aimed at all workers, regardless of their position in the organization, including contractors, with more than 650 workers participating so far. Also, in addition to the essential role in risk awareness and accident prevention, both at work and at home, it contributes to the creation of a culture of safety within Chimpex, practically promotes an environment where safety is a core value rooted in the company culture.

The objectives and targeted results can be systematized as follows:

- Changing the managerial focus from systems and KPI's to people;
- Moving from the reactive approach, focused on control measures, to a proactive-generative one that includes the psychosocial factors that influence the risk;
- Understanding the role of personal example and influence that managers have on the way people think and make decisions about risk;
- Making participants aware of the need to immediately address and report non-conformities and incidents;
- Equipping participants with the attitudes and skills necessary for behavioral change;
- Use of simple and practical tools for risk assessment at individual level;
- Resuscitating HSE meetings by equipping managers with interactive methods;
- Creating a culture of responsibility and mutual care;
- Increasing the impact and efficiency of safety induction programs;
- Equipping OSH specialists with effective accident investigation methods.

Consequently, safety-based behaviors contribute to the reduction of occupational accidents, as indeed happened in Chimpex. Being a leader in safety is not equal to holding a management position, but this program was started starting from the Management Team.

3.12. Risk perception - practical study

In 2022, before the launch of the Safety Leadership Training project, practical studies on the perception of safety were carried out, in which members of the management team participated. The studies were based on three different poles:

• Safety perception survey;
• Appetite for risk
• Roles and Responsibilities

The questionnaire used for the safety perception survey comprised a set of 12 questions, summarized in Table 3, along with a selection of responses:

Table 3. Safety Perception Questionnaire

1	***Incidental causes*** Most accidents and incidents happen because of:	Managers	40%	7	***Rewards*** For good safety results we are encouraged/rewarded	Always	
		Rules	16%			Often	
		Workers	41%			Seldom	
		Equipments	3%			Never	
2	***Personal behavior*** I, personally, respect the safety rules	Always		8	***Zero accidents*** I believe that accidents can be prevented	All of them	
		Often				Most of them	
		Seldom				Just a few	
		Never				No one	
3	***Our safety*** The number of accidents in the company, compared to other similar companies, is:	Very high		9	***Violation of rules*** Most of the time, people break the rules because of:	Commodity	0%
		High				Routine	38%
		Acceptable	76%			Ignorance	50%
		Very low	24%			Rush	12%
4	***Discipline*** All those who violate the safety rules are subject to disciplinary action	Always		10	***The support of the leaders*** My safety comes first to my bosses, they congratulate me when I turn down an assignment	Always	
		Often				Often	
		Seldom				Seldom	
		Never				Never	
5	***The example of leadership*** Our managers set a personal example in complying with safety rules, they are a model	Always		11	***Liability*** Responsibility for the safety of people and equipment belongs:	Direct bosses	
		Often				OHS experts	
		Seldom				Workers	
		Never				Managers	
6	***Compliance with rules*** The safety rules are respected by the employees and contractors I work with	Always		12	***Work conditions*** The working conditions (locker rooms, offices, equipment and tools) are:	Very good	
		Often				Good	
		Seldom				Weak	
		Never				Very weak	

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A summary of the responses received concludes that the role of managers is not fully understood. Also, they still do not know the organization and do not have a clear vision of the needs and requirements of subordinate workers. The role of ignorance in an accident is overrated. Lack of awareness due to routine ("*low risk*") and convenience ("*benefits*", trying to make life easier) are more common. Managers say that people are involved in accidents out of ignorance, but who should train them?

The study also highlighted positive aspects, the role of managers in accident prevention being understood and there being a well-balanced vision of the system. Although there are accidents at work, according to the results, the need for change is small, the current results are accepted.

To ***measure risk appetite***, participants viewed 12 photos in 36 seconds, basically 3 seconds for each photo. According to their own perception, each framed the photos in a certain level of risk. Why 3 seconds, because in life, when we face limited situations, the reaction time is very short. The study's findings reconfirmed that risk perception is subjective, dependent on personal experiences (and attention). The study shows that we function better in a team, while individually we still have work to do. Most of the participants believe that certain risks, such as smoking, cannot affect us greatly, although there are many studies that indicate otherwise. On a scale from 1 to 4, the average of the answers is 3, but the differences from one respondent to another are very large, which means that awareness programs are needed (figure 13).

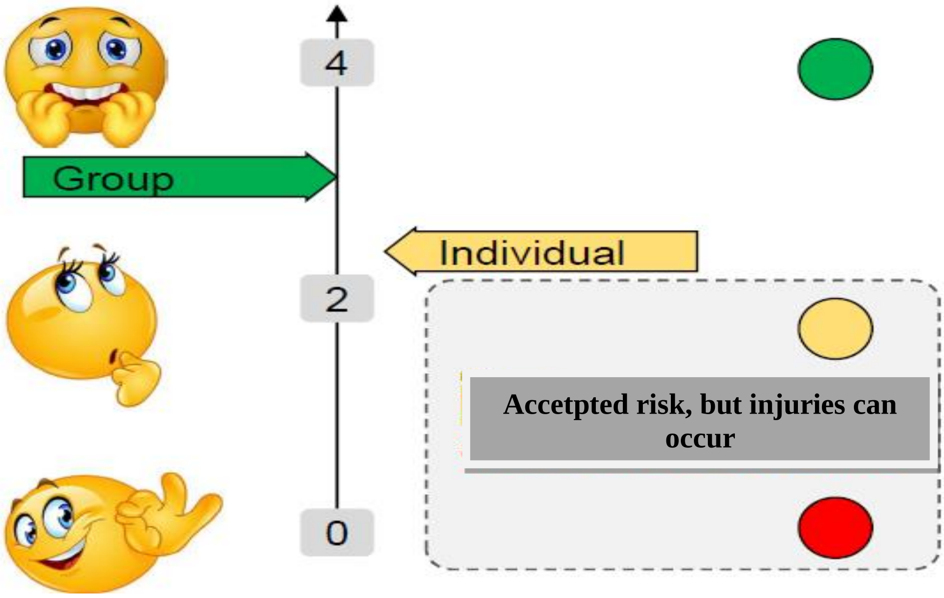

Fig. 13. Interpretation of risk appetite survey results

To establish ***roles and responsibilities***, respondents were given a questionnaire with 12 responsibilities (table 4), and were required to mark whether that responsibility rested with the management team or safety specialists.

Table 4. Results obtained from the safety roles and responsibilities questionnaires

No.	WHO DOES WHAT?	Management [%]	OSH specialist [%]
1.	Coordinates all site safety activities	58	42
2.	Investigate accidents/incidents	4	96
3.	Conduct "*safety dialogues*" in the field	40	60
4.	Develops procedures to carry out work safely	36	64
5.	Initiates programs and activities for work safety	12	88
6.	Training employees on OSH	42	58
7.	Conducts OH&S training with Supervisors	12	88
8.	Leads work safety meetings	28	72
9.	Analyzes site-wide safety needs	38	62
10.	It determines the objectives and targets regarding work safety	52	48
11.	Apply the discipline for the aspect of work safety	68	32
12.	Establish and ensure compliance with work safety rules	52	48
	AVERAGE	37%	63%

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Practically, the results indicate that the management considers that these responsibilities are the responsibility of the safety specialists:

- the results are considered very good, and the need for change is small.
- the concept of prevention is not very well understood.
- reporting all accidents (including "near-misses") and assessing potential risk can increase the need for change.

At this stage of maturity, safety professionals have limited capabilities to improve performance. Leaders should change the safety culture by accepting their responsibilities. Considering all these results, as well as a detailed analysis of what the points obtained indicate, the content of the Safety Leadership Training program was defined for the near and medium term future.

4. Conclusions

For most safety-forward companies, the way forward is to move to a culture that encourages better collaboration between management and workers on safety issues. The safety culture, which reflects the importance that the organizational culture gives to safety, is gradually built by all participants in the work process: the company directors, the different management echelons, the support departments (HSE, HR, procurement, etc.) and workers. For Chimpex "zero accidents" is just a slogan It is strongly believed that "Zero accidents" does not guarantee the existence of safe workplaces! Conversely, a strong organizational culture, in this case a safety culture strongly rooted in company values, leads to a reduction in workplace accidents. Moreover, the company has chosen to view safety not as a cost, but as an opportunity to achieve superior business performance. Not surprisingly, good safety also generates good business results. As a result, Chimpex is the market leader in terms of generated profit, occupying a leading place in the Top Companies in Romania by turnover.

Through numerous awareness programs supported and constantly analyzed, investment projects, and especially through permanent discussions with workers, today the graph regarding the evolution of work accidents has acquired a different look (figure 14).

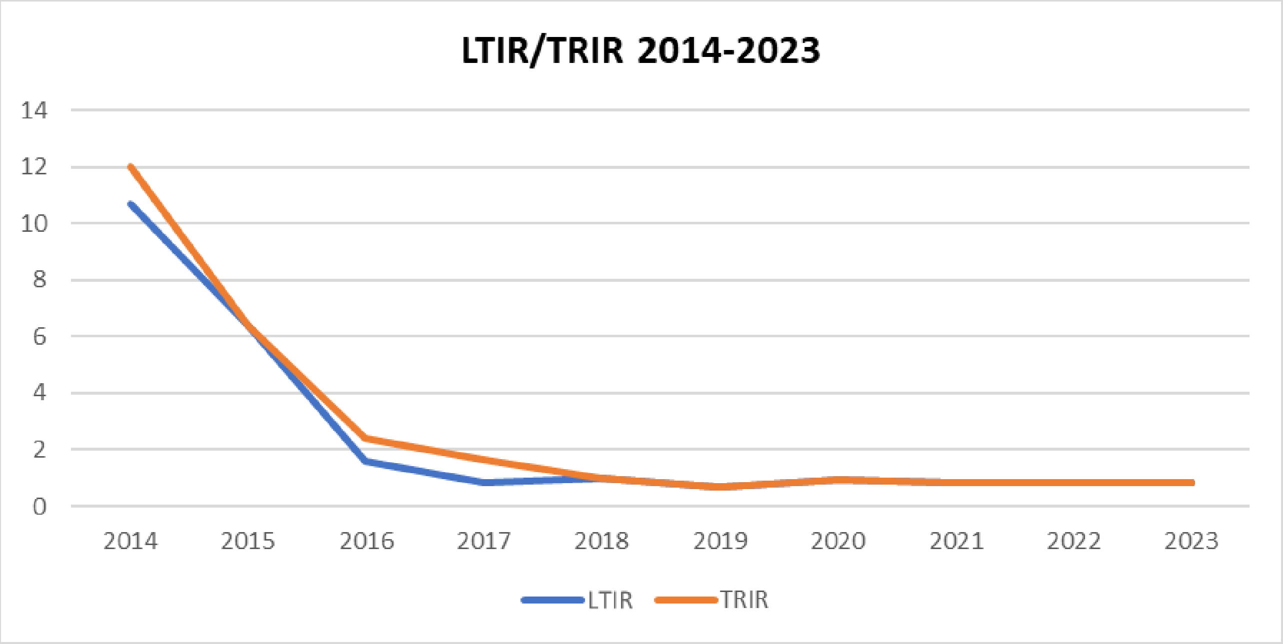

Fig.14. The evolution of LTIR and TRIR for the last 10 years in the analyzed company

where:

LTIR= rate of accidents with temporary incapacity for work (No. LTI / hours worked x 10^6)
TRIR= total rate of work accidents (No. FTL+LTI+RWC+MTC/ hours worked x 10^6)
FTL: fatalities
LTI: accidents with temporary incapacity for work
RWC: restricted work cases
MTC: medical treatment cases

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However, the implementation of numerous awareness programs, investments in improving working conditions, did not lead to the reduction of work accidents to zero. Accidents happen and will continue to happen. Not all accidents can be prevented, not everything is in the company, but we need continuous commitment, continued investment in people and in improving their working conditions, so that a new, gentler history is written. The journey to strengthen the safety culture continues, it will be long and difficult, with small and sure steps, and it will never end. And because the role of the OH&S expert is to identify those system elements that are partially working, or not working, and to improve them, the journey expands to new opportunities, starting from the following premises:

- Management is responsible
- Employees must be trained, constantly
- Management must do audits/verifications
- All deficiencies must be corrected immediately
- Safety is very important in the workplace
- Safety is good business
- Contractors are our mirror
- People are the most important element

Safety is not a priority! Safety is a value! Because priorities come and go. Safety is not a project or a campaign, it must be continuously supported and integrated into all business processes.

Studies show that the effectiveness of managers in preventing accidents depends on the behavior they demonstrate towards employees. Strong commitment and modeling good and safe behavior involves many facets, including:

- Establishing safety as a value for all workplaces;
- Making decisions that take safety into account;
- Providing all necessary safety equipment and motivating employees to use it;
- Thorough investigation of accidents and correction of identified problems;
- Inspecting the workplace regularly and promptly eliminating hazards;
- Ensuring the necessary training for employees;
- Establishing safety committees to involve employees in solving problems and improving workplace safety;
- Receiving employee suggestions to make the workplace safer;
- Listening seriously to employees when they report dangers and taking immediate action to correct them;
- Encouraging employees to attend safety training.

Another aspect that has proven its effectiveness is communication. Managers must communicate and encourage communication. Safety role model managers also talk about safety—a lot, in fact, as much as they do about productivity. Management should take every opportunity to ***provide feedback and communicate*** safety information to employees.

Also, face-to-face communication with employees about safety is the most effective method of communication. For example, if a manager is walking through a work area and sees employees wearing mandatory personal protective equipment and following safety procedures, he or she should stop for a minute and send a message of appreciation to that team. And supervisors should always talk to their employees about safety and provide performance feedback—not just at weekly safety meetings or during training sessions, but every day. Managers are the basis for the objective of developing a safety culture, they are the ones who can catalyze this process, and to the same extent, the ones who can slow down or even stop this process. Safety is the responsibility of managers. After an accident, no excuses work...

The role of managers is to lead the organization, controlling all aspects of the business (starting with the safety of people). Leaders are the ones who give direction to the organization and create the environment necessary to achieve the objectives.

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