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Analysis of the Stabilty of the Mining Site Slope on Bunyu Island, Bulungan Regency, North Kalimantan Province

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ABSTRACTS
Slope collapse can occur due to the reduction of shear strength and the addition of shear stress to the soil layer that forms the slope. This study aims to analyze the slope stability in the mining area of PT Garda Tujuh Buana on Bunyu Island, North Kalimantan. The research locations are in the South Block and West Block with open pit mining methods, which have a high risk of slope landslides. An evaluation was carried out on the existing slope geometry using the Morgenstern-Price method approach with the help of the Rocscience Slide 6.0 software. The geotechnical parameters analyzed include the physical and mechanical properties of the materials that make up the slope such as cohesion, inner shear angle, and content weight, as well as external factors such as rainfall and groundwater level.The results of the analysis show that some slopes, especially in Sections 3, 4, and 5 in both blocks, have a Probability of Failure (PoF) value above the threshold set by the Ministry of Energy and Mineral Resources No. 1827 K/30/MEM/2018, even though the Factor of Safety (FS) value still meets the minimum criteria. Through the trial and error method, new geometric recommendations were made with changes in the angle of slope, level height, and removal of soil material that has low shear strength. The results show a significant increase in the value of FS and a significant decrease in PoF until it reaches national stability standards. This study contributes to efforts to mitigate landslide risks and improve the safety and efficiency of mine operations.

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INTRODUCTION

Bunyu Island, which is located in North Kalimantan Province, is part of the Tarakan Basin area which has the potential for abundant natural resources including excavated materials that can be used so that mining activities ranging from oil and gas and coal can be found on the island (Fraser & Ichram, 1999; Wight et al., 1993). There are several companies that take advantage of the potential of these excavated materials, one of which is PT Garda Tujuh Buana which is engaged in coal mining. Coal mining in this company uses the *open pit mining* method which causes it to occur not according to the progress of the mine.

In the open mining method, the activity of moving a layer of soil or rock that is above the reserve of excavated materials is carried out so that the stability of the slope in the open pit mine requires more attention to the continuity of mining activities because this is directly related to the increase in production of a mining company and the safety of workers (Arif, 2016).

The factors that affect slope landslides include the physical and mechanical properties of rocks and slope geometry (Anwar et al., 2018; Arif, 2016; Romana, 1993). In addition, changes in slope stability to create slipping fields can occur due to lifting, lowering, excavation, stockpiling, erosion or other activities around the slope (Sudarsono & Pangular, 1986). With diverse geological conditions, morphology and activity, it is important to conduct an in-depth study of the slope stability in this region.

Journal of Geology & Exploration
Vol. 5, No. 1, June 2026 : 1 – 20
E-ISSN 2963-2869

LITERATURE REVIEW

The research area located on Bunyu Island, Tarakan City, North Kalimantan is part of the Tarakan Basin area which is one of the three Main Tersies basins located in the Eastern part of Kalimantan (Wight et al., 1993). These three basins emerged due to a large stretch in the middle Eocene, causing the basin to be filled with clastic deposits originating from plains, shallow waters, carbonates to the deep sea. Sedimentation in the Tarakan Basin occurred since the middle Eocene, along with the expansion of the Makassar Strait that separated the islands of Kalimantan and Sulawesi. The basin opens to the east, where the process of transgression originating from the west precipitates the shallow sea clay from the Sembakung Formation and covers the older basement rocks (Fraser & Ichram, 1999).

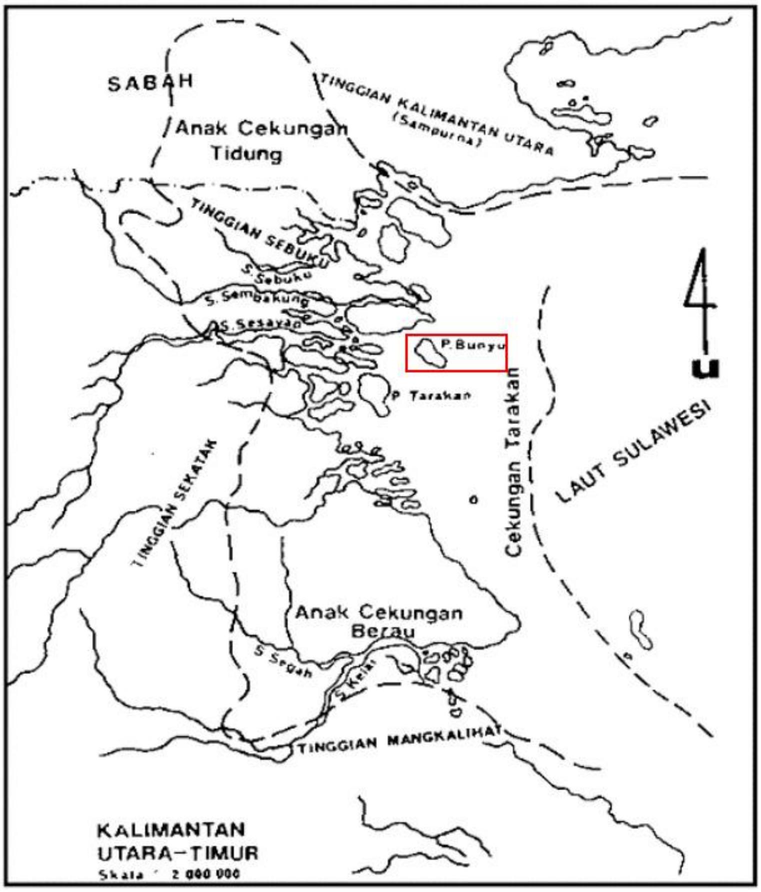

Figure 1. Physiography of the Tarakan basin (Situmorang & Burhan, 1992)

Journal of Geology & Exploration
Vol. 5, No. 1, June 2026 : 1 – 20
E-ISSN 2963-2869

Regional Stratigraphy of Research Areas

The regional stratigraphy of the Tarakan Basin generally refers to Achmad and Samuel (1984). The stratigraphic explanation begins with the existence of bedrock and the oldest sedimentary deposition in the Tarakan Basin. It is then divided into 5 groups of differentiated deposition cycles. The 1st deposition cycle to the 4th deposition cycle can be distinguished because each cycle begins with a lifting event which then causes an inconsistency. The 5th deposition cycle is distinguished by the presence of marine onlap which indicates an inconsistency. This misalignment is the boundary of each group of deposition cycles. (Pertamina BPPKA, 1996)

The asymmetrical Aluvium formation above the Tarakan formation was deposited during the transgression phase of the Holocene age. Lithology consists of mud, limestone, sandstone, gravel and coral which are deposits of beaches, rivers and swamps. The Sajau/Tarakan Formation is associated with a Pliocene-aged delta system, developing in the north, within the Tidung Sub-basin and the Tarakan Sub-basin. It consists of sandstone, shale, and clay coal inserts and a layer of coal (lignite) that is part of the plain-fluvial delta fasies. The total thickness of this reaches 800 meters which is found in the abbreviation (Achmad & Samuel, 1984). These formations are deposited asynchronously on top of older formations. The volcanic deposits called Tuf Sijin are locally under the Tarakan/Sajau Formation and are of Late Miocene age. The tuff in this area was deposited at the time of volcanic activity that coincided with events in the Late Miocene.

RESEARCH METHODS

Administratively, the location of the research is on Bunyu Island, Bunyu District, Bulungan Regency, North Kalimantan Province. While geographically it is located at the coordinates of 117°47'11" – 117°50'6.2" East Longitude and 03°31'9.3" – 03°34'06" North Latitude.

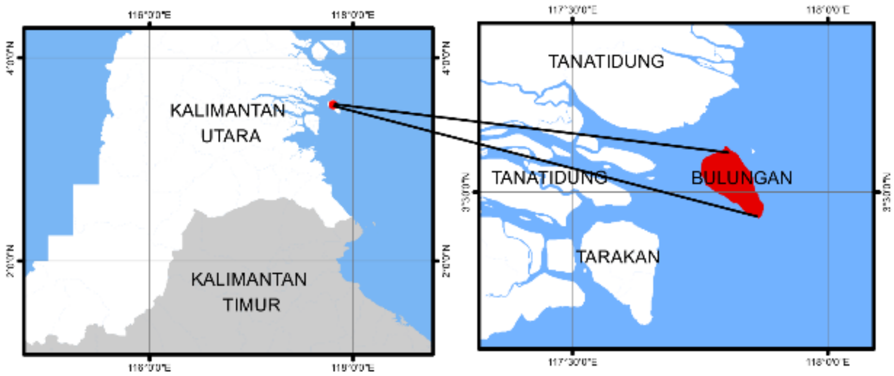

Figure 2. Map showing the location of the research area

The research area can be reached in two ways, namely sea and air travel. Sea travel by boat with a starting point from Makassar Port - Tarakan Port with a travel time of ±47 hours depending on the weather. Meanwhile, air travel through Sultan Hasanuddin Airport to Juwata Airport with a travel time of ±3 hours then use a speedboat with a travel time of ±1 hour to Bulungan Island.

In carrying out this research, several activity approaches were used, namely field orientation, data collection, data processing and data analysis. This activity also collects information from mining experts/practitioners who work at the research site. The data used is divided into two, namely primary

Journal of Geology & Exploration
Vol. 5, No. 1, June 2026 : 1 – 20
E-ISSN 2963-2869

data and secondary data. The data was processed using the *Morgenstern Price* method (Gideon et al., 2017), with the help of the Rocscience Slide 6.0 Software program (Rocscience Inc., 2021) to analyze the stability of slopes that are still active in *loading, hauling and digging* activities in the West and South blocks.

RESULT AND DISCUSSION

The slope modeling to be analyzed uses input parameters in the form of geometry, physical and mechanical properties of rocks, groundwater levels, and seismic factors (Supandi, 2022). Slope modeling simulations depict and represent actual slope conditions in the field.

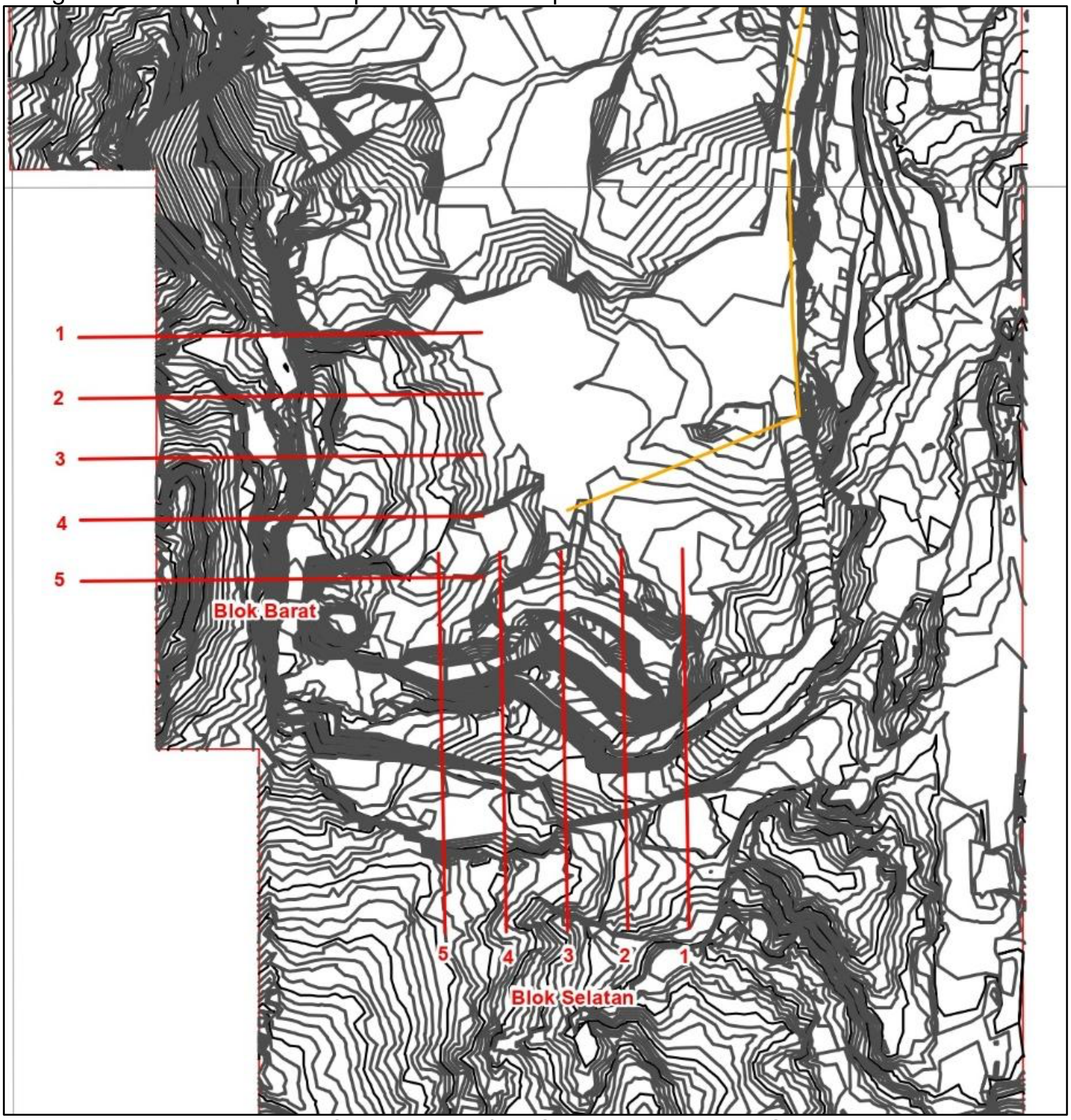

Figure 3. Cross-section of the South and West Block Slopes

In this study, the cross-section used is the actual slope geometry in the South and West blocks in October 2024.

Journal of Geology & Exploration
Vol. 5, No. 1, June 2026 : 1 – 20
E-ISSN 2963-2869

Table 1. Material value on the slope of the South Pit (source PT Garda Tujuh Buana)

Litologi	Bobot isi Jenuh (kN/m3)	Kohesi (kN/m2)	Sudut Geser Dalam
Soil	18	60	15
Sandstone	19.67	300	25.18
Claystone	19.47	340	28.87
Coal	11.7	300	11.3
Siltstone	23.8	367.5	19.5

In this study, the depth of the groundwater level was made with a state of water saturation because it reflects the worst – case condition. When the soil is saturated, the porous water pressure increases thereby reducing the effective stress which plays a direct role on the shear strength of the soil (Das, 1995; Hardiyatmo, 2018). In addition, saturation also increases the weight of the soil so that the driving force of the landslide is getting bigger. The following is a graph of rainfall on the PT Garda Tujuh Buana Tbk site starting from August 2024 – June 2025.

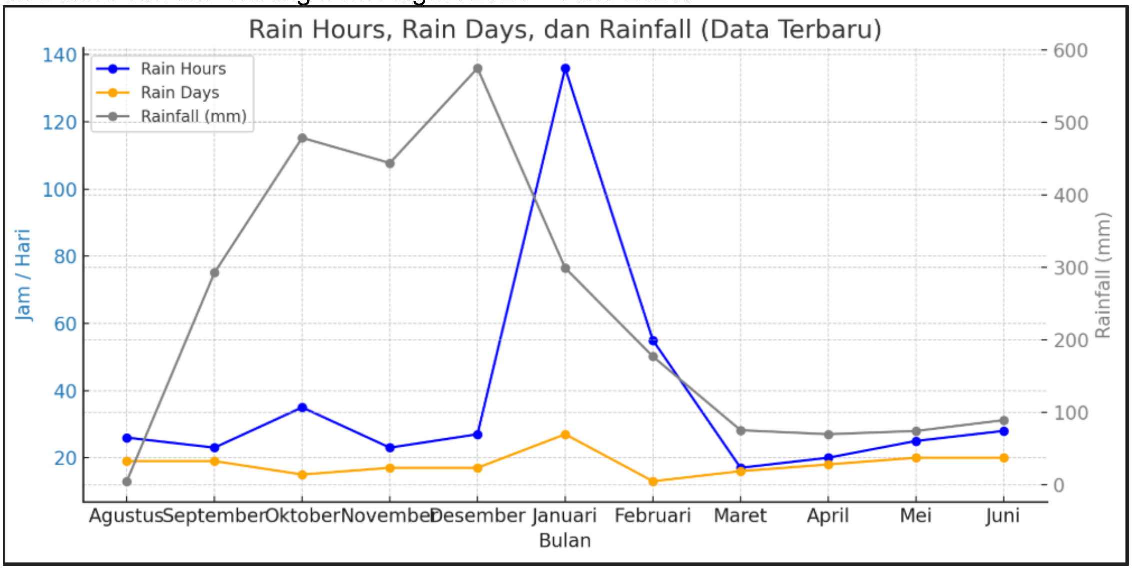

Figure 4. Rainfall Graph (Source: PT Garda Tujuh Buana)

Based on the rainfall graph, the highest peak of rain duration occurred in January with a total of about 135 hours of rain, much higher than in other months, while the number of rainy days also increased to more than 25 days. However, rainfall actually decreased from December to January. This indicates that in January the rains tend to occur more frequently and for longer, but with a lighter intensity than in December. Therefore, in December and January there is a good chance that the soil will be in a saturated condition.

Journal of Geology & Exploration
Vol. 5, No. 1, June 2026 : 1 – 20
E-ISSN 2963-2869

In this study, data related to seismic factors are considered as one of the dynamic loads that have the potential to affect slope stability. Therefore, the seismic factor used is an assumption of the earthquake factor in the form of a *seismic load* of 0.1 based on the 2017 earthquake source and hazard map (Ministry of Public Works and Public Housing).

Slope Design Geometry

The geometric model on the slopes of the South and West Blocks is carried out by inputting topographic data that has previously been made by the surveyor and then a 2D model is made in geotechnical software to be used as an actual cross-section of each section. The results of the slope geometry modeled in the South Block and the West Block are as follows.

a) South Block

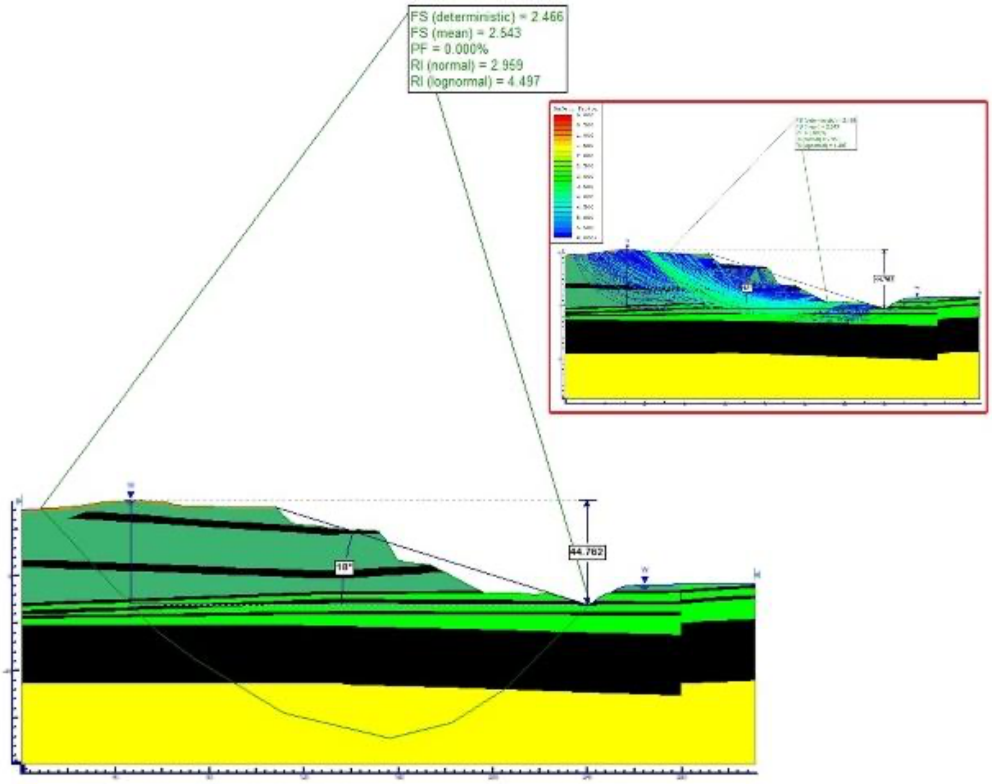

Figure 5. Analysis Results in section 1 of the South Block

Journal of Geology & Exploration
Vol. 5, No. 1, June 2026 : 1 – 20
E-ISSN 2963-2869

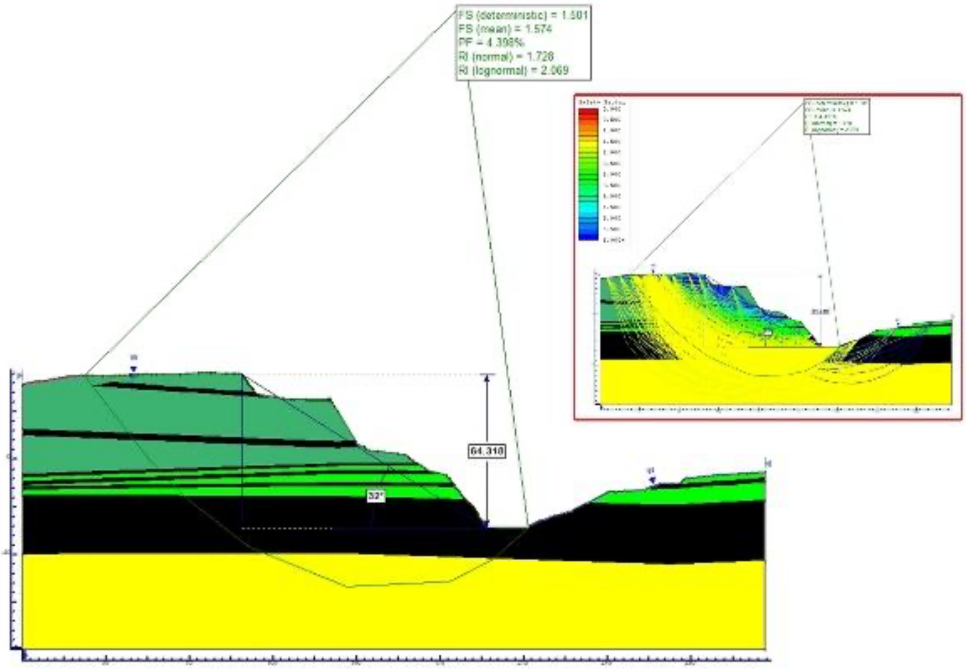

Figure 6. Results of analysis of section 2 of the South Block

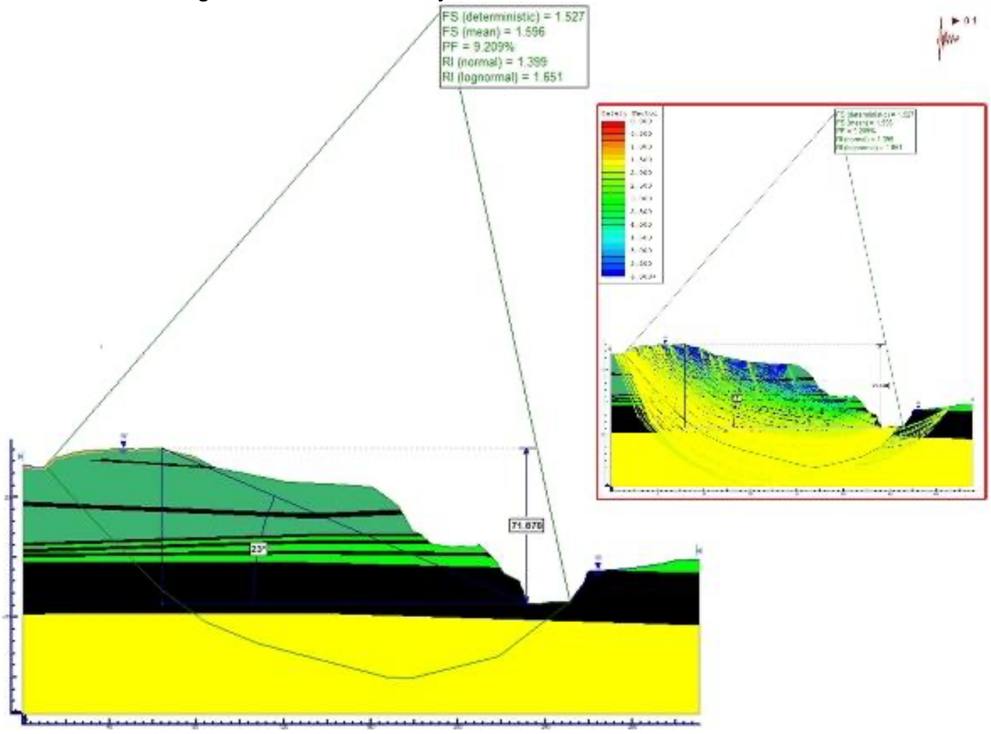

Figure 7. Analysis Results section 3 South Block

Journal of Geology & Exploration
Vol. 5, No. 1, June 2026 : 1 – 20
E-ISSN 2963-2869

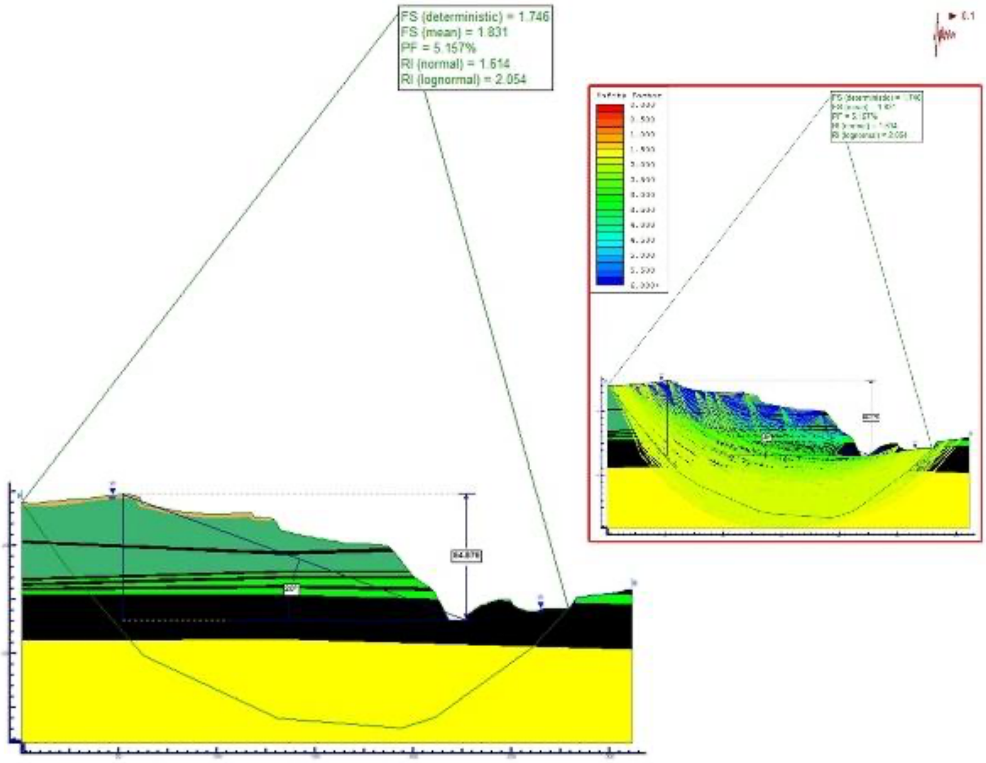

Figure 8. Results of analysis section 4 of the South Block

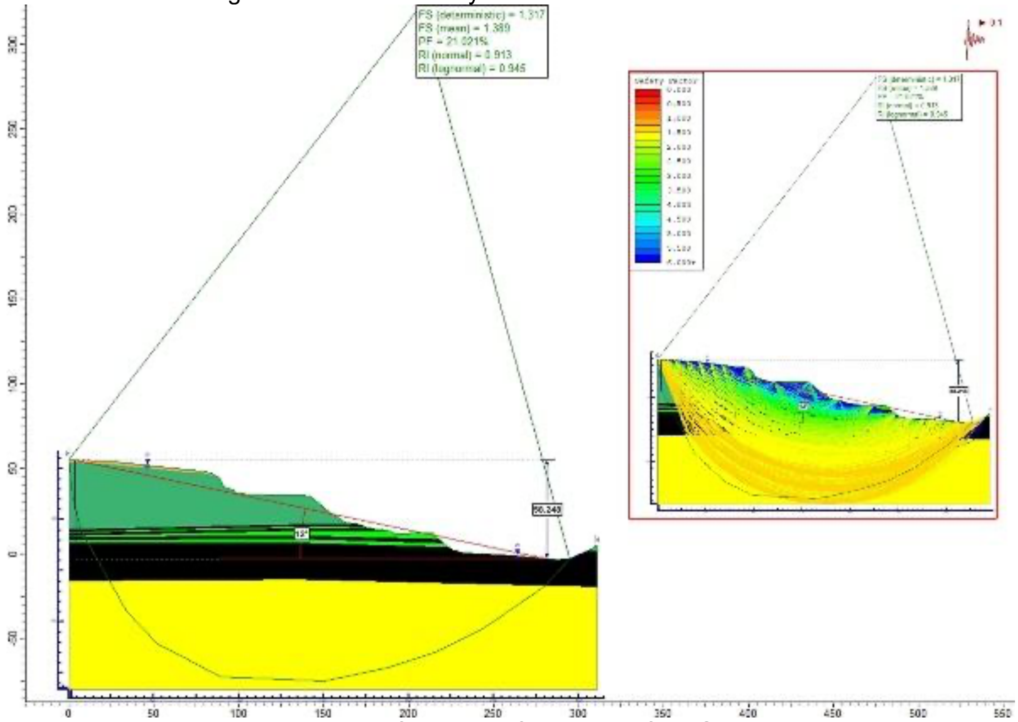

Figure 9. Results of analysis of section 5 of the South Block

Journal of Geology & Exploration
Vol. 5, No. 1, June 2026 : 1 – 20
E-ISSN 2963-2869

b) Western Block

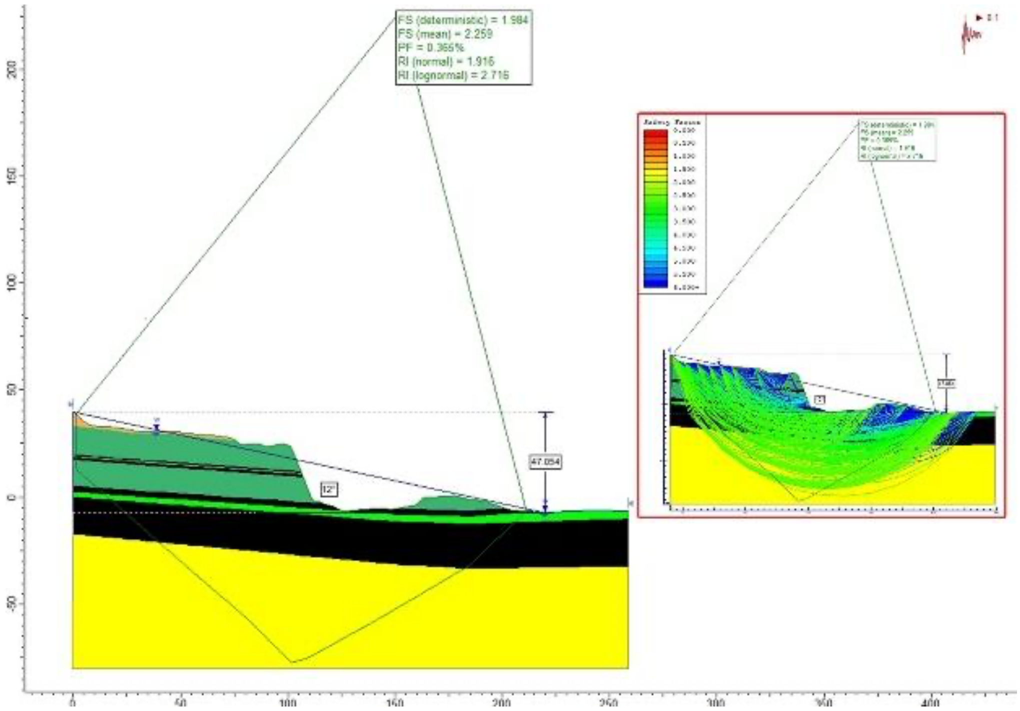

Figure 10. Results of analysis of section 1 of the West Block

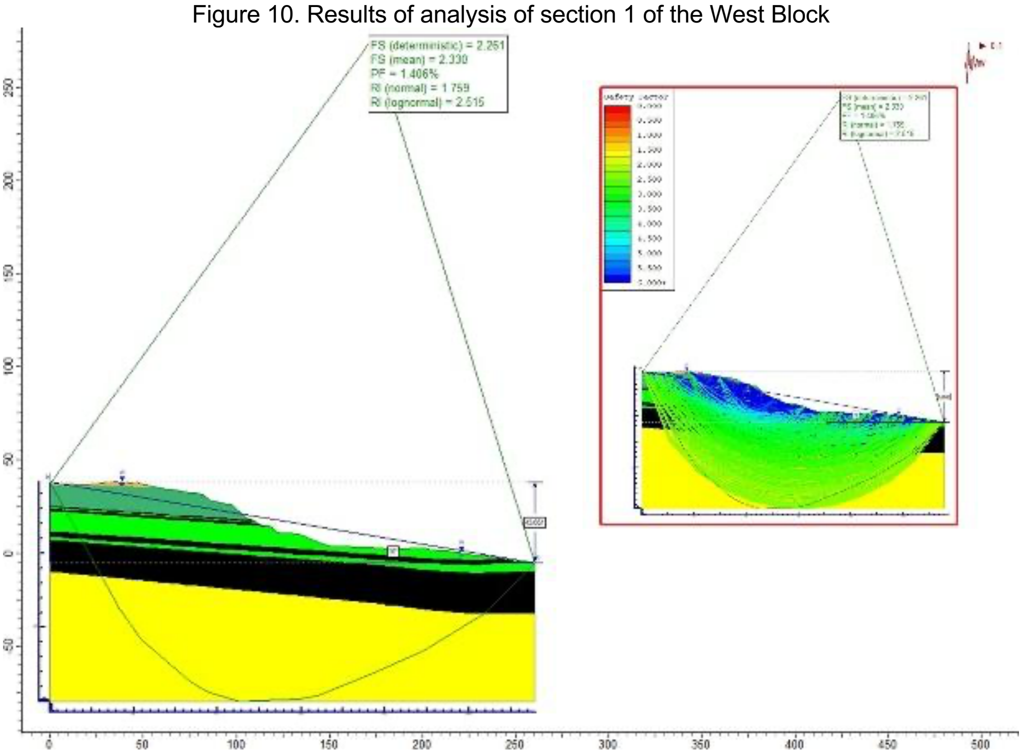

Figure 11. Results of analysis section 2 of the West Block

Journal of Geology & Exploration
Vol. 5, No. 1, June 2026 : 1 – 20
E-ISSN 2963-2869

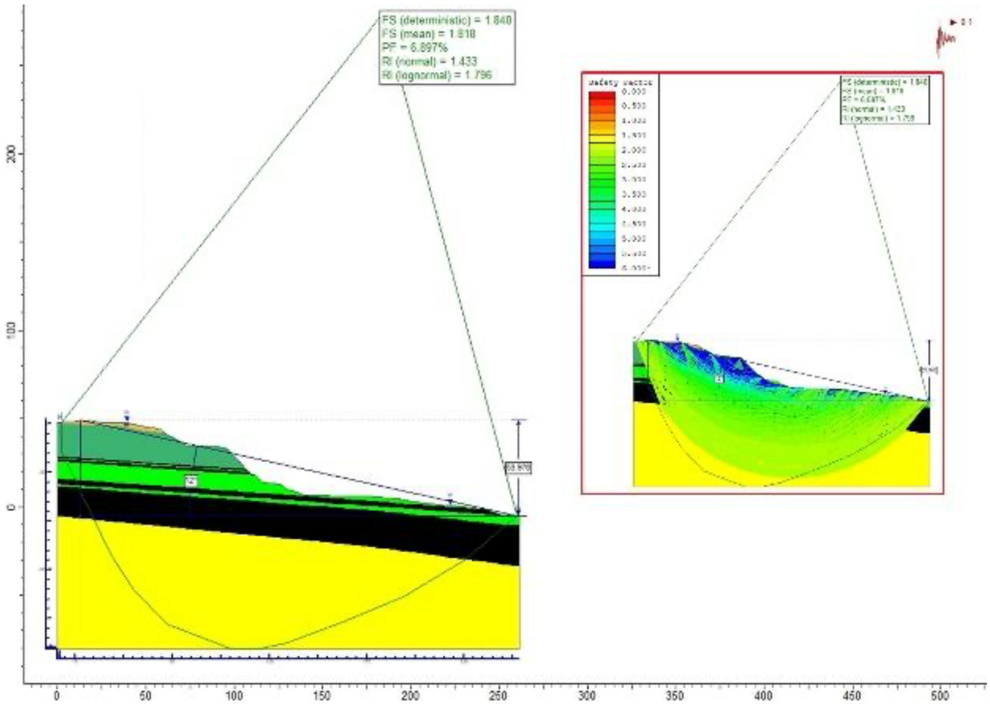

Figure 12. Results of analysis section 3 West Block

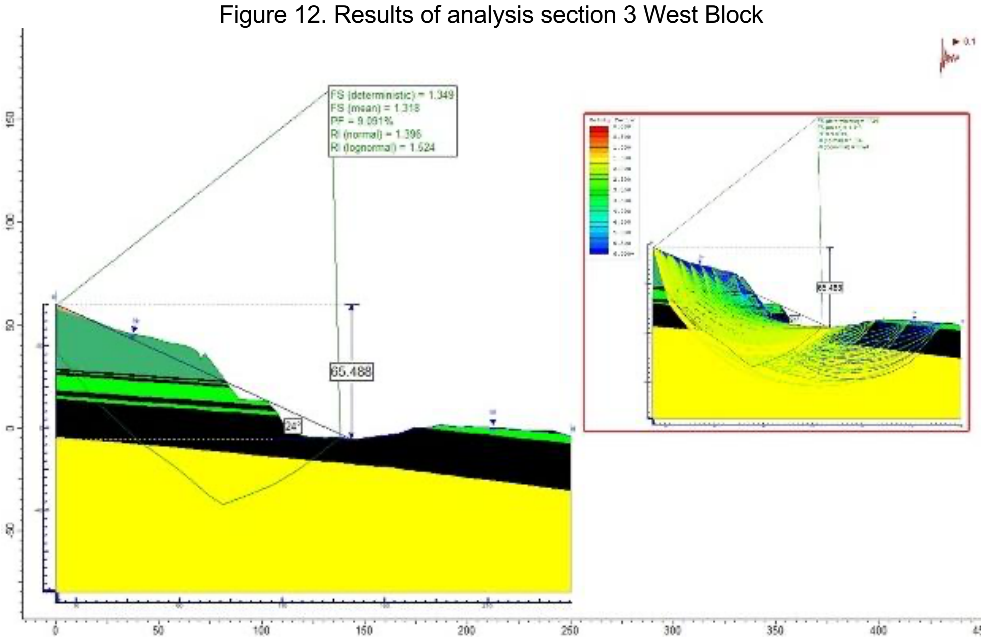

Figure 13. Results of analysis section 4 of the West Block

Journal of Geology & Exploration
Vol. 5, No. 1, June 2026 : 1 – 20
E-ISSN 2963-2869

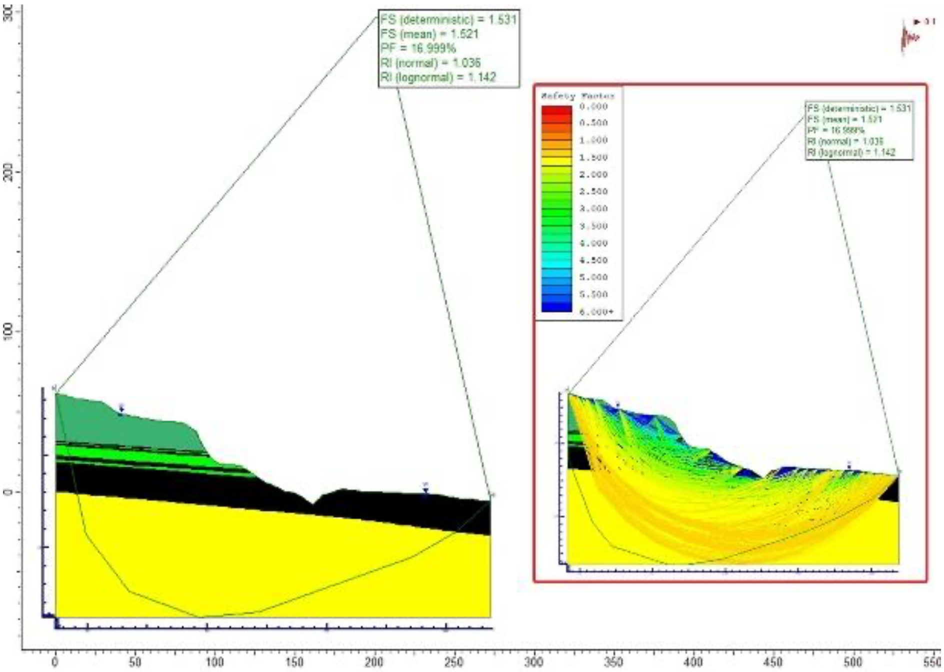

Figure 14. Results of Section 5 Western Block

Table 2. The results of the analysis of the overall slope (Overall slope)

BLOK	SECTION	OVERALL SLOPE		Faktor Keamanan	Probability of failure
		Height (meter)	Slope (degree)		
Selatan	Section 1	44.762	18	2.543	0.00%
	Section 2	64.318	32	1.574	4.39%
	Section 3	71.678	23	1.596	9.20%
	Section 4	64.876	20	1.831	5.15%
	Section 5	58.248	12	1.389	21.02%
Barat	Section 1	47.054	12	2.324	0%
	Section 2	43.651	10	2.33	1.41%
	Section 3	53.976	12	1.818	6.90%
	Section 4	65.488	24	1.318	9.09%
	Section 5	69.197	23	1.521	17%

Journal of Geology & Exploration
Vol. 5, No. 1, June 2026 : 1 – 20
E-ISSN 2963-2869

Table 3. Value of the safety factor of the entire slope of the mine (KEPMEN of Energy and Mineral Resources No. 1827K/30/MEM/2018

Jenis Lereng	Keparahan Longsor (*Consequences of Failure / CoF)*	Kriteria dapat diterima (*Acceptance Criteria)*		
		Faktor Keamanan (FK) Statis (Min)	Faktor Keamanan (FK) Dinamis (min)	Probabilitas Longsor (*Probability of Failure*) (maks)
Lereng Tunggal	Rendah s.d. Tinggi	1,1	Tidak ada	25 – 50%
Inter-ramp	Rendah	1,15 – 1,2	1,0	25%
	Menengah	1,2 – 1,3	1,0	20%
	Tinggi	1,2 – 1,3	1,1	10%
Lereng Keseluruhan	Rendah	1,2 – 1,3	1,0	15% - 20%
	Menengah	1,3	1,05	10%
	Tinggi	1,3 – 1,5	1,1	5%

In table 3, it can be seen that some slope conditions that have a safe Safety Factor (FK) value but for the Probability of Failure (PoF) value, have unstable conditions or have a chance of landslides based on the KEPMEN Regulation Number 1827, so it is necessary to make recommendations on the slope.

Actual Conditions of Research Locations

Slope stability analysis research was carried out on slopes that are still active in the process of mining activities, namely in the western and southern blocks of PT Garda Tujuh Buana Tbk, Bunyu Island Site, Bunyu District, Bulungan Regency, North Kalimantan Province. The lithology in this area is composed of an interchange of Sand Rock, Batulanau, Coal and Coal

Figure 15. Slope conditions of the research site

Journal of Geology & Exploration
Vol. 5, No. 1, June 2026 : 1 – 20
E-ISSN 2963-2869

From the results of observations in the field, there was material movement/landslide on the slope of the western block that occurred due to saturated soil. High and intensive rainfall causes water to seep into the slopes, increasing the pressure of the pores and reducing the shear strength of the soil. This makes the slope unstable and vulnerable to mass movement. The increase in the weight of the soil mass due to the accumulation of rainwater also adds to the load on the slope which ultimately triggers slope failure and landslides (Bowles, 1989; Moore, 2011).

Slope Stability Analysis

The analysis of slope stability used is the type of slip plane (*surface type*) that is expected to form if the slope experiences a non-circular (not circular) on the grounds that the lithological conditions on the slope are not homogeneous and tiered (Liong & Herman, 2012). This approach allows the software to effectively identify the most widespread failure trajectories, which tend to follow weak material layers, according to the principles described by Abramson et al. (2002) and Rocscience Inc. (2021).
Collapse criteria (*strength type*) In analyzing the slope stability of all materials used, the criteria *Mohr-Coulomb* (Das, 1995), where the strong shear characteristics of the soil are represented by the cohesion parameter (c) and the assumed deep shear angle of constant value.

South Block

Based on the results of the analysis of the geometry of the slope of section 1 which has a slope height of 44,762 meters and a slope slope of 18°, a *Factor of Safety (FoS)* value of 2,543 was obtained with a *Probability of Failure (PoF)* obtained of 0% in a fully saturated condition which means that the slope geometry in section 1 is declared stable according to the KEPMEN 1827 standard.

Then for the results of the analysis of the geometric stability of the slope section 2 which has a slope height of 64,318 meters and a slope slope of 32°, it produces a value of *Factor of Safety (FoS)* 1,574 with *Probability of Failure* is 4.39% (Figure 14) in the water saturated condition (*full saturated*) which means that the slope geometry in section 2 is declared stable according to the KEPMEN No.1827 standard.
In section 3 with a slope height of 71,678 meters and a slope of 23°, the value of *Factor of Safety (FoS)* of 1,596 with *Probability of Failure (PoF)* is 9.20% in the water saturated condition (*full saturated*). Although the FoS value is still above the minimum limit, the magnitude of the PoF value shows that the slope geometry in this section tends to be unstable according to the KEPMEN No.1827 standard.

The analysis in section 4 has an altitude of 64,876 meters and a slope of 20°. The safety factor of this section is 1,831 with Probability of failure is 5.15% in the water saturated condition (*full saturated*) which means that the slope geometry in section 4 is declared unstable according to the KEPMEN No.1827 standard.

The geometry of the South Block Slope section 5 has an altitude of 58,248 meters and a slope of 12°. The safety factor of this section is 1,389 with Probability of failure is 21.02% in the water saturated condition (*full saturated*) which means that the slope geometry in section 5 is declared unstable according to the KEPMEN No.1827 standard.

Journal of Geology & Exploration
Vol. 5, No. 1, June 2026 : 1 – 20
E-ISSN 2963-2869

Western Block

The results of the analysis on the slope geometry of the West Block section 1, which has a height of 47 meters with a slope angle of 12°, showed a *Factor of Safety (FS)* value of 2.324 and a *Probability of Failure (PoF)* of 0% in fully saturated conditions. Based on the KEPMEN ESDM No.1827 standard, this value indicates that the slope geometry in section 1 is in a safe and stable condition.

Furthermore, the Slope Geometry of the West Block Section 2 with an altitude of 43,651 meters and a slope angle of 10° obtained a safety factor value of 2.33 and a probability of failure of 1.41% in water saturated conditions. Based on the same standard reference, the slope geometry in Section 2 is included in the stable category because the value of the safety factor is still far above the minimum limit of slope stability.

In Section 3, the Geometry of the West Block Slope has a height of 53.9 meters with a slope angle of 12° and produces a safety factor value of 1.818 and a probability of failure of 6.90% in water saturated conditions. Although the FS value still exceeds the minimum threshold, the magnitude of the probability of failure shows that the slope geometry in Section 3 is categorized as unstable according to the criteria of the Ministry of Energy and Mineral Resources No. 1827.

The analysis in Section 4 of the West Block Slope Geometry shows a slope height of 65.4 meters with a slope angle of 24°. The value of the safety factor obtained was 1.318 with a probability of failure of 9.09% in water saturated conditions. Based on the applicable KEPMEN standards, this section is classified as unstable so it requires special attention and further mitigation measures.

Finally, the West Block Slope Geometry Section 5 has a height of 69.19 meters and a slope angle of 23°. The value of the safety factor obtained was 1.521 with a probability of failure of 17% in fully saturated conditions. Based on the slope stability assessment criteria from the Ministry of Energy and Mineral Resources No.1827, this section is declared unstable and recommended for design evaluation and handling efforts to minimize the potential for avalanches.

Based on the results of the slope analysis, the safety factors for the *overall slope* (*overall slope*) at the research site has met the standards set in the Decree of the Minister of Energy and Mineral Resources Number 1827 K 30 MEM 2018 concerning landslide safety factors on the mining slope, namely > 1.3 (KEPMEN ESDM, 2018). However, for the *probability of failure* From some slopes, it is still >5% where the chance of landslides is still high.

Slope Geometry Recommendations

Slope geometry recommendations are carried out by the *trial and error* method, namely by making several options or alternatives for slope configurations consisting of several benches with variations in width, elevation and inclination angle (Hasan & Heriyadi, 2018; Riandi, 2021).

South Block

The results of the analysis of incision 3 in the South block, which previously had slope geometry, had reached a safe safety factor value of 1,596, but the probability of failure value still did not meet the standard with a value of 9.20%. In this reconstruction process, the overall slope was maintained at 23° but the elevation was lowered from 71.6m to 70m. The recommendations made on this incision resulted

Journal of Geology & Exploration
Vol. 5, No. 1, June 2026 : 1 – 20
E-ISSN 2963-2869

in a safety factor value of 2,249 and a probability of failure value of 0% and was declared stable according to the standard.

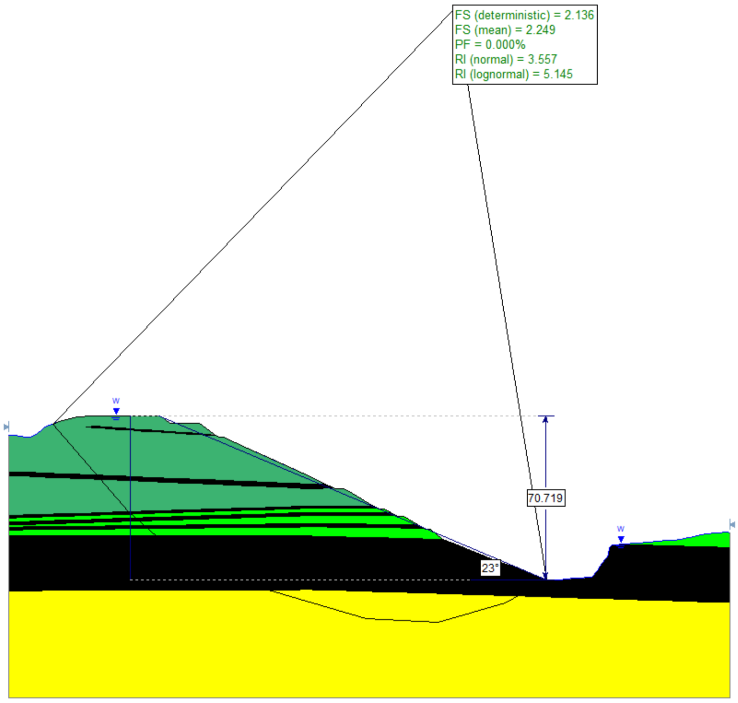

Figure 16. Recommendations for slope geometry section 3 South Block

The results of the analysis of incision 4 in the South block, which previously had slope geometry, had reached a safe safety factor value of 1,831, but the *probability of failure* value still did not meet the standard with a value of 5.15%. To optimize the design, reconstruction was carried out by adding new benches, lowering the elevation from 64.8 m to 62 meters and raising the *overall slope* from 20° to 21°. The recommendations made in this incision resulted in a safety factor value of 1,854 and a *probability of failure* value of 0%.

Journal of Geology & Exploration
Vol. 5, No. 1, June 2026 : 1 – 20
E-ISSN 2963-2869

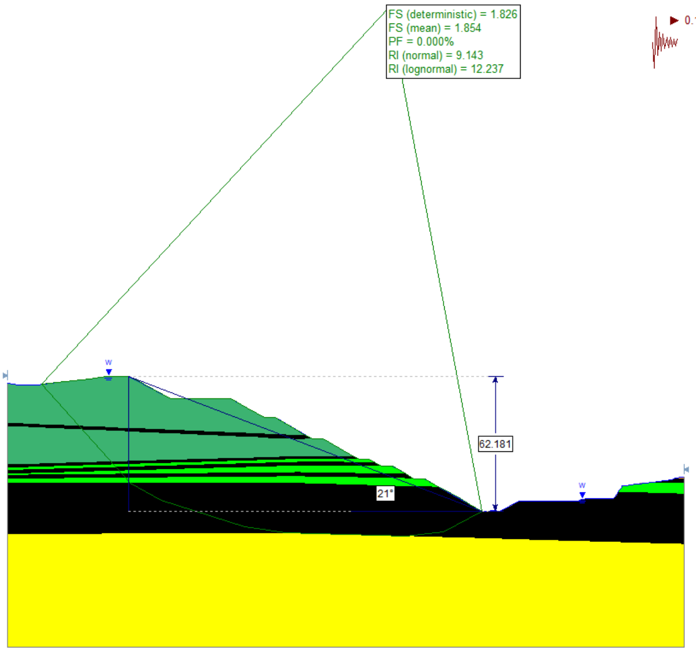

Figure 17. Recommended slope geometry section 4 South Block

The results of the analysis of incision 5 on the South block, which previously had slope geometry, had reached a safe safety factor value of 1,732, but the *probability of failure* value still did not meet the standard with a value of 9.09%. The technique functions to reduce the thrust force, enlarge the retainer field. The recommendations made in this incision resulted in a safety factor value of 1,414 and a *probability of failure* value of 0%.

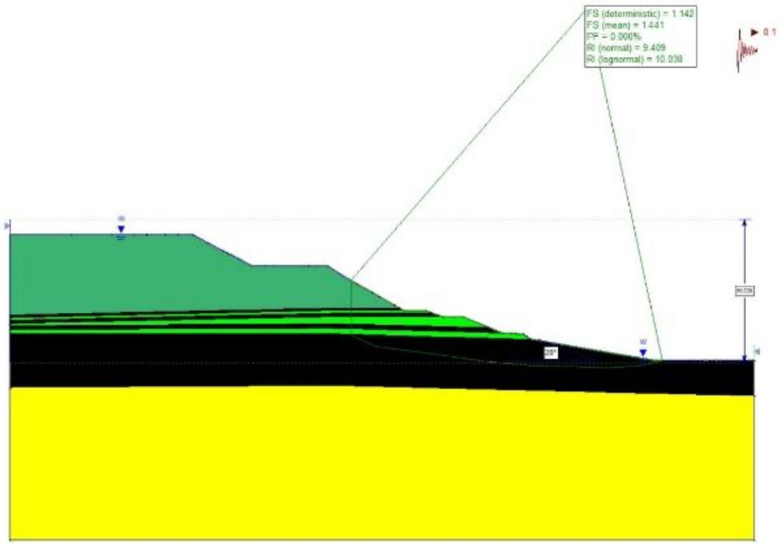

Figure 18. Recommendations for slope geometry section 5 South Block

Western Block

The results of the analysis of incision 3 on the West block, which previously had slope geometry, had reached a safe safety factor value of 1,818, but the *probability of failure* value still did not meet the standard with a value of 6.9%. The reconstruction carried out in this section still maintains the overall

Journal of Geology & Exploration
Vol. 5, No. 1, June 2026 : 1 – 20
E-ISSN 2963-2869

slope elevation but changes were made to the *overall slope* from 12° to 17°. The results of the analysis showed that the slope optimization carried out resulted in a safety factor value of 2,343 and a *probability of failure* value of 0%.

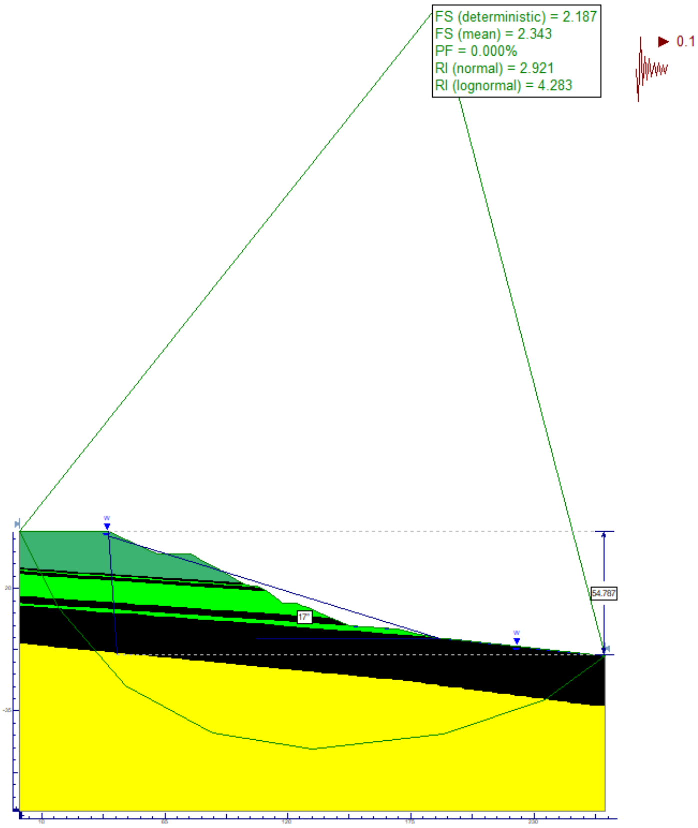

Figure 19. Recommendations for slope geometry section 3 West Block

The results of the analysis of incision 4 in the South block, which previously had slope geometry, had reached a safe safety factor value of 1,318, but the *probability of failure* value still did not meet the standard with a value of 10.28%. To improve the stability of the slope, reconstruction was carried out by reducing the elevation of the slope from 65.4m to 51.2m. The recommendations made in this incision resulted in a safety factor value of 2.0 and a *probability of failure* value of 0%

Journal of Geology & Exploration
Vol. 5, No. 1, June 2026 : 1 – 20
E-ISSN 2963-2869

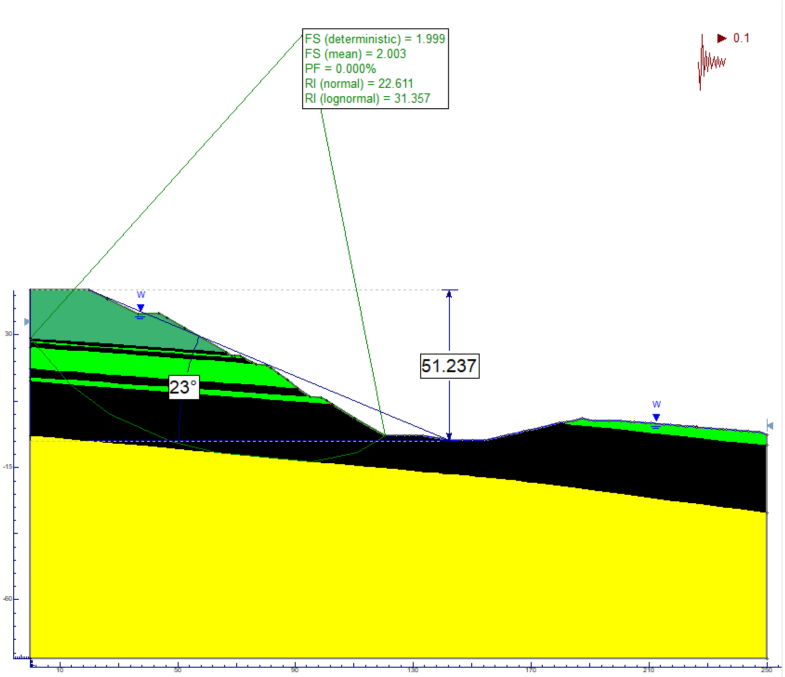

Figure 20. Recommended slope geometry section 4 West Block

The results of the analysis of incision 5 in the South block, which previously had a slope geometry, had reached a safe safety factor value of 1,521, but the *probability of failure* value still did not meet the standard with a value of 17% because in actual conditions, this section has a relatively steep bench geometry so that reconstruction was carried out but with an *overall slope* which is 23° and the slope elevation of 69m is maintained. The results of the slope geometry analysis after reconstruction resulted in a safety factor value of 2,245 and a *probability of failure* value of 0%.

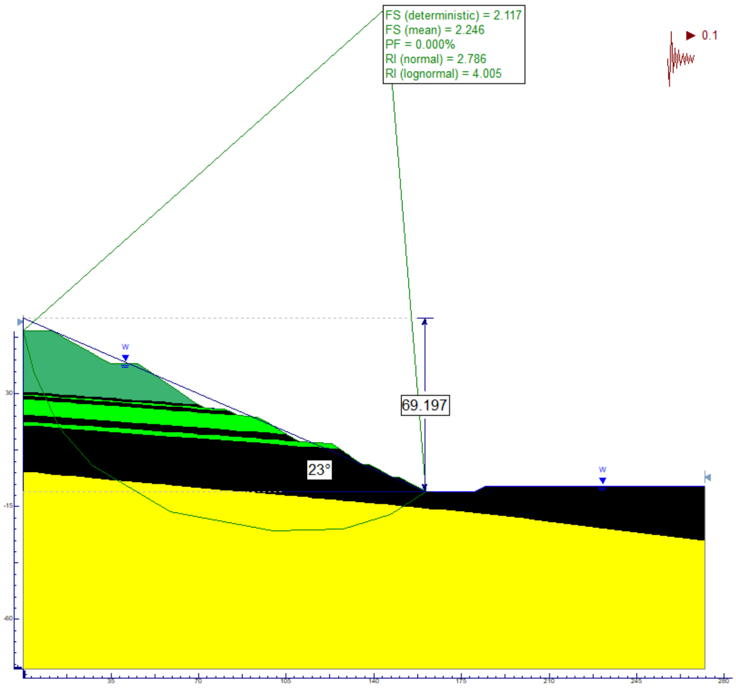

Figure 21. Recommended slope geometry section 5 West Block

CONCLUSION

Based on the results of engineering geological studies and numerical analysis, the slope stability at the research site is influenced by several main factors, namely slope geometry (slope height and slope angle), physical-mechanical properties of the materials that make up the slope (cohesion, deep shear angle, content weight, and weathering rate), as well as external factors in the form of groundwater conditions, drainage, and loads acting on the slope (Arif, 2016; Hardiyatmo, 2018). The higher and steeper a slope, and the lower the cohesion value and shear angle in the constituent material, the stability of the slope will decrease. In addition, increased pore pressure due to rainwater infiltration also increases the potential for avalanches. The results of the slope geometry analysis showed that sections 1 and 2 of the South and West blocks had high safety factor values and low *Probability of Failure (PoF)* values (0%) so that they met the safety standards of the Ministry of Energy and Mineral Resources No. 1827. Meanwhile, sections 3, 4 and 5 of the South and West blocks have not met the safety standards where the value of the *Probability of Failure (PoF)* >5% even though the value of the safety factor of the section has been qualified. So it is necessary to optimize the geometry on the slope. Efforts to improve slope stability are carried out by recommending improvements to slope geometry through reducing slope angles, lowering slope height, and increasing level width. By using the *trial and error* method, the *Probability of Failure (PoF)* values and safety factors from sections 3, 4 and 5 of the South and West blocks have met the safety standards of the Ministry of Energy and Mineral Resources No. 1827.

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