RESEARCH PAPER

Evaluation of gold (au) particle distribution in Grasberg mine material of Freeport Indonesia: fire assay approach

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Abstract: Freeport Indonesia is one of Freeport-McMoRan Copper & Gold Inc. affiliate companies. Freeport Indonesia conducted a series of mining and exploration processes for ore containing gold, silver, and copper. Grasberg is the mining location in PT Freeport, Indonesia. This research aimed to determine the distribution of gold (Au) particles in Grasberg rock samples with relatively high gold content. The method used for analyzing the gold content was Fire Assay. The research results indicated that the sample size affected the gold distribution in Grasberg Mine samples. An uneven distribution tendency of gold was observed in the distribution comparison of Splitter and Screen variations with normal Au content.

Keywords: Au distribution, Grasberg Mine, Fire Assay

INTRODUCTION

Gold (Au) is a precious metal with high economic value and is widely used in the jewelry, electronics, and investment industries. The Grasberg Mine, located in the province of Papua, Indonesia, is the largest gold mine in the world and has been the main source of gold production in Indonesia for several decades. The mine is operated by Freeport Indonesia [1]. The Grasberg surface mine was one of the world's largest copper and gold mining operations until mining there ceased in January 2020. The mine is now focused on mine closure activities, including overburden stabilization, infrastructure demolition, and reclamation [1]. The overburden stabilization project at the Wanagon Overburden Stockpile is a large-scale and technically challenging project focused on mitigating slope stability and overburden erosion rates [1].

The Fire Assay method, a well-established and reliable technique, was commonly used in the gold mining industry to analyze the distribution of gold particles in ore materials. This method, employed for centuries, proved accurate in determining the gold content in mineral samples. Several studies utilized the Fire Assay method to examine various aspects of gold analysis. These studies encompassed characterizing samples from Ponce Enriquez's mine [1], analyzing concentrate samples [2], investigating pre concentration techniques for platinum group metals (PGMs) and gold determination [3], establishing a novel bismuth fire assay (Bi-FA) method combined with inductively coupled plasma mass spectrometry (ICP-MS) for ultra trace gold detection[4], and conducting a comparative study between bulk leach extractable gold (BLEG) and fire assay methods[5]. These investigations demonstrated the effectiveness of the Fire Assay method in determining gold grades, analyzing concentrate samples, and quantifying PGMs and gold, providing valuable insights for the gold mining industry and contributing to scientific knowledge in the field.

The research on the distribution of gold particles in the material of Grasberg Mine PT Freeport Indonesia using the Fire Assay method can provide valuable insights for the gold mining industry in general. The Fire Assay method is a commonly used technique to determine the content of precious metals, such as gold, in mineral samples or ores. By analyzing the distribution of gold particles, this research could provide a better understanding of how gold particles were dispersed in the material of the Grasberg Mine. This information could have been used to optimize gold mining strategies and ore processing in other mines. By knowing where the higher or lower

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concentrations of gold were, mining companies could have directed their efforts to extract ore with higher gold content, thus increasing operational efficiency and profitability. Similar studies have been conducted on the characteristics of gold particle distribution in mineral rocks. The findings of this research provided valuable information to the mining industry as it could have been used to optimize gold mining strategies and ore processing in other mines. By knowing where the higher or lower concentrations of gold were, mining companies could have directed their efforts to extract ore with higher gold content, thus increasing operational efficiency and profitability [6]–[10].

Furthermore, this research can also contribute to general research and development in gold mining. The information obtained from this study can be used as a reference for other researchers interested in studying the distribution of gold particles in other gold mines. It can encourage the discovery of new knowledge and innovation in gold mining and ore processing methods.

MATERIALS AND METHODS

This research was conducted at the QC-Assay Laboratory of PT. Freeport Indonesia, Tembagapura, Timika, Papua. The data for this study consisted of the results of the Fire Assay method analysis using three sample preparation techniques: 166 grams, 20 grams, and Screen (+65, +200, +400, and -400) mesh. The equipment used included Rotary Splitter, Dry & Wet Screen, Filter Press, Fischer Scientific Drying Oven, Jaw Crusher, Boyd Crusher, Pulverizer, Bowl & Disc, Filter Paper, Oven, Vacuum, Fume Hood, Analytical Balance, Fire Assay Furnace, Crucible, Porcelain Crucible, Cupel, reaction tubes, and PerkinAlmer Type 400 AAS (Atomic Absorption Spectroscopy). Meanwhile, the materials used were flour, Ore Flux, Silica, Borax, and Hydrochloric Acid.

Procedures of Research

Crushing Sampel Grasberg Mine

The wet and dry samples were separated, and the wet samples were dried for 4-6 hours. All 5-8 kg samples were placed into the Jaw Crusher. The Boyd Crusher was cleaned before crushing the samples. All the samples (5-8 kg) were poured into the Boyd Crusher funnel and Rotary Splitter. 500-800 grams of sample were taken from the collection pan and transferred to a smaller pan, with a labeled pulp bag placed. The rejects were discarded, and the process continued to the next sample. The samples were dried with labeled bags until completely dry (approximately 2 hours).

The pan containing the sample and the labeled sample bag was removed and cooled for 10 minutes. All the samples to be pulverized were placed into a clean bowl that had been appropriately cleaned

according to the disc pulverize. The bowl was ensured to be tightly closed. Methanol was added to the bowl containing the sample to be pulverized. The bowl was placed in a locked position with a clamp until it was tightly secured. The cabinet cover was closed, then START was pressed on the pulverizer machine to initiate the pulverization process for approximately 4 minutes. After approximately 4 minutes, STOP was pressed to stop the machine, and the machine was allowed to come to a complete stop before removing the bowl containing the sample. The cabinet cover was lifted, the bowl was lifted, and the sample was manually transferred and poured onto the paper. A brush was used to remove any remaining sample sticking to the bowl. Lastly, all the samples (500-800 grams) were placed into the labeled pulp bags.

Grasberg Mine Sample Splitter

The equipment and collection bottles were cleaned. Next, the collection bottles were attached to the rotating crown. The sample was poured into the pouring funnel. The machine was turned on, and the crown started to rotate. At the same time, the vibrating channel directed the finely crushed sample into the crown's input cylinder, ensuring that the sample was uniformly distributed into the collection bottles. The machine was turned off once all the samples were evenly distributed. The bottles were removed from the rotating crown. The samples in the bottles were poured into the sample bags according to the labels.

Screening Grasberg Mine Samples

The screening process had two techniques: Wet Screening and Dry Screening. In this study, the researcher used the Wet Screening technique. The first step was to weigh the reject sample from the Splitter, amounting to 200-300 grams. Then, screens with sizes of +65 mesh, +200 mesh, and +400 mesh were selected. The sample was poured into the screens according to their placement on the portable wet sieve shaker. It was ensured that the finer mesh screen was positioned below, the coarser ones (the +65 mesh screen was placed on top of the +200 and +400 mesh screens). The sieve shaker switch was turned on. The sample was allowed to pass through while the water was flowing. The screening process was conducted carefully to prevent sample spillage or scattering outside the screen device. The -400 fraction of the sample was collected in a container or bucket. Next, the size-fractioned samples were poured into aluminum pans and dried in an oven at approximately 170°C for about 30 minutes until dry. The dried samples were then removed from the oven using heat-resistant gloves. The -400 sample fraction underwent a dewatering process, and the resulting sediment was dried in the oven. After drying, the sample was removed from the oven and pulverized using a pulverizer machine. The final step was to weigh the

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dried size-fractioned samples and input the data into the software.

Fire Assay Testing for Low-Grade Samples

The first step was to prepare 40 grams of crucibles for each sample to be melted. Approximately 150 grams of flux ore were added to the crucible. The sample, weighing approximately 20 grams, was then added to the crucible. 2 grams of flour were added to the crucible that already contained flux ore and the sample (for certain samples, 4 grams of silica were added). The sample mixture was stirred until homogeneous, and several grams of borax was added. The sample was placed in the furnace at 1000°C for 60 minutes. The molten sample was taken from the furnace and poured into an iron mold, then left to cool until solidified. The button was removed from the mold by being hit with a hammer. The button was placed on a cupel, and then the cupel was placed in the cupellation furnace at a temperature of approximately 1000°C for about 60 minutes.

Mineral Extraction Using Wet Assay Procedure

The cupel was taken from the furnace and left to cool, then the beads on the cupel were collected in sequence. The beads were placed in a 10 mL reaction tube, and 0.5 mL of HNO_3 was added. The sample was heated in a water bath until it became colorless. Then, 0.5 mL of 37% HCl and distilled water were added to the solution to reach the exact volume of 10 mL, followed by shaking and letting it sit for a few minutes. The final step was to analyze the sample using the PerkinAlmer Type 400 Atomic Absorption.

Spectrophotometer instrument in the QC-Assay Laboratory.

RESULTS AND DISCUSSION

This study used samples from Grasberg Mine, which were analyzed using three methods: (1) particle size comparison with screens, namely +65, +200, +400, and -400 mesh, (2) normal samples, and (3) sample separation by splitting into several samples.

Distribution of gold with different sieve sizes

In particle analysis using mesh sizes, smaller mesh sizes allowed smaller particles to pass through the sieve, while larger particles got trapped by the sieve. In the context of gold content analysis, if the mesh size was smaller, smaller-sized particles passed through the sieve and accumulated in the #-400 mesh fraction, while larger-sized particles were trapped in larger fractions such as #+65 mesh, #+200 mesh, and #+400 mesh. Therefore, generally, it was expected that the gold content in the #-400 mesh fraction (smaller particles) would be higher than in the fractions with larger particle sizes.

The gold content in larger mesh sizes tended to be higher than in smaller mesh sizes, as shown in Table 1. It occurred because larger gold particles were more likely to be retained on sieves with larger mesh sizes. As a result, fractions with larger mesh sizes (such as #+65 mesh) had a higher gold concentration because larger gold particles tended to get trapped on those sieves.

Table 1. Fire Assay Analysis Results Data

ID Sample	#+65	Re:#+65	#+200		#+400		#-400	
313005402842	23.68		13.172	15.35	7.01	8.504	4.332	4.234
313005402824	46.223	9.192	15.1	12.38	5.408	6.544	4.635	4.592
313005402834	4.707		5.348	5.207	5.243	4.25	4.971	4.896
313005402832	12.906		11.717	8.034	6.758	6.29	4.065	3.7
313005402838	5.458		6.099	8.551	3.648	4.627	5.831	5.522

On the other hand, as the mesh size became smaller (such as #-400 mesh), larger gold particles could not pass through the sieve and were retained in fractions with larger mesh sizes. Therefore, fractions with smaller mesh sizes (such as #-400 mesh) would likely have a lower gold content. The data obtained from the +65 mesh screen sample showed Gold Nugget or free gold because the +65 mesh sample had relatively large pores. However, during the Wet Screening process, the sample could not penetrate the pores of the +65 mesh, indicating the presence of coarse-sized gold particles. This uneven distribution of gold samples from +65 to +400 was the result. Thus, in Table 1, the increase in gold content in larger mesh sizes (such as #+65 mesh) and the decrease in gold

content in smaller mesh sizes (such as #-400 mesh) might have reflected the preference for gold distribution in larger-sized particles within the sample.

Distribution of Gold with Different Split Masses

The sample with ID 313005402842 had a measured gold content (Au Calc) of 6.077, but when split into masses of 20 grams and 166 grams, the gold content increased to 6.610 and 7.240, respectively. However, the average Au in the normal process was only 5.515. It indicated a difference in the distribution of gold in this sample. Fluctuations or measurement errors might have occurred while splitting the gold into different masses.

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The sample with ID 313005402824 had a measured gold content (Au Calc) of 8.221. When split content became 7.014 and 9.248, respectively. The average Au in the normal process was 7.938. This difference indicated variation in the distribution of gold into masses of 20 grams and 166 grams, the gold in this sample. There might have been variations in mineral composition or heterogeneity within the gold sample, resulting in different split results

Table 2. Calculation and Method Comparison Results

ID Sample	Au			
	Au Calc	Split to 20 g	Split to 166 g	Average Au normal Proc.
313005402842	6.077	6.610	7.240	5.515
313005402824	8.221	7.014	9.248	7.938
313005402834	4.928	4.949	4.507	4.321
313005402832	5.347	7.814	9.472	7.115
313005402838	5.765	4.527	9.137	5.750

The sample with ID 313005402834 had a measured gold quantity (Au Calc) of 4.928. After being split into 20 grams and 166 grams, the gold quantity increased to 4.949 and 4.507, respectively. The average Au during the normal process was 4.321. This difference indicated variations in the gold distribution within this sample. There might have been fluctuations in mineral composition or heterogeneity within the gold sample. The sample with ID 313005402832 had a measured gold quantity (Au Calc) of 5.347. After being split into 20 grams and 166 grams, the gold quantity increased to 7.814 and 9.472, respectively. The average Au during the normal process was 7.115. It indicated differences in the gold distribution within this sample, which could be attributed to variations in mineral composition or heterogeneity within the gold sample. The sample with ID 313005402838 had a measured gold quantity (Au Calc) of 5.765. After being split into 20 grams and 166 grams, the gold quantity became 4.527 and 9.137, respectively. The average Au during the normal process was 5.750. This difference indicated variations in the gold distribution within this sample. There could have been fluctuations in mineral composition or heterogeneity within the gold sample. The difference in the distribution of gold between the measured gold quantity and the split results into different masses is due to the variation in mineral composition or heterogeneity within the gold sample [11]–[13]. The gold in the sample may be distributed unevenly, resulting in different outcomes when split into different masses. Also, measurement errors or fluctuations during the splitting process can contribute to these differences. Therefore, it is important to understand and account for the variations in gold distribution when analyzing the sample [14].

Split with a Mass of 20 grams

Table 3 shows that the gold content varied among the samples. Sample 2 had the highest gold content with an assay result of 9.125, followed by Sample 4 with a gold assay 6.625. Sample 3 had a slightly lower gold content with an assay result of 5.968, while Sample 1 had the lowest with an assay result of 4.722. The conclusion drawn from this analysis was that there was variation in the gold content among the tested samples. Sample 2 had the highest gold content, while Sample 1 had the lowest. This variation could have had important implications in relevant contexts, such as the mining industry or evaluating raw materials' quality. Further analysis might have been needed to understand the causes of this variation and its implications in a broader context.

Table 3. Results of 20-gram Assay Splitter

ID Sample	Assay Split to 20 g			
	Sample 1	Sample 2	Sample 3	Sample 4
313005402842	4.722	9.125	5.968	6.625
313005402824	6.123	4.784	7.48	5.046
313005402834	4.85	4.96	5.167	4.818
313005402832	9.103	8.297	7.841	21.851
313005402838	4.258	3.792	5.18	4.876

These differences in results were influenced by the uneven sample quantities during the separation process using the 20-gram rotary splitter. During the pouring of samples into the rotary splitter machine, there was non-uniformity caused by the rotational speed of the rotary splitter, resulting in an uneven sample distribution. Some +65 mesh samples were still relatively coarse (Table 1), which was attributed to the pulverizing process where the samples were not finely ground. Due to this, it was possible that there were still

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coarse gold contents that were not well-distributed during the screening process using three different mesh sizes.

Split with a Mass of 166 grams

In the data from the Grasberg Mine samples, the assay analysis results of the 166g splitter showed unstable distribution compared to the duplicate samples from the 166g splitter. The duplicate samples exhibited relatively high Au content, as shown in Table 4. The second duplicate sample with ID 313005402824 and the fifth duplicate sample with ID 313005402838 (Table 4) had significantly high Au content. It was likely due to the presence of cross gold in the samples during duplication and uneven distribution during the 166g splitting process.

Table 4. Results of 166-gram Assay Splitter

ID Sample	Assay Split to 166 g	
	Sample 1	Sample 2
313005402842	6.003	8.476
313005402824	6.362	12.133
313005402834	4.38	4.634
313005402832	10.963	7.98
313005402838	4.596	13.678

From the provided table, we can observe the results of the Assay Splitter using a sample weighing 166 grams. The results showed variations in the assay values between Sample 1 and Sample 2 for each sample ID. For example, in sample ID 313005402842, the assay value for Sample 1 was 6.003 grams, while for Sample 2, it was 8.476 grams. It indicated variations in the gold content between the two samples. The table also revealed variations in the gold content among the tested samples. For instance, in sample ID 313005402824, Sample 1 had an assay value of 6.362 grams, while Sample 2 had an assay value of 12.133 grams. This variability indicated differences in the distribution of gold particles within the tested material, which could affect the potential gold extraction at the site. The high assay values in this table indicated significant gold potential in the tested material. For example, in sample ID 313005402832, Sample 1 had an assay value of 10.963 grams, while Sample 2 had an assay value of 7.98 grams. It indicated a relatively high concentration of gold in those samples. This information could be used to evaluate the quality and gold potential in the Grasberg Mine material of PT. Freeport Indonesia.

An improved separation procedure could reduce overall standard deviation since pouring the sample through a container into a rotary splitter and a rotating funnel was not uniform due to slight influences from changes in the sediment suspension pouring speed into the rotary splitter system and funnel, resulting in uneven sample distribution in the separation bottle and filter membrane. However, this issue could be easily avoided by using a funnel that directed the delivery of a homogenous suspension.

The differences in gold content among the tested samples can be attributed to several factors [12], [15]–[17]. Geological variability, such as rock formation, geological structure, or the process of mineral deposit formation, can influence the gold content in each sample. Additionally, non-homogeneous or non-representative sample collection, variability in the splitting process, and errors in the assay analysis can contribute to the observed differences. Other contextual factors, such as the timing of sample collection, pre-analysis treatments, or the presence of other mineral compositions, can also impact the assay results. Understanding these factors is crucial for accurately interpreting the variations in gold content among the samples. Further analysis may be required to identify more specific causes in certain cases.

CONCLUSION

The Grasberg Mine samples were of the High-Grade type, meaning that the Grasberg Mine material had a high gold content. The Grasberg Mine samples had a high Au content based on the data obtained. The sample size significantly influenced the distribution of gold in the Grasberg Mine samples, as seen from the data obtained using the Screen method. On the +65 mesh screen, it was found that the sample labeled 313005402824 contained Cross gold with a very high Au content of 46,223 ppm. In the distribution comparison between the 20 g splitter sample, 166 g splitter sample, and the screen sample with normal Au data from QC-Lab, it was observed, based on the graph data, that the sample distribution was uneven. This tendency was particularly evident in the 166g sample, and the main cause identified was that during the sample preparation process, the sample was not finely ground before being tested in the subsequent stages. For example, in the Pulverize process, ensuring that the sample was thoroughly ground before proceeding to the next testing stage was crucial.

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