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An Analysis of Hole Deviation and its Effect on Production

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Abstract

An analysis of hole deviation and its effect on production at Chirano Gold Mines Limited has been carried out. Chirano Gold Mines Limited employs sublevel stoping and open stoping methods where production holes are drilled in the form of rings. Complete control of borehole directions sometimes was not obtained during drilling. This problem caused shortfalls in the burden, spacing and hole depth parameters. The boretrak instrument was used to measure the drill hole deviations at the stopes during this study. The analysis was based on 29 holes in 5 rings which recorded total deviations of 4.4 m, 1.9 m and 16.8 m in the burden, spacing and hole depths parameters respectively. The result showed 31.2% deviation in the burden, 2.8% deviation in spacing and 3.2% deviation in the hole depth. The effect of the hole deviations on production was portrayed by an increased output of 1965.85 t of materials representing 23% deviation from the planned. This result also showed that there would be ore dilution which may decrease the mill head grade. This undoubtedly would increase the cost of production of the mine through extra energy requirement to blast and to process these waste materials. From the results obtained, it was recommended that more boretrak surveys should be carried out for informed decisions to be made by planners during the preparation of the charge plans. Also, deviations in the toe burden should be minimized by drillers using competent machines to drill accurately.

1. Introduction

Rock fragmentation involves the breaking up of in-situ rock into pieces or fragments of desired sizes for end-use. Fragmentation of rock is one of the major problems in maximizing economic efficiency in the exploitation of mineral deposits [1]. Drilling and blasting are the primary processes used in breaking and loosening in-situ rock formations in both underground and surface operations. Blasting is the second phase in the fragmentation process after drilling whereby rocks are disintegrated into smaller particles using explosives. The explosives provide the main source of energy for breaking the rock mass. In underground mines, blasting can be subdivided into the short hole and long hole blasting. In short hole blasting, the diameter and length of short holes are usually limited to 43 mm and 4 m respectively. It is usually used in breast stoping for narrow, tabular orebodies such as gold or platinum reefs. According to [2], ring blasting, bench blasting and vertical crater retreat (VCR) are the three long-hole blasting systems in underground operations. In all, drilling operation is one of the critical stages of the overall excavation process with a major influence on the efficiency of the downstream processes such as blasting, scaling, loading, hauling and support operations.

Drilling involves making holes and excavations in the rock formation using the appropriate equipment or tools known as drill rigs or rock drills. In underground mining, drilling is normally carried out with top hammer rotary percussive jumbo drills [3]. Drilling is generally carried out for exploration, hydrology and drainage, and production for mineral exploitation [4]. At underground, production drilling methods include slot drilling, ring drilling and long-hole drilling. Slot, necessary for rock expansion is essential for conventional sublevel stoping where vertical rings or rows are blasted. These slots can be initiated at a slot raise driven by conventional raising methods, raise boring, drop raising i.e. predrilling and blasting raise from the top using small diameters (200 mm holes for relief) or crater blasting. The slot mostly stretches from the extraction level to the back of the stope. It is usually expanded to full stope width by long hole slashing and must be 4 m to 5 m wide [5]. At end pillar raise or a control, slot raise is initially blasted from wall to wall, from which successive slabs rounds break [6]. The raise is opened either by shrinkage stoping or long hole drilling across the full width and height of the stope and forms a free face for blasting to be initiated. Hole sizes for drop raising applications generally vary from 101 mm to 165 mm [7]. Putting the slot at the center of the stope will double the working areas in the stope, however, this can cause ground control problems, particularly in large stopes and hence it is rarely used [8]. The process of designing production rings for underground operations is critical for maintaining productions, however, it is labour-intensive and time consuming [9]. In ring drilling or fan drilling, holes are drilled radially outward from an access drift in a plane to a slot raise or open stope. The purpose of the blast and inherent stability of the formation after blasting will determine the number of rings. According to [10], where ring drilling is applied, the cross-section of the stope is a long hole drilled from the sublevel drifts. Generally, long-hole mining demands two excavations within the ore at different elevations below the surface (15 m – 30 m) apart [2]. Long-hole drilling and large-volume production blasting require even and fairly well-designed orebodies [8]. Drilling pattern for underground operations includes the square pattern, rectangular pattern and the staggered pattern [4].

Drill hole deviation is the major quality criteria of the geometric difference between the drilled or actual hole and the designed path. This difference is called the center of deviation. Depending on the drilling diameter and utilized drilling tool, the center of deviation can achieve values up to 0.5 mm per meter of drilling depth. One approach to measuring the center of deviation is to measure the wall thickness from the outside of the workpiece with an ultrasonic system. The disadvantage is the susceptibility of the ultrasonic system towards the rough environment [11]. A laser-guided deep-hole boring tool with integrated piezo-actors also used by [12] to measure the center of deviation. Four position-sensitive diodes were utilised during the process. This system also was unsuitable for full drilling operations. Other systems were based on alignment telescope or autocollimators. In the mining industry, the ability to charge and blast a production borehole is fundamental. However, if a rock mass conditions are challenging, with cavities, fractured zones or uneven floor conditions, the positioning of the drilling equipment to get the desired or planned paths of the boreholes become difficult [13, 14]. This may cause a deviation in the burden, spacing and even the desired borehole depth [15]. Drilling accuracies can be jeopardized by many factors including; inaccurate placement of drill reference marks, incorrect drill set-up, inconsistent drill operation; and geological structure [16].

In a bid to further investigate the effect of hole deviation on production, the drilling and blasting practices at Chirano Gold Mines Limited (CGML) were analysed. At CGML, slots are drilled at the end of ore drives to create a free face for subsequent blasts. Solo machines are used for production hole drilling. CGML employs Sublevel Stoping and Open Stoping methods where production holes are drilled in the form of rings in a fan-shaped order. Currently, complete control of borehole directions is sometimes not obtained during drilling. This problem consequently causes shortfalls in the burden, spacing and designed hole depth which in effect, have adverse effects on production since it leads to the creation of toes (bridges), boulders, ore dilution and ore losses.

This paper therefore sought to analyse drill hole deviation and its effect on production at Chirano Gold Mines Limited (CGML). The objectives of this paper were to study the deviations between actual and planned drill paths of the mine, identify the effect of hole deviation on production and suggest possible ways to minimize its occurrence.

1.1. Information about the Study Area

Chirano Gold Mines Limited (CGML) is an underground and open-pit gold mine in the Western Region of Ghana, within the Bibiani gold belt. It is owned by Toronto-based Kinross Gold Corporation. CGML was explored and developed in 1996 by Red Back Mining NL, an Australian company that moved to a Canadian listing in April 2004. CGML began production in October 2005. Kinross Gold acquired the mine on 17th September, 2010. The mine consists of 11 deposits: Akwaaba, Suraw, Akoti South, Akoti North, Akoti Extended, Paboase, Tano, Obra South, Obra, Sariehu and Mamnao. Akwaaba and Paboase operate underground with the remaining on open-pit. Open-pit and underground ore are processed at the Chirano plant. The capacity of the mill is approximately 3.5 million tonnes per annum. Processing involves crushing, ball mill grinding, leaching, and Carbon in Leach. Gold is recovered by an elution circuit [17].

Chirano Gold Mine Limited (CGML) is situated in southwestern Ghana, precisely Bibiani in the Western Region, 100 km south-west of Kumasi. The town of Bibiani lies 15 km NNE (North North East) of the mine area, approximately 37 km by road. Access to the mine from Accra, capital is through a highway to Kumasi and then highway running southwest towards Bibiani and onwards to the town of Sefwi-Bekwai. The final approach is through a 13 km road whose junction is approximately 9 km beyond Sefwi-Bekwai. Mine infrastructure comprises a centrally located processing plant, tailings storage facility, water storage facility, staff village, workshops and offices [18].

Figure1: A Map of Ghana showing the Location of CGML (Source: Anon, 2014)

The CGML area lies within the Proterozoic terrain of southwest Ghana, along a major structure separating the Sefwi belt to the west from the Kumasi basin to the east known as the Bibiani Shear Zone. The Chirano gold deposits lie to a splay off the main Bibiani shear zone known as the Chirano Shear. The two are separated by a small inlier of younger Tarkwaian epiclastic sediment. The Chirano gold deposits are hosted by fractured and altered mafic volcanics and granite, and include stacked arrays of parallel veinlets, veinlet stockworks and mineralized cataclasites. The geometry and the shape of the deposit range from tabular (Obra) and pipe-like (Tano), to multiple parallel lodes (Paboase). The mineralized zone thickness ranges from a few meters to over 70 m. Most deposits dip very steeply towards the west or southwest and also plunge very steeply. Generally, the gold mineralization is fine-grained and is associated with 1% to 5% pyrite, and the distribution of gold appears to be closely associated with the presence of pyrite. The hydrothermal alteration assemblage is characterized by silica, ankerite, albite, sericite and pyrite [19].

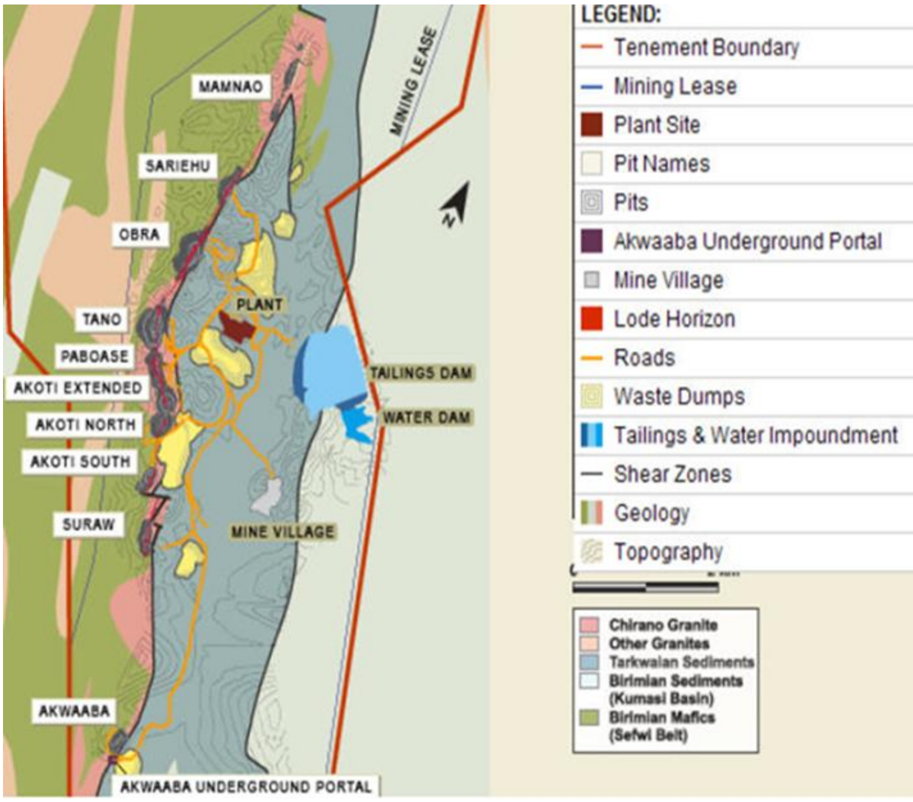

Figure 2: Geology of Chirano Mine (Anon, 2014)

The main stoping method employed at Paboase Deep is sublevel stoping. Ramp or Decline is the main hauling way and access to the workings. In sublevel stoping, the ore is divided into sublevels with comparatively close vertical spacing. At Kinross Chirano mines Paboase Deep, the spacing between levels is 25 m. The levels are interconnected by a ramp system which is the main haulage route to the surface. Each sublevel is developed with a regular network of drives covering the complete ore section. The ore immediately above each sublevel drift is drilled with long hole drills in a fan-shaped pattern designed by the CGML engineers using RingKing® software. The drilling of the fan-holes is done upwards. Drilling is done as a separate operation, well before blasting. Several sublevels can be drilled before blasting and loading start. Usually, production drilling and blasting are done separately in different sublevels. The blasting on each sublevel commences at the hanging wall or the far end of the ore body and retreats towards the level access. Ore extraction normally retreats along an approximately straight front which means that adjacent drifts (on a given sublevel) are worked simultaneously.

2. Methodology

To carry out this research, relevant literature was reviewed. There was a field visit at the mine site of Chirano Gold Mines Limited for data collection where there was an opportunity to have a personal interaction with personnel from the drilling crew. The Boretrak survey was conducted by the Quality Assurance, Quality Control (QAQC) section of the Technical Service Department monthly but this survey was done for a period of 4 months. This period ranged from July to October 2018. For this work, a total of 29 holes were selected upon which analysis was made. To analyze the data collected MS-Excel was used.

2.1 Determination of Drill Hole Designs

Drill hole designs at CGML were generated by the mine production planners with Surpac and RingKing® software. Drill parameters such as burden, spacing, hole length, hole diameter and drill hole inclination designed for the mine were based on geological and geotechnical factors of the area. The mining engineers used these accepted design parameters with the aid of the above-mentioned software to generate a drill plan for the mine. Table (1) shows the drilling parameters designed for CGML. The drill plan was further approved by the various sections of the Technical Service Department and the Underground Operations Department before final approval was given for the drilling to commence. The approved drill design was then sent to the underground surveyors to set out the pivot points and laser lines required by the drill rig to drill. The solo machine is used for production drilling.

Table1: Drilling Parameters Designed for Chirano Gold Mines Limited

Hole Diameter (mm)	102
Burden (m)	2.8
Spacing (m)	2.5
Hole Inclination (°)	90
Dump (°)	75

2.2 Drilling Procedure

The Sandvik drill rig DL420-15C ("Solo") used the pivot points marked on the roof and laser lines marked on the side walls by the surveyors together with the instruction on the drill plan to set-up and execute the drilling work. The drill rod was positioned at 90° to the appropriate pivot points of the rings to be drilled. The driller, depending on the dump angle specified on the drill plan, tilted the drill rig to an angle of 75°. Once the correct collar position was located, the hole was drilled to its appropriate length. The rod length of the solo machine was 1.2 m with a diameter of 102 mm.

Upon personal interaction with some drilling personnel during the data collection exercise, it was revealed that:

i. There was sometimes an interference of temporal roof support materials;
ii. Some marked holes were not drilled; and

iii. Depending on how much the collar of a hole deviated from the start, the toe of the respective hole was also affected causing deviation of the actual toe burden and spacing from the designed.

2.3 Boretrak Survey Procedure for Hole Deviation

The fieldwork involved the measurement of the actual parameters such as hole depth, burden and spacing after drilling operations.

The Boretrak equipment consists of a quarry log, probe and a fiber rod. The probe and the quarry log were synchronized together after which they were separated. The probe was then connected to the fiber rod. Some parameters such as the intervals at which the holes would be measured and the angle indicating the directions at which the holes would be measured were keyed into the quarry log device. The fiber rod was then pushed into the hole, recording at every 5 m on the log until the whole length was exhausted. The inclinations of the holes were measured as well. The records were downloaded from the quarry log onto a computer, where the planned was superimposed on the actuals using the surpac software as shown in the sample images (a - d) in figure 3 where the slope distances of the planned and the actual drill paths were measured. Data were collected from the various rings understudy for further analysis. Deviation is the difference between the designed and the actual parameter as shown in Equation (1) as well as percentage deviation in Equation (2):

$$\text{Hole deviation} = \text{Designed hole parameter} - \text{Actual hole parameter} \tag{1}$$

$$\%\,\text{Deviation} = \frac{\text{Deviation}}{\text{Designed Hole Parameter}} \times 100\% \tag{2}$$

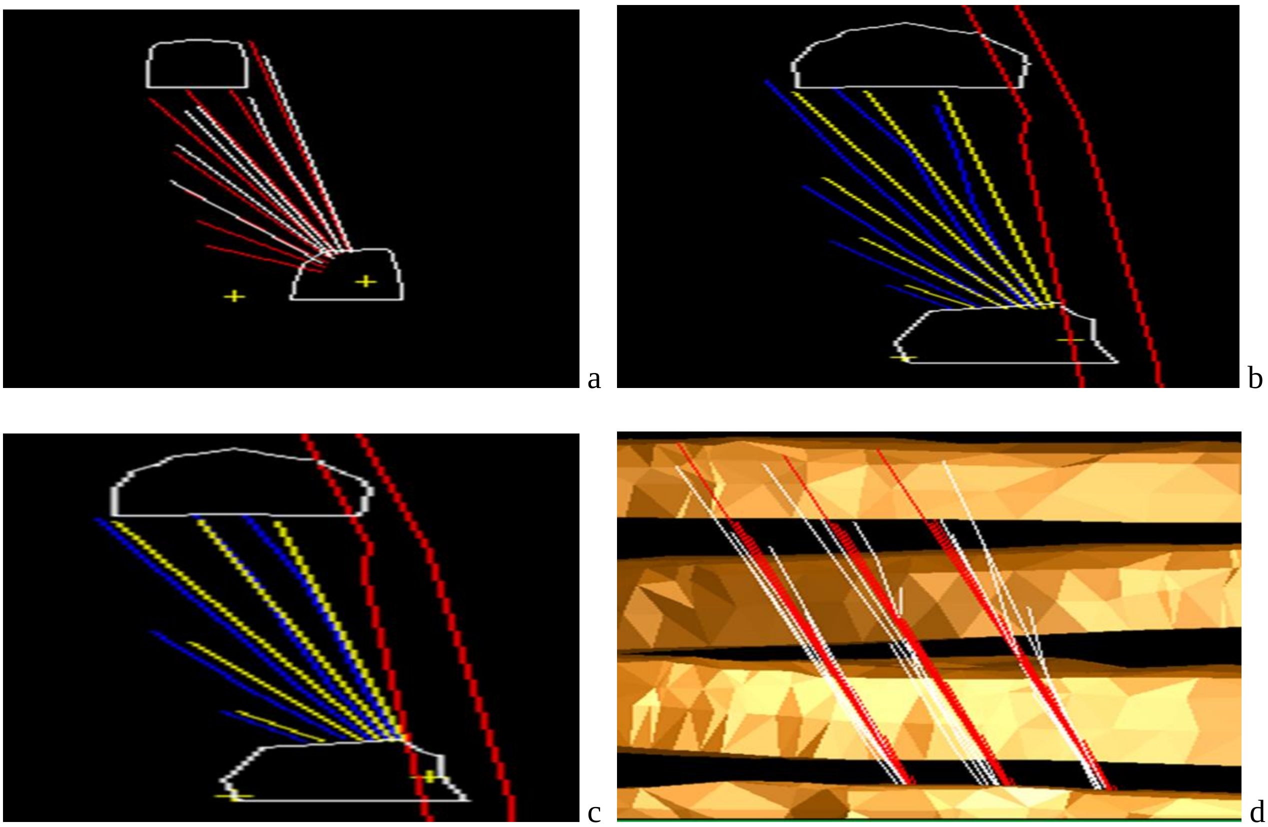

Figure 3: Samples of Data Collected

3. Results and Discussion

Figure 4 shows a bar chart of the total planned depth against the total actual depth of the rings. A total planned and actual depth of 520.2 m and 503.4 m was achieved respectively. The deviation between the actual hole depth and the planned hole depth attained was 16.8 m which gave a percentage deviation of 3.2% from the planned.

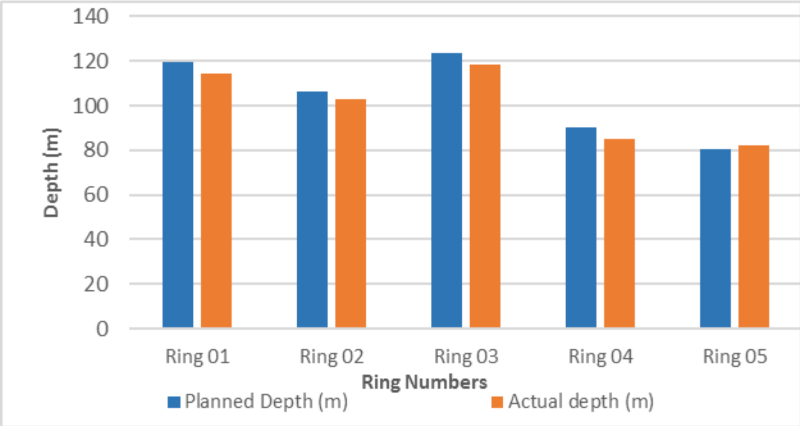

Figure 4: Planned Depth vs. Actual Depth

Table 3 shows the total actual toe spacing of the various rings and the total designed toe spacing. The total planned toe spacing was recorded to be 61.2 m and an actual of 59.3 m. The deviation of the actual toe spacing from the planned toe spacing was 1.9 m with a percentage deviation of 2.8%.

Table 3: Planned Toe Spacing vs Actual Toe Spacing

Ring Number	Planned Toe Spacing (m)	Actual Toe Spacing (m)
Ring 01	12.06	13.08
Ring 02	10.03	11.91
Ring 03	14.43	8.25
Ring 04	14.29	15.12
Ring 05	12.20	12.66
Total	**61.2**	**59.3**

Figure 5 shows the bar chart representation of the actual toe burdens against the planned toe burdens. The results gave a total planned toe burden of 13.9 m and an actual of 18.3 m. The deviation between the actual burden and the planned burden was 4.4 m with a percentage deviation of 31.2%.

3.1 Production Output

The density factor or specific gravity of ore at CGML is 2.75. The planned and expected outputs achieved from the rings were governed by Equations (3) and (4):

$$\text{Planned Tonnage (t)} = \text{Density factor} \times \text{Average Planned (spacing} \times \text{burden)} \times \text{Total hole depth} \quad (3)$$

$$\text{Achieved Tonnage (t)} = \text{Density factor} \times \text{Average actual (spacing} \times \text{burden)} \times \text{Total hole depth} \quad (4)$$

With reference to Table 5, the total planned output of the holes in the rings was 8421.3 t whilst the actual output achieved from the field was 10387.2 t. This showed an additional tonnage of 1965.9 t which gave a percentage deviation of 23% due to the deviations in the burden, spacing and the hole depth.

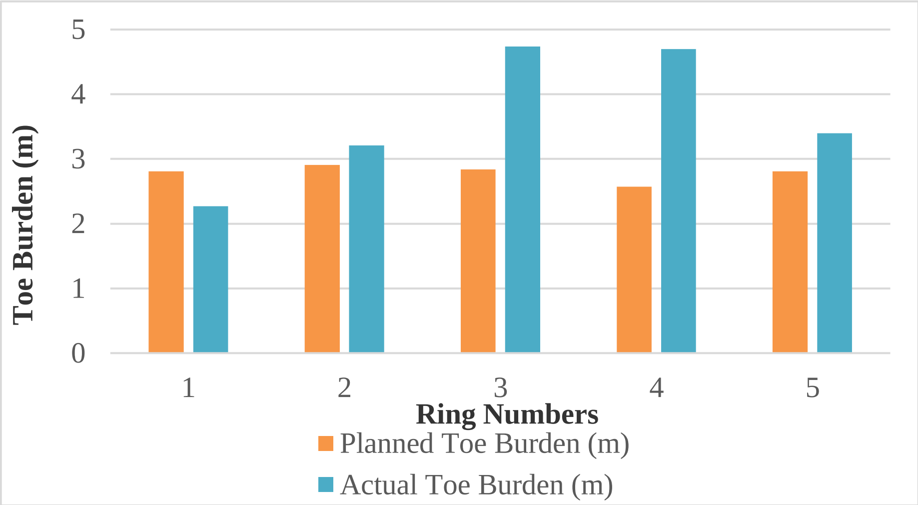

Figure 5 Planned Toe Burden vs. Actual Toe Burden

Table 5: Planned Output vs. Actual Output

	Planned	Actual	% Deviation
Density Factor	2.75	2.75	0
Average Spacing (m)	2.11	2.05	2.8
Average Burden (m)	2.79	3.66	31.1
Hole Depth (m)	520.2	503.4	3.2
Tonnage (t)	**8421.3**	**10387.2**	**23**

Toe burden contributed much to the increased output since it recorded the highest percentage deviation of 31.2% as compared to the toe spacing of 2.8% and the hole depth of 3.2% deviation.

3.2. Ore Losses and Dilution

Ore dilution is the addition of waste rock material to an ore during the process of mining whilst ore loss occurs when part of the ore material is left in the stopes during mining. Addition of waste rock to the ore decreases the grade of the ore and increases the tonnage of an estimated ore reserve and for this reason, geostatistians refer to dilution problems as ore losses [20].

Due to the increased tonnage as illustrated in Table 5, dilution would occur to the estimated tonnage of the rings under study. This would thereby reduce the mill head grade of the estimated material, consequently reducing the ounces of gold contained in the mined ore. Much energy would also be required to blast and to process the additional waste materials which would increase production cost in the mine.

4. Conclusion

Analysis of hole deviation and its effect on production has been carried out using the Boretrak instrument. The results obtained showed percentage deviations of 31.2% in the burden, 2.8% deviation in spacing and 3.2% in the hole depth. Result also showed an increased output of 1965.85 t of materials representing 23% deviation from the planned output. The result therefore depicted ore dilution which would decrease the mill head grade; and also, would increase the cost of production through extra energy requirement to blast and to process these waste materials.

It was therefore recommended that more of Boretrak surveys should be carried out for pre-informed decisions to be made by the planners during the preparation of charge plans. Also, more detailed information should be acquired about the ground formation to be able to identify all the weak and hard zones to help drillers when drilling.

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