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THE ANALYSIS OF THE MINE CALL FACTOR IN GOLD MINING, WITH SPECIFIC REFERENCE TO WESTERN HOLDINGS MINE.

Ernst Jakobus de Jager

A thesis submitted to the Faculty of Engineering, University of the Witwatersrand, Johannesburg, in fulfilment of the requirements for a degree of Doctor of Philosophy.

Johannesburg, 1 7.

THE ANALYSIS OF THE MINE CALL FACTOR IN GOLD MINING, WITH SPECIFIC REFERENCE TO WESTERN HOLDINGS MINE.

Ernst Jakobus de Jager

Volume 1 of 2.

DECLARATION

I declare that this thesis is my own, unaided work. It is being submitted for the Degree of Doctor of Philosophy in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

E J de Jager

1st day of February 1997

ABSTRACT

Unaccounted for gold in the mining industry amounts to millions of Rand on a daily basis. In Freegold this gold loss amounts to approximately 2500kg a month which equates to R113 million (R45 000/kg) (Graph 1). Approximately 35 percent of the gold mined underground at Western Holdings Mine is **unaccounted for** on a monthly basis. Since 1986 the highest Mine Call Factor was 93 percent while the lowest to date, 58 percent, occurred in April 1995 (Graph 2). The Mine Call Factor recovered to a still unacceptable level of 67 percent in January 1996. The Mine Call Factor is also decreasing at some of the other mines in the Freegold stable. (Graph 3-12)

The monthly **gold called for** on Western Holdings mine is approximately 3047kg, while the corresponding amount **accounted for** is currently 1835kg (September 95, y.t.d.). The gold **unaccounted for** is therefor 1212kg and in this instance results a theoretical loss of at least R 54 million per month (R 45 000/kg).

The **gold unaccounted for** considered in this instance is the difference between the **gold estimated** by the surveyors to be in the ore mined and that which is finally **accounted for** by the metallurgist in the plant.

The ultimate gold mining efficiency is the **Mine Call Factor (MCF)**. It is the ratio, expressed as a percentage, which is the specific product accounted for in recovery plus residues bears to the corresponding

product called for by the mine's measuring methods[10]. It should ideally equate to approximately 100 percent.

The **unaccounted for** gold or **theoretical gold loss** can be separated into **apparent gold loss** and **real gold loss**.

The only avenue to explain the **Mine Call Factor** issue is to determine the **real gold loss** by means of experimentation. The remaining loss is inferred as **apparent gold loss**.

The mining industry is riddled with sometimes mythical connotations to the possible causes of the **unaccounted for** gold. This thesis followed a systematic scientific approach to distinguish fact and fallacy from one another. It includes statistical analysis and large scale experimentation on the gold estimates in situ, some mining methods and results in the metallurgical plant in an effort to explain the **unaccounted for** portion of the gold. The study was confined to Freegold and with specific reference to Western Holdings Mine.

The correlation between the stope grade and the Mine Call Factor on Western Holdings Mine was statistically insignificant and therefor the accuracy of grade estimation (Table 21) was questioned. The overriding causes of the **apparent gold loss** was established as being the *rudimentary method of underground skin sampling* of the ore reserves and *relative density allocation* of the rock. The specific gravity of the ore at 2 780kg/m³ is overstated, which results in the tonnage being overcalled as well as the grade overestimated. It should be in the

region of 2700kg/m³ and can influence the gold called for by as much as ± 10 percent. The combination of the aforementioned results in subsequent inaccurate estimations of the gold **called for**. Diamond blade saws are being introduced on Western Holdings Mine to improve the accuracy of the skin samples to be taken in future (January 1996).

It is recommended that the *underground sampling methods be refined by using a new methodology*. Relative density allocations to the rock should differentiate between the sampled portion and that of the surrounding rock in which the grade is to be extrapolated to. This will assist to have a more accurate estimate of the gold in situ.

Another factor contributing to a low Mine Call Factor is that *broken ore is not brought to surface timeously* for processing. The latter is coined as *dirty mining*. The legendary areas where gold is lost in large volumes and finally *concentrated into high grade concentrations underground were unfortunately not found*. The *cracks in the footwall* that could contain gold were vacuum cleaned but, with disappointing results. This is probably because it did not exist in the first instance.

It remains important to get the ore blasted underground as soon as practicable processed in the plant. Ore remaining underground in the worked out areas is a major cause for the gold 'lost'. It is also required that more than 100 percent, say 105 percent of the broken ore, be removed to surface to cater for falls of ground and overbreaking, etc.

Positive tonnage discrepancy accounts for gold that was not called for during the particular period in question. Although it assists in obtaining a better Mine Call Factor, the problem of the **apparent gold loss** remains (Table 25). The real extend of the Mine Call Factor problem in these cases will be understated.

Statistical analysis indicated that the Mine Call Factor is not explained significantly by the amount of sweepings done. It is suggested that sweepings is merely an indicator that the majority of the tonnage broken was removed from the back areas of the working places (Table 7, 17, 27, 37, 47, 57).

Gold theft (confidentiality), plant efficiencies (metallurgical technical issue) and ore valuation methods (established science) per sé were not explored in great detail in this thesis.

The Mine Call Factor at Western Holdings has not reached acceptable levels as yet, but some recommendations have been implemented and an improvement is expected.

"It is a lot easier to live with old fallacies than with new facts". (German proverb)

DEDICATION.

This thesis is dedicated to my wife Linda and daughters, Lauren and Carmen.

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LIST OF DEFINITIONS.

Apparent gold loss, is the difference between the calculated gold loss and the real gold loss. This is gold that was not there in the first instance.

Calculated gold loss is that gold loss as determined by the difference in the gold called for and the gold accounted for.

Gold Called For, includes the gold called for from all sources expressed in grams. It could include that from stopes, development and old areas in certain instances.

Gold Accounted For, is the gold produced in the plant, as well as the gold accounted for as lost in the plant's residues.

Gold Produced, is the gold produced in the metallurgical plant.

Gold in Residue, is the gold contained in the residue dumped on the slimes dam.

Mine Call Factor, is the ratio of the gold accounted for over the gold called for, expressed as a percentage.

Real Gold Loss, is that portion of the total gold loss that can actually be found in the underground situation.

Sweepings, is the final clean-up of ore on the reef horizon. It is normally performed concurrent with blasting operations, lagging the panel approximately by 9m. The clean-up is performed using shovels and brooms and in most cases this is done using water. Dry sweepings, in which a minimum amount of water is used, is practised in reef zones of a carbonaceous nature.

Tramming, means the transportation of ore from the working place in hoppers to be tipped.

Vamping, means the final removal of ore from gullies.(as per sweepings)

Vacuum Cleaner is an industrial machine that is electrically operated, creating a suction by means of a Roots blower or a water-ring. It is used to transport ore of a diameter of less that 100mm in diameter inside approximately 150mm plastic pipes to a hopper from where the material is tipped.

Waterjet, is a tool which allows water to be discharged through a nozzle at a pressure of at least 7MPa. The design can include a shut-off valve or otherwise the water is allowed to flow continuously.

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C H A P T E R 1.

ISSUES RELATING TO THE MINE CALL FACTOR PROBLEM AT WESTERN HOLDINGS MINE.

1.1. INTRODUCTION.

The primary objective of any business is to maximise the profits of the concern over the life of such operation. Mining, per sé, poses many challenges, but the efforts of the employees on Western Holdings Mine are severely hampered by the fact that all the gold that is **called for** from underground mining operations is not **accounted for** in the plant. A significant proportion of the product is 'lost' during the mining process (Graph 13).

The **unaccounted for** gold in the South African mining industry amounts to millions of Rand per annum. Freegold has approximately 2 500kg of gold **unaccounted for** on a monthly basis (Graph 1) which amounts to a loss in potential earnings loss of R113 million per month, if it is assumed that a Mine Call Factor of 100% is achievable (Au=R45000/kg). This amount remains significant even at lower acceptable levels of the MCF such as 85 percent. It is therefore imperative to explore the **Mine Call Factor** issue in detail. The focus of this thesis is on **Freegold** with specific reference to **Western Holdings Mine.**

1.1.1. Freegold.

The Free State Goldfields are situated in the Witwatersrand system. The gold deposition consists of the eastern portion where the reef dips to the west and a western portion where the reef dips to the east. The first prospecting borehole commenced in October 1933 and the Basal reef was intersected during September 1939. The Second World War curtailed prospecting operations, but shaft sinking was commenced on St Helena Mine in November 1946.(32)

Free State Consolidated Gold Mines Limited (Freegold) is situated around the city of Welkom, Free State, Republic of South Africa (Diagram 3). It was created on 24 February 1986 and consists of Freddies, **Western Holdings**, Free State Geduld (which was incorporated into the two aforementioned mines as from 1 April 1995), President Brand, President Steyn and Saaiplaas mines. The mines were managed as separate entities before the amalgamation, but each mine is presently managed under its own management structure within Freegold. It is ultimately managed by Anglo American Corporation of South Africa.

Freegold is the world's largest gold mine and the mining lease area covers 27 903 hectares. It has 24 operating shafts as well as six metallurgical plants treating the ore. It has a production output of 101 tons of gold per annum (1995)(30) which declined from 112 tons in 1991. This equates to approximately 17 percent of the South African gold production.

Approximately 85 000 people were employed during 1995 which decreased by about 15 000 since 1990. The level of employment is still decreasing due to the lack of mineable, payable ore reserves.

1.1.2. Western Holdings Mine.

Western Holdings Mine is responsible for approximately 27.6 percent of Freegold's gold production, but by the same token is responsible for 35.8 percent of the monthly **unaccounted for** gold. It is considerably higher when compared to that attributable to other mines (Graph 13). There were approximately 17 800 persons employed on the mine(1995) but was decreasing due to certain areas becoming unprofitable to mine. Mining takes place underground, predominantly from the Basal and Leader reef horizons in the greater Witwatersrand deposition.

Currently the mine is nearing the end of its production life after 49 years in operation as the first shaft sinking commenced during 1947. The mine consists of nine surface shafts, serving a lease area of approximately 8 000 hectares. The underground working places are widely dispersed and concentrated mining is practised on a limited scale. The majority of the mining takes place in pillars, which are less than 4 000 square metres in size and are remains of previously worked stopes.

On Western Holdings the **unaccounted for** gold is amounts to approximately 1112kg per month. This 'loss' in monetary terms equates to approximately R50 million in potential earnings (Au=R45 000/kg). The annual loss in earnings amounts to approximately R600 million if it is **assumed that all**

the gold called for can be **accounted for** during the operation. The accounting for gold is therefore of paramount importance in order to determine where the gold is 'lost'.

The ultimate measure of mining efficiency is referred to as the **Mine Call Factor (MCF)**. This thesis consists of investigations into **unaccounted for** gold and associated experiments to distinguish between myths and facts relating to the Mine Call Factor issue.

1.2. Mine Call Factor.

The **Mine Call Factor** is the ratio, expressed as a percentage, of the **gold called for** from all sources to the **gold recovered** plus **residues** in the metallurgical plant. An efficiency of 100 percent would equate to complete success, but a figure of at least 95 percent would be considered acceptable.

Unfortunately the Mine Call Factor (MCF) on many mines is below acceptable norms (Graph 2-12). This not only leads to frustration and despair on the part of the production personnel, but the deficit affects the cash flow situation of some mines detrimentally. An improvement in the **gold accounted** for would boost the profit situation from the current marginal contribution of Western Holdings Mine (38 profit/revenue ratio) to significant levels.

The Mine Call Factor accounting method is not standard on all the mines, but it is still the only criteria for determining the overall mining

efficiency. It is at times adapted to the requirements of a particular mine. An example of this adaptation would be not to call for tonnage from previously mined areas and to allow the **accounted for** side of the equation to remain as is. The affect of this 'manipulation' is the attenuation of the actual **unaccounted for** gold. The **gold accounted** for is invariably significantly less than the **gold called for**.

1.2.1. Gold accounted for.

It is normal to find that many uncoordinated attempts by individuals are made on a mine with a Mine Call Factor problem. The aim of these investigations are to determine where the gold loss occurs or where there is a tonnage lock-up. The first line of attack to explain the gold loss is normally the **gold accounted for** side of the MCF equation. The defender in this case is the metallurgical plant 'who loses the gold' due to the plant efficiency. Although it is a fact, known by most, that the residue leaving the plant is included in the **gold accounted for** and that improved efficiency in the plant will not alter the **MCF**, this possibility is normally followed with rigour, by some mining men. It will, however, result in more gold produced and less in residue [gold accounted for(kg) = gold produced(kg) + gold in residue(kg)]. The residues of gold left in the after-plant-pulp are measured as effectively as possible to confirm plant efficiency. The gold loss from this part of the operation is dictated by current gold recovery technology and will be accepted as inevitable for purposes of this thesis. The MCF, however, could improve if all the gold in residue is

not accurately accounted for in the first instance. An experiment was conducted to examine this issue and is further discussed under 5.2.1.

1.2.1.1. Gold theft.

The gold stolen from the plant cannot accurately be accounted for because only a certain number of persons are caught in the act or otherwise. It is a known fact that gold is constantly being stolen from the operation, both underground and on surface. However, when known theft cases are taken as a sample of the population, the amount of gold lost in this fashion does not explain the gold that is **unaccounted for**, by far. It is mostly caused by other variables which will be investigated in this thesis. The information on gold theft is confidential and the issue is therefore not further explored.

1.2.2. Gold Called for.

The **gold called for** is the summation of the gold called from stopes and development ends. At the end of each measuring month, which lasts approximately 24 production shifts, the responsible surveyor would calculate the tonnage and grade delivered to the Metallurgical plant. The production of gold is expressed in grams.

The gold in inventories, as well as gold in the stockpiles are taken into consideration in this equation.

1.2.2.1. Gold loss.

The **unaccounted for** gold is the difference between the gold **called for** and the gold **accounted for**. It is a **theoretical gold loss** that can be split into **apparent gold loss** and **real gold loss**. The **real gold loss** occurs within the mining and recovery cycle and can be prevented to a certain extent. The **apparent gold loss** occurs in the **gold called for** side of the equation and is in all probability gold that was not there in the first instance. This hampers efforts to find the **real gold loss** underground as attention is focused on inappropriate areas.

The **theoretical gold loss is** categorised in table 1.1.

Theoretical Gold Loss	
Apparent Gold Loss	**Real Gold Loss**
Underground skin sampling.	Dictated by mining method and layout.
Different densities of the rock.	Sweepings not done properly.
Over/under measurements, i.e. stoping width, m^3 mined.	Reef remaining in Hanging and footwall.
Assay methods including silver corrections.	Old area tonnage and mud not taken to surface for treatment.
	Theft from underground and surface.
	Losses while tramming and hoisting.
	Reef to waste
	Metallurgical plant process.

Table 1.1. Theoretical gold loss

1.2.2.2. Mining methods and other issues.

Gold loss due to the nature of the mining methods is as follows:

Sweepings.

Fines are likely to be lost during any part of the mining process, with the greatest chance of this happening in the stope. Sweepings in a stope refers to the removal of the finely-divided ore in which it is **believed** much of the richest portion of the ore is found. This operation is routinely performed concurrently with stoping, most of the time. However, there is normally an unexplained delay in performing this task as a simultaneous part of the mining cycle, resulting in month end rushes to get the job done. When this part of the mining cycle is delayed in areas with bad hanging wall conditions, the gold lock-up can be lost forever. Falls of ground in the back areas prevent the future recovery of these losses. It is therefore important to do the sweepings concurrently with blasting operations.

The MCF is **believed** to be strongly influenced by both the quantity and quality of sweepings done during a specific production period. This concept was statistically evaluated and it was found that sweepings, per sé, is not the major contributor to a good MCF, but that it is rather an indicator that the majority of the tonnage was removed from the stope. This does not mean that the focus on sweepings should be reduced as this tonnage remains a major contributor in meeting targets. An experiment

was also conducted to compare the results of dry vs. wet sweepings and is discussed further under Chapter 5.

Sweepings are accomplished by using brushes to sweep up the footwall. This is done subsequent to the blasted rock being removed from the panel using scrapers. A minimum amount of water is used during this stage, as it is believed that the fine gold particles are washed into the crevices. The footwall is finally washed down with water to remove the gold left behind.

Footwall cracks.

Fine cracks in the footwall are the recipients of the minute free gold particles. This loss is due to blasting, scraping and sweeping operations that takes place in the face. The particle size (microns) and spatial location of the gold particles lends itself to being lost. The use of water for allaying dust, transporting of rock and the general washing-over of the working surfaces in a stope enhances the propensity for the loss of gold. Water must be used at an optimum pressure (150kPa) to prevent finer particles from becoming deposited and compacted into footwall cracks. It is believed that the use of waterjets as a method for transporting ore falls into the aforementioned category.

A fractured footwall condition in a stope will enhance the possibility of gold loss. This condition will obviously be worsened if water of a higher than optimum pressure is used to transport the ore.

In general the gully footwall is quite smooth due to the abrasion effect of the scraper on the original footwall. Experiments done to quantify the cumulative gold enriched in footwall cracks have only found insignificant amounts of gold.

Water usage and the use of waterjets.

Conventional mining methods require the use of water during the cycle. The amount of water used, expressed in tons of water used to tons of rock produced, could play a negative role in the gold loss underground. It is perceived that the finer particles of gold released during the mining operation could be washed away during the washing over or drilling portion of the mining cycle. The introduction of waterjets on a large scale as cleaning tools, is perceived as increasing the possible loss in gold. It is believed that more water is used through waterjets and that the increased water pressure assists in depressing the small particles into footwall cracks.

The velocity of the water used to move the rock on the footwall of a working place is such that it transports the coarser material, but the free gold is separated. The irregular flow of water when transporting the ore in a stope face encourages the loss of gold. The reef type mined will dictate its infinity for gold loss due to its inherent characteristics. It is perceived that a carbonaceous reef type must be mined dry because of the free gold particles that can get lost using water. It is, however, conceivable that gold loss is inevitable in some of the carbonaceous reef types even without the use of water. In the

case of strongly mineralised reef, such as Leader reef, the use of water does not contribute significantly to the loss of gold. The disturbing aspect of this type of gold loss is that it will in all probability not be economical to recover. It should rather be prevented in the first instance.

An experiment was conducted underground to prove/disprove this hypothesis. The results are described in Chapter 5.

Reef types.

The make-up of the ore underground varies from area to area within the mine. One of the major concerns is the method of mining carbonaceous reefs. It is conceivable that gold, being hydroscopic, is being lost when using water during the mining process. Experiments have been conducted to reconcile the gold broken in the stope to the gold trammed from such a stope. The results are discussed in Chapter 5.

The reef types encountered on Western Holdings Mine are described in detail in Chapter 4.

Vacuum cleaners.

The use of vacuum cleaners underground is becoming fashionable. St Helena Mine in the Welkom area has been using up to 40 large 70kW vacuum cleaners in the carbonaceous reef section underground. The volume of rock broken underground was curtailed significantly as a direct result

of this mining method, but it was claimed that the gold recovered has increased to such an extent that the mine was in a profit situation during 1994/5. Vacuum cleaners were also used to recover tonnage left behind in previously worked-out areas. This gold was not called for in the Mine Call Factor calculations. Recently (1995), small crushing units were installed in some of the underground working areas to increase the production throughput. It was believed that this method would reduce the areas for potential loss of gold because the gold is captured directly at the working face and thereafter transported in a closed circuit.

The Mine Call Factor will improve if the tonnage vacuumed from worked out areas is significant in relation to the tonnage broken. It cannot be assumed that a mine's grade problems will be resolved with the use of vacuum cleaners. Both a significant grade and tonnage vacuumed is required to make this operation viable. Vacuum cleaners used to clean-up areas where gold bearing ore remained from previous mining operations can be viable. This will primarily be the case if a minimum infrastructure is required to remove the ore.

Vacuum cleaners used to prevent gold loss in a working stope will only be successful if the gold is in fact lost in the stope. As will be seen in Chapter 5, experimentation has indicated that only a limited amount of gold remains in a stope after being passed as swept and vamped conventionally.

Mud loading.

Mud loading in haulages and other access ways has been neglected during recent years, the reason being that labour has been reduced to such an extent that the loading of mud has suffered tremendously. It is perceived that a large volume of gold is locked up underground as a result of this. Mud loading gangs are currently being re-introduced selectively in the higher grade areas underground. Mechanised mud loading systems were designed to improve productivity. However, at the time of writing this thesis, manual labour using shovels to load mud into hoppers proved to be the most efficient method. The gold content of mud is generally perceived as being significant but, findings to the contrary are discussed in Chapter 5.

Blasting barricades.

One of the possible solutions to gold loss reduction is to contain the ore in a limited production zone by the use of blasting barricades in the stopes. Areas that have been swept clean before can therefore not be contaminated again.

Various types of blasting barricades, such as wooden planks or poles, HDPE pipes and polymer type blankets, are installed underground onto the second line of permanent support. This method assists in containing the blasted ore within the production zone of the face. The barricades are carried parallel to the face. Several hundred barricades were installed at all the shafts during the period of research. It is, unfortunately a

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