School of Mining Engineering

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An Investigation of Mine Call Factor Variation at Modikwa Platinum Mine - 2013 to 2020

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A research report submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Master of Science in Engineering.

Johannesburg, 2023

DECLARATION

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ABSTRACT

A Mine Call Factor (MCF) is the ratio between the total recovered mineral product versus the planned estimated mineral product based on sampling and modifying factors. Problematic MCF issues have haunted mines throughout time, some commodities more than others. To mitigate and control the challenges around a problematic MCF, proper protocols and the enforcement of them are required. From 2014 to 2017, Modikwa Platinum Mine (MPM) had a fluctuating MCF below the historical 95% average mark. This research study was carried out for the period between 2013 to 2020, collecting historical data to establish what areas had a negative influence on the MCF during this period and to clarify if these losses were real or apparent.

DEDICATION

I would like to dedicate this research report to my loving wife for her continuous support and words of encouragement. Her patience, faith and love helped me through strenuous times.

ACKNOWLEDGMENTS

First and foremost, I give thanks to the Almighty God for His blessings and guidance throughout my research work to complete the report successfully.

I would like to express my special thanks of gratitude to my research supervisor, Dr Gordon L Smith for his invaluable guidance throughout this research. It was a great honour and privilege to work under his guidance. Furthermore, I would also like to thank the General Manager of Modikwa Platinum Mine, Mr H J Kruger for permitting me to carry out the research on the mine.

Special appreciation to the Modikwa Mining and Technical Services teams, particularly Mr Grobbelaar and Mr Britz for their assistance and knowledge shared.

Last but not least, I would like to thank my wife Cindy and son Xander for their moral support, encouragement, understanding and prayers throughout this research report.

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3D -	Three dimensional
4E -	Four Platinum Group Elements (platinum, palladium, rhodium and gold)
AAP -	Anglo American Platinum
ASG -	Advance Strike Gully
Au -	Gold
BMS -	Base Metal Sulphides
BRC -	Bottom Reef Contact
Cu -	Copper
FW -	Footwall
g -	gram
g/t -	gram per ton
HW -	Hanging wall

HAM -	Hanging wall Anorthosite Marker
Inc. -	Incorporated
ISO -	International Organization for Standardization
LPP -	Leuconorite Parting Plane
m^2 -	square meter
MCF -	Mine Call Factor
MPM -	Modikwa Platinum Mine
MRM -	Mineral Resource Management
NNW -	North North West
NW -	North West
OSC -	Optimal Stoping Cut
Pd -	Palladium
PGE -	Platinum Group Elements

PGM - Platinum Group Metals

Pt - Platinum

PTO - Planned Task Observation

QA/QC - Quality Assurance and Quality Control

RF - Radio Frequency

RFID - Radio Frequency Identification Device

RGSW - Recommended Geological Stoping Width

Rh - Rhodium

RIF - Reef in Foot

RIH - Reef in Hang

SAMREC - South African Mineral Reporting Codes

SCF - Shaft Call Factor

SSE - South South East

SW -	Stope Width
SWA -	Stope Width Analysis
t/m^3 -	ton per meter cube (volume)
TRC -	Top Reef Contact
TSD –	Technical Services Department
UG2 -	Upper Group Two

1 INTRODUCTION

1.1 Problem Statement

For a mine to operate efficiently, it must compare the product recovered to the anticipated outcome. This comparison is essential to be as close as possible to each other, and the aim is to achieve 100%. In practice this may not be possible as factors such as mineral loss between blast face to processing plant, grade estimation inaccuracies and unplanned dilutions are all contributors that affect the MCF with variations above and below 100%.

When a potentially economic mineral deposit is identified, it enters an exploration stage. Drilling, metallurgical tests, environmental assessments, 3D modelling, and mine designs are used to increase confidence in the project (New Age Metals Inc., 2019). A Mineral Resource can then be estimated based on geoscientific information with contributions from other relevant disciplines.

When the project enters the mining phase, a Resource block is converted to a Reserve (Figure 1) via a higher Mineral Resource estimate confidence in the Mineral Reserve block, including modifying factors. Mineral Resource definition of Modifying Factors are considerations used to convert Mineral

Resources to Mineral Reserves. These include, but are not limited to, mining, processing, metallurgical, infrastructure, economic, marketing, legal, environmental, social, and governmental factors (SAMREC Code, 2016).

A Reserve is an economically mineable block and is estimated to deliver a certain amount of product once processed. The MCF is the ratio between the total recovered mineral product versus the planned estimated mineral product based on sampling and modifying factors. Investors expect maximum returns on their investment, a lower than expected MCF has a negative impact and deters future investors.

The average historical data for the MCF at MPM has been 95%. To use 100% in current and future calculations will result in an over-estimation of called for metal. Thus, the historical average of 95% is used as a planned figure (De Kock, 2021).

MPM had a significant drop in their MCF between 2014 to 2017, and although it has risen above the historical average of 95% from 2018 onwards (Figure 2), the need to compare these two periods and what was implemented to rectify the MCF estimate is required. This ensures that the findings will shield future endeavours from the same mistakes.

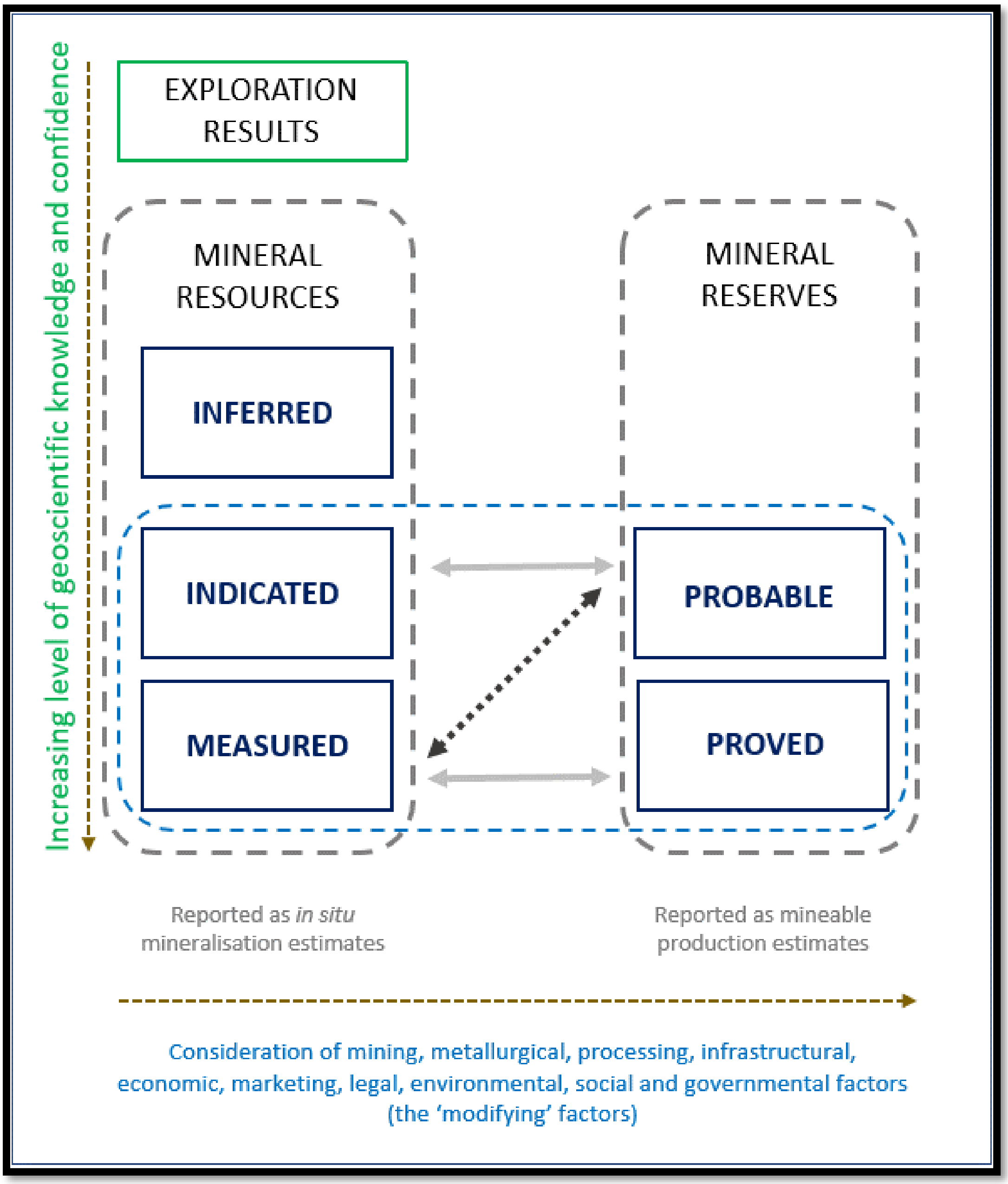


Figure 1: Relationship between Exploration Results, Mineral Resources and Mineral Reserves (after SAMREC Code, 2016)

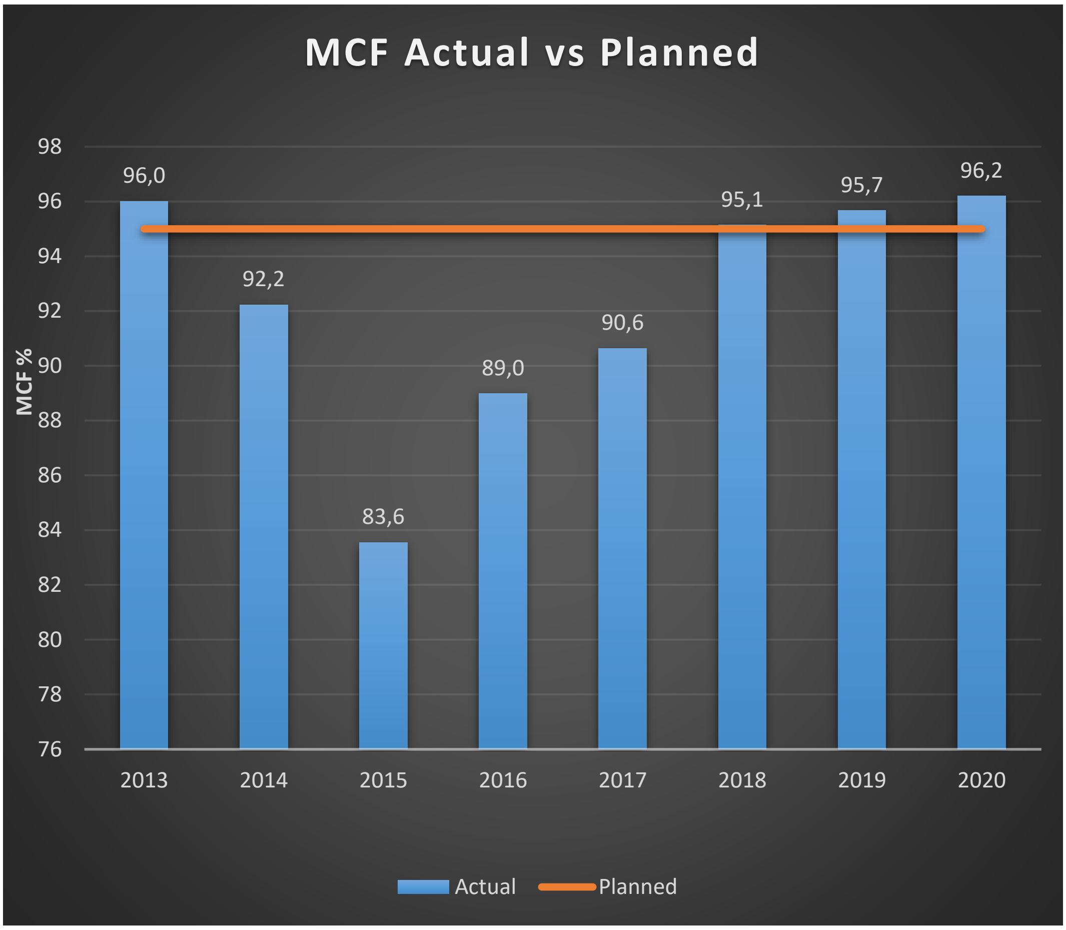


Figure 2: MPM 2013-2020 Mine Call Factor (de Kock, 2021)

1.2 Justification for Research

This study aims to identify underlying causes which led to the drop in the MCF. Compared to the planning expectations the revenue loss in this period was material, and the need to identify and mitigate its recurrence is essential.

Metal accounting is the process that involves sampling, analysing and accounting for metal / mineral content through the mining and metallurgical processes (Soni, 2013). Metal accounting is the estimation of a marketable metal in a mine, which is produced over a defined time period. Practical metal accounting is required to ensure that the mineral resource mined is efficiently transformed into a marketable product, by minimizing mineral resource content loss along the value chain. To maximize stakeholder returns, controlling issues such as dilution, extraction, and recovery are critical to the long-term value and profitability of a mine. Every mine has the goal to optimize extraction, increase profitability, and be able to do it safely.

1.3 Previous Work

1.3.1 Anglo Platinum Corporate Audit (Anderson et al., 2016)

A detailed Grade Audit was performed by Anglo Platinum Corporate, led by Mr. Anderson (Survey and MRM Systems Manager) on MPM in March 2016. The audit was to ensure complete alignment with the Company Standards and Procedures due to the low MCF achieved and focused on;

- Inputs from Survey, Geology and Planning Departments,
- MRM reporting and System utilisation, and

- Concentrator process metal accounting from an Ore Flow perspective.

Not all findings have been included, only those relevant to this report.

1.3.1.1 The findings include but are not limited to:

Best Cut Mining - Relates to the safest SW mineable, while concurrently delivering optimal grade. A review of the Mining-Cut was proposed in light of lithological changes brought upon by increased depth and the position of the Hanging wall Anorthosite Marker (HAM) between North 1 And South 1 Shafts. The geotechnical component of the Hanging wall (HW) required the resource cut to be reassessed. Reviewing the Best Cut in light of the lithological changes associated with depth was recommended.

Photogrammetry Department (SW Observations) – This task is done by a stope observer, an employee that visits a working panel to measure and map the panel face and compile a report indicating planned and actual widths, grade and dilution. The benchmark for stope observation coverage is 100% of the working panels per month. An average of 119 panels worked during 2015 and was covered by four stope observers. The coverage obtained was very low at only 89%. It was recommended to increase the coverage to a minimum of 100% by adding a Stope Observer to increase the complement to five employees.

Histograms (Explained in Chapter 3.2) – The grade histograms were reviewed in January 2016 and are reviewed quarterly as per protocol. The histograms are created according to Structural domains instead of Facies or Geological Zones. On examination of the Sampling Best Cut Report compared to Histograms it was noted that several panels reflected a higher Stope Grade than the Best Cut Grade. A narrow actual channel width was pointed out in these panels. Due to this, the “Keep Normalised Channel cmg/t Constant”, which is a “Tick-On” function in the Histogram system was used, this is where the evaluation is then made to keep the channel grade constant. It is required to validate this assumption, as this function could have an unfavourable outcome on the evaluation process. This was encouraged when an exercise was done on the panels affected for February 2016, and the “Tick-On” function was not used, producing a 3% decrease in the evaluation figures. A sampling campaign was recommended to investigate the channel width grade relationship. This was to compare where the Channel Width variation differs significantly from the average width.

It was recommended to investigate the alignment of the Histogram Zones (Facies/Geo Zones as opposed to Structural Zones) and reduce it from 14 to 4 Zones.

MRM System Inputs – In summary, the MRM system was not utilized to its full potential (Anderson et al., 2016). It required an MRM Systems Specialist to unlock the benefits of this system. The concerning problems identified were calendars not maintained, no milling calendar, and Ore Reserves that could not be administered or accurately maintained. It was recommended to train the Systems Administrator to become the MRM Systems Specialist.

1.3.2 Modikwa Internal Grade Audit (Bronn, 2018)

In 2018 an internal audit was done, led by Mr. Bronn (Technical Services Leader - Modikwa), on the low MCF on Modikwa, as the average MCF for 2017 was 90.6%.

1.3.2.1 The findings include but are not limited to …

Sampling coverage - The average sampling coverage for 2017 was 32.9%, as portrayed with a green line in Figure 3. Sampling coverage is achieved with one Sampler and no Sampling Assistants. From February 2017, labour restructuring on the Sampling Assistants caused that underground face sampling was only done when Survey Assistants were available. The MCF may have suffered since it was difficult to identify in-situ grade changes due to insufficient sampling. A coverage of 100% was recommended to achieve the minimum confidence necessary to evaluate all workplaces, and drive quality mining effectively. Due to the workload, additional personnel are needed to remedy the sampling coverage challenge.

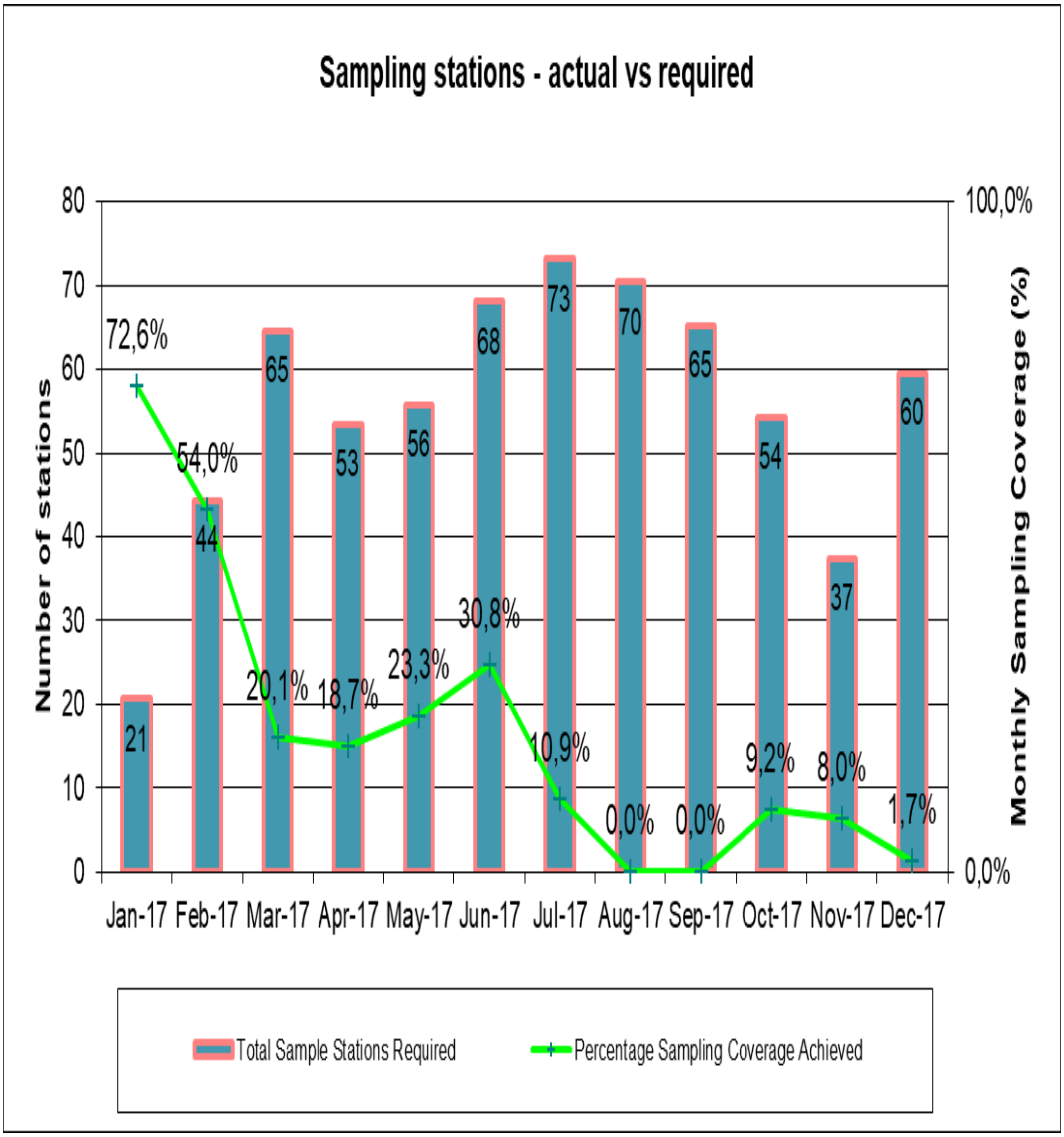


Figure 3: Modikwa sampling coverage 2017 (Author, 2023)

SW Control - The average stoping width for 2017 was 117.2cm. The SW of 117.2cm is currently 12% higher than the Resource Cut (Champion Cut) of 103cm. This is related to the following conditions:

- The intersection of the Northern Dyke Swarm at North 1 Shaft, with little to no surface drilling due to community issues and later no funding. The lack of surface drilling limited the accuracy in predicting the position and ground stability around the dykes, this in turn caused a higher than expected SW and increased off-reef mining, than planned.
- Areas at South 1 Shaft where the HAM was closer than one metre to the UG2, causing fall-outs. This led to higher Recommended Geological Stoping Width (RGSW) due to safety reasons.
- Reef rolls at South 2 Shaft led to excessive Footwall (FW) over break and Reef In Foot (RIF) due to poor drilling control and lack of experience in mining of reef rolls.

Off Reef Mining - A decrease in off reef mining had been recorded from 2015 to 2017. See Table 1 below.

Table 1: Off reef mining 2013 to 2017 (Britz, 2018)

	2013	2014	2015	2016	2017
Total m²	432,841	344,952	362,632	412,443	432,349
Reef m²	425,287	337,833	353,744	404,110	426,359
Off Reef m²	7,594	7,120	8,886	8,334	5,989
% Off Reef m²	1.8%	2.1%	2.5%	2.0%	1.4%

The reduction in off reef mining from 2015 to 2017 was achieved through coaching mining crews underground, Planned Task Observations (PTO's) and penalties implemented on crew bonuses, via Grade Awareness Campaigns and Grade-MCF-Action Plans.

North Shaft off reef mining (m²) decreased with 46% from 2016 to 2017, with a 164% increase at South 2 Shaft due to rolling reef and lack of drilling experience. For Modikwa there was still a 28.1% reduction in total off reef mining recorded for this period.

An inconsistent MCF may exist from excessive waste dilutions, since not all off reef mining was recorded, as staff shortage brought on by budget cuts caused many panels not to be visited. An action plan and audit PTO list were put in place for 2018 to investigate the off reef prospect, i.e., all TSD staff (Geology, Sampling/Grade, Survey, Rock Engineering and Ventilation Departments) were instructed to record and plot off reef areas daily.

The current four Grade Observers need to cover detailed Stope Width Analysis (SWA) per panel for 111 panels, they are achieving below 100% coverage of panels mined per month. The number of Grade Observers was cut from eight to four in 2015 due to restructuring. This is considered to have adversely affected the grade calculations, due to the reduced observation data per panel producing unreliable inputs, hence the MCF irregularities.

An experienced Valuator was required to assist the current acting Valuator. The Section Valuator from Tumela Mine was sourced to assist and coach the current acting incumbent. The focus was on relevant and up to date grade Histograms, correct density inputs used when calculating tonnages, and correct utilization of Histograms when evaluating panels.

Ore Density - Density checks were done and were within acceptable limits. These densities are used in the valuation histograms (Chapter 3.2) and MRM inputs (Chapter 3.4). Some histograms made use of a density value of 3.72t/m^3 for the UG2 Main Channel, and were required to be corrected to 4.18t/m^3 in the MineRP system (MineRP is an open, standards-based digital integration platform for mines). When the MineRP programme was initiated it had a systems problem with the density software, as it incorporated the HW and FW waste into the RD calculation for the Main Chromitite Channel. This issue was isolated and corrected so that the software would discard the HW and FW waste when allocating a value to the Main Chromitite Channel. The actual density for the UG2 Main Channel is 4.18t/m^3, whilst that of the surrounding waste rock is 3.25t/m³. The new MineRP software was rolled out to Modikwa in 2018 and the issue has been resolved.

Tonnage Broken, Tons Delivered, and Milled reconciliation - The tonnage reconciliation portrayed in the internal grade audit done in early 2018 indicated that the broken tonnage calculated and tonnage vamped checked well with the delivered tonnage. These were measured over the scales on surface, and the difference also corresponds with the tonnage estimated to be locked-up underground. This statement was only intended for 2017, as large tonnage variants were noted for 2014 and 2015. The author of the audit report further states that this could be due to cross tramming of waste development ore, as the discrepancy between the waste tonnage broken and the waste tonnage transported to the waste dump had a remarkable difference.

The author of the Internal Grade Audit also stated that the reef tonnage reported was correct, and that there was possibly an over-valuation of ounces, that could perhaps have been the reasoning behind the low MCF recorded in 2017.

Table 2: Tonnage Reconciliation 2014 - 2017 (Bronn, 2018)

Tonnage Broken, tons Delivered and Milled reconciliation				
	2014	2015	2016	2017
Tons broken	1610506	1659608	1932186	2057734
Vamping	85399	105561	146785	143630
Total tons available for Hoisting	**1695905**	**1765169**	**2078971**	**2201364**
Difference	-145569	-167079	12113	85591
Tons Delivered to Concentrator	**1841474**	**1932248**	**2066858**	**2115773**
Difference	4360	20781	28719	-2198
Tons Milled	**1837114**	**1911467**	**2038139**	**2117971**

1.3.2.2 Conclusions**:**

It is probable that the lack of experience of the acting Valuator has produced misleading grade data that has impacted estimation of the MCF. Procuring an experienced Valuator to assist the current acting incumbent is required, to focus and guide on the following points;

1. Sampling result interaction with Histograms to be compared for correctness. Assay results must fit the evaluation Histogram, any outliers must be discarded.
2. Panel-by-panel Valuation methodology to be checked.

3. Validation of MineRP software utilized for Histogram valuation to be confirmed.
4. Confirm and check density, grade, and value allocation to Histograms and MRM inputs, to eliminate data irregularities.
5. Reporting of accumulations (broken ore lock-ups underground).
6. Reporting of on-reef/off-reef mining timeously, to reduce unplanned waste dilution.
7. Reporting of mining quality conditions.
8. QA/QC technical training. The acting Valuator requires formal evaluation training, this is to ensure correct grade Histograms are available in the MRM System to allow for correct metal ore calculations.
9. Evaluation of Monthly actuals and Month End Estimates confirmation.
10. Improve RGSW and cross-tramming audit trails.

1.3.2.3 Way Forward:

- Employment of a Grade Observer as per Anglo Platinum Grade Audit recommendation.
- MRM system calculations to be checked for correctness.
- Reporting of Off-Reef areas should be checked to ensure no Off-Reef areas are valuated as On-Reef.

- RFID tag usage should be intensified to identify and lessen cross tramming.
- Introduce sampling of thinning reef channel close to pothole edges to compare the grade with the normal channel.

1.4 Research Methods

To determine if the losses were real or apparent or both, data collection, comparisons, and conclusions were made for the points under investigation in the report.

A Metal Accounting Flow Process diagram shows the points of reconciliation from mine to mill in Figure 4, these points are used to measure and reconcile the ore flow and final metal product. Reconciliation measurements are conducted at various points during the metal flow process and are as follows;

Reconciliation Point 1:

1. Survey measurements done on all excavations mined for the month.
2. SW Analysis visits done to determine width mined for each on reef excavation, to convert square metres mined into a volume. A grade is also allocated to each on reef excavation during this process.

3. Relative densities calculated to determine broken ore tonnage anticipated, for reef and waste excavations.

<u>Reconciliation Point 2:</u>

1. Only measures the ore tonnage conveyed over a weightometer, both reef and waste ore. No grades are reconciled at this point, only tonnages.

<u>Reconciliation Point 3:</u>

1. Measures the ore tonnage conveyed over a weightometer on surface, before the reef ore is deposited on the surface stockpile. This measurement allows for ore reconciliation between planned and actual tonnages.

2. Measures the waste rock conveyed before discarding it on the waste dump. These measurements are used to calculate any accumulation of waste tons not removed and is still left underground, or if not stored underground, then cross-trammed as reef.

<u>Reconciliation Point 4:</u>

1. Reef ore conveyed to the concentrator plant once again goes through a weight measuring process before entering the Plant silos. The ore is then sampled after the milling process and then again before being dispatched to the smelter in Polokwane.

2. The final measuring of PGM concentrated ounces produced for the month is then reverted back to the budget plan to produce a MCF.

   Storrar (1981) defines the MCF as *the ratio, expressed as a percentage, which the specific product accounted for in recovery plus residue bears to the corresponding product called for by the mine's measuring methods.*

   $$MCF = \frac{sum\ of\ metal\ produced\ in\ recovery\ plus\ residue}{metal\ called\ for\ by\ mines\ measuring\ methods} \times 100\%$$

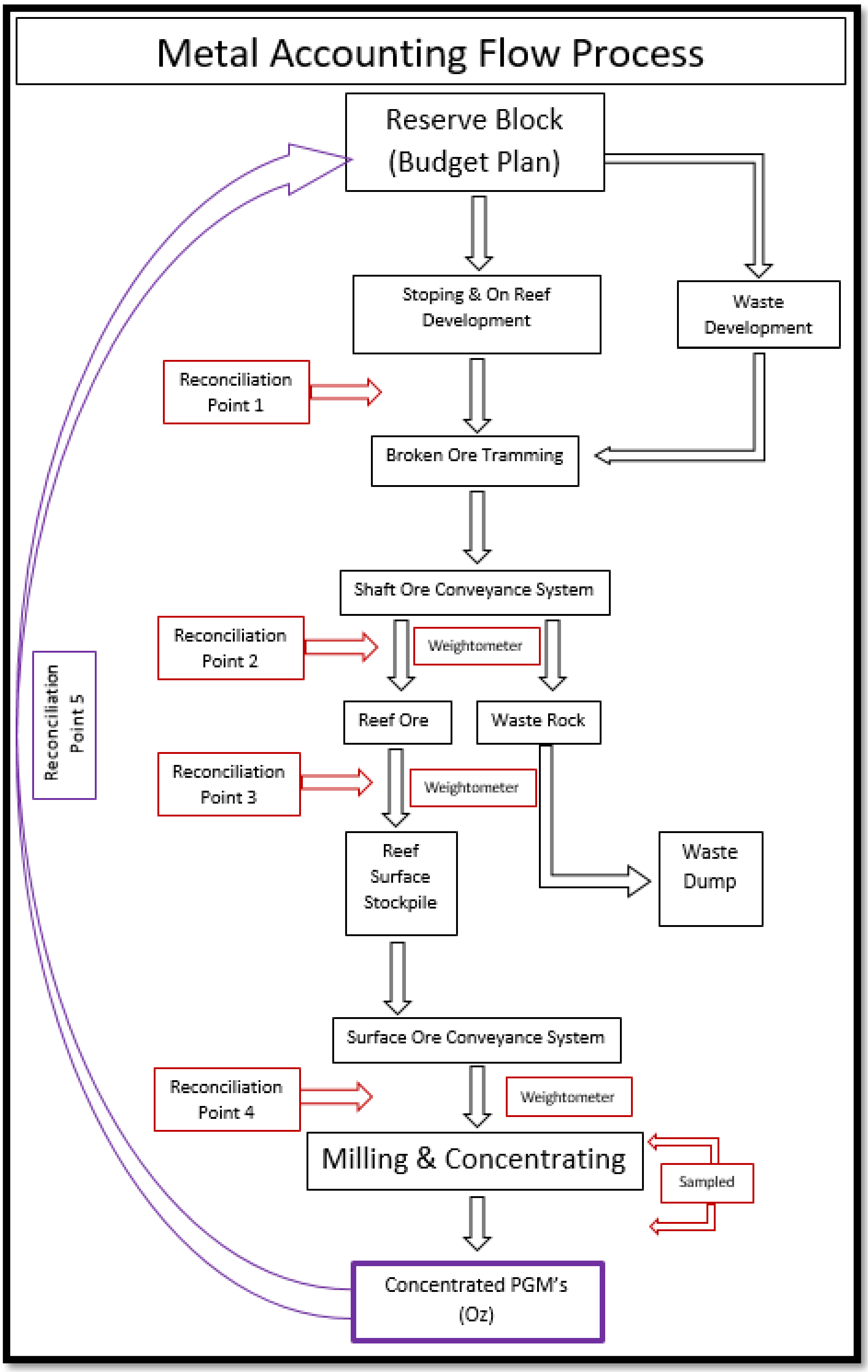


Figure 4: Metal Accounting Flow Process diagram (Author, 2023)

Sampling compliance to Protocol and Standards - Collection of sampling data for the period to compare grid spacings, laboratory QA/QC is adhered too, and PTO done on Sampler to ensure compliance to sampling standard. Comparisons between actual and estimated data will be produced to identify any irregularities that would have a relevant impact on the MCF.

Histograms – Quarterly/Half-yearly reviews, usage of the “tick-on” function, and Zone/Domain alignment will be investigated per MPM requirements.

Broken Ore Densities – Check if densities used were correct, updated, and validated.

Optimal Stoping Cut and SW Control - Was it appropriate for the 2013 to 2020 timeline and were the SWA visits sufficient as per Company Standards to satisfy a trustworthy and comprehensive database.

Cross Tramming –RFID Tag data collection for the study period to identify cross-tramming dilutions and if discrepancies were included in the MRM system calculations.

Dilutions – Consolidation of all dilution data to determine if inputs were incorporated in the MRM system.

Once this has been concluded, the information can be cross-checked with previous audits and discussions. Only then can the issues that affected the MCF during 2014 to 2017 be pin-pointed and answers to the question on real and/or apparent losses be produced.

To understand what process/es failed during the timeline in question, the processes will be mapped, performance observations done, and then corroborate findings through engagement with the accountable persons.

1.5 Data Sources

Historical data from 2013 to 2020 was retrieved from the mines database. Tonnage, grade, ounces and measuring data for the timeline was recovered and used to compile and compare data.

Literature reports published on similar subjects were used to assist with identifying areas that require consideration along the value chain.

1.6 Structure of the Research Report

This research report compromises of five chapters. The first chapter presents the introduction, problem statement, justification for research, previous work, research methods, data sources, the structure of the research report, mine overview, geology and mineralization, orebody and mineralization, and mining methods and infrastructure. The second chapter reviews the relevant literature. Chapter three focuses on areas that would deliver an apparent loss: grade control – sampling and QA/QC, histograms, density checks, and the MRM system (Chapter 3.4). Chapter four focuses on real loss issues, namely OSC, SW Control, Cross Tramming, and Dilution. Chapter five summarizes the key findings of chapters three and four and contains the conclusion and recommendation of the research study.

1.7 Modikwa Mine Overview

Exploration in the mine area started in the late 1920s with the discovery of the Merensky Reef on the Maandagshoek farm. A diamond drilling exploration programme was undertaken in the 1960s to delineate the orebody and its characteristics. During the late 1970s to early 1980s multiple limited underground operations were established, which identified the UG2 Reef as the primary target due to its grade consistency, geological continuity, and metal values (Anglo American Platinum Limited - Ore Reserves and Mineral Resources Report, 2020).

Exploration drilling commenced in the late 1980s on the UG2 and Merensky Reefs, which led to a completed feasibility study for the exploitation of the UG2 Reef. In 2001, a 50/50 Joint Venture agreement was signed between Anglo American Platinum (AAP) and African Rainbow Minerals (ARM)

Mining Consortium Limited. ARM’s effective stake in Modikwa is 41.5%, through its 83% ownership of the ARM Mining Consortium. The Mampudima and Matimatjatji community companies each hold an equal share of 8,5% through their 17% shareholding in the ARM Mining Consortium (ARM Mineral Resource and Reserves Report, 2020). The mining operations started in 2001 as a project, which reached production in 2003. North 1 and South 1 shafts commenced simultaneously in 2001 and was joined by South 2 shaft in 2013.

MPM is located approximately 20 kilometres NW of the town Burgersfort and 15 kilometres NNW from the town Steelpoort in the Limpopo Province, South Africa (Figure 5).

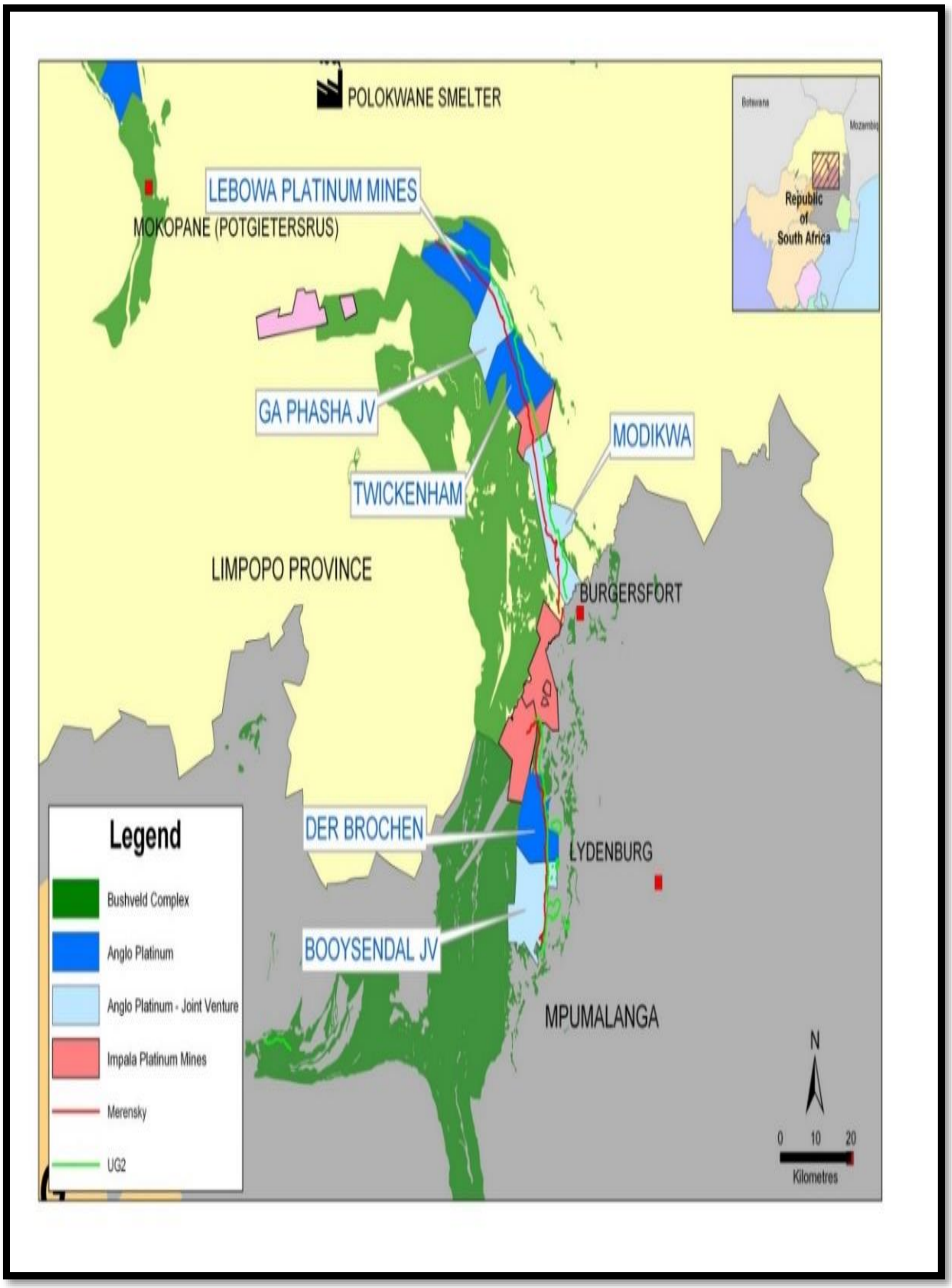


Figure 5: Location of Modikwa Mine in the Bushveld Complex - Eastern Limb (Britz, 2008)

Figure 6 shows the lease area of Modikwa Mine, the Merensky and UG2 outcrops striking NNW-SSE are shown in red and green, respectively. This indicates a strike length of roughly 25 kilometres for the Merensky and UG2 reef respectively, dipping towards the southwest at a dip between 9 to 14 degrees. The topographical relief contours shown in 20-meter intervals are super-imposed in light-brown. To the southwest of the UG2 and Merensky outcrops, the topography rises intensely for several hundred metres, producing the Leolo Mountain Range and creating a problematic situation for exploration drilling. The topography is reasonably intense, as there is a broad low-lying valley that strikes due north-south and is underlain by the rock units of the upper critical zone of the Bushveld Complex. The middle and lower critical zone regularly forms a succession of elongated but remote hills situated on the area to the east. On the west, the land surface rises abruptly as the escarpment to the Leolo Mountains is approached. (Modikwa UG2 Resource Modelling Report, 2019).

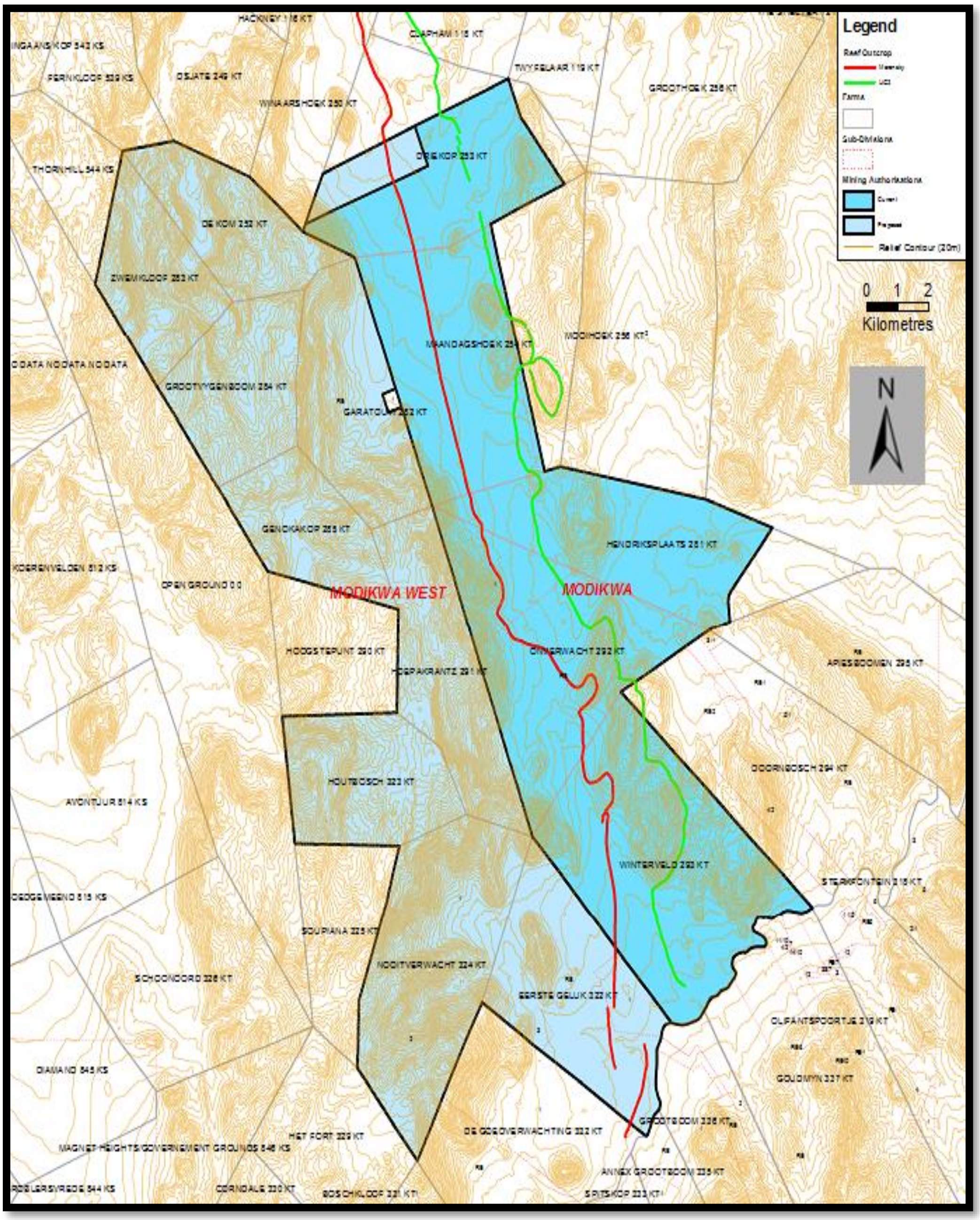


Figure 6: Topographic relief over the Modikwa Mine lease area, which incorporates Driekop (subdivided into Mineral areas), Maandagshoek, Hendriksplaats, Onverwacht and Winterveld farms (Britz, 2008)

1.8 Geology and Mineralization

1.8.1 Regional geology

About 2.1 billion years ago, a column of immense igneous material was forced up into the lateral planes of the sedimentary Transvaal rocks, but this material never reached the surface. This concealed magmatic chamber cooled down slowly and formed an extraordinary sequence of layered rocks called the Bushveld Igneous Complex (Magson et al., 2018).

It is the world's most extensive layered intrusion, with the edge being eroded over millions of years, exposing three separate segments known as the Eastern, Western, and Northern Limbs. The Bushveld Complex is 9 to 12 kilometres thick and over 250 kilometres long and 350 kilometres wide, covering an area of roughly 66,000 square kilometres, as portrayed in Figure 7. The Platinum Group Metals (PGM) occurs within three reefs in the Bushveld Complex, namely the Merensky Reef, Upper Group 2 (UG2) Chromitite Reef, and the Platreef. The UG2 and Merensky reefs are found around the Eastern and Western Limbs, with the Platreef found along the eastern edge of the Northern Limb (Perritt et al., 2007).

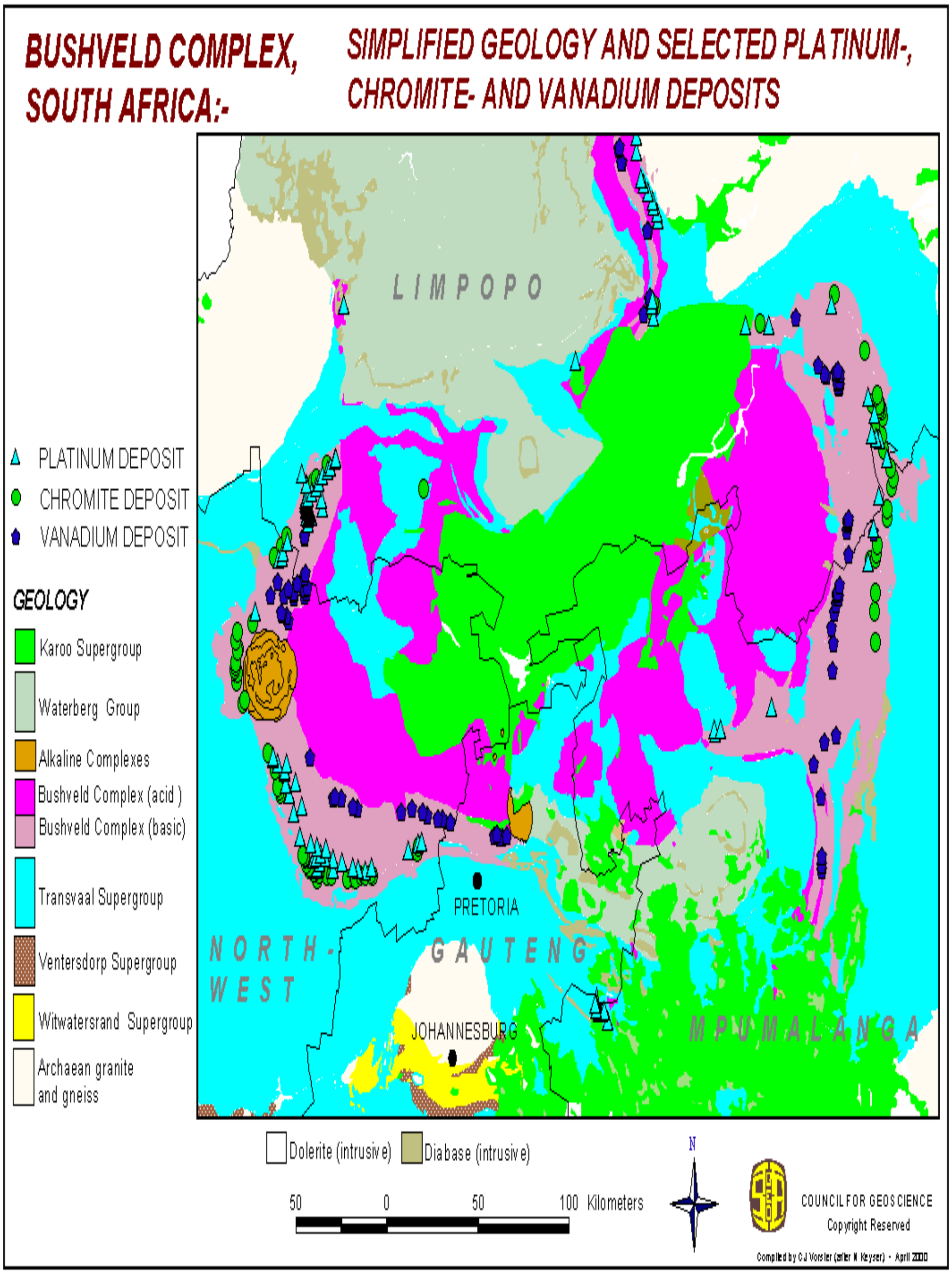


Figure 7: Bushveld Complex, South Africa (Council for Geoscience)

1.8.2 Mine geology

The Critical and Main Zones underlie the surface area of the Modikwa mining area. The Main Zone comprises of gabbros and ferrogabbros, whereas the Critical Zone contains alternating sequences of gabbros, norites, anorthosites, pyroxenites, and the chromitites (Perritt et al., 2007).

The reef sequence strikes NNW to SSE, dips on average 9° to 12° to the SW, although the dip can vary up to 20° in isolated areas. The outcrop of both economic horizons (UG2 and Merensky Reefs) typically occur in low relief areas and is covered mainly by black turf soil. In certain regions the UG2 outcrops in a series of hills, located on the Maandagshoek, Onverwacht, and Winterveld farms (ARM Mineral Resources and Reserves Report, 2020).

1.9 Ore-body and Mineralisation

The PGM mineralization is hosted within the UG2 and Merensky Reef packages (A stratigraphic column of Modikwa Mine shown in Figure 8). The UG2 Reef occurs as a chromite seam varying between 50 to 70cm in thickness, either as pure chromite or a dense collection of chromite accompanied by fine crystalline plagioclase and/or orthopyroxene. Mineralization occurs throughout the UG2 Reef seam, but significantly higher values are seen at the top and bottom of the seam. The immediate FW of the UG2 is a pegmatoidal feldspathic pyroxenite, which fluctuates in thickness from a few centimetres up to 1 metre. The pegmatoidal feldspathic pyroxenite contains some base-metal sulphides. Generally, it includes a low metal content with erratic high values due to an irregular and jagged contact, producing scattered chromite and chromitite stringers. The UG2 is superimposed by a medium to course grained feldspathic pyroxenite, which may contain up to 3 thin 1 to 10-millimetre chromitite stringers, at different thicknesses between each stringer. A one to three-centimetre anorthosite layer occurs above the chromitite stringers and is referred to as the Leuconorite Parting Plane (LPP). HW samples do not contain significant Platinum Group Elements (PGE) values, although occasional grades above 5 g/t have been encountered on the chromitite stringers.

The feldspathic pyroxenite rocks inside the Merensky reef package host chromite, precious, and base metal sulphide build-ups. PGE mineralization occurs as separate metals that are typically associated with and surrounded within the base metal sulphides (BMS) and silicates. These comprise PGE sulphides, sulpharsenides, arsenides, bismuthides, tellurides, bismuthotellurides, and alloys. The BMS occur as separate particles, sharing interstitial space with plagioclase feldspar, within a silicate framework of orthopyroxene. There is a strong association of the PGM's with the chromitite stringers, generally defining the upper and lower contacts of the Merensky Reef. Higher PGE values are noted at these chromitite contacts. Mineralization above and below the chromitite contacts decrease to trace values, while sporadic higher values can be encountered (Colquhoun, 2019).

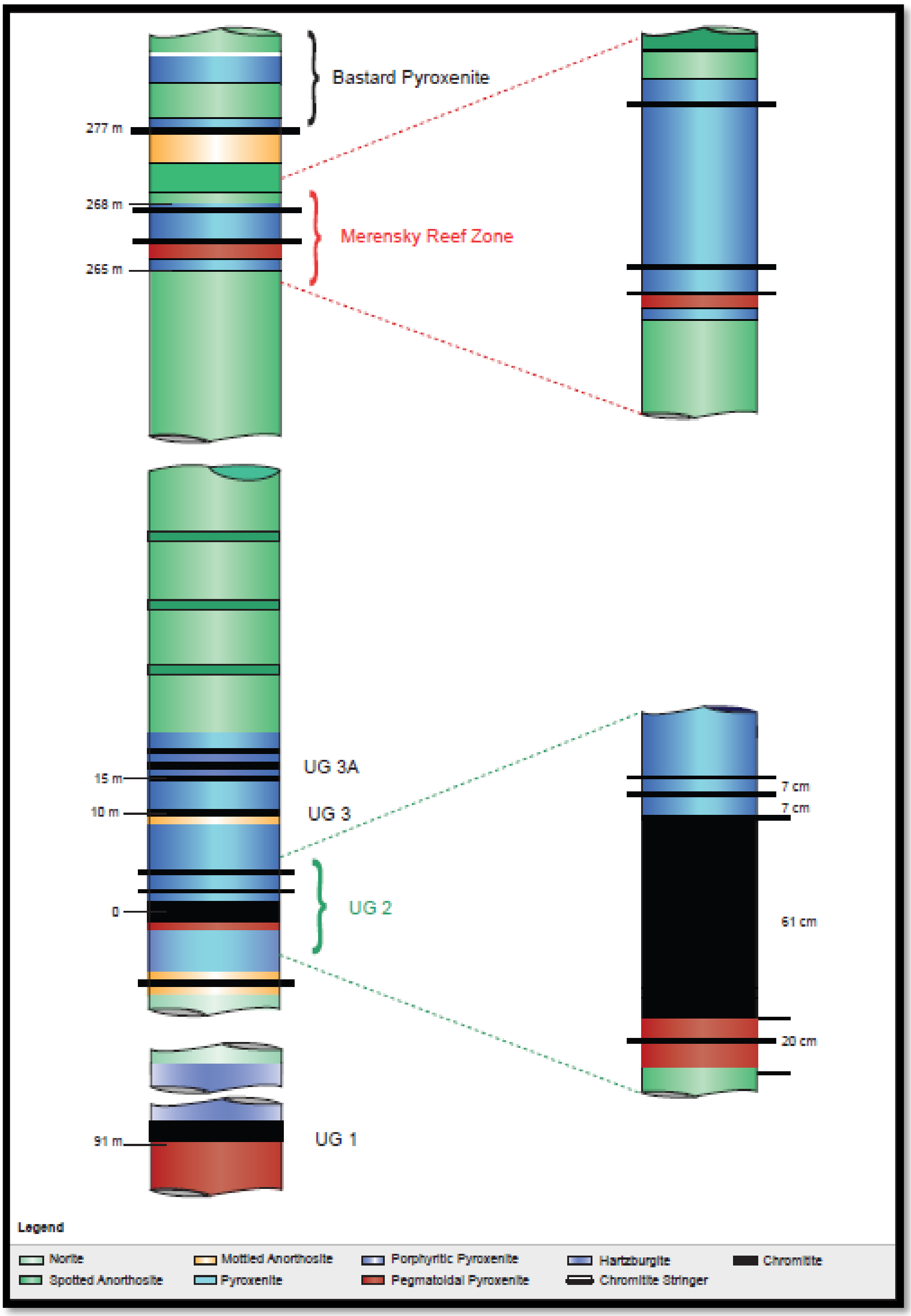


Figure 8: Generalised stratigraphic column on Modikwa Mine (ARM - Mineral Resource and Mineral Reserves, 2020)

1.10 Mining Methods and Infrastructure

It is a hybrid operation with mining consisting of mechanized trackless development and conventional breast stoping with strike pillars. The UG2 is accessed via three primary decline shafts (North 1, South 1, and South 2), with three adits on the Onverwacht Hill. Mined tonnage is fed via a conveyor belt system to be processed at the Modikwa concentrator plant. The PGE-rich concentrate is road hauled to Anglo Platinum's Polokwane smelter and refining facilities (Anglo American Platinum Limited - Ore Reserves and Mineral Resources Report, 2020).

2 LITERATURE REVIEW

Theoretically for a MCF to be 100%, no metal loss between mine to plant should occur. Meaning that perfect sampling, assaying and tonnage measurements occur during all stages, from handling to processing (Tetteh, et., al, 2014).

However, metal loss in the value chain has been occurring throughout mining history, with some metals being more susceptible to certain losses than others, but the fundamentals are the same. Metal accounting is a critical factor in MRM, the primary goal is to balance the metal content, by capturing the quantity and quality of ore planned against the actual end product (Mpofu, 2018).

Storrar (1981) further notes that reasons for losses based on investigation undertaken by mines are:

- Undermeasuring of stope areas,
- Using incorrect relative densities for tonnage calculations,
- Not allowing for scaling of side and hang walls of stopes, and
- The ripping of FW by scrapers.

These points will have a undesirable effect on any MCF, as it influences the tonnage and grade and produce a lower than planned metal content.

Though it is impossible to eradicate dilution fully, it can be measured and controlled if the orebody is properly delineated and extraction volumes effectively measured (Xingwana, 2016)

Any shortfall in an MCF will mean that there was metal loss somewhere in the ore flow; this loss can be further established as either real or apparent. The outcome of both real and apparent losses is to reduce the MCF to below 100%. As Real Losses are traceable and are a result of misplaced ore during mining operations, these losses can be located along the mining ore flow. If the loss cannot be found, then the loss is apparent. This loss is a result of over-estimation during the evaluation process resulting in metal called for that was never there in the first place. Apparent loss contributors are poor sampling standards, incorrect relative density applied for mass calculations and over-estimation of block evaluation (Cawood, 2003).

Chapters three and four reviews the data and literature related to the factors that influenced the MCF efficiencies on MPM. This is done by addressing sampling, density and measuring system for Apparent loss, and SW controls, cross-tramming and dilutions for Real loss.

3 APPARENT LOSS

3.1 Sampling

A persistent low MCF of less than 80%, according to Storrar (1981), raises concerns at all levels of management since mine sampling might be inflating the content of ore mined. Poorly enforced sampling protocols and QA/QC systems can result in raised mining risk by increasing grade inconsistencies, and produce financial and apparent loss.

Sampling is extremely important and requires suitable attention to reduce variability and allow for a trustworthy evaluation model.

3.1.1 Grade Control – Sampling

Grade control involves the sampling and mapping of mining stope faces and dilution monitoring. It aims to deliver quality metal tonnes to the concentrator plant by ensuring that high quality and representative samples are taken to produce an accurate evaluation model.

Sampling is a critical process in the planning and extraction of an ore-body, as it allows for the estimation of the 4E grade and content of the ore-body.

The four platinum group elements (4E) consist of platinum (Pt), palladium (Pd), rhodium (Rh) and gold (Au). Although other elements such as ruthenium, iridium, osmium, and even base metals such as nickel, copper and cobalt sulphate are present in PGM's, only the 4E are refer to during grade and content reporting.

It consists of collecting small portions of a larger rock mass so that the samples represent the average grade of that rock mass.

Samples are most representative of the ore-body when taken on a regular grid pattern; this allows for the samples to have equal influence. Samples are typically taken on the outer perimeter of a block of ore in tabular ore bodies, except where diamond drilling holes are available; this additional sampling information can then be added to the evaluation of the block of ore. The frequency of the metal content in the mineral ore-body and its distribution affect sampling protocols and grid patterns.

Set sampling Protocols and Standards are necessary to guarantee that each selection is taken consistently with the succeeding sample and at a fixed grid pattern; this is to eradicate biased sampling and ensure that the selection is representative. It is essential to ensure that Protocols and Standards are in place and adhered to; hence QA-QC at the laboratory must be enforced and overseen by the Valuator or Geologist. MPM follows the Anglo-American Platinum Sampling Standard. This Standard aims to mitigate any possible sampling bias and or sampling errors, enabling a elevated confidence in resource estimates and lessening business risk with improved evaluation and reconciliation of the Mineral Resource (Langwieder, 2018).

The highest standard possible is required when sampling, as it is the basis of a robust evaluation model. A 95% sampling confidence is used for modelling purposes on MPM.

The sampling technique used on MPM is a diamond saw cutter and chip sampling method; this is to ensure the highest integrity of each sample section is achieved, as per the mine’s procedure.

Sampling dimensions are required to be 4cm wide by 4cm thick and can vary between 10cm to 20cm long, dependent on the facies but never exceeding 20cm (Figure 9).

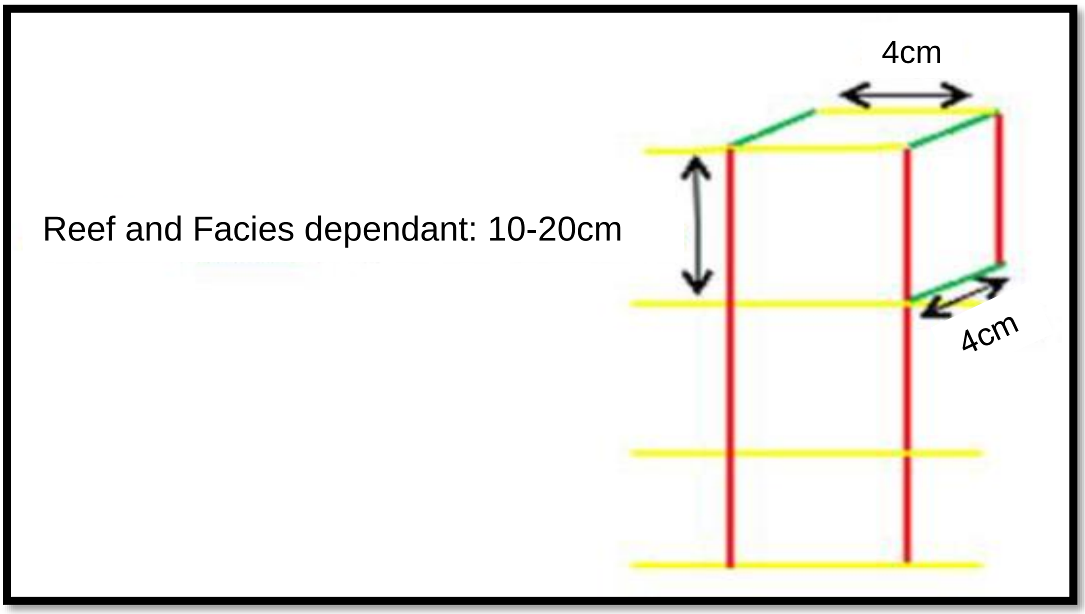


Figure 9: Isometric view of sample section (Langwieder, 2018)

An entire section is sampled from HW to FW, by adding 2cm HW to the TRC and 2cm FW to be added to the BRC, the rest of the UG2 reef is then sampled at 15cm intervals. The HW is sampled at 15cm intervals to the top limit of the excavation, whereas the first FW sample would be taken at 15cm and the remainder at 20cm intervals. This is due to known minimal mineralization present in the UG2 FW (Figure 10).

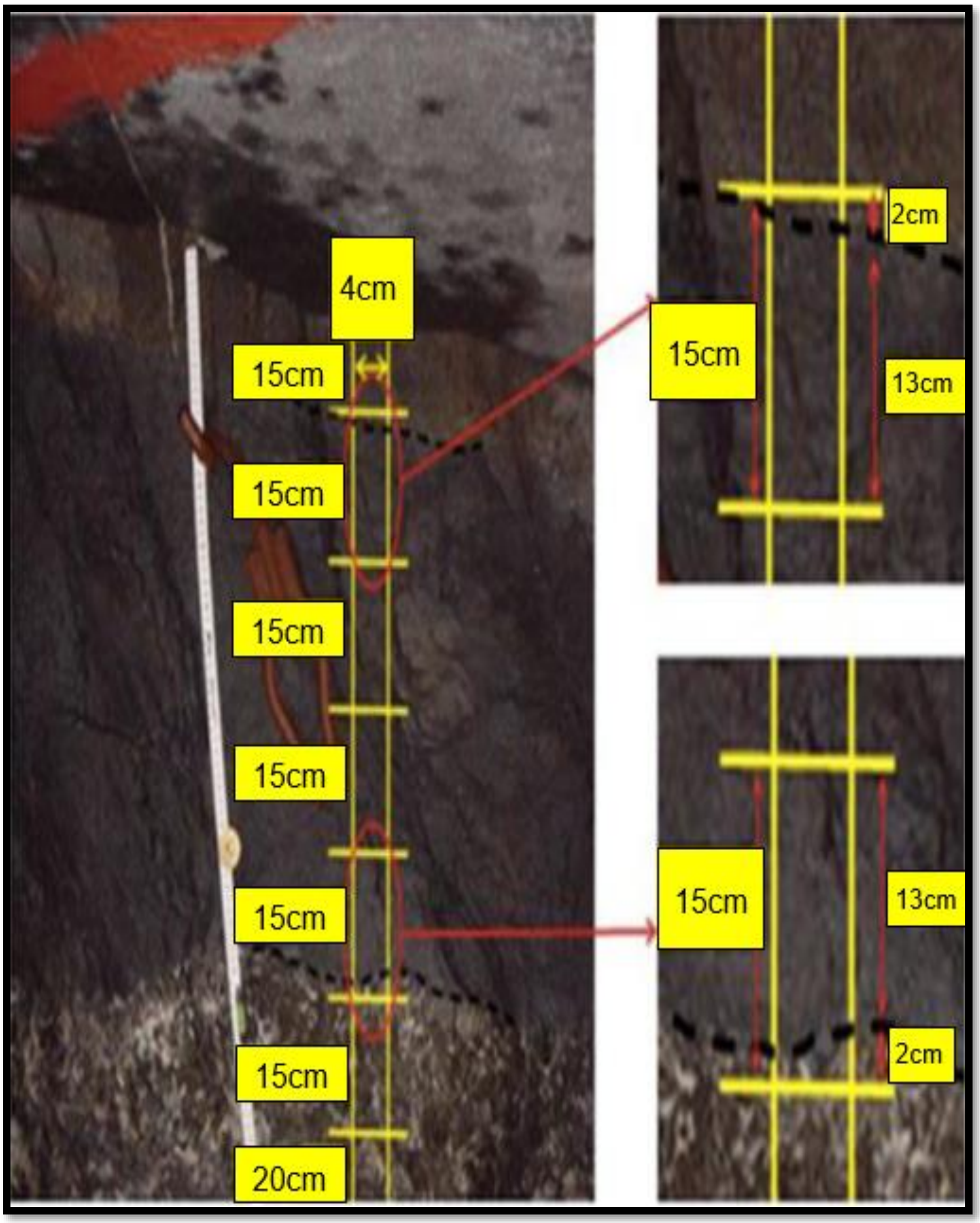


Figure 10: Sampling section intervals (Langwieder, 2018)

The sampling section grid is laid out in a 30x30m pattern. All raise and winze development sample sections are sampled at starts + 15m, after that 30m sampling intervals are marked off. Stope panel sampling as shown in Figure

11, are sampled as the panel advances, the first station sampled at 15m from the start of the ASG, after that intervals of 30m.

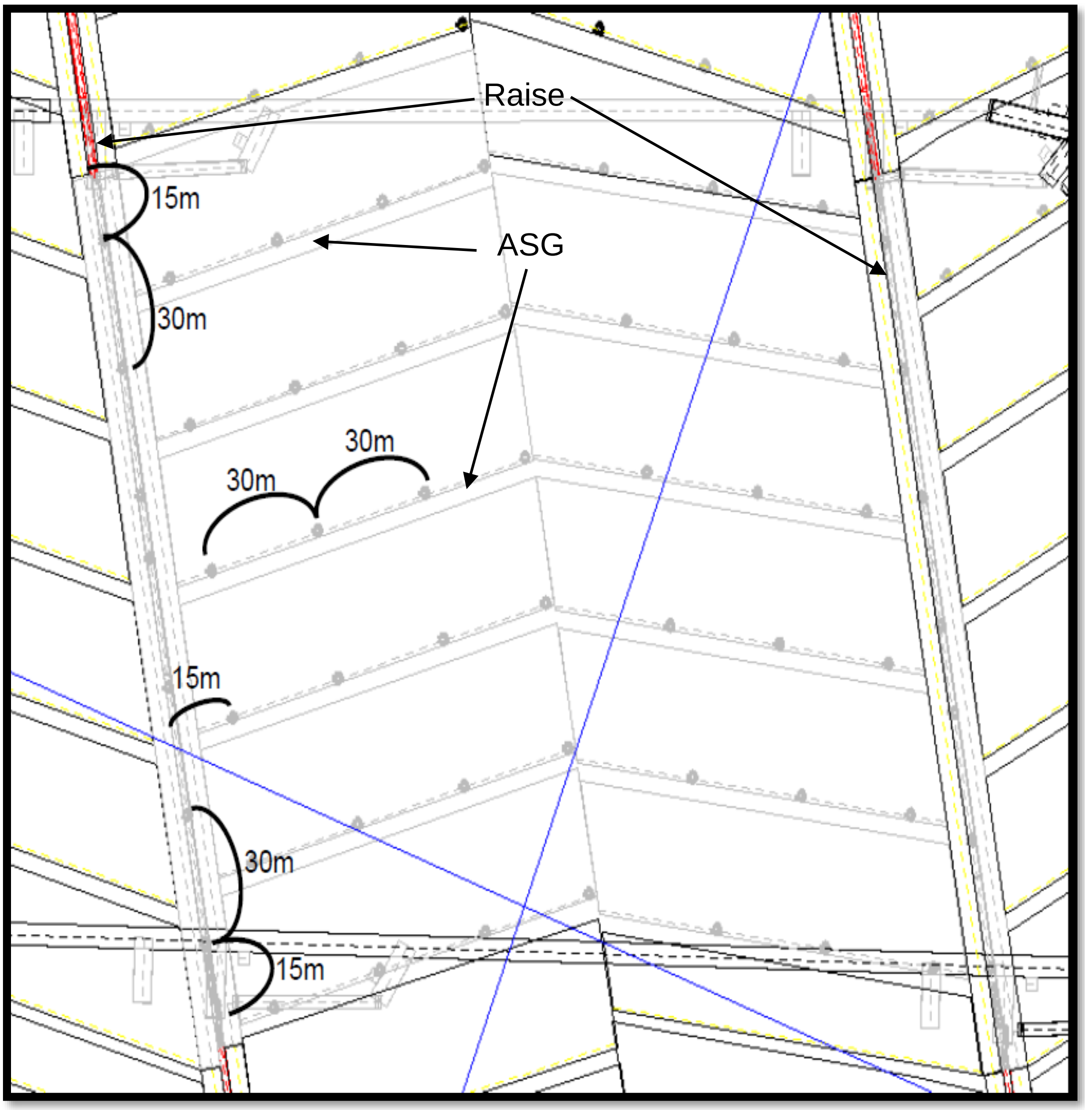


Figure 11: UG2 sampling grid for MPM (Sampling protocol, 2016)

Once the sampling section positions have been allocated, each section face must be cleaned, washed, and barred of all loose rocks that could contaminate the sample or pose a safety risk. The section is then drawn from HW to FW, at right angles to the reef contact. The sample demarcation lines must be drawn perpendicular to the section lines. These lines are then cut with a diamond saw, at a depth of 4cm, ensuring that each sample weighs the minimum 300 grams mass required by the laboratory. Each block is chipped out individually by hand with a chisel and hammer, starting from the bottom upwards, preventing contamination of the lower samples. The dish must be positioned to ensure that no rock chips are lost, with each sample bagged and tagged with a ticket number and correctly assigned in the sampler's field book.

The sampling procedure must be adhered to by the Sampler and his team, to ensure compliance, PTO's must be conducted on the Sampler by the Valuator. A set check list is used to check compliance and identify areas that require additional training and coaching (Figure 12).

MODIKWA PLATINUM MINE
Sampling Process MTTM

Planned Task Observation **Multi Task Team Members**

MTTM: **W/Place: ……………………………** **Date:……………..**

U/G Sampling activities - Prepare for a sampling shift	**YES**	**NO**
1. Prior to proceeding u/g must check with Resource Technician Sampling that:		
1.1 Where intended working place is.		
1.2 Check that team is properly equipped for the day's work.		
1.3 Ensure that daily equipment and consumable maintenance checks have been carried out.		
1.4 Make sure all equipment goes U/G.		
U/G Sampling activities - On site preparation	**YES**	**NO**
1. Ensure that the working place has been barred down and made safe by a responsible mine official.		
2. Do not cut or chip near misfires or sockets. Move the sampling site if necessary.		
3. Do not cause sudden shut down of any operating machine.		
4. Wash down sidewall to be sampled (and mapped).		
5. Clear the footwall at sampling site of any loose boulders and ensure that the operator have a secure foothold.		
6. Lock out winch.		
7. Stack equipment not being used out of the way.		
U/G Sampling activities – Safety on site	**YES**	**NO**
1. Stand clear of rock saw.		
2. Use protective clothing.		
3. Team member to assist with holding hoses still while cutting is in progress and look out for danger.		
4. When using a portable ladder adhere to risk analysis recommendations.		
5. Ensure safe transportation of people and equipment.		
U/G Sampling activities – Cutting of samples	**YES**	**NO**
1. With the pneumatic saw cut a shallow groove (pilot cut) from the bottom up along the chalk line.		
2. Cut the 2nd groove parallel to the 1st groove from the bottom up (or top down).		
3. Now cut both grooves to the required depth.		
4. Cut the short (horizontal) cuts between samples to the required depth.		
5. A team member to assist the person cutting and be on the lookout for any danger.		
U/G Sampling activities – Collecting and bagging of samples	**YES**	**NO**
1. Samples collected (chipped) from bottom to top.		
2. Chip even samples. No over or under break.		
3. Catch samples in a clean dish.		
4. Prevent pieces of sample being lost.		

5. Place large plastic sheet on ground to catch pieces.		
6. Transfer sample from dish to plastic bag.		
7. Put allocated ticket in plastic bag with sample.		
8. Close plastic bag securely with rubber band.		
9. Each sample station's samples to be put in a separate, marked, big plastic bag.		
10. Each sample station's samples to be counted before closing the big plastic bag.		
Multi Task Team Members		
Assist Resource Technicians	**YES**	**NO**
1 Work as a team U/G to connect hoses and prepare sampling sites.		
2. Help measure and mark sampling station sites from a survey peg.		
3. Help check for misfires and sockets.		
4. Help wash and trim station sites.		
5. Help clear footwall at station sites.		
6. Cut samples using pneumatic saw.		
7. In turns will chip, bag and number samples.		
8. Help measure and map development end.		
9. Help pack away equipment.		
10. Help carry equipment and samples to pick-up point.		
11. One to stay with equipment and samples and wait for pick up by LDV.		
12. Help carry hoses and rock saw to storage facility.		
13. After U/G shift make sure equipment is ready and clean for next shift, replacing used items.		
Equipment maintenance	**YES**	**NO**
1. Check and account for all tools & equipment before leaving working place u/g.		
2. Clean all equipment & tools on surface.		
3. Replace damaged and used spares & equipment.		
4. Check diamond saw blades.		
5. Check diamond saw oil supply.		
6. Sharpen pencils and chalk.		
7. Ensure adequate pages in book.		
8. Ensure adequate number of tickets.		
9. Ensure adequate number of clean small and big plastic bags.		

Resource Technician Sampling:……………………… Date:……………………

Valuator:………………….. Date: ……………………

Figure 12: Sampling Process PTO Check list (Coetzee, 2013)

Once on surface, the Valuator or Resource Geologist is responsible for ensuring that the samples are dispatched to the laboratory, bagging each sample section individually.

From 2010 MPM has sent all samples to SGS Laboratories for analysis, where they are routinely analysed for platinum, palladium, rhodium, gold, and copper. The laboratory is ISO 17025 accredited, and this accreditation is the most essential standard for testing and calibration at laboratories. It corroborates that a specific laboratory can produce precise and consistently reliable testing and calibration data.

Sampling data from 2013 to 2020 was collected, including the on-reef stoping and development mined for the same period. The total Stoping centares and On-Reef Development has been tallied to produce the number of sampling sections required to achieve 100% coverage. This was then compared to the Authorised Sections Sampled (these are sampled sections that have been checked and verified by the Valuator or Senior/Resource Geologist) to produce a percentage figure. The variance between the required versus actual samples done per year is portrayed in Table 3, and shows a downwards trend from 2016, as only half of all metal mined was sampled in 2016 and only approximately 8% for 2020. This must have had an unfavourable impact on the MCF, and produce an inconsistent monthly MCF due to a lack of sampling values to create representative Histograms and an accurate Evaluation Model.

Table 3: Sample Stations – Percentage Achieved (Author, 2021)

Variance	2013	2014	2015	2016	2017	2018	2019	2020
	95%	92%	68%	52%	26%	6%	9%	8%

A bar chart showing all Authorised Sampled Sections that have been performed from 2013 to 2020 is shown in Figure 13. A notable downward trend in sampling sections can be seen, with a distinguished plunge after 2016.

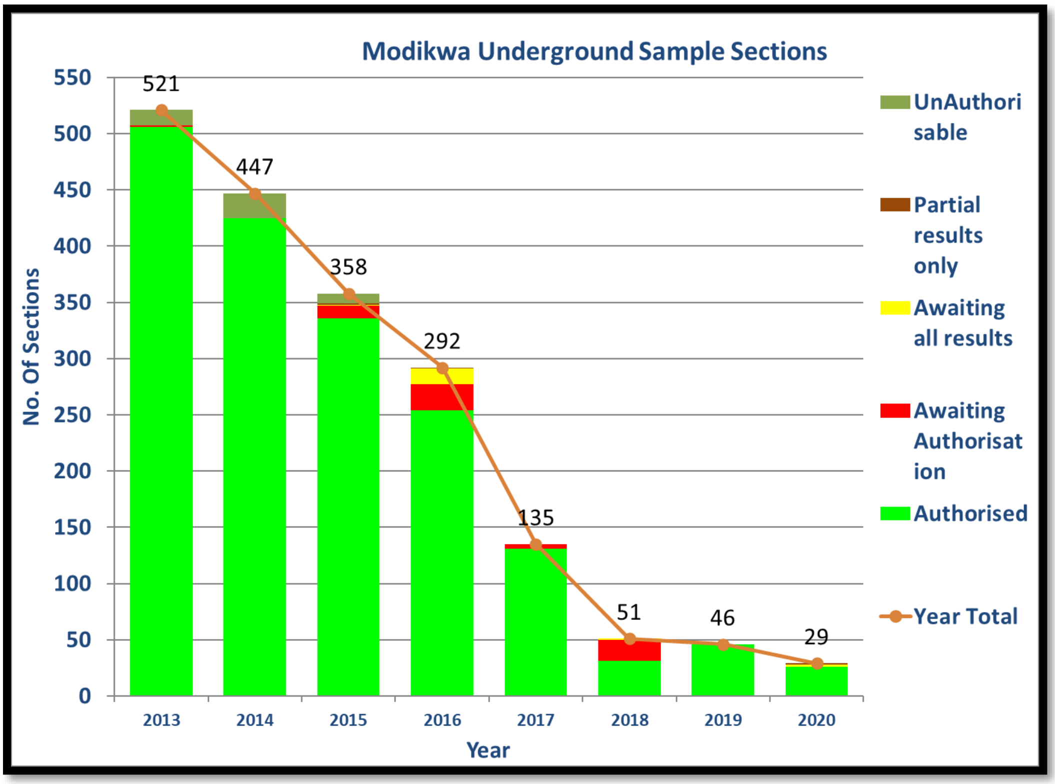


Figure 13: MPM underground sample section 2013 - 2020 (Sibiya, 2021)

Sampling plans showing the authorised sampling sections (green dots) for North Shaft (Figure 14) and South 1 & 2 Shafts (Figure 15), confirming that a lack of adequate sampling occurred in this period.

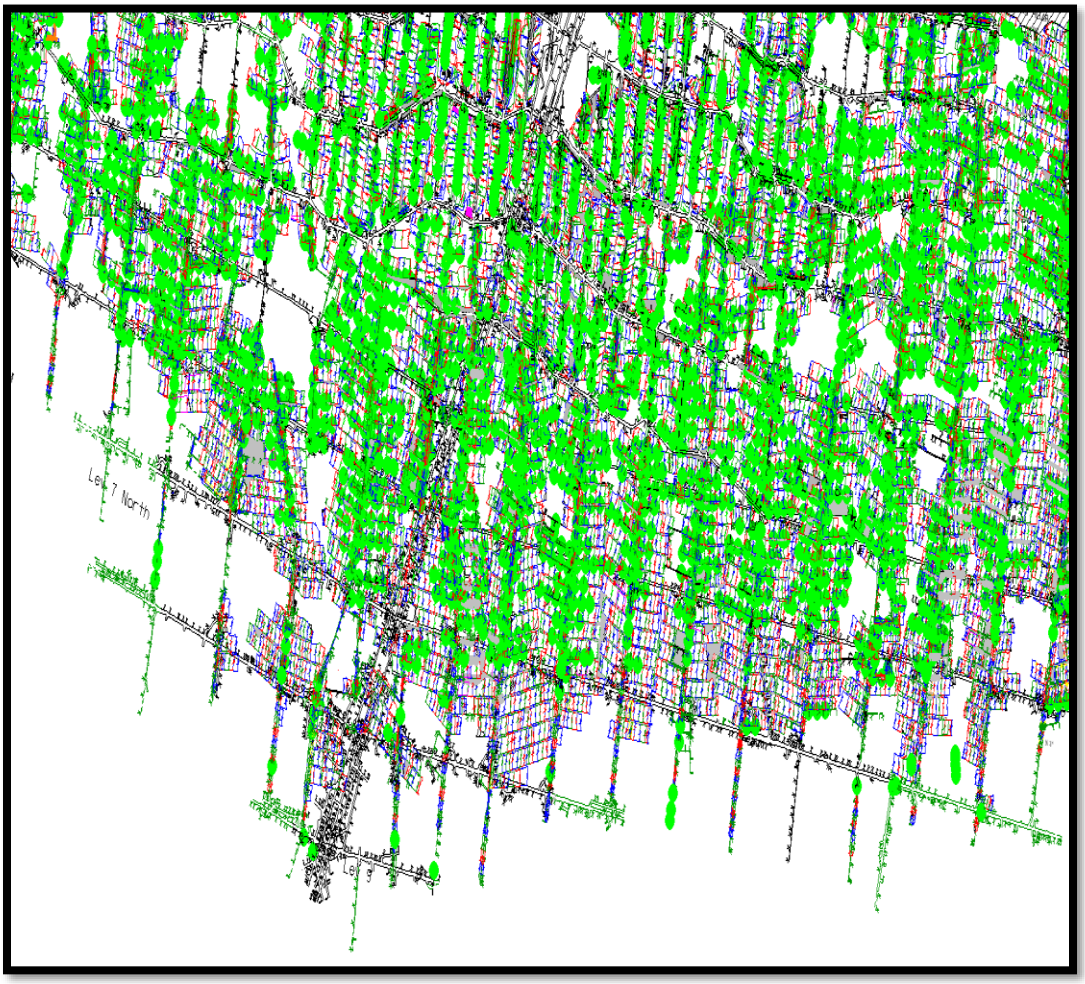


Figure 14: North Shaft Map showing sampled sections (Sibiya, 2021)

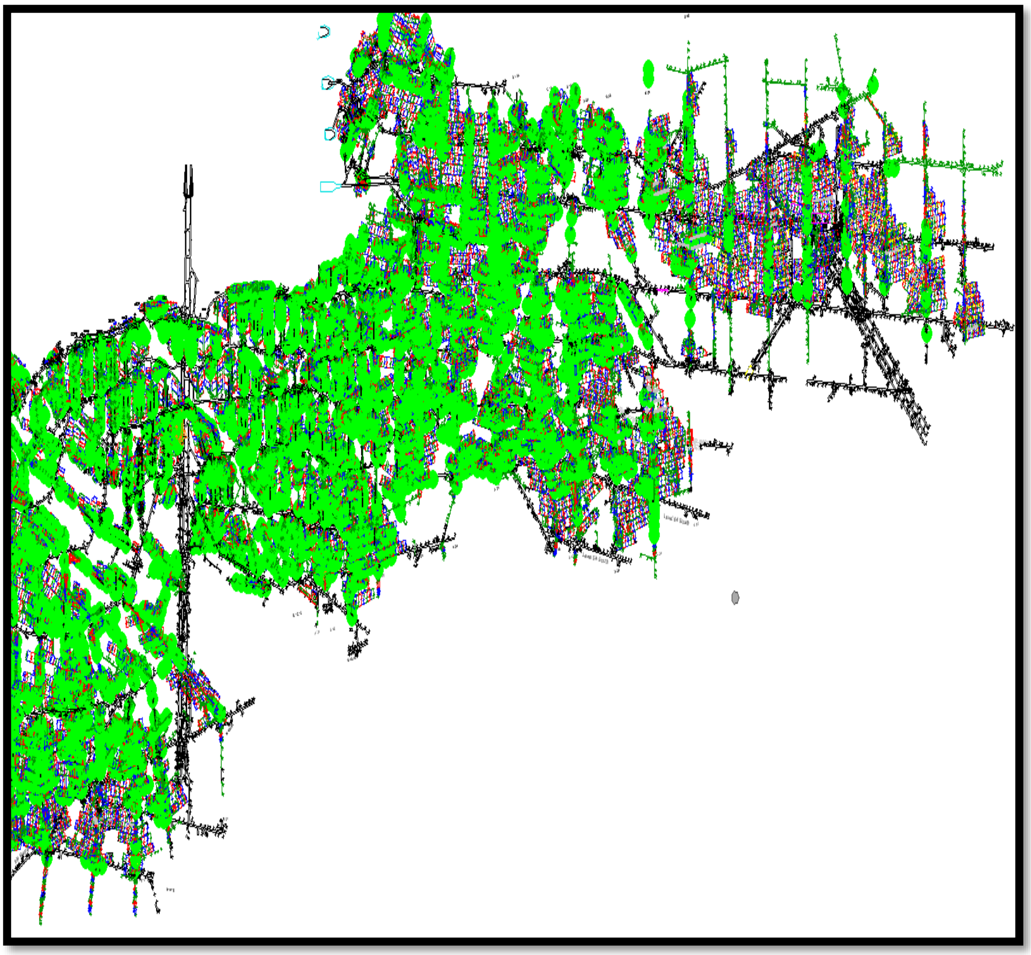


Figure 15: South 1 & 2 Shafts Map showing sampled sections (Sibiya, 2021)

3.1.2 Quality Assurance/Quality Control (QA/QC)

To confirm that samples had been taken to the company's sampling procedure, PTO's are required to show compliance. A signed-off Sampling PTO Check List paper trail must be available and completed quarterly. This is the most critical step in the mines valuation process if a sample is not taken correctly, all the steps that follow will be based on inaccurate values. A partial paper trail was available, it was scrutinized and showed no significant variation from the set protocol. The required PTOs were not done regularly from 2016 onwards, but this could be due to the low attained sampling rates during these years.

A QA/QC procedure aims to confirm accuracy and precision of the laboratory assay process, this programme identifies various phases that may negatively affect the accuracy and precision of a sample. Apart from the laboratory QA/QC process, all sampling values received from the laboratory is checked by the Valuator and authorised for use if correct. Any values that do not comply will not be permitted for use and are categorised as unauthorized. An unauthorized sample may be anything from a contaminated sample not processed, incorrect labelling, or a missing value causing the full sample to be erroneous. An observation noted in Table 4 was that there were no unauthorized samples from 2016 onwards. This is the period where the sampler was used as a Valuator.

Table 4: Sampled sections 2013-2020 (Sibiya,2021)

Year Sampled	2013	2014	2015	2016	2017	2018	2019	2020
Authorised	506	425	336	254	131	31	46	26
UnAuthorisable	14	22	9					
Awaiting Authorisation	1		11	23	4	19		
Awaiting all results			1	14		1		2
Partial results only			1	1				1
Year Total	**521**	**447**	**358**	**292**	**135**	**51**	**46**	**29**

To comply with QA/QC protocols, SGS Laboratories have a wide-ranging assay quality control system that includes blanks, certified reference materials, in-house reference materials, and twin streaming / replicate analyses. SGS is an ISO 17025 registered company and functions according to international quality standards (Britz, 2021).

Investigation into the problematic period between 2014 to 2017 to understand what changed produced the following observations.

A commodity price drop from the end of 2014 (see Figure 16) had forced MPM to freeze positions and introduce severance and early retirement packages till 2016. At this time, the Valuator retired (October 2014), and the job position was terminated; the Sampler was then used as an acting

Valuator, and the Sampling Assistants positions were cut. The Senior Geologist positions were also removed from the budget, and only Junior Geologists were kept to oversee the shafts. Sampling was then only done on weekends when overtime employees were available to assist the Sampler. This also created problems of its own, as supervision and logistics were lacking over weekends, ending up in little to no sampling done.

Although this could contribute to the lower than expected MCF, why was the MCF corrected from 2018 onwards with declining sampling figures? It may be due to the reasonably homogenous grades found on the UG2 Reef, which mitigated the low sampling percentage, allowing the outdated histograms to be reasonably accurate to represent the blocks valuated.

Figure 16: Platinum Historical Price Chart (FOCUSECONOMICS, 2020)

3.2 Histograms

A histogram is a graphical image that arranges a group of data points into user-specific ranges. Like a bar graph, the histogram summarizes a data series into an easily understood chart by taking multiple data points and clustering them into sensible ranges or bins (Chen, 2021).

A grade histogram represents a distribution of mineralization along a transect line generally perpendicular to the reef plane. As the top contact of the UG2 seam is regular, the sample sections are aligned on the top contact and not the bottom contact as it is jagged and irregular (Figure 17).

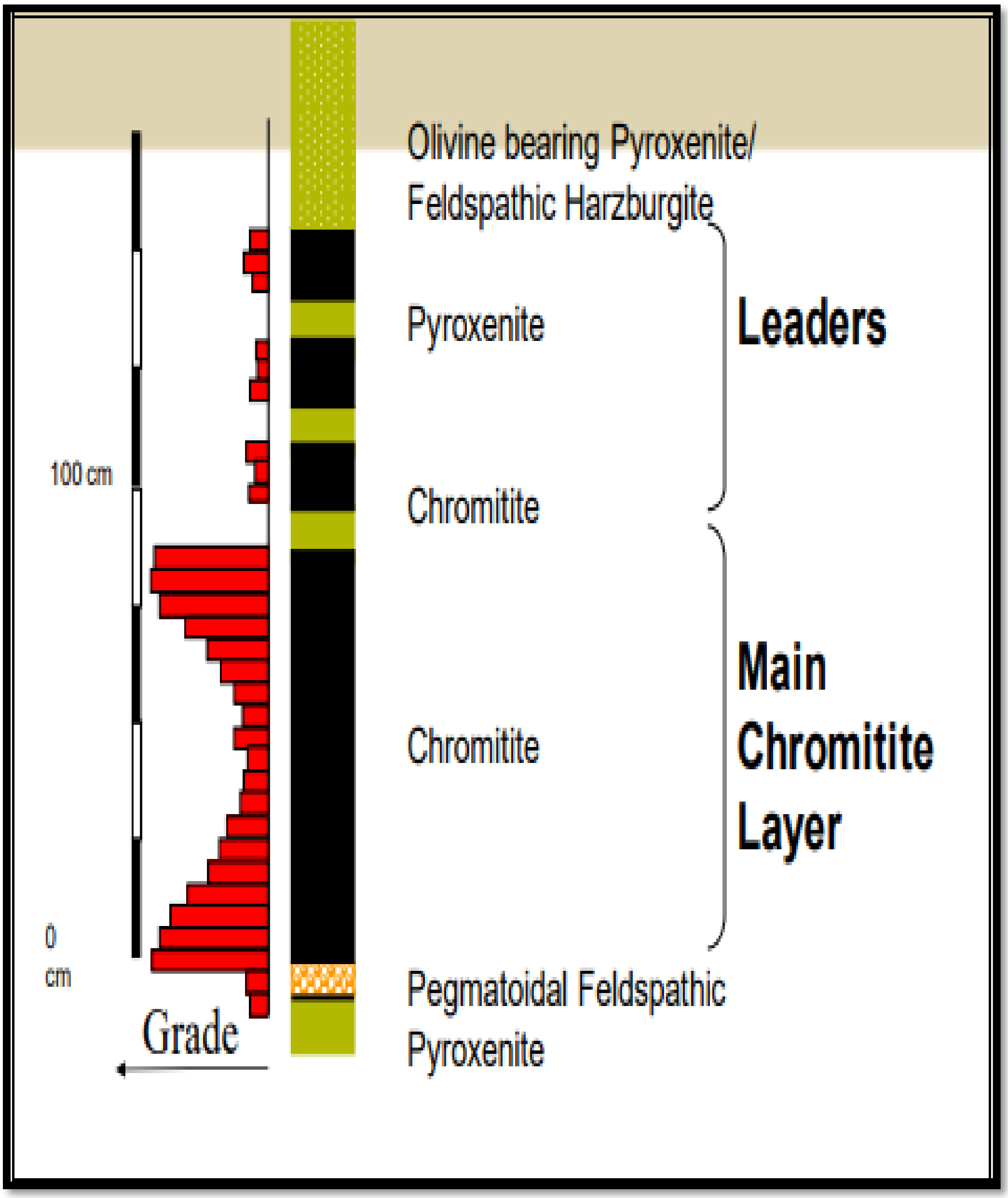


Figure 17: Example of a UG2 Chromitite Layer Histogram (Lomberg, 2014)

Monthly evaluation is based on sampling histograms and SWA reports for the areas being mined. The purpose is to create a diligent, uniform, and auditable method to ensure high standards and transparency throughout the evaluation process. The accountability for the evaluation process for each mine requires a competent person to be appointed. Such a person will be required to undertake regular audits of the system implemented at each shaft (Botha, 2016).

The histogram shown in Figure 18, captured as a screen shot from the software used, to determine the metal grade expected for a mining block or zone. It is essential to check for any irregularities in the histograms used in the period to ensure impartiality and consistency. Grade inaccuracies would overwhelmingly contribute to a distorted MCF.

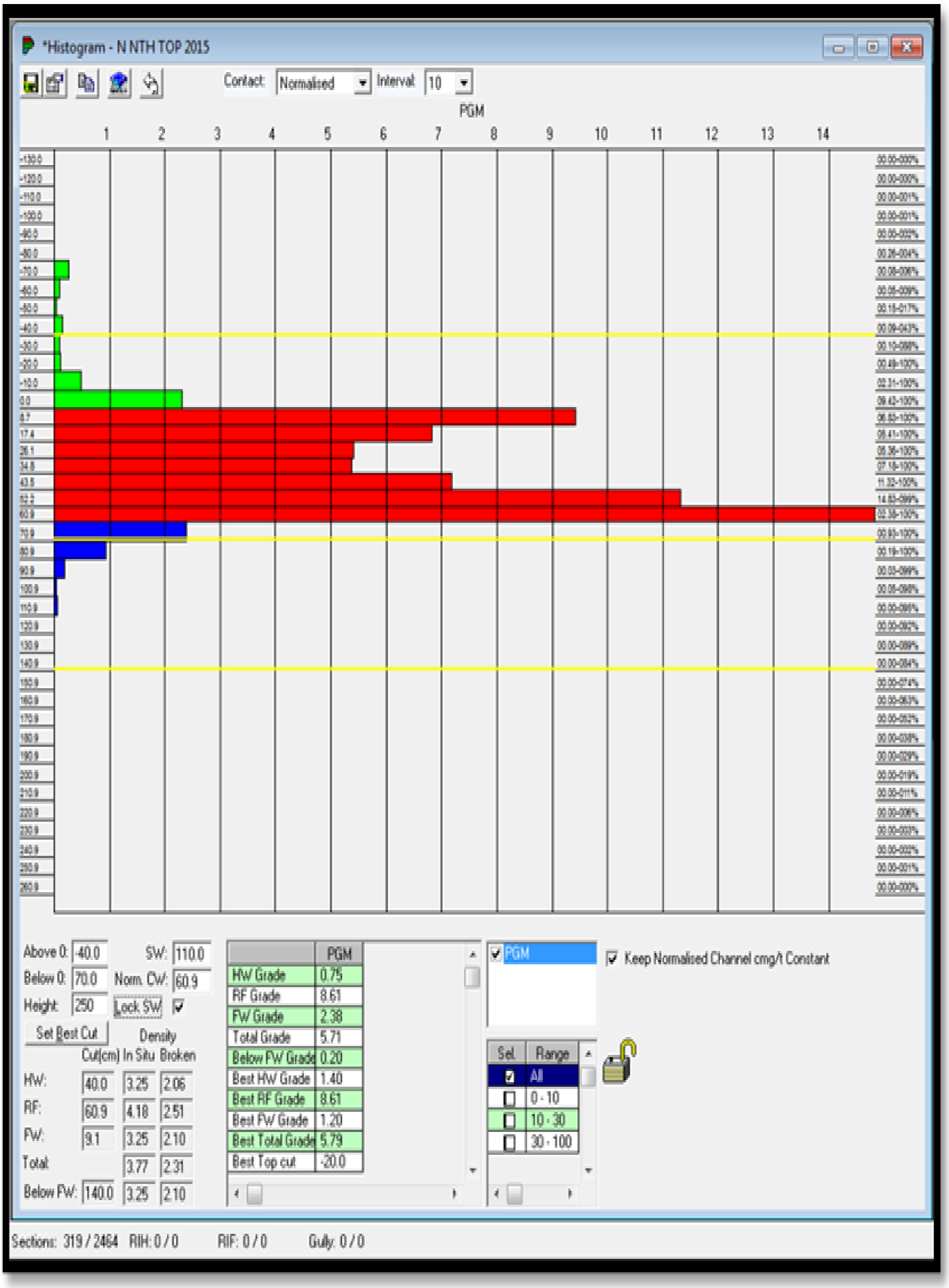


Figure 18: Modikwa North Shaft Histogram (Britz, 2021)

The mines standard required that histograms be updated and signed-off per zone, the frequency of histogram creation can be increased where the sampling frequency is higher than normal, but the norm is bi-annual. Based on the low sampling rate from 2017 to 2020, it was found that the histograms could not be updated regularly, as very little data (poor sampling coverage) was available to do this, and the outdated histograms were used to evaluate the zones. The histograms on MPM are created according to structural domains (geo-zones) opposed to facies zones, as no facies zones have been found on Modikwa.

3.2.1 Geo-Zones

To zone areas for evaluation (histograms), the orebody must be divided into blocks or zones that show similar characteristics (e.g., Reef thickness and grade).

Facies are the general appearance and features of a rock element, differentiating the element from other elements around it. It is distinguished by its structure, texture, source, and mineralogy.

Sedimentary facies of the Carbon Leader Reef and a section of a channel facies are shown in Figure 19. It is used to compare the grade to the different reef facies. This, in turn, allows identifying the ore pay shoot that will be mined and the areas that are to be targeted, and those that are to be discarded. An ore pay shoot (Figure 20) identifies the deposit region with different values; this allows for proper evaluation and designing of the ore block to be able to mine at an average set grade. This is done by controlling the mining mix between the different grade areas, to deliver an average established grade. This allows for maximum metal extraction and minimal metal sterilisation.

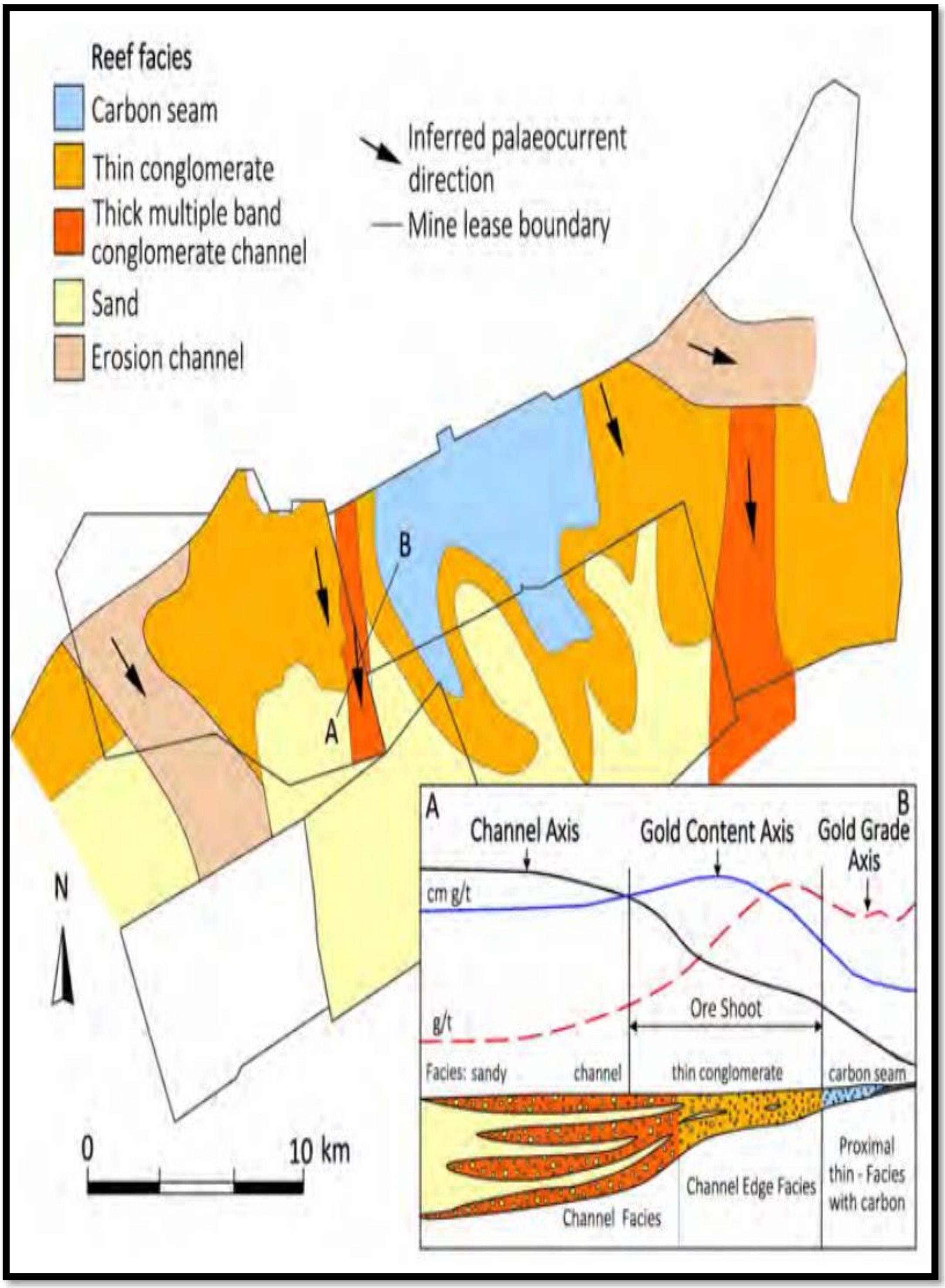


Figure 19: Sedimentological facies in the Carbon Leader Reef (Tucker, et., el, 2016)

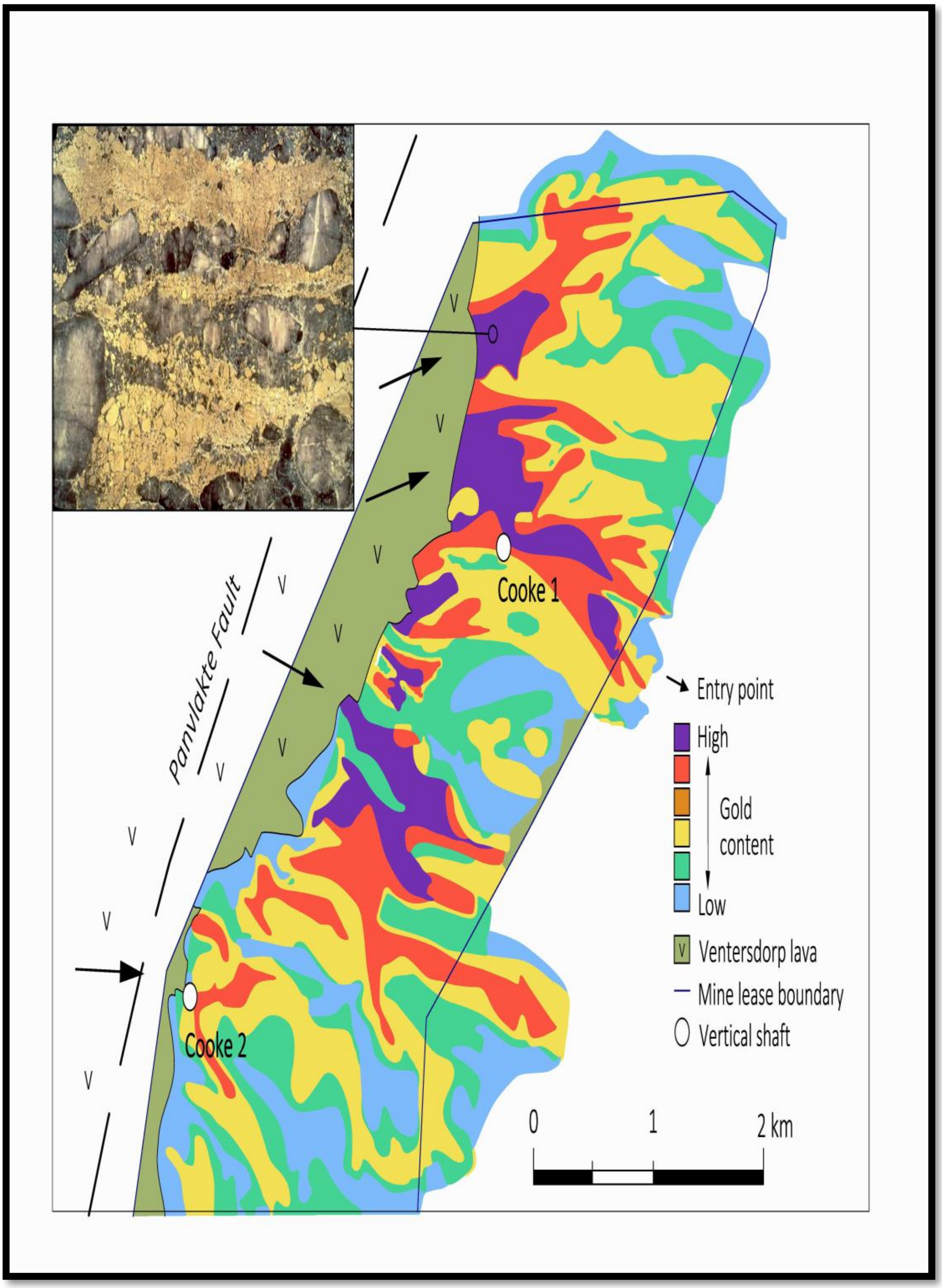


Figure 20: A pay shoot pattern for the Elsburg Composite Reef. (Tucker, et., el, 2016)

MPM has not identified any UG2 Facies (Figure 21), as the UG2 Reef channel thickness and grades are reasonably homogenous. Histogram zones are thus divided into North & South and Upper & Lower Geozones, which stop on major geological structures.

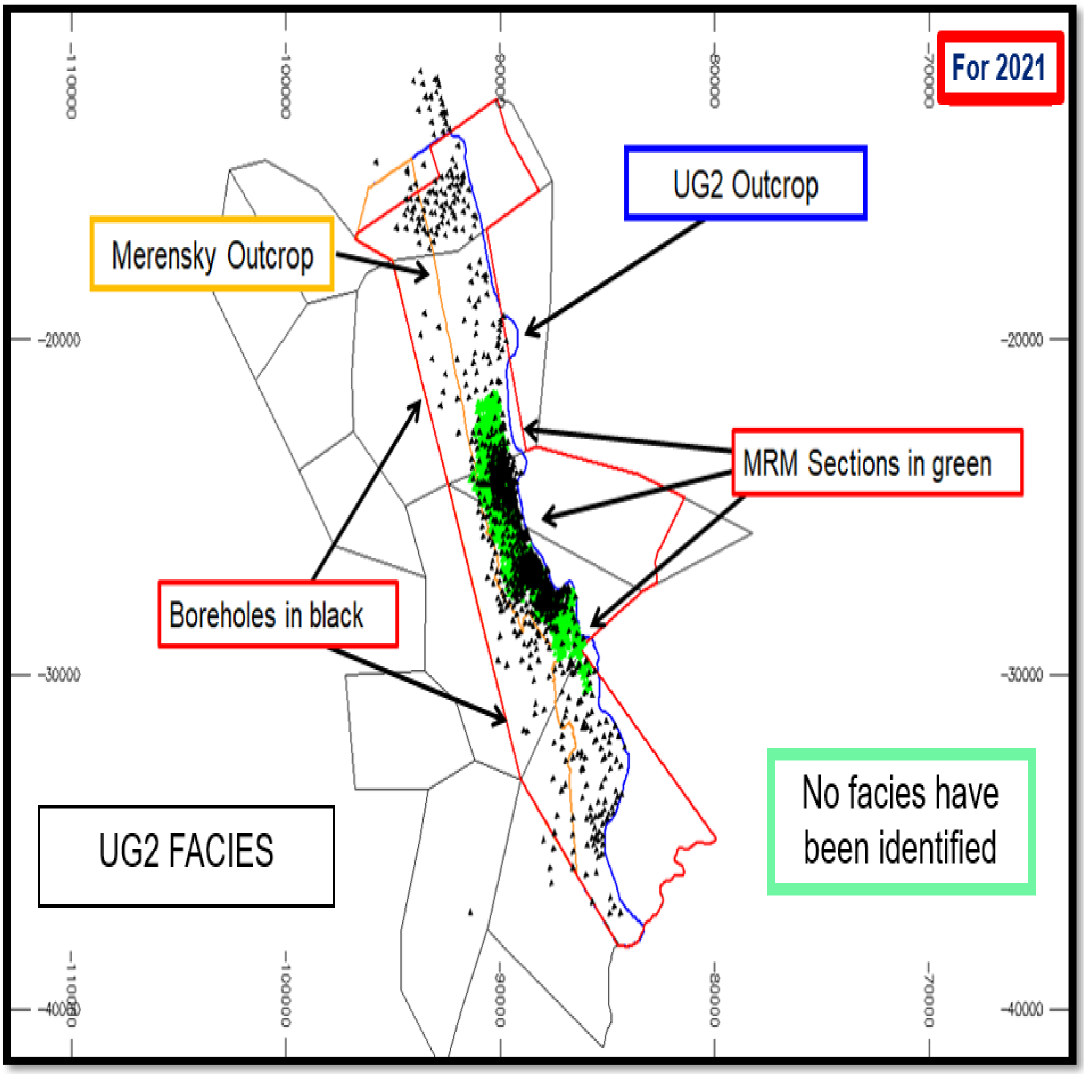


Figure 21: Map of MPM Facies/GeoZones (Britz, 2021)

3.2.2 Histogram Software

In the histogram software programme there is a “Tick On” function named “Keep Normalised Channel cmg/t Constant” this function is used for areas with a narrower actual channel width (less than 50cm) where the evaluation is then made to keep the channel cmg/t constant. For a standard thickness reef with no geological anomalies, the tick is required to be off. This was not the case at Modikwa as it was left on during the evaluation process, due to limited experience from the Sampler doing the Valuators work. It was found that a small percentage of panels mined had a thin Main Channel of less than 50cm, as shown in Table 5. In January 2018, the “Tick On” was left off for the evaluation process and produced a 5% decrease in the grade. This would have presented an over-evaluated block model, calling for metal that was never there and presenting a below-average MCF during this period. This factor was identified by the Geology Resource Leader in 2018 to have had the most notable influence on the improvement of the MCF to the required 95% mark (Britz, 2018).

Table 5: Percentage Panels Mined with a Thin Main Channel (Author,2021)

Year	% Panels with Thin Channel
2017	13.8%
2018	12.6%
2019	10.2%

3.3 Density Checks

Density is specified as the mass of a substance per unit volume. Due to mineralogical and pore spacing variances in different rock types, bulk density will fluctuate significantly among different rock types (Klein and Carmichael, 2021).

These checks are essential to ensure the correct density is applied to call for the correct tonnages. The incorrect density will result in expected versus actual tonnage discrepancies.

Horton & Lipton (2014, p.97) stated, “there are three fundamental inputs to any Mineral Resource estimate: grade, volume and bulk density.” As a geological resource is modelled as a volume, a density is added to convert it to a mass. Therefore, density is an integral part of a resource estimation process, as Arseneau (2015) noted in his publication “*Estimating Bulk Density For Mineral Resource Reporting*” that a reliable bulk density database is vital in defining the suitable modelling method to minimise the errors in mineral resource statements.

From 2010 all MPM samples were sent to SGS Laboratories for analysis. All samples are analysed for density in the laboratory by using a pycnometer (Figure 22), it is designed to measure the volume of solid objects. This is achieved by employing Archimedes’ principle of fluid displacement to determine volume. In this case, the displacement fluid is a gas that can infiltrate the most refined pores to produce maximum accuracy. Helium gas is used since its atomic dimension ensures penetration into crevices and pores.

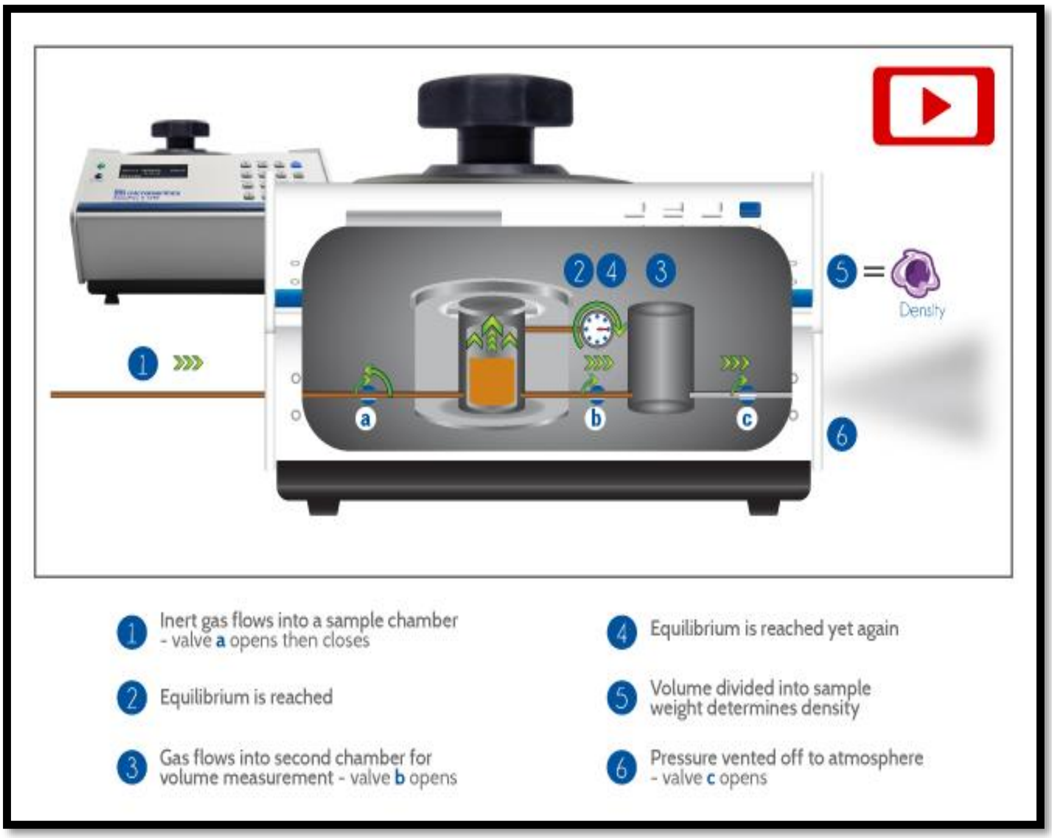


Figure 22: Pycnometry System Diagram (ATA Scientific, 2020)

The pulped sample is placed in a sample cup sealed in an air-tight cylinder. The sample cup is filled to $^{3}/_{4}$ capacity, typically 10g of sample. The displaced gas is measured by observing the pressure upon filling the sample chamber and then discharging it into a second empty chamber. The run precision mode allows good repeatability to be achieved. The instrument repeatedly purges water and volatiles from the sample and then replicates the analysis until successive measurements produce a consistent result (Britz, 2021).

The densities for MPM are being compiled by the Principal Resource Geologist from Anglo American, and no changes to the densities have been done since 2013.

In Figure 23, the densities across the different zones are shown; these densities are incorporated into the histogram to allow for the correct tonnages allocated for each workplace mined. Concern was raised, pre-2013, that the density estimate for the UG2 channel was too high but was later proven to be correct. The 3.72 t/m^3 incorporating the HW and FW waste, above and below the main Chromitite Channel was subsequently shown to be incorrect, was discarded and replaced with 4.18t/m^3 .

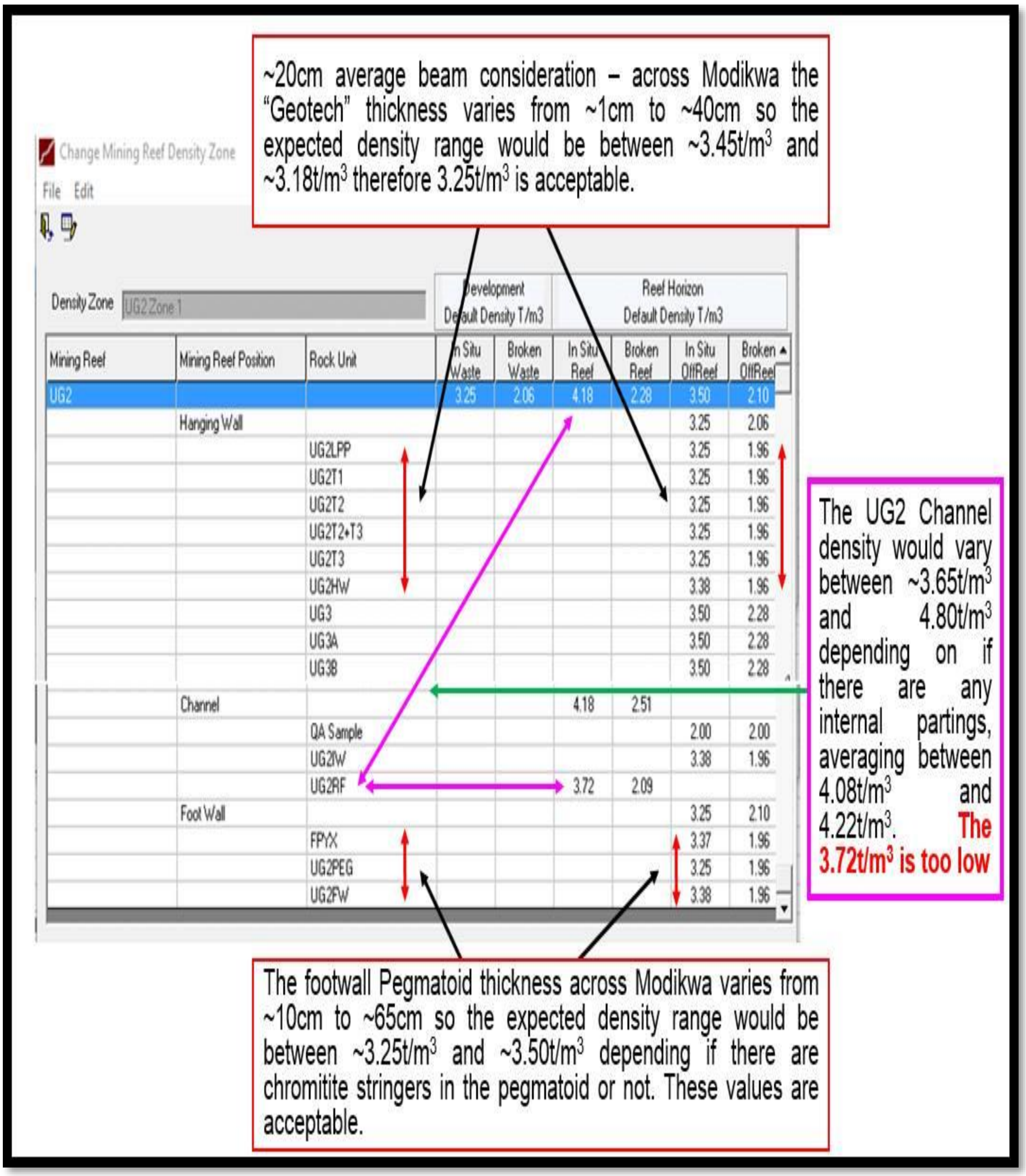
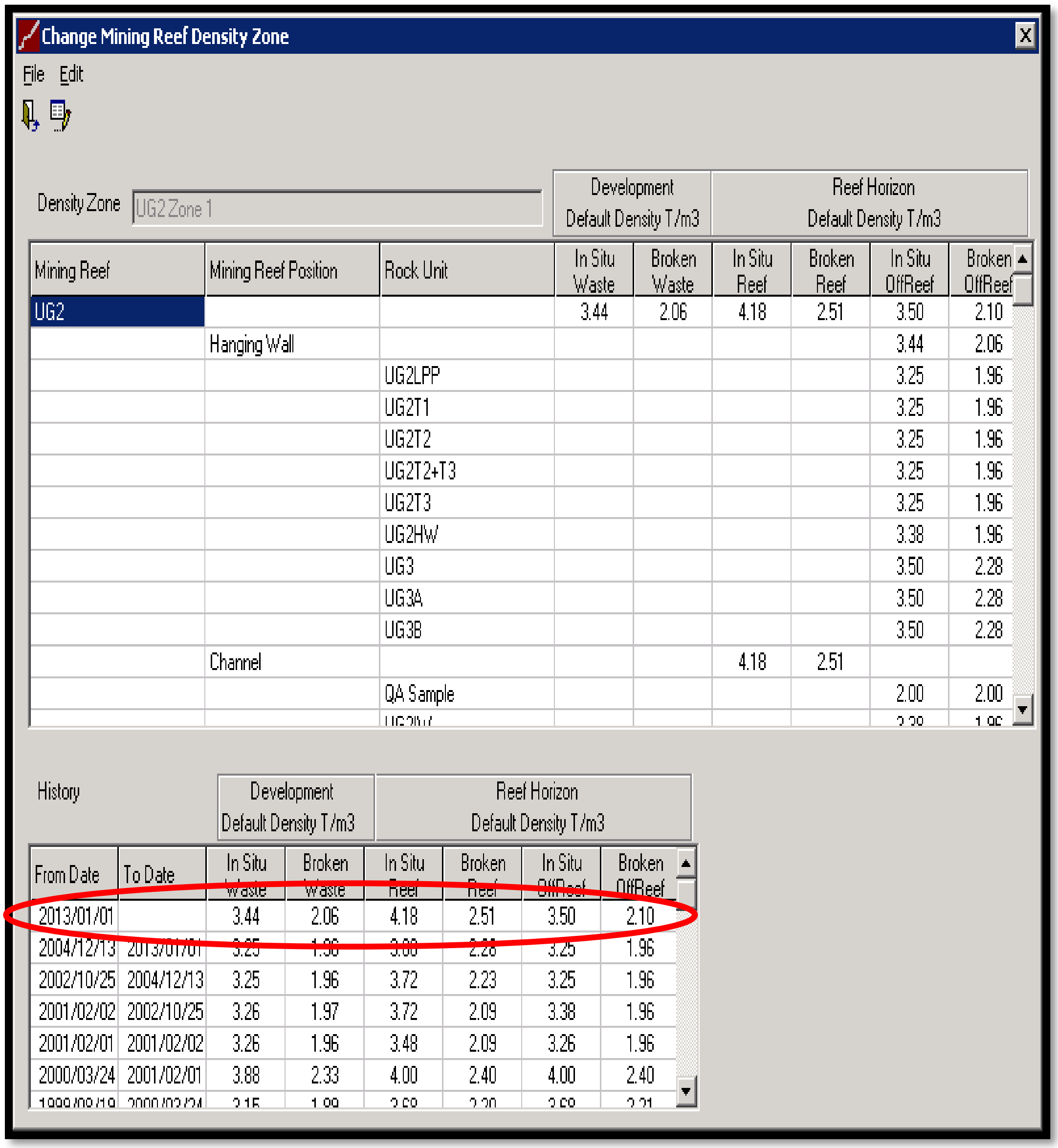


Figure 23: MPM Density Zones (Colquhoun, 2017)

The history for the density zones used on MPM was extracted from the MRM database, displaying no changes to the densities since January 2013, as circled in red on Figure 24.



Change Mining Reef Density Zone

File Edit

Density Zone: UG2 Zone 1

Mining Reef	Mining Reef Position	Rock Unit	Development Default Density T/m3: In Situ Waste	Development Default Density T/m3: Broken Waste	Reef Horizon Default Density T/m3: In Situ Reef	Reef Horizon Default Density T/m3: Broken Reef	Reef Horizon Default Density T/m3: In Situ OffReef	Reef Horizon Default Density T/m3: Broken OffReef
UG2			3.44	2.06	4.18	2.51	3.50	2.10
	Hanging Wall						3.44	2.06
		UG2LPP					3.25	1.96
		UG2T1					3.25	1.96
		UG2T2					3.25	1.96
		UG2T2+T3					3.25	1.96
		UG2T3					3.25	1.96
		UG2HW					3.38	1.96
		UG3					3.50	2.28
		UG3A					3.50	2.28
		UG3B					3.50	2.28
	Channel				4.18	2.51		
		QA Sample					2.00	2.00

History

From Date	To Date	Development Default Density T/m3: In Situ Waste	Development Default Density T/m3: Broken Waste	Reef Horizon Default Density T/m3: In Situ Reef	Reef Horizon Default Density T/m3: Broken Reef	Reef Horizon Default Density T/m3: In Situ OffReef	Reef Horizon Default Density T/m3: Broken OffReef
2013/01/01		3.44	2.06	4.18	2.51	3.50	2.10
2004/12/13	2013/01/01	3.25	1.96	3.00	2.28	3.25	1.96
2002/10/25	2004/12/13	3.25	1.96	3.72	2.23	3.25	1.96
2001/02/02	2002/10/25	3.26	1.97	3.72	2.09	3.38	1.96
2001/02/01	2001/02/02	3.26	1.96	3.48	2.09	3.26	1.96
2000/03/24	2001/02/01	3.88	2.33	4.00	2.40	4.00	2.40

Figure 24: Modikwa Historic Density Calculations (Author, 2021)

The relative density had been proven and was constant throughout the period in question, as no changes to the relative densities were made between 2013 to 2020, demonstrating that it did not affect the MCF during the timeline in question. Although the density was consistent, it is crucial to establish if the SWA per panel was representative, to be able to produce a correct histogram and finally a correct tonnage figure. This subject is discussed in the SW Control section later on.

3.4 Mineral Resource Management (MRM) System

A portion of the MRM system is used for metal accounting, and it incorporates all tonnages broken on the mine for the month, including vamping tons (this is broken ore that has been left underground for longer than 24 months). A grade is allocated to these tonnages, producing expected metal compared with the final metal recovered from the plant. The difference delivers the MCF as a measure of mining efficiency for the month.

The MRM System process is as follows (Figure 25);

1. Sampling of the metal ore done underground is sent to the laboratory for assaying.

2. The samples are assayed at the laboratory, following their QA/QC process. Once the values of the samples are returned, the Valuator/Resource Geologist authorises the samples.

3. A grade Histogram is created for the samples per area, this is done according to the Geo-Zones.

4. Each workplace is then linked to their representative Histogram.

5. The SW Observation data done per workplace is then incorporated into the system.

6. The monthly measuring done by the Survey Department per workplace is entered, this is to allocate a square metre blasted for that month.

7. The evaluation is then done by combining the SW, survey measurement and Histogram data. This produces the expected metal content per workplace.

8. These figures are then checked and approved by the Survey Resource Leader. After this, the measurements are locked to ensure that no changes are done once the final figures for that month is released.

9. The final expected tons, grade and content output for that month is obtained. This number is then compared to the metal ore concentrate produced from the concentrator plant, and a MCF for that month is calculated.

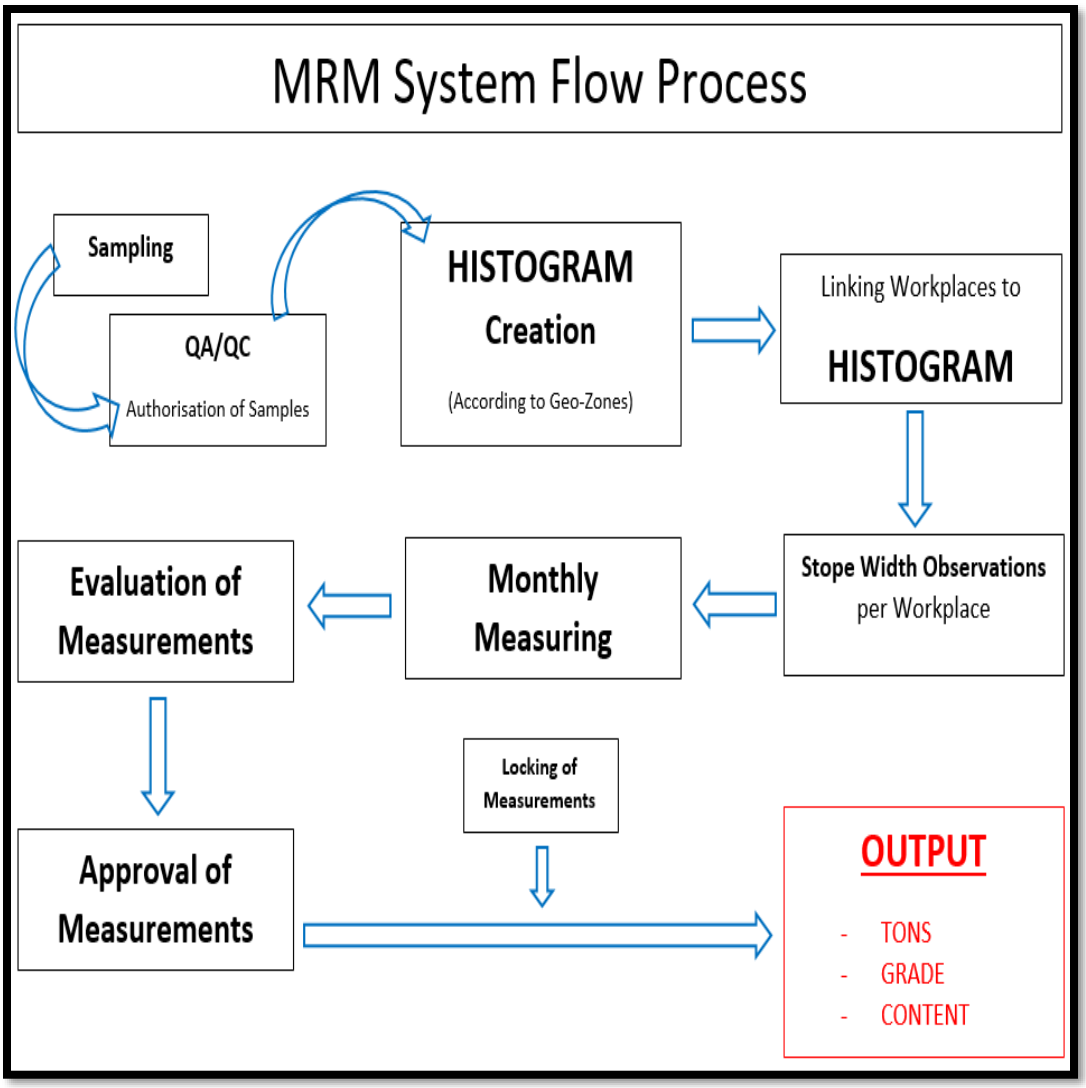


Figure 25: MRM System Flow Process (Author, 2023)

A mine ore-flow sheet is generally imprecise, this is due to not fully taking into account aspects such as illicit stockpiles (stockpiles not authorised/planned), ore-loss along tramming routes, and lock-up tonnages. Furthermore, all chances for cross-hoisting, cross-tramming, and surface ore transfers must be considered (Macfarlane, 2013).

The MRM system is only as accurate as the input data received; exact measurements and valuation are critical for this system to work effectively.

4 REAL LOSS

4.1 Optimal Stoping Cut or Champion Cut

The OSC or Champion Cut is the absolute minimum that can be mined to extract the maximum grade from the mineral resource, including safety factors (See Figure 26). This is used to calculate the expected tonnages, if the OSC has not adhered to it will affect the called-for grade negatively. Therefore, it is essential to ensure compliance by employing regular checks on adherence and corrective actions imposed.

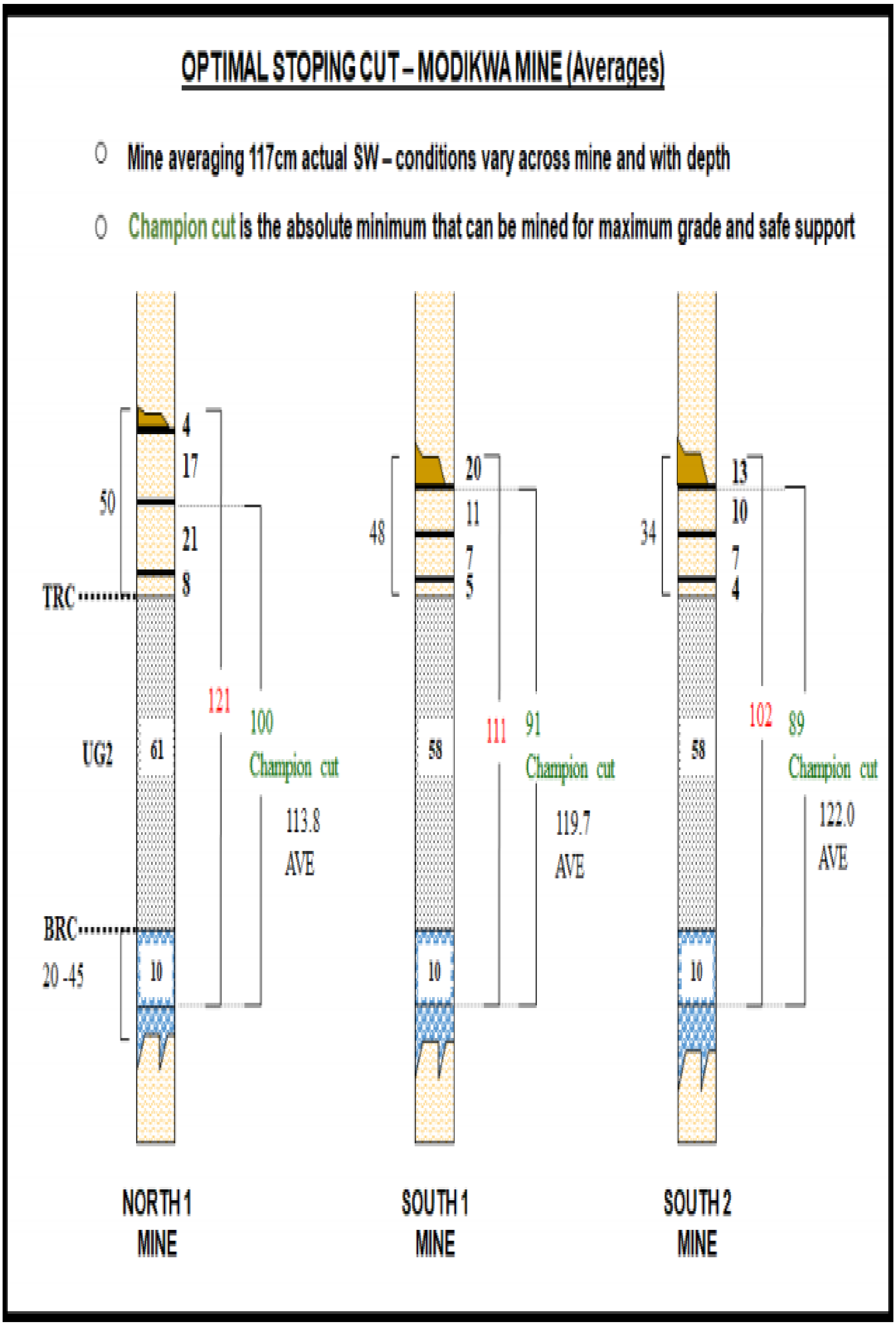


Figure 26: MPM Optimal Stoping Cut Diagram (Britz, 2020)

The OSC varies across the mine, and with increased depth, it is also affected by areas with adverse geological features. The OSC is recommended per workplace and panel, but unexpected factors may affect this cut. Recommendations from the Rock Engineering Department on increased stoping cut due to safety factors may occur and must be incorporated into the tonnage and valuation calculations.

Figure 27 shows the average actual SW compared to the recommended SW (best cut) during the timeline. A remarkable difference from 2015 is visible due to the following Geostructures encountered as stated in the Internal Grade Audit done in 2018;

- The Northern Dyke Swarm was intersected on North 1 Shaft, with little geological information due to no 3D Seismic Survey, or Surface Drilling done in the area due to community issues and later to no funding. Dykes at Modikwa display scissoring, undulation, and associated joint structures, causing unpredictable mining conditions.
- Areas at South 1 Shaft, the HAM was closer than one meter to the UG2; this caused HW fall-outs due to unstable HW beams. This led to higher SW because the OSC increased in these areas for safety reasons.
- Reef rolls at South 2 Shaft lead to excessive over breaking and off-reef mining due to poor drilling control and unpredictable geological anomalies encountered.

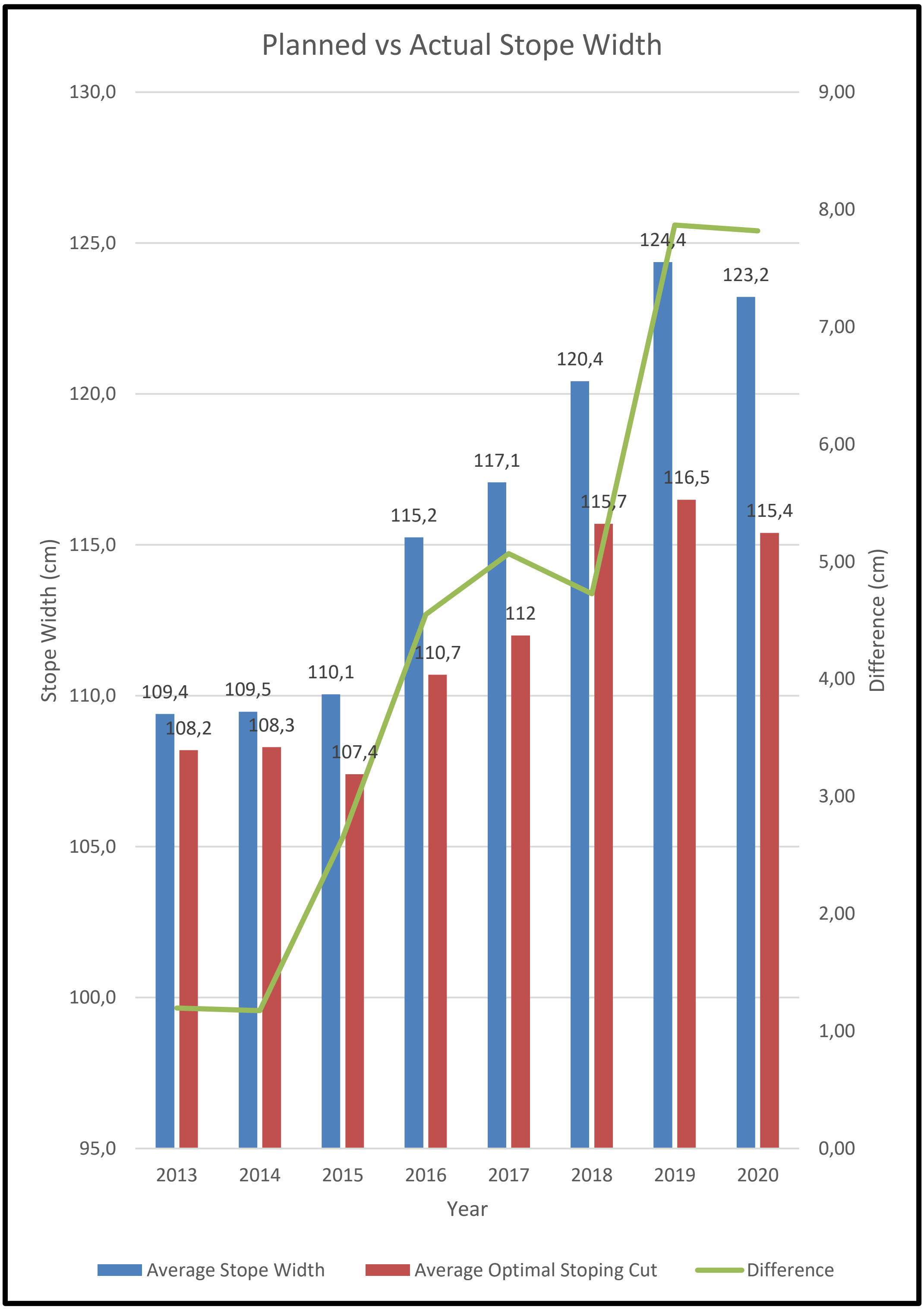


Figure 27: Historical Planned vs Actual Stope Widths (Author, 2021)

The SW variation increased year on year from 2015 to 2020, this however, did not seem to have a notable effect on the MCF as it normalized above the historical average from 2018 onwards.

4.2 Stope Width Control

A RGSW is the optimal mining cut allocated to a stoping area. A Stope Observer checks the SW of a panel by measures the height of the area at 5-meter intervals on the face to establish a stope panel Face Width, and then 3-metres back to confirm the SW. The Face Width is usually lower than the SW; this SW must be as close as possible to the RGSW, as this is the measurement used to establish the tonnages and grade expected from this stope.

The Grade Observer must supply a detailed SWA per panel; this is extracted from the MRM reporting system. This report incorporates a face section mapping, mining-cut, SW, RGSW, over/under breaks, RIH/RIF, off-reef, and a comparison between the optimal grade and expected grade of the current SW. This data is then used to produce a representative histogram per workplace.

The grade observers map and measure the stope panels to obtain the necessary information. The AAP Standard visits per stope panel is 300%, meaning each mining panel is obligated to be visited three times in a month to achieve the confidence necessary to evaluate the month's production effectively (AAP Standard – Stope Width Control, 2022).

To be able to regulate and ensure that the OSC has been adhered to, the actual SW is compared to the OSC, and when it exceeds 5% above or below the required parameter, the crews are penalized on their bonus.

At MPM, the minimum required coverage to achieve the minimum confidence necessary to effectively evaluate the month's production is 100%, meaning that every panel blasted must be visited once per month (a third of the industry average). If a panel is not covered for that month, it was noted that the previous month's SWA data was used.

Data collected for North 1 and South 1 Shafts from 2013 to 2020 and South 2 Shaft from May 2015 as this was when it started production, was used to produce a graph (Figure 28). The coverages for each shaft had not achieved the minimum required coverage, and the over break dilutions had increased from 2015. This was due to the production from South 2 Shaft, which contributed to the spike in unexpected waste dilution. The undulating rolling Reef at South 2 Shaft leads to excessive FW over break and RIF. Due to the anomaly and the unpredictability of the geological feature, it would be expected that these areas be targeted for regular analysis by the Grade Observer; this would be to achieve a representative dilution and tonnage figure. With an increase of more than 5cm in the total SW for 2016, South 2 Shaft contributed 62% to the over-breaking figures in 2016 and 57% in 2017 (Figure 29). With a SWA coverage of 92% and

88% respectively, questions arise on the accuracy of the tonnages calculated. In 2016 an average of 1111.8 linear metres where mined at South 2 #, with a 150 SWA visits conducted, producing a ratio of 1:7 (one visit for every seven metres advanced). With difficulty in mining the ground accurately, as stated in the internal audit of 2018, the chances of underestimating the over-breaking for South 2 Shaft is material and would cause a tonnage and grade deficit. The density difference between the UG2 Main Channel of 4.18t/m^3 and waste rock of 3.44 t/m^3 is substantial, and requires accurate measurements and calculations to achieve the correct tonnage and grade calculations. This can only be achieved with adequate SW data, as a lower tonnage will be expected if the panel has a thin UG2 channel or has encountered off-reef due to a geological anomaly. With insufficient data, the chance of over-estimation on tonnage and ounces is real and will produce an apparent loss and a distorted MCF.

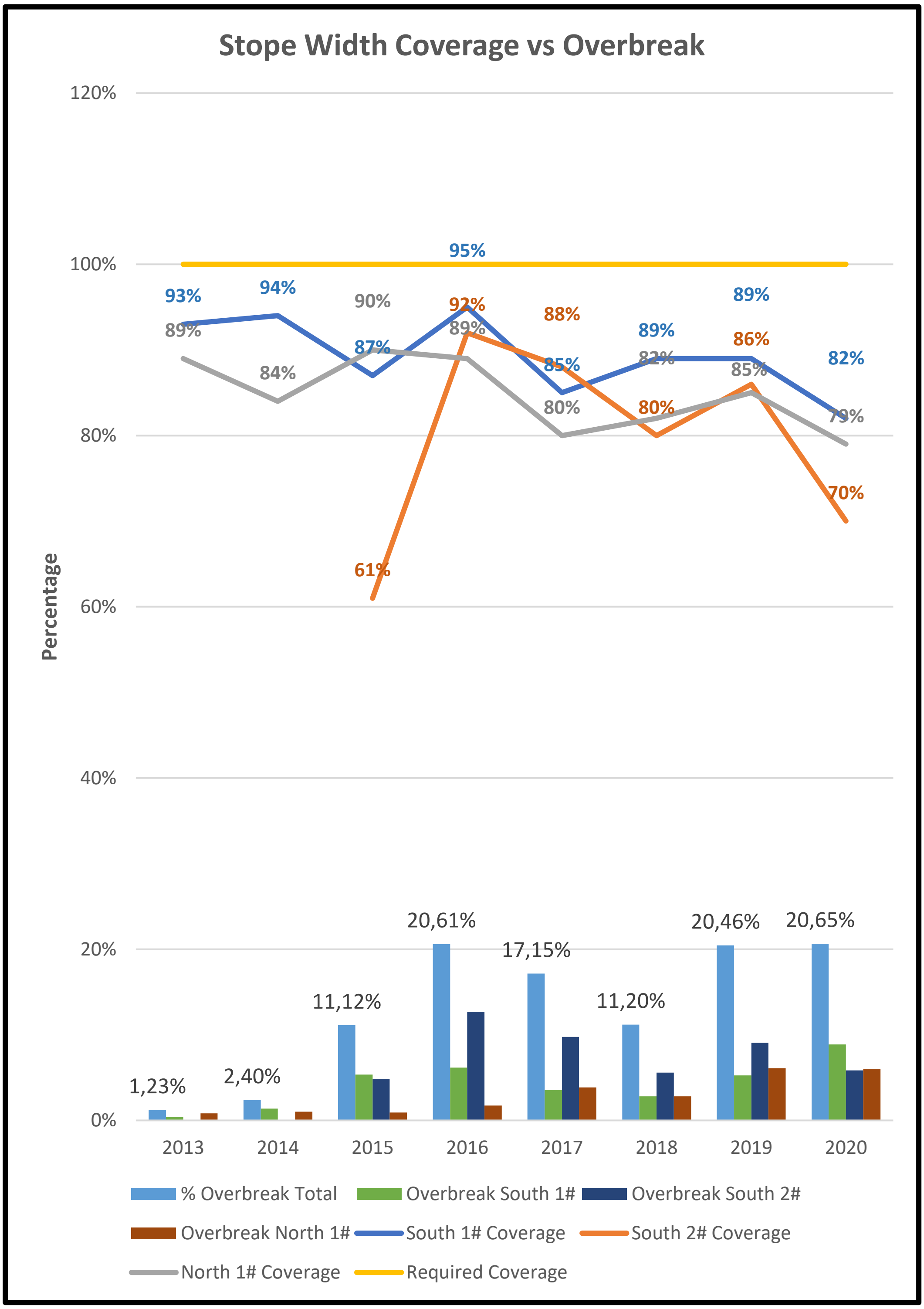


Figure 28: Stope Width Coverage vs. Over break 2013 – 2020 (Author, 2021)

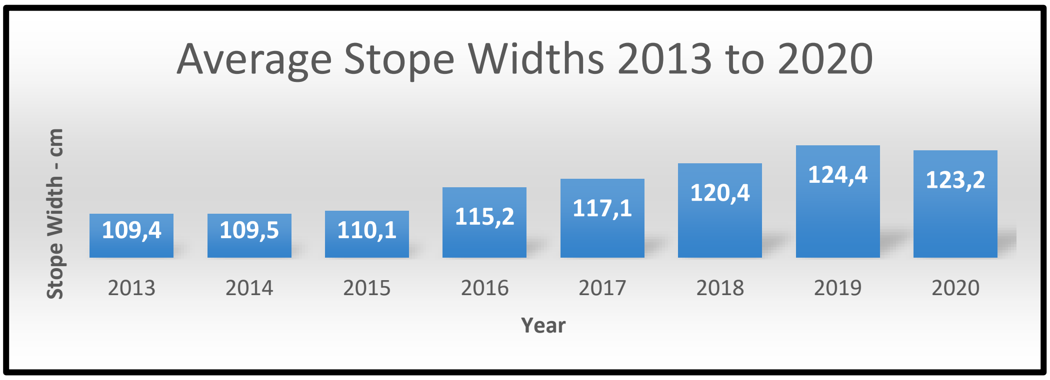


Figure 29: Average Stope Widths 2013 to 2020 (Britz, 2021)

4.3 Cross Tramming

Cross tramming occurs when tramming of ore is tipped into the wrong ore transporting system, i.e. When Reef is tipped into the waste system and vice versa.

To monitor and track ore movement from underground to surface and detect cross tramming, MPM uses RFID Tags shown in Figure 30. RFID Tags are a wireless system comprising of two components, namely electronic tags or transponders (Figure 31) and a reader (Figures 32 & 33). The reader consists of a radio frequency transmitter, an antenna, and a receiver. The electronic tag is a tiny microchip with stored information, and this information is an identification number allocated to the tag. The Mineral Resources Department team members place these tags in different mining areas, and the Ore Accountant oversees tracking. Once the tag is placed underground and the tag number is booked, the location, date, and ore type (Reef or waste ore) is given to the Ore Accountant to monitor.

This system also assists in determining the timeline of the broken ore from underground to the Concentrator Plant and waste dump. If any tags are flagged for cross-tramming, the relevant crews are reprimanded. The concern is that the tonnage associated with the flagged tag is unknown, so the discrepancy is not included in the MRM system.

Figure 30: Radio Frequency Identification Device Tags – Top Tag for UG2 & Bottom Tag for Waste (Bruwer, 2021)

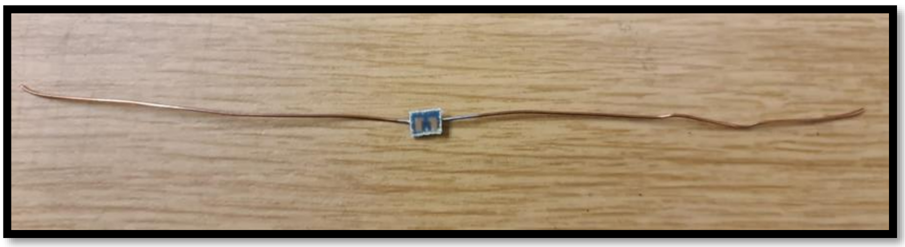


Figure 31: Microchip inside tag (Bruwer, 2021)

Figure 32: Tag Issuing Reader (Bruwer,2021)

Figure 33: Tag Reader on Conveyor Belt System (Bruwer, 2021)

Collecting the historic RFID Tag data from 2013 to 2018 and comparing tags placed versus tags recovered produced a 67% recovery rate, with a 3,3% cross-tramming average per year (Figure 34). Data irregularities were noted for years 2019/2020, so no comparisons could be conducted, and these two years were therefore not included in the data comparisons. The tagging numbers dropped remarkably in 2015 due to the system being out of commission for eight months of that year, the same time that the MCF reached its lowest during the timeline. Due to this, it was challenging to produce a definite answer if cross tramming was a contributor during that year, and if so, how much did it contribute (Figure 35).

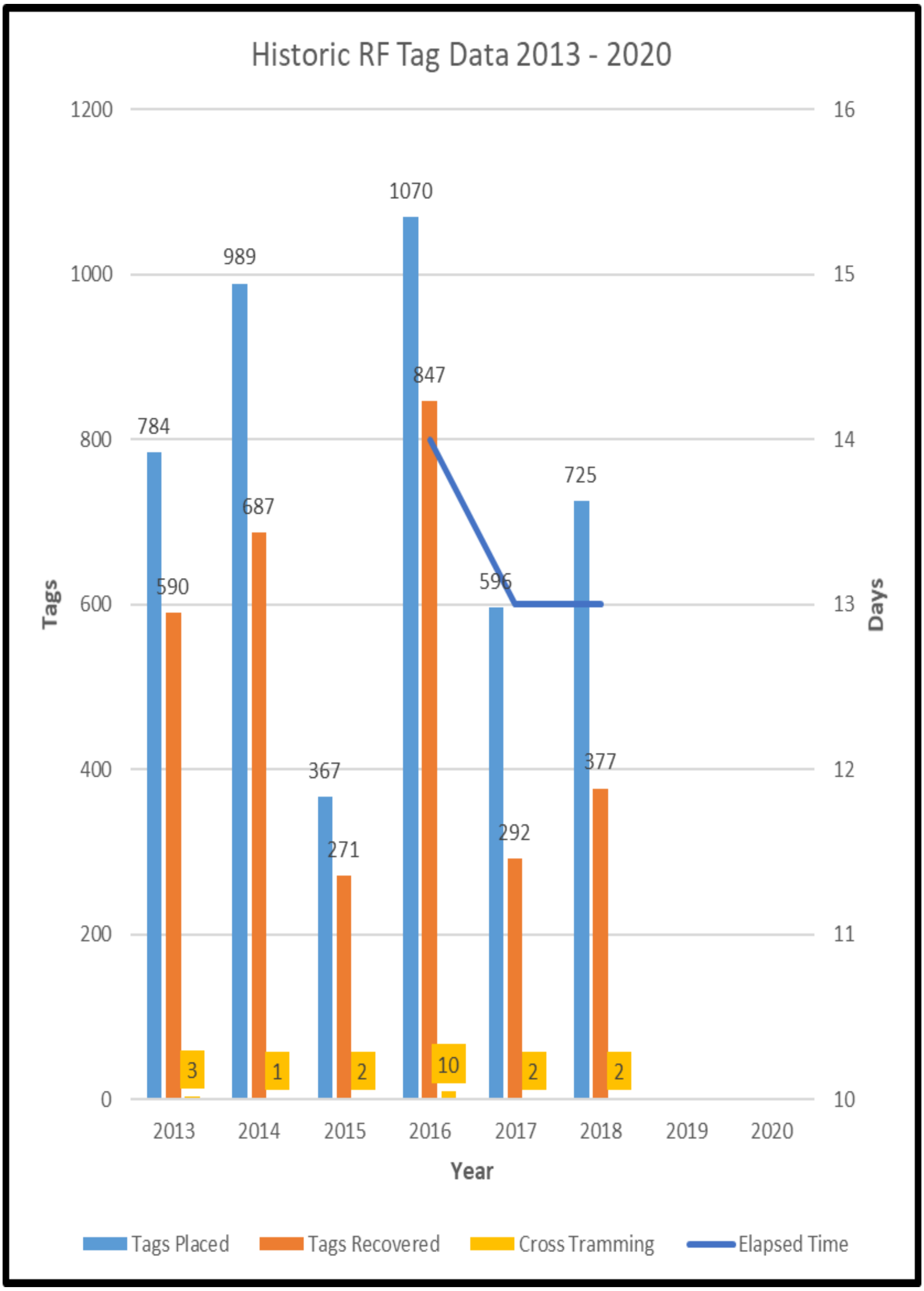


Figure 34: Historic RFID Tag Data Comparisons 2013-2020 (Author,2021)

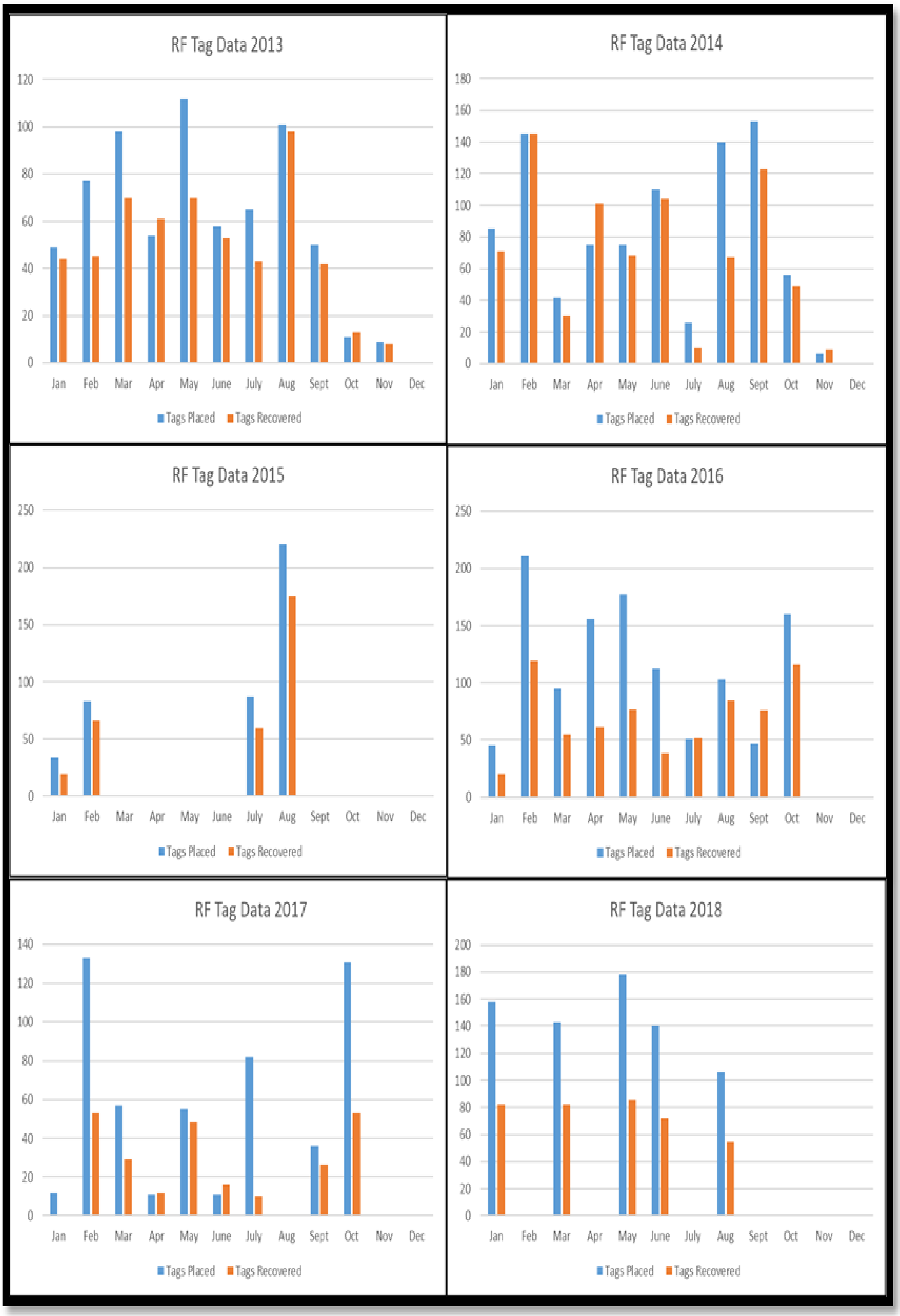


Figure 35: Historic Monthly RFID Tag Data 2013 - 2018 (Author,2022)

Investigation into the tag recovery rate delivered that the most significant contributor to the unaccounted tags were miners that remove tags from the ore flow system and discard them; this was to reduce the chance of being reprimanded. To mitigate this, a new method named "Stealth Tag" is currently on trial at MPM and has produced a 97% recovery. It works by drilling a hole into a broken rock and inserting the microchip into the hole, and the gap is then plugged by hammering a wooden wedge into the opening. It is virtually undetectable, but the down side is that it is time-consuming and fairly more expensive to implement than the current system.

A study into the higher cross-tramming number in 2016 found that the elapsed time frame for these tags averaged around 132 days. The assumption was that waste ore was possibly mucked (ore moved) into an old excavation; this occurs when a higher demand to tram reef ore arises, opening the possibility of overlaying the waste ore after it was tagged with reef ore during a later period. The risk of leaving ore underground for an extended period of time and not to visibly marking it produces a higher risk for cross tramming, which introduces unplanned dilution into the reef system or metal ounces lost on the waste dump. Even visibly marking the mucked ore underground still produces a risk of cross tramming and should instead be trammed to the surface in the shortest time possible.

From 2016 to 2018, data was compiled by the Ore Accountant to monitor the time it took for a tag to reach the surface. An average of 14 days for 2016 and 13 days for 2017 and 2018 was noted for the reef ore (Figure 33). Unfortunately, the data comparison is of a short time-span and would have produced a better understanding of the ore-tagging system data stream was constant and uninterrupted. An assumption was made with the available data that the time taken to convey the metal was not a contributing factor towards the MCF variation, as the MCF normalized in 2018 with no notable dissimilarity.

The tagging system works well to identify cross tramming and time taken for the ore to reach the surface after blasting, but still, the ability to allocate a tonnage figure to the cross trammed ore is absent and will influence the MCF negatively if not controlled.

4.4 Dilutions

Dilution refers to unplanned waste-ore materials (no economic grade) added to the ore during the operation and has reduced the quality of the mined ore. It decreases the bulk grade and increases the tonnage, expanding the mining cost per ton of ore produced and lowering the metal content.

Mining profitability is directly affected by unplanned dilution and ore loss. They are the most critical factors disturbing the economics of underground stoping (Jang et al., 2015).

Dilution can unintentionally enter the value chain by any means. To be able to account for waste entering the system, proper measuring of over-breakings above planned dimensions are required, ore tracking to ensure no cross-tramming transpires and ensuring that the “Optimal Mining Cut” is not deviated from, and if so, that the deviations are measured and included in the MRM system inputs.

5 CONCLUSIONS AND RECOMMENDATIONS

The purpose of this study was to establish the probable underlying causes of the reduction in the MCF over the period between 2014 to 2017 from a historical average of 95% to a low of 83,6% in 2015 before recovering to the benchmark of 95% in 2018.

To understand the nature (real or apparent or both) and drivers of the discrepancy, the investigation followed the ore accounting value chain from ore reserve definition to concentrate dispatch reconciliation.

The underground linear sampling rate had shown a prominent downward trend, as the grade sampling performance was below 50% in 2017 and below 10% from 2018 to 2020 (Table 3). If the sampling does not adhere to a 100% sampling rate, the anticipated sampling grid to warrant a representative grade for the targeted ore block will be affected. During the difficult period the sampling rate averaged at 49%, and throughout the corrected period from 2018 onwards the sampling rate averaged at only 8%. This led to believe that the homogeneity of the UG2 grade had mitigated the lower sampling rate.

Due to the poor underground grade sampling rate during 2014 to 2020, the grade histograms should have had an unfavourable influence on the MCF. Minimal grade data was available to update and ensure that the grade histograms where representative. Although it was assumed that the reasonably similar grade assisted in keeping that impact low, the MCF corrected itself in 2018 without improving in the sampling rate and updating of the histograms.

The lack of expertise from the Sampler to relieve as a competent Valuator had been noted to have had a significant impact during this timeline, primarily due to his limited knowledge on histograms and application impact in the MRM system. The “Tick-On” on the histogram function in the MRM system keeps the channel constant, assuming that although the channel had decreased, the grade remained constant. This caused the evaluation block model to be over-evaluated, as on average, only 12% of all panels mined had a narrow channel. Yet, the function was used for the entire evaluation process. The grade bar chart (Figure 36) compares the grades from 2015 to 2020. The monthly evaluation process used the histograms to assign a value to the blocks planned to be mined. The tonnage calculated to be extracted multiplied by the grade for that block produced the expected metal content from the stope panels before dilution and development were included (grade shown in blue, Figure 36). Once the total ore and grade planned to be extracted from underground sources have been included, the total hoisted grade for milling can be established (shown in red). This grade is used to produce the expected metal content for the month. If this grade is under or over-stated it will significantly influence the expected metal produced. There was an average of 0.73 g/ton decrease in the Hoisted

Planned Grade from 2018, and this was the period when the grade histogram corrections were implemented (Chapter 3.2.2).

The decision to remove the Valuator position from the budget during the commodity price drop impacted the quality of the histogram utilisation. There was no experienced supervision over the Sampler (acting Valuator) to oversee and rectify the error before the evaluation block model was utilized.

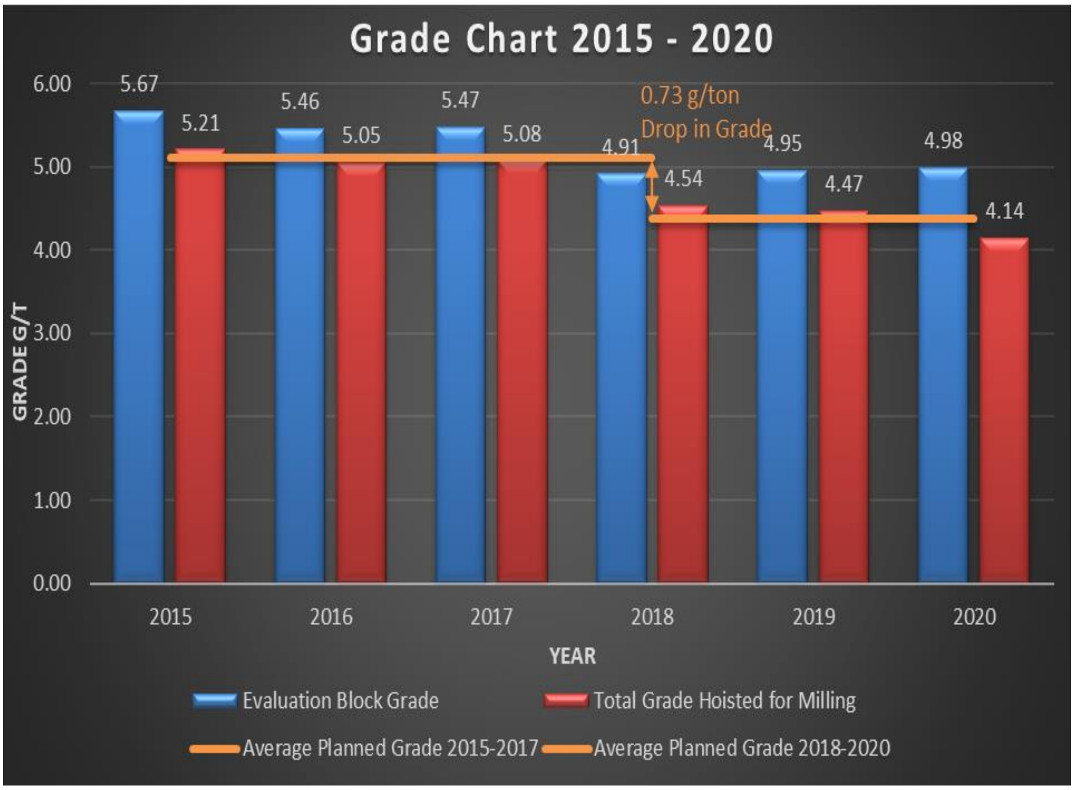


Figure 36: Historic Grade Chart 2015 - 2020 (Author, 2022)

Ore and waste density estimates have had limited impact on MCF estimates due to a significant and consistent data set with limited variation over the period under consideration during the investigation.

The OSC is recommended to be revised, as an increase in the actual SW was noted from 2015 and had amplified year on year (Figure 27).

The researcher was unable to ascertain why MPM accepts a SWA coverage of 100%, when the industry average is three times higher. The Anglo Platinum industry average of 300% coverage delivers an improved average per panel mined SW. This implies that MPM accepts a single visit to be sufficient to calculate a SW per panel over a full production month. By analysing the data collected, it was observed that the over break figure could be distorted and misleading due to the poor SW coverage obtained (Figure 37). Between 2013 to 2020, the average linear SW coverage delivered a downwards trend and may be linked to an increase in the average linear SW over break. This could be due to multiple issues such as 1) observations that were not representative for the average stope panels for the month, 2) mining into the problematic geologically structured ground, and 3) insufficient staff to cover the required visits, subsequently forcing the Valuator to consider the previous month's data due to a lack of current information.

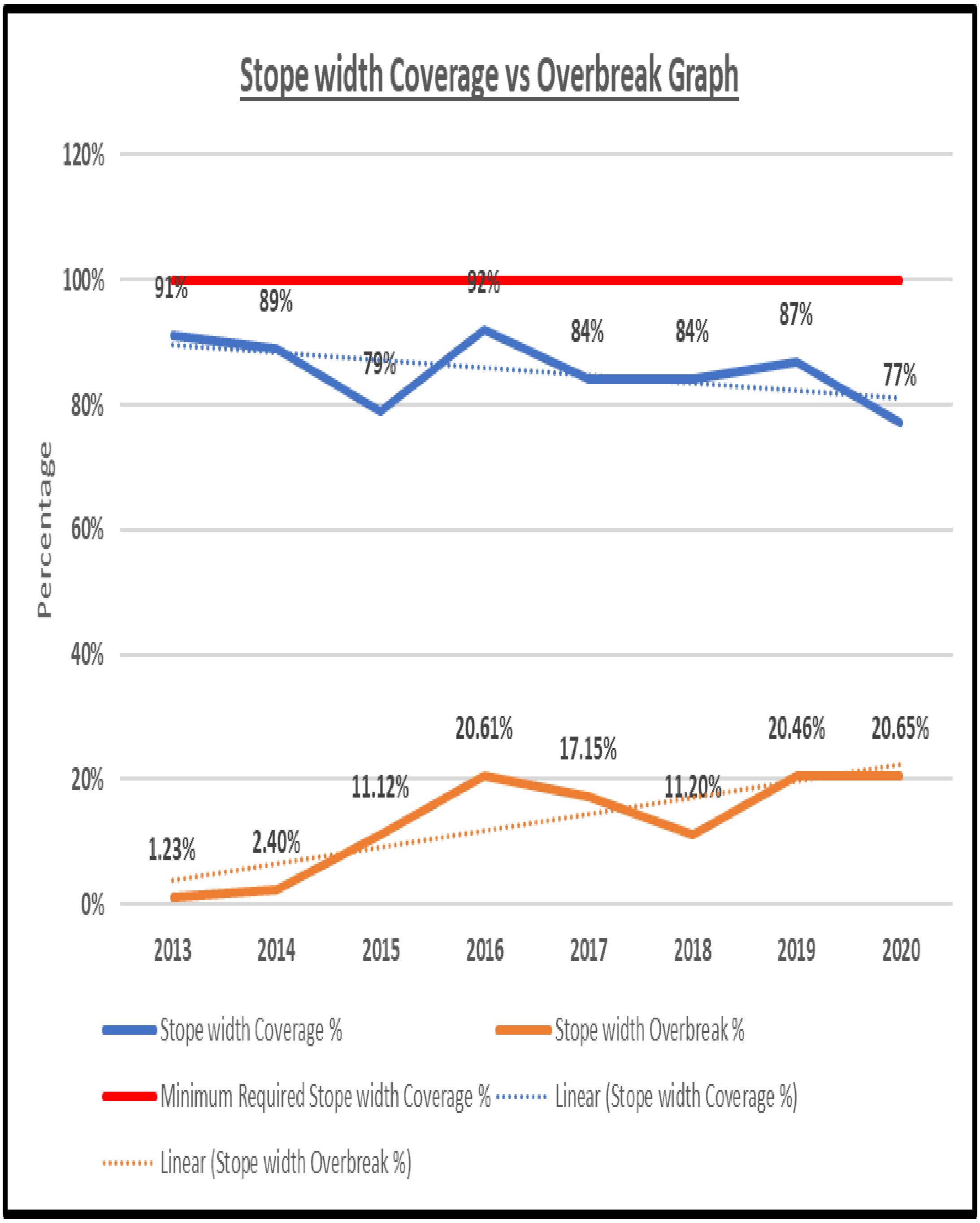


Figure 37: Stope Width Coverage versus Over break 2013 -2020 (Author, 2022)

Another factor that may be investigated for future consideration, is that more stope mining occurred in the HAM area of South 1 Shaft from 2016 onwards. It is known that the HAM area poses excessive Stoping Widths due to the hanging wall over break (HWOB) that occurs due to the removal of the HAM for safety purposes. Secondly, more stope mining up to the LPP occurred at South 2 Shaft from 2019 onwards, due to removal of the HW waste up to LPP due to reef rolls, and ultimately for safety purposes (Figure 38).

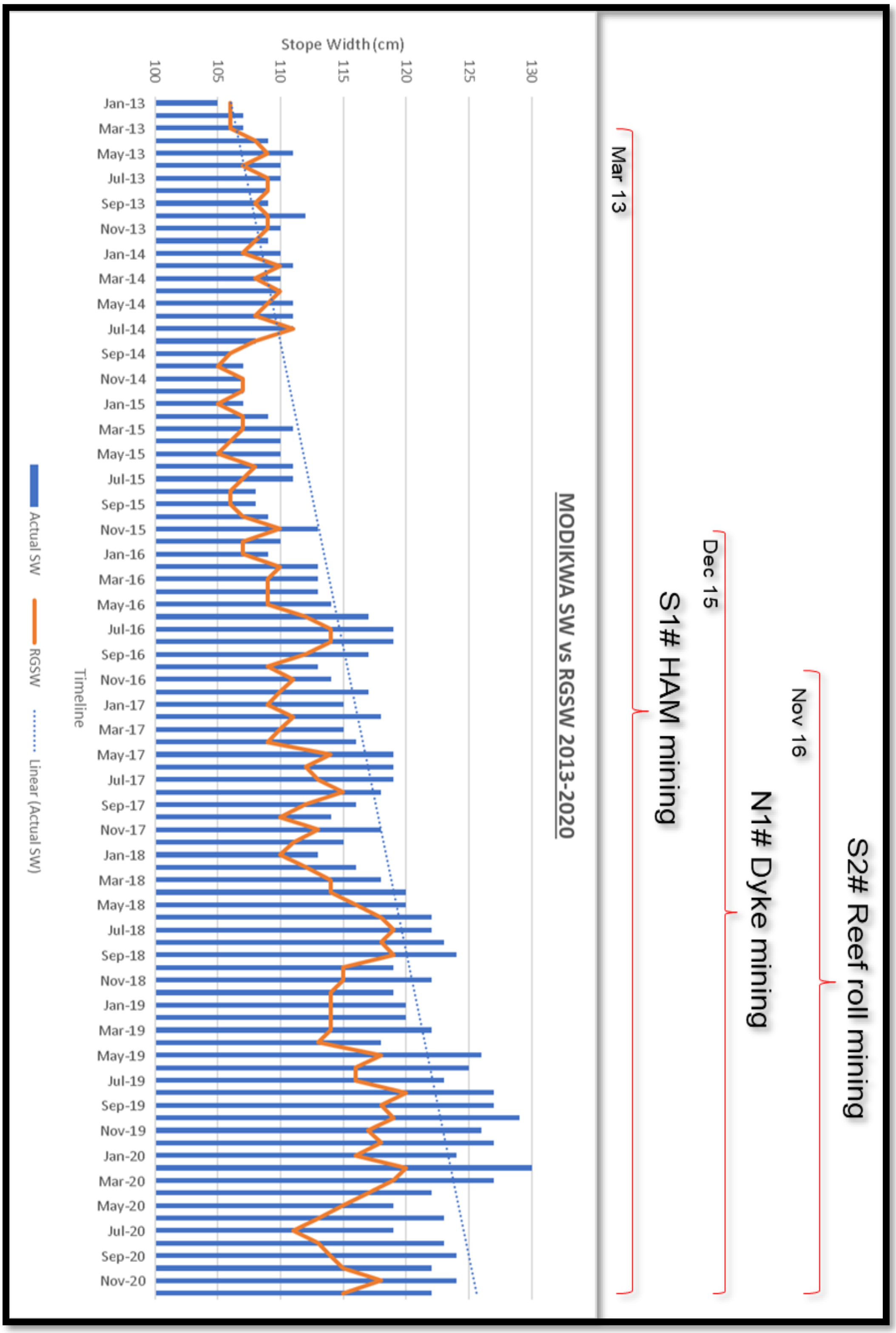


Figure 38: Modikwa Actual SW versus RGSW 2013 - 2020 (Author, 2022)

The additional waste ore mined to ensure a safe HW cut would also directly affect the tonnage called for, as the different lithology densities across the planned and actual mined Width require precise measurements to ensure an accurate tonnage figure is obtained.

The RFID Tag system worked well to assist with the identification of cross tramming and the time taken for ore to move from underground to surface. Still, the ability to allocate a tonnage figure to the cross-trammed ore needs to be addressed as to be able to incorporate the cross trammed metal loss into the MRM system calculations. The system was also not used to its full potential, as long durations with no data were noted due to poor utilisation or the system not being operational (Figure 34). The tagging system was barely used during 2015, and this was also the time when the MCF was at its lowest at 83.6%. A drive to intensify the tagging was noted in 2016, during which the MCF strengthened to 89%. Throughout 2018 the MCF stabilised above the historical average of 95%, but the tagging system used for this period was erratic and not appropriately exploited. Creating the belief that the RFID Tag system assisted in the deficit of the MCF during the period 2014 - 2017, but was not a prominent contributor since the MCF stabilised above the historical 95% margin and yet the tagging system usage declined.

An Anglo-American MRM Multi-discipline team carried out a Grade Audit on Modikwa Mine in 2016. Amongst other findings, they highlighted that the MRM System was not utilized to its full potential. The main system issues observed were related to concerns that would not have directly affected the MCF to such an extent. These included production calendars, milling calendars, and ore reserves inaccurately maintained. The MRM system is dependent on the quality and accuracy of available input data and user experience. Quality and accuracy criteria become more so as multiple disciplinary users exist in the MRM department. All data inputs are reconciled to produce a final expected figure, with data inaccuracies skewing the output and creating discrepancies. These findings could infer that the MRM system directly contributed to the MCF discrepancy because of imprecise data inputs into the system and not the system itself - garbage in, garbage out.

The final concentrate reconciliation check point is done at the concentrator plant, this is measured before the marketable concentrate metal ore is dispatched to the smelter in Polokwane. The concentrated PGM's is then reconciled back to the monthly plan and a MCF is calculated accordingly.

Comparison graphs (Figures 39 to 41) of the tonnage, grade and metal content expected versus achieved for each year were compiled and the following found;

Planned and achieved High Grade (HG) ore tonnage data from 2013 to 2020 was retrieved to show the variance per year. This is tonnage achieved per year versus tonnage planned to be extracted, see calculation below.

$$\textit{Tonnage Variance} = Achieved\ Tonnage - Planned\ Tonnage$$

The tonnage for each year remained reasonably constant with no major variance observed (Figure 39). Meaning that the planned tonnage called for was achieved within the budgeted boundaries.

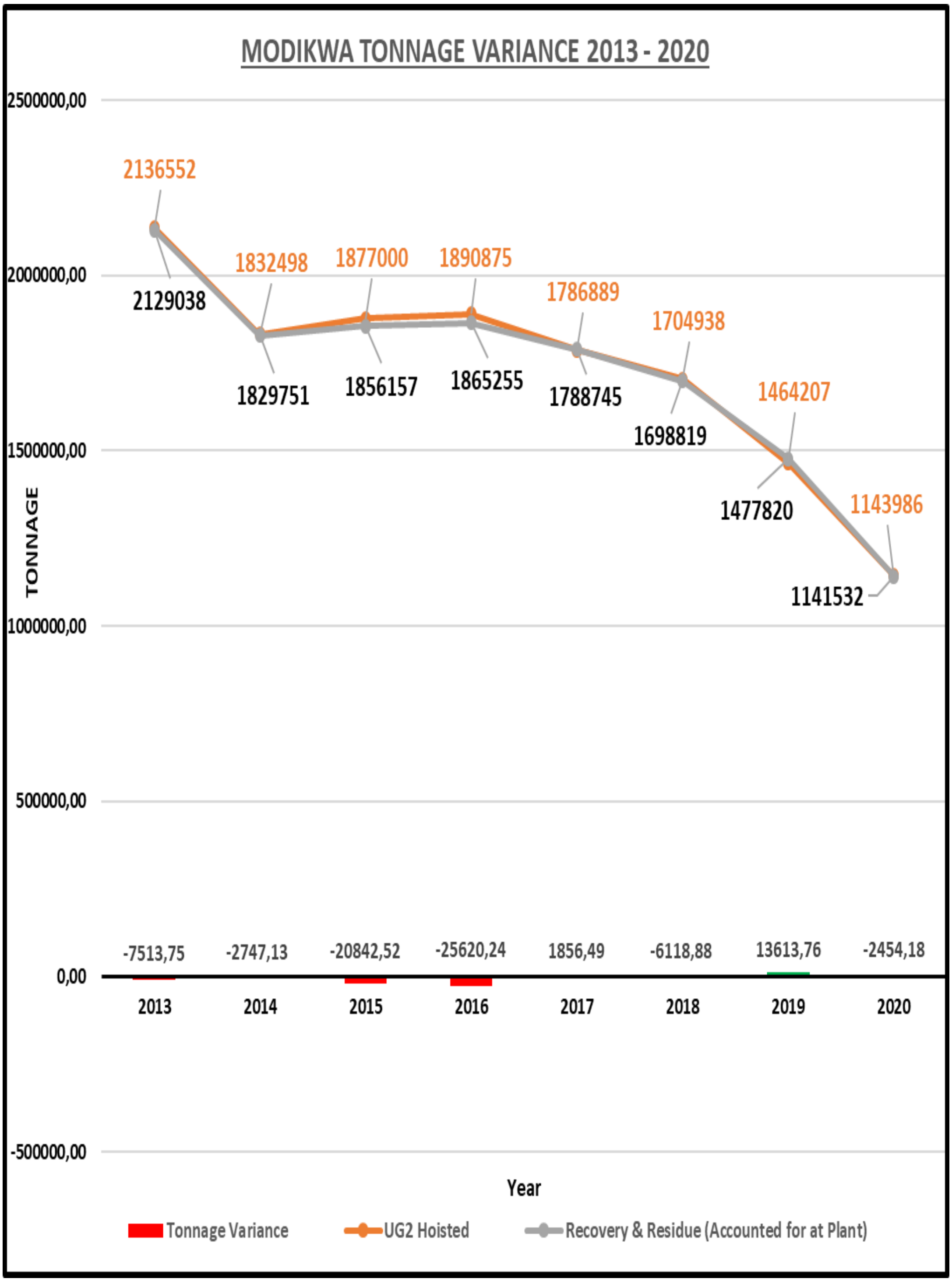


Figure 39: Tonnage Variance 2013 – 2020 (Author, 2022)

Planned and recovered grade data from 2013 to 2020 was retrieved to show the variance per year. This is grade planned to be achieved per year against recovered grade. Grade is calculated by dividing recovered ounces into total tonnage to produce achieved grade.

The grade variance had a significant variation in years 2016 and 2017, it shows that from 2015 a discrepancy developed and was only corrected in 2018 (Figure 39). Factors that could have caused this can be over-valuation of the block model, over breaking during mining allowing dilution to enter, as well as cross tramming. All of these could have allowed for a lower than planned grade to be achieved, but the dominant factor discussed in the report tends to the over-valuation of block values. This graph supports the findings of the Histogram theory that the block grade values were over-valuated due to the "tick-on/tick-off" not utilized correctly by the acting Valuator. The correction made to the Histograms (Figure 35) from 2018 onwards and the positive shift in the grade variance graph relate with each other.

The notable variance between Hoisted and Actual Grade in 2020 was due to the change from FW Haulages to On-Reef Haulages, and a mix of higher-grade ore (high-grade sludge) introduced from mid-2019 onwards and assisted in a higher than planned grade output seen on the graph.

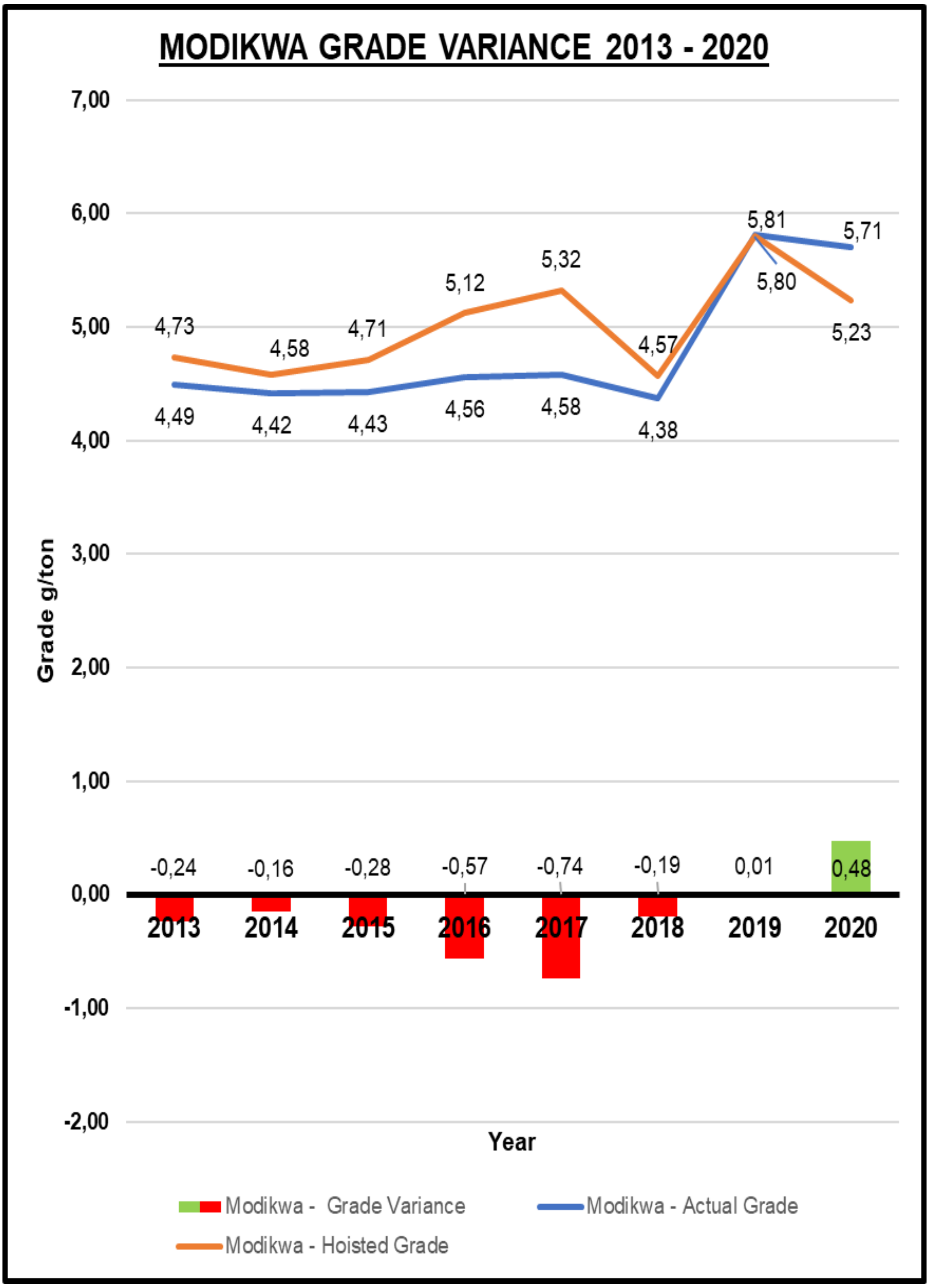


Figure 40: Grade Variance 2013-2020 (Author, 2022)

The variance between Hoisted and Actual 4E Content from 2015 to 2017 is visible in Figure 41. This is the content planned to be available for sale versus the actual metal content produced. Metal content is formulated by multiplying the tonnage by the grade. If one or both are lower than planned, it will produce a lesser metal concentrate achieved.

Although the tonnage target was achieved, the expected grade was not attained. This therefore delivered a lower than planned metal content output at the concentrator plant during the period in question.

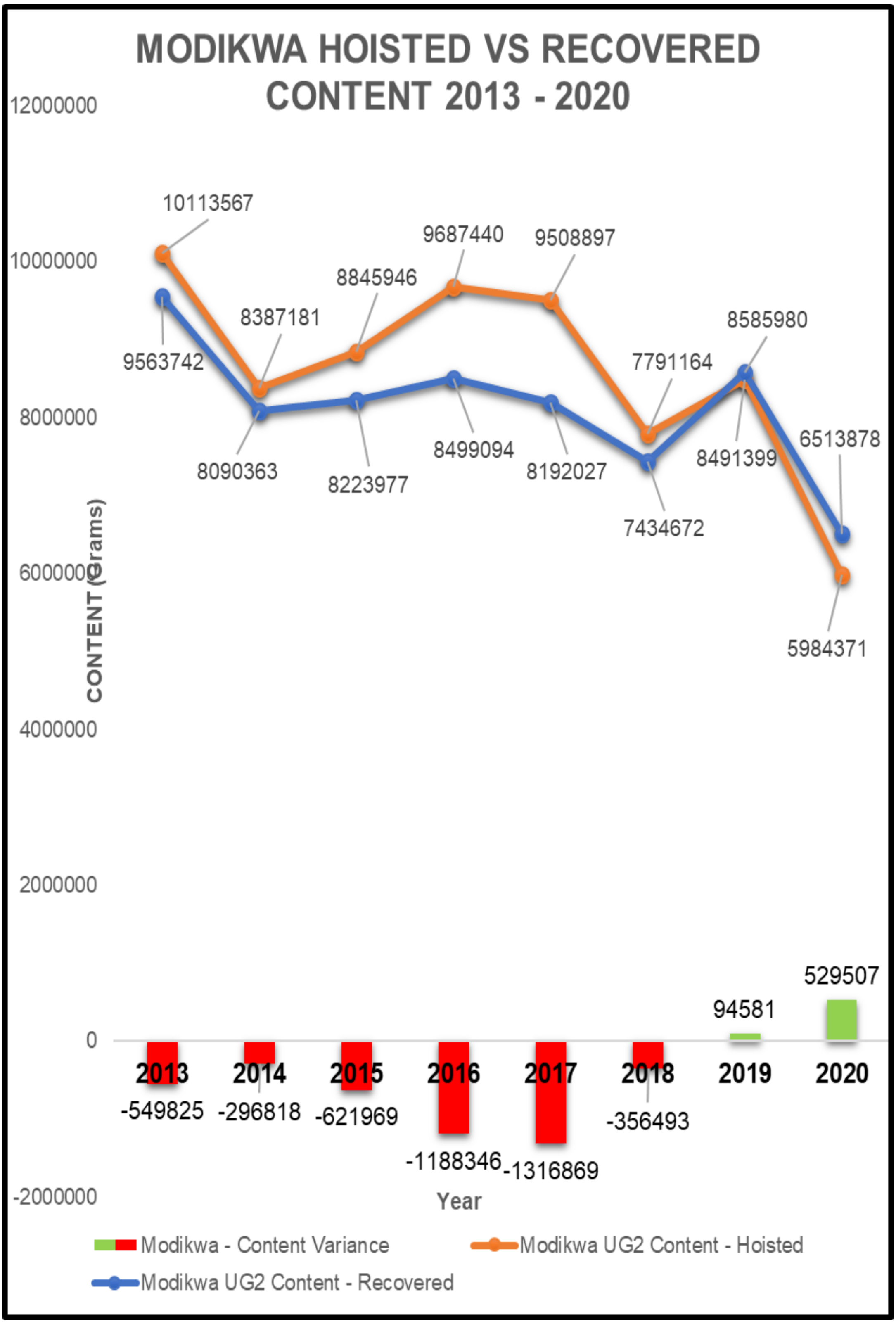


Figure 41: 4E Metal Content Variance 2013-2020 (Author, 2022)

It was concluded that the discrepancy in the MCF estimate over the period 2014 to 2017 was largely due to grade inaccuracies (histograms). This was the only factor that produced a notable change in the MCF after corrections were implemented. Other factors may have contributed to the MCF loss, but was minimal compared to the grade miscalculation in the histogram function.

This contribution led to a mineral loss that was perceived to be primarily apparent by nature, meaning the metal grade was never there in the first place and cannot be retrieved at a later stage.

To prevent the reoccurrence, the researcher recommends that the experience of a qualified Valuator or Resource Geologist and adequate sampling teams are required to ensure that a representative evaluation block model is achieved, sustained and correctly utilised. The need for additional SW Observers to increase the SWA observations to the industry average requires consideration. The other systems discussed in the report are adequate but require proper utilisation and monitoring to achieve full potential.

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