

**THE IMPACT OF APPLYING HIGH GRADE DOMAINING AS A METHOD OF
DEALING WITH GOLD OUTLIERS IN OTJIKOTO MINE GRADE CONTROL
MODELLING SYSTEM, NAMIBIA**

A MINI THESIS SUBMITTED IN PARTIAL FULFILMENT

OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE (APPLIED GEOLOGY)

OF

THE UNIVERSITY OF NAMIBIA

BY

JOB NATANGWE SHIKONGO

200611518

July 2020

SUPERVISOR: DR A. VATUVA

ABSTRACT

B2Gold Otjikoto open pit mine is located in the Northern Zone of the Pan African Neoproterozoic Damara Orogenic Belt. The ore is open ended at depth and the mine is considering underground mining in the near future. The orebody depicts gold grade zonation, with the highest grades hosted in the cores of the ore shoots within the shorter limbs and hinges of the intrafolial folds in distinctive en-echelon veins, whilst the lower grades make up the peripherals of the ore shoots. Approximately 70% of the total gold reserve in the deposit appears as free gold. Nugget effect is the variability seen between samples that are closely spaced. The orebody variogram modeling shows a high nugget effect of 0.64, and a longest range of 74 m in the 200° direction at 15° plunge. The grade control geologists are therefore dealing with high risk of resource overestimation due to the high nugget effect. The 200° direction is also the direction of high continuity, which represents the plunging direction of the orebody.

The High Grade Capping (HGC) method currently used during grade control resource modelling at B2Gold Otjikoto mine is associated with undue reduction in the estimated grades. Grade reconciliation at B2Gold Otjikoto mine, has consistently shown a grade underestimation by the Grade Control model against the plant processed feed grade. Therefore, the study evaluated the impact of employing High Grade Domaining (HGD) method at the mine.

Two ordinary kriging grade block models were populated using both methods. The results were evaluated to quantify the impact of the two methods on the grade estimates. The result shows a 3% increase in the overall grade of the HGD model ore material compared to the HGC model ore material. Both models estimated similar grade and tonnage in ore material from lower grade zones, however, significant variations in the grades and tonnage occurs between the models

in ore material in the in grade categories above 4.5 g/t Au cutoff. The study recommends employing the HGD method in resource modelling for mining in the high grade zones.

Conference Proceedings

Shikongo, J., Vatuva, A. (2-8 March 2020). Geostatistical methods of dealing with outliers in nuggety gold deposits: Otjikoto Gold Mine, Namibia. Accepted for oral presentation during 36th IGC, Dheli, India. (The congress was called off due to COVID-19 virus pandemic).

Contents

1	INTRODUCTION	1
1.1	Background of the Study	1
1.2	Statement of the Problem	3
1.3	Aims and Objectives.....	4
1.4	Project History.....	Error! Bookmark not defined.
2	GEOLOGY OVERVIEW.....	5
2.1	Regional Geology	5
2.1.1	Evolution of the Damara Belt	6
2.1.2	The Geology of the Northern Zone of the Damara Belt	8
2.2	Local Geology	9
2.2.1	Chuosi Formation	11
2.2.2	Okonguarri Formation	11
2.2.3	Ghaub Formation.....	12
2.2.4	Karibib Formation.....	12
2.3	The Ore Deposit.....	13
2.4	Orogenic Gold Deposits	14
2.5	Otjikoto Deposit Model.....	16
3	BACKGROUND TO GEOSTATISTICAL MODELLING METHODS	18
3.1	Nature of Mineral Deposits	18
3.2	Resource Modelling Methods	19
3.2.1	Conventional Methods.....	19
3.2.2	Geostatistical methods	19
3.3	Variogram.....	21
3.4	Managing Outliers.....	21
3.5	High Grade Domaining.....	22

3.6	High Grade Capping	24
4	METHODOLOGY	26
4.1	Introduction	26
4.2	Data Collection	27
4.3	Sampling Method	28
4.4	Sampling Quality Control - Quality Assurance (QAQC)	29
4.5	Analytical Methods	30
4.6	Resource Modelling	31
4.6.1	Modelling Flow Chart	31
4.6.2	Data Validation	32
4.6.3	Processes Done for Both Models (HGC and HGD)	32
4.6.4	Processes for the HGC Method	36
4.6.5	Processes for HGD Method	36
4.6.6	Gold Grade Interpolation	37
4.6.7	Model Validation	38
5	RESULTS AND INTERPRETATION	41
5.1	Introduction	41
5.2	Data	41
5.3	Geology Domaining	43
5.4	Variograms	44
5.5	Indicator Kriging	46
5.6	High Grade Capping	46
5.7	High Grade Domaining	48
5.8	Grade Block Models Figures	49
5.9	Block Model Graphics	50

5.10	Grade-Tonnage Curve	58
5.11	Grade Outliers Spatial Distribution	59
6	DISCUSSIONS	63
6.1	The Spatial Distribution of Outliers in the Otjikoto Orebody.....	63
6.2	HGC and HGD Block Modelling	65
6.3	The Impacts of Applying HGD as a Method of Dealing with Gold Outliers in a Mine Grade Control System.....	67
6.4	The Optimum Method of Dealing with Gold Outliers in the Grade Control System at Otjikoto Mine	68
7	CONCLUSIONS AND RECOMMENDATIONS	70
7.1	Conclusions	70
7.2	Recommendations	71
8	REFERENCES	72
9	APPENDICES.....	79

List of Tables

Table 4-1: Ore material grade classification at B2Gold Otjikoto mine.	27
Table 5-1: Statistical measures of drill holes gold assay data in the study area.	41
Table 5-2: Sector 2 Variography Parameters.	46
Table 5-3: Decile analysis for the study area sample assays to determining the high grade capping value, and the conditions for capping.	47
Table 5-4: Grade and tonnage variation summary between the HGC and HGD models at different grades cutoffs.	50

List of Figures

Figure 1-1: 2016 operating Mines in Namibia. Modified after the Chamber of Mines 2016....	2
Figure 2-1: Neoproterozoic orogenic belts during the formation of Gondwana craton. Modified after Gray et al. (2008).....	5
Figure 2-2: The Stratigraphy and the tectonostratigraphic columns of the Damara Belt with known gold deposits (Modified after De Kock, 2001; Miller, 2008; Rankin, 2015).	7
Figure 2-3: Tectonostratigraphic zones of the Damara orogeny (modified after Miller, 2008).	9
Figure 2-4: Otjikoto Mine local geology map. Source: Garagan et al., (2018).	12
Figure 2-5: A simplified cross section of Otjikoto deposit showing three prominent thrusts in the area (Garagan et al, 2018). The trust planes appear to define the extend of the mineralization.	14
Figure 2-6: Tectonic settings of orogenic gold deposits and other gold deposit types (Goldfarb and Groves 2015).	16
Figure 3-1: Geostatistical estimation work flow, Zhang (2011).	20
Figure 3-2: Sectional (explicit) and semi-automated (implicit) method of grade domaining. After Leuangthong and Nowak (2015).	23
Figure 4-1: Otjikoto phase 2 pit May 2019 mined out surface and the study area.	26
Figure 4-2: Grade control RC drillholes in the study.	27
Figure 4-3: Regularized drill grid pattern covering Otjikoto phase2 pit, with mining block boundaries, all blocks in the picture are within the study area.	29
Figure 4-4: Project modelling flow chart.	31
Figure 4-5: B2Gold Otjikoto phase2 pit grade control modelling geostatistical sectors and the associated search ellipsoids. The study area falls within the red polygon.	34

Figure 4-6: Drill holes intersections with grade intersections and the block model grade estimates for the model drill holes correspondence validation.....	39
Figure 4-7: Otjikoto mine equal cells block model.	40
Figure 5-1: Study area gold assay samples histogram plot, showing exponential distribution of the data, with more data concentrated at lower grades bins compared to high grade bins.	42
Figure 5-2: Histogram plot of the assay data showing different data populations circled in red in the data.....	43
Figure 5-3: RC grade control drill holes displaying lithology, and the grade block model displaying the coded domains: with blue being domain 1, black being domain 2. The red polyline indicating the top of the AM1 unit.....	43
Figure 5-4: Downhole correlogram of sector 2 showing a very nuggetty Otjikoto ore body with a nugget value of 0.642 gamma.	44
Figure 5-5: Directional variograms for sector2 Domain 1 with search distance factors at gamma 90%.	45
Figure 5-6: Sector 2 domain 2 directional variograms, with search distance factors at gamma 90%.	45
Figure 5-7: The Ore envelope polygons digitized around the block model cells with indicator values above 0.30, the block model cells with indicator values above 0.30 shows block model cells which are likely to be in the ore envelop.....	46
Figure 5-8: High grade domain polygon digitised around high-grade gold values along a section of drilled RC grade control holes with gold intersections.	48
Figure 5-9: explicit modelled high grade domains in the study area.	48
Figure 5-10: Distribution of estimated grades with grades of at least 0.25 g/t Au in the study area. Image A represents the HGC model, while image B represents the HGD model. There	

are no visible significant variations between the two models at this cut-off grade, because the grade estimation on the peripherals of the ore body populated similar grades.....53

Figure 5-11: The distribution of estimated grades with gold grades of at least 1.00 g/t Au in the study area. Image A represents the HGC model, while image B represents the HGD model. There are no significant variations between the two models at this cut-off grade, as the grade estimates in both models used similar estimation parameters. Similar mineralization orientations can be traced in both models.....54

Figure 5-12: The distribution of estimated grades with gold grades of at least 3.00 g/t Au in the study area. Image A represents the HGC model, while image B represents the HGD model. Visible variations occurs around the peripherals of the ore shoots and in the cores of the shoots, there appears an increase in the numbers of block cells in the HGD model compared to the HGC model. Estimations of grades at these cut-offs used the domained grades in the HGD model and capped grades in the HGC model, hence the differences.....55

Figure 5-13: The distribution of estimated grades with gold grades of at least 4.5 g/t Au in the study area. Image A represents the HGC model, while image B represents the HGD model. There is more block cells in the HGD model compared to the HGC models at this cut-off. At this cut-off, the block model cells represent the core of the ore shoots.....56

Figure 5-14: The distribution of estimated grades with gold grades of at least 6.0 g/t Au in the study area. Image A represents the HGC model, while image B represents the HGD model. The images represents the cores of the ore shoots. There are more cells with grades above the cut-off of 6.0 g/t Au in the HGD model compared to the HGC model. Material above this cut-off were enclosed within the lower grade materials.57

Figure 5-15: Grade tonnage curve of the two model. The grade trends start showing a diverging behavior after the 3.0 g/t cutoff.....58

Figure 5-16: High grade domain polygon surrounding high grade values. The high-grade values in the section with gold grades above 8.3 g/t would have been assigned 8.3 g/t value in the estimation, which could have resulted in reduction in grade estimates.59

Figure 5-17: High grade domains in the study area. The high-grade domains show a similar orientation to that of the study area gold grade search ellipsoid.....60

Figure 5-18: Section showing the zoned distribution of the gold mineralization across the drill holes section, the core of the ore shoot is made up of the highest-grade material in the ore shoot, and lower grade material around the peripherals of the ore shoots. The blue polygon marks the outlines of the shoot, while the red polygon marks the richer core of the shoot.61

Figure 5-19: Plan view of the grade distribution across the ore shoot, with the richer grades distributed within the core of the shoot, with a zoning distribution observed toward the peripherals of the shoots.61

Figure 5-20: The core of the shoots, grades above 3.0 g/t Au, in relation to the high grade domains. Block model cells outside the high grade domains were populated from isolated outliers which could not be mapped/grouped into domains, and mostly had grade values less than the determined capping value.62

List of Abbreviations or Acronyms

3D	Three Dimensional
AM1	Albitite Marker 1
Au	Gold
g/t	Grams per Ton
HGC	High Grade Capping
HGD	Hig Grade Domaining
MStorque	Minesight Torque Database
RC	Reverse Circulation

Acknowledgements

Firstly, I would like to thank the Mighty God for the courage and strength during this project and throughout my entire life, his love and protection has brought me here today. Secondly, I would like to thank my loving wife Linea and my two brilliant boys Job and Jonea for the patience, support, and love they have provided me during this study, and always.

My highest appreciation to my supervisor, Dr Absai Vatuva, who has been the pillar behind this work, thank you for believing in me and in this project, your guidance made this project possible.

I would also like to thank B2Gold Namibia for funding my study and allowing me to carry out this project on the Mine. Finally, my highest appreciation to my colleagues at B2Gold Otjikoto Mine, especially for the geological discussions and support they have given me during this study.

Dedications

I dedicate this work to the beautiful hardworking lady, my beautiful Linea. She has always believed in me. “Beautiful”, thank you for always pushing me to be a better person, I love you.

DECLARATION

I, Job Shikongo, declare that this research report has been composed solely by myself, and where others work was used it was duly acknowledged. It is being submitted for the Degree of Masters of Science in Applied Geology at the University of Namibia, Windhoek, and it has not been submitted for any qualification at any other University.

Job Shikongo

Date:.....

Signature:.....

1 INTRODUCTION

1.1 Background of the Study

The B2Gold Otjikoto mine is located on the Northern Zone of the Pan African Neoproterozoic orogenic Damara Belt in Namibia. It is the second open pit gold Mine in the Damara Belt after the Navachab Gold Mine. The B2Gold Otjikoto Mine is located approximately 250 km North East of the Navachab Gold Mine and 96 km to the North of Otjiwarongo (Fig. 1.1). According to Garagan et al. (2018) gold occurs in size variation between 5 μm to 400 μm , it can be locked or partially locked in sulphides, garnets, magnetite, amphiboles and chlorite, or as free gold in quartz and carbonates veins. Approximately 70% of Otjikoto ore body gold occurs as coarse free gold (nuggets), which is recovered through the Nelson gravity concentrators in the plant. The remaining 30% of the gold is recovered through the conventional leaching process.

According to Dominy and Annels (2001), the higher the nugget, the more likely there could be errors in the estimated model, because the high variability makes it difficult to estimate the unsampled locations with a high degree of confidence. Resource estimation could result in overestimation if the high grade outliers are not managed (Sinclair & Blackwell, 2002). Different methods are therefore applied to deal with the grade outliers depending on the geology of a specific deposit. The suitability of a chosen methodology can be measured by how close the plant production figures are to the estimated reserve of the plant head. Leuangthong and Nowak (2015), described in detail three widely used methods of dealing with grade outliers in resource estimation; High Grade Capping (HGC), High Grade Domaining (HGD), and limiting the spatial influence of the outliers by reducing the search distance in the estimation.

The B2Gold Otjikoto Mine applies HGC as a means to constrain the undue influence of the high grade outliers on the final grade and tonnage estimates. The assay data within the area of interest are put through a decile analysis, as outlined by Parrish (1997), to determine the

preferred lower risk capping value. This determined capping value is applied as the top-cap to the data. There are divergent schools of thought regarding the handling of grade outliers by HGC during resource estimation. On one extreme, Kim et al. (2018) regards capping as “manipulation of data” rendering it unrepresentative and therefore a bad practice. On the other extreme, Leuangthong and Nowak (2015) considers capping as a “prudent” practice that is aimed at delivering realistic estimates especially on isolated outliers where high grade domaining cannot be performed. Leuangthong and Nowak (2015) further cautioned that grade capping may result in reduction of grade estimates, especially in areas where outliers show a spatial relationship and distribution. They argue that spatially distributed and clustered outliers are likely to represent a high grade domain within the ore body.

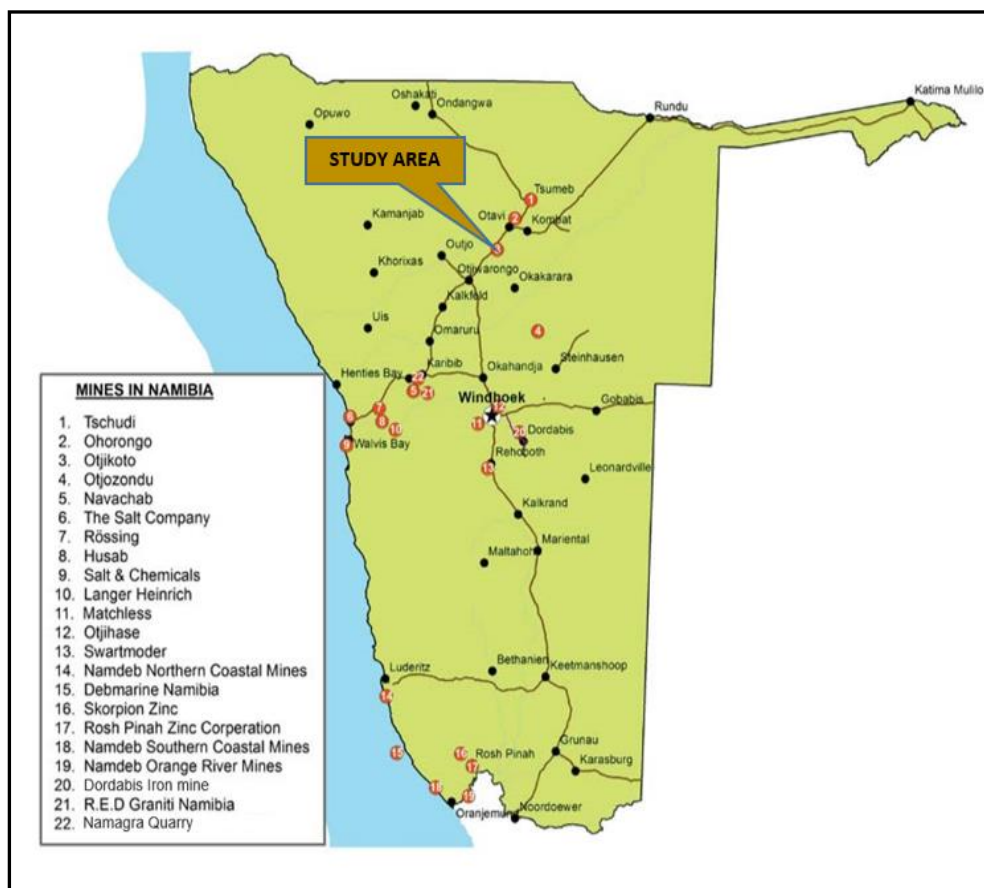


Figure 1-1: 2016 operating Mines in Namibia. Modified after the Chamber of Mines 2016.

When it comes to the grade reconciliation at B2Gold Otjikoto Mine, the Grade Control model has consistently shown a grade underestimation against the plant processed feed grade. It is therefore, hypothesized that grade capping at B2Gold Otjikoto Mine, could be among the factors contributing to the consistent grade variances observed between the grade control feed grades and the plant head grades.

The Minesight three dimensional software was used to interrogate a three dimensional drillholes assay sections. The ore shows a conspicuous grade zonation, with the highest grades concentrating into the cores of the shoots and can be domained into zones of high grade gold ore. This study therefor applied the HGD method in in comparison to the HGC method which is currently employed at B2Gold Otjikoto Mine deposit in order to quantify the impacts of the HGD in the Mine grade control system. The HGD method is able to model the high grade zones in the presence of high grade outlier values without outliers estimates smearing into low grade areas, or low grade estimates smearing into high grade areas. The HGD is therefore preferred and recommended by this study.

1.2 Statement of the Problem

The B2Gold Otjikoto Mine has been experiencing grade underperformance of the HGC derived grades when reconciled with the actual Plant processed grade. Many researchers, such as Leuangthong and Nowak (2015) and Kim et al. (2018), argued against employing HGC especially on outliers which show a spatial relationship. The high grade mineralization in Otjikoto appears to be concentrated, in shorter limbs and within the hinges of the intrafolial folds, in distinctive en-echelon, thus depicting a spatial relationship. However, the distribution, continuity and nugget effect of high grade outliers in Otjikoto Mine has not been properly studied to inform on the choice of the methods of dealing with the outliers. Therefore, it was herein hypothesized that the HGD could be ideal for the grade control modelling at B2Gold Otjikoto Mine.

1.3 Aims and Objectives

The main aim of the study is to investigate the impact of applying HGD as a method of handling grade outliers in the grade control modelling system at the Mine, by constructing resource models employing the two methods and comparing the results of the two models. The objectives of the study were:

- a. To demonstrate the spatial distribution of outliers in the Otjikoto orebody.
- b. To produce two grade block models of the orebody, one model employing the HGD and the second model employing HGC as a method of managing gold grade outliers.
- c. To quantify the effects of applying HGD as a method of dealing with gold outliers in a mine grade control system.
- d. To determine the optimum method of dealing with gold outliers in the grade control system at Otjikoto mine.

2 GEOLOGY OVERVIEW

2.1 Regional Geology

The B2Gold Otjikoto Mine area is located in the Northern Zone of the Damara Belt (Fig. 2.2). The Damara Belt forms part of the Pan African Neoproterozoic Orogenic Belts, reflecting the western Gondwana suture (Gray et al. 2008, Miller, 2008). The Damaran Orogeny is marked by the inland Damara Belt and the coastal Kaoko Belt (Miller, 2008). The inland Damara Belt formed during the collision of the Congo and Kalahari cratons, while the coastal Kaoko Belt formed from the collision of the Rio Delta Plata and Kalahari Craton (Lehmann et al. 2015, Gray et al. 2008, and Miller 2008).

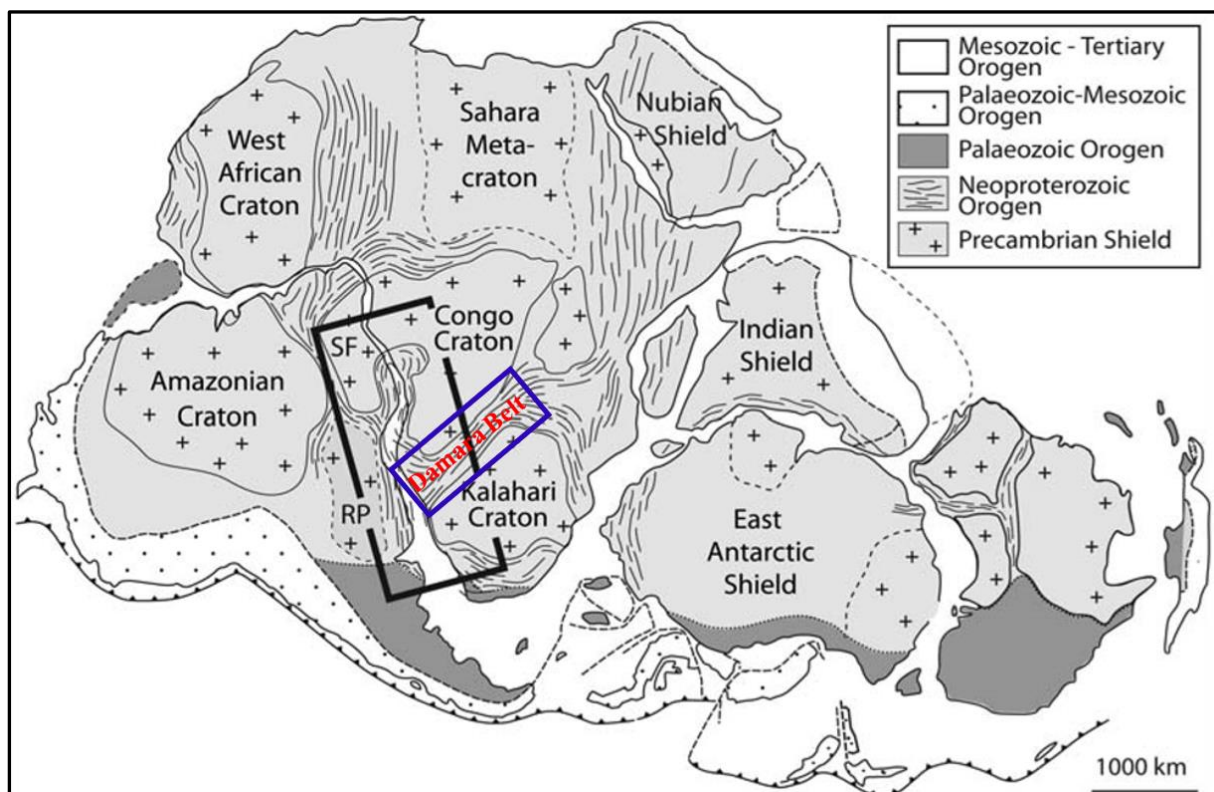


Figure 2-1: Neoproterozoic orogenic belts during the formation of Gondwana craton. Modified after Gray et al. (2008)

The Damara Belt represents suture zones between cratons which joined during the formation of Gondwana Continent (Frimmel et al. 2011).

2.1.1 Evolution of the Damara Belt

The Damara Belt formed through a sequence of continental rifting, spreading, subduction, and collision between 900 Ma and 460 Ma (Miller, 2008, Gray et al. 2008). The Damara Belt consist of metasedimentary (Fig. 2.2) rocks which were unconformably deposited on the basement Abbabis Complex in the Khomas Sea during the breakup of Rodinia Supercontinent. (Miller, 2008). The basal unit of the Damara Belt is composed of quartzite, arenite, and conglomerate, making up the Nosib Group (Miller, 2008).

The Nosib Group deposition was followed by the deposition of carbonate and siliciclastic units of Otavi and Swakop Groups (Gray et al. 2008, and Miller 2008). Within these Groups are deposition of the glaciomarine diamictite units, namely the Chuos Formation and Ghaub Formations, which were deposited during the snowball events (Miller, 2008). The deposition of the Ghaub Formation was followed up by continental rapture which resulted in the deposition of carbonate formations such as Karibib and the Tsumeb subgroup carbonates (Miller, 2013, and Miller, 2008). The subsidence, which resulted in the deposition of thick sequence of turbidite units of the Kuiseb Formation (Miller, 2008, and Gray, 2008).

The transpressive convergence of the Congo craton and Kalahari Craton resulted into large scale uplifting, erosion and deposition of syntectonic flysch and molasses successions of the Mulden Group on the Northern platform (Miller, 2013 and Miller, 2008).

According to Miller, 1983, crustal convergence between the Congo and Kalahari craton started between 580 – 550 Ma giving rise to the D1 event defined by large scale thrusting and recumbent folding. The intensive collision (D2) between the Congo and Kalahari Cratons occurred between 550-540 Ma, giving rise to the NE trending structures (Miller, 1983). Crustal thinning and extension followed the collision, which also involved intrusion of numerous post and late tectonic granites which is associated with high temperature low pressure metamorphic events in the central Damara Belt (Gray et al., 2008).

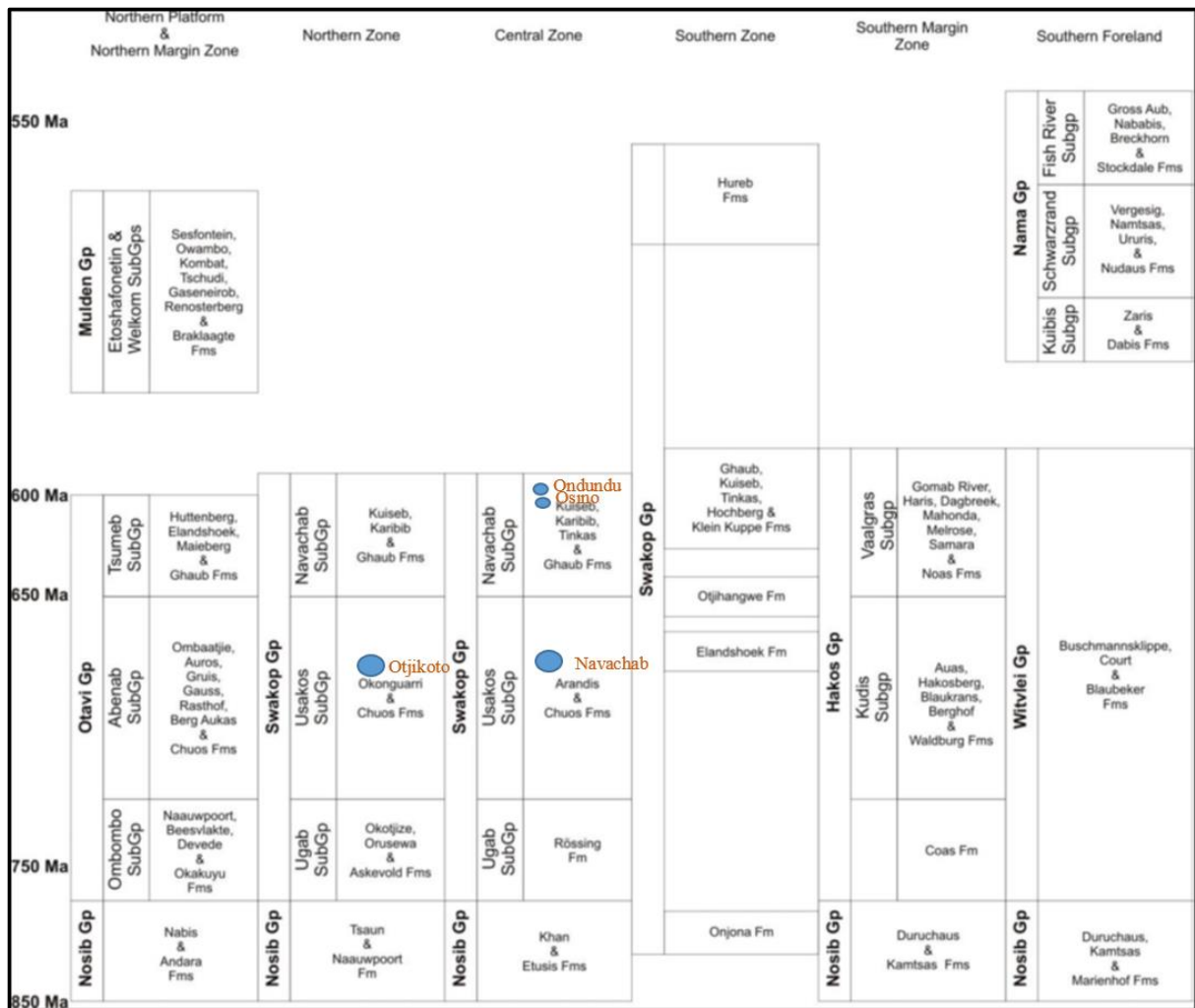


Figure 2-2: The Stratigraphy and the tectonostratigraphic columns of the Damara Belt with known gold deposits (Modified after De Kock, 2001; Miller, 2008; Rankin, 2015).

According to Miller (2008), the Damara Belt can be subdivided into different tectonostratigraphic zones (Fig. 2.3), where the grade of metamorphism increases from the edges of the belts toward the central zones, which is marked with igneous activities.

There are three main preserved deformation events in the Damara Orogen (Lehmann et al. 2015). Subtle relict structures and fold pattern analysis reveal the presence of a D1 event, a N-S shortening event, whose structures were almost annihilated by the stronger D2, a E-W convergence, which resulted in fold interference patterns visible from space (Lehmann et al. 2015). The final NW-SE D3 event related to the collision of Congo and Kalahari craton produced the NE striking deformation signature in the metasedimentary rocks. The Central Zone of the Damara Belt displays orogeny parallel stretch and shortedning at high angles to

the orogeny and pure shear deformation with lateral orogeny-parallel stretch (Kisters et al. 2004).

Pirajno and Jacob (1991), discussed the occurrences of gold mineralization in the Damara orogenic belt. They grouped hydrothermal gold occurrences in the belt into four categories, namely; (1) gold associated with thrust zones example such at Natas Mine, (2) gold quartz association in shear zones which occurs in basement rocks and in Nosib group rocks, (3) turbidite hosted gold mineralization such as at Ondundu and Otjikoto gold mineralization, (4) and the calc-silicate-hosted gold mineralization such as that at Navachab gold Mine. Navachab deposit is hosted in the Arandis Formation in the Central Zone, and which is a similar Formation and seat at the same stratigraphic position, as the Okonguarri Formation which host the Otjikoto deposit in the Northern Zone.

2.1.2 The Geology of the Northern Zone of the Damara Belt

The Northern Zone includes rocks of Nosib and Swakop Group (Miller, 2008). According to Miller (2008), the Zone was thrust northward onto Otavi, Mulden and pre-Damara rocks, and its southern edge is defined by the Autseib fault and Otjihorong thrust while the Khorixas-Gaseneirob thrust defines its northern limit. The Zone is intruded by Damara granites on the western end (Miller, 2008).and metamorphism within the zone reached lower amphibolite grade in the Zone (Garagan, et al. 2018).

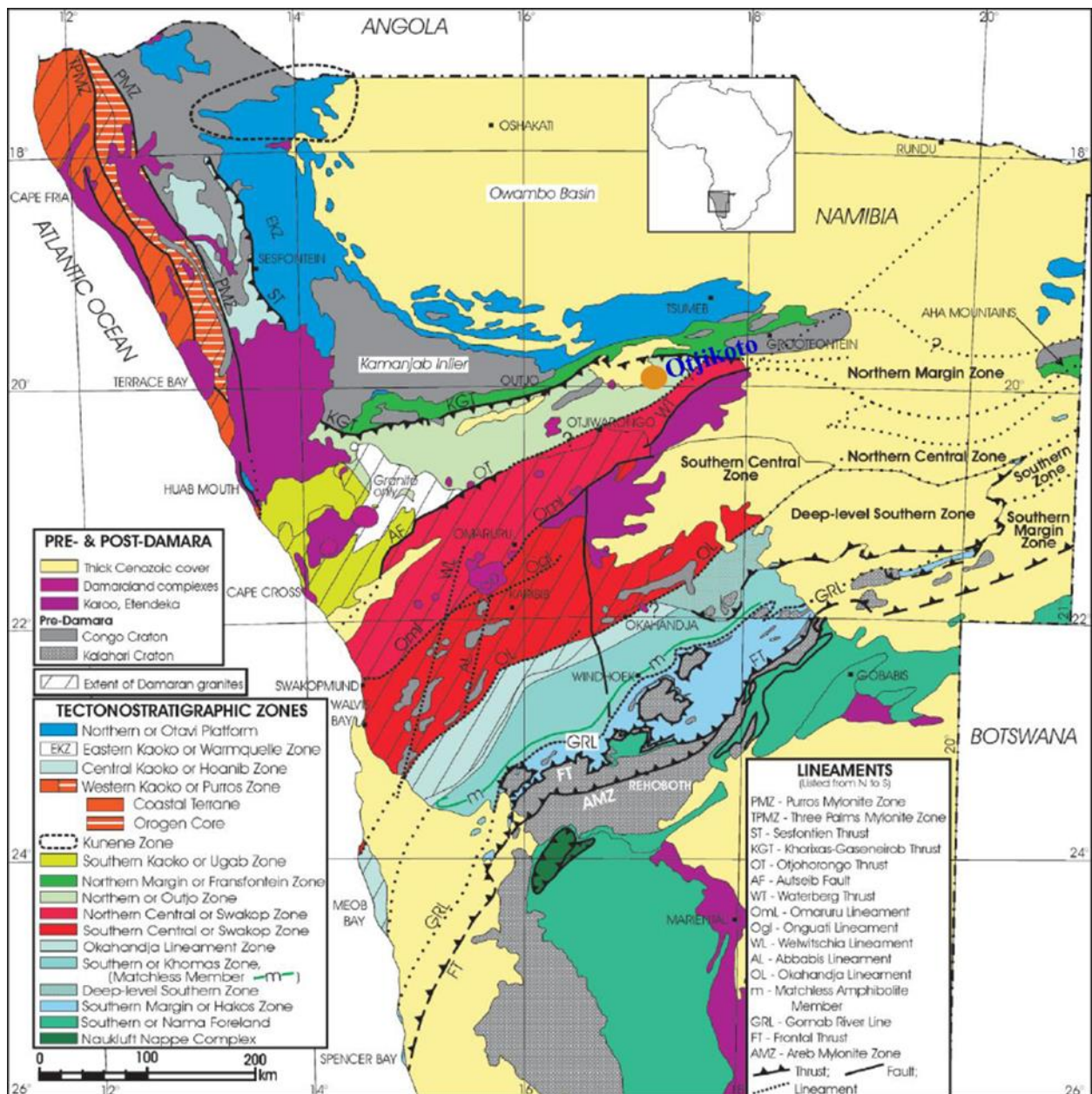


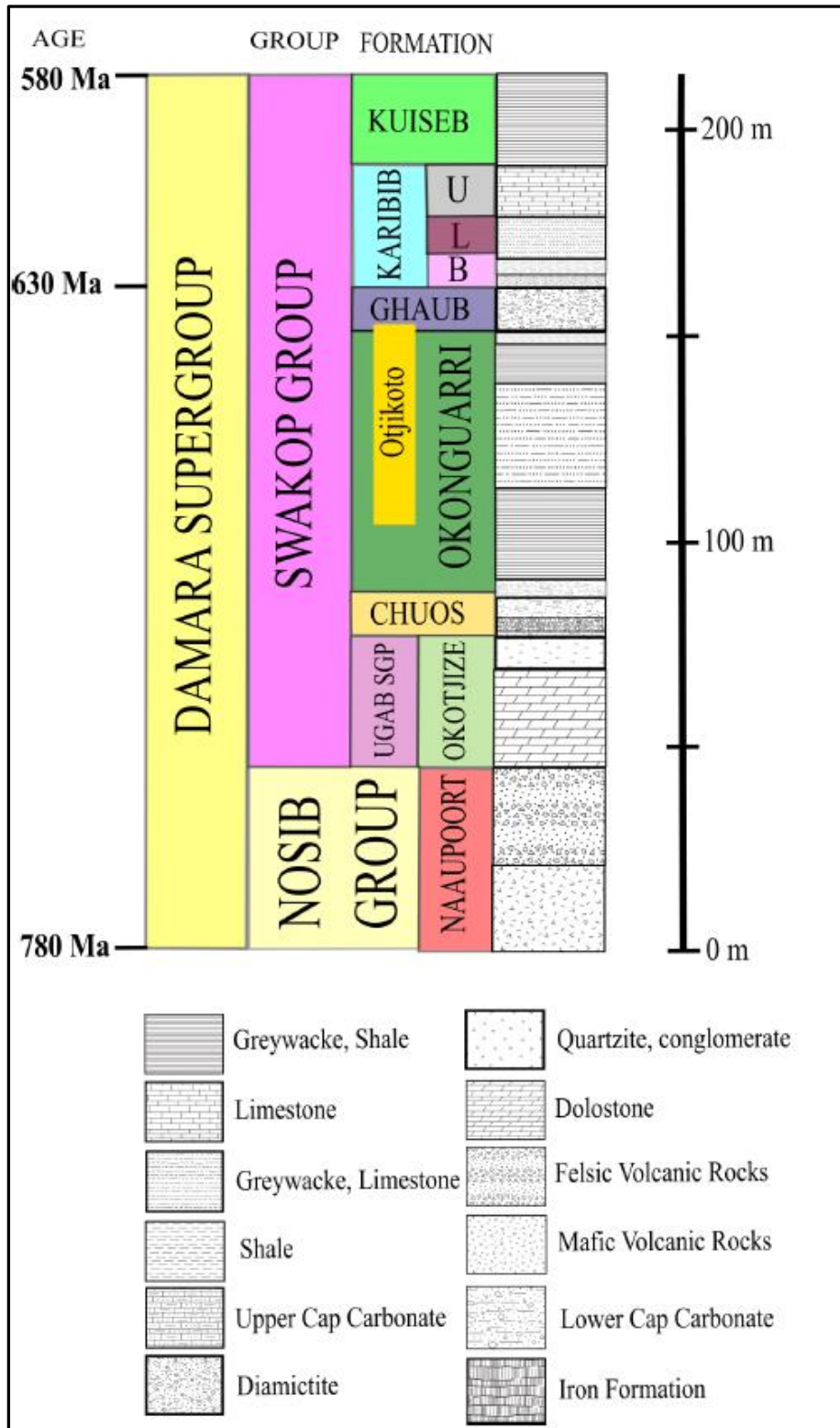
Figure 2-3: Tectonostratigraphic zones of the Damara orogeny (modified after Miller, 2008).

2.2 Local Geology

There was little known of the geology of the area up until the late 1990s when exploration activities started off in the Mine area (McDonald et al., 2011). The area is underlain by the Swakop Group rocks which are extensively covered by calcrete, there are notable marble hills in the area. Otjikoto Mine falls within the Northern Zone tectonostratigraphic setting of the Damara orogeny. The Okonguarri Formation albitites of the Swakop Group host the ore deposit

and it is overlain and underlain by regional diamictite Formations, namely Ghaub and Chuos Formations (Garagan et al, 2018), (Table 2.1).

Table 2-1: B2Gold Otjikoto Mine local stratigraphy, After Lytle et al., (2012), Hoffmann et al., 2014 and Negonga (2018).



2.2.1 Chuos Formation

According to Miller (2008), the Chuos Formation, which is a diamictic formation, is widely found in many parts of the Damara Orogenic Belt. Miller further states that the formation is associated with iron Formation facies and underlies the Okonguarri Formation in the Swakop Group.

2.2.2 Okonguarri Formation

Okonguarri Formation thickens to 4000 meters within the Northern Zone (Miller, 2008). The Formation consist of schist units, three marble units, and albitite units (Garagan et al, 2018). According to Miller (2008), the Okonguarri Formation is made up of calcareous turbidite units interbedded with calcareous biotites schist, quartzites and carbonates, and the formation fine upward from coarse grain units at the base to schist units at the top, a scenario observed well in Otjikoto Mine Pit. Okonguarri Formation hosts the Otjikoto Ore Body mineralization.

The mine area is dominated by metasedimentary units and few intrusive bodies (Fig. 2.5). The Okonguarri Formation has been sub-categorized into four units namely Otjikoto A (OTA), Otjikoto B (OTB), Otjikoto C (OTC) and Otjikoto D (OTD). OTA is made up of biotite schist and it host minor veins that are parallel to bedding, OTB is made up of the calcitic marble and it is not mineralized, OTC is made up of albite-hornfels unit and host most of the mineralization, and the OTD which is a biotite schist, it hosts minor mineralized veins (Garagan et al., 2018).

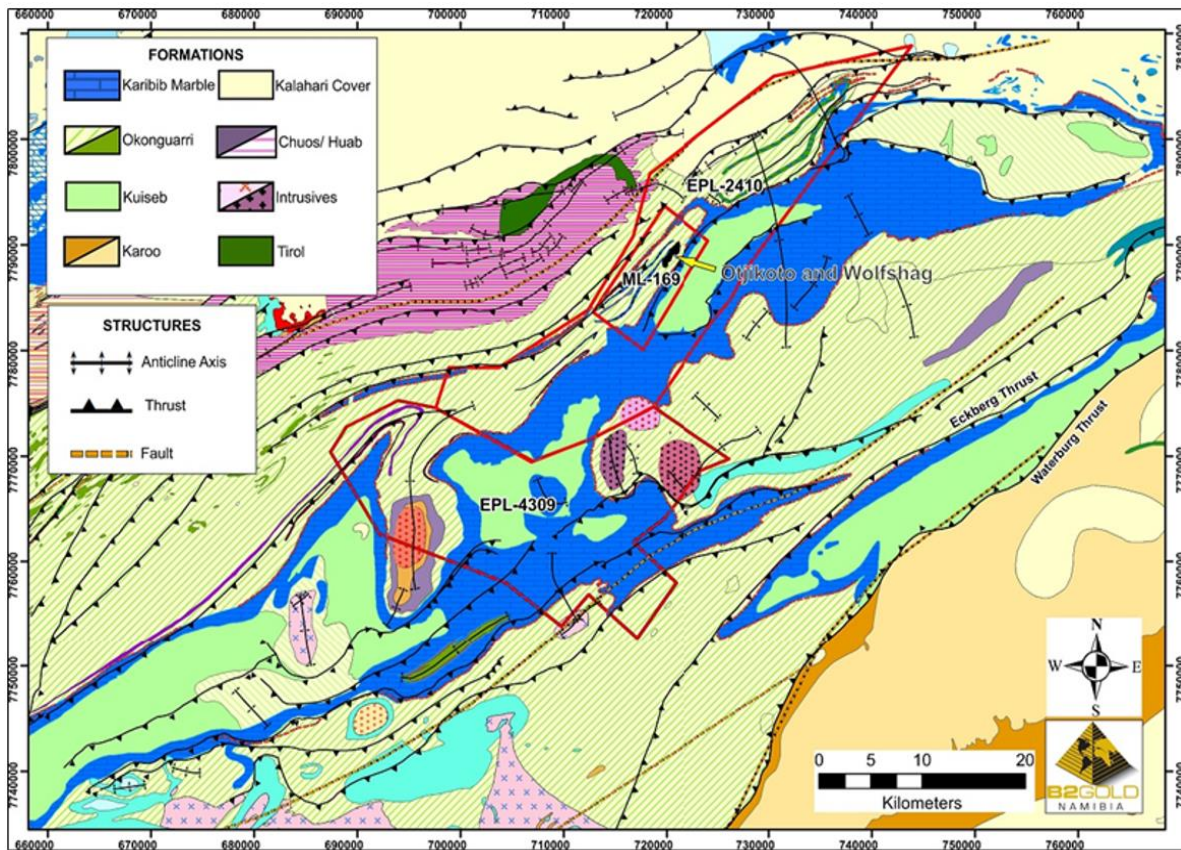


Figure 2-4: Otjikoto Mine local geology map. Source: Garagan et al., (2018).

2.2.3 Ghaub Formation

The Ghaub formation overlies the Okongurri Formation rocks (Garagan et al., 2018 and Miller 2008). The formation consists of diamictite units and it attains a maximum thickness in the range of tens of meters (Miller, 2008). Apart from the diamictites, the formation consists shale units, siltstones, and an overlying cap carbonate (Garagan et al., 2018 and Miller, 2008).

2.2.4 Karibib Formation

The Karibib Formation is well preserved in the area and forms a very important stratigraphic marker horizon. The formation is extensively preserved across the Damara belt from the Southern Zone to the Northern Zone (Miller 2008). The Karibib Marble is folded in an open synformal structure immediately to the east of the Otjikoto ore deposit (Garagan et al., 2018 and Wilton et al., 2002).

2.3 Otjikoto Ore Deposit

The Otjikoto orebody is made up of multiple ore shoots (Fig. 2.4) over a strike distance of 2.6 km and has been drilled up to a depth of 475 m (Garagan et al., 2018). Otjikoto gold mineralization is associated with sheeted veins hosted in the metamorphosed turbidite units, namely hornfel and albitite units. The ore shoots are concentrated in fold closures, which range in folding intensity from open folds to tight s-folds. There are sulphide veins that range in width from 1 – 10 cm (Wilton et al., 2002), however, thick sulphide veins of up to 1 m wide have been observed in the pit. There appears a strong degree of degree of structure control on the mineralisation. The ore shoots are aligned parallel to the regional D2 structures, oriented NE-SW, and the high grades appears to be concentrated in fold closures.

The veins consists of pyrite, pyrrhotite, magnetite, calcite, garnet, and visible gold. Significant mineralization is hosted in the albitite and amphibole granofel units compared to the schist units. According to Wilton et al. (2002), albitization observed at the mine, applies critical deep-seated events which resulted in the alteration of the original pelitic and carbonate-bearing units.

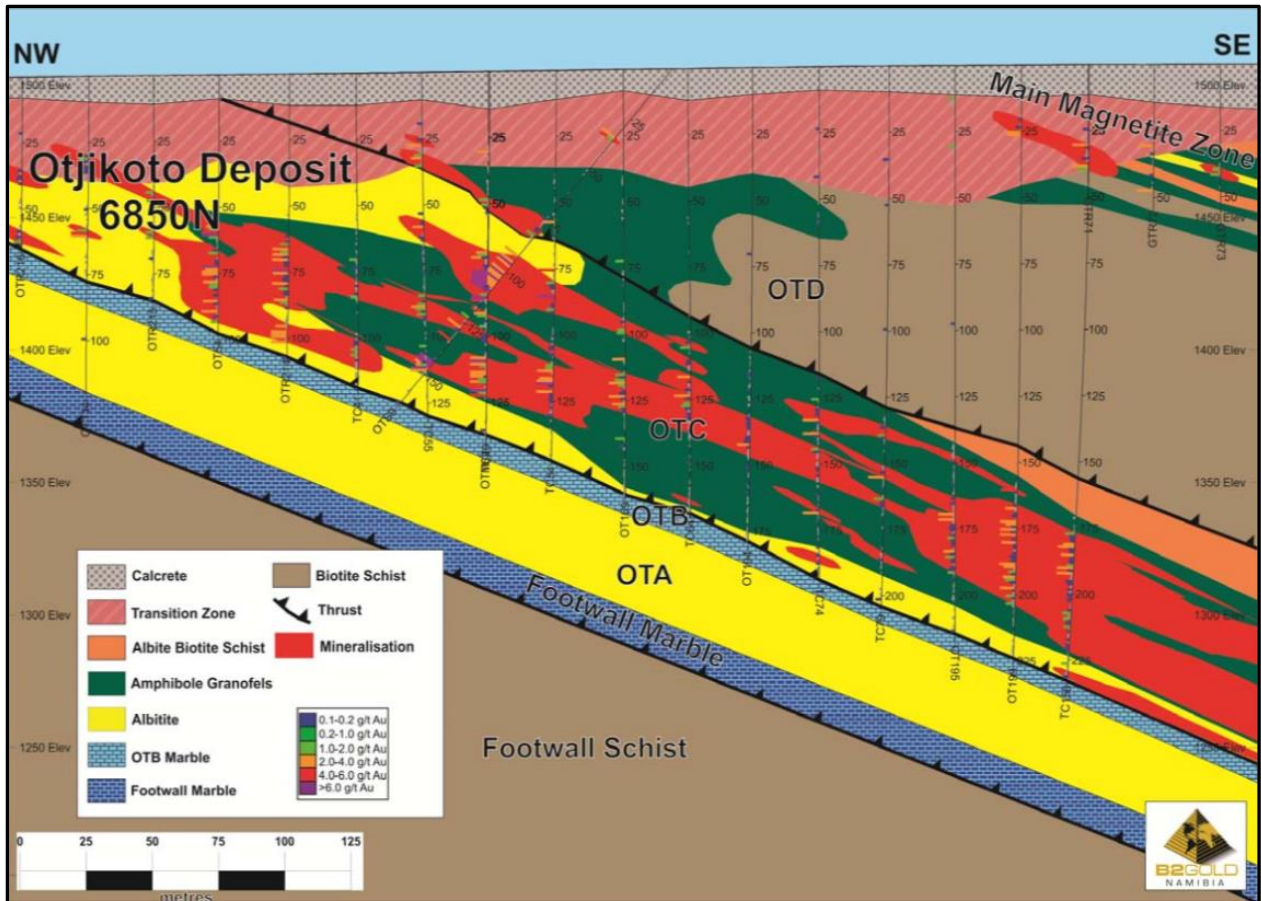


Figure 2-5: A simplified cross section of Otjikoto deposit showing three prominent thrusts in the area (Garagan et al., 2018). The thrust planes appear to define the extend of the mineralization.

High grade shoots appear in the shorter limbs and within the hinges of intrafolial folds between planar beds (Garagan et al., 2018). High grade gold mineralization occurs in distinctive en-echelon veins oriented between 010° to 020° north–northeast and plunging about 12° South South-west (Garagan et al., 2018). Gold occurs within the veins as free coarse gold with size variation between 5 µm to 400 µm, and the gold has been found adjacent to and within sulphides, along fractures, adjacent to and within garnets, within magnetite, on the edges of amphiboles and chlorite, and as free gold in quartz and carbonates (Garagan et al., 2018).

2.4 Orogenic Gold Deposits

Gold deposits forms in many geological settings (Fig. 2.6). According to Groves et al. (1998), orogenic gold deposits are associated with deformed metamorphic terranes of all ages, mostly within greenschist facies rocks, however they are also found in lower and upper metamorphic

terrane. These deposits are classified by quartz, sulphide and carbonate dominated veins and associated with mineral alteration zones (Groves et al., 1998). According to Dominy and Annels (2001), orogenic gold deposits are classified by a richer core surrounded by lower grade material on the peripherals.

According to Groves et al. (1998) there is a strong structural control of mineralization at different scales. Orogenic gold deposits are location adjacent to first order large scale crustal to lithospheric faults or shear zones (Groves et al. 2016). The first order crustal faults acts as conduits for source fluids from deep sources (groves et al. 2016). At deposit scale, gold mineralization may be hosted in second order structures which are adjacent to crustal scale faults and shear zones and which pre-date the gold mineralization (Groves et al. 2018). Second and third order faults systems that make up complex interconnected fault networks around large orogenic gold deposits (Groves et al. 2000) represents a good deposition control. Asymmetrical folds with overturned back limbs, such as anticlines, represents another robust form of control of deposition of gold mineralization (Groves, et al. 2000).

Orogenic gold deposits gold rich fluids are interpreted to have formed at depth as the rocks go through metamorphic facies changes, where by hydrous and carbonate minerals break down to form H₂O and CO₂, and sulphide minerals release the metals (Pitcairn et al., 2006; Phillips and Powell, 2010). According to Groves et al. (2016), two common models of source of fluids exist, namely the regional metamorphism from deep-crustal metamorphic model and the devolatilization model. The regional metamorphism model says that the gold forms late in the metamorphism from deep crustal metamorphic fluids, while the devolatilization model says that the gold is mostly likely sourced from devolatilization of pyritic sediments above a subduction zone (Groves et al. 2016). Granitic intrusions are common components in orogenic gold deposits, however, there are no clear genetic relationships between deposits and granitic intrusions (Groves et al. 2018).

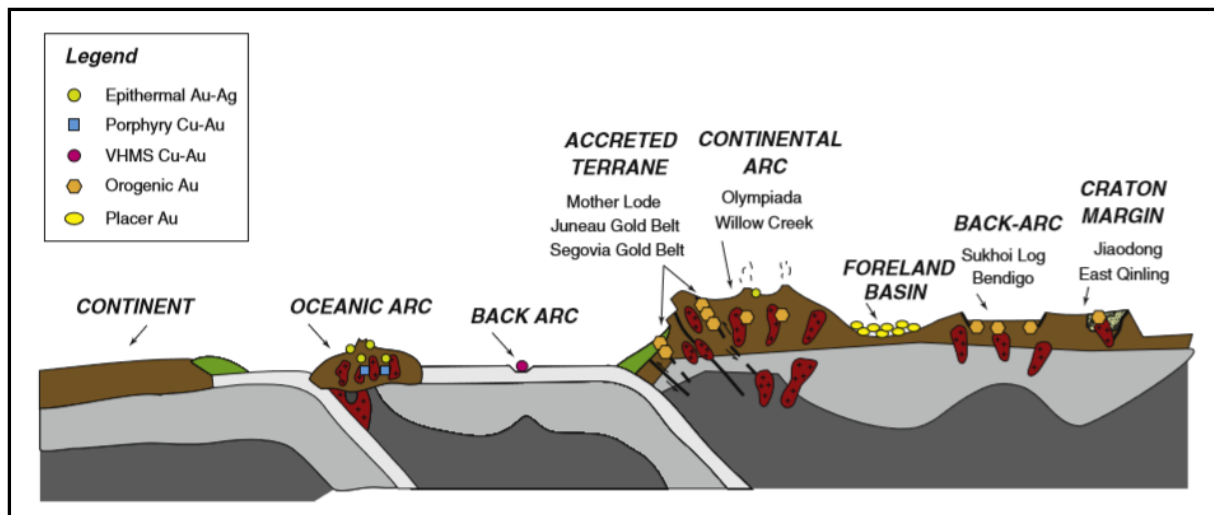


Figure 2-6: Tectonic settings of orogenic gold deposits and other gold deposit types (Goldfarb and Groves 2015).

2.5 Otjikoto Deposit Model

Otjikoto deposit is hosted in deformed metasedimentary rocks, of up to amphibolite facies, and it is associated with extensive albertyisation and alteration of the host rocks. Otjikoto deposit is hosted in second order structures such as shear zones, faults and thrust planes (Negonga, 2018). Structural and veining features in the hosting units signifies reverse to oblique thrust movement along faults and shear zone (Tomkinson, 1999). The gold mineralization is hosted in quartz, sulphide, and carbonate veins. Veins fluid inclusion study by Negonga (2018) indicated that Otjikoto deposit formed at temperatures between 535-555°C, which falls within the Orogenic gold deposit classification temperatures of formation range (200 – 650°C; Groves 1993; Groves et al., 1998; and Goldfarb et al., 2001).

Garagan et al. (2018) states that due to the fact that the ore bodies at Otjikoto mine are open ended at depth, and are continuous both laterally and vertically down the plunge of the shoots is an indication of a deep looted source which is typical of orogenic gold deposits. There are at least three deformation events preserved in the area (Garagan et al., 2018). D1 resulted in the formation of recumbent folds, D2 resulted in series of double plunging anticlines and synclines with folding varying in intensity from tight to open folding, and D3 was a doming event which resulted in the refolding of D2 fold structures (Garagan et al., 2018).

Mineralization is structurally controlled, with the ore deposits aligned parallel to the local and regional D2 structures, and contained in fold closures, where the high-grade ore shoots display parallel orientation to the fold axis of the hosting fold structures. The ore body display grade zoning with the high-grade ores hosted in the cores of the ore shoots and surrounded by lower grade material. Therefore, the characteristics of Otjikoto gold deposit largely satisfy the classification criteria of the orogenic gold deposit model.

2.6 Project History

According to Fletcher et al. (2013) and Wilton et al. (2002), Otjikoto gold deposit was discovered in 1999 by Avdale Namibia through aeromagnetic surveys. Follow up ground geophysical surveys in the form of detailed magnetic, electromagnetic, and IP were done by Avdale which resulted in the identification and delineations of numbers of geophysical domains (Wilton et al., 2002).

Geochemistry survey then followed, where shallow percussion boreholes were drilled to geochemically test the geophysical responses (Wilton et al., 2002). Eventually, follow up diamond and reverse circulation (RC) drilling discovered the gold mineralization over strike length of 2.5Km (Wilton et al., 2002). African Rainbow Minerals (ARM) acquired Avdale in 2003 (Fletcher et al., 2013), and defined a resource of 26 million tons at gold grade of 1.06 g/t (Van der Merwe et al., 2005). From 2005 to 2010, the project ownership was transferred from ARM to Teal and finally to Auryx Gold who eventually sold to B2Gold in 2011 (Fletcher, 2013). B2Gold eventually developed the project into a Mine and poured the first gold bullion in December 2014. The Mine employs close to 1000 employees and it has been consistently producing over 150 000 oz. of gold per year since 2015.

3 BACKGROUND TO GEOSTATISTICAL MODELLING METHODS

3.1 Nature of Mineral Deposits

Mineral deposits can be defined as aggregates of minerals or elements in a certain form in the earth surface and subsurface that have potential for economic benefit (Leuangthong & Nowak, 2015, and Ridley, 2013). Evans (1993) in Zaghlol (2019) categorized the formation of mineral deposits based on physical process into five categories namely; due to internal processes, due to hydrothermal processes, due to metamorphic process, due to surficial processes, and due to sedimentary processes. Importantly, all ore deposits form due to geological processes. Mineral deposits can be classified according to composition, form of deposit, associated host rocks, and geological structures (Gandhi & Sarkar, 2016).

The world is faced with a challenge of keeping up with increasing demand of supply of mineral resources, and the difficulty of discovering new economic mineral deposits. It is becoming hard for exploration companies to discover economic mineral deposits nowadays compared to 50 years ago, as most surface outcropping deposits have already been discovered. Lusty and Gunn (2014) propose that more scientific research and improved mineral deposit models, and new baseline datasets and mineral exploration technologies will lead to the discovery of new mineral deposits.

Ore body modelling techniques of a discovered mineral resource are very important in developing it into a Mine. It is through resource modelling results where economic decisions of whether to (1) develop a project into a Mine, (2) abandon a project, or (3) do more exploration work are based. Mineral exploration is a very expensive business; significant economic decisions of a project are based on geostatical model of the deposit.

Geostatistical modelling is associated with challenges such as the nugget effect, and grade outliers, which must be dealt with in the modeling process to yield a good resource model. Gold deposits, especially those that are associated with coarse gold, are characterized by high

to extreme nugget effects (Dominy et al. 2003). Therefore, it is very important that resource modelers employ the best possible methods to produce the best possible deposit grade model.

3.2 Resource Modelling Methods

3.2.1 Conventional Methods

Resource modelling has evolved over the last 100 years from conventional estimation methods to geostatistic methods. Knudsen (1975) describes in details the commonly used conventional methods in resource estimation, which are polygonal, and inverse distance. In polygonal method, the assay values influence is extended half way to the adjacent hole, where if the block model is used, each block is assigned the assay of the nearest drill hole (Knudsen, 1975). He describe inverse distance method as a method where the blocks are assigned values which are weighted average of all the holes surrounding the block, where the weights assigned are a function of distance and sum up to 1. Ore grade values are considered to be one of the regionalized variables (e.g Clark 1979). However, conventional methods do not consider the direction of the high continuity of the mineralization but the positioning of the area being estimated to the holes, therefore, they consider the grades to be randomly distributed within the mineral deposit (Zhang, 2011).

3.2.2 Geostatistical methods

Unlike conventional methods, geostatistical methods assume that there is a trend in a given dataset and there should be correlation variations within the data sets. Mineral deposits formed through geological processes which imprint relationship in the distribution of elements in the deposit. Geostatitics make use of the correlation of two values separated by a lag distance (h) and use the information to make predictions at unsampled locations (Rashad et al., 2007). According to Clark (1979), Geostatistics is based on assumptions that; (1) differences between the values of samples are based on their relative spatial orientations, (2) that the mean and

variance depend on their relative orientation, (3) for convenient there is no trend on the deposit which is likely to affect values within the scale of interest.

Zhang (2011) states that geostatistics uses estimation and simulation as the basis of predicting the spatial distribution of a deposit. Zhang (2011) and Clarks (1979), further explains that, estimation (kriging) is based on sample data and variogram (Fig. 3.1), while on the other hand, in simulation many equal –likely maps of the deposit are produced using a variogram as required in estimation.

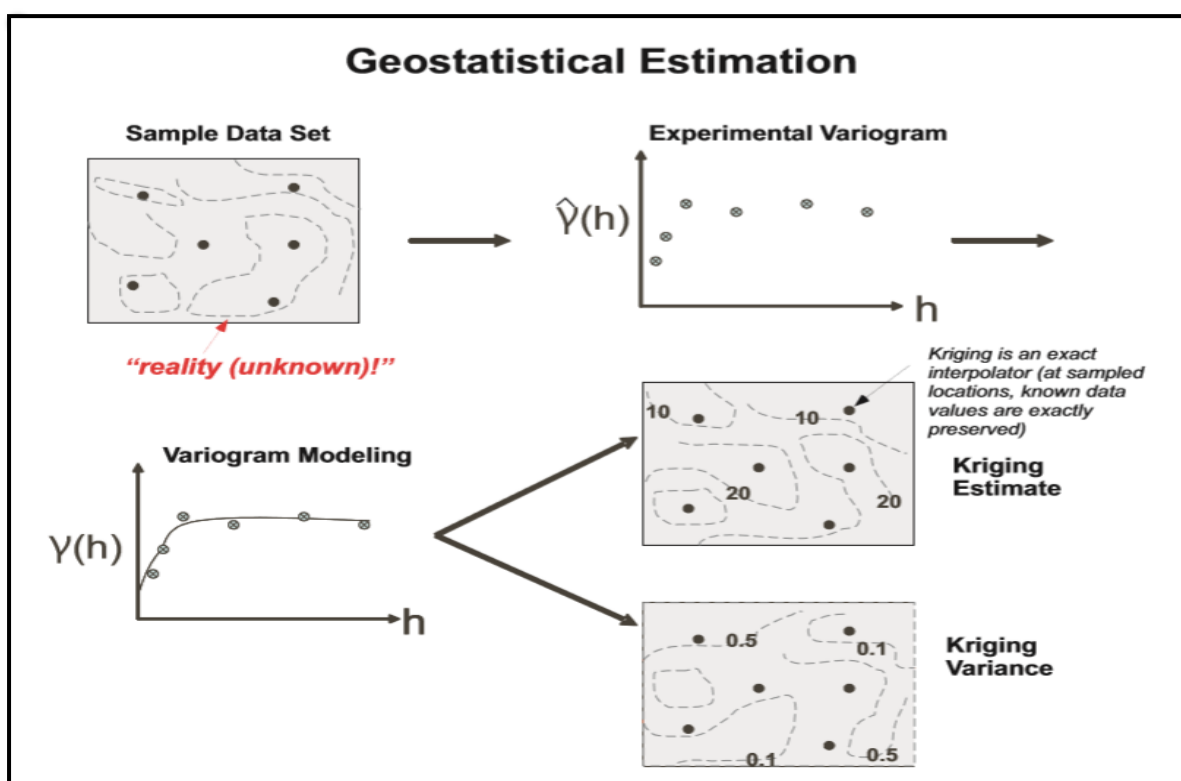


Figure 3-1: Geostatistical estimation work flow, Zhang (2011).

Zhang (2011) describe in details 3 steps involved in geostatistical estimation, which are (1) examining the similarities between sample data points through variogram modelling, (2) fitting a mathematical function to the experimental variogram, and (3) conducting a kriging estimation interpolation using the mathematical function.

3.3 Variogram

Ore deposits are formed due to geological processes. In geostatistics, a variogram is a function that defines how two values are correlated in space due to their position in the mineral deposit (Clarks, 1979). Variograms are the most common measure of spatial correlation in geostatistics, based on regionalized random variables $Z(x)$ and $Z(x+h)$, where x and $x+h$ represents spatial positions separated by vector h

$$\gamma(h)=0.5E[Z(x+h)-Z(x)]^2 \quad (\text{Bachmaier and Backes, 2011; Clarks, 1979}).$$

Different data populations within a given set of data may show different grade trends; therefore, different population data should be mapped out, analysed and be treated accordingly. Assumption of same parameters throughout the dataset could result in bad estimations.

3.4 Managing Outliers

Resource estimation involves dealing with surprisingly higher values known as outliers which poses mathematical difficulties in modelling grade distributions (Costa, 2003). Hawkins (1980) describes an outlier as an observation that deviates from other observations within a group of data. Commodity grades are distributed through a wide range of values within a given ore deposit giving rise to the presence of lower values and extreme values.

Outliers produce a sense of excitement when intersected in mineral exploration or in a mining environment, in fact many exploration companies are happy to report high intersections to the market to boost their stock values (Leuangthong & Nowak, 2015). However, Sinclair and Blackwell (2002) argue that outliers pose a challenge in resource estimation as they receive too much weight in the estimation or a negative estimation which could result in unrealistic estimations. High grade outliers would result in high grade estimates smearing into lower grade areas. Therefore, concerns related to possible overestimation of resources led to the development of different methods of reducing the effect of outliers in resource estimation.

Kim et al. (2018) categorizes outliers into two main groups; isolated and grouped outliers, and detailed how they could impact differently on resource estimation. Different users in resource modelling prefer different methods of dealing with different outliers. According to Kim et al. (2018), isolated outliers pose more risks in resource estimation as they tend to have different continuity than most of the data, and therefore must be treated differently to grouped outliers which could represent a significant high grade domain. Isolated outliers pose a risk of smearing grades estimates into the lower grade areas surrounding them. Therefore, Kim et al. (2018) recommends assessment of the type of outlier in the deposit before deciding the method of dealing with such outliers.

Many consider grade capping/top cutting as the ultimate primary approach to dealing with outliers in resource modelling (Leuangthong & Nowak, 2015). It is a simpler method, hence it has become the most common used method. However, grade capping is just one of many methods of dealing with grade outliers and it has its shortcomings such as an undue reduction in the estimated grade (Kim et al., 2018). There are other methods, and potentially better solutions proposed in resource modelling such as High Grade Domaining and modelling with outliers by limiting their influence (Leuangthong & Nowak, 2015). Nevertheless, high grade capping continues to be the most common used method, and it has been successful in many mines.

3.5 High Grade Domaining

Geological domaining is a common practice in almost all resource modelling (Leuangthong & Nowak, 2015). Duke and Hanna, (2001) define a domain as zone which is geologically and/statistically homogenous. Kim et al (2018), states that, the more abundant, clustered outliers may represent a sufficiently large domain, which has spatial relationship and distribution and can be mapped out into individual grade domains.

The main objective of high grade domaining is to ensure that high grade values are not smeared into low grade areas and low grade values are not smeared into high grade areas (Leuangthong & Nowak, 2015). Stegman (2001), states that the understanding that the high grade distribution and continuity may be different from the low grade distribution required to enable better defining of the grade domains. In most cases the low grade forms rims around the high grade core (Dominy et al., 2003).

There are two main methods of generating grade domains, which are explicit and implicit modelling (Cowan et al., 2002). Explicit modelling involves manual digitizing of polygons across the drillholes sections to define the domain, which are then linked from section to section to form a triangulated 3D solid body (Leuangthong, and Nowak, 2015), (Fig. 3.2.). This study used the explicit as it was the best option with the Minesight 3D software package available at the mine. Implicit modelling on the other hand makes use of the fast boundary modelling approach based on the use of radial basis functions to create equal grade (isograde) surfaces (Leuangthong, and Nowak, 2015).

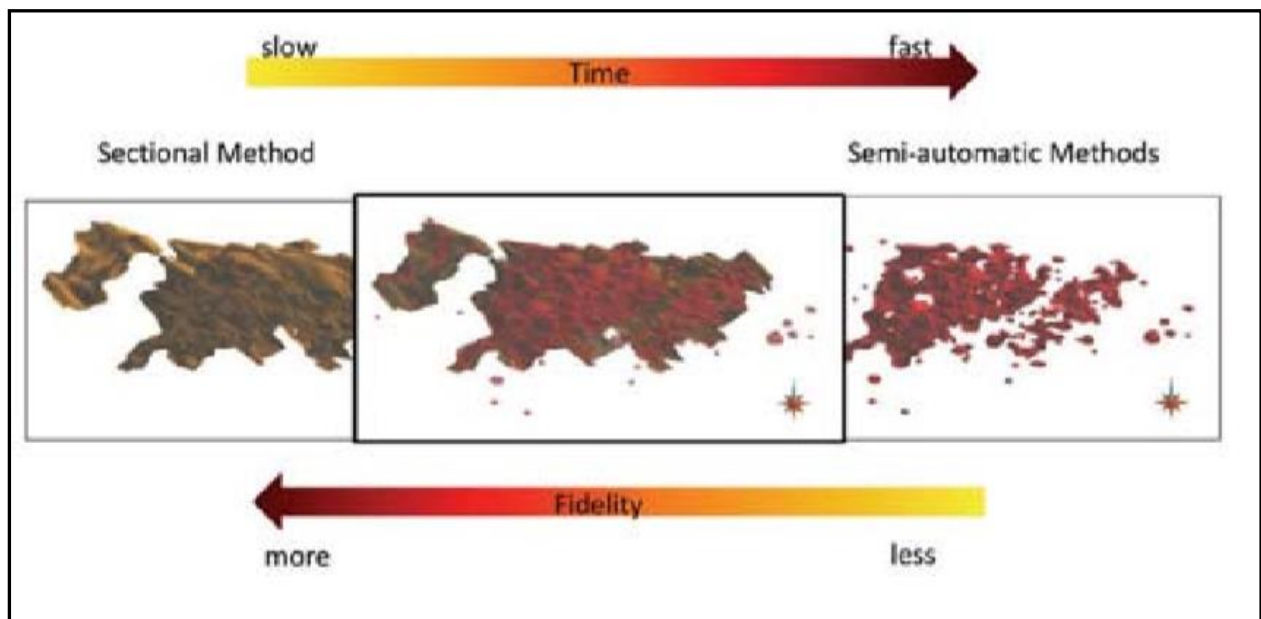


Figure 3-2: Sectional (explicit) and semi-automated (implicit) method of grade domaining. After Leuangthong and Nowak (2015).

Ortiz and Emery (2006) discussed in details three problems associated with geological domaining as; (1) definition of the domains is a subjective process, (2) delineation of geological boundaries associated with errors, and (3) the difficulty in defining the boundaries of the domains. Boundaries between different domains can be defined as hard contact when there is an abrupt change in features defining the boundary, or soft contact when there appears a transition zone between the two domains (Ortiz & Emery, 2006). Stegman (2001) identified incorrect direction of continuity, domains that are too broad, resulting in smearing of grades, underestimation of grade and overestimation of tonnages, and domains that are too small resulting in models assuming greater spatial continuity of high grades resulting in overestimation of grades. Inconsistence in strike limits of the domains is another problem associated with HGD (Stegman, 2001).

3.6 High Grade Capping

In a scenario where HGD is not viable, then HGC may be recommended (Leaunghong & Nowak, 2015). Kim et al. (2018) states that the outliers which do not conform to the distribution of the other assays should be capped to avoid resource overestimation as they pose more risk in the resource estimation. The process of top cutting/ grade capping involves reducing the significance of those values deemed to be outliers in a resource estimation to a lower cap value deemed safe enough not to cause an overestimation.

According to Leaunghong and Nowak (2015) there are two main reasons for grade capping which are: (1) there is a risk that the uncapped grade will overstate the average grade of the deposit, and that (2) the possibility of a risk to overstate the resource should be a good motivation to do grade capping. However, Kim et al. (2018) further caution that grade capping should not result in an undue reduction of estimated grade.

Different methods of determining the appropriate capping value have been developed in resource estimation. Nowak et al. (2013) discussed in detail the most common methods used in identifying the appropriate capping values which are, (a) probability plot, (b) decile analysis, (c) cutting curves, and (d) cutting statistics. Parrish (1997) introduced decile analysis which assesses the content of the metals in a decile. According to Parrish, if the top decile contains more than 40% of the metal or twice the metals contained in the 80 - 90% decile then capping must be done as there is more risk of overstating the resource. Otjikoto mine uses decile analysis to determine the appropriate capping value.

It is commonly agreed that applying top capping in a resource estimation could result in resource understating (Kim et al., 2018, Leuangthog & Nowak 2015, and Stegman 2001). Kim et al. (2018), argues against grade capping on grouped outliers as they could represent a high grade subdomain. They further argue that even though the isolated and clustered outliers may have the same grade value, their impact in the estimation may be different according to whether they are clustered outliers that are spatially connected or appear as single outliers that are surrounded by low grade areas, and they are not spatially connected. Instead, Kim et al. (2018) proposed a different capping method, which uses a 3D hot spot analysis which analyses the spatial relationship of outliers in space and determine whether the outliers are grouped or isolated before applying the capping. Kim et al. (2018) further argues that the top capping method has not yet been standardized, therefore it is subject to the analyst discretion.

4 METHODOLOGY

4.1 Introduction

This chapter describes the methods and analytical procedures employed in the study. The approach to the study was tackled in three stages. The first stage involved determining the study location within the Otjikoto deposit, this stage focused in finding an area with sufficient RC drillholes cover and known grade variances between the grade control model feed grade and the process plant head grade. The second part involved validating of the data and resource modelling of the two grade models. The final stage involved analyzing the results of the models into tables and graphs to enable better understanding of the models.

The study was focused on Otjikoto phase 2 south pit covering four benches (40 m) between elevation 1405 and 1455 (Fig. 4.1). The study location is located below the weathered zone, which ends at elevation 1465 in the mine area. There were 41827 reverse circulation (RC) gold assays used in the study, which were assayed by screen fire assays analysis method at the mine in-house laboratory (see section 4.5).

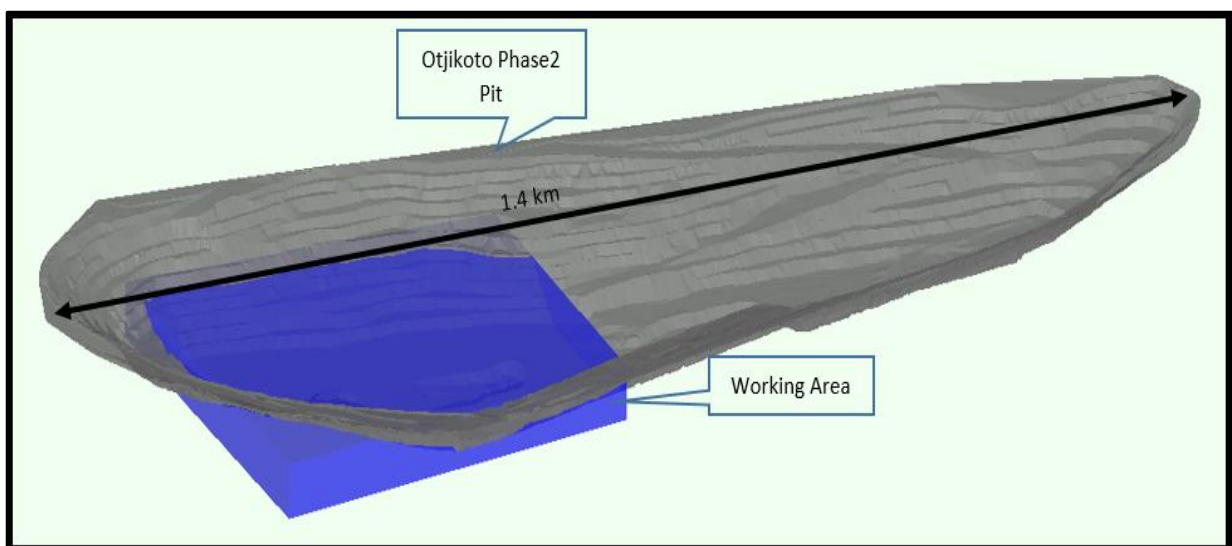


Figure 4-1: Otjikoto phase 2 pit May 2019 mined out surface and the study area.

The thesis is structured to outline the modelling process used in creation of the two models in section 4.6.

4.2 Data Collection

The study area has sufficient geochemical sample data, covered by 5062 RC drill holes (Fig 4.2). The drillholes data are managed in the sequel MStorque database readable in Minesight 3D modelling software. Only RC drill holes samples were used in the study.

Figure 4-2: Grade control RC drillholes in the study.

A 0.25 g/t Au grade was considered as the lower ore cutoff grade, which is the same cutoff as the mine low grade cutoff, the mine super-high grade lower cutoff of 1.80 g/t Au was used as lower cutoff for the high grade domains. Materials in the grade control database, and block model, are classified into grade material categories as shown in table 4.1 below.

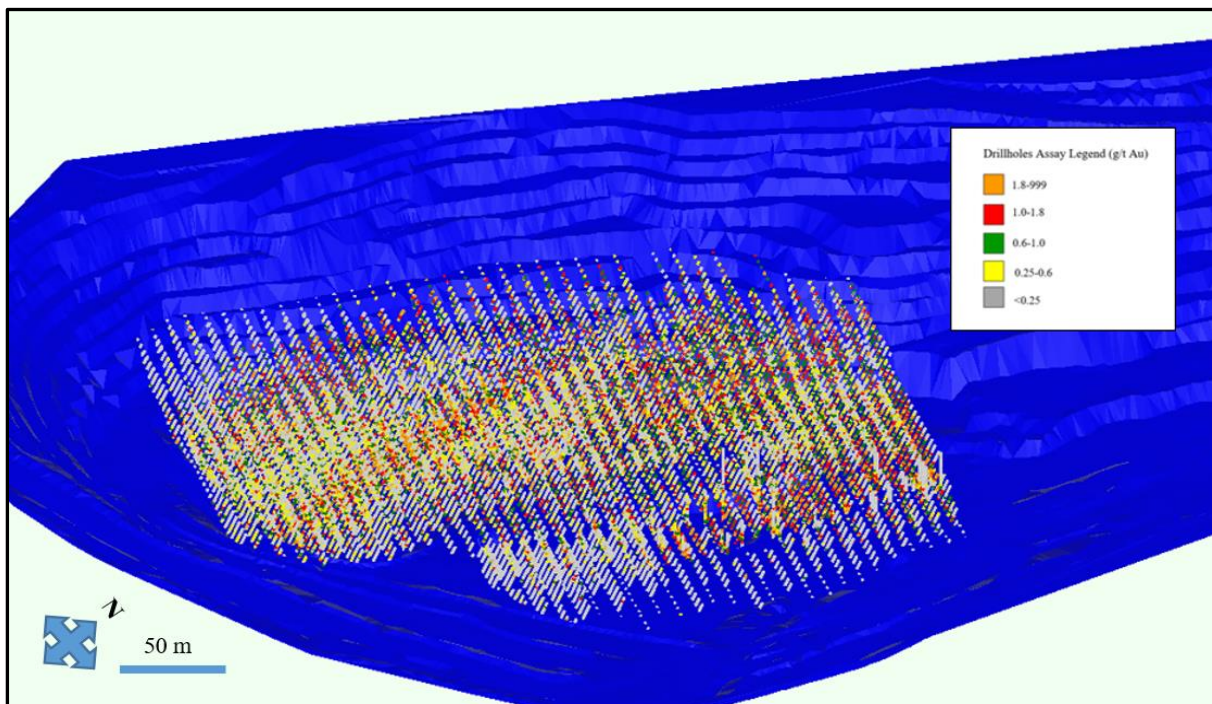


Table 4-1: Ore material grade classification at B2Gold Otjikoto mine.

Material	Color	Grade Range Au (g/t)
Low Grade (LG)	Yellow	0.25 – 0.60
Medium Grade (MG)	Green	0.60 – 1.00

High Grade (HG)	Red	1.00 – 1.80
Super High Grade (SHG)	Orange	1.80 – 999.00

4.3 Sampling Method

The Mine carries out reverse circulation (RC) drilling to obtain 2 m grade control samples. The holes are drilled at -60 ° toward azimuth 302 °. Drilling is ceased every 2 m to collect the sample, until a final drilling depth is achieved (26 m or 14 m per hole depending on the location of the holes).

The samples are collected and sent to the cyclone where they are homogenized and split into three samples A, B and C. Sample A is collected, labelled, and then send for gold assaying at the Mine laboratory, the B sample is collected to extract rock chips for lithological logging, and sample C is a discarded. Samples are weighted as a quality check to assess the distribution of the sample as it goes through the cyclone.

A regularized drilling grid pattern that covers the pits area is used to locate RC drill holes collars. Otjikoto pits use a 6 m x 12 m drill pattern to locate new RC drillholes for drilling (Fig. 4.3). The pattern has a longer spacing along the strike/plunging direction of the ore body where longer grade continuity is assumed and observed through variography analysis, and a shorter drill hole spacing across the ore body where a greater grade variation is observed.

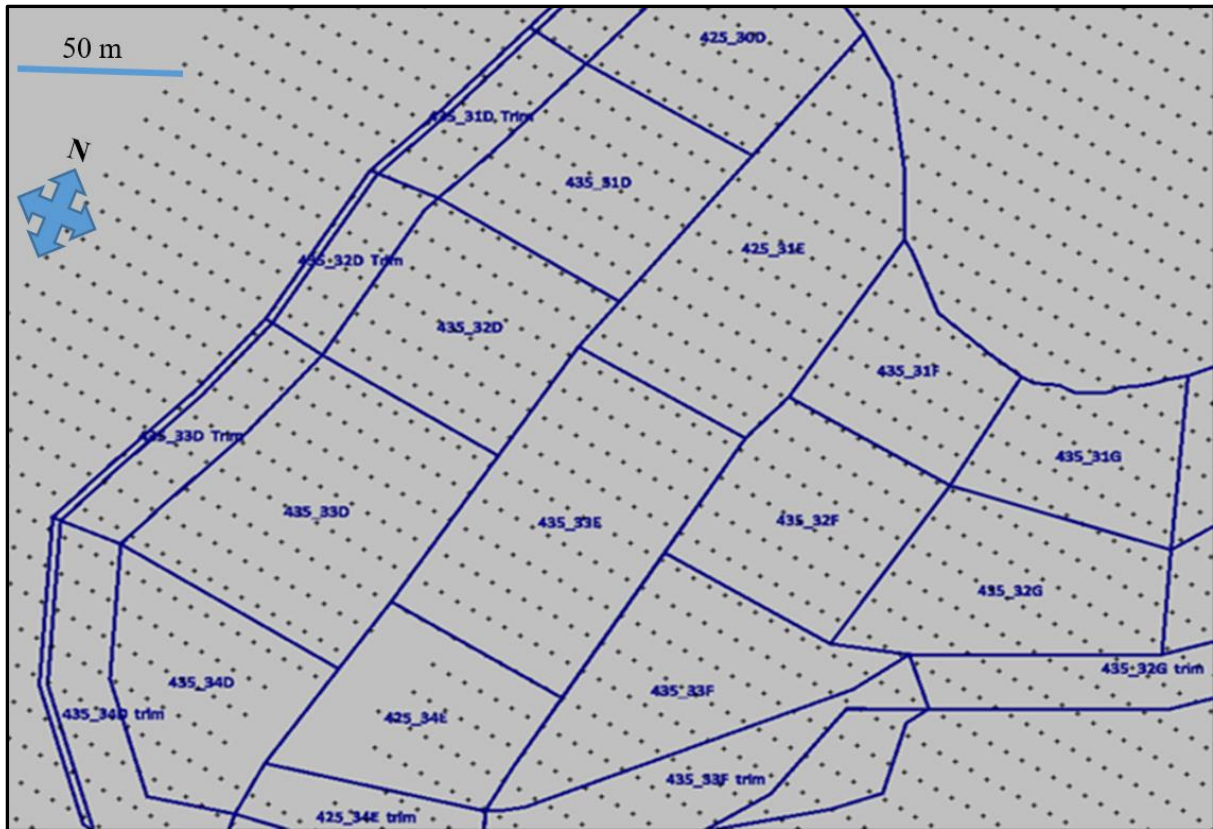


Figure 4-3: Regularized drill grid pattern covering Otjikoto phase2 pit, with mining block boundaries, all blocks in the picture are within the study area.

4.4 Sampling Quality Control - Quality Assurance (QAQC)

QAQC checks are employed during the sampling process to ensure that quality is maintained throughout the sampling process. The drilling bit diameter is consistently measured to ensure that the drill bit used is not worn out which could impact the sample support, as a reduction in the sample collected would result in an increased variance (Goovaerts, 2016). The drilling dip angle is constantly measured with a clinometer to ensure drilling is carried out at the right inclination and drilling alignment lines are drawn parallel to the drillhole collars to ensure that the drill rig is positioned and is drilling in the desired azimuth direction. Mine surveyors are tasked with staking out the drill collars in the field and picking-up the as-drilled positions in the field. The cyclone is cleaned after every sample to minimize the impact of sample contamination.

4.5 Analytical Methods

Reverse circulation samples are analysed at B2Gold Otjikoto Mine in-house laboratory. The samples received at the laboratory are reconciled with the samples submission list. Deviations, leaking samples, samples without labels and or missing samples are reported to the geology department.

Approximately 70% of Otjikoto ore body gold occurs as coarse free gold, 70% of the gold in the deposit get recovered through gravity circuit, and therefore a screen fire assay method is used for gold assay analysis at the Mine to determine grade distribution at different coarse fractions.

The moisture content of the samples is visually inspected at the laboratory. When excessive high moisture content is observed, the samples are dried prior to screening, crushing, and splitting. Samples with low moisture content are screened, crushed, and split without drying.

Pulverized samples are weighed and mixed with fluxing agents which helps in the melting and fusion of the sample at a specific temperature. The method uses high temperature and flux to melt the rock and allow gold to be collected. At high temperatures, the gauge minerals and the flux are melted to a liquid form and the liberated metals are collected at the base of the fusion crucibles. The collected metals are then dissolved in hydrochloric or in nitric acid and the concentration is determined by means of atomic absorption spectroscopy.

QAQC samples were sent to the laboratory to measure the performance of the laboratory. The study area was drilled and mined between 2017 and 2019, the QAQC performance charts for that period are found in the appendices. One blank and one standard sample was included in every batch of 40 samples to be send for assaying. Any single failure by a standard or a blank sample will the whole batch to be re-assayed.

4.6 Resource Modelling

This section describes the methods and steps taken in populating the two gold grade block models, which employed the two different methods of dealing with high grade outliers in resource estimation, namely the HGC method and the HGD method.

4.6.1 Modelling Flow Chart

Figure 4.4 shows the resource modelling flow chart with the steps used in the study.

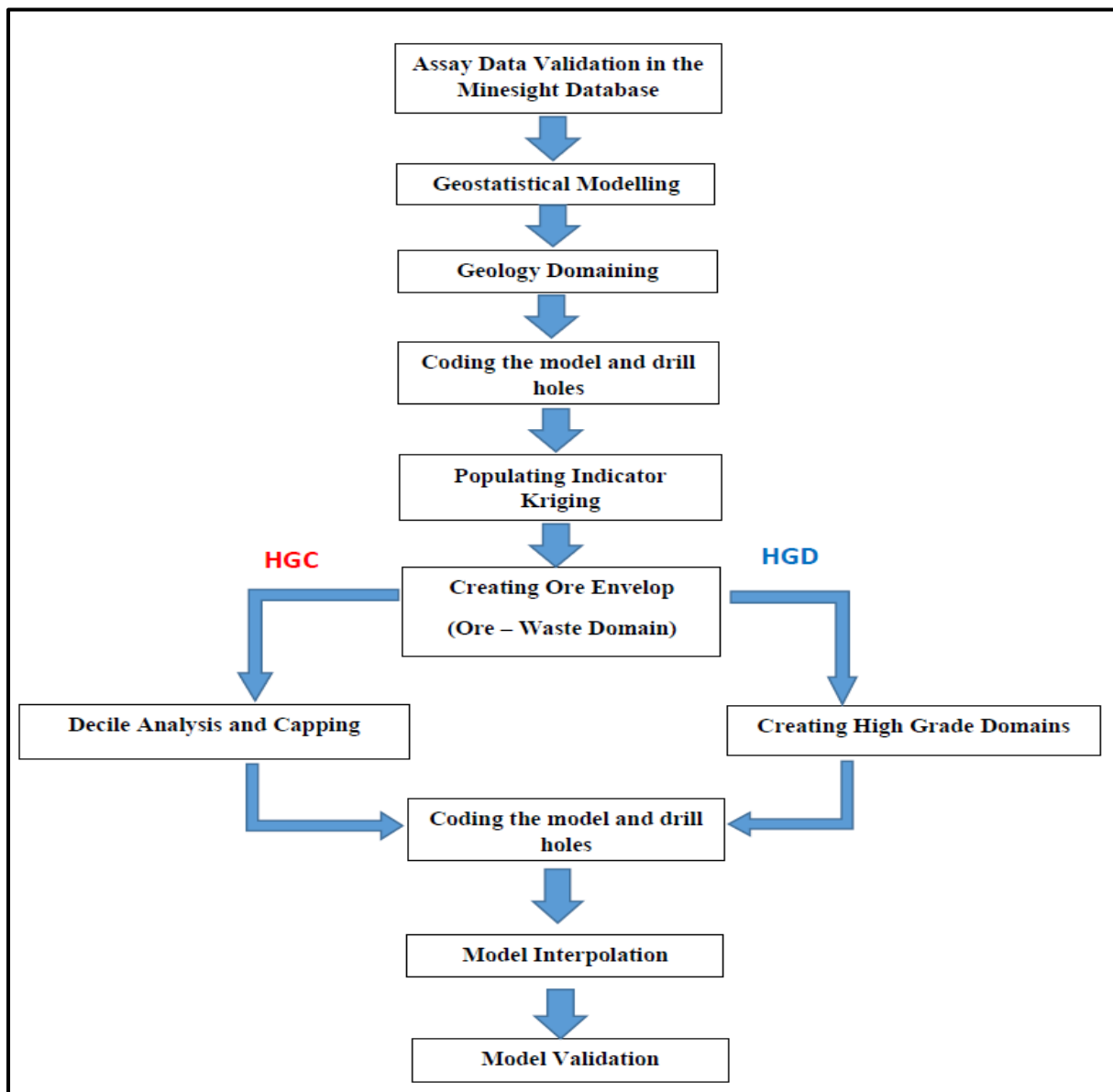


Figure 4-4: Project modelling flow chart.

4.6.2 Data Validation

Data validation is a very important stage in resource modelling and it should be the first stage in any resource estimation. Data validation enables mapping out database errors which could be wrongly included in a resource estimation and thus negatively influencing the outputs of the estimation. It does not matter how experienced the modelling geologist is, if the input data are wrong or full of errors, estimates will be wrong. The resource model can only be as good as the input data. Therefore, data validation is a crucial stage in resource modelling to ensure that a reliable resource model is produced. The data in the study area were analyzed for the following errors;

- duplication of collar data,
- missing collars,
- erroneous entry of drill hole attributes such as depth, and drill holes dipping in abnormal directions.

There were no errors found in the data during the data validation stage.

4.6.3 Processes Done for Both Models (HGC and HGD)

Geology Domaining

There are two main geological domains in Otjikoto deposit, whereby gold mineralization shows different geostatistical parameters and different variography. AM1 marker is an albitite layer unit approximately 20 m thick. The AM1 unit marks the boundary between the two domains. The domain 1 being everything above the AM1 marker and the domain 2 being everything below the top of the AM1 unit.

Gold mineralization distribution behaves differently either side of the AM1 unit, and therefore, estimation parameters are different for the gold grade estimates either side of the AM1 unit. Field observations shows that there is more and bigger fold structures below the AM1 marker

compared to above it. The gold mineralization can also be traced over a longer distance below the AM1 than above it. Therefore, it is important to code the drills holes assays and the block model cells with their respective geology domain in which they belong, to ensure that correct assay intersections are used to populate grade estimates for block cells in a specific geology domain. The geology domains were created for the study and were coded to their respective drill holes data and block model cells in preparation for the resource estimation.

Geostatistical Sectors

The Otjikoto Mine grade control geologists have divided the deposit into three geostatistical sectors (Fig. 4.5). Each sector displays different estimation and variography parameters from the other sectors. The estimation parameters of each sector were modelled using a combination of exploration diamond drill holes assays, exploration RC drill holes assays, and grade control RC drill holes assays data, using a SAGE2001 geostatistical modelling software.

The geostatistical attributes for the study were evaluated and found to be similar with the Mine geostatistical parameters for sector 2. The study thus used the Mine geostastictic parameters for sector 2 in the resource estimations, as they were formulated from more widespread data than the study area data.

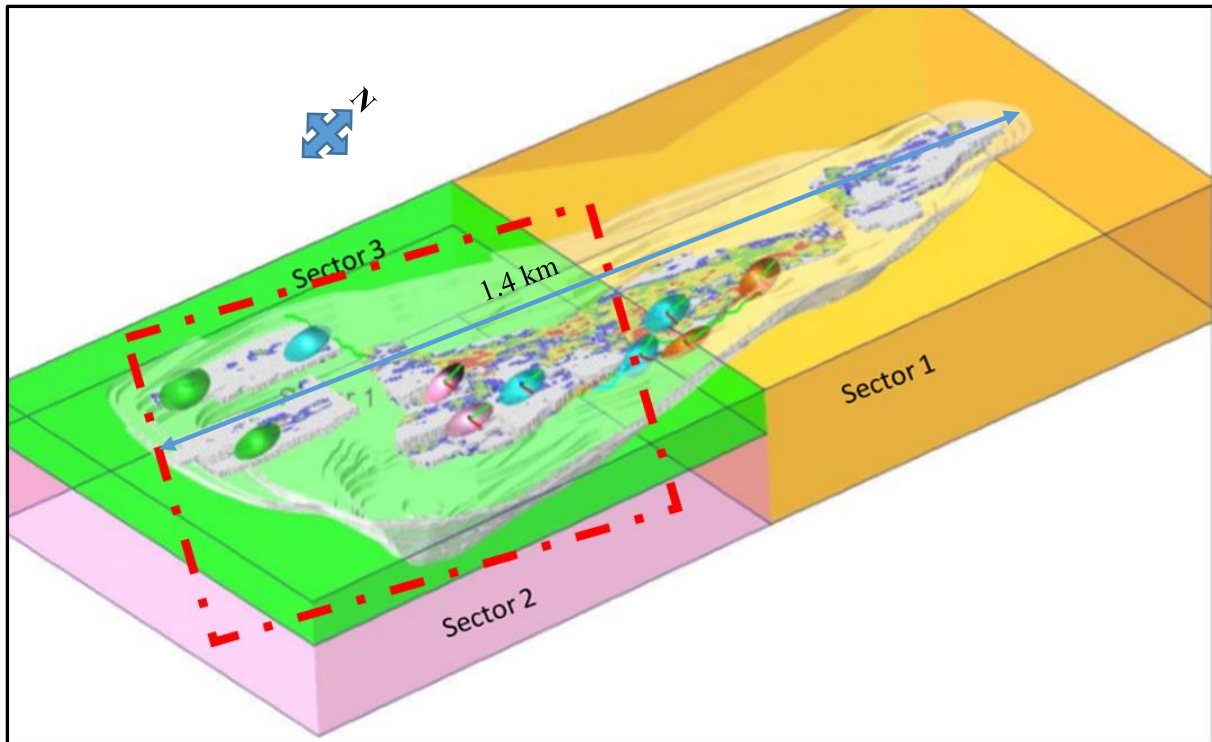


Figure 4-5: B2Gold Otjikoto phase2 pit grade control modelling geostatistical sectors and the associated search ellipsoids. The study area falls within the red polygon.

B2Gold Sector 2 Variography

This section describes the estimation and variography parameters employed in the study. The variography information for the mine grade control system were used for the study. The downhole variogram were used to determine sector 2 nugget effect, and the directional spherical variograms were calculated to establish the relationship of the grade distributions of the ore body in Sector 2.

Downhole Variogram

The downhole variograms defines the relationship/ correlation between two close samples, by calculating the variance between the two samples, it is a measure of how related are two closely spaced samples. The measure of the variance between two close related samples yield the nugget effect value between them, which is the measure of variance between the two samples separated by the minimum distance (Dominy et al., 2003). The higher the nugget effect, the more variable the grade distribution is in the ore body (Dominy and Annels, 2001). Vein

deposits could be associated with a higher nugget effect due to high variance of grades across the units as the veins changes across the unit (Dominy et al., 2003).

Directional Variograms

Directional variograms are very important in defining the direction of best continuity/correlation for a group of data. During geostatistical analysis of the data, different search directions were modelled until the direction with the best continuity was obtained. The orebody shows an anisotropic behavior. A combination of geostatistical analysis, and a good understanding of the geology of the ore body such as dip direction, plunge direction, veins orientation, and dip angle, were vital in obtaining the best direction of continuity during directional variogram modelling.

Ore Envelope

The ore envelope defines the ore-waste boundary based on ore grade cutoff of 0.25 g/t Au. The process of constructing the ore envelope started off with running the indicator kriging of the study area. The indicator kriging is used at B2Gold Otjikoto Mine to populate probability values which are used to define the possibility of a particular block model cell to be enclosed within the mineralization zone. The indicator kriging used the ore body geostatistical parameters for sector 2, and drill holes assays to populate indicator values. A block model cell with a 100% chance of being within the mineralization shoot populated an indicator value of 1 and a block model cell with a 0% chance of being within the ore shoot has an indicator value of 0.

The ore envelope allows for gold estimations to occur within the mineralized areas without grades smearing into waste areas, and also ensure that estimation inside the waste areas are not smeared into the mineralized areas, which could result in undue reduction in the estimated grades. The ore envelope is basically a waste-ore domain which separates the ore and waste

areas. The drillholes intersections and block model are coded with the ore envelope to indicate which drill holes assay samples to use to populate grades for block cells within the ore envelop.

Polygons were digitized manually in Minesight software around the block cells with indicator value of at least 0.30 (30%) probability. The sections were then linked together to form 3D gold shell wireframes. The gold shell wireframes were coded to the drill holes and to the block model under attribute “gold envelope” to indicate which drill holes data to use when estimating grades for the block cells within the ore envelop.

There is an advantage in using the indicator kriging in digitizing the ore envelope as opposed to manual digitizing around the ore intersections on the drill holes. Indicator kriging is based on 3-dimensional analysis of data using the ore body geostatistical parameters as opposed to manual sectional digitizing which is only based on a single drill holes section view.

4.6.4 Processes for the HGC Method

High Grade Capping

The ore envelope solid was coded to the drill holes to mark the samples which are contained within the mineralized area. High grade outliers are found within the mineralized zones, therefore, only those samples within the ore envelope were used for grade capping analysis.

The assays were exported from the MStorque database, and were analyzed for a HGC value through decile analysis. The samples were filtered using the ore envelope code to ensure that only the samples from the study area, and within the ore envelope were included in the analysis. Samples were then copied to the decile analysis excel sheet which assesses the recommended capping value (Table 5.3) as according to Parrish (1997). There were 21514 samples used in the decile analysis for the high grade capping value.

4.6.5 Processes for HGD Method

High Grade Domaining

HGD Polygons were digitized across the drill holes sections in the study area. Polygons were only digitized across drill holes sections which have (1) gold grade values of at least 1.8 g/t and (2) have enclosing gold grades with grades larger than the determined capping value of 8.3 g/t. High grade polygons were joined to form high grade domain wireframes. High grade domain solids were validated prior to coding to ensure there are no open ends, intersecting triangles, and cross intersections, which could cause errors during the coding stage. HGD solids were coded to the drill holes to indicate the samples which will be used for interpolation within the high-grade domain areas. The high grade domain areas were also coded to the block model. A total of 1330 samples were found enclosed in the high grade domains.

Internal dilution (inclusion of grades with gold grades less than 1.8 g/t Au) was included to make domains polygons larger enough to be joined into high grade domain solids, and where the lower grade values are enclosed by the outlier values. A 1.8 g/t Au cutoff is the Mine super high-grade ore cutoff, and it was also used for the high grade domain cutoff for the study.

4.6.6 Gold Grade Interpolation

Two ordinary kriging block models were populated using sector 2 geostatistic parameters in Minesight modelling software. The 2 m composites were populated on the assays in the MStorque database. Although the samples are collected at 2 meters intervals, meaning the 2 meters composites have same values as the sample assays, compositing was done entirely due to the Minesight software requiring composites to be populated before the interpolation.

During grade estimation for the HGC block model, outliers were capped to 8.3 g/t, determined by decile analysis, which means that all the values above 8.3 g/t were assigned a value of 8.3 g/t in the estimation. Grade estimates for a given block cell within an ore envelope and a given geological domain only used the assays which falls within those conditions. Estimates were run for both areas inside and outside the gold envelop.

During grade estimation for the HGD block model, the outliers were left uncapped in the estimations, which means their true values were used in the population of grade estimates, however, their influence in grade estimations were confined to their respective high-grade domains. Thus, apart from the ore envelope domain, and geological domains, high grade domains were also applied as a support for the estimations of given block cell grade.

4.6.7 Model Validation

Model validation is very crucial in order to build confidence in the modelled results. There are many ways of validating a resource block model, such as the panel traversing method proposed by Kim et al. (2018). Chanderman et al. (2017) propose that a simple graphical visualization inspection of the drill holes against the model correspondence can be used for a resource model validation.

The study used a visual inspection of the drill holes correspondence against the block model grade estimates. The validation method looked at comparing the drill holes gold intersections against the nearby or surrounding block model estimated grades (Fig. 4.6). Section checks for grade versus drillholes intersection were carried out throughout the study area after every 12 meters a. A good drill holes intersection against block estimates correspondence was generally observed throughout. The validation method was done on both the HGC and the HGD models.

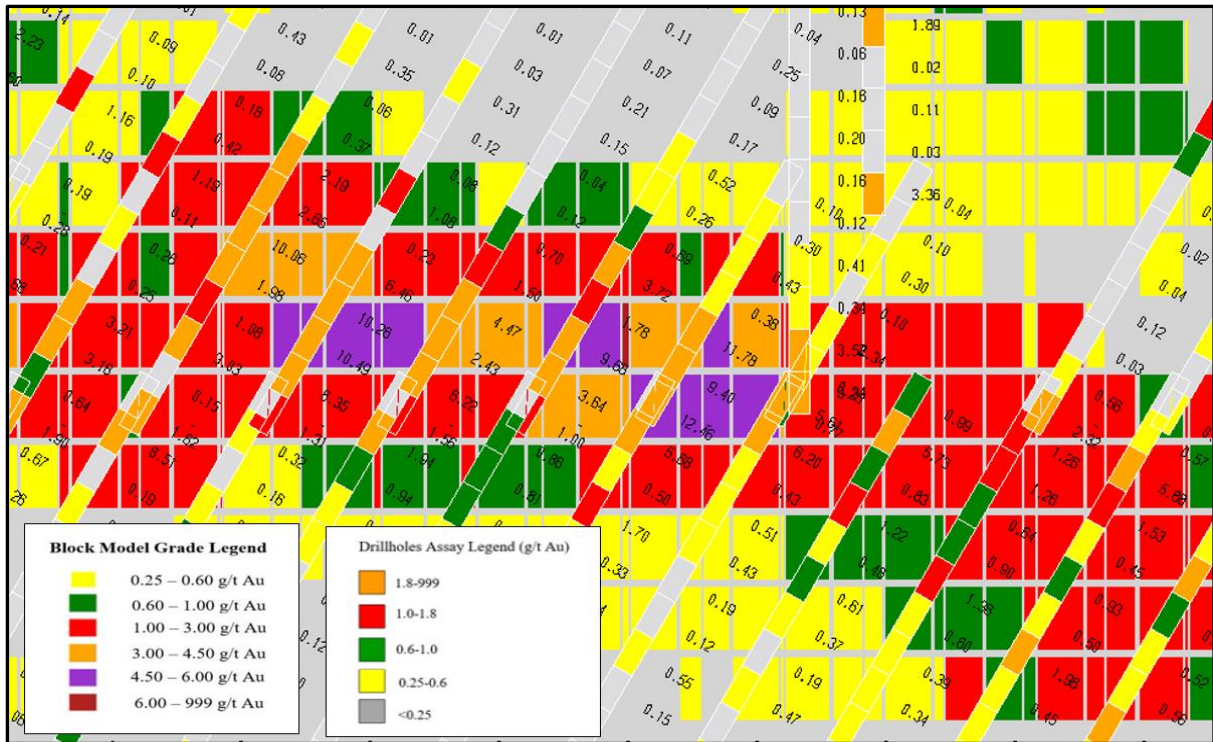


Figure 4-6: Drill holes intersections with grade intersections and the block model grade estimates for the model drill holes correspondence validation.

Block Model

The mine uses an equal cells block model; which means all block model cells have equal dimensions (Fig. 4.7). The block model cells sizes are X = 2m, Y = 2m, Z = 3.33. Block cells cut by two domains are assigned combined grades proportional to their portions in the given domains.

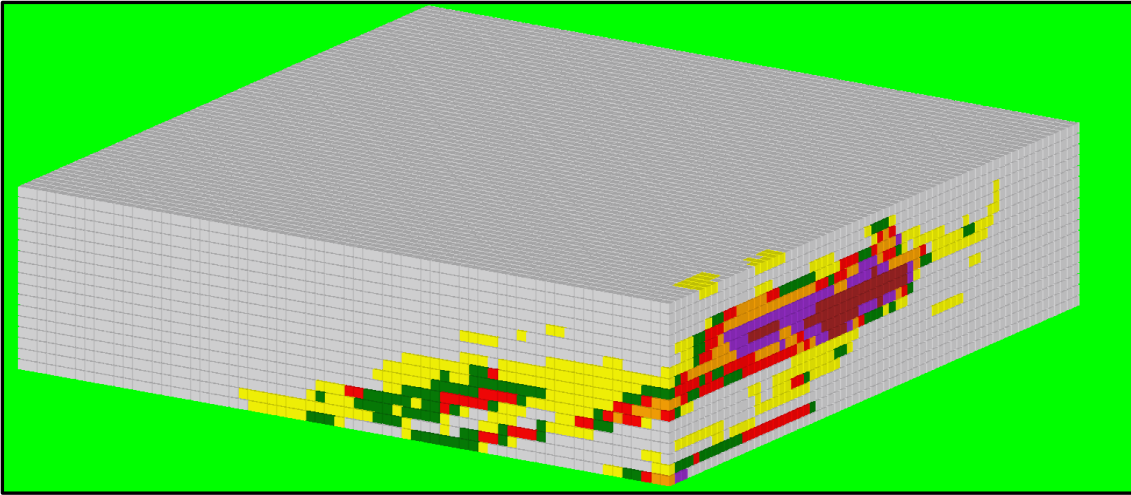


Figure 4-7: Otjikoto mine equal cells block model, block model cells are 2 m in x direction, 2 m in y direction and 3.33 m in z direction.

5 RESULTS AND INTERPRETATION

5.1 Introduction

This chapter presents the findings of the study. The results includes the findings from the raw assay data analysis, grade and tonnage figures from the two ordinary kriging gold grade block models. The results are presented in tables, graphs and images, with the main aim of highlighting the variances between the two methods of dealing with gold grade outliers in resource estimation.

5.2 Data

Drill holes assay data in the study area were analyzed for basic statistics, the results are shown in Table 5.1.

Table 5-1: Statistical measures of drill holes gold assay data in the study area.

<i>Universe Descriptive Statistics</i>	
Mean	0.74
Standard Error	0.01
Median	0.21
Mode	0.00
Standard Deviation	2.08
Sample Variance	4.35
Kurtosis	584.72
Skewness	16.50
Range	114.21
Minimum	0.00
Maximum	114.21
Sum	31105.23
Count	41827

The raw assay data histogram plot indicates an exponential distribution of the data, showing more data skewed toward the lower grade values (Fig. 5.1)

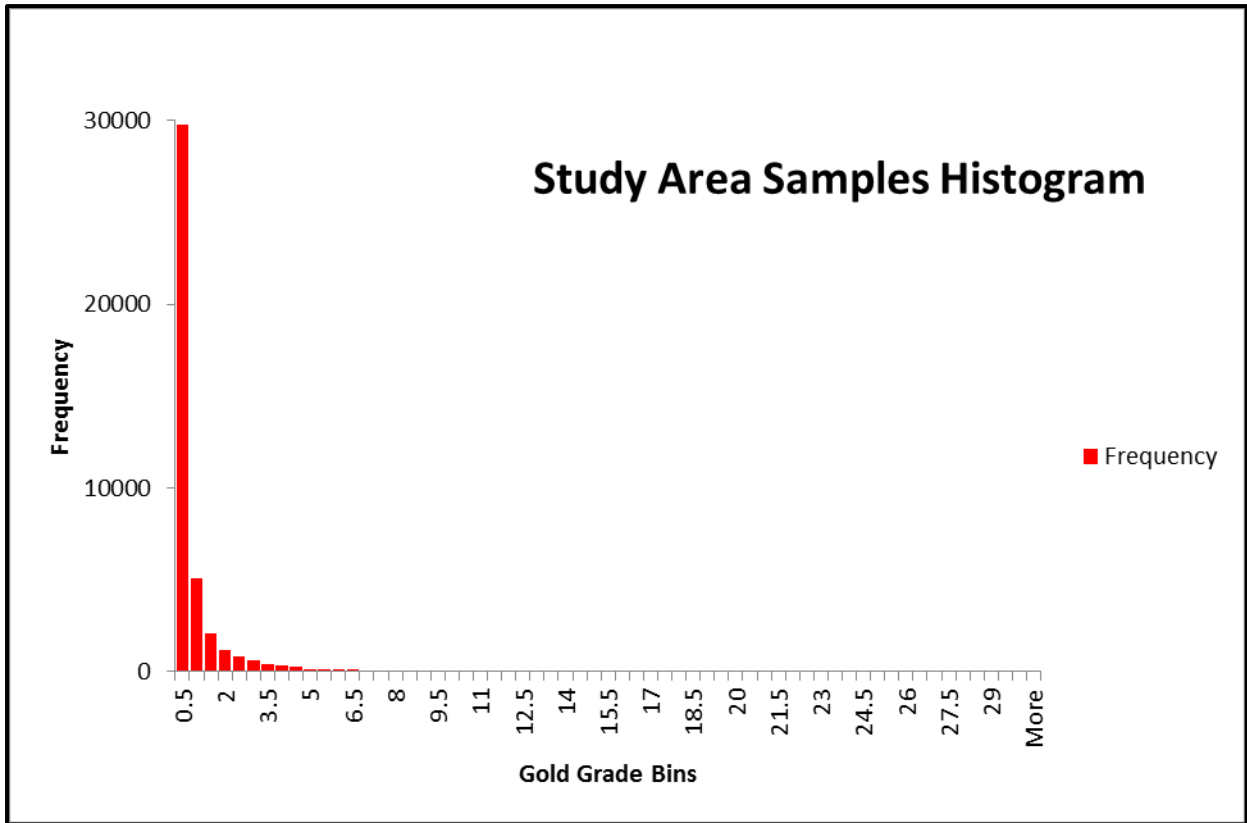


Figure 5-1: Study area gold assay samples histogram plot, showing exponential distribution of the data, with more data concentrated at lower grades bins compared to high grade bins.

Histogram plot of raw assay data indicates a skewed distribution of data. Data are skewed toward the lower grade assays. Furthermore, histogram analysis of the data indicates the presence of different data populations at higher grade assays in the study area (Fig. 5.2). The plot shows a big population which consist most of the data with the first break in the histogram appearing after 20.5 g/t cutoff. The histogram displays good continuity at low grade values and a highly variable distribution at high grade assay values, which could signify the wide range of grade distribution and populations within the ore body.

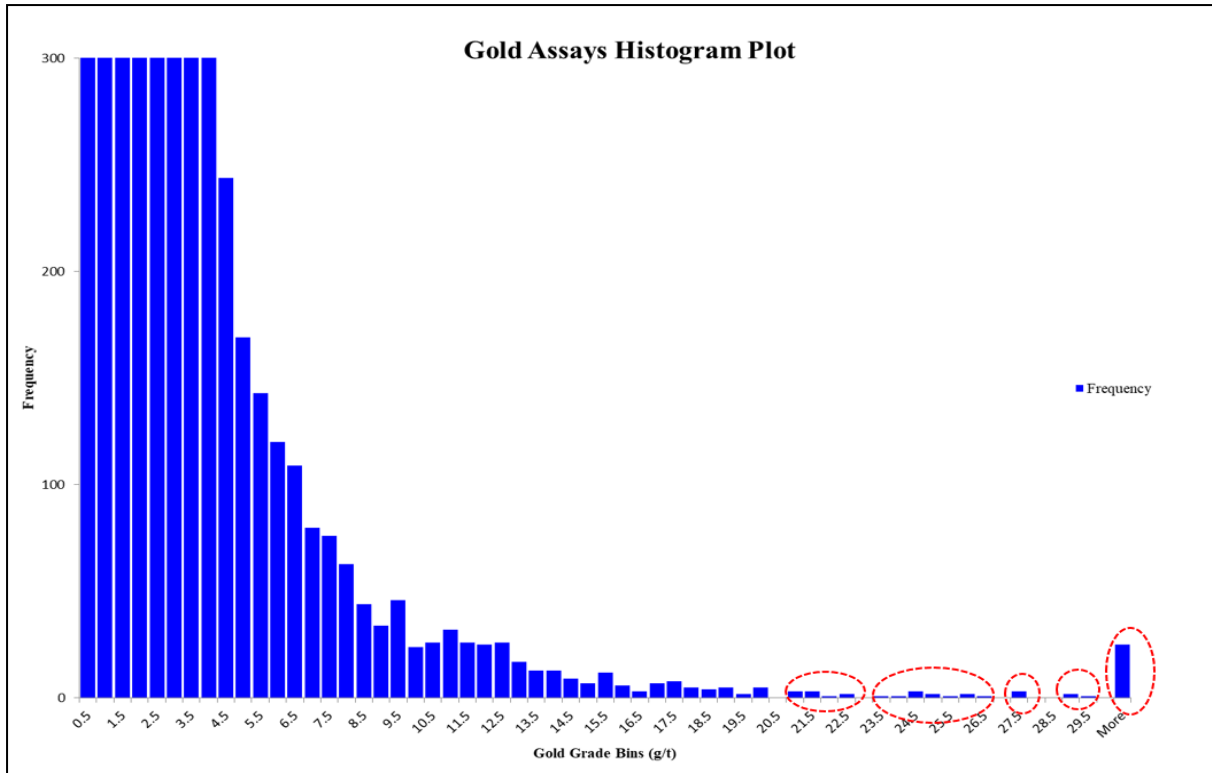


Figure 5-2: Histogram plot of the assay data showing different data populations circled in red in the data.

5.3 Geology Domaining

Figure 5-3 shows the two geology domains used in the study.

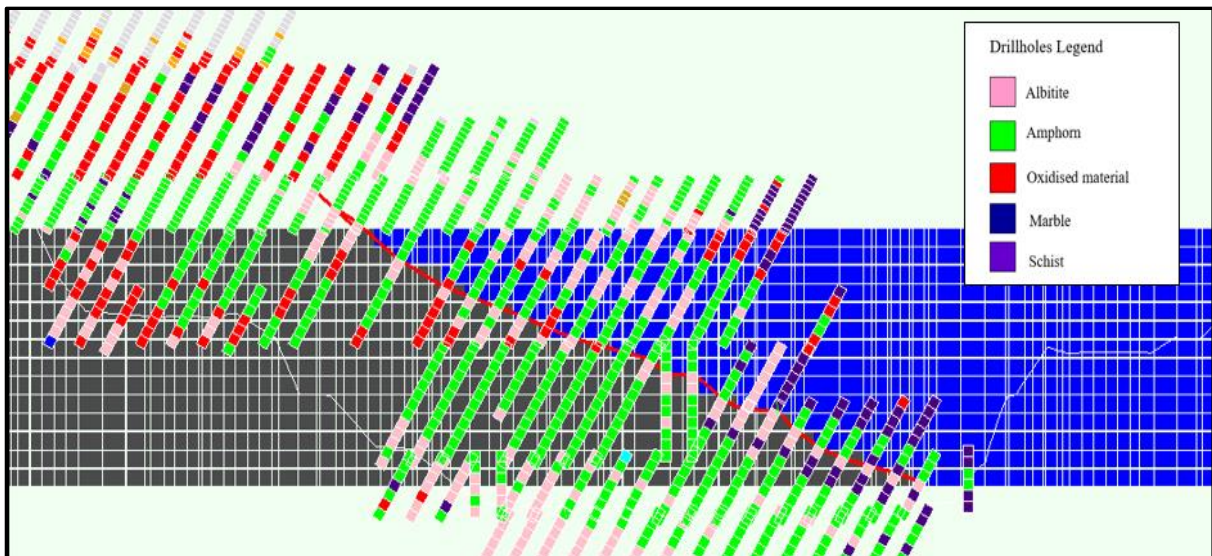


Figure 5-3: RC grade control drill holes displaying lithology, and the grade block model displaying the coded domains: with blue being domain 1, black being domain 2. The red polyline indicating the top of the AMI unit.

5.4 Variograms

Downhole variogram analysis for the samples in the study area gave a high nugget value of gamma 0.642 (Fig. 5.4), which means there is a possibility of 64% variance between two closely spaced samples separated by lag distance 0. The high nugget value indicates the high variance in the nature of vein type ore at B2Gold Otjikoto Mine, making it very challenging in grade modelling and during metal accounting between the mined grade and the processed grade.

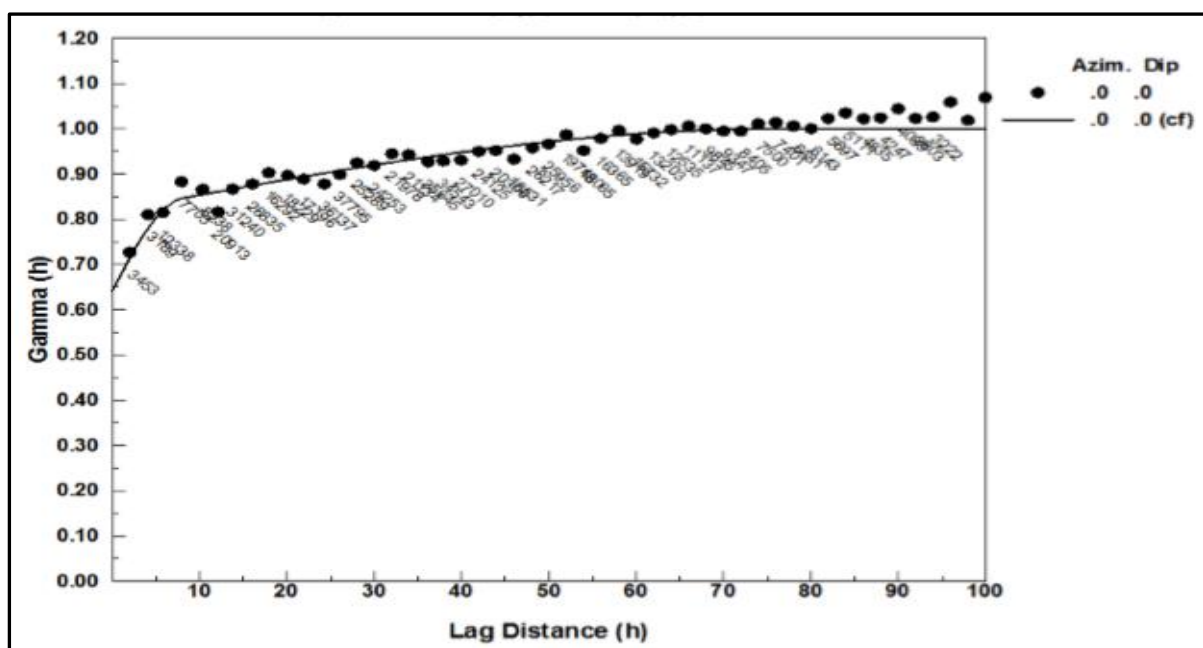


Figure 5-4: Downhole correlogram of sector 2 showing a very nuggetty Otjikoto ore body with a nugget value of 0.642 gamma.

Variogram calculations and the understanding of the geology of the orebody have mapped out azimuth 200 ° at -15 ° dip as the direction of the best continuity of mineralization for the ore body in the study area, with the range of 40 meters in domain 1 and up to 70 meters in domain 2 (Fig. 5.5 and Fig. 5.6). The search distance factors were obtained at 0.9 gamma, 90%, and normalized with the longest search distance to obtain accurate search distances in the three directions. The variogram calculations for both domain 1 and domain 2 have shown an

anisotropic variogram output, meaning there is a preferred direction of continuity. The direction of most continuity was found to be parallel to the ore body plunge direction.

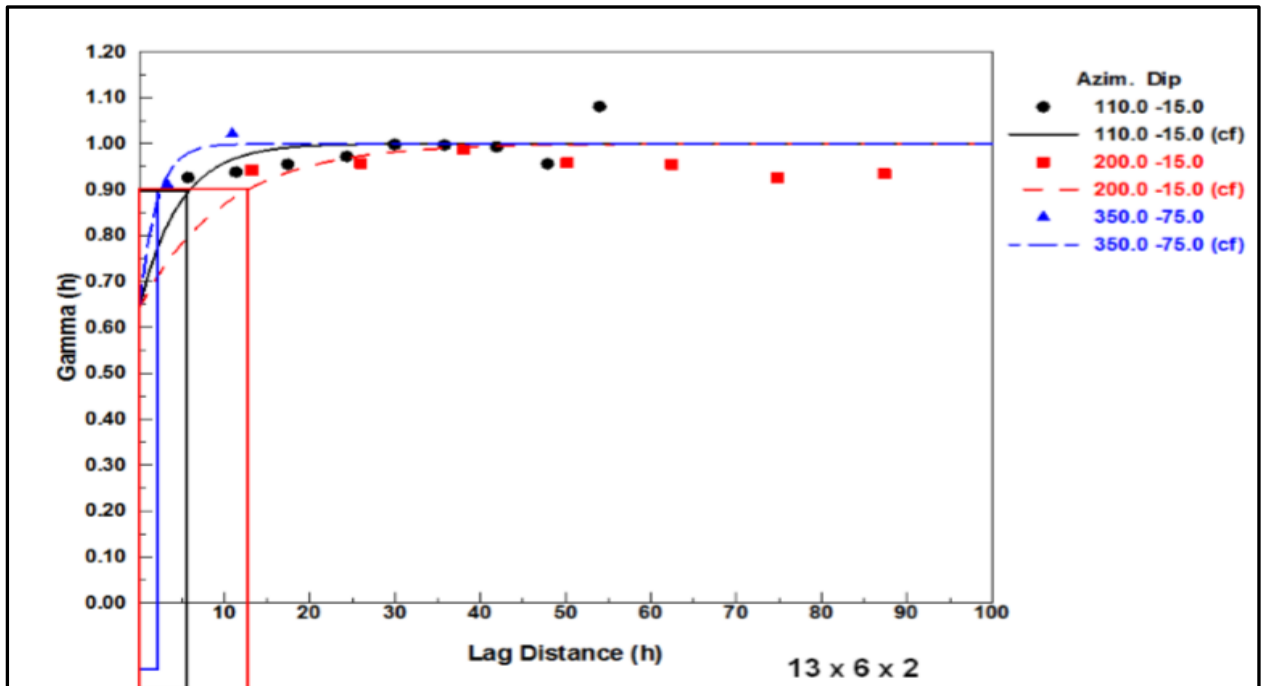


Figure 5-5: Directional variograms for sector2 Domain 1 with search distance factors at gamma 90%.

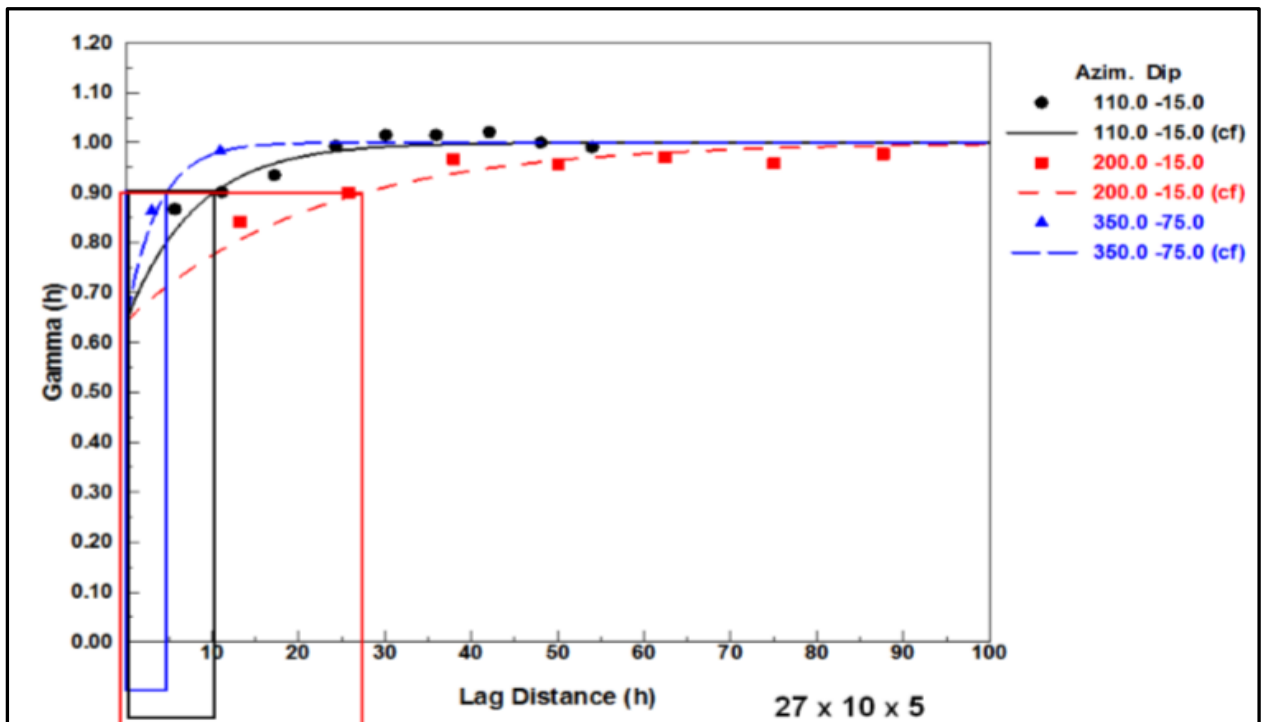


Figure 5-6: Sector 2 domain 2 directional variograms, with search distance factors at gamma 90%.

Sector 2 shows good continuity in both domains in azimuth direction 200° at dip of -15°, however, different search ellipsoid parameters in Domain 1 and Domain 2 were observed (Table 5.2).

Table 5-2: Sector 2 Variography Parameters.

Domain	Description	Nugget	Major Range	Minor Range	Vertical Range
1	Above AM1 Marker	0.642	38 m	15 m	6 m
2	Below AM1 Marker	0.642	74 m	23 m	12 m

5.5 Indicator Kriging

Indicator kriging was used to populate probability values which gives the probability of a block model cell being included in the gold envelop. The gold envelope polygons were digitized around the block model cells with indicator kriging value of at least 0.30 (30% chance), (Fig. 5.7).

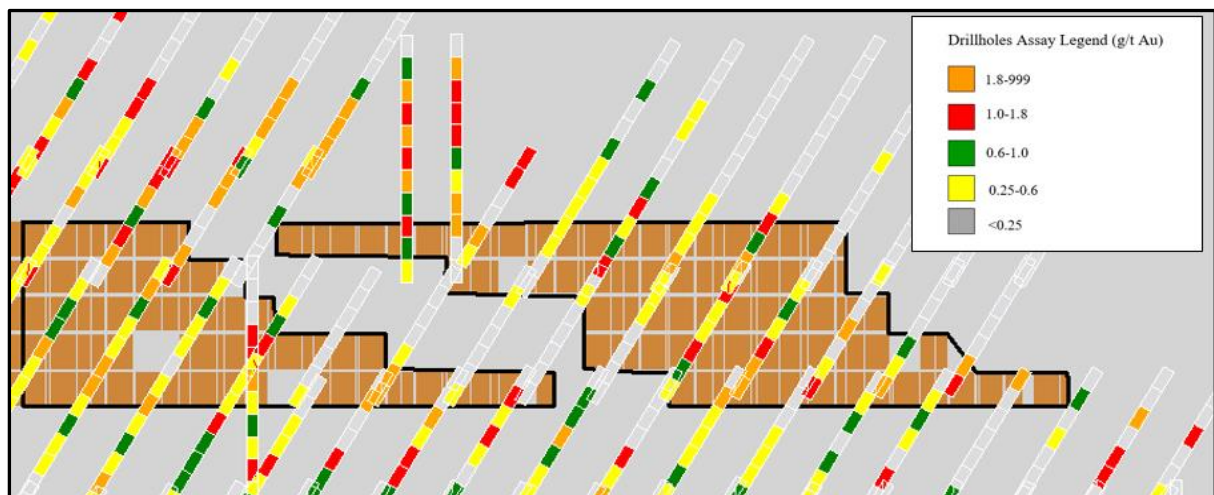


Figure 5-7: The Ore envelope polygons digitized around the block model cells with indicator values above 0.30, the block model cells with indicator values above 0.30 shows block model cells which are likely to be in the ore envelop.

5.6 High Grade Capping

The samples range in grade from 0.20 g/t to 114.21 g/t. The decile analysis obtained a capping value of 8.3 g/t Au, Table 5.3. That means all the grades above 8.3 g/t were assigned a default

value of 8.3 g/t Au in the estimation. 422 samples were found to have a gold value larger than the determined capping value, making it only 2 % of the data to be classified as high grade outliers in the study area.

Table 5-3: Decile analysis for the study area sample assays to determining the high grade capping value, and the conditions for capping.

Project Title:		Study Area				
Decile Analysis (Parrish, 1997)			Run Desc: Inside ENVE			
Decile	Count	Average	Min	Max	Metal	%Total
0 - 10	2143	0.223	0.20	0.24	4.0180	0.4%
10 - 20	2151	0.272	0.24	0.30	4.3450	0.5%
20 - 30	2159	0.337	0.30	0.37	5.3870	0.6%
30 - 40	2144	0.409	0.37	0.46	9.8270	1.0%
40 - 50	2152	0.516	0.46	0.58	14.9650	1.6%
50 - 60	2149	0.645	0.58	0.78	18.6940	2.0%
60 - 70	2155	0.932	0.78	1.10	50.3330	5.4%
70 - 80	2153	1.366	1.10	1.72	81.9830	8.7%
80 - 90	2151	2.295	1.72	3.09	160.6190	17.1%
90 - 100	2157	6.206	3.09	114.21	589.5950	62.7%
90 - 91	218	3.200	3.09	3.35	35.1980	3.7%
91 - 92	218	3.484	3.35	3.60	31.3530	3.3%
92 - 93	216	3.752	3.60	3.92	30.0120	3.2%
93 - 94	214	4.100	3.92	4.31	32.8010	3.5%
94 - 95	219	4.505	4.31	4.85	58.5650	6.2%
95 - 96	216	5.241	4.85	5.61	94.3460	10.0%
96 - 97	216	6.139	5.61	6.63	49.1090	5.2%
97 - 98	106	7.027	6.63	7.28	35.1340	3.7%
98 - 99	121	7.994	7.28	8.30	15.9880	1.7%
99 - 100	422	15.031	8.30	114.21	210.4400	22.4%
Capping Result						
Condition A:	TRUE	<i>Top decile contains > 40% of the total metal in deposit</i>				
Condition B:	TRUE	<i>Top decile contains 2X metal of next decile</i>				
Condition C:	TRUE	<i>Top percentile contains >10% of the total metal</i>				
Condition D:	FALSE	<i>Top and next percentile each contain >10% of the total metal</i>				
Indicated Cap Value:		8.3	g/t			

5.7 High Grade Domaining

Figure 5.8 shows the digitized high grade polygons and figure 5.9 shows the high grade domains in the study area.

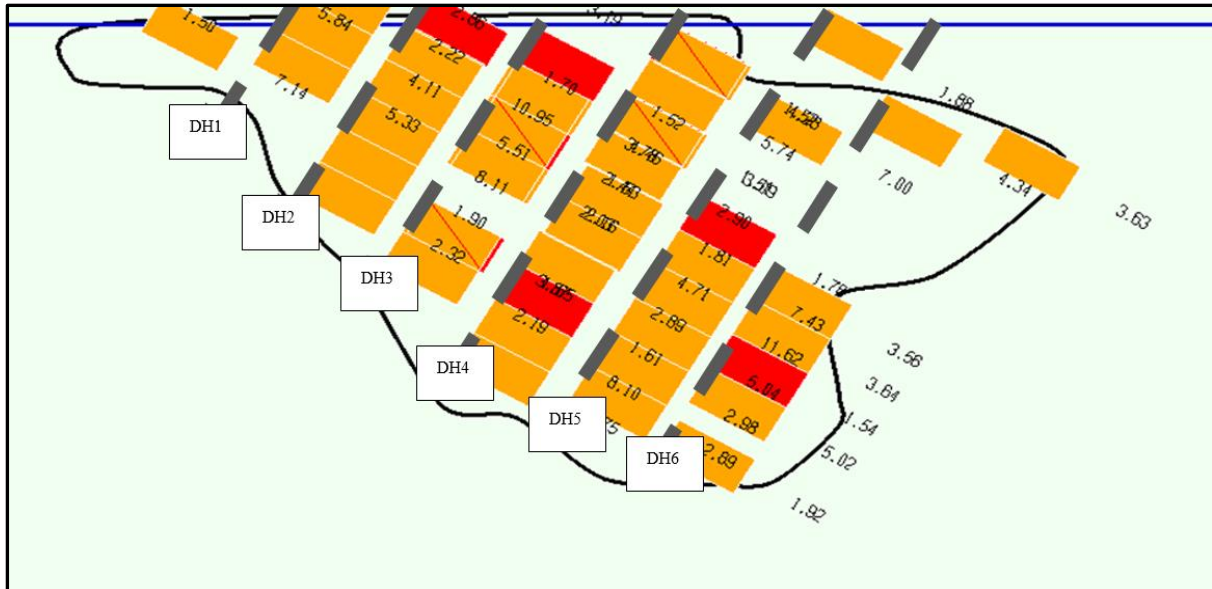


Figure 5-8: High grade domain polygon digitised around high-grade gold values along a section of drilled RC grade control holes with gold intersections.

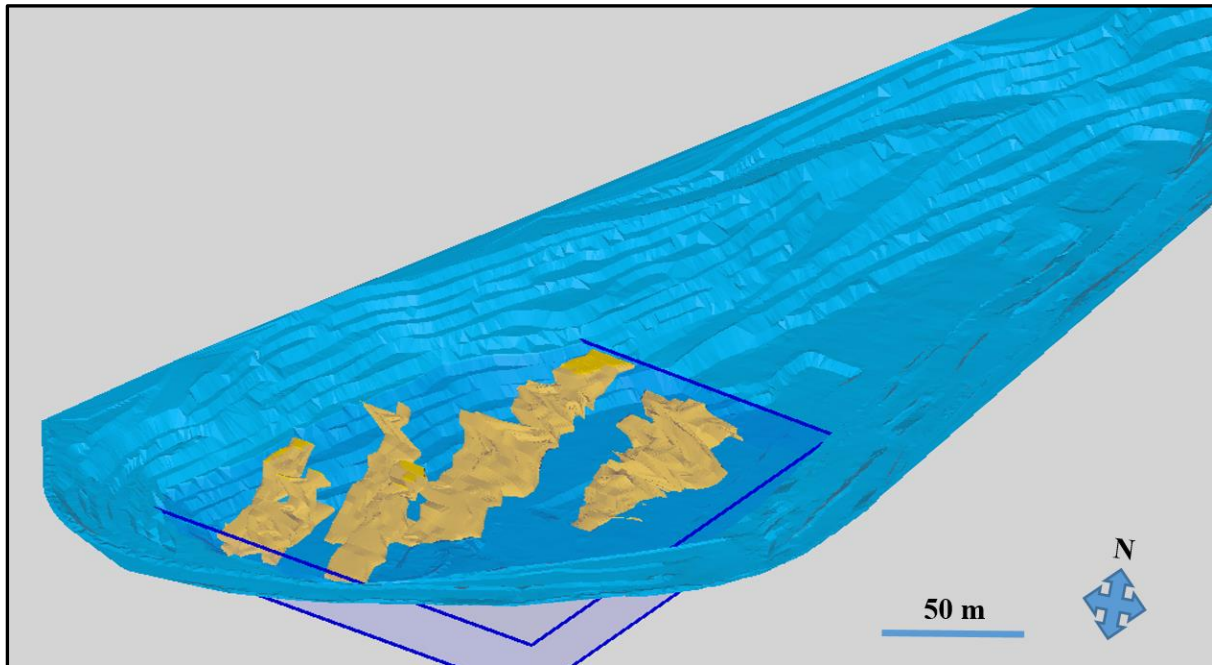


Figure 5-9: explicit modelled high grade domains in the study area.

5.8 Grade Block Models Figures

Two ordinary kriging block models were successfully populated for the study using Minesight 3D modelling software. The HGC model was populated by employing the HGC method to deal with gold grade outliers, whereby grade outliers were capped to the decile analysis capping value of 8.3 g/t Au. The HGD model employed the HGD method of dealing with high grade outliers in resource estimation, where outliers left uncapped in the estimation, however, their influence was confined to their respective high grade domains.

The grades and the tonnage variations between the HGC and HGD models at different cutoff grades are summarized in Table 5.4. Material below the mine economic cutoff grade (waste) were excluded from the table. The table shows a 3% increase in the overall grade of the HGD model ore compared to the overall grade of the HGC model ore material, however, the overall tonnage remains similar in the two models.

The ore material in the grade categories below the 2.0 g/t Au grade cutoff shows similar grade and tonnage figures in both models. However, notable grade and tonnage variations appears between the models in ore material in grade categories between the 2.0 to 3.0 g/t grade cutoffs, whereby the figures show a drop in both the grade and the tonnage in the HGD model compared to the HGC model tonnage and grade figures. Furthermore, significant grade and tonnage variations between the models are observed in the ore material in the grade categories above 3.0 g/t grade cutoff, where significant increase in grade and tonnage is observed in the HGD model compared to the HGC model.

Table 5-4: Grade and tonnage variation summary between the HGC and HGD models at different grades cutoffs.

Grade Category/Cutoff (g/t Au)	High Grade Capping		High Grade Domaining		Variance (HGD/HGC)	
	Tonnage	Grade (g/t)	Tonnage	Grade (g/t)	Tonnage	Grade
0.25 - 0.60	3056670	0.40	3045657	0.40	100%	100%
0.60 - 1.00	1900663	0.78	1900613	0.78	100%	100%
1.00 - 2.00	1954212	1.40	1950745	1.40	100%	100%
2.00 – 3.00	642249	2.48	602289	2.41	94%	97%
3.00 – 4.50	333707	3.68	315239	3.61	94%	98%
4.50 – 6.00	91620	4.78	107446	5.12	117%	107%
6.00 - 999	39781	6.34	78136	7.79	196%	123%
Total	8018902	1.12	8000125	1.15	100%	103%

5.9 Block Model Graphics

Graphical displays of the HGC and HGD models showing the distribution of the gold grades in the study area at different grade cutoffs were done to highlight the graphical variances between the two methods. Since the geostatistical parameters used in the study to populate the two models were the same, the variances observed between the models are entirely due to the method used. Figure 6.9 to 6.18 shows graphical representations of the distribution of the gold grades in the two block models at different grade cutoffs as shown by the respective color coding.

As previously noted in table 6.4, the lower grade areas, such as those with ore material with grade values not more than 1.0 g/t Au appears similar in both models in the graphics (Fig.

5.10). The ore material in those categories makes up the bulk of the ore in the shoots, and the material is located around the peripherals of the ore shoots.

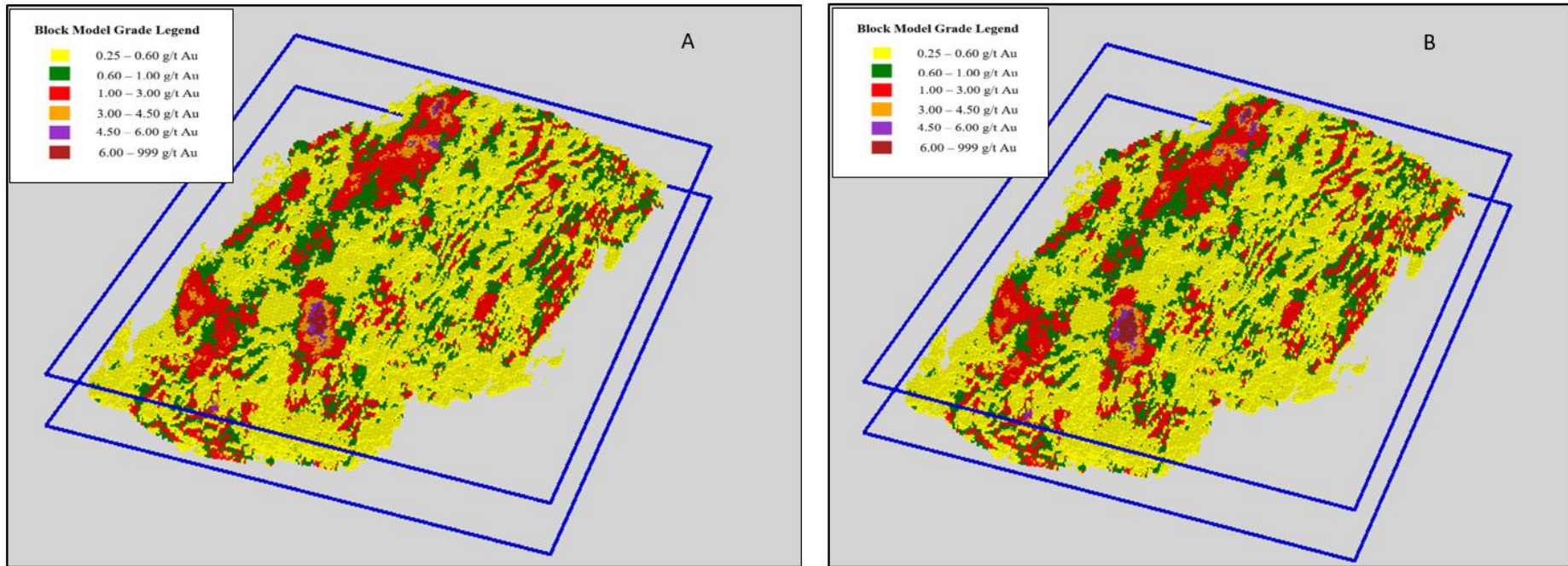


Figure 5-10: Distribution of estimated grades with grades of at least 0.25 g/t Au in the study area. Image A represents the HGC model, while image B represents the HGD model. There are no visible significant variations between the two models at this cut-off grade, because the grade estimation on the peripherals of the ore body populated similar grades.

The grade distribution of all ore material with gold values above the 1.0 g/t Au grade shows similar shoots orientations in both models (Fig. 5.11), with variations of grade distribution observed in the core of the shoots. The ore shoots are characterized by high-grade ore in the cores with the grades decreasing outward toward the peripherals.

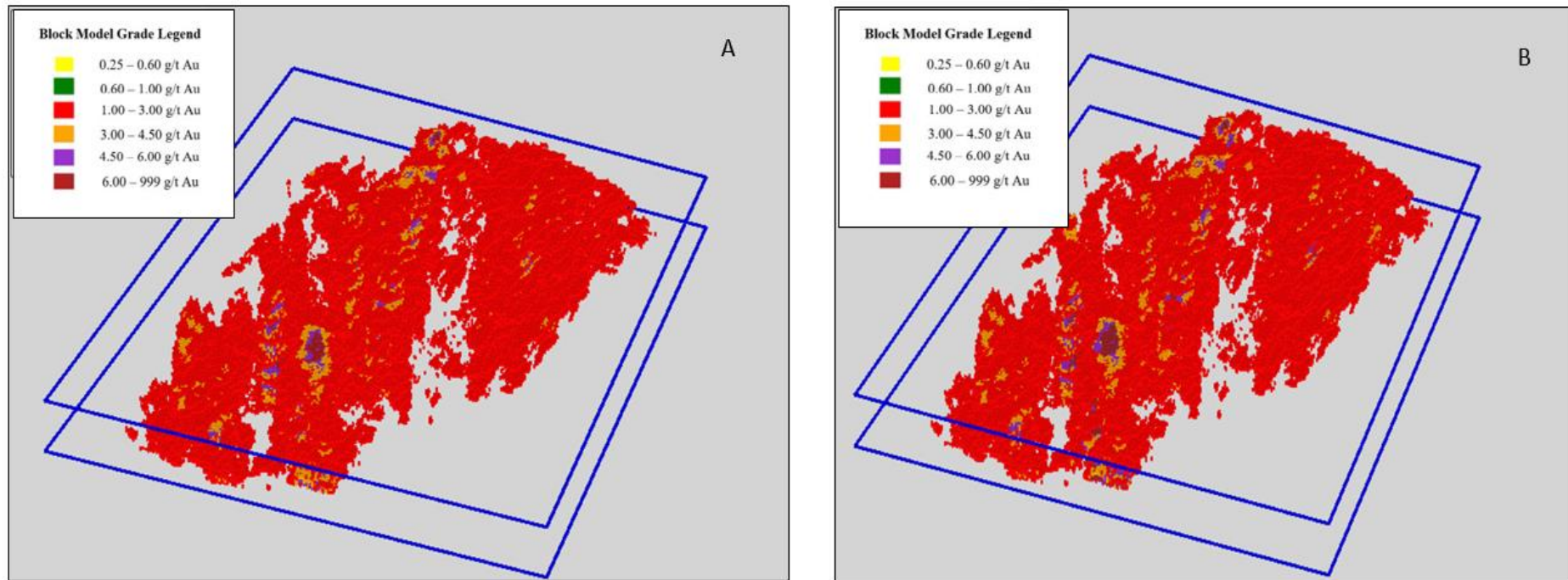


Figure 5-11: The distribution of estimated grades with gold grades of at least 1.00 g/t Au in the study area. Image A represents the HGC model, while image B represents the HGD model. There are no significant variations between the two models at this cut-off grade, as the grade estimates in both models used similar estimation parameters. Similar mineralization orientations can be traced in both models.

Ore materials with gold grades of at least 3.0 g/t grade show similar ore shoots trends in both models, with notable graphical variances observed in the cores of the shoots and around the peripherals of the ore shoots (Fig. 5.12). The ore material above the 3.0 g/t grade category define the outlines of the core of the shoots.

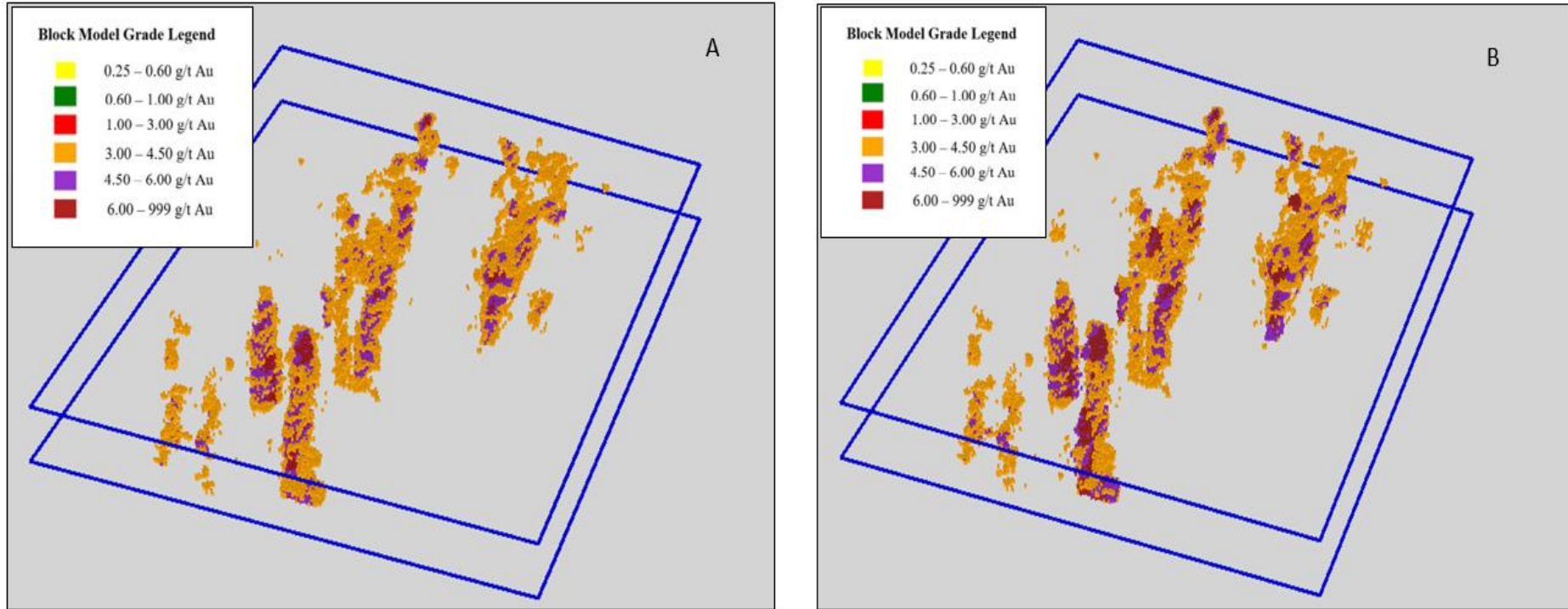


Figure 5-12: The distribution of estimated grades with gold grades of at least 3.00 g/t Au in the study area. Image A represents the HGC model, while image B represents the HGD model. Visible variations occurs around the peripherals of the ore shoots and in the cores of the shoots, there appears an increase in the numbers of block cells in the HGD model compared to the HGC model. Estimations of grades at these cut-offs used the domained grades in the HGD model and capped grades in the HGC model, hence the differences.

Significant differences occur between the two models in ore material above the 4.5 g/t Au grade cutoff, where more higher-grade block cells appear in the core of the shoots, and more block model cells appears through the shoots in the HGD model compared to the HGC model, however, similar ore shoots trends are maintained in both models (Fig. 5.13).

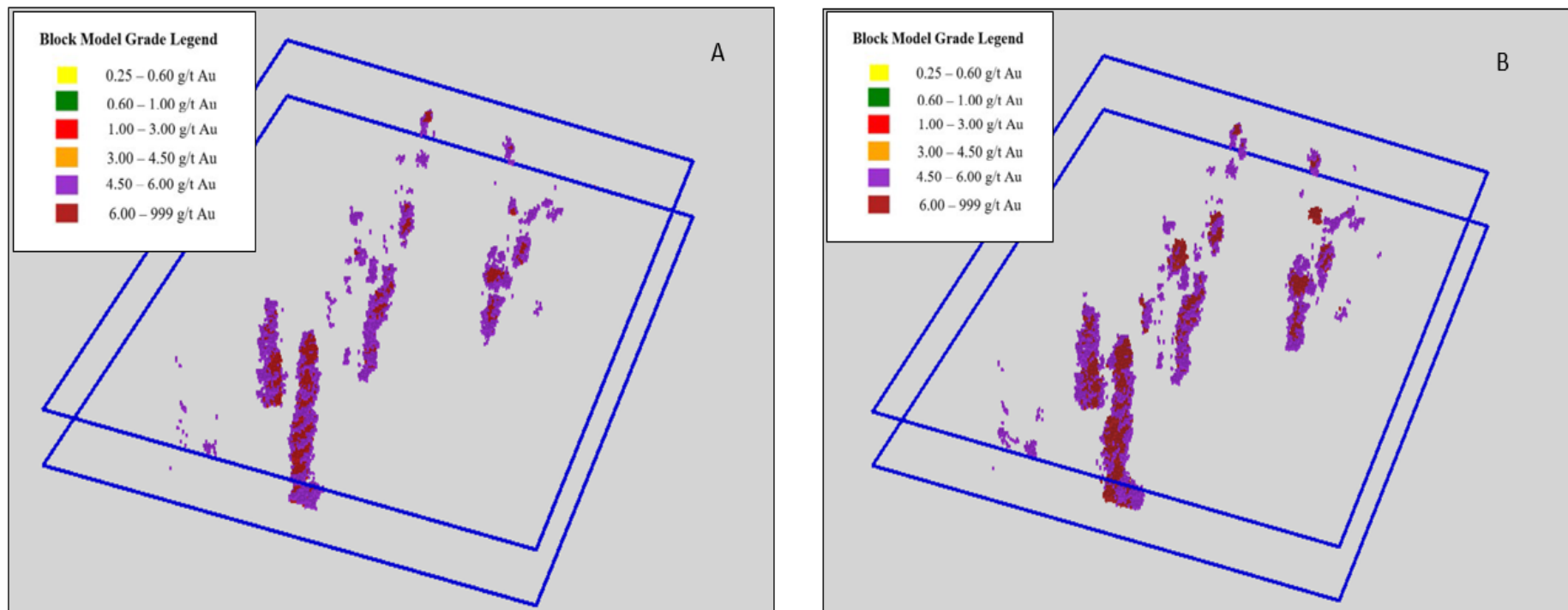


Figure 5-13: The distribution of estimated grades with gold grades of at least 4.5 g/t Au in the study area. Image A represents the HGC model, while image B represents the HGD model. There is more block cells in the HGD model compared to the HGC models at this cut-off. At this cut-off, the block model cells represent the core of the ore shoots.

In ore material above the 6.0 g/t grade cutoff, the HGD model display significant ore materials compared to the HGC model (Fig. 5.14). The general trend of the mineralization is maintained in both models. The ore material in this category makes up the richest zones in the study area. At this grade cutoff, the ore shoots in the HGD models appears more continuous and well defined compared to the ore shoots in the HGC model.

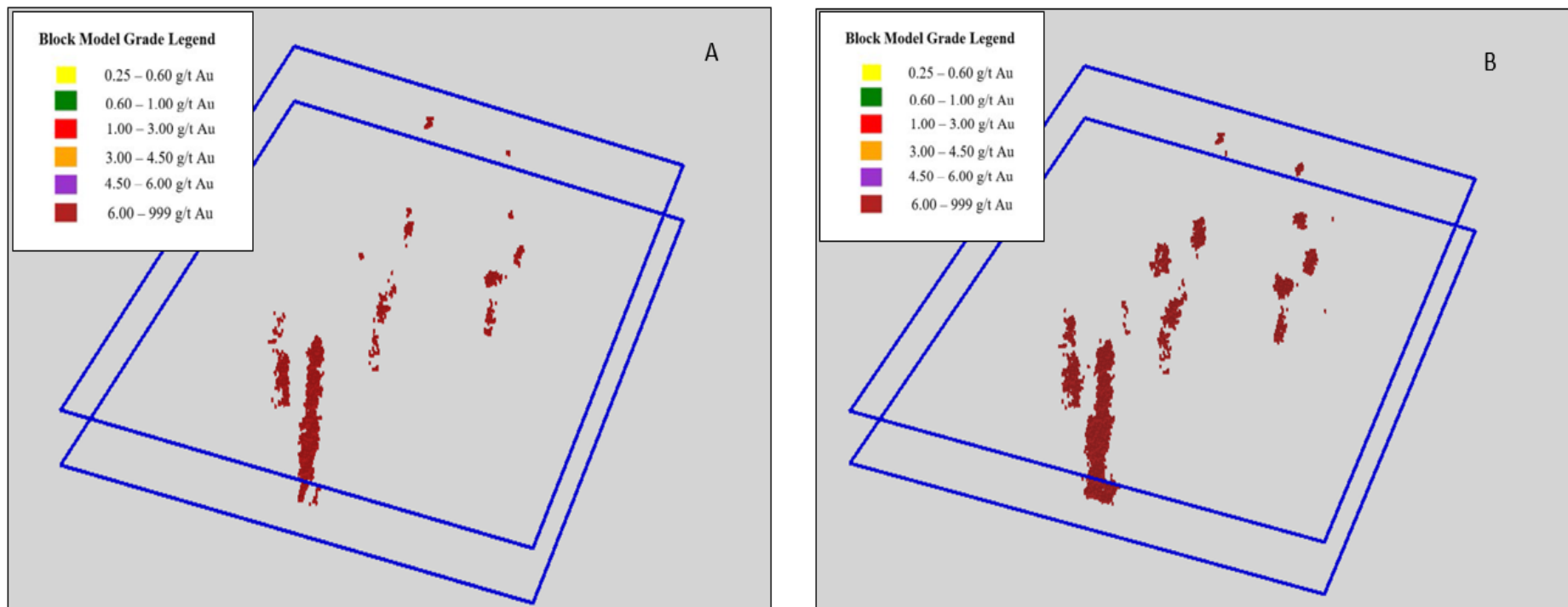


Figure 5-14: The distribution of estimated grades with gold grades of at least 6.0 g/t Au in the study area. Image A represents the HGC model, while image B represents the HGD model. The images represent the cores of the ore shoots. There are more cells with grades above the cut-off of 6.0 g/t Au in the HGD model compared to the HGC model. Material above this cut-off were enclosed within the lower grade materials.

5.10 Grade-Tonnage Curve

Figure 5.15 show the grade tonnage curve displaying the grade tonnage distribution of the two block models. Overall, the models display similar grade tonnage trends at lower grade cutoffs, with significant variances only appearing at higher grade cutoffs, such as those above 3 g/t Au, where the grade trends start to diverge.

Above the mine ore grade category grade of 0.25 g/t, the grade-tonnage curve shows similar tonnage figures until at 3.0 g/t Au grade cutoff. The ore material contained in higher grade categories, such as those with gold grades above 3.0 g/t Au, makes up a small proportion of the total contained material in the study area, however, significant percentage variances occurs between the two models at those categories as earlier shown in Table 6.4.

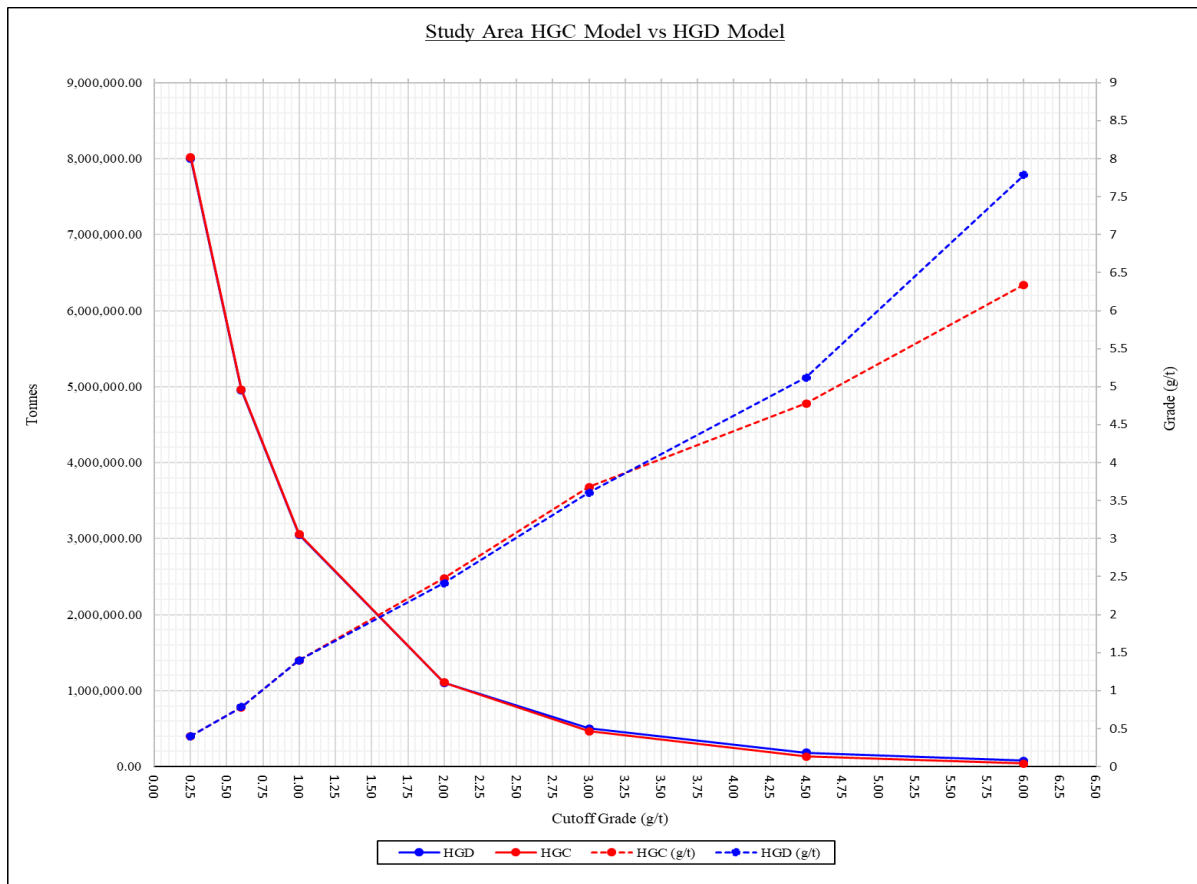


Figure 5-15: Grade tonnage curve of the two model. The grade trends start showing a diverging behavior after the 3.0 g/t cutoff.

5.11 Grade Outliers Spatial Distribution

At Otjikoto mine, high grade outliers, especially those with the gold grade values above the determined capping values, occur in spatially connected zones or clusters, which were mapped and grouped into high grade domains (Fig. 5.16). High grade domains polygons were explicitly digitized around drill holes sections in Minesight software, focusing on zones with at least 1.8 g/t Au grade, the mine SHG cutoff, and containing assay grades with gold grade values more than the determined 8.3 g/t capping value.

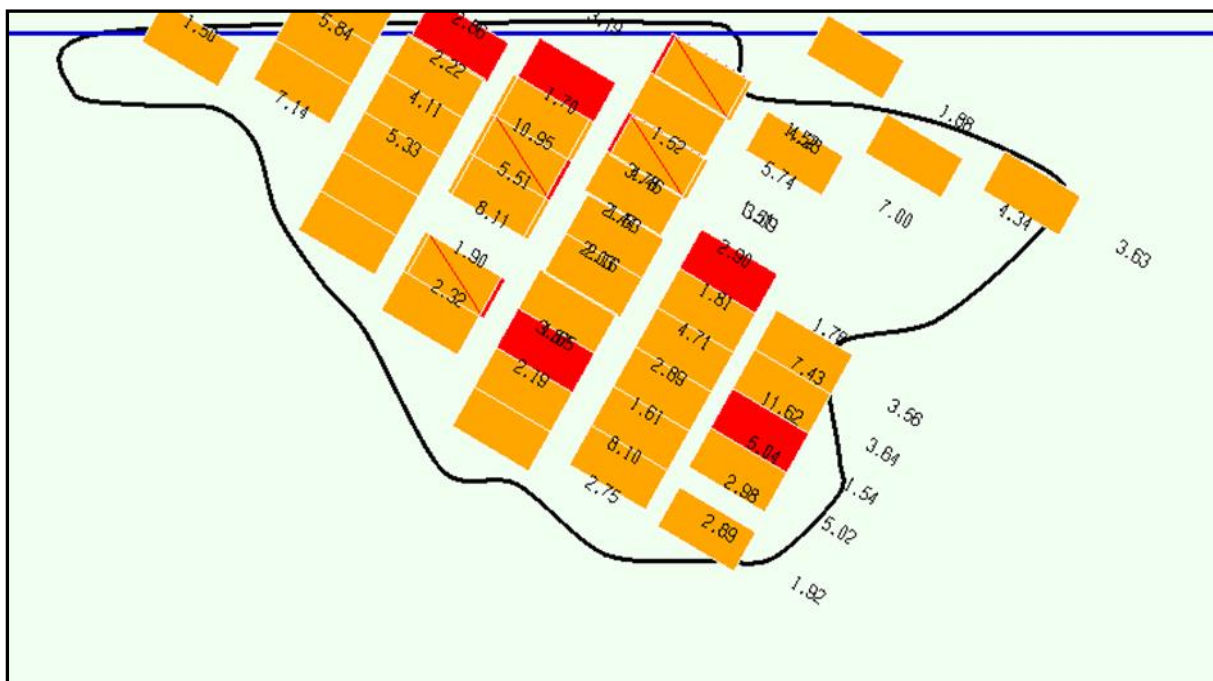


Figure 5-16: High grade domain polygon surrounding high grade values. The high-grade values in the section with gold grades above 8.3 g/t would have been assigned 8.3 g/t value in the estimation, which could have resulted in reduction in grade estimates.

Some assay intersections with gold grade values less than 1.8 g/t Au were included in the domains, because they are surrounded by higher grade values and therefore could not be excluded from the polygons, which somehow resulting in internal dilution within the domains. Lack of continuity was also observed in some sections, where the grade continuity does not continue to the next section making it the end of a certain domain, or where the domains become narrower in the following section.

The modelled high-grade domains trends show similar orientation to the study area search ellipsoids (Fig. 5.17). The domains are elongated in shape, plunging about 15° toward 202° and ranging in length, down plunge, from tens of meters to over 300 m. The orientation the plunge orientation of the high grade domains is aligned parallel to sub-parallel to the general mine lithology strike and to the fold axis of the structures in the ore body.

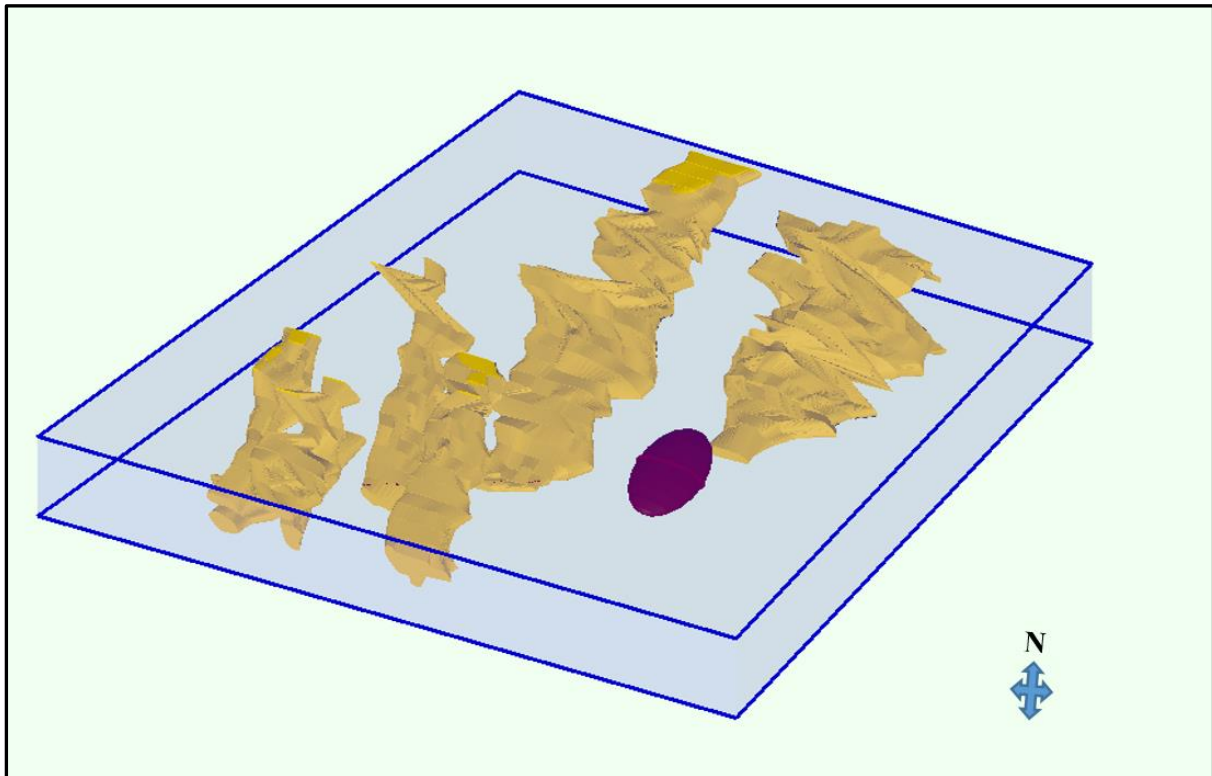


Figure 5-17: High grade domains in the study area. The high-grade domains show a similar orientation to that of the study area gold grade search ellipsoid.

The study area drill holes intersections versus block model grade interpolation shows that high grade domains make up the richer core of the shoots, the high-grade zones, while lower grade zones make up the peripherals of the shoots (Fig. 5.18 and Fig. 5.19).

The gold grade estimates also display a zoned distribution of the grades, with the high grades concentrated in the core of the shoots and surrounded by low grade materials. The estimated high-grade zones conform well within the high grade domains (Fig. 5.20).

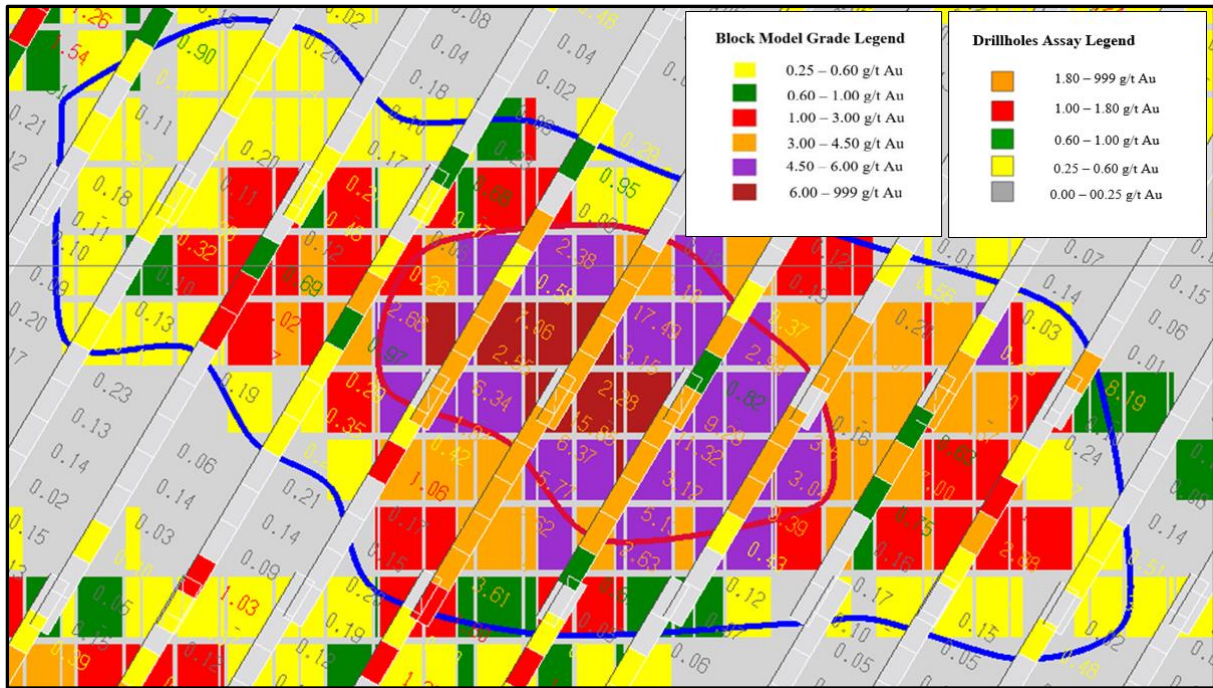


Figure 5-18: Section showing the zoned distribution of the gold mineralization across the drill holes section, the core of the ore shoot is made up of the highest-grade material in the ore shoot, and lower grade material around the peripherals of the ore shoots. The blue polygon marks the outlines of the shoot, while the red polygon marks the richer core of the shoot.

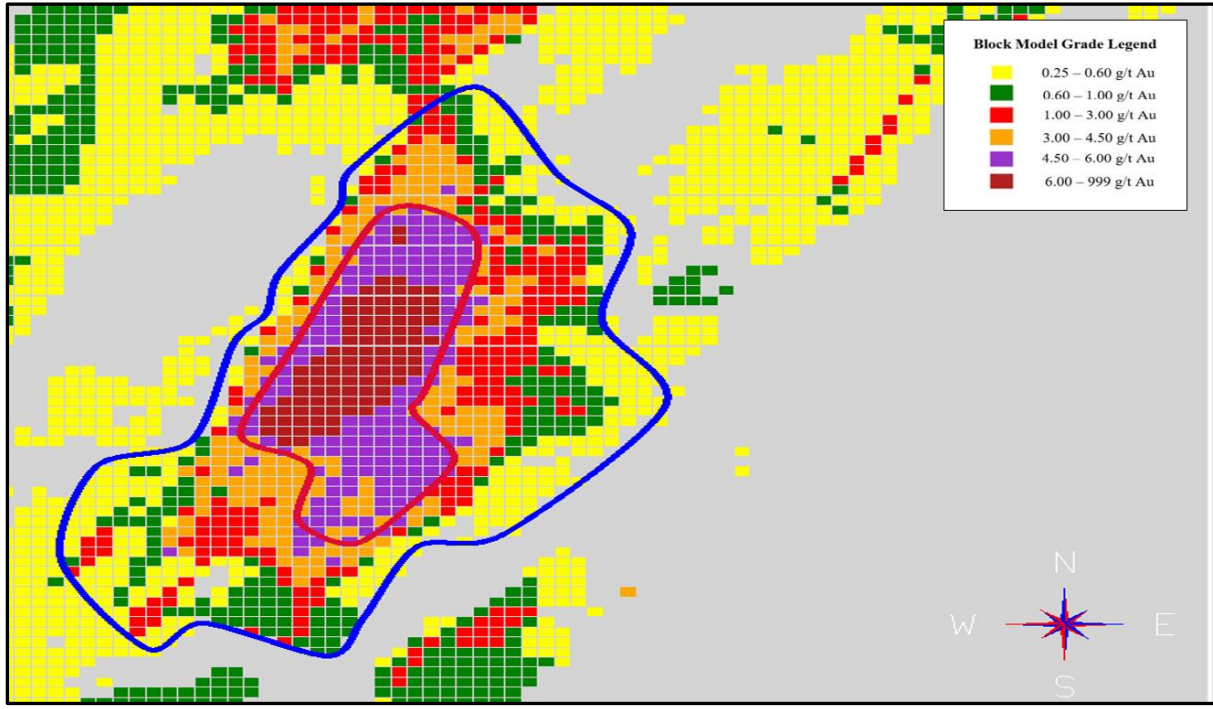


Figure 5-19: Plan view of the grade distribution across the ore shoot, with the richer grades distributed within the core of the shoot, with a zoning distribution observed toward the peripherals of the shoots.

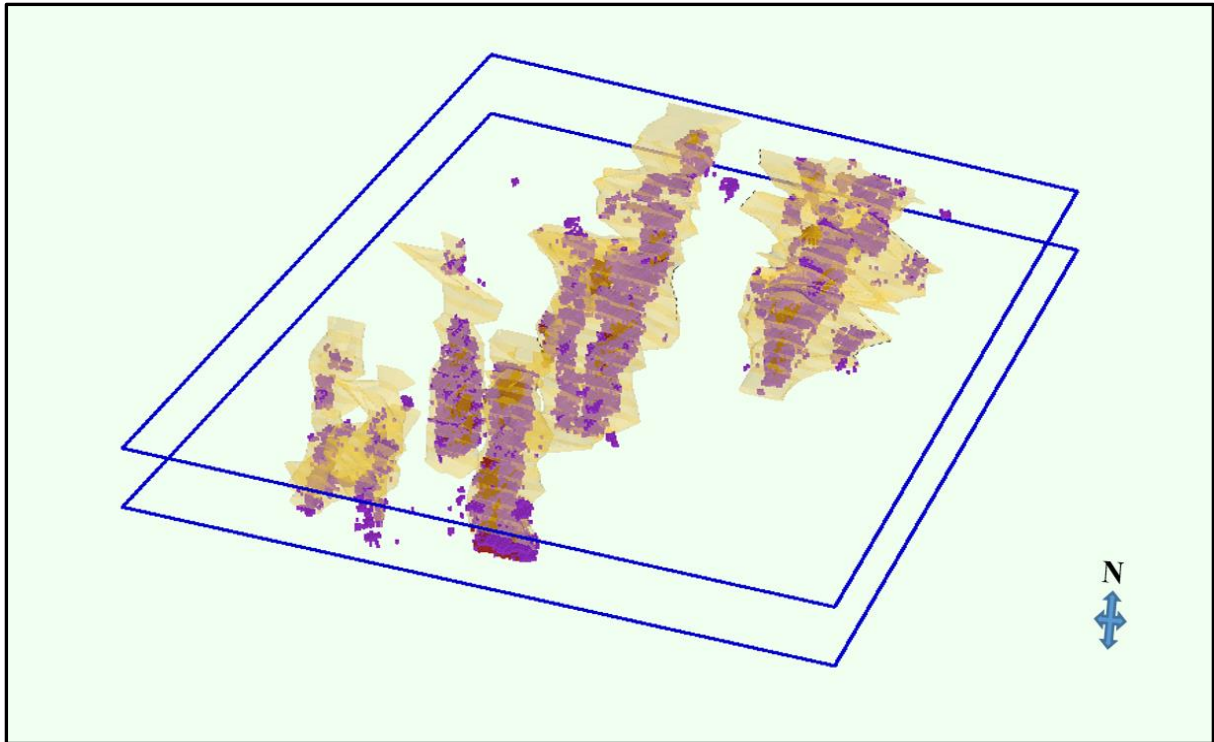


Figure 5-20: The core of the shoots, grades above 3.0 g/t Au, in relation to the high grade domains. Block model cells outside the high grade domains were populated from isolated outliers which could not be mapped/grouped into domains, and mostly had grade values less than the determined capping value.

6 DISCUSSIONS

6.1 The Spatial Distribution of Outliers in the Otjikoto Orebody.

The understanding of the spatial distribution of grade outliers in a mineral deposit is an important criterion in determining the appropriate method to use in containing the influence of high grade outliers in a resource estimation (Kim et al. 2018). Applying a wrong method could result in resource overestimation or an undue reduction in the estimated grades, a situation which must be minimized as it could have significant financial implications on a mining project.

Data statistics summary is useful in detecting visible or evident trends in the data, in plotting data distributions, in defining subset within the data, in mapping out outliers and in establishing if relationships exist (Glacken and Snowden, 2001). The data shows a wide range of gold grade values, and a lower median (Fig. 6.2); indicates that most data are distributed toward the lower grades values. However, the presence of higher gold values, such as the 114.21 g/t Au assay, is an indication of the presence of extreme values in moderately low-grade gold mineralization.

Deformation events on deposits produce different styles of mineralization, which could result in variability in the grades at a vein scale (Domniy, 2003). According to Garagan et al. (2018) Otjikoto local geology has undergone, at least, three deformation events. If the gold formed earlier than any of the deformation events, it could result in gold remobilized resulting into localised enrichments of the grades within the ore body. Field inspections shows that the veins appear folded in most places, therefore the gold might have formed during or pre/syn at least on deformation event. The high nugget nature of the ore body can be attributed to the variability of the gold grades across the veins, in the limbs, the hinges of the intrafolial folds of the ore body, as observed by Garagan et al. (2018) at the Mine. Localised enrichments within the ore body resulted in different data populations as observed in the assays histogram plot. The

histogram plot; (Fig. 6.2) shows a general continuous distribution of data, and isolated populations at higher grades cutoffs which could be attributed to the secondary enrichment of grades in the ore body, however, local enrichment could also be due to deposition of gold in favourable structures.

The study has shown that majority of high grades outliers in Otjikoto deposit are found in clusters or groups which were mapped and modelled into high grade domains (Fig 6.8). According to Dominy and Annels (2001) orogenic gold deposits are associated with grade zoning. The study has shown enriched core of the shoots in the deposit (Fig. 6.23 and Fig. 6.25), these are areas of grade enrichment such as in the hinges of the fold structures, where gold enrichment occurred due to deformation movement into low stress zones. The directional variograms analysis picked up the ore body plunging direction as the direction of the best continuity (Fig. 6.6). Dominy et al. (2003) argues that orogenic gold deposits are associated with deep rooted structures, which acts as conduits of mineralisations, which becomes the directions of the longest continuity of mineralization in the ore body.

The variography analysis has shown that Otjikoto deposit is a highly nuggety ore body, with up to 64% possible variance between two closely spaced samples (Fig. 6.4). However, despite the nuggety nature of the ore deposit, a good continuity was traced at high grade cutoffs within the ore deposit resulting in the creation of high grade domains. Furthermore a range of up to 74m obtained from the variogram modelling (Fig. 6.6) shows a continuous ore body. Garagan et al., 2018 observed that the deposit underwent three deformation events, for a good continuity to be maintained in a nuggety ore body, it should have been superimposed and enrichment by structurally controlled fluids.

6.2 HGC and HGD Block Modelling

Two kriging block models were populated, with each employing a different method of dealing with gold grade outliers in resource estimation. Overall, the results show an overall 3 % increase in grade in the HGD model compared to the HGC model (Table 6.4). The grade variance can be attributed to the significant percentage increase in the grade and tonnage of ore material in high grade categories, such as those with grades above the 4.5 g/t Au, in the HGD model compared to the HGC model (Fig. 6.16 to 6.19). HGC is associated with undue reduction in grades (Kim et al., 2018, and Leuangthong and Nowak, 2015), especially at higher grade cutoffs where the impact of capping is experienced. Although there are significant percentage increases in grade and tonnage in the material above 4.5 g/t cutoff in the HGD model, the total tonnage in at those categories only makes up 2 % of the total ore tonnage in the study area.

The block models display similar grade and tonnage patterns at lower grade cutoffs, such as in the material with grade values below the 3 g/t Au cutoff (table 6.4 and Fig 6.10 to 6.15). The lower grade assays have similar effects in both models giving rise to similar kriging effects in lower grade areas. In the HGC model only assay values above 8.3 g/t grade were capped, and only areas with gold grades values above 1.8 g/t and with contained assay values with grades above the capping value of 8.3 g/t Au were domained in the HGD model. Most of those areas with such grades are contained in the cores of the ore shoots, and where variances between models are expected. The two models shows that the Otjikoto deposit is made up of lower grade ores surrounding the high grades in the cores of the shoots (Fig 6.8), which are possibly areas where grade enrichment occurred.

The results show a drop-in grade and tonnage in the HGD model compared to the HGC model figures in ore material in grade categories of 2.00 g/t Au and 3.0 g/t Au (Table 6.4). The overall lower grades observed in those categories in the HGD model can be attributed to the fact that most higher-grade outliers were domained into higher grade zones, whereby their influence in

the estimation were confined to their containing high-grade domains, resulting in a drop in the overall grades of ore material in the HGD model in those categories. The elevated grades observed in the HGC model in those categories can be attributed to the influence of the higher-grade values in the estimation of the HGC model. Even though, the high grade values were capped to the 8.3 g/t capping value in the HGC model, their influence was not restricted to a specific domain like in the case of the HGD model, thereby giving rise to an overall elevated grades of material in those categories.

The drop-in tonnage experienced in the HGD model compared to the HGC model tonnage in 2.00 g/t Au and 3.0 g/t Au grade categories can be attributed to the number of tonnes enclosed in high grade domains which have been elevated to higher grade cutoffs. In the HGC model, higher capped values gave influence to a larger area resulting in grades smearing into lower areas giving rise to elevated tonnage. As discussed by Leungthong and Nowak (2015), HGD method allowed for modelling in presence of outliers, however, the influence of the outliers in the estimation was only restricted to the confining domains, thereby limiting the influence of the higher grade values into lower grade areas.

The ore material in the high grade categories of 4.5 and 6 g/t cutoffs, shows elevated grade and tonnage figures (Table 6.4) in the HGD model compared to the HGC model. Higher grade outliers' areas of influence in the estimation were confined to their hosting domains in the HGD model, resulting in limited dilution from lower grade intersections which could have resulted in lowered grades and consequently resulting in some tonnage lowered to the lower grade categories. Additionally, high grade outliers' actual assayed values were used in the estimation of the HGD model giving rise to higher estimated grades within the domains. In contrast, the HGC model high grade outliers were capped to 8.3 g/t Au in the estimation, their overall influence in the estimation was also lowered by the contribution of the surrounding lower grade assay values during the estimation.

6.3 The Impacts of Applying HGD as a Method of Dealing with Gold Outliers in a Mine Grade Control System.

By comparing the two block models' all ore material above the 0.25 g/t cutoff, there are no significant variations between the two models (Table 6.4, Fig 6.10 and 6.11). Significant differences are only observed at higher grade cutoffs, such as those above 4.5 g/t Au. Such variations are observed in the core of the shoots where high-grade values are found, and that is where the effect of high grade capping, in HGC model, and high grade domaining, in the HGD model, occurred and made differences in the models.

Otjikoto deposit is characterized by grade zoning (Fig 6.4), with the highest grades concentrated in the cores of the shoots and with the lower grades making up the peripherals of the ore shoots. The grade distribution is defined by a soft boundary, whereby a gradual grade transition occurs from the highest grades in the cores of the ore shoots to the lower grades on the peripherals of the ore shoots. The mineralization toward the peripherals of the shoots is made up of lower grade material which was not affected by the capping or domaining method during the estimation. Therefore, the gold grades distribution appears similar in lower grade areas in both models. The HGD method does not show any significant impact on the peripherals of the shoots, which makes up the bulk of the ore body, changes are only observed in high grade ore in the cores of the shoots, which makes up approximately only 2% of the total contained ore. Kim et al. (2018) and Leuagthong (2015), argue that high grade capping can result in undue reduction of estimated grades, however, massive impact of capping can be minimal in the lower grade ore bodies such as Otjikoto deposit, where there are fewer high grade outliers.

In the core of the ore shoots, where the richest grades within the shoots are found, significant grade variations occurred between the models. At higher grade cutoffs, such as those above 4.5 g/t Au, more tonnage and higher grade appears in HGD model compared to the HGC model

(table 6.4). The impact of capping and domaining is observed in the cores of the shoots. Here, the high grade outliers are capped to the determined capping value in HGC, additionally, there is an influence of surrounding lower grades in the estimations in these areas in the HGC model. In contrast, in the HGD model the high grade outliers are domained into higher grade zones and there is no influence of surrounding lower grades in the estimation as the domains act as hard boundary, giving rise to higher grades and more tonnage in the HGD model.

Tonnage, average grade, and grade cutoffs are critical parameters in the economic analysis of mineral resources and mining operations (Qingfei et al. 2010). The two methods show similar grade-tonnage curve patterns at lower grade categories, however significant differences occurs at high grade categories (Fig 6.20). The grade tonnage curve demonstrate that there are no significant changes at lower grade categories in both models, therefore, similar tonnes at similar average grades are observed in both models at lower grade categories. However, significant grade and tonnage increases are observed in the HGD model compared to the HGC model at high grade categories. The HGD method allowed for selective modelling where narrower richer zones in the ore body were estimated without the influence of surrounding lower grade assays. The grade tonnage curve plot shows that in general a grade cutoff of less than 3 g/t Au would yield similar tonnage in both models at Otjikoto Mine, meaning the estimates in those categories appears similar in both models. The average mining grades of ore blocks at B2gold Otjikoto Mine Otjikoto pits are less than 3 g/t Au. Therefore, there will not be changes to the mining grades and tons if either method is used to model ore blocks for open pit mining at the Mine.

6.4 The Optimum Method of Dealing with Gold Outliers in the Grade Control System at Otjikoto Mine

The two block models show similar model outputs with significant variations only observed at high grade categories (Table 6.4), such as those with gold grade values above 4.5 g/t, however,

there are no significant variations to the total contained metal, as material above the 4.5 g/t Au cutoff only makes up 2 % of the total contained metal in the HGD model. The HGD model modelling process took approximately three times more time to complete than the HGC model modelling process. Moreover, the overall life of Mine mining grade at B2Gold Otjikoto Mine is approximately 1.50 g/t Au for the open pit mining, a grade at which both models yield similar grade and tonnage figures (Figure 6.20). Therefore, due to the above reasons, the HGC modelling process can be considered as the most efficient modelling process for grade control modelling at the Mine. Grade control modelling process requires regular updating of the model as the assay results become available from the laboratory, the HGD modelling process would become a tedious process which yield similar figures to the current method at the Mine. In most cases ore mining blocks are blasted before their grade control models are completed. There is limited time between completing the modelling process and availing the ore block for mining. This work has clearly demonstrated that the HGC method does not allow for good selective high grading as compared to the HGD method (Fig 6.16 to 6.19), nevertheless, the current mining grades at B2Gold Otjikoto Mine do not require high grading. However, for high grading such as for underground mining, where mining of narrower high-grade materials at high grade cutoffs is required, the HGD method for resource estimation would become a more appropriate method. Underground mining is, usually, associated with exploration drives which allows for advanced grade control drilling way ahead before mining, therefore the time length required to complete the HGD modelling process may not be a limiting factor.

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

- The study has clearly demonstrated that HGD method can be used as a method of controlling the influence of grade outliers in resource estimation in the grade control system at Otjikoto mine. As a result, two kriging block models, using two different methods of controlling grade outliers, were populated for the study.
- The study has also demonstrated that there are no significant changes between the two model outputs when compared at lower grade categories, however, significant percentage variations were observed on both tonnage and grade at higher grade categories such as those above the 4.5 g/t Au between the models.
- When comparing the results of the two methods, the study has demonstrated that the HGC method can result in reduction in grades and tonnage estimates at higher grade categories, however, the overall impacts may be minimal in lower grade ore bodies with few outliers.
- The majority of Otjikoto deposit high grade outliers are spatially related, as a result the outliers were grouped into higher grade domains, which enabled the HGD method to be used for the study. The high-grade outliers were found to be spatially continuous in the core of the ore shoots.
- The study has shown that the two methods have little impact at lower grade categories, because of the grade zoning nature of the deposit, whereby higher grades are concentrated in the cores of the shoots, and lower grade ore at the peripherals of the shoots. However, there is a significant metal loss in the estimation at higher grade categories in the HGC model, where the relationship established has shown that the higher the cutoff grade the higher the variances between the two methods.

- The HGC method is currently the optimum grade control method at the Mine, however, the HGD modelling process could be a suitable method for the purpose of high grading such as for underground mining.

7.2 Recommendations

There is a need to understand the mineralogy of the ore deposit. The ore body is associated with visible gold, commonly found during mining. It is also classified by ore shoots which are either pyrite enriched or pyrrhotite enriched. The information on ore mineralogy will, possibly, reveal more information which could help in understanding the high nuggety nature of the deposit.

8 REFERENCES

- Bachmaier, M., Backes, M., 2011. Variogram or Semivariogram? Variance or Semivariance? Allan Variance or Introducing a New Term?. *Mathematical Geosciences*. 43, 735-740. doi:10.1007/s11004-011-9348-3
- Chamber of Mines: Annual Review, 2016. <https://www.chamberofmines.org.na/index.php/publications/annual-reviews/> (accessed 10.11.19).
- Chanderman, L., Dohm, C.E., Minnitt, R.C.A., 2017. 3D geological modelling and resource estimation for a gold deposit in Mali. *The Journal of the Southern African Institute of Mining and Metallurg*. 117, 189-197. doi:10.17159/2411-9717/2017/v117n2a10
- Clark, I., 1979. *Practical Geostatistics*. Applied Science Publishers, London. <http://www.kriging.com/PG1979/>. Accessed (17.04.2020).
- Costa, J. F., 2003. Reducing the Impact of Outliers in Ore Reserves Estimation. *Mathematical Geology*. 35, 323–345. doi:10.1023/A:1023822315523
- Cowan, E.J., Beatson, R.K., Fright, W.R., McLennan, T.J., Mitchell, T.J., 2002. Rapid Geological Modelling, *Applied Structural Geology for Mineral Exploration and Mining International Symposium Abstract Volume*. Australian Institute of Geoscientists Bulletin, 36:39-41.
- Dominy and Annels, S.C., Platten I.M., Raine M.D., 2003. Grade and geological continuity in high-nugget effect gold–quartz reefs: implications for resource estimation and reporting. *Applied Earth Science*. 112, 239-259. doi:10.1179/037174503225003116.
- Dominy and Annels, S., Annels, A., 2001. Evaluation of gold deposits - Part 1: Review of mineral resource estimation methodology applied to fault- and fracture-related systems.

- Applied Earth Science : IMM Transactions section B. 110, 145-166.
doi:10.1179/aes.2001.110.3.145
- Duke, J. H., Hanna, P.J., 2001. Geological interpretation for resource modelling and estimation. Monograph Series - Australasian Institute of Mining and Metallurgy. 23. 147-156.
- Fletcher, B.A., Mackinnon, H. F., Lombard, A. P. J., 2013. Otjikoto gold deposit: Discovery and exploration of Namibia's second major gold mine. Geological Report. Windhoek: B2Gold Corp. pp. 2-6.
- Frimmel, H.E., Basei, M.S., Gaucher, C., 2011. Neoproterozoic geodynamic evolution of SW-Gondwana: a southern African perspective. Int. J. Earth Sci. (Geologische Rundschau) 100, 323–354. doi:10.1007/S00531-010-0571-9
- Gandhi, S.M., Sarkar, B.C., 2016. Mineral Deposits: Types and Associations. Essentials of Mineral Exploration and Evaluation. 23-52. doi:10.1016/B978-0-12-805329-4.00009-0
- Garagan, T., Montano, P., Jones, K., Rajala, J., 2018. OTJIKOTO GOLD MINE Namibia NI 43-101 TECHNICAL REPORT.
- Glacken, I., Snowden, D., 2001. Mineral Resource Estimation. Monograph Series - Australasian Institute of Mining and Metallurgy. 23.
- Goldfarb, R. J., Groves, D. I., 2015. Orogenic gold: Common or evolving fluid and metal sources through time. Lithos. 233. 2-26. doi:10.1016/j.lithos.2015.07.011.
- Goldfarb, R.J., Groves, D.I., Gardoll, S., 2001, Orogenic gold and geologic time: A global synthesis: Ore Geology Reviews. 18, 1–75.
- Goovaerts, P., 2016. Sample Support. doi:10.1002/9781118445112.stat07754.pub2

- Gray, D., Foster, D., Meert, J., Goscombe, B., Armstrong, R., Trouw, R. A., Passchier, C., 2008. A Damara orogen perspective on the assembly of Southwestern Gondwana. Geological Society, London, Special Publications. 294, 257-278. doi:10.1144/SP294.14
- Groves D. I., 1993. The crustal continuum model for late-Archaean lode-gold deposits of the Yilgarn Block, Western Australia. Miner Depos. 28, 366–374. doi:10.1007/BF02431596
- Groves, D.I., Goldfarb, R.J., Knox-Robinson, C.M., Ojala, J., Gardoll, S., Yun, G.Y, Holyland, P., 2000. Late-kinematic timing of orogenic gold deposits and significance for computer-based exploration techniques with emphasis on the Yilgarn Block, Western Australia. Ore Geology Reviews. 17, 1-38. doi:10.1016/S0169-1368(00)00002-0
- Groves, D.I., Goldfarb, R.J., Gebre-Mariam, M., Hagemann, S.G., Robert, F., 1998. Orogenic gold deposits: A proposed classification in the context of their crustal distribution and relationship to other gold deposit types: Ore Geology Reviews. 13, 7–27. doi:10.1016/S0169-1368(97)00012-7
- Groves, D.I., Goldfarb, R.J., Santosh, M., 2016. The conjunction of factors that lead to formation of giant gold provinces and deposits in non-arc settings. Geoscience Frontiers 7, 303-314.
- Groves, D.I, Santson, M., Goldfarb, R.J, Zhang, L., 2018. Structural geometry of orogenic gold deposits: Implications for exploration of world-class and giant deposits. Geoscience Frontiers. Vol. 9, 1163-1177. doi: 10.1016/j.gsf.2018.01.006
- Hawkins, D.M., 1980. Identification of Outliers. Chapman and Hall, London

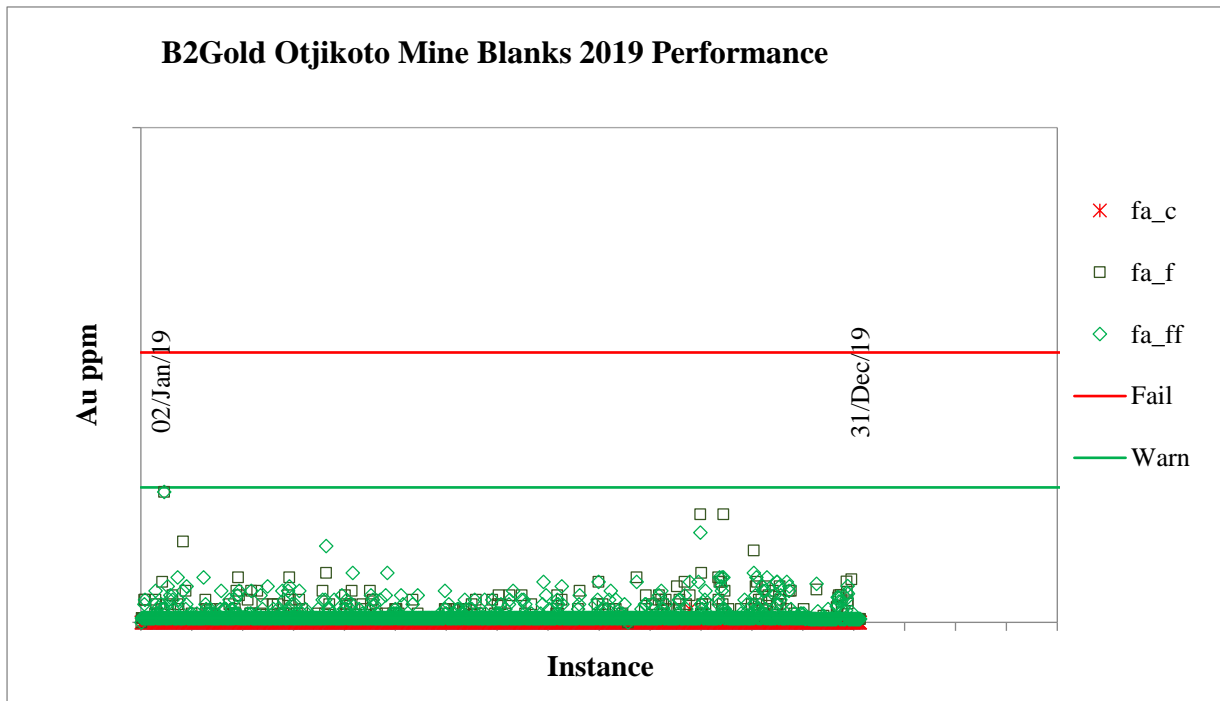
- Jung, S., Hoernes, S., Mezger, K., 2000. Geochronology and petrogenesis of Pan-African, syn-tectonic, S-type and post-tectonic A-type granite (Namibia): products of melting of crustal sources, fractional crystallization and wall rock entrainment. *Lithos*, 50(4), 259-287. doi:10.1016/S0024-4937(99)00059-6
- Kim S. M., Choi, Y., Park, H. D., 2018. New Outlier Top-Cut Method for Mineral Resource Estimation via 3D Hot Spot Analysis of Borehole Data. *Minerals*. 8, 348. doi.org/10.3390/min8080348
- Kisters, A.F.M., Jordaan, L.S., Neumaier, K. 2004. Thrust-related dome structures in the Karibib district and the origin of orthogonal fabric domains in the south Central Zone of the Pan-African Damara belt, Namibia. *Precambrian Research*, 133, 283–303. doi:10.1016/j.precamres.2004.05.001
- Knudsen, H.P., 1975. A comparison of the geostatistical ore reserve estimation method over the conventional methods. The University of Arizona. <https://repository.arizona.edu/handle/10150/554906>. (Accessed 17.06.19).
- Leuangthong, O., Nowak, M., 2015. Dealing with high-grade data in resource estimation. *The Journal of The Southern African Institute of Mining and Metallurgy*. 115, 27-36. doi:10.17159/2411-9717/2015/v115n1a3.
- Lusty, A.J., Gunn, G.A., 2014. Challenges to global mineral resource security and options for future supply. Geological Society, London, Special Publications. 393. doi:10.1144/SP393.13.
- McDonald, A., 2011. Otjikoto Gold Project, North-Central Namibia. NI 43-101 Technical Report. B2Gold Corp. pp.10-70.

- Miller, R., 2013. Comparative Stratigraphic and Geochronological Evolution of the Northern Damara Supergroup in Namibia and the Katanga Supergroup in the Lufilian Arc of Central Africa. *Geoscience Canada* 40 (20), 118–140. doi.org/10.12789/geocanj.2013.40.007
- Miller, R., 2008. *The Geology of Namibia*. 3rd ed. Windhoek: Ministry of Mines and Energy of Namibia, Geological Survey. Pp.113-180.
- Negonga, L., 2018. *Geochemistry, Stable Isotopes and Fluid Inclusion Studies of the Otjikoto Gold Deposit, Central Namibia*. Master dissertation, University of Cape Town, South Africa.
- Nowak, M., Leuangthong, O., Srivastava, R. M., 2013. Suggestions for good capping practices from historical literature. *Proceedings of the 23rd World Mining Congress 2013, Montreal, Canada, 11-15 August 2013*. Canadian Institute of Mining, Metallurgy and Petroleum. 10 pp.
- Ortiz J. M., Emery X., 2006. Geostatistical estimation of mineral resources with soft geological boundaries: a comparative study. *Journal of the South African Institute of Mining and Metallurgy*. 106, 577-584.
- Parrish, I.S. 1997. Geologist's Gordian knot: to cut or not to cut. *Mining Engineering*. 49, 45-49.
- Phillips GN, Powell R., 2010. Formation of gold deposits: a metamorphic devolatilization model. *J Metam Geol*. 28, 689–718. doi:10.1111/j.1525-1314.2010.00887.x
- Pirajno, F., Jacob, R.E., 1991. Gold mineralisation in the intracontinental branch of the Damara orogen, Namibia: A preliminary survey. *Journal of African Earth Sciences*. 13, 305-311.

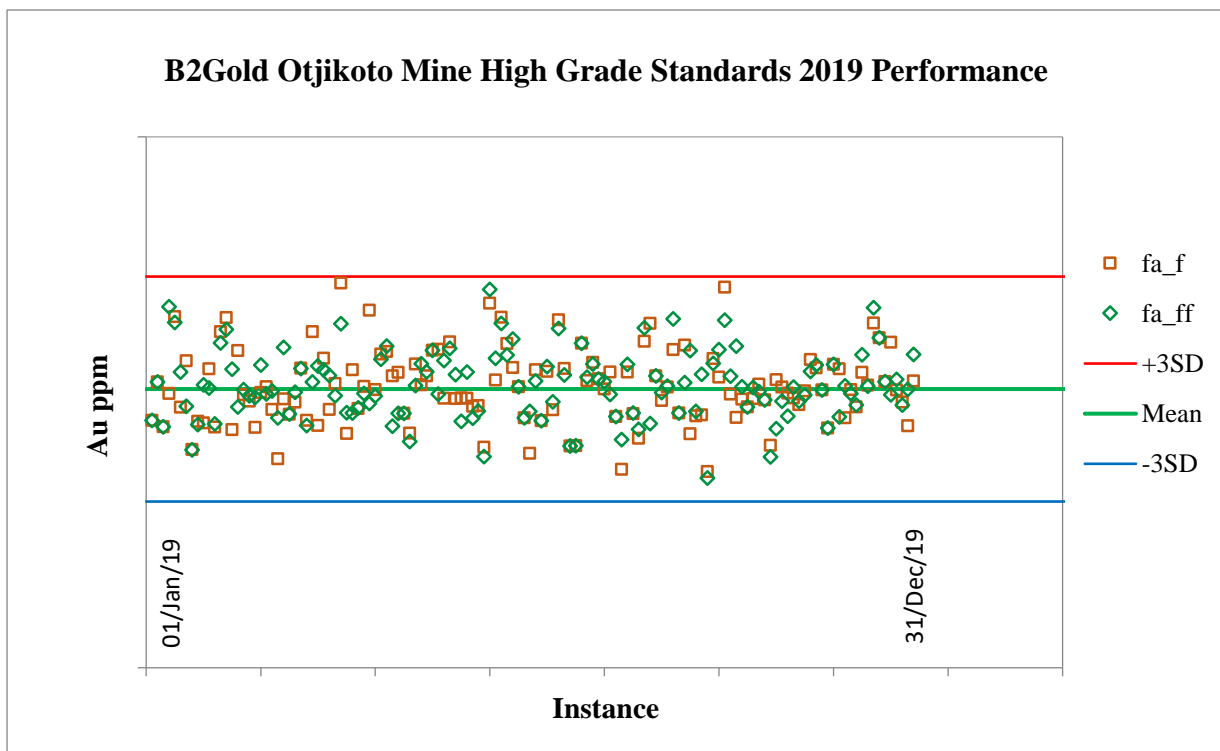
- Pitcairn I. K., Teagle D. A. H., Craw D., Olivo G. R., Kerrich R., Brewer T. S., 2006. Sources of metals and fluids in orogenic gold deposits: Insights from the Otago and Alpine Schists, New Zealand. *Econ Geol.* 101, 1525–1546. doi:10.2113/gsecongeo.101.8.1525
- Qingfei, W., Deng, J., Zhao, J., Liu, H., Wan, L., Yang, L., 2010. Tonnage-cutoff model and average grade-cutoff model for a single ore deposit. *Ore Geology Reviews.* 38, 113-120. doi:10.1016/j.oregeorev.2010.07.003
- Rankin, W., 2015. Cross-Border correlation of the Damara Belt in Namibia and equivalent lithologies in north western Botswana from potential field and magnetotelluric interpretations. MSc thesis. Johannesburg: University of Witswatersrand, South Africa.
- Rashad, M. Z., Tahlawi, M. R., Ahemd, S. S., Anwar, A. A., 2007. Selection of Variogram Model for El Shagara Gold Mine, Eastern Desert, Egypt. https://www.researchgate.net/publication/257354592_Selection_of_Variogram_Model_for_El_Shagara_Gold_Mine_Eastern_Desert_Egypt/citation/download (Accessed 17.07.19).
- Ridley, J., 2013. What is an ore deposit? In *Ore Deposit Geology*. Cambridge: Cambridge University Press. doi:10.1017/CBO9781139135528.002
- Sinclair, A. J., Blackwell, G.H., 2002. *Applied Mineral Inventory Estimation*. Cambridge University Press, Cambridge. doi:10.1017/CBO9780511545993.
- Stegman, C.L. 2001. How domain envelopes impact on the resource estimate -case studies from the Cobar Gold Field, NSW, Australia. *Mineral Resource and Ore Reserve Estimation - The AusIMM Guide to Good Practice*. Edwards, A.C. (Ed.). Australasian Institute of Mining and Metallurgy. Melbourne.

- Tomkinson, M., 1999. Observations on exploration projects in Namibia. Memorandum. Epigenesis Consulting Pty. (Ltd). 3-50.
- Van der Merwe, A.J., Jones, C., 2005. Otavi Exploration Project, Namibia. Technical Report. RSG Global Consulting Pty (Ltd). 7-60.
- Wilton, J., Lombard, P.J.A., Philpot, H.G., 2002. Discovery of the Otjikoto gold deposit. Windhoek: Proceedings of the 11th Quadrennial IAGOD Symposium and Geocongress 2002 Anglovaal Namibia (Pty) Ltd. 2-5.
- Zaghlol, K., 2019. ORE DEPOSITS (Ore Geology). Department of Exploration, Egyptian mineral Resource Authority. doi:10.13140/RG.2.2.35334.42561.
- Zhang, Y., 2011. Introduction to Geostatistics-Course Notes. University of Wyoming. Dept. of Geology & Geophysics. <http://geofaculty.uwyo.edu/yzhang/files/Geosta1.pdf>

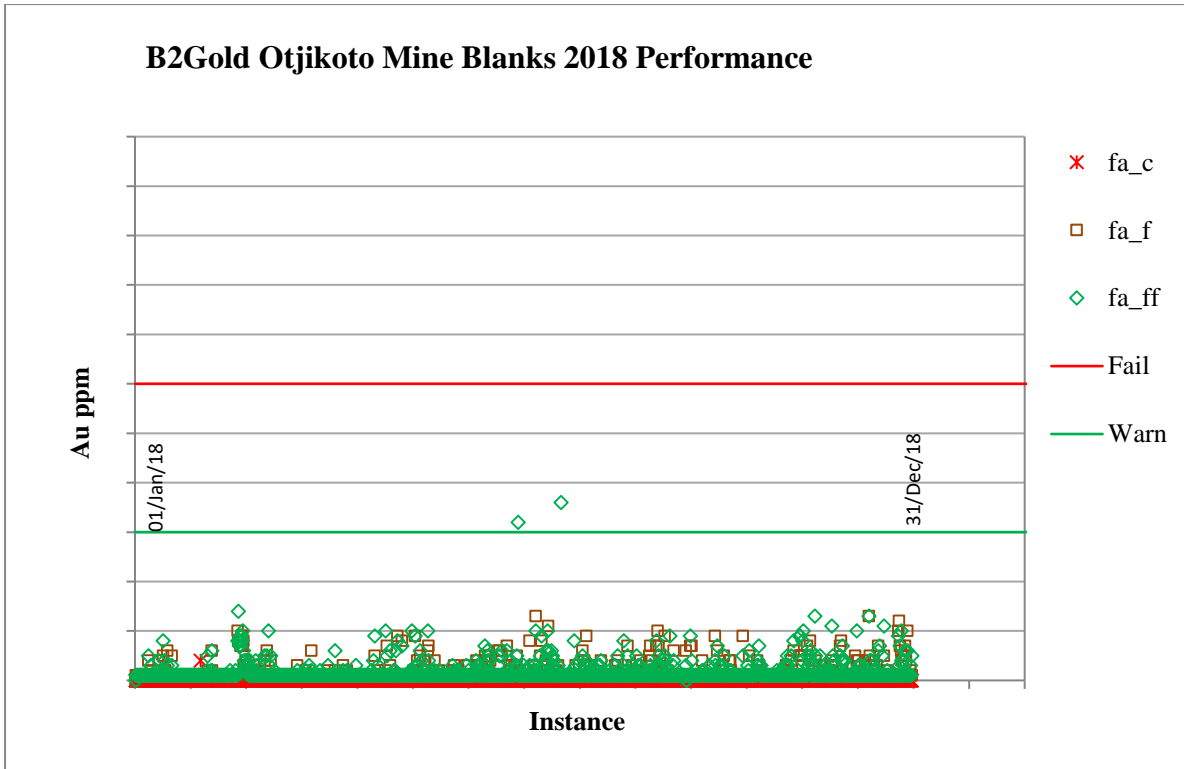
9 APPENDICES



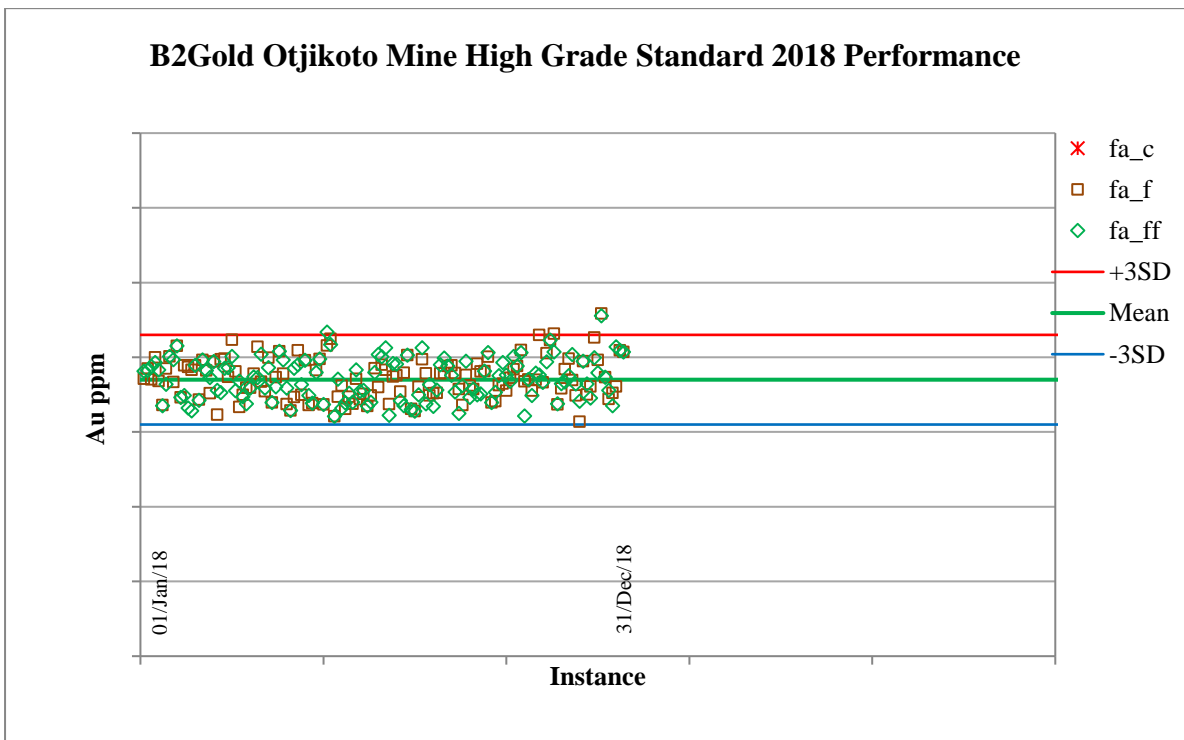
Appendix 1. B2Gold Otjikoto mine 2019 geology blanks performance.



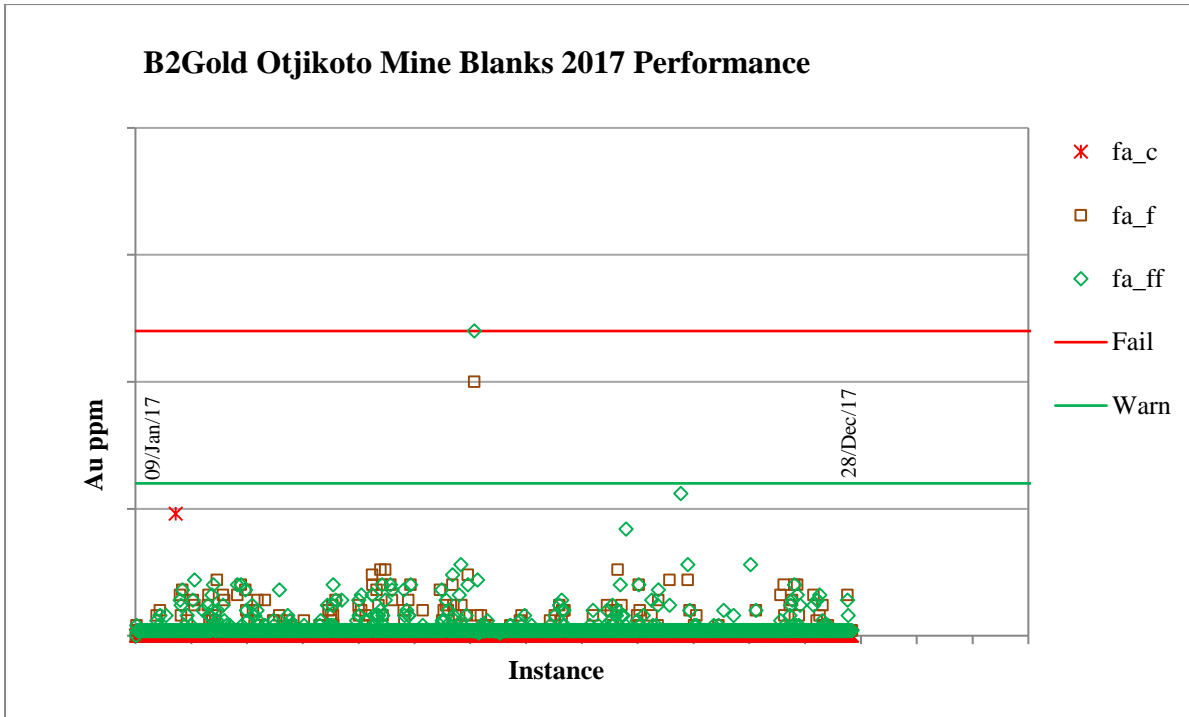
Appendix 2. B2Gold Otjikoto mine 2019 geology high grade standard performance.



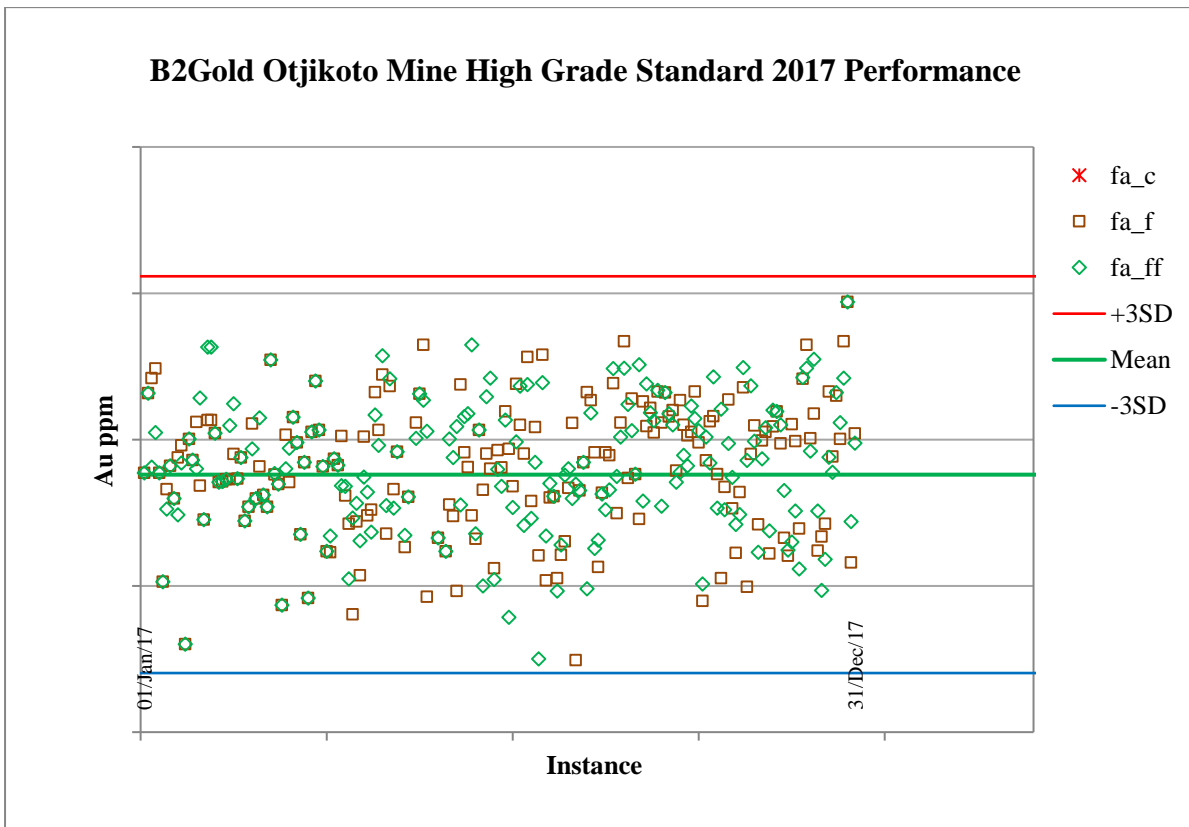
Appendix 3. B2Gold Otjikoto mine 2018 geology blanks performance.



Appendix 4. B2Gold Otjikoto mine 2018 geology high grade standard performance.



Appendix 5. B2Gold Otjikoto mine 2017 geology blanks performance.



Appendix 6. B2Gold Otjikoto mine 2017 geology high grade standard performance.