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**THE SEDIMENTOLOGY AND DEPOSITIONAL MODEL OF VS5
REEF AT BEATRIX MINE AND SURROUNDING AREAS OF
THE FREESTATE GOLDFIELD, SOUTH AFRICA.**

By

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Declaration

I, Steven Shivambu, declare this dissertation to be my own work. It is submitted in fulfillment of the Degree of Master of Science at the University of Rhodes. It has not been submitted before for any degree or examination in any other University or tertiary institution.

Signature of the candidate: 

Date:15-08-2016

Dedication

I dedicate this thesis to my late parents Hasani Samson Shivambu and Mamaila Rosinah Hlungwane for their virtuous effort in providing me a basic education during their life time.

Also to my beautiful wife Vuthlari Ophilia, my son Masingita Steven-Junior and my daughter Xihlovo Pearl for their love, support and patience while I was away in Grahamstown for extended period of time.

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Terminology

Crosscut: Development tunnel developed on reef dip from a strike haulage intended to intersect reef, at which point raises are developed on the reef dip.

Geozones: Zones of regionally homogenous reef characteristics. Also commonly referred to as facies plans, geozone plans are continuously updated by adjusting boundaries as new information is obtained through drilling, mapping and sampling. These geozones are given numerical names e.g. 1, 6, 8, 9, 12, 51 etc., (these names are not related to gold values contained in the ore).

Non-durables/Durables: Soft mineral and/or clast components of sediments; materials that are readily broken down. Immature coarse sediments/conglomerates contain more non-durables (e.g. clay) compared to **durable** materials (e.g. quartz). Increased re-working of a sediment or maturity – will remove non-durable components and increase the relative proportion of resistant components, or **durables**.

Oligomictic: Conglomerate comprising of two or less types of pebbles.

Panel: An active stoping area.

Polymictic: Conglomerate consisting of more than two types of pebbles.

Raise: Inclined development tunnel developed on reef dip.

Reef: Layer of rock (ore) that contains significant concentration of a particular element or mineral. The Witwatersrand reefs are mainly conglomeratic units enriched with gold and uranium mineralization.

Stope: Mined out reef panel advancing on reef strike or on dip

Waste on Contact: A situation where the conglomerate is not developed, footwall in direct contact with hanging wall.

Abstract

Historically, placers of economic importance at Sibanye Gold's Beatrix No. 3 Shaft were Beatrix Reef, Aandenk Reef and Composite of the two reefs. Recently, the VS5 placer has emerged to be a significant contributor of ore tonnages mined on the Shaft as mining advances into deeper levels towards the northern portion of the mine lease area. Gold concentration in the VS5 Reef is highly variable from uneconomic, through marginal to economic gold values. A good knowledge of the sedimentological framework of the VS5 Reef was considered necessary in order to interpret the variable distribution of the gold within the VS5 placer. The aim of this study was to determine the depositional environments that played a major role during the formation of the VS5 placer by means of investigating the macroscopic sedimentological parameters of this particular reef. These sedimentological parameters were used as the basis for the subdivision of VS5 Reef into different facies recognized in the mine and surrounding areas.

It was recognized that the VS5 placer was formed in a distal, braided fluvial environment by the reworking of the pre-existing Aandenk Reef by new materials containing significant amount of non-durable materials (see definition on page xii) such as shale detritus. Where there is no evidence of reworking of the older Aandenk Reef, the VS5 Reef occurs as poorly sorted, polymictic conglomerate with abundance of non-durable detritus. This is referred to as the Immature (IV) VS5 facies and occurs in the northern portion of the study area. The degree of reworking of the gravel bars by waves and current action resulted in the formation of well sorted, oligomictic conglomerates of the Beatrix facies in the southern portion of the mine. At the boundaries between the Immature VS5 and Beatrix facies occurs the Transitional (Sub-mature) VS5 facies, characterized by reef comprising a polymictic upper portion and a basal more mature oligomictic unit. The Transitional VS5 facies extends across the current central northern mining faces of Beatrix No. 3 Shaft with a northwest-southeast trend.

There is a strong correlation between the VS5 lithofacies and distribution of gold mineralization. The Immature VS5 facies is poorly mineralized, with gold values averaging 200 c.m.g/t and lower. The Transitional (Sub-mature) VS5 facies has elevated gold values, ranging from 300 c.m.g/t to 1500 cm.g/t. Mineralization in this unit tend to be bottom loaded as well as at the base of each cyclic unit. The Beatrix facies records the highest grades averaging >1500 cmg/t. The improved understanding of the VS5 lithofacies made it possible to predict gold mineralization and aid planning to mine into viable VS5 areas.

Key words: *Beatrix Mine, Witwatersrand Basin, Welkom Goldfield, Elsburg Formation, VS5 Reef.*

Chapter 1

Introduction

1.1 Overview of Beatrix Gold Mine

Beatrix Gold Mine is a subsidiary of the newly registered Sibanye Gold (Pty) Ltd, a South African based gold mining company formed from unbundling of Goldfield's South African operations from its international operations in 2013. The mine is located in Theunissen, some 35 km south of Welkom, Free State Province, South Africa (Figure 1.1). Geologically, the mine is situated in the Welkom Goldfield of the geologically unique and world-renowned Witwatersrand Basin and forms the southern-most gold mining operation in Witwatersrand Basin (Figures 1.1 and 1.2).

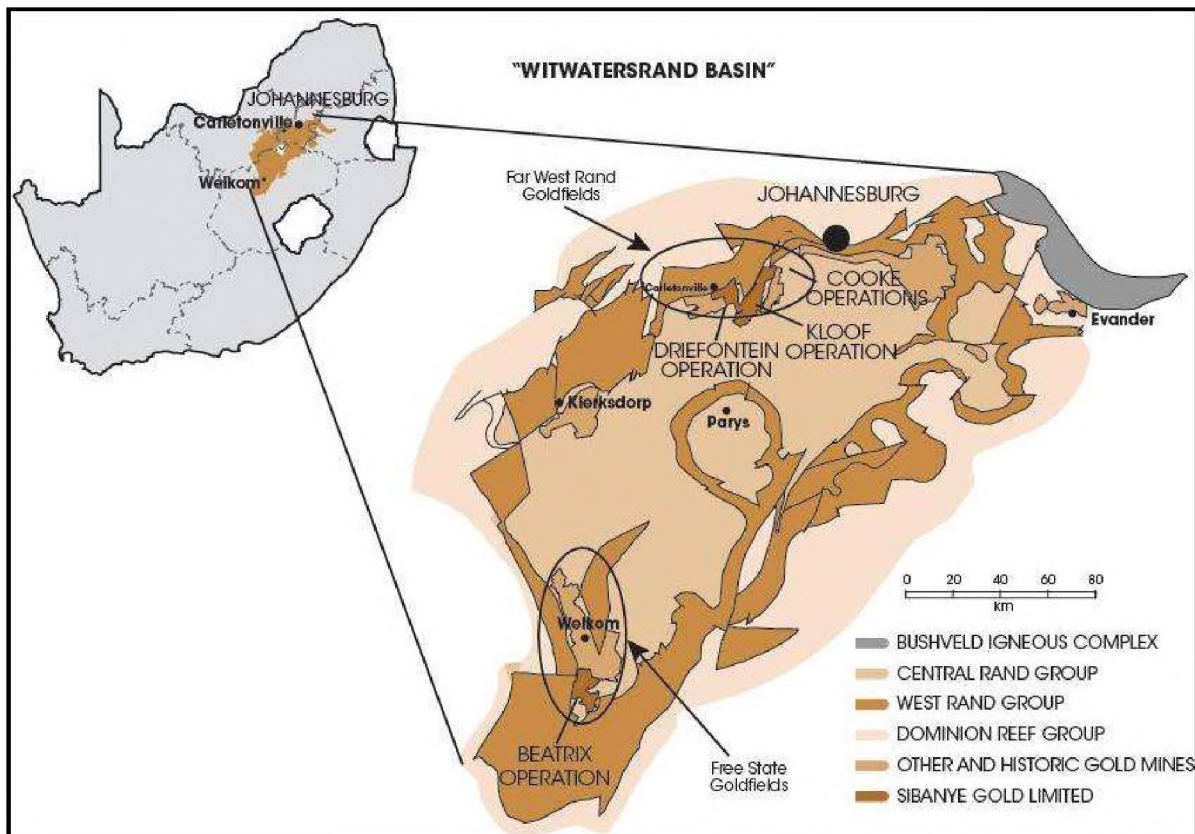


Figure 1.1: Geographical location of the Witwatersrand Basin, South Africa showing the locality of Beatrix Mine in the Freestate Goldfield. (From: Competent Person's Report on the Mineral Assets of Beatrix Gold Mine, 2012, Sibanye Gold Ltd).

Beatrix No. 4 Shaft (West Section) was commissioned in 1981 to exploit uranium, but the mine was closed in 1984 due to the low prevailing uranium price and was later opened for gold production in 1993 exploiting the Kalkoenkrans (KKR) Reef. Beatrix Mine's No. 1 and 2 Shafts (South Section) were sunk in 1981 and commissioned in 1985 exploiting the unique Beatrix Reef in the region. Beatrix's No.3

Shaft (North Section) sinking commenced in 1995 and completed in 2001 to exploit the Beatrix Reef, Aandenk Reef, VS5 Reef and composite of the stated reefs. The orebodies in all Beatrix Shafts are relatively flat dipping, thin tabular conglomerates and are exploited by means of conventional hard rock mining methods involving drilling, blasting, scraping, tramming and hoisting (Competent Person's Report on the Mineral Assets of Beatrix Gold Mine, 2012). Beatrix Gold Mine produces approximately 10 tons of gold annually. The mineral resources and reserves of Beatrix Gold Mine are summarized below in Tables 1.1 & 1.2 respectively.

Table 1.1 Beatrix Mine's Mineral Resources estimates as at December 2013,

<https://www.sibanyegold.co.za/operations/beatrix/resources-and-reserves>

Classification	Tons (Mt)		Grade (g/t)		Gold ('000oz)	
	2013	2012	2013	2012	2013	2012
Underground						
Measured (A1)	16.2	18.5	6.2	7.1	3,210	4,252
Indicated (A1)	21.1	13.2	5.6	7.2	3,822	3,053
Indicated (B1)	8.8	5.4	3.5	5.7	1,001	981
Total underground	46.1	37.2	5.4	6.9	8,034	8,286
Total (A1)	37.3	32.4	5.9	7.0	7,033	7,305
Total (B1)	10.5	5.4	3.5	5.7	1,001	981
Surface						
Indicated surface rock dumps	8.8	11.7	0.4	0.4	134	148
Total Mineral Resources	56.1	48.	4.5	5.4	8,168	8,434

Table 1.2. Beatrix Gold Mine's Mineral Reserves estimates as at December 2013,

<https://www.sibanyegold.co.za/operations/beatrix/resources-and-reserves>

Classification	Tons (Mt)		Grade (g/t)		Gold ('000oz)	
	2013	2012	2013	2012	2013	2012
Underground						
Measured (A1)	15.2	9.6	3.8	4.7	1,836	1,462
Indicated (A1)	15.5	14.4	3.4	4.0	1,706	1,859
Indicated (B1)	–	–	–	–	–	–
Total underground	30.7	24.0	3.6	4.3	3,543	3,321
Surface						
Probable surface rock dumps	7.5	4.0	0.4	0.3	88	37
Total Surface	7.5	4.0	0.4	0.3	88	37
Total Mineral Reserves	38.1	28.0	3.0	3.7	3,631	3,357

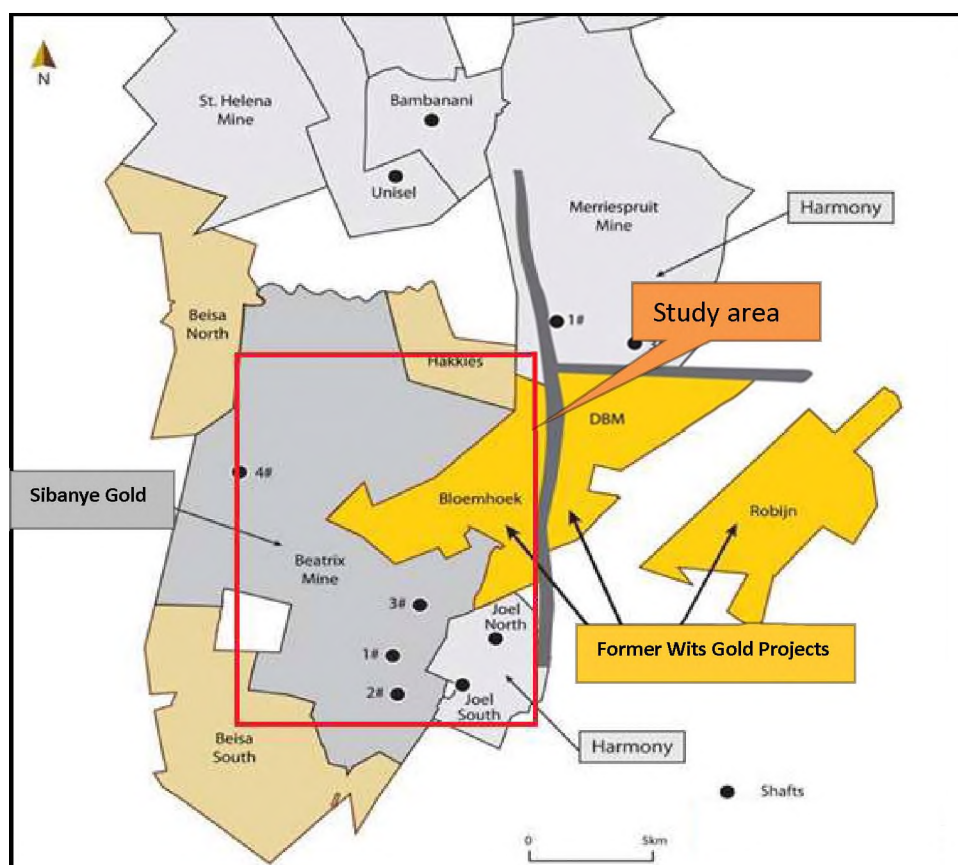


Figure 1.2: Outline of the study area and the location of Beatrix Gold Mine in the Southern Free State Goldfield. (Modified from Munting *et al.*, 2015).

1.2 Problem Statement

Historically, the principal placers exploited at Beatrix Mine No. 3 Shaft (North Section) were Beatrix Reef, Aandenk Reef, and Beatrix/Aandenk Composite Reef. Recently, the VS5 Reef has emerged to be a major contributor of ore tonnages mined at Beatrix No.3 Shaft and will become a significant reef type for the future of the shaft as mining advances into deeper levels towards the north. The high grade Beatrix and Aandenk Reefs will be exhausted in the mine lease area in the foreseeable future and the VS5 Reef will form an integral part of gold production from the shaft.

A vast amount of research work in the past has been focusing on the Beatrix and Aandenk Reefs as the important placers in the mine area and therefore these reefs are fairly understood compared to the VS5 Reef. Gold grades in the VS5 Reef are highly variable from uneconomic through marginal to economic zones. In order to aid mine planning and scheduling into economic zones of the VS5 Reef, it was suggested that a detailed depositional model and sedimentological study of the VS5 Reef be undertaken. There was also an uncertainty as to whether the VS5 and Beatrix Reefs occur on the same unconformity and their subcrop relationship; therefore this study gave a good platform to ascertain the stratigraphic relationship of the two reefs.

The mine has also recently acquired some ground further north of the current mine lease area (Bloemhoek block) comprising of VS5 Reef, hence this study will aid in predicting the grades and geology when mining into the area commences.

1.3 Aim and Objectives of the study

The main aim of this study was to determine the sedimentological and depositional model of the VS5 Reef as it occurs at Beatrix Mine No. 3 Shaft (North Section), its correlation with the stratigraphic sequences of the rest of the Free State Goldfield and its relationship to the underlying Aandenk Reef and the adjacent Beatrix Reef by means of detailed sedimentological investigations. The correlation between the sedimentological parameters and gold grades would then be used to delineate VS5 facies to aid in prediction and delineating VS5 zones which are economically viable. The writer aims to identify pertinent sedimentological and morphological characteristics of the placer which will be shown to be important from an exploration and mine valuation view point. This can be obtained by achieving the following objectives:

- To provide a detailed description and quantification of the sedimentology of the VS5 Reef as it occurs at Beatrix Mine and the surrounding areas.

- To determine the sedimentological controls on lateral and vertical gold concentrations in the VS5 Reef and predicting areas of elevated gold grades in the VS5 Reef areas of the mine lease area.
- To ascertain the relationship between the VS5/Beatrix unconformity and the Aandenk unconformity.
- To construct a model for the environment or formation of the VS5 Reef in the entire region
- Sub-divide the VS5 into different lithofacies.

The author of this thesis accumulated new geological information through mapping of underground mining exposures and borehole core logging. This was supplemented by information gathered from an examination of sampling data gathered from Beatrix Mine between the years 2013 to 2015. Additional historical data was obtained from database archives, verified and incorporated with the new data. The author's understanding of the gold reefs on Beatrix was augmented by knowledge gathered from colleagues during day to day discussions, geology meetings and workshops as well as mini-projects undertaken on the VS5 Reef. The author's findings were compared to and tested against observations shared by colleagues in the department and other sections.

The author was solely responsible for the synthesis of the data, and all interpretations and conclusions presented below.

1.4 Methodology

The VS5 placer is examined both geologically and statistically to determine the controls of gold mineralization within this particular reef. Data were recorded from underground mining exposures and cores of underground drilling from Beatrix No. 3 Shaft and regional surface boreholes. Data collection comprised the following:

- Compilation of detailed sedimentological profiles from underground mining exposures as well as underground and surface boreholes.
- Determination of paleo-current direction using indicators such as channel edges, scours and crossbedding.
- Quantitative investigation of the VS5 pebble size distribution.

Data were processed in Datamine and Cadsmine; Surfer was used for contouring.

1.5 Literature Review

Attempts to determine the intimate relation of the gold to sedimentary features in the Witwatersrand Basin began as early as the 1930's (Genis, 1990). However, it was only after the work of Steyn (1963) that systematic sedimentological investigations were carried out in trying to resolve the origin of the reefs. Most researchers in the Free State Goldfield have focused on other placers including the Basal/Steyn Reef, Leader Reef, B-Reef, A-Reef, Kalkoenkrans (KKR) and Beatrix Reef and little focus on the VS5 Reef. One major contributing factor to this is the fact that the VS5 Reef has lower gold concentrations and is not as economically viable to mine at the current economic conditions as the other placers therefore attention was given to the economically viable placers.

Although there is scarcity of published literature on the VS5 Reef, the sedimentology of VS5 Reef in the Welkom Goldfield has been addressed in a few internal reports for mining and exploration companies over the years. Young and Viljoen (1994) documented the stratigraphy, sedimentology and gold distribution of the VS5/Beatrix Composite Reef at H.J Joel Gold Mine which shares a common boundary on the east of Beatrix Mine property. This publication indicated that the VS5/Beatrix Reef occurs at the base of the Elsburg Formation of the Central Rand Group and is considered to unconformably overlie the lowermost Main Formation of the Central Rand Group. Young and Viljoen (1994) described the VS5/Beatrix Reef at Joel Mine to be composed mainly of clast supported conglomerates, planar bedded conglomerates interbedded with pebbly quartzite and trough cross bedded quartzite. The pebble assemblage consists of silicified yellow shale clasts, white, black and gray vein quartz pebbles (Young and Viljoen, 1994).

The VS5/Beatrix Reef at Joel area is interpreted to have formed by the desegregation of the pre-existing Beatrix Reef. The lower gold values recorded in the VS5/Beatrix Reef compared to the underlying placers (Beatrix and Footwall Reefs) was interpreted to result from dilution of Beatrix Reef material by barren VS5 material combined with the primary sedimentary factor of the relatively smaller pebble sizes of this reef type forming poor gold concentration traps (Young and Viljoen, 1994). Minter *et al.* (1988) carried out sedimentological and mineralogical investigations of the conglomerates at the base of the Eldorado (Elsburg) Formation of the Central Rand Group intersected in exploration boreholes north of the study area. They concluded that fluvial and debris flow sediments on the Elsburg palaeo-surface contain placer concentrates derived from the recurrent reworking of the sub-cropping placers.

Kingsley (1987) studied the Eldorado (Elsburg) Formation in the Welkom Goldfield and concluded that the Elsburg Formation gravels and sands were deposited from west to east as alluvial fans and

redistributed longitudinally as gravel and sand bars on a broad braid plain down a south-eastward palaeo-slope. The transport direction of the VS5/Beatrix Reef is in the north-southerly direction. The depositional environment of the VS5 Reef was described by Young and Viljoen (1994) to be more likely a proximal facies within a braided fluvial environment.

Smith (1991) studied the sedimentology of the auriferous Aandenk and VS5 Reefs within the Lekkerlewe block which is situated just to the north of Beatrix Mine and immediate environments. He sub-divided the VS5 Reef into 3 types of conglomerates namely:

Polimict VS5 - is a colorful polymictic class-supported conglomerate. The maximum pebble size of this conglomerate is generally smaller than in the oligomictic VS5 variety.

Oligomict VS5 - is an oligomictic clast supported conglomerate composed entirely of smokey and milky vein quartz pebbles.

Composite VS5 - comprises a polymictic top which gradationally changes into an oligomictic base. This oligomictic base consists entirely of large well rounded smokey/milky vein quartz pebbles. The sources of these pebbles are thought to be from the underlying Aandenk Reef.

Mapping by Beatrix Mine geologists over the years has enabled the VS5 to be subdivided into different lithofacies in the basis of variations in the maturity of conglomerate, pebble assemblage and mean maximum pebble size. Three main lithofacies of VS5 are recognized; Immature, Sub-mature and Mature VS5.

Chapter 2

Geological Setting

2.1 Introduction

The lithologies observed at Beatrix Mine are all units of the Witwatersrand Supergroup. This chapter highlights the geology and evolution of the Kaapvaal Craton, the Witwatersrand Basin with emphasis on the Central Rand Group which hosts most of the auriferous conglomerates units preserved in the Welkom Goldfield. Included in this chapter is the local geology of Beatrix Gold Mine.

2.2 Kaapvaal Craton

The Kaapvaal Craton represents an ancient segment of the continental crust formed in Southern Africa by a complex combination of processes analogous to modern-day plate tectonics episodically over the 1000 million year period from 3.7 Ga to 2.7 Ga (Robb and Meyer, 1995). These processes involved magmatic arc formation and accretion as well as tectonic amalgamation of numerous, discrete terranes or blocks (Poujol *et al.*, 2003). De Wit *et al.* (1992) envisaged a two-stage process in which the cratonic nucleus formed by initial tectonic imbrication of slabs of hydrated oceanic lithosphere which then partially melted between 3.2 and 3.1 Ga; and was then modified and enlarged by Cordilleran-type subduction-accretion processes between 3.1 and 2.6 Ga. Lana *et al.* (2002), pointed out that the Kaapvaal Craton of Southern Africa (Figure 2.1) and the Pilbara Craton of Australia represent the only two extensive and largely pristine preserved mid-Archean crustal fragments on earth that provide most direct record of ancient planetary evolution. However, the complex mechanisms of formation and stabilization of the early continents are still incompletely understood (Schmitz *et al.*, 2004).

Poujol *et al.* (2003), subdivided the Kaapvaal Craton into the Eastern, Western, Northern and Central domains. The Northern domain comprises the Giyani, Murchison and Pietersburg greenstone belts. The Western domain consists of the Gaborone Granite Complex, the Amalia, Kraaipan, and Madibe greenstone belts, along with the granitoid terrain in the Kimberley region. The Eastern domain consists of the Barberton greenstone belt as well as all granitoids extending northwards to Hazyview and southwards into Swaziland, including the Pongola Supergroup. The Central domain includes the Johannesburg Dome, the Rand Anticline and the Vredefort Structure. The volcano-sedimentary rocks of the Witwatersrand Supergroup accumulated in a basin developed in the Central Domain of the Kaapvaal Craton.

Much of the Kaapvaal Craton is covered by younger Neoproterozoic-to-Palaeoproterozoic volcano-sedimentary sequences and penetrated by numerous Late Archean granites, therefore good exposures of basement exist in only a few areas (Poujol *et al.*, 2003; Anhaeusser and Walraven, 1999). The Barberton mountain Land region represents an exceptional three-dimensional exposure and represents the type area for Archean crustal evolution on the craton (Poujol *et al.*, 2003).

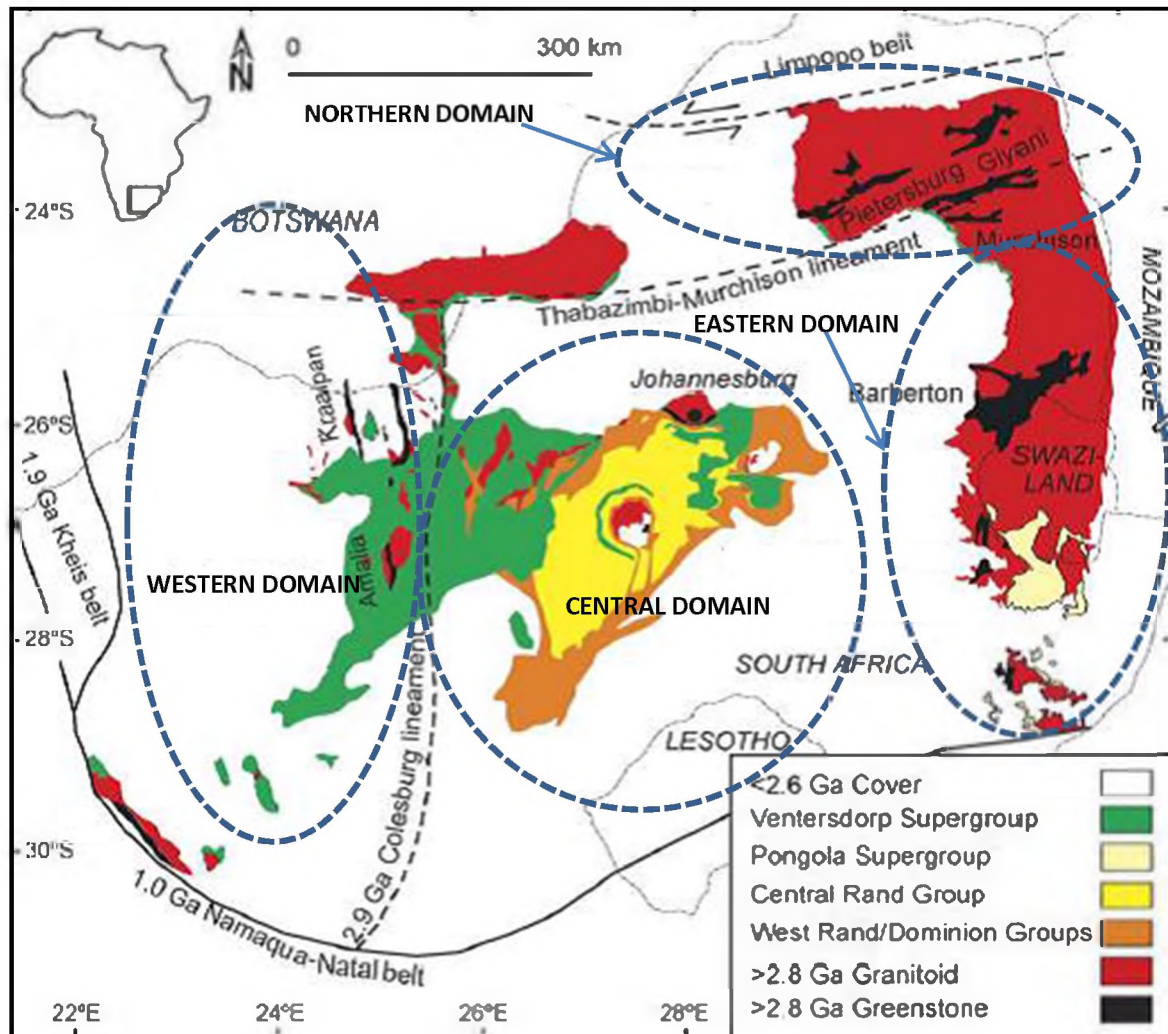


Figure 2.1: Simplified diagram showing the outline of the Kaapvaal Craton and the main geological components as well as the location of the Eastern, Central, Northern and Western domains (modified after Schmitz *et al.*, 2004)

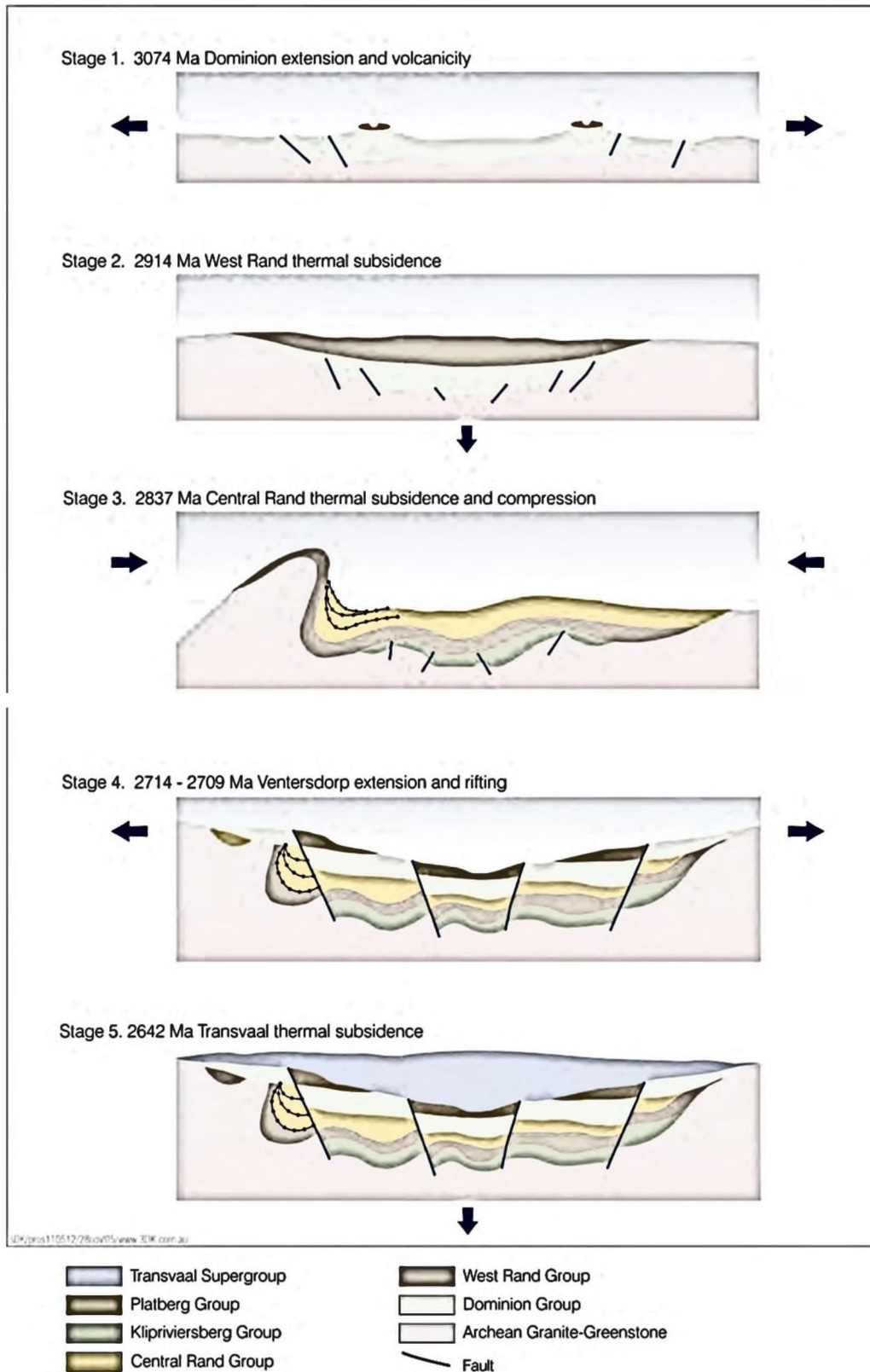


Figure 2.2: Tectonic evolution of the Kaapvaal Craton 3 074 Ma to 2 600 Ma (Tweedie, 1986).

2.3 Witwatersrand Supergroup

The Witwatersrand Basin is the largest known repository of gold in the Earth's history, making South Africa a dominant producer of gold in the past century, responsible for 40% of the world's gold production (Gibson and Reimold, 1999; Wilson & Anhaeusser, 1998) and 90% of South African gold production. Although production is declining significantly due to socio-economic factors and increasing mining depths, the Witwatersrand Basin will continue to fuel the country's economy and provide jobs and income to people of South Africa for a long time to come (Wilson & Anhaeusser, 1998). Historic gold production in the Witwatersrand Basin is estimated to be in excess of ~52 000 t and remaining reserves and resources were estimated at ~16 400 t in 2014 (Frimmel and Hennigh, 2014).

The Witwatersrand Basin is situated approximately in the central part of the Archean (3.7-2.7 Ga) aged Kaapvaal Craton (Ainslie, 1981; Greathead and Graad van Roggen, 1986), occupying an area of 24000 km² that extends across the Gauteng, Northwest and Free State Provinces of South Africa (Figure 2.1; Jolley *et al.*, 2004; Robb and Meyer, 1995). Numerous models have been proposed to explain the formation of the Witwatersrand Basin including a **taphrogenic** model proposed by Pretorius (1981), a **plate-tectonic** model proposed by van Biljon (1980), a **cratonic foreland** model proposed by Winter (1987) and an **intracratonic, alluvial-plain / lacustrine** model proposed by Vos (1975). The basin is an intracratonic basin formed in an Andean-style collisional setting during the Archean eon (Jolley *et al.*, 2004, Armstrong *et al.*, 1986; Large *et al.*, 2013). Stratigraphically, the Witwatersrand Supergroup overlies the basement granites and greenstone belts and the 3.1 Ga volcanic and sedimentary rocks of the Dominion Group (Figure 2.2). The Witwatersrand Supergroup is unconformably overlain by the late-Archean (2.7 Ga) Ventersdorp Supergroup comprised of mafic and ultramafic lavas of the Klipriviersberg Group, succeeded by the mixed mode volcanics and sediments of the Platberg and Pniel Groups. Unconformably overlying the Ventersdorp Supergroup are the clastic and carbonate sediments of the early Proterozoic (2.6 Ga) Transvaal Supergroup. This in turn is covered by the younger (280 Ma) Karoo sequence (Jolley *et al.*, 2004; Wilson & Anhaeusser, 1998).

The southwest-northeast elongated basin formed in a fluvio-deltaic environment in which several depositional and post-depositional events gave rise to the approximately 7km thick sequence of sedimentary rocks. The Witwatersrand Supergroup consists of the shale and sandstone dominated West Rand Group and the Central Rand Group, composed mostly of sandstones along with gold and uranium bearing conglomerates (Figure 2.3; Van den Heever, 2008; Phillips and Law (2000). Using U-Pb zircon dating techniques Robb *et al.* (1990) and Robb and Meyer, (1995) constrained the ages of

the West Rand Group to between 2970-2914 Million years and those of the Central Rand Group to between 2894-2714 Million years old.

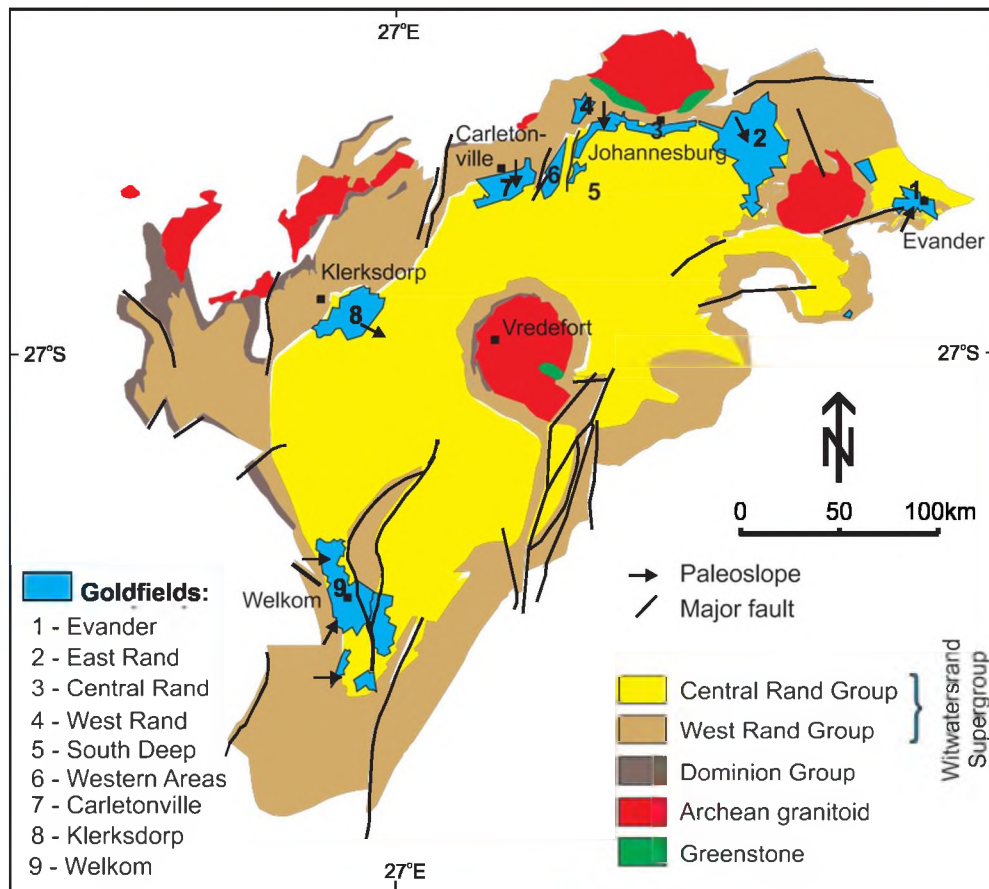


Figure 2.3 Outline of the preserved remnants of Witwatersrand Basin showing the stratigraphic sequences, Goldfields within the basin and paleo-current directions of sediments influx into the individual Goldfields (adapted from Frimmel *et al.*, 2005).

2.3.1 West Rand Group

The West Rand Group forms the basal portion of the Witwatersrand stratigraphy sequence and demarcates the presently preserved extents of the basin (Figure 2.3). It consists mainly of shallow marine to subtidal argillaceous and arenaceous sediments (shales and sandstones) occurring in approximately equal proportion. Small pebble conglomerates also occur in the West Rand Group associated with unconformities but contain insignificant gold concentrations. The Group is subdivided into three Subgroups. The basal Subgroup is the **Hospital Hill Subgroup** comprised of foredeep shales and sandstones. Sea level fluctuation in the basin resulted in the deposition of shales, sandstones and conglomerates of the overlying **Government Subgroup**. Evidence of the first known glaciation on Earth

is represented by the Promise diamictite (McCarthy and Rubidge, 2005; SACS Task Group, 2006). Lastly, the **Jeppestown Subgroup** was formed by the accumulation of mud and sand during a period of equal sedimentation and subsidence of the basin.

2.3.2 Central Rand Group

The Central Rand Group unconformably overlies the West Rand Group and hosts the majority of auriferous conglomerates exploited in the Witwatersrand Basin (Gartz and Frimmel, 1999; Utter, 1979). This Group formed at a time when the Kaapvaal Craton was experiencing uplift, where mountains and valleys were forming on the terrain, leading to thick accumulations of river deposits into these sub-basins (McCarthy and Rubidge, 2005). The Central Rand Group is composed predominantly of sandstones and numerous intercalated conglomerates with minor shale units. The sandstone/shale ratio of this Group is 12:1 compared to 1:1 recorded in the West Rand Group (Wilson & Anhaeusser, 1998 and references therein).

The Central Rand Group is subdivided into the Johannesburg and Turffontein Subgroups. Unconformities with conglomerates beds at their base were used to further subdivide these Subgroups into Formations. Both the Johannesburg and Turffontein subgroups contain concentration of conglomerates in the upper portions (Wilson and Anhaeusser, 1998). The Johannesburg Subgroup is further subdivided into from oldest to youngest, the Randfontein, Krugersdorp and Booyens Formations listed from oldest to youngest. The overlying Turffontein Subgroup is subdivided into the Kimberley, Elsburg and Mondeor Formations (Figure 2.3).

This study will focus mainly on the Elsburg Formation which hosts the VS5 placer Au Reef in the Welkom Goldfield.

2.3.3 The Free State Goldfield

Nine individual goldfields have been identified in the Witwatersrand Basin, each with different-paleo current directions (Figure 2.3). The Free State Goldfield, also referred to as the Welkom Goldfield is located in the most south- westerly extent of the basin in the Welkom area (Figure 2.3) and extends from Allanridge in the north to midway between Virginia and Theunissen in the south (Dwyer, 1993). The auriferous reefs in the Welkom Goldfield occurs within the Central Rand Group and can be correlated, in broad terms, with the Klerksdorp and Central Rand Goldfields of the north and west parts of the basin. Studies show a south-west source of sediment influx into the basin. Several mines

are operating in the Welkom Goldfield including the Harmony, President Steyn and Sibanye Gold operations. The Basal Reef discovered in 1939 forms the major economic horizon in the Goldfield and more than 7900 tons of gold has been produced from the Free State Goldfield (McCarthy, 2006).

The West Rand Group is poorly understood in the area. The Central Rand Group rocks are in excess of 2km thick in the northern parts of the Goldfield and thin drastically southwards to about 0.5 km towards the edge of the basin. The thinning is a consequence of internal erosion and resulting sub-cropping of formations towards the edge of the basin. The mineralized Beisa conglomerate (5 to 150cm thick) marks the base of the Central Rand Group (Figure 2.4). The Beisa Reef is then overlain by argillaceous and siliceous quartzites of the Main and Randfontein Formations. Overlying the Randfontein Formation is the Luipaardsvlei Formation, its base marked by the Intermediate Reef conglomerates overlain by cross-bedded quartzites which are locally gritty. The Luipaardsvlei Formation is overlain by the economically important Basal and Steyn conglomerates reefs that comprise the base of the Krugersdorp Formation. These placers are in turn overlain by khaki shales. Disconformably overlying this sequence is the Leader Reef which onlaps southwards to form the base of the Booyens Formation. The sequence fines upwards to shale. Disconformably overlying the Booyens Formation is the Kimberley Formation with the mineralized B Reef conglomerate forming the base of the sequence. The Aandenk conglomerate Reef occurs in the upper part of the Kimberley Formation. Above the Kimberley Formation is the Elsburg Formation with the mineralized Beatrix Reef in the south and VS5 Reef in the north forming the base of the formation. Capping the stratigraphy of the Central Rand Group in the Welkom Goldfield is the Mondeor Formation comprising of a clastic wedge which coarsens both upwards and to the west where boulder conglomerates are developed (McCarthy, 2006).

The Central Rand Group is then overlain by the Ventersdorp Supergroup with its base marked by the locally mineralized Ventersdorp Contact Reef (VCR) conglomerate. The younger Karoo sediments cover the whole Goldfield (Minter, 1976b).

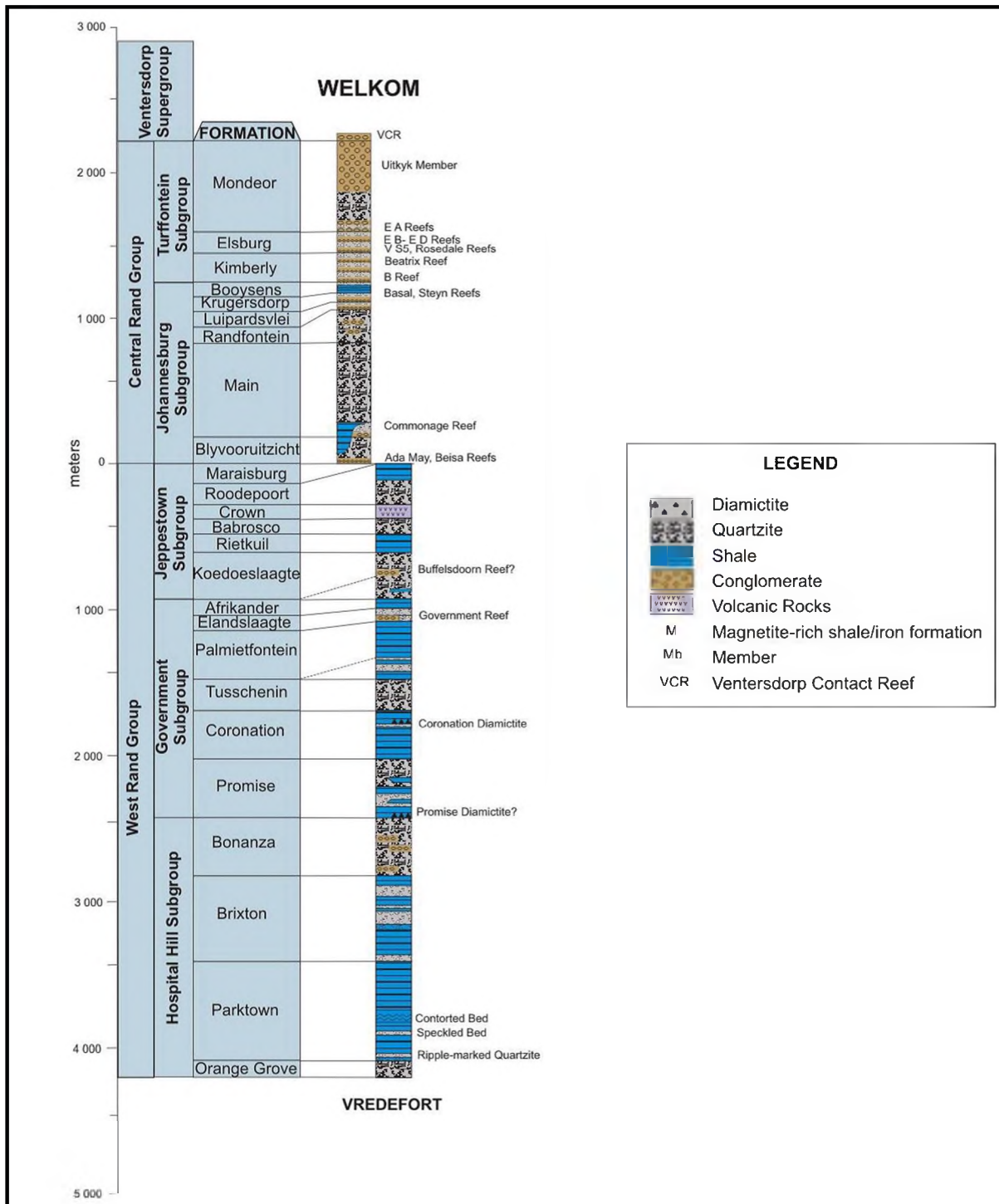


Figure 2.4: Stratigraphy of the Witwatersrand Supergroup in the Welkom Goldfield. (Wilson and Anhaeusser, 1998)

2.4 Stratigraphy at the Beatrix Mine

The Beatrix Gold Mine is located in the south-western portion of the Welkom Goldfield (Figure 1.2). In the mine area, about 500m thick sequence of flat lying Karoo sediments overlies the Ventersdorp and Witwatersrand Supergroups. The West Rand Group of the Witwatersrand Supergroup overlays the Archean basement rocks in the area. The conglomerates of the Free State Goldfield are hosted in the Central Rand Group. The Central Rand Group varies in thickness from over 2015 m in the northern part of the Welkom Goldfields down to 1000m thick in the Beatrix Mine area (Figure 2.6). This change in thickness from north to south is the result of truncation of parts of the lower Central Rand Group Formations by on-lapping of unconformities towards the edge of the basin (Figure 2.5).

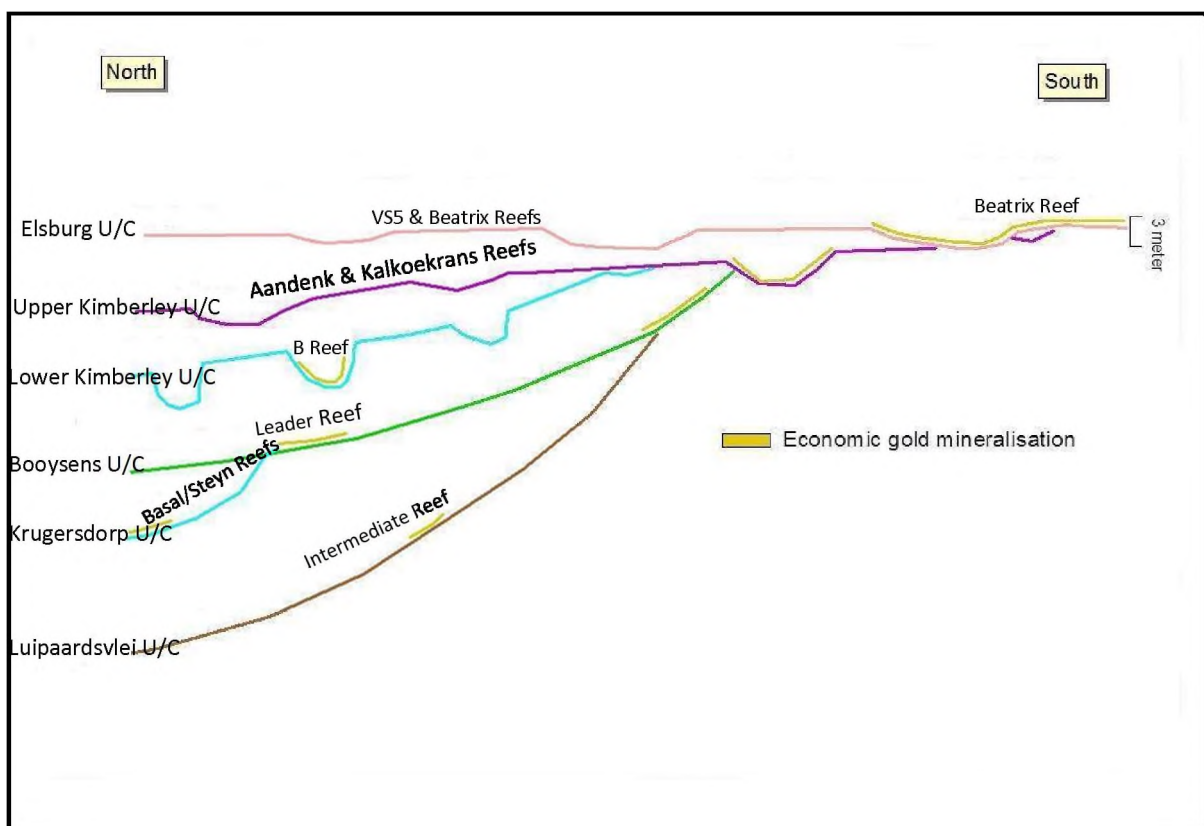


Figure 2.5 Schematic north-south section showing the on-lapping relationships of unconformities across the study area. Modified after Muntingh *et al.* (2015), Sibanye Gold internal company report.

The on-lapping nature of Formations towards the southern edge of the basin has resulted in the elimination of major gold producing units of Basal/Steyn Reefs and Leader Reef at Beatrix Mine area. In the Southern reaches of Beatrix Mine where the No.1 and No.2 Shafts are located, the Beatrix placer at the base of the Elsburg Formation rests directly on the Main (Virginia) Formation which occurs at the base of the Central Rand Group (Figure 2.3). Towards the north of the mine area, evidence from stoping panels indicates that the Beatrix Reef transforms to VS5 conglomerate at the same

unconformity (Figure 2.6). Here the VS5 overlies the Aandenk/Kalkoenkraans placers of the Kimberley sequence.

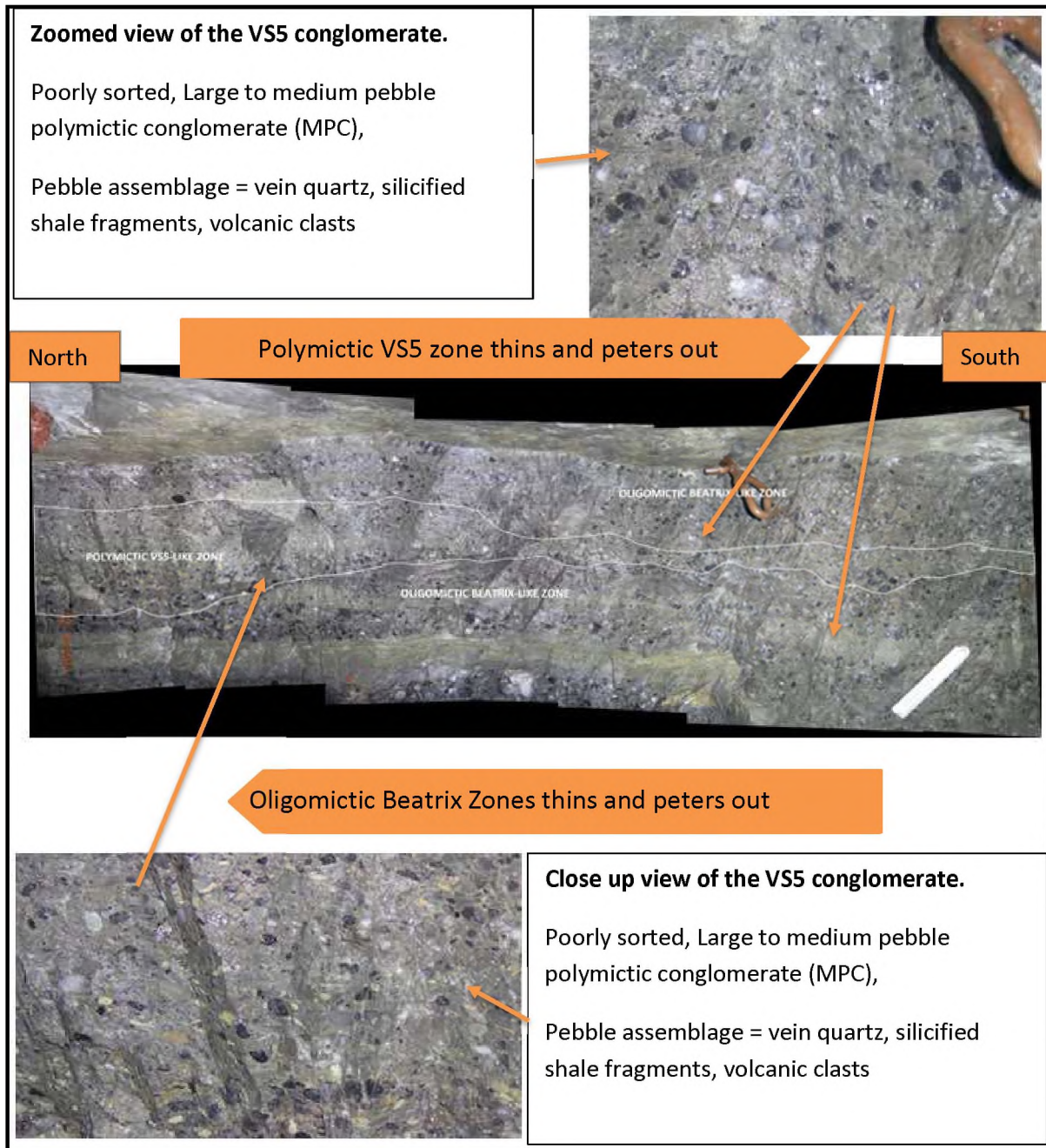


Figure 2.6: Stratigraphic relationship between VS5 and Beatrix Reefs as observed at 26A 47 E8 panel. Note the thinning and eventual disappearing of VS5 into Beatrix towards the south and Beatrix Reef towards the north (images courtesy of Dirk Muntingh).

2.4.1 Main & Blyvooruitzicht Formations

The Main and Blyvooruitzicht (formerly referred to as Virginia) Formations in the Beatrix Mine area form the base of the Central Rand Group. At the base of the Blyvooruitzicht Formation lies the gold

and uranium bearing Beisa Reef which rests on top of the West Rand Group sequence (Figure 2.7). The Main Formation forms the immediate footwall to the Beatrix Reef in the south and is overlain by the Aandenk Formation towards the north in the Beatrix area. The Main Formation represents the Lower-footwall succession whereas the Middle-footwall and the Upper-footwall beds are represented by the Randfontein and the Luipaardsvlei Formations respectively. The upper parts of this Formation are eroded and truncated by the Elsburg unconformity towards the south. The Main and Blyvooruitzicht Formations are further subdivided into six units based on lithological variations. The units have been named LF1 to LF6 in increasing order with depth.

The lowermost unit is the LF6 which overlies the Jeppestown Subgroup of the West Rand Group. The Ada-May or Beisa Reef which is a placer mineralized with uranium and traces of gold is taken as the base of the Blyvooruitzicht Formation (Minter *et al.*, 1986) and is overlain by the LF6 succession. The LF6 quartzites coarsen upwards into thin, small pebble lag layers interbedded with lithic arenites. The transition to LF5 is marked by the appearance of shale beds interbedded with siltstone.

The 2-8m thick LF5 forming the base of the Main Formation is dominantly composed of interbedded shale and siltstone which contains evidence of soft sediment deformation. It is the only dark colored shale or very fine grained lithology in the Johannesburg Subgroup throughout the area south of the Sand River. Transition to LF4 is marked by an erosional surface truncating at the top.

The LF4 comprise a monotonous sequence of medium to coarse grained lithic arenites. It characteristically contains angular granules and small pebbles of chert. Transition to LF3 is marked by the disappearance of chert materials and decrease in grain size of arenites.

The LF3 forms the immediate footwall to the Beatrix Reef in the south and southwestern parts of Beatrix Mine. It consists of medium grained, grey sub-lithic arenite. The arenite is dominated by quartz grains with chert and fine grained- wacke grains forming minor components. Larger grains and small granules of quartz, chert and silicified shale occur scattered throughout the succession.

The LF2 varies in thickness from 1 to 3m consistently throughout the area and consists of grey medium grained quartz arenite. The cross-bedded quartz arenite is well sorted and contains dark grey, fine-grained silty materials as partings on the bedding planes.

Finally, the LF1 occurring at the top of the Virginia Formation forms the immediate footwall to the Beatrix Reef over most of the Beatrix Mine area. The upper parts of LF1 is eroded and truncated by the unconformities at the base of the Aandenk and Eldorado Formations. In the southwestern areas of the mine lease area the LF1 is completely eroded away. The unit consists predominantly of medium to coarse grained, sub-lithic arenite. The matrix consists predominantly of sericite which documents

alteration and metamorphic recrystallization to muscovite. The LF1 coarsens upward from medium grained arenite at the base to coarse grained arenite which is conglomeratic in parts.

2.4.2 Randfontein Formation

Overlying the Main Formation to the north of the mine is the Randfontein Formation representing the middle footwall succession. Towards the south of the mine area, the Randfontein Formation is completely eroded or has been truncated by the Kimberley and Elsburg unconformities. The middle footwall sequence is subdivided into MF1 to MF4 based on lithological variations.

MF1- is a Khaki colored argillaceous quartzite interbedded with polymictic conglomerates. The conglomerates have an argillaceous matrix. The packing of the conglomerates decreases downwards to pebbly quartzite.

MF2 – is similar to MF1 but contains no conglomerate. The MF2 quartzite is grey, glassy coarse-grained with prominent cross bedding in places.

MF3- is comprised of a Yellowish-grey, coarse grained to gritty dirty quartzite. The zone contains scattered grits and poorly developed poorly mineralized Small pebble conglomerate (SPC) to medium pebble conglomerate (MPC) bands, the latter being prominent towards the base of the zone. The fragments consist mainly of quartz, chert and shale beds commonly up to 16 cm thick.

MF4-This zone is composed of alternating beds of light grey, clean sub glassy fine grained quartzite and yellowish-grey, dirty, coarse grained to gritty quartzite. Shale bands (up to 9 cm thick) occur occasionally. The Intermediate Reefs and Upper footwall (UF) successions (Luipaardsvlei Formation) and the Leader Reef in the Krugersdorp Formation are missing at the Beatrix Mine area due to onlapping of Formations towards the basin edge (Figure 2.6). Overlying the Randfontein Formation is the Kimberley Formation.

2.4.3 Kimberley Formation

The Kimberley Formation occurs at the base of the Turffontein Subgroup of the Central Rand Group. In the area south of the Sand River, the Kimberley Formation thins rapidly towards the south due to truncation by the Elsburg unconformity (Figure 2.4). In the southwestern parts of Beatrix Mine only remnants of the Upper Kimberley (Aandenk) Formation is preserved below the Beatrix Reef. In the northeastern parts of the mine lease area, the Aandenk Formation remnants occur below the VS5

Reef. The Kimberley Formation eroded and overlies the Main Formation in the area with a well pronounced basal scour. Evidence of erosion is indicated by the inclusion of footwall quartzite material as pebbles and matrix at the base of the Aandenk Formation.

The base of the Kimberley Formation is marked by the appearance of the Aandenk/Kalkoenkrans placer sitting on an erosional unconformity. The Kimberley Formation comprises siliceous quartzites and conglomerates with interbedded argillaceous quartzites (Minter *et al.*, 1976a). The Aandenk and Kalkoenkrans placers have similar characteristics comprising of channelized very large to large pebble conglomerate (VLPC-LPC) with siliceous matrix interbedded with siliceous quartzites. The two reefs were given different names as they are located in different farms, but stratigraphically occur in the same position.

2.4.4 Elsburg Formation

The Elsburg Formation Forms the Upper parts of the Turffontein Subgroup of the Central Rand Group and overlies the Kimberley Formation to the north of Beatrix Mine lease area. Due to erosion and onlapping of formations towards the edge of the basin, the Elsburg Formation rests directly on top of the footwall succession of the Main Formation in the southwestern parts of the mine (Figure 2.6). The base of the Elsburg Formation is marked by the VS5 conglomerate to the north which changes to Beatrix Reef conglomerate towards the south (Figure 2.5). Previous workers on the Beatrix Reef e.g. Genis (1990), documented that the Beatrix Reef and the VS5 occurs on different unconformities with the VS5 disconformably overlying the Beatrix Reef. It was proposed that the Beatrix Reef is a relatively local and a minor unconformity-bounded unit within the VS5 Formation (Genis, 1990) However evidence from current mining areas at Beatrix No. 3 Shaft indicates that the VS5 and Beatrix Reefs occurs in the same unconformity with a short transition area (about 20m) where the two reefs occurs together Figure (2.6).

The Elsburg series in the Beatrix area and areas south of the Sand River was divided into VS2 to VS5 sub-units based on lithological variations and the relative abundance of conglomerate beds (Genis, 1990). The VS5/Beatrix placers occurs at the base of the Elsburg unconformity and is overlain by VS4 comprising of about 30m of an upward fining sequence of dark grey, medium to coarse grained quartzite with cores to grit size white and black cherts, yellow shale and occasional lava fragments with small pebble conglomerates at the base. The VS4a conglomerate at the base of the Rosedale Member is generally poorly mineralized, but locally well mineralized zones have been sampled in the mine where the VS4a have reworked the underlying Beatrix and Aandenk Reefs. The VS4a forms the immediate hangingwall to the Beatrix and VS5 Reefs in the mining areas. The VS4a sequence fines upwards and are capped by fine grained arenites and shale in some places (Genis, 1990).

Overlying the Rosedale member is the Van den Heerersrust Member (VS3) comprising an approximately 120m upward coarsening sequence of lithic arenites with an erosional base and is occasionally defined by a gravel / grit bed. In the basal part of the zone, thin black shaly and silty lamina are common but decreases in frequency as the arenites become coarser grained. Towards the top of the member, poly-mictic granule size conglomerates become more prevalent. The clasts are generally angular to sub-rounded and consist predominately of quartz, chert and silicified shale. Lithic arenites are interbedded with sub-lithic arenites but do not reach the maturity of quartz arenites. Fine grained, rounded pyrite grains frequently concentrate on the foreset lamina in the more mature arenites (Genis, 1990).

Occurring at the top of the Elsburg Formation is the Uitkyk Member (VS1 & VS2) comprising of approximately 200m of upwards coarsening sequence of oligomictic and polyomictic well packed small pebble conglomerate beds, interbedded with sub lithic arenites as well as lithic wacke to lithic arenite with scattered pebbles. The VS1 unit has been separated and represents the Mondeor Formation marking the end of the Central Rand Group and the Witwatersrand Supergroup.

2.5 Ventersdorp Supergroup

Unconformably overlying the Central Rand Group in the area is the volcanic rocks of the Klipriviersberg Group of the Ventersdorp Supergroup and is in turn overlain by the sedimentary rocks of Platberg Group. The Klipriviersberg Group is composed of Light grey to greenish grey amygdaloidal and none amygdaloidal andesitic lavas. The Lavas are truncated to the south by the pre-Karoo erosional surface. The overlying Platberg Group is comprised of clastic sediments varying from coarse, polyomictic boulder conglomerates to black shales and fine grained quartzites. Genis (1990, and references therein) interpreted the rapid facies change from boulder conglomerates to fine grained shales as alluvial fans deposits, with the coarse sediments representing the proximal facies and the fine grained quartzites and shales representing the distal facies.

2.6 Karoo Supergroup

The whole of the Welkom Goldfield is covered by the younger flat lying sediments of the Karoo sequence which were deposited in Carboniferous to Triassic times. The base of the Karoo Supergroup is marked by the 0-300m thick Dwyka Formation composed of tillite with local intercalations of sandstones and shales representing a period of glaciation in the Permian era. Overlying the Dwyka Formation is the white to grey, fine to coarse grained sandstone of the Eccca Group which is often micaceous. Micaceous shales, carbonaceous shales and coal seams constitute minor lithologies in the Vryheid Formation of the Eccca Group. Overlying the Vryheid Formation is the grey-blue to black coloured shales of the Volksrust Formation. Concluding the Karoo sequence in the area are the shales of the Beaufort Group.

Chapter 3

Structure

3.1 Introduction

Structural features such as faults and folds played a major role in preserving the Witwatersrand rocks from being eroded away during or immediately after deposition (Stewart *et al.*, 2004). This section aims at reviewing structural features affecting the Welkom goldfield with special focus to the structures affecting the Beatrix Mine area.

3.2 Regional structure

Tectonic activity after the deposition of the Witwatersrand basin modified the distribution of reefs in the region. Folding and faulting events resulted in the formation of anticlines, synclines, overturned folds, horst and graben structures in the basin. The western margin of the basin is marked by a prominent overturned fold structure. There are four well known major faults in the Free State Goldfield namely the De Bron Fault, with a throw of well over a thousand meters, and the Stuurmanspan, Dagbreek and Ararat Faults (Figure 3.1). These major normal faults strike north-south and are known to have large dextral displacements. These faults resulted in the formation of horsts and graben blocks. Faulting is estimated to have occurred during the middle Venterdorp times (Minter *et al.*, 1986). Up-faulted Central Rand Group sediments in horst blocks were eroded during the Venterdorp times but those sediments in grabens were preserved (Minter *et al.*, 1986). Major reverse faults and monoclinical folds are key features of the Welkom Goldfield but are unimportant to the structure of the VS5-Reef at Beatrix Mine.

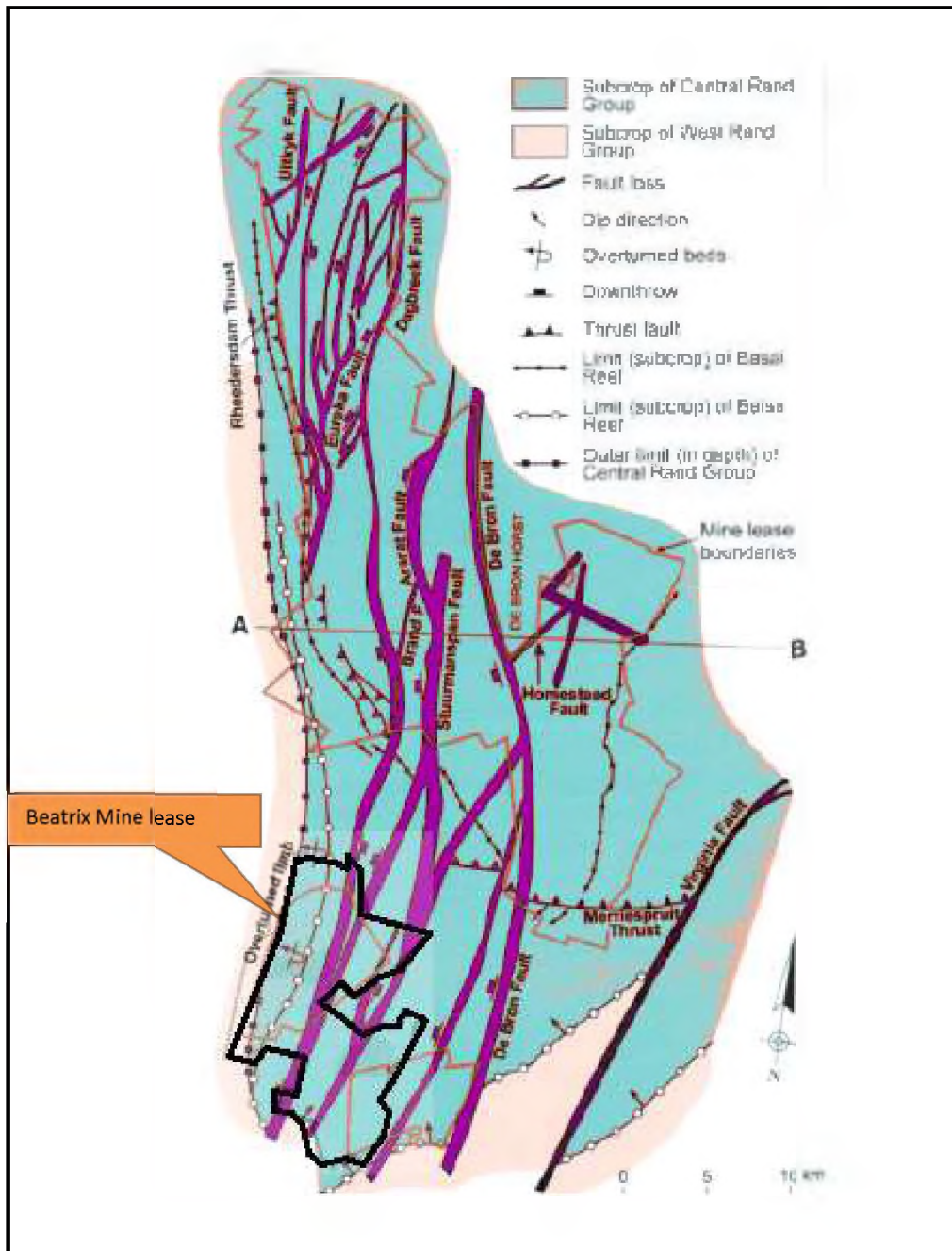


Figure 3.1: Simplified structural map of the Welkom Goldfield. (Modified after McCarthy, 2006).

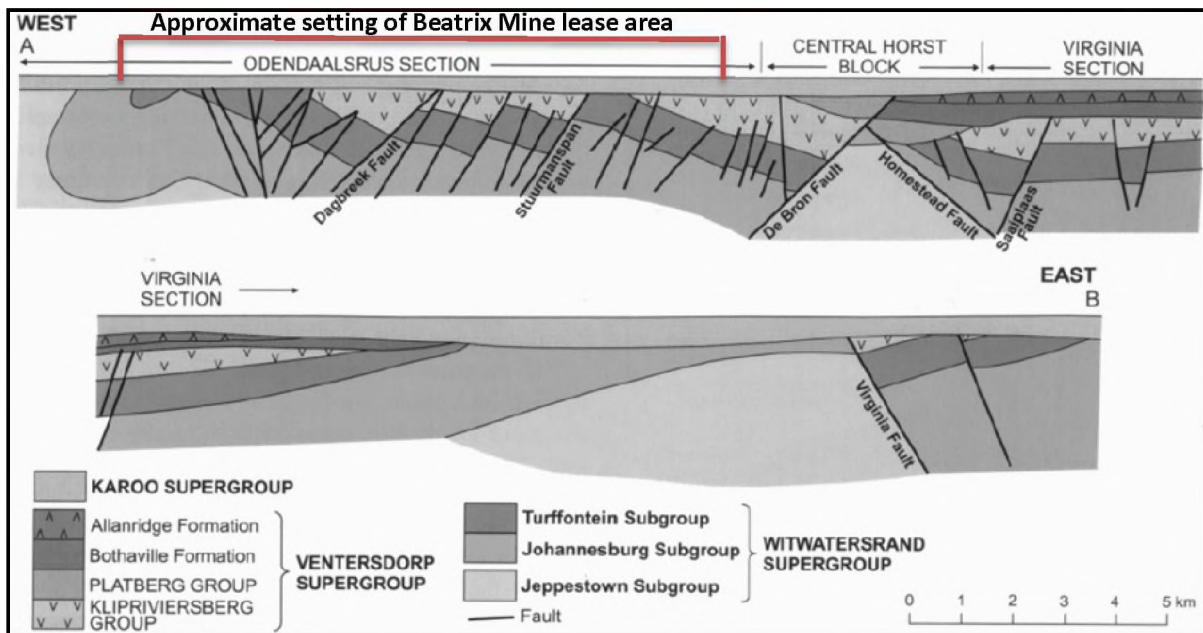


Figure 3.2: West-east section across the Free State Goldfields (Modified after McCarthy, 2006).

3.3 Geological structures at the Beatrix Mine area.

The Beatrix Mine lease area is bounded in the east by a north-south trending major normal fault (De Bron fault) with a throw of over 1000m. The western margin is defined by an overturned fold structure (also referred to as the border structure); the Beatrix No. 4 shaft being located on the fold axis of this structure (Figures 3.1, 3.2 and 3.3). Graben structures from these major faults played a significant role in preserving the Witwatersrand and Ventersdorp sediments. The main structural features at Beatrix No.3 shaft are the Stuurmanspan fault in the central portion, North fault in the eastern side, and unnamed fault in the west (Figure 3.4). All these faults have a downthrow component to the west of between 50m and 200m and follow the regional trends of north-south strike. Dykes and sills have an E-W orientation and are generally younger than the faults as such they displace the faults but have little effect on the disposition of the reef. Complex minor faults (as seen from the detailed structure map of Beatrix No. 3 Shaft area shown in Figure 3.4) with throws ranging between 1m and 20m are abundant resulting in little horsts and graben blocks causing difficulties during mining operation. The faults are largely normal faults type. They result in several different structural blocks of reef (Figure 3.5) which are evaluated separately and treated separately in terms of mining strategies.

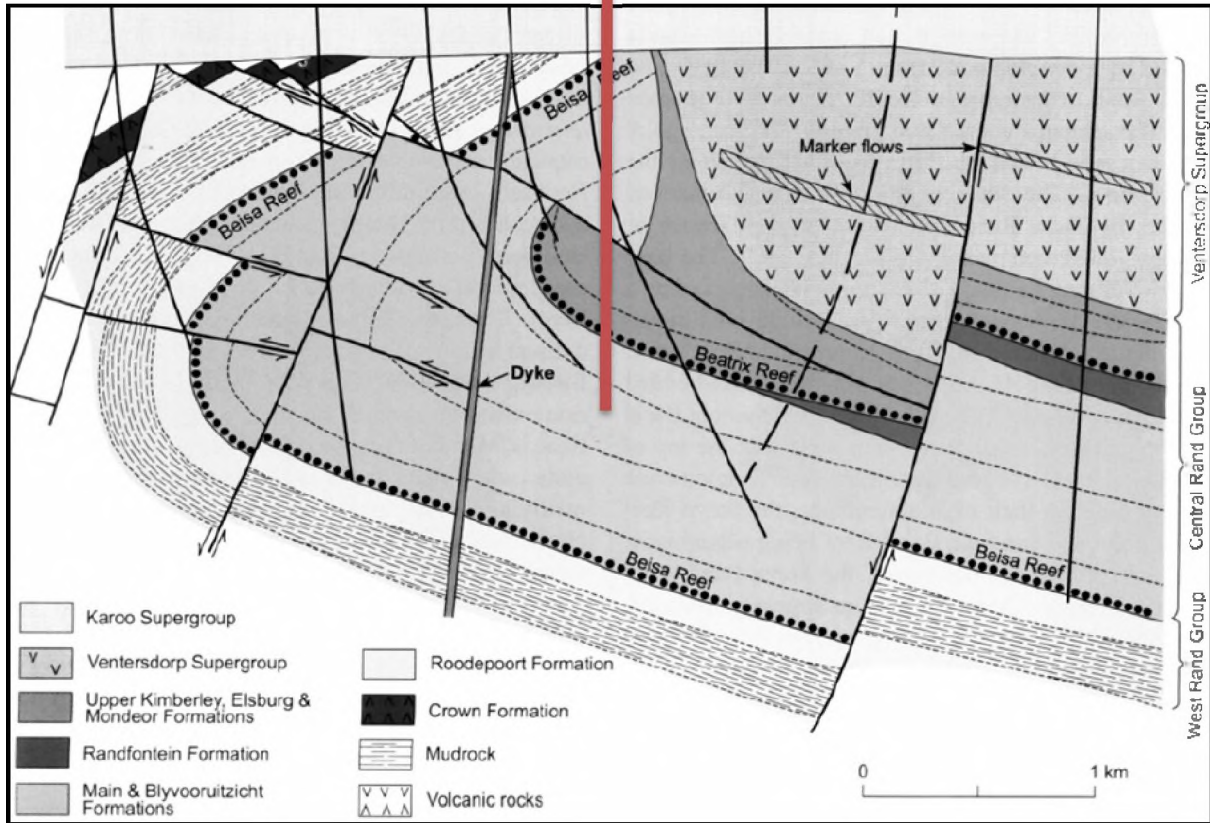


Figure 3.3: Section showing the structure of the south-western margin of the Welkom Goldfield. The Beatrix No.4 Shaft is located at the edge of the overturned structure (Modified after McCarthy, 2006).

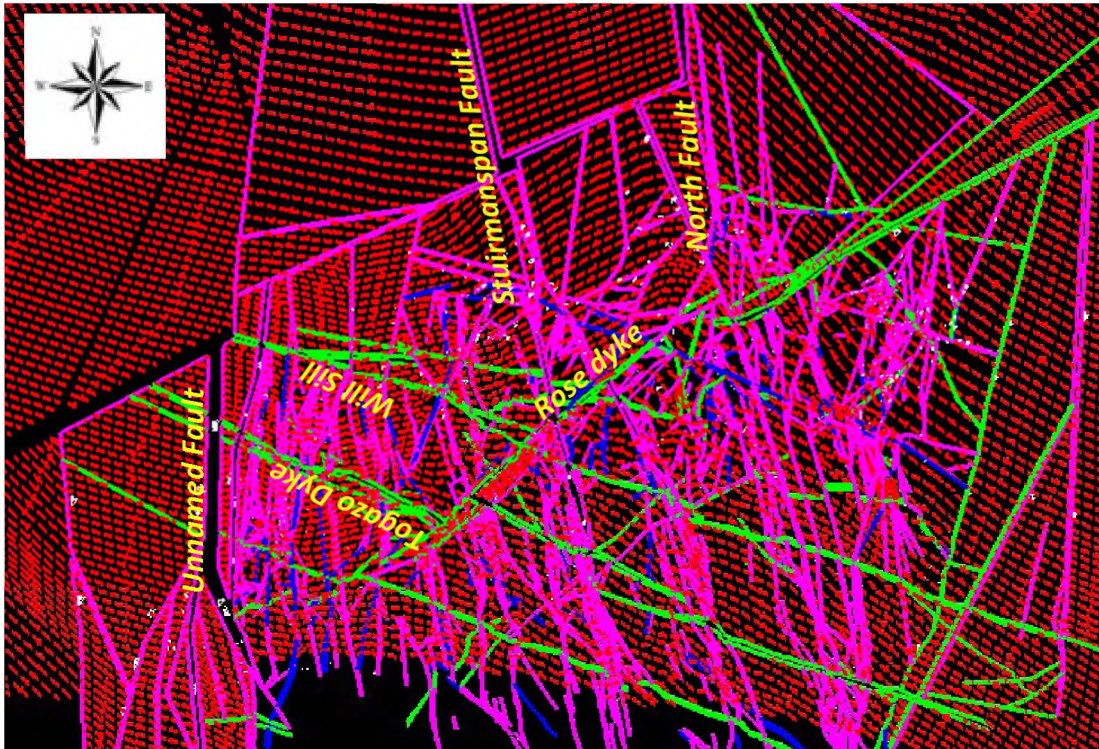


Figure 3.4: Geological structures at Beatrix No. 3 shaft. Normal faults (purple) trend N-S, dykes (green) trend east-west.

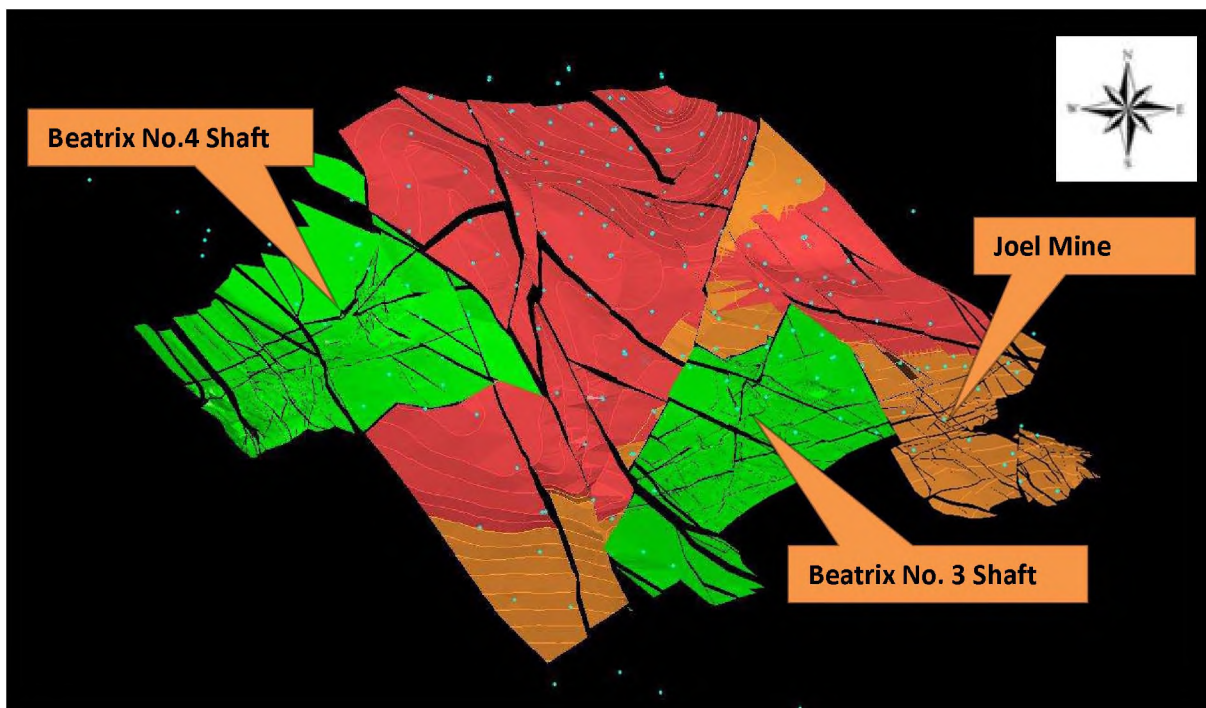


Figure 3.5: 3D structural Model of Beatrix. Red areas are below current Beatrix Mine infrastructure.

Chapter 4

Sedimentology of the VS5 Reef

4.1 Introduction

The VS5 Reef at Beatrix Mine refers to the conglomerate and the interbedded quartzite deposited at the base of the Elsburg (Eldorado) Formation. The VS5 rests on the Main Formation to the south and overlies the Aandenk Formation towards the northern portion of the mine. It fines gradationally upwards into VS4 hangingwall quartzite (Figure 2.6). There are distinct differences between the lithologies of the Elsburg Formation which host the VS5 Reef and the underlying Aandenk Formation. The VS5 is also different to the Beatrix Reef occurring in the southern parts of the mine area. The different placers have different clast assemblages, matrix composition as well as gold grades. These reefs are further subdivided into different facies based on sedimentological characteristics such as channel width and percentage conglomerate. This section describes the sedimentology of the different Reef types mined at Beatrix Mine with emphasis on the sedimentology of the VS5 Reef.

4.2 Placers mined at Beatrix Mine

As mentioned previously: due to the progressive on-lap of Formations southwards towards the edge of the basin, some important placers (including the Basal/Steyn and Leader Reefs) of the Welkom Goldfield have been eliminated in the Beatrix Mine area. Only the upper placers of the Central Rand Group are observed in the Beatrix Mine area. The dominant reef mined at Beatrix South Section (No.1 & No.2 Shafts) is Beatrix Reef and the Aandenk Reef which occur in the northern extents of No. 1 Shaft. Beatrix West Section (No.4 Shaft) exploits the Kalkoenkrans (KKR) Reef occurring on the Kimberley unconformity. Beatrix North Section (No. 3 Shaft) exploits the Aandenk Reef occurring on the Kimberley unconformity as well as Beatrix and VS5 Reefs occurring at the base of the Elsburg unconformity (Figure 4.2). The VS5 in the No.4 Shaft area is uneconomic and forms the hangingwall to the KKR Reef. Figure 4.1 below is the Beatrix geozone plan (see definition on page xii) of 2015 compiled by mine geologists in conjunction with mine evaluators using mapping and sampling data. Each geozone represents a domain of homogenous reef characteristics (lithofacies and block values). The conglomerates exploited at Beatrix Mine are described in details below.

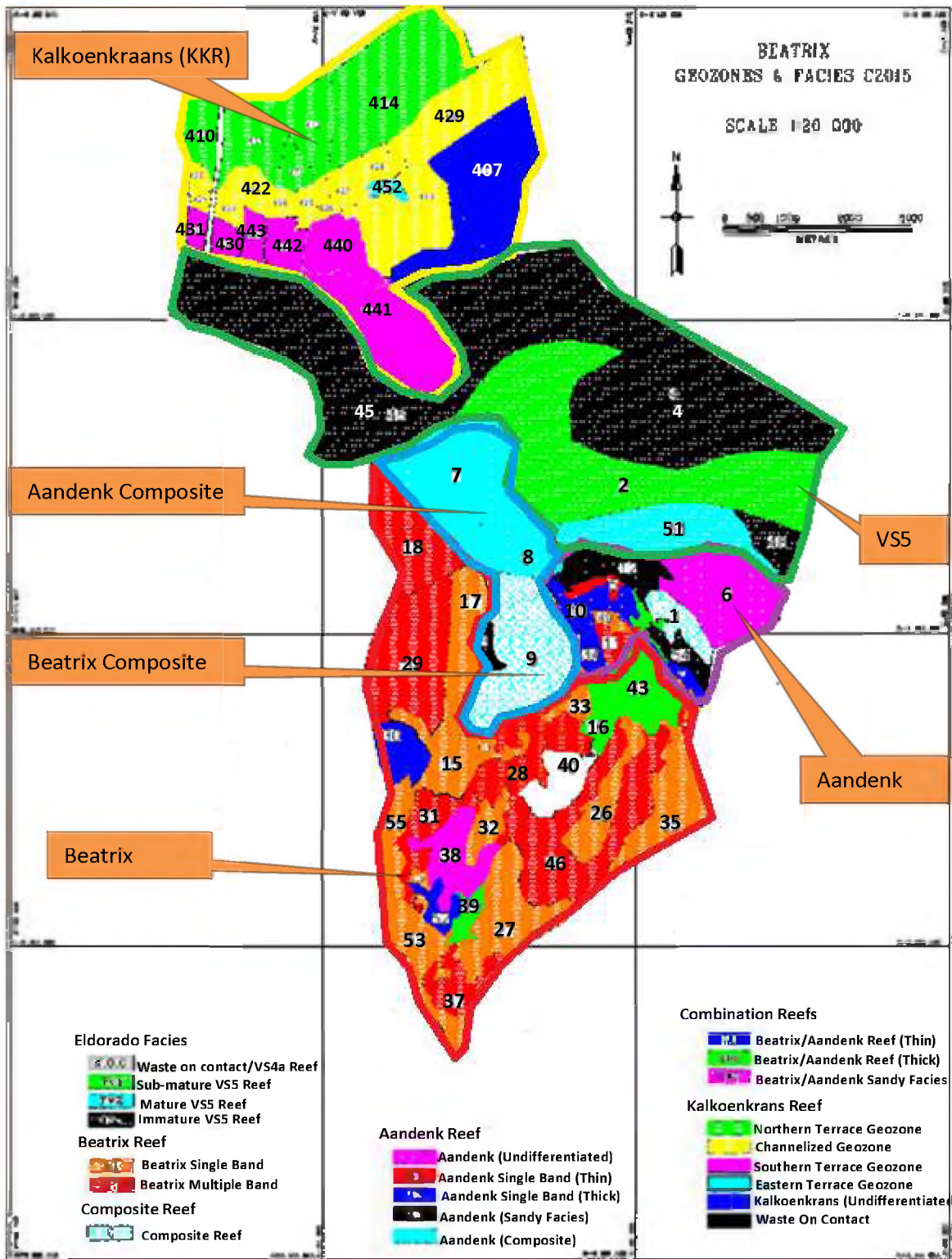


Figure 4.1: Beatrix Mine Geozones and Facies plan F2015.

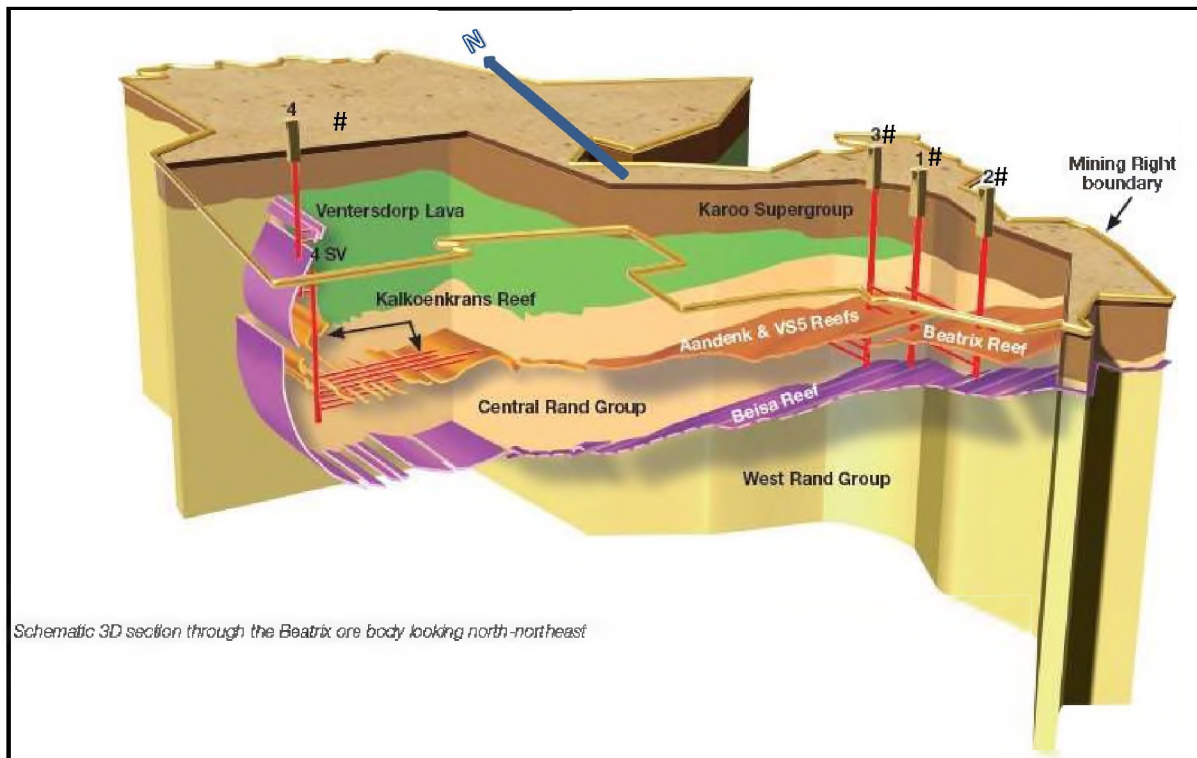


Figure 4.2: Schematic 3D section through the Beatrix ore body. Competent Person's Report on the Mineral Assets of Beatrix Gold Mine, 2012, Sibanye Gold Ltd.

4.2.1 Aandenk Reef

The Aandenk Reef is an oligomictic, matrix to pebble supported conglomerate occurring at the base of the Kimberley Formation. This conglomerate is characterized by medium to very large vein quartz pebbles with a distinctly yellow, quartz sub-lithic arenite matrix. It consists of a well-packed, clast supported conglomerate (Figure 4.3) as well as a poorly packed matrix supported pebbly quartzite (Figure 4.5) as two end member facies. The conglomerate may thin to a pebble lag Aandenk Reef (Figure 4.4) or may even be absent with hangingwall in contact with footwall (referred to as waste on contact). The well packed conglomerate facies consists predominantly of sub-rounded to well-rounded, large pebble to small cobbles size milky and smoky vein quartz with the former constituting higher proportion. The Aandenk sandy facies consist of a poorly packed, medium grained arenite with scattered vein quartz pebbles. The Aandenk has reworked the underlying footwall quartzite and incorporated some footwall material in the matrix and in some cases it is difficult to distinguish between Aandenk quartzite and the footwall quartzite. The Aandenk Reef is confined to the northern parts of the Beatrix mining area and truncated by the Elsburg unconformity towards the south (Figure 2.4).

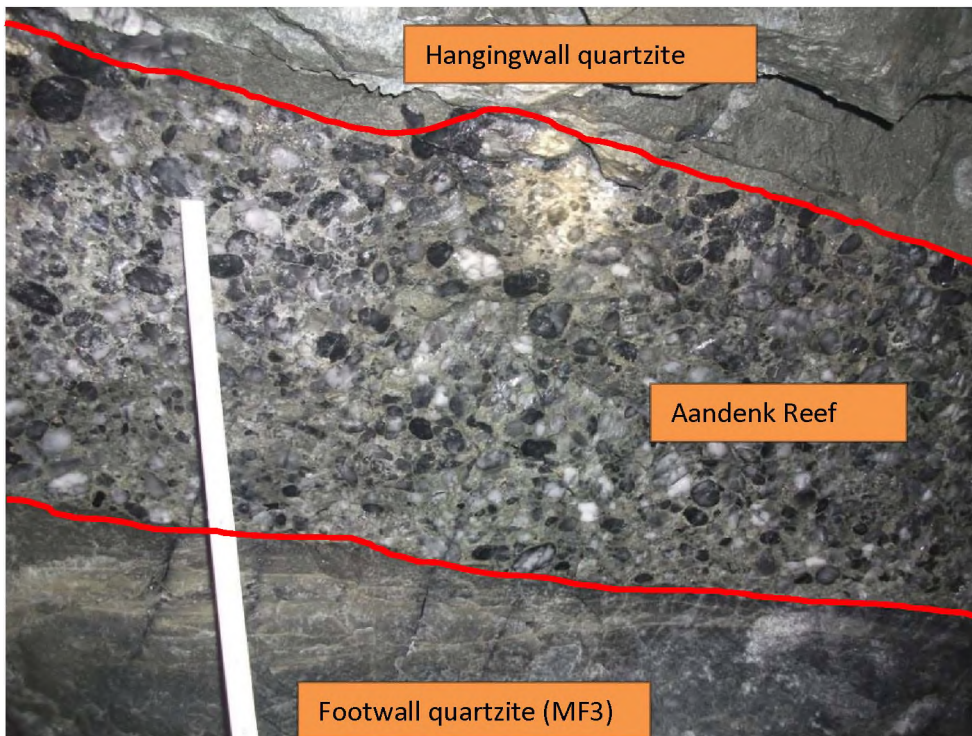


Figure 4.3: Well packed Aandenk conglomerate. Note the typical Aandenk type, very large, vein-quartz pebbles.

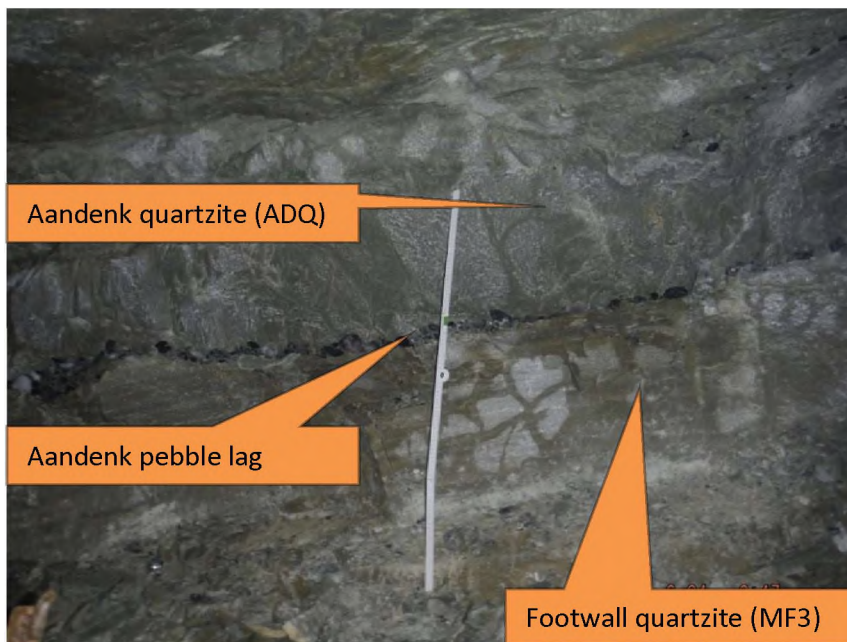


Figure 4.4: Pebble lag Aandenk Reef overlain by a quartzite with scattered pebbles.

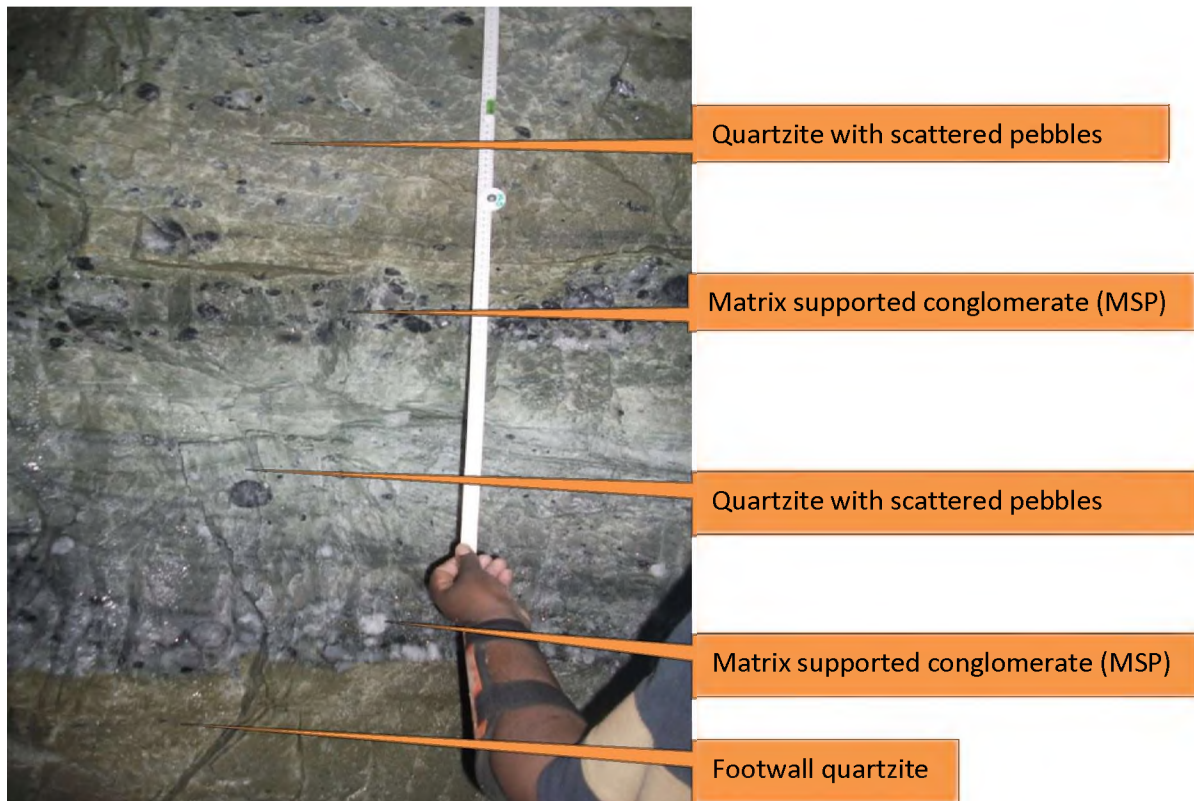


Figure 4.5: Sandy facies Aandenk Reef comprised of interbedded conglomerates and cross-bedded quartzite beds.

4.2.2 Kalkoenkrans Reef (KKR)

The Kalkoenkrans (KKR) and the Aandenk Reefs occur at the same stratigraphic position overlying the Main Formation. They share the same lithological and sedimentary characteristics but were named differently because they are located on different farms (Kalkoenkrans & Aandenk respectively) and exploited by different Shafts. The KKR Reef occurs as a well packed, well sorted, medium to very large pebble single band conglomerate (Figure 4.8) as well as a poorly sorted multiple band conglomerate interbedded with quartzite (Figure 4.7). The pebble assemblage is comprised of well-rounded milky and smoky vein quartz and sub rounded (5-10%) black chert in a grey siliceous to sub-argillaceous matrix. A pebble lag (also referred to as single pebble) conglomerate facies is also recognized associated with paleo-highs and terrace depositional settings (Figure 4.6). KKR Reef is the main economic horizon at Beatrix No. 4 Shaft.



Figure 4.6: Pebble lag Kalkoenkrans (KKR) Reef. Image courtesy of Augustine Zulu.

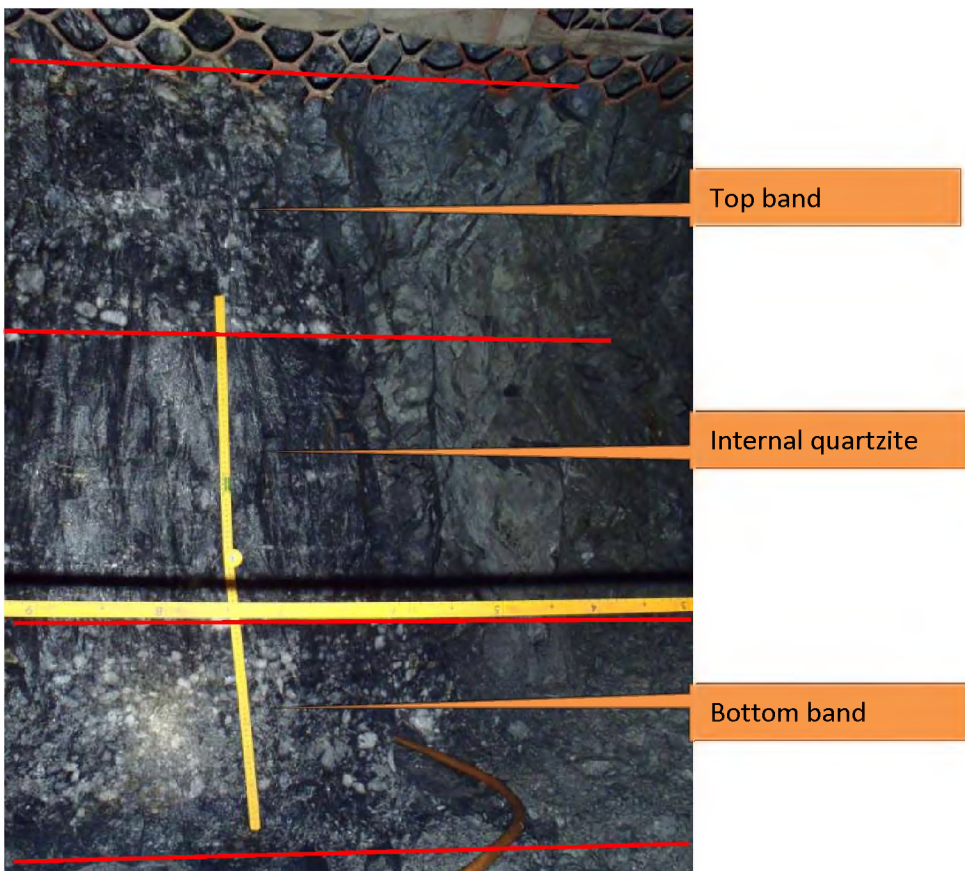


Figure 4.7: Multiple-bands Kalkoenkrans (KKR) Reef. Image courtesy of Augustine Zulu.

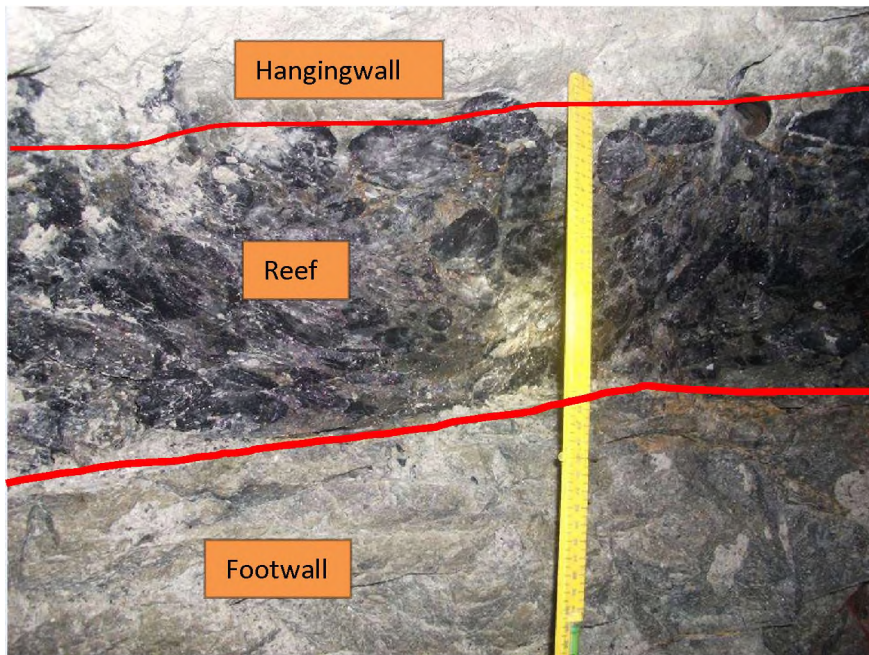


Figure 4.8: Well packed single-band Kalkoenkrans (KKR) Reef. Image courtesy of Augustine Zulu.

4.2.3 Beatrix Reef

The Beatrix Reef is the main economic horizon on which the Beatrix Gold Mine was founded. It is recognized as an oligomictic, pebble supported conglomerate overlying Virginia Formation in the south and Aandenk Formation in the north at an angle of 2 degrees. Similar to the Aandenk Reef, the Beatrix Reef occurs as a thick, well packed single band conglomerate (Figure 4.9) or thick interbedded conglomerate with internal quartzite as well as single pebble lag. The conglomerates are composed of small to medium-size milky and smokey vein quartz pebbles with the latter predominating. Larger pebbles occur in the northern parts of the mine where the Beatrix Reef has reworked the underlying Aandenk Formation. Black chert pebbles are a minor component. The matrix consist of a dark grey siliceous quartzite material and a dark grey argillaceous matrix with yellow chert grits as well as fine grained pyrite referred to as “pyritic mud matrix” by Beatrix geologists (Figure 4.9) . The bottom contact may be angular but becomes gradational where there has been local reworking of the underlying Aandenk. The Beatrix Reef occurs on its own in the south of the mine and overlies the Aandenk Reef towards the north. It is overlain by the VS4 quartzite forming its immediate hangingwall.

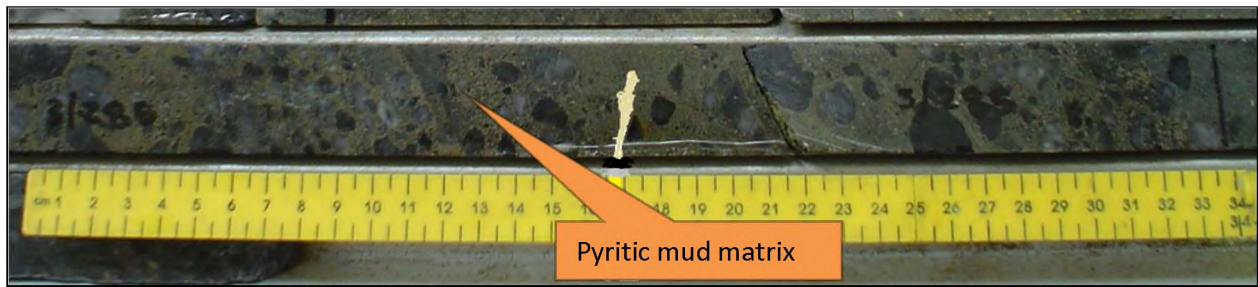


Figure 4.9 Typical Beatrix Reef showing the characteristic fine grained pyrite matrix.

4.2.4 Composite Reef

The Composite Reef was described by Lambert (1999) as consisting of VS4a hangingwall that reworked the Beatrix Reef and possibly the Aandenk Reef. Meyer (1990) was the first to identify the role of VS4a in reworking the Beatrix in the northern parts of Beatrix Mine. The Composite Reef consists of at least 60% milky and smokey quartz vein pebbles and 40% siltstone and silicified yellow and grey shale clasts. The reef grades upwards into VS4a hangingwall conglomerate and eventually fines upwards into a VS4 quartzite interbedded with shales and gritty quartzites. The VS4a hangingwall conglomerate can be locally mineralized with elevated gold grades but regionally is poorly mineralized. Remnants of Beatrix and Aandenk sometimes occur at the base of the Composite Reef. The Composite Reef occurs in the north-western areas of Beatrix No. 3 Shaft and has been mined extensively in the upper levels (20 to 23 levels). The Composite Reef has the same clast assemblage as the VS5 Reef but the latter has smaller size non-durable pebbles and abundant clasts derived from the eroded Beatrix and Aandenk Reefs.

4.2.5 VS5 Reef

The VS5 Reef occurs in the same stratigraphic horizon as the Beatrix Reef overlying the Aandenk Formation in the northern parts of Beatrix No: 3 Shaft (Figure 2.6) and forms the hangingwall to the Kalkoenkrans (KKR) Reef in the Beatrix No. 4 Shaft area. Stratigraphically it occurs at the base of the Elsburg (Eldorado) Formation in the upper parts of the Central Rand Group of the Witwatersrand Supergroup (Figure 2.6). It is easily distinguishable from other reefs by its typically colorful polymictic nature. The VS5 Reef occurs both as a poorly packed, very poorly sorted, immature, polymictic pebble supported conglomerate (Figure 4.10) and as a moderately packed, poorly sorted, sub-mature polymictic pebble supported conglomerate (Figure 4.13). The VS5 consists of one or more

conglomerate units interbedded with gritty quartzite or argillite in an upwards fining cycle. It develops to a mature oligomictic Beatrix Reef to the south. It eventually fines upward to VS4a which is a conglomerate lag forming the immediate hangingwall.

The placer is presently of subordinate importance and is mined selectively at Beatrix No. 3 Shaft. The sedimentology of VS5 Reef is described in detail in the following section.

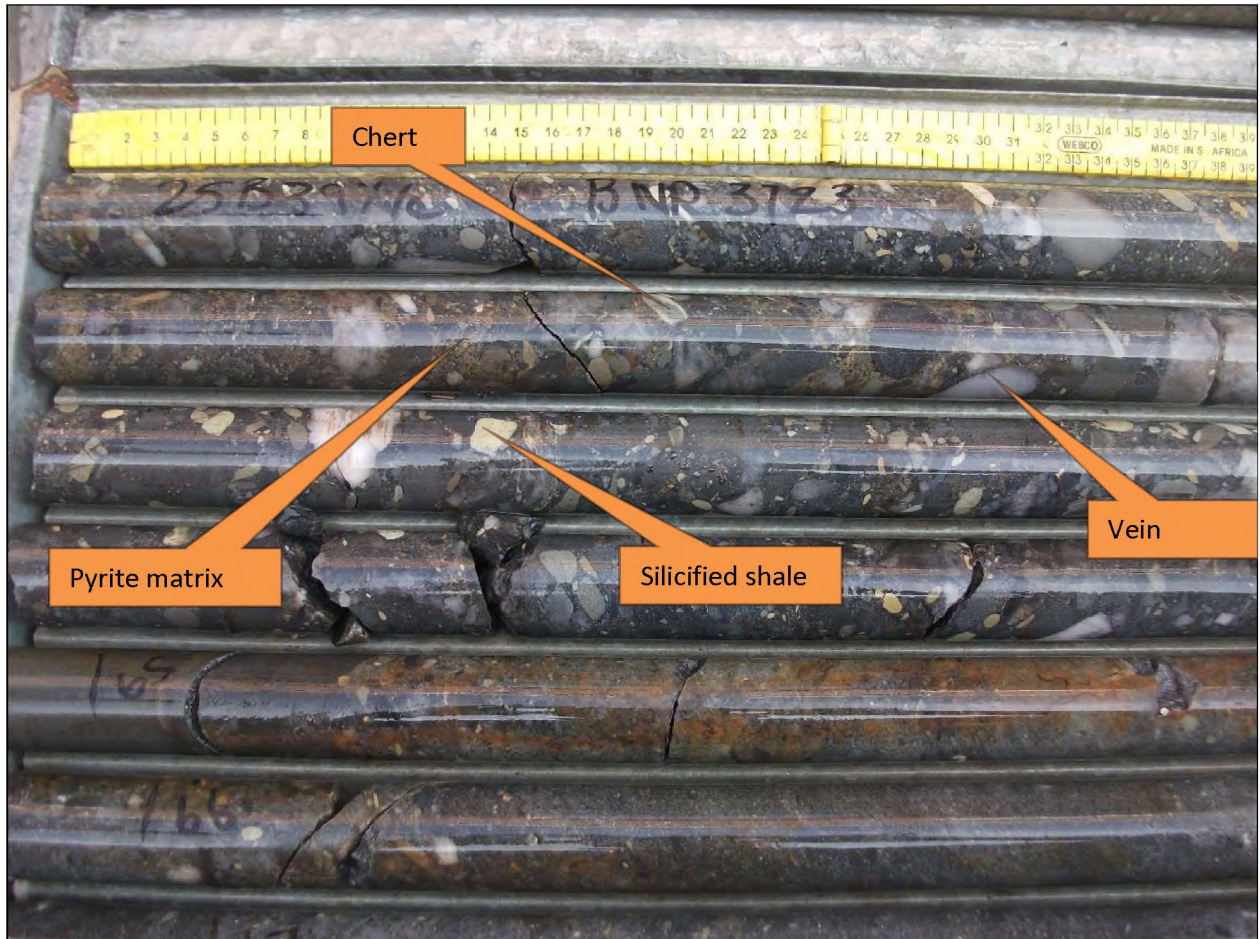


Figure 4.10: Typical VS5 Reef showing the polymictic nature of the reef. Diverse pebble types ranging from vein quartz, chert, silicified shales and basaltic rock fragments.

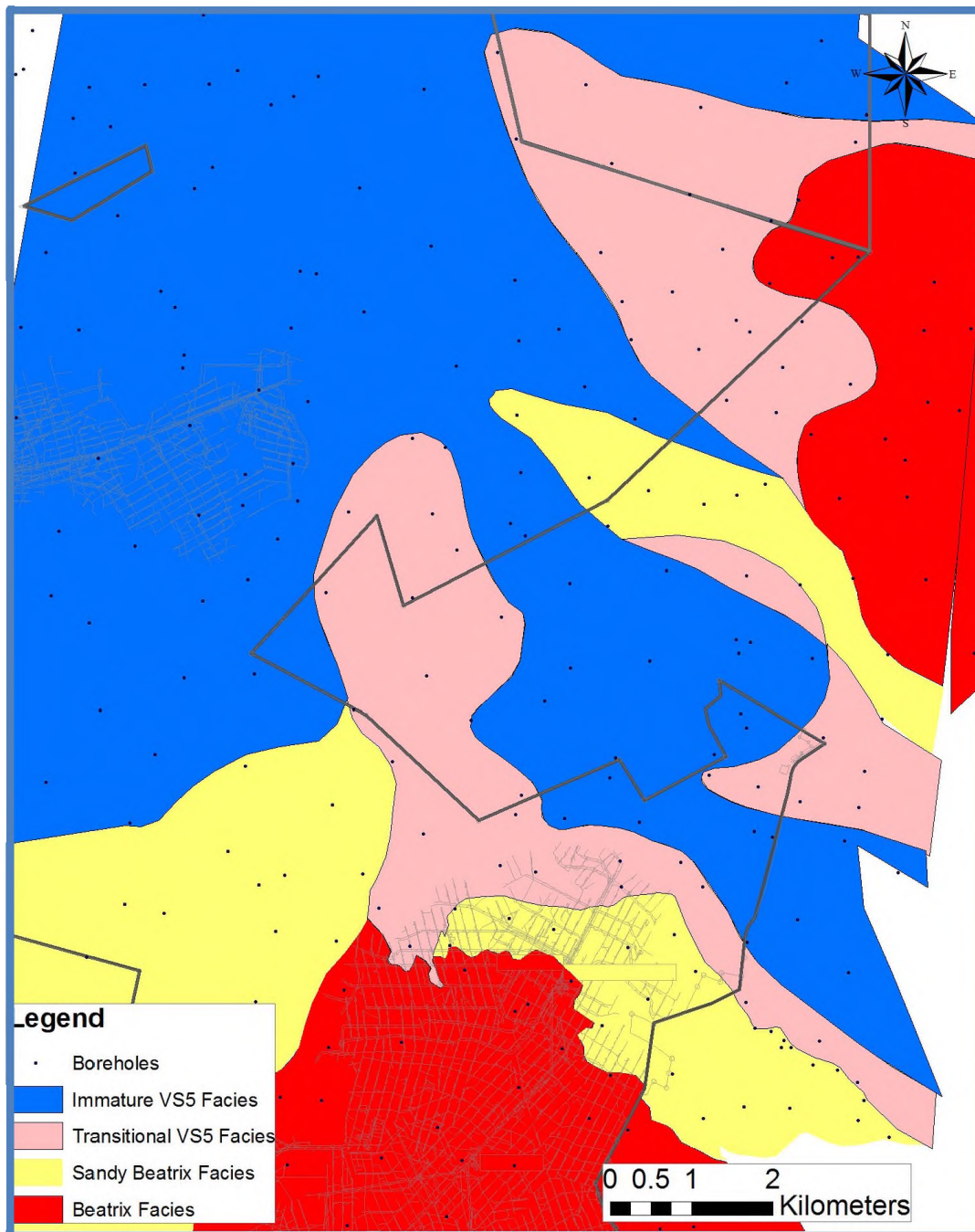


Figure 4.11: Lithofacies distribution on the Eldorado Unconformity (Muntingh *et al.*, 2015).

4.3 Lithological and sedimentary facies of the VS5 Reef

This investigation, along with the research project taken by Dirk Muntingh *et al.* (2015), and work conducted by Beatrix Mine geologists in the study area has resulted to subdivision of VS5 into three different lithofacies. The sub-division was based on variations in sedimentological parameters, especially compositional maturity of the reef. The maturity was measured by the percentage composition of non-durable clast content. The sedimentological characteristics coupled with gold concentrations were used to classify the different facies. The three gold-bearing litho-facies

recognized along the Elsburg Unconformity in the mine lease area are: Immature VS5, Sub-mature (Transitional) VS5 and Beatrix facies (Figure 4.11).

4.3.1 Immature VS5 facies

The Immature VS5 Facies occur within a north-west to south-east trending channel extending from Beatrix No.4 Shaft, through the central western half of Bloemhoek block into the far north-east of Beatrix North Section, and on into the north of Joel Gold Mine (Figure 4.11). The Immature VS5 conglomerate is composed of a very poorly sorted, small, medium to large pebble, highly polymictic (30% to 90% non-durables) conglomerate (Figure 4.12). The pebbles of the Immature VS5 are mostly sub-angular to sub-rounded. The presence of a high percentage of angular to sub-angular non-durable pebbles (silt, shale, quartzite, etc.) are indicative of very little reworking of the sediments during deposition. In the Beatrix No.3 Shaft area, immature VS5 occurs in areas where the Aandenk Reef was poorly developed. Towards the northwest, the VS5 separate from the Aandenk/KKR paleo-surface. There is no reworking of the bottom placers resulting in a poorly mineralized immature facies. The regional isopach maps of VS5 indicate that the immature facies records the highest channel width (Figure 4.16) as well as the highest percentage of non-durable pebbles (Figure 4.18).



Figure 4.12: Immature VS5 facies with abundant sub-angular to sub-rounded non-durable pebbles (silicified silt and shales, igneous rock fragments, etc). Note the deficiency of large vein quartz pebbles and lack of pyrite mineralization.

4.3.2 Sub-mature (Transitional) VS5 facies

The Sub-mature (Transitional) VS5 Reef occurs between the Immature VS5 and the mature Beatrix facies and extends over most areas of the current central northern mining stopes of Beatrix No.3 Shaft (Figure 4.11). The Transitional VS5 facies is characterized by a more mature base (10-40% non-durables) overlain by a less mature VS5 (50% non-durables) (Figure 4.13). Reworking of the older Aandenk Reef is evidenced by the presence of the large (35mm – 50mm) type quartz clasts usually at the base of the reef which are the characteristic of the Aandenk. Throughout the central northern regions, the VS5 has partially or completely reworked the Aandenk Reef resulting in increased amount of durable pebbles, buckshot pyrite and elevated gold concentrations. In some areas pockets of preserved unreworked Aandenk Reef is observed below the VS5 Reef. Cyclic units are recognized with the base of each cycle characterized by a scour surface with abundant mineralization and large vein quartz pebbles that decrease in size upwards.

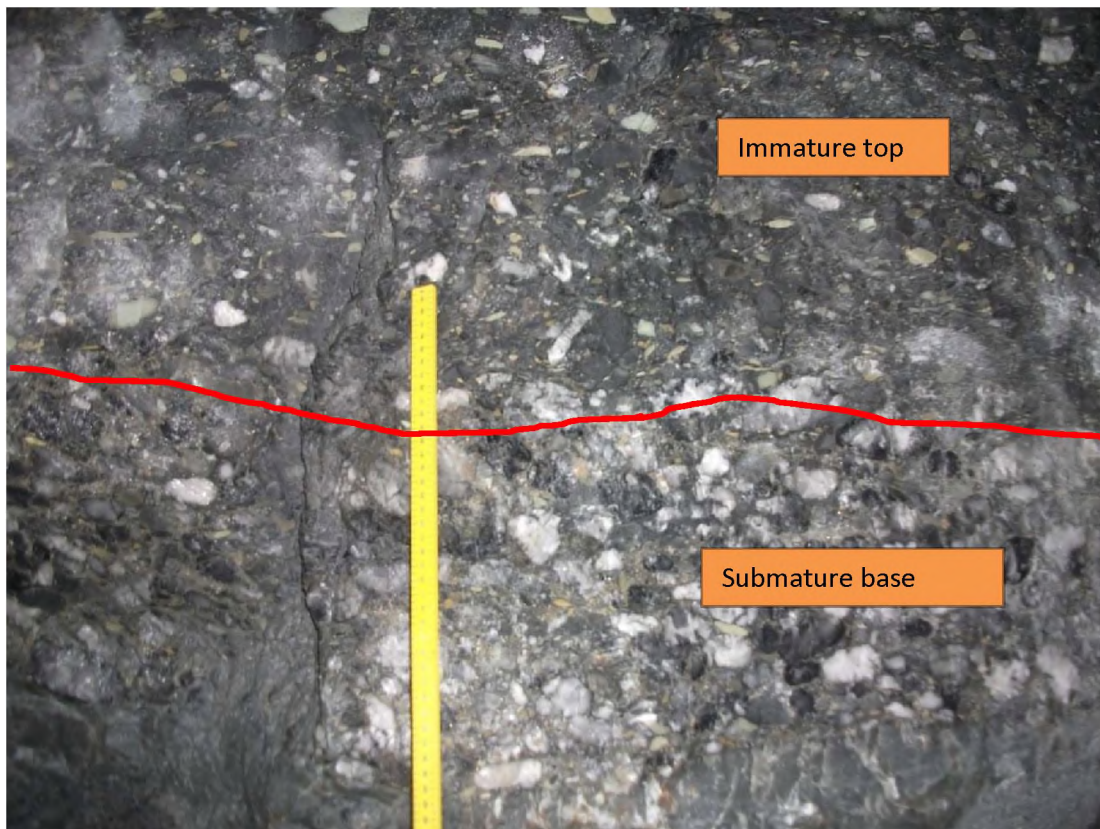


Figure 4.13: Sub-mature VS5 showing a more mature base and an immature top. Note the change in the amount of large vein quartz pebbles between the two units. Large quartz pebbles eroded from the underlying Aandenk Reef.

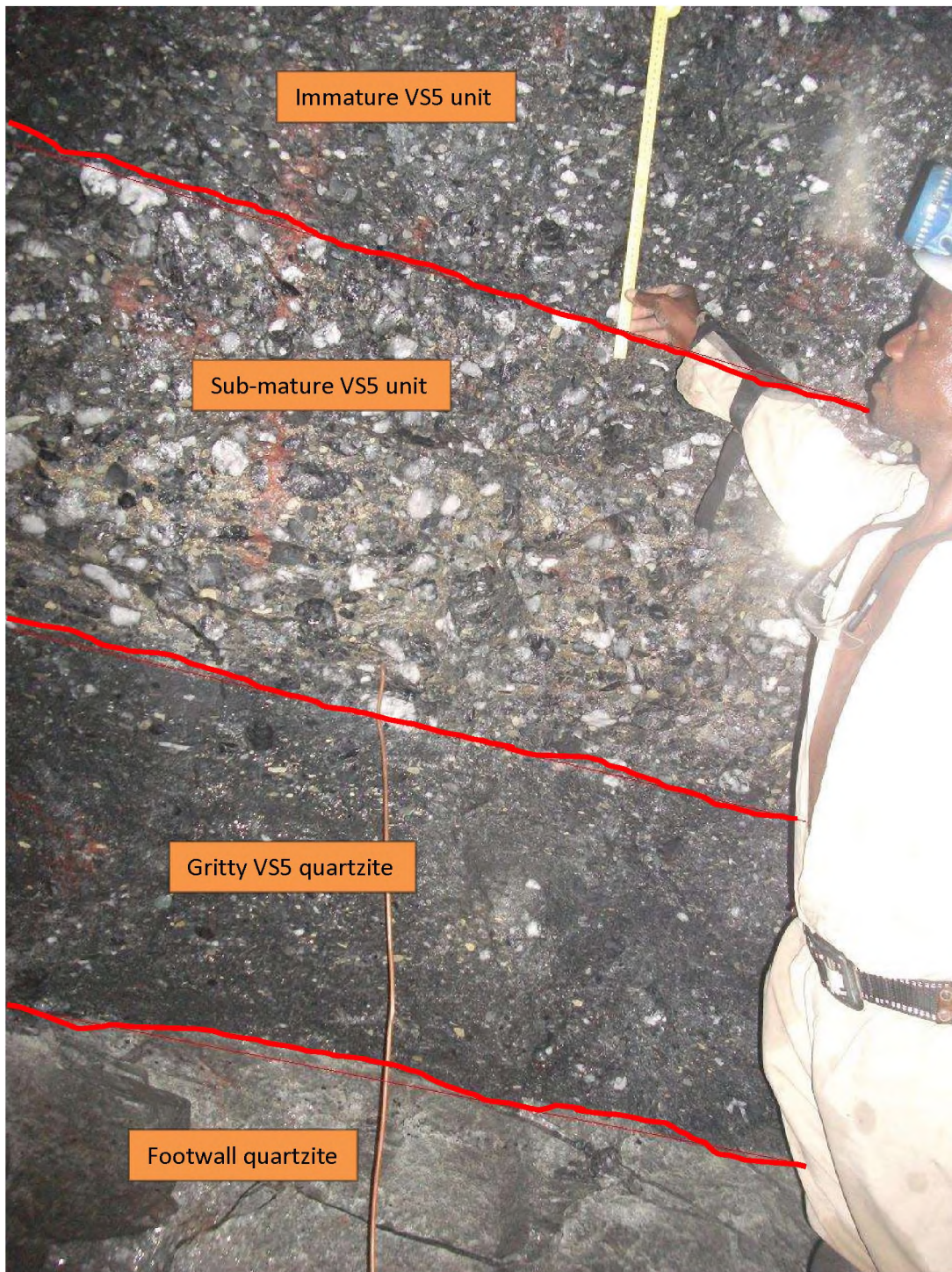


Figure 4.14: Cyclic nature of the sub-mature VS5 facies. A gritty quartzite occurs at the base, overlain by a sub-mature conglomerate which is in turn overlain by an immature VS5 conglomerate. The middle unit is associated with sulphides and gold mineralization.

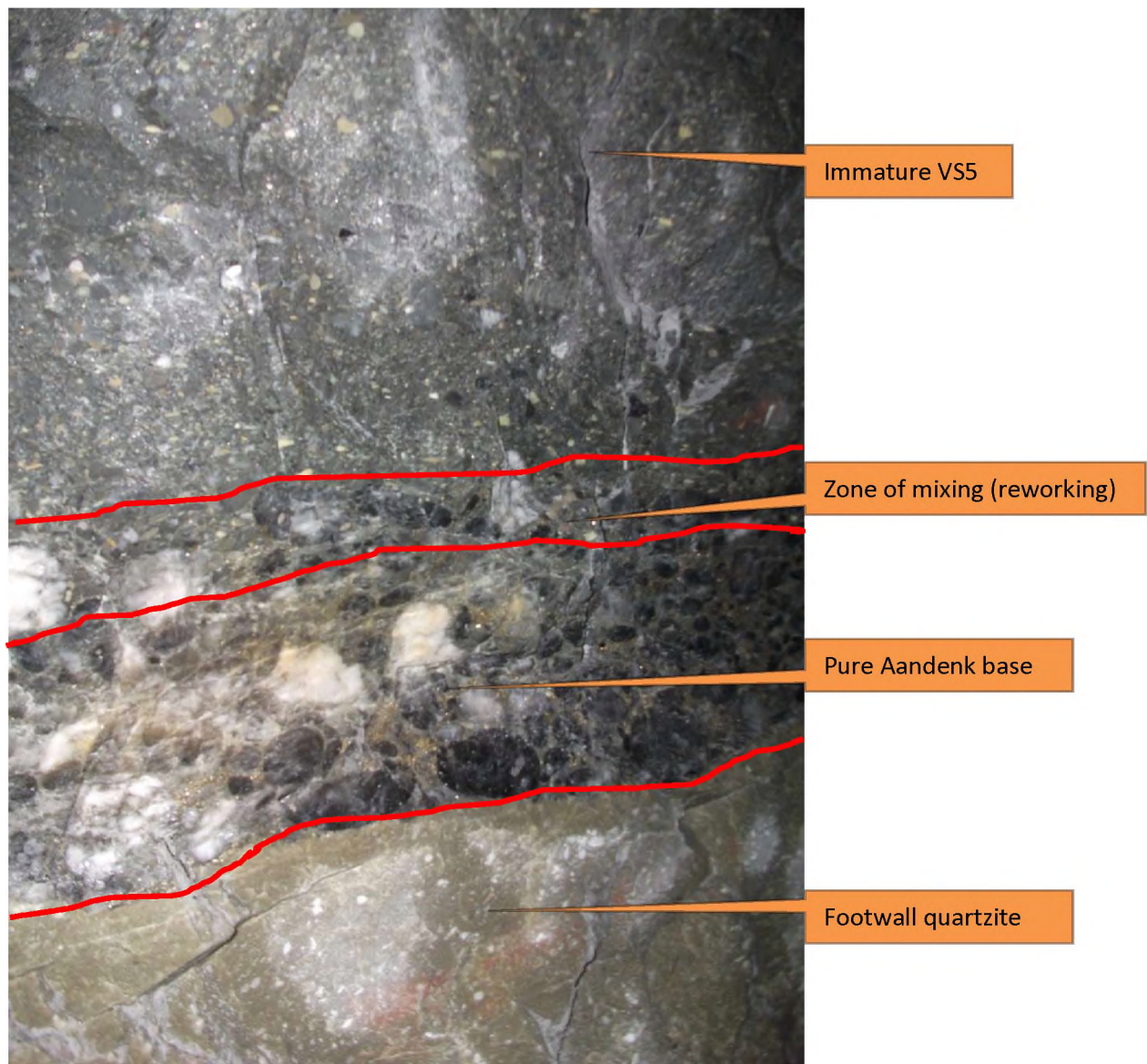


Figure 4.15: Preserved (remnant) Aandenk overlain by an immature VS5 Reef. High gold values associated with the Aandenk base and the reworking zone.

4.3.3 Beatrix facies

Typical Beatrix Reef is found in the southern portion of the mine lease area (Figure 4.11). It comprises a mature conglomerate occurring at the base of the Eldorado Formation. It is oligomictic and contains more durable clasts than the VS5 conglomerate facies. Muntingh *et al.* (2015) describes the Beatrix Reef as a distal equivalent of the VS5 Reef. The Beatrix Reef experienced a high degree of reworking which resulted in a mature, well sorted, well rounded oligomictic medium pebble conglomerate.

The relative age and genetic relationship between the Beatrix and VS5 Reefs have long been a point of dispute. This contact was exposed in the 26 A 47 and 26A 45 stopes and can be described as rapidly transitional over a distance of some 40 m. Starting as a 1.87 m thick typical VS5 polymictic Reef, it progressively matures (compositionally) in a southerly direction, the proportion of quartz clasts increasing at the expense of the non-durables typical of the VS5 whilst thinning to channels averaging 1.2 m thick. The increase in quartz clasts is more rapid along the top and basal portions, but eventually all non-durable clasts are lost in a southerly direction with the reef then assuming the oligomictic character of the Beatrix Reef (Figure 2.6). The age relationship displayed at this exposure suggests the two reefs may have been deposited simultaneously. The observed rapid transition from two such very different reef types is unlikely to occur within the same depositional system. A more likely scenario is that the observed rapid transition represents interference at the flanks of two coeval depositional systems (Muntingh *et al.*, 2015).

Table 4.1: Description of reef types mined at Beatrix Mine

REEF TYPE	LITHOLOGY	PEBBLE ASSEMBLAGE	MATRIX TYPE	MINERALISATION
1. Beatrix	Medium to large pebble supported to matrix supported conglomerate (MPC-LPC)	Milky & smokey vein quartz, chert. Smokey quartz pebbles > milky quartz pebbles	Grey quartzite matrix, pyritic mud	Generally well mineralised with both buckshot and crystalline pyrite
2. Aandenk	Very Large pebble to matrix supported conglomerate with associated pebbly-quartzite	Milky & smokey vein quartz. Milky quartz pebbles > smokey quartz pebbles	Light grey siliceous quartzite, yellow sericite	Well mineralised conglomerate facies, poor to moderately mineralised sandy facies and pebble lag facies.
3. Composite	Small to medium pebble supported conglomerate (SPC-MPC)	White & smoky vein quartz, silicified shale, chert, volcanic fragments	Grey argillaceous quartzite	Moderate to well mineralised
4. VS5 Reef	Large pebble conglomerate (LPC)	White & smoky vein quartz, silicified shale, chert, volcanic fragments	Grey to dark grey argillaceous quartzite	Poor to moderate mineralisation

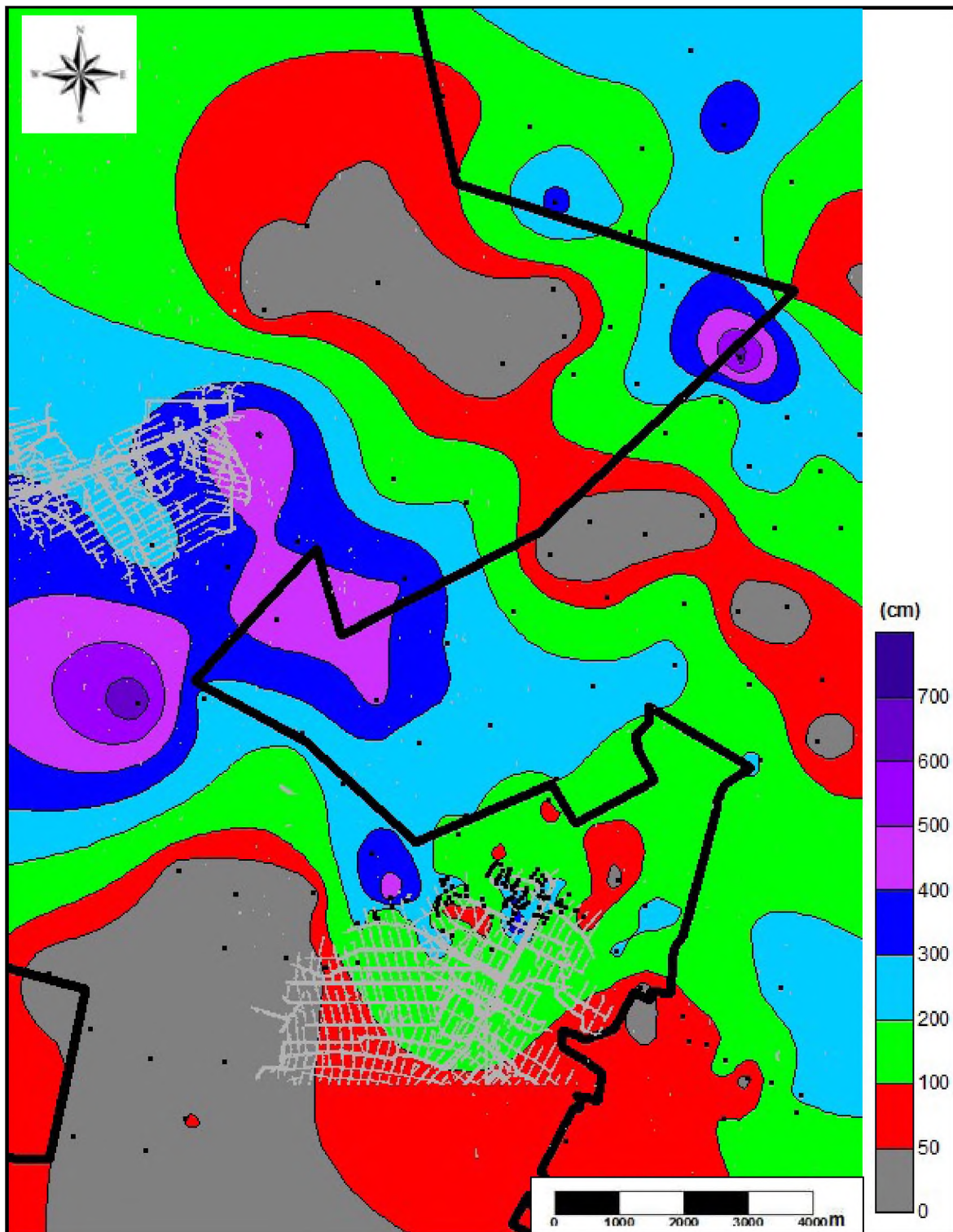


Figure 4.16: Contour map of the cumulative conglomerate thickness (cm) in the Beatrix/VS5 Reef.

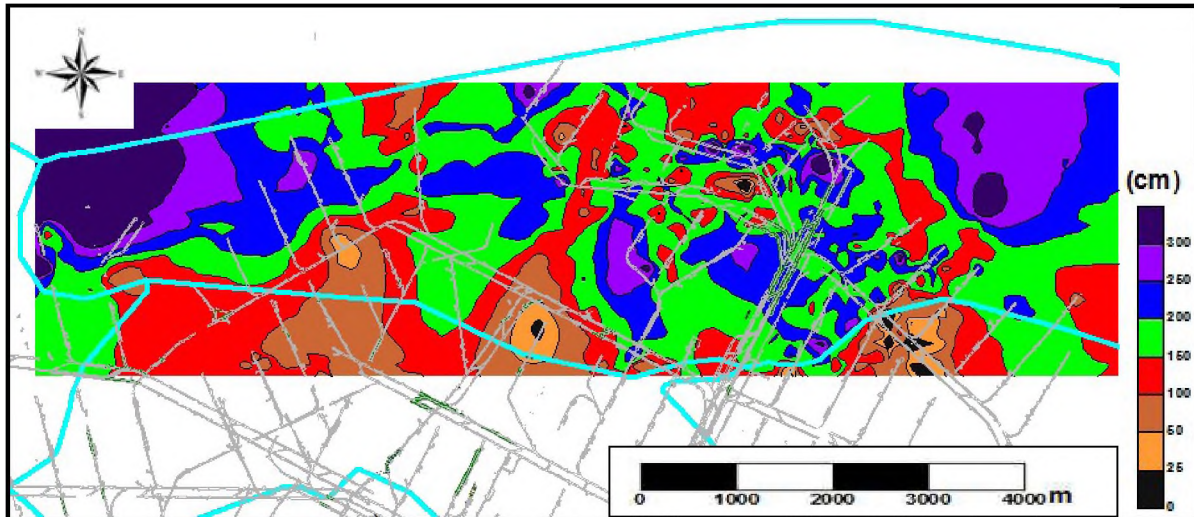


Figure 4.17: Contour map of the cumulative conglomerate thickness (cm) in zone 51 (VS5 Reef)

At the Beatrix Mine No. 3 Shaft area, the VS5 channel width averages between 100-200 cm and thins to about 50cm, eventually terminating towards the south (Figure 4.17). It widens to more than 300cm thick towards the north. In some areas it has eroded into the underlying Aandenk Reef and the erosional base is marked by the presence of a scour surface accompanied by a change from an oligomictic to polymictic conglomerate.

Regionally, non-durable clasts increase in abundance towards the northwest indicating possible source areas for the VS5 sediments inputs from this direction (Figure 4.18). Vertical variation in non-durable clasts is also observed locally at No.3 Shaft, abundances normally increasing upwards in the sub-mature facies but the inverse can be true locally. Clast size also shows a similar trend with largest clasts recorded close to the presumed source of sediments in the northwest (No.4 Shaft region)(Figure 4.19). Very large pebbles and boulders will be deposited in proximal areas and smaller pebbles will be deposited further away from the source area. At a local scale, there is both lateral and vertical variation in largest clast composition. As will be indicated in the next chapter, this variation is controlled by reworking along the Aandenk paleo-surface. The better developed the Aandenk post-erosional channel, the higher the percentage large quartz pebbles in the resultant VS5 Reef. These large quartz pebbles are likely to have been scavenged from the Aandenk Reef.

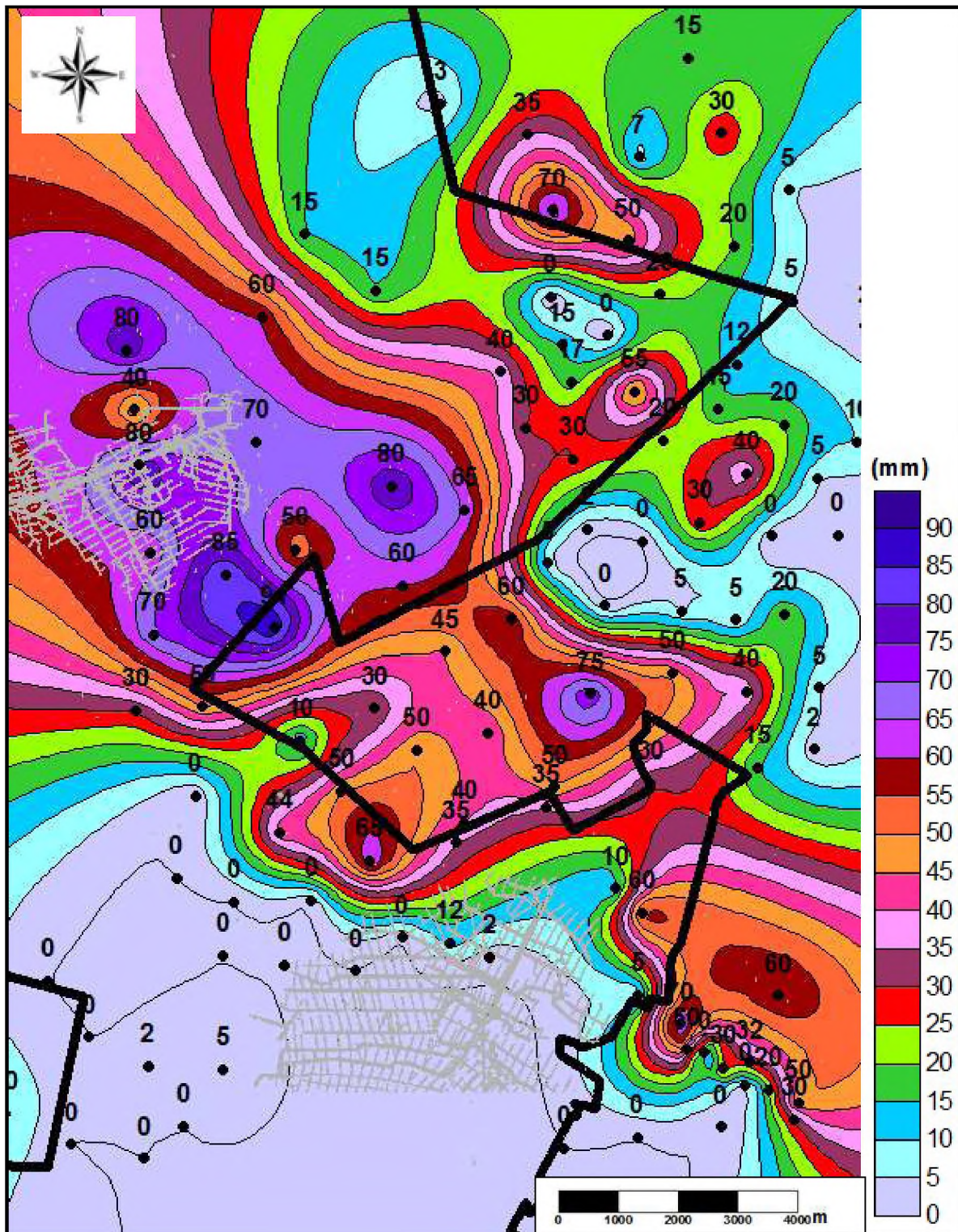


Figure 4.18: Contour map of the minimum percentage non-durable clasts in the Beatrix/VS5 Reef.

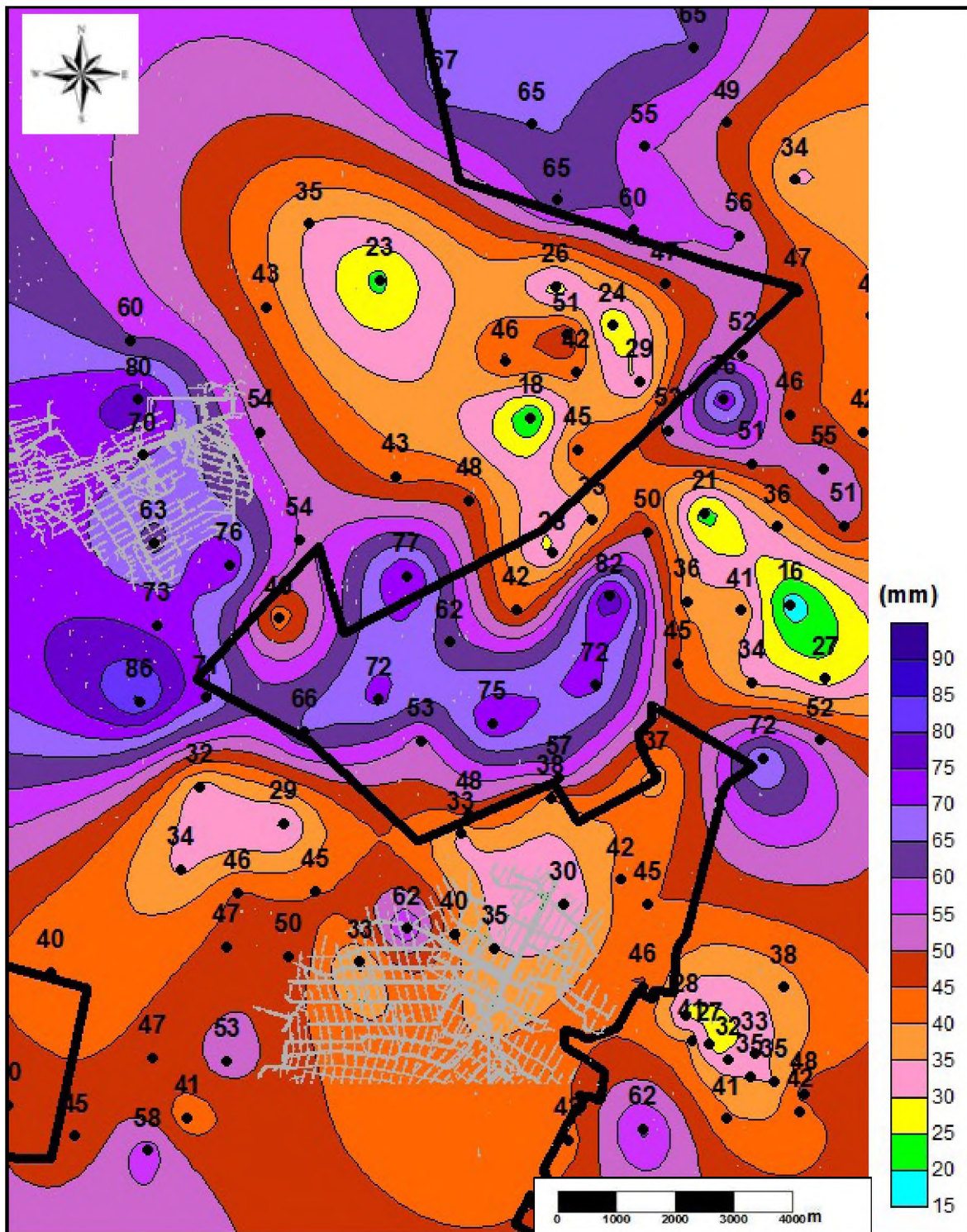


Figure 4.19: Contour map of the largest clast (mm) in the VS5/Beatrix Reef.

Chapter 5

Gold Mineralization

5.1 Introduction

Gold grade (measured in grams per tonne, g/t) refers to the average concentration of gold contained in the portion of ore, whereas gold accumulation (reported in centimeter grams per tonne, cmg/t) is a measure of the gold content in a vertical section of the reef, calculated by multiplying the gold grade by the reef thickness. Gold accumulation and grade values differ between the different placers mined at Beatrix Mine. For this study, the relationship between gold concentration and accumulation with sedimentary parameters was investigated from data gathered in underground mining exposures, underground and surface borehole cores, and available historical mine data.

Concentrations of heavy minerals which include gold, uranium and pyrite occur along scour surfaces within the arenites, and as matrix constituents surrounding pebbles in conglomerates. The heavy mineral suite in all the reefs mined at Beatrix Mine is similar to that found in normal Witwatersrand type placers consisting of pyrite, chromite, ilmenite, leucoxene, zircon, uraninite, brannerite, galena and various Cu and Fe sulphides such as pyrrhotite, pendlandite, and chalcopyrite (Feather and Koen, 1975; Zhou *et al.*, 1995). Pyrite is the most abundant heavy mineral and accounts for well over 85% of the heavy mineral suite.

The Beatrix Reef records the highest grades (9 g/t) followed by the Aandenk Reef and KKR at 5 g/t. Gold grades in the V5 Reef vary significantly from 0.1g/t for Immature VS5 facies to 6 g/t for the sub-mature VS5 facies. The Beatrix, Aandenk and KKR Reef grades are relatively consistent and more economical to mine. Gold values in the VS5 are highly variable ranging from uneconomic, marginal to economic gold values.

5.2 Beatrix Reef

Gold mineralization is associated with pyrite (85%) and uraninite and brannerite as the major constituents of the heavy mineral suite. Other heavy minerals comprise less than two percent of the Beatrix ore and include chromite, ilmenite, zircon, galena and other Fe and Zn sulphides (Genis 1990). The enhanced gold grades in the Beatrix resulted from the reworking and concentration of heavy minerals. As a distal depositional facies, the Beatrix Reef was exposed to higher degrees of reworking by both fluvial and shallow marine processes resulting in a well sorted oligomictic conglomerate with

well-rounded pebbles. In the sandy Beatrix facies, mineralization occurs along bedding planes and scour surfaces. The basal erosional scour is normally associated with a spike in gold concentration. Gold distribution in the well packed conglomerate facies is evenly distributed except for its top where the reef grades into VS4a conglomerate, and at the basal scour (Figure 5.1). No major problems on amount of gold (grades below pay limit) are encountered in the Beatrix Reef except in zones where the channel is very thin (> 10 cm) or hangingwall in contact with footwall without conglomerate developed. Small (1-2mm) spherical chlorite nodules are common in the conglomerate facies of Beatrix Reef (Phillips and Dong, 1994), interpreted by Genis (1990) as alteration products of silicate heavy minerals such as garnets. Gold deportment studies in the Beatrix Reef indicate that gold grains are mostly associated with carbon, as inclusions in pyrite as well as free gold particles.

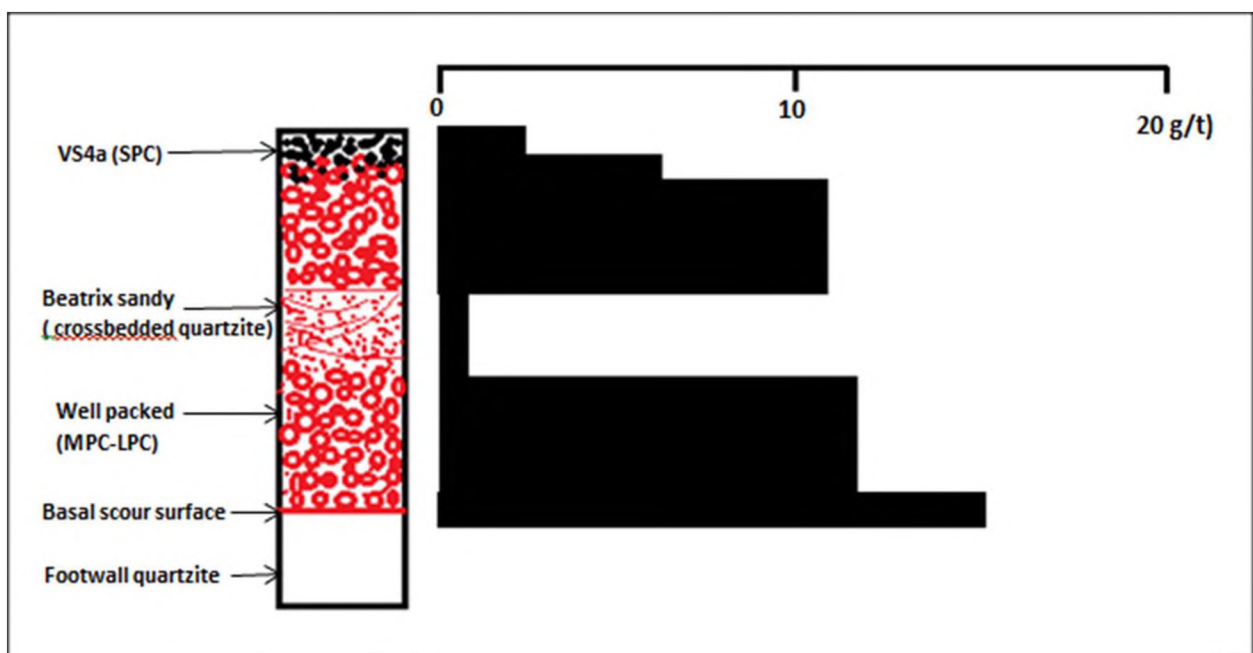


Figure 5.1: Vertical gold distribution in the Beatrix Reef. Note elevated gold content at the basal scour and drop in value in the internal quartzite.

5.3 Aandenk Reef

Similar to the Beatrix Reef, the Aandenk Reef shows highest values in the well packed conglomerate facies. Pyrite is the most abundant mineral of the heavy mineral suite as in the Beatrix Reef distributed as matrix around pebbles. The internal quartzites of the Aandenk Reef normally record poorer grades than those in the Beatrix Reef. A study by Rose (2006) found no significant relationship between the pyrite abundance and gold grade, but identified a strong positive correlation between gold grade and channel width. The more extensively the conglomerate was reworked, the greater the sorting and the

higher the gold content. Where the Aandenk Reef is overlain by Beatrix Reef (to the south of the mine), the Beatrix Reef has elevated gold grades as a result of reworking that concentrated the gold. Basal scours in contact with footwall returns higher gold values (Figure 5.2). Values in the Aandenk Reef average 900 cmg/t at an average grade of 6 g/t.

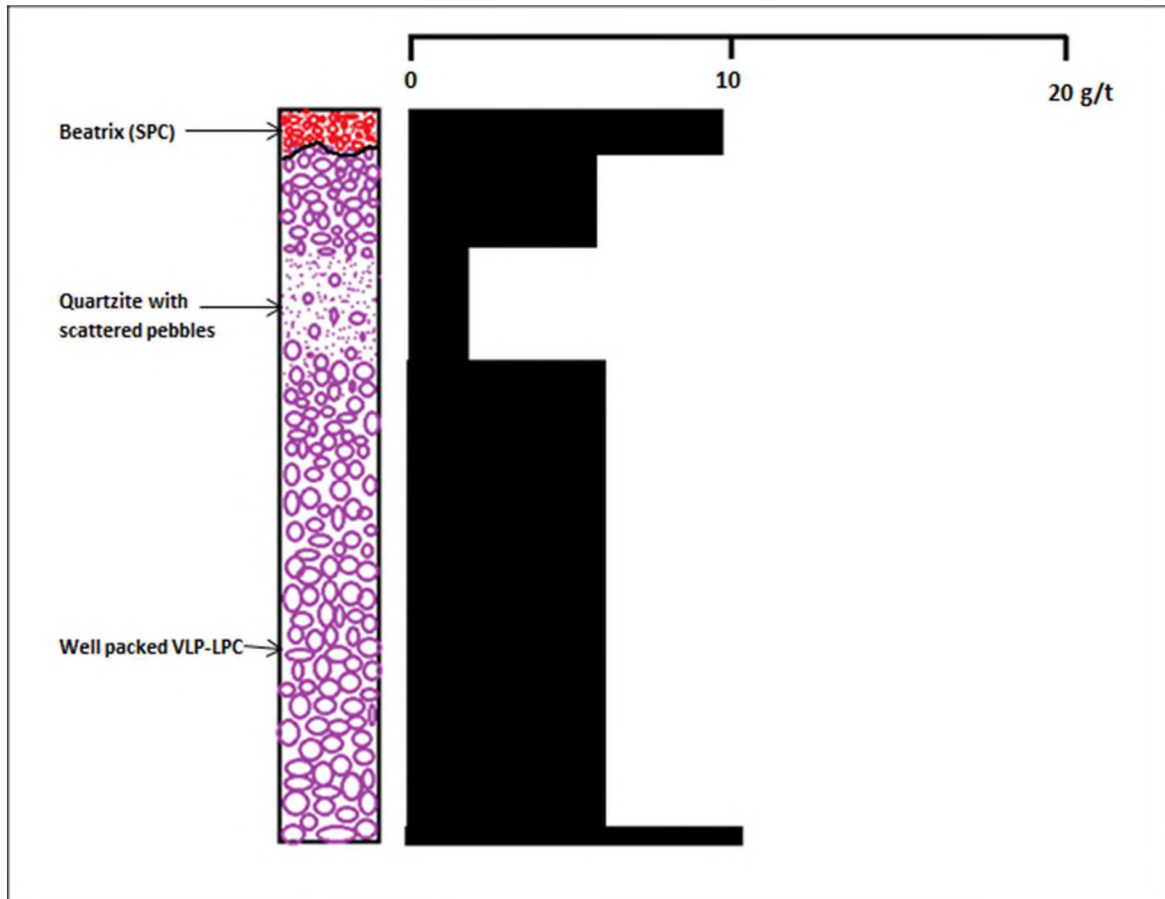


Figure 5.2: Vertical gold distribution in the Aandenk Reef.

5.4 Composite Reef

As mentioned previously, the Composite Reef represents a unit of Aandenk/Beatrix/VS5 reworked by VS4 material during the sedimentation of the VS4 therefore mineralization in the Composite Reef is a function of the original levels of Au reworked placer. The Aandenk/Beatrix Composite (geozones 8 & 9, Figure 4.1) shows good grades whereas the VS5 Composite (western parts of zone 51, Figure 4.1) is associated with poor values. Sometimes it is difficult to distinguish between VS5 Reef and Composite Reef as both reefs have similar pebble assemblages and appearance.

5.5 VS5 Reef

Early researchers on the VS5 Reef regarded it as uneconomic to mine (Body, 1992). While this is true for the immature VS5 facies lying to the north and northwest of the Beatrix Mine, further south, VS5 becomes more mature and, while it can be barren locally, average Au grades increase to economic levels. Mineralogical studies have shown that the gold mineralization is associated with detrital uranium, rutile/leucoxene, zircon, chromite, kerogen, pyrite, sphalerite, and chalcopyrite (Body, 1992).

At Beatrix No. 3 Shaft the VS5 Reef shows wide variations in gold grade both laterally (Figures 4.6 & 4.9) and vertically (Figure 4.4). To mine this reef economically in the current economic situation (late 2015), pay zones need to be identified and selectively mined. Grades range from as low as 0.1 g/t for the immature facies to about 9 g/t in the sub-mature facies.

Unlike other reefs where gold concentration is influenced by channel width, there is little to no correlation between channel widths and gold content in the VS5.

Gold concentration in the VS5 is controlled by the reworking of the older Aandenk Reef by the VS5 sediments during the VS5 times, the higher the degree of reworking, the higher the gold grades and vice versa. The Aandenk paleo-surface played a significant role in the variability of grade in the VS5. In-channel, well packed pre-VS5 Aandenk sediments having high gold content resulted in higher grade VS5 Reef after reworking; by contrast, high standing areas of Aandenk in the paleo-surface resulted in poorly mineralized VS5 after erosion and deposition.

Correlative studies on pebble size and composition have revealed a strong relationship between gold mineralization and large vein-quartz pebbles. Units with a high abundance of large Aandenk-sourced quartz pebbles have elevated gold grades; grade falls progressively with decrease in both abundance and size of vein quartz pebbles. The reworked unit is mostly indicated by a "mixing zone" between the immature VS5 and Aandenk material and possesses characteristics of both. Immature VS5 Reef zones have a lack of vein quartz pebbles and tend to be poorly mineralized. Again the effect of erosion of the underlying Aandenk becomes a significant parameter in controlling gold mineralization in the VS5 in the area.

A degree of correlation has been observed between the amounts of pyrite and gold in the VS5 Reef: high pyrite content tends to coincide with elevated gold grades whereas units with little to no pyrite are barren. However, care needs to be exercised in using this relationship to predict grade because some units of the immature zone contain abundant pyrite but without significant gold mineralization.

This can be attributed to the VS5 source rocks having low gold contents but abundant pyrite and other heavy minerals.

The B-west block at the No.3 Shaft records the highest Au grades in the VS5 Reef (Figure 5.5). The facies in this area is sub-mature and consist of large pebble conglomerate with cyclic scours. Vertical gold distribution in this zone shows no consistent preferred position apart from always being highly concentrated in scours at the base and top of the unit. This zone was possibly derived from reworking of a well-developed Aandenk conglomerate deposition of the VS5. Here the gold is associated with high concentrations of buckshot pyrite.

Poorly mineralized argillites and pebbly quartzites comprised of argillaceous materials constitutes the Immature facies of the VS5. The immature VS5 is left in the hangingwall at No. 4 Shaft due to the poor grades. Cumulative sum plot of VS5 Reef (Figure 5.6) indicates an exponential increase in gold value from 100cm to 200cm channel widths and above that the values increase at a reduced rate. Investigation of sampling data and borehole data indicates that the VS5 Reef is bottom loaded and the bottom 1500cm of the reef provides the best mining cut.

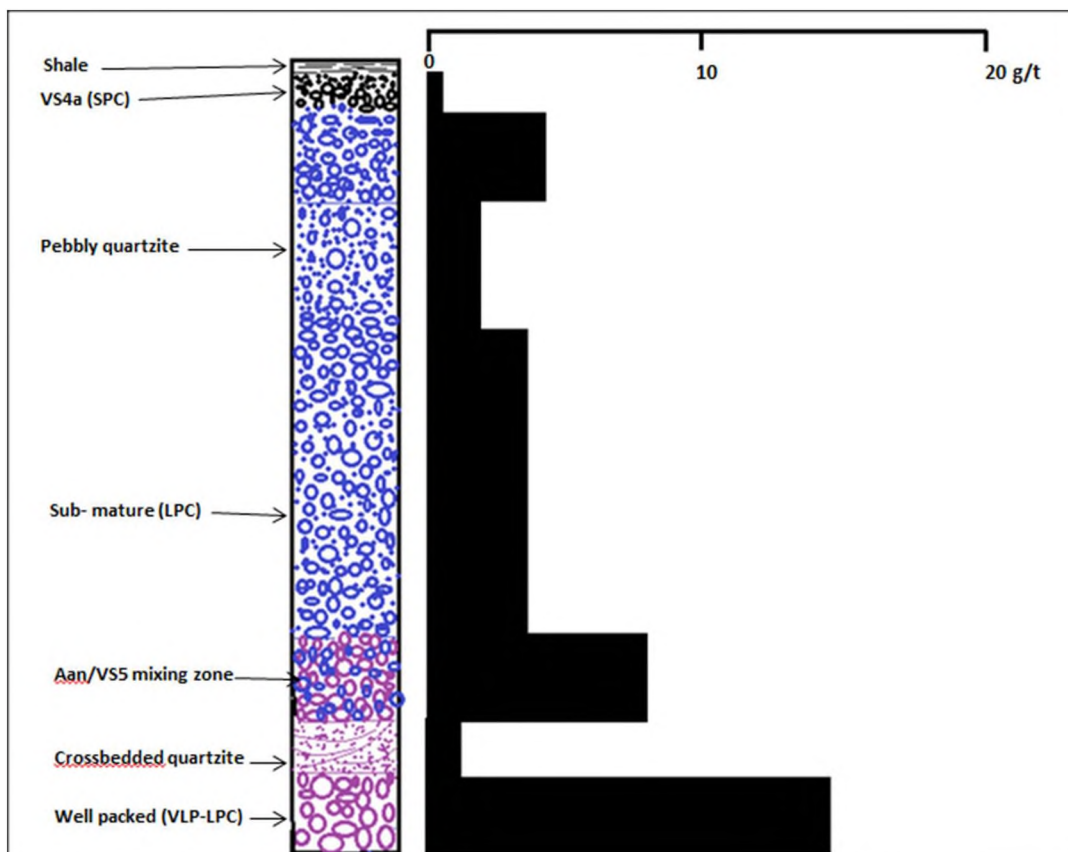


Figure 5.3: Typical vertical profile of the sub-mature VS5 showing gold distribution with a preserved Aandenk Reef base.

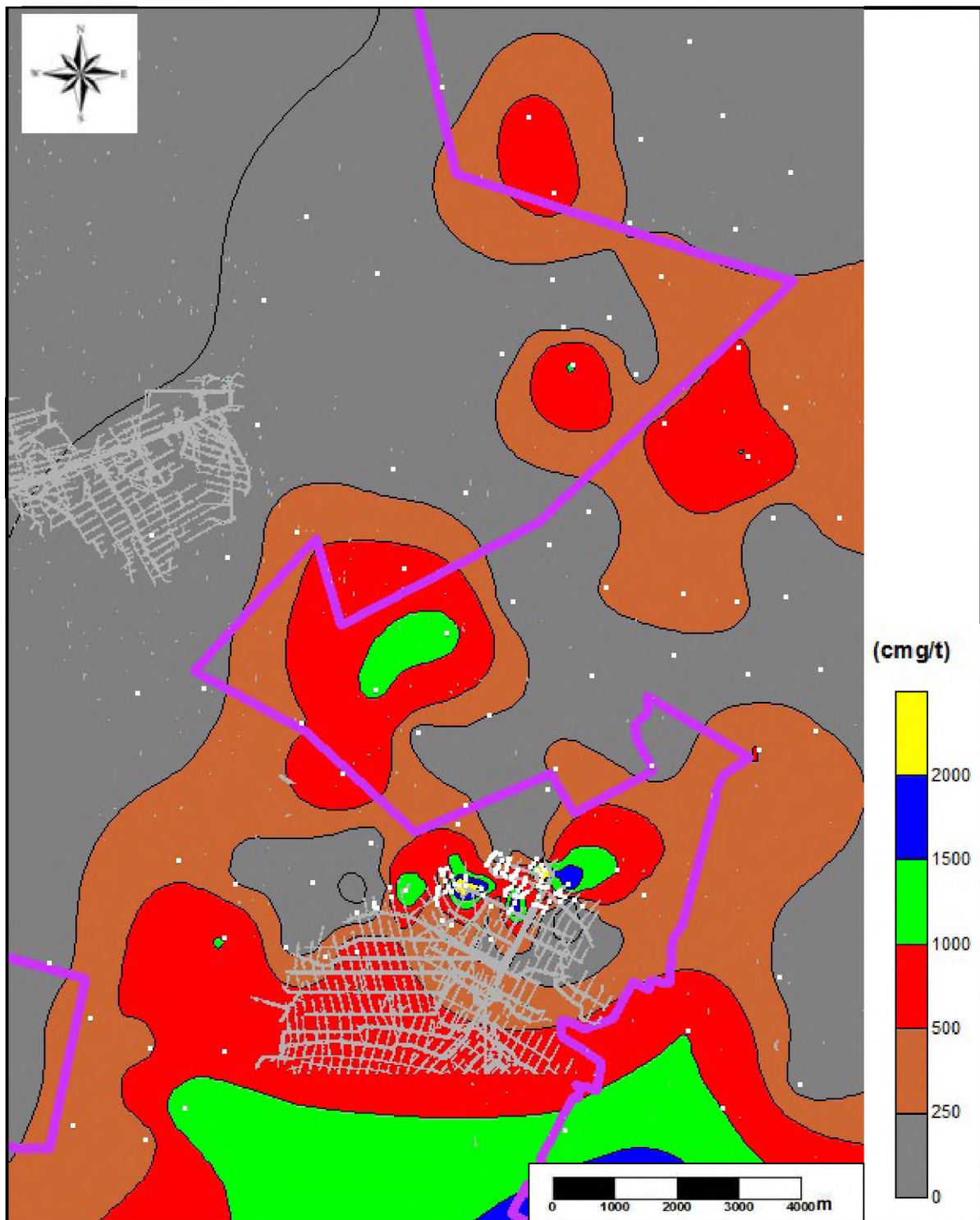


Figure 5.4: Contour map of the average gold accumulation (cmg/t) of the VS5/Beatrix Reef from surface and underground boreholes.

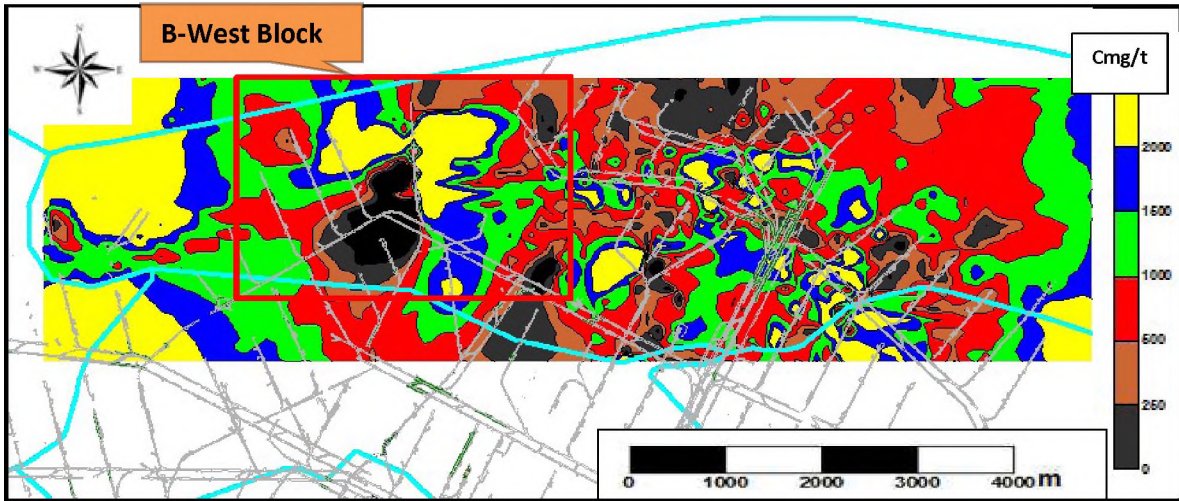


Figure 5.5: Contour map of the average gold accumulation (cmg/t) of zone 51 (VS5 Reef) from underground sampling data.

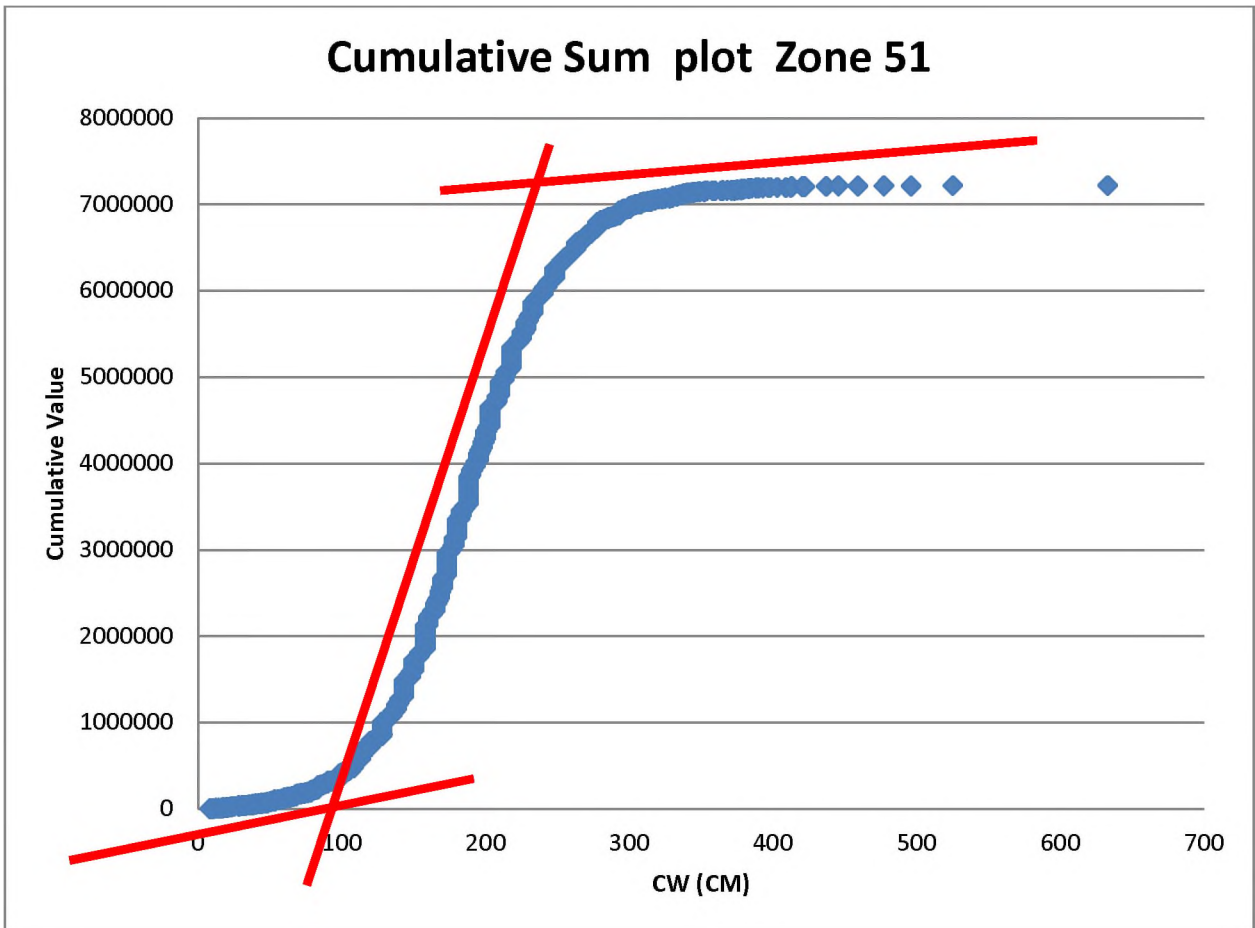


Figure 5.6: Cumulative Sum Plot for zone 51 (Sub-mature VS5 Reef)

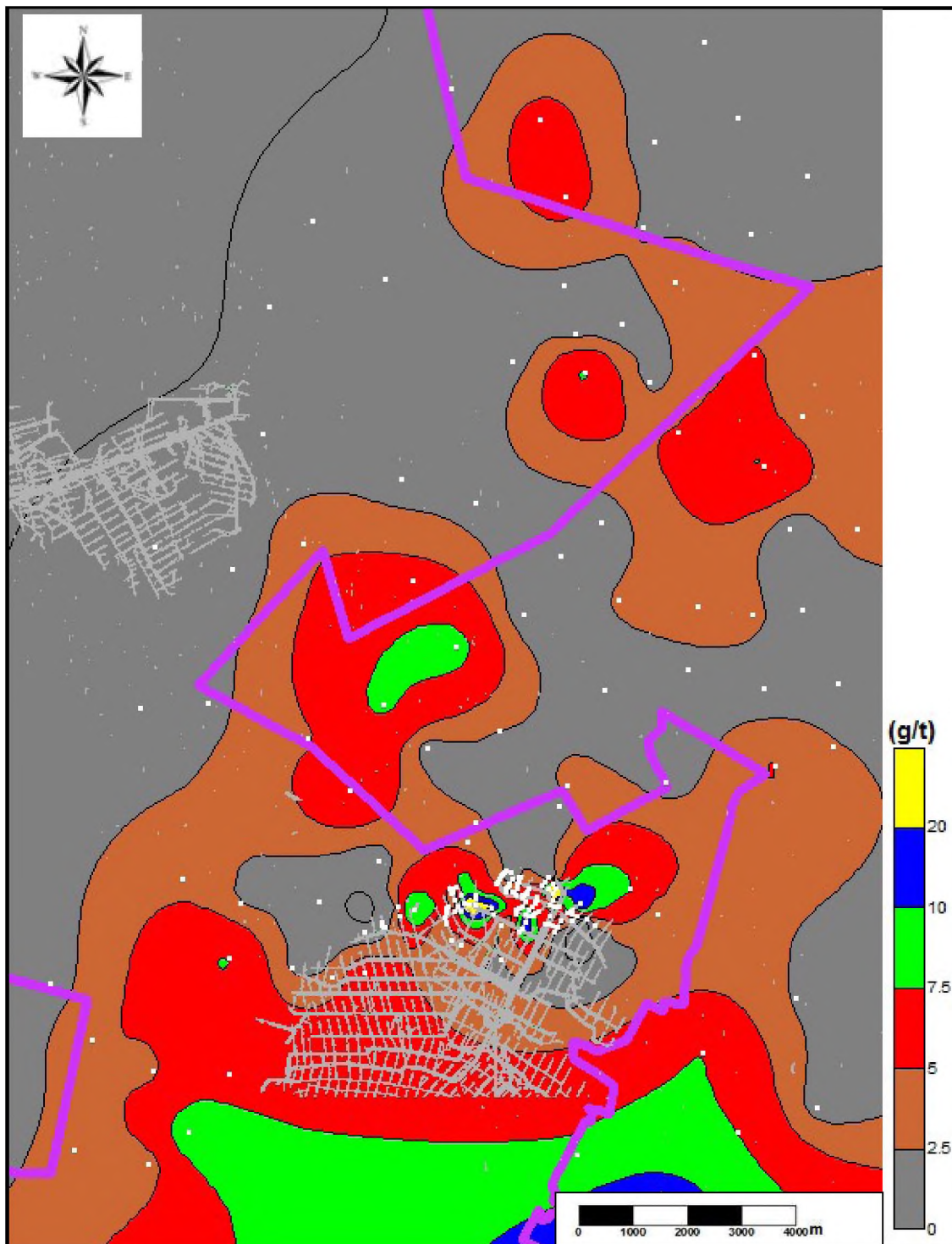


Figure 5.7: Contour map of the average gold grade (g/t) of the VS5/ Beatrix Reef from surface and underground boreholes

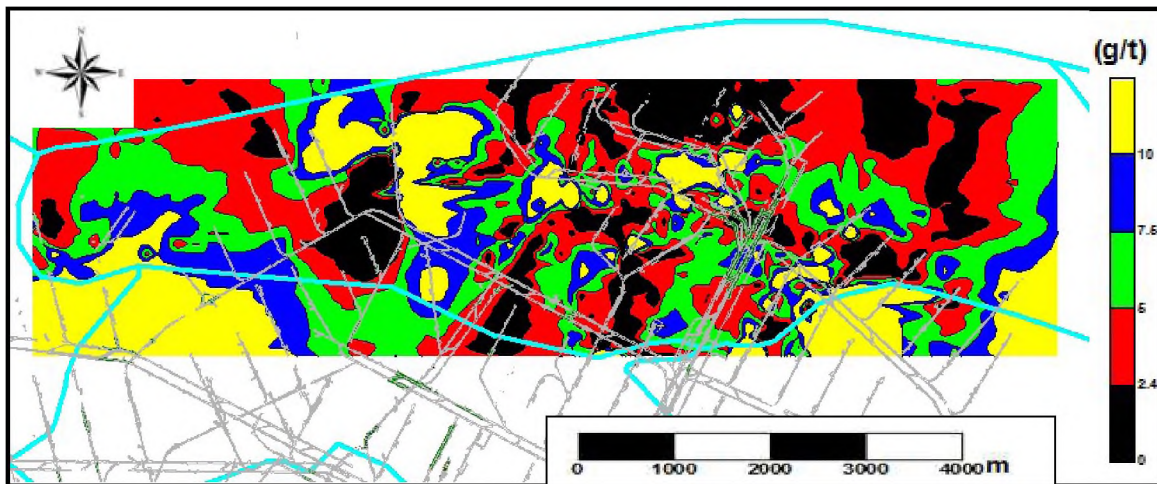


Figure 5.8: Contour map of the average gold grade (g/t) of zone 51 (VS5 Reef) from underground sampling data.

5.6 Origin of the gold

The origin of the gold in the Witwatersrand goldfields remains controversial after more than hundred years of mining and research (Robb and Meyer, 1990; Robb and Meyer, 1991). Mellor (1916) proposed a Placer model that considers gold, uranium and pyrite as detrital material derived by erosion, transportation and deposition from Archean greenstone terranes surrounding the Witwatersrand sedimentary basin. This hypothesis was supported by numerous subsequent researchers e.g. Viljoen *et al.* (1970); Minter (1978); Minter *et al.* (1992); Minter (1999); Kirk *et al.* (2001), MacLean and Fleet (1990); and Pretorius (1981); but challenged by others advocating a hydrothermal origin for the gold in the Witwatersrand Basin (Graton, 1930; Barnicoat *et al.*, 1997). A metamorphic- hydrothermal model was proposed by Phillips *et al.* (1987) and Phillips and Myers (1989). The main argument for the hydrothermal model is that gold occurs late in the paragenetic sequence. Frimmel *et al.* (1993) concluded from a study on the degree of post-depositional alteration to which detrital gold particles on the Basal Reef had experienced, that metamorphism caused homogenization and partial mobilization of the original placer gold. Phillips and law (1994) also described the significance of metamorphism in the Witwatersrand conglomerates.

These arguments can be summarized as three general genetic models namely: the placer model, hydrothermal model and modified placer model.

A detailed discussion on the source of the gold mineralization is beyond the scope of this study; however, evidence from mining exposures in the Beatrix workings, and the Welkom area as a whole, strongly supports an essentially unmodified detrital origin for the gold in these goldfields.

There is an overwhelming correlation between sedimentological features and gold mineralization. It is recognized basin-wide that high gold tenor occurs mainly at the base of conglomerates and in scour surfaces. The presence of detrital pyrite and lack of mineralization in quartz veins associated with intrusives and structures supports the hypothesis that the Au mineralization was introduced as detrital material and concentrated by essentially hydrodynamic processes. Observations that support a degree of hydrothermal remobilization are the occurrence of buckshot pyrite indicating growth from a hydrothermal fluid; and the noteworthy association of enhanced gold mineralization in close proximity to the major structure Stuurmanspan fault. Both hydrodynamic and hydrothermal processes are likely to have been responsible for the origin and final concentration of the abundant gold in the Witwatersrand Basin. Table 5.1 below summarizes the main arguments against the two proposed models for the origin of gold in the Witwatersrand Basin.

Table 5.1: Arguments against Placer and Hydrothermal Models for the origin of gold in the Witwatersrand Basin.

Arguments against the placer model for source of gold in Witwatersrand Basin	Arguments against the hydrothermal model for source of gold in the Witwatersrand Basin
1. Source of such a large volume of gold	No evidence of hydrothermal fluid channelways
2. Absence of gold nuggets	Absence of hydrothermal zoning
3. Small particle size compared to recent placers	Association of low permeability pyritic quartzites
4. Secondary crystalline and hack ley habit of Au	Blocks of isolated mineralised conglomerate in barren quartzites
5. Low fineness of gold	High spatial correlation of heavy minerals (Au, U and detrital zircon)
6. Association of Au, Fe, As, S and Au carbon is epigenetic, not syngenetic	Relation between heavy mineralization and sedimentary structures
7. Abundance of idiomorphic pyrite	Rich accumulation on unconformities
8. Gold in end-member electrum is epigenetic	Zircon, chromite, uraninite and pyrite in hydraulic equilibrium

Chapter 6

Depositional model

6.1 Introduction

Sedimentary depositional environments are characterized by distinctive vertical profiles containing various lithologies and vertical arrangement of sedimentary structures and textures (Miall, 1977; Miall, 1978). Most of the Witwatersrand placers are channelized indicating that braided rivers were the principal agents for sediment transportation and deposition (Pretorius, 1976a; Hiller and Mason, 1982; Verrezen, 1987). This channelization process resulted in a thick reef package, characterized by robust, clast-supported conglomerates interbedded with a relatively high percentage of quartzites (Els, 1991). The aim of the sedimentological model is to relate gold and uranium distribution to sedimentary structures and textures which can be applied as a tool in exploration and mineral resource evaluation. This chapter describes the environment of deposition of the VS5 placer as it occurs at Beatrix Mine and the surrounding areas south of the Sand River.

6.2 Depositional model of VS5

After the deposition of the Kimberley Reefs, there was a break in deposition which resulted in the formation of the erosional unconformity at the base of the VS5 and Beatrix Reefs; subsequent tectonic uplift and subsidence of the basin resulted in a new episode of sedimentation. As noted in the preceding chapter on gold mineralization, the erosion and reworking of the Aandenk Reef in the area exerted a major control on gold distribution in the VS5. The clast assemblage in the VS5 Reef indicates derivation from source areas rich in non-durable materials and barren in heavy minerals. The VS5 depositional system displays several characteristics indicative of a fluvial depositional environment; these include: unidirectional paleo-current indicators, channels and scour surfaces, repetitive upward-fining conglomerate/sandstone cycles, large and medium-scale trough and planar crossbedding, large grain size variation etc. (Burton and Fralick, 2003).

Sedimentological evidence indicates that the source of the VS5 sediments was from the west and north of the Goldfield and were dispersed by braided alluvial systems. Evidence for this includes the

Table 6.1: Lithofacies and sedimentary structures described in modern and ancient braided stream deposits (Miall, 1977, Table 1)

Facies Code	Lithofacies	Sedimentary structures	Interpretation
<i>Gms</i>	massive, matrix supported gravel	none	debris flow deposits
<i>Gm</i>	massive or crudely bedded gravel	horizontal bedding, imbrication	longitudinal bars, lag deposits, sieve deposits
<i>Gt</i>	gravel, stratified	trough crossbeds	minor channel fills
<i>Gp</i>	gravel, stratified	planar crossbeds	linguoid bars or deltaic growths from older bar remnants
<i>St</i>	sand, medium to v. coarse, may be pebbly	solitary (theta) or grouped (pi) trough crossbeds	dunes (lower flow regime)
<i>Sp</i>	sand, medium to v. coarse, may be pebbly	solitary (alpha) or grouped (omicron) planar crossbeds	linguoid, transverse bars, sand waves (lower flow regime)
<i>Sr</i>	sand, very fine to coarse	ripple marks of all types	ripples (lower flow regime)
<i>Sh</i>	sand, very fine to very coarse, may be pebbly	horizontal lamination, parting or streaming lineation	planar bed flow (l. and u. flow regime)
<i>Sl</i>	sand, fine	low angle (<10°) crossbeds	scour fills, crevasse splays, antidunes
<i>Se</i>	erosional scours with intraclasts	crude crossbedding	scour fills
<i>Ss</i>	sand, fine to coarse, may be pebbly	broad, shallow scours including eta cross-stratification	scour fills
<i>Sse, She, Spe</i>	sand	analogous to <i>Ss, Sh, Sp</i>	eolian deposits
<i>Fl</i>	sand, silt, mud	fine lamination, very small ripples	overbank or waning flood deposits
<i>Fsc</i>	silt, mud	laminated to massive	backswamp deposits
<i>Fcf</i>	mud	massive, with freshwater molluscs	backswamp pond deposits
<i>Fm</i>	mud, silt	massive, desiccation cracks	overbank or drape deposits
<i>Fr</i>	silt, mud	rootlets	seatearth
<i>C</i>	coal, carbonaceous mud	plants, mud films	swamp deposits
<i>P</i>	carbonate	pedogenic features	soil

progressive change in maximum pebble size from very large pebble to cobble; occurrence of immature conglomerates in the western and northern areas (No. 4 shaft region) changing to smaller sub-rounded pebbles with mature siliceous matrix of the Beatrix facies in the south and south east areas (Figure 3.18). The largest pebbles will be deposited in close proximity to the source whereas

smaller pebbles will be transported and deposited further downstream. The Immature VS5 facies was deposited in the proximal setting of alluvial fans and is dominated by debris flow deposits (equivalent to the Gms facies of Miall, 1977- see Table 6.1) comprising poorly sorted, sub-angular to sub-rounded conglomerates interbedded with quartzite.

As the gradient of the river decreased and the river valley widened, there was a change from an alluvial fan to a braided depositional environment. This change resulted in the local erosion of older sediments (including heavy minerals), transportation and deposition in more distal environments. These distal areas of braided rivers are dominated by well sorted, relatively small to medium pebble gravels (Gm facies) with mature siliceous matrix associated with cross bedded sand (St Facies). The mature Beatrix facies provides a good example of facies formed in these environments. Heavy minerals detritus including gold in distal areas were probably eroded from existing sediments and concentrated by hydraulic reworking processes. Channel migration resulted in reworking of inter-channel bars forming internal erosional bars and quartzite lenses observed in the Beatrix Reef.

Well-developed conglomerates of the Beatrix facies accumulated in major channel ways and point bars where deposition resulted from a decrease in flow velocity. Work by Genis (1990) and Rose (2006), indicates NW-SE channel edge orientations for both the Beatrix and Aandenk Reefs. Other reefs in the northern parts of the Welkom goldfield such as the A and Leader Reefs, indicate NW to SE paleo-current directions (Blamey, 1992).

From the cumulative conglomerate thickness contour map (Figure 3.16) and evidence from underground mapping, it can be inferred that the paleo-current direction of the VS5 system was dominantly from NW-SE a smaller N-S trend. The percentage of non-durable pebbles increases towards the western margin of the basin supporting the idea that sediment influx into the Goldfield was from the west (Figure 3.16). The Sub-mature (Transitional) VS5 facies was deposited in the transitional zone of the alluvial fans and braided streams. A period of transgression period followed which resulted in the deposition of the shale layer above VS5 traced over the whole mine area.



Figure 6.1: Ripple marks in the hangingwall indicating Paleo-current direction.

Figure 6.2 below shows a north-south cross section across Beatrix No.3 Shaft mine area. Different reef types with their various facies are recognized. The Beatrix Reef zone occurs in the south and overlies the Aandenk Reef towards the north. The three major economic reef zones are recognized as indicated on the sketch. Complex shapes of channels with internal bars and inter-channel areas characterize the braided depositional systems responsible for the deposition of V55 and the other placers in the region. Pebble lag deposits represent paleo-high depositional environment. After deposition of the Aandenk Reef sediments there was a period of no deposition during which the unconformity below the VS5 Reef developed.

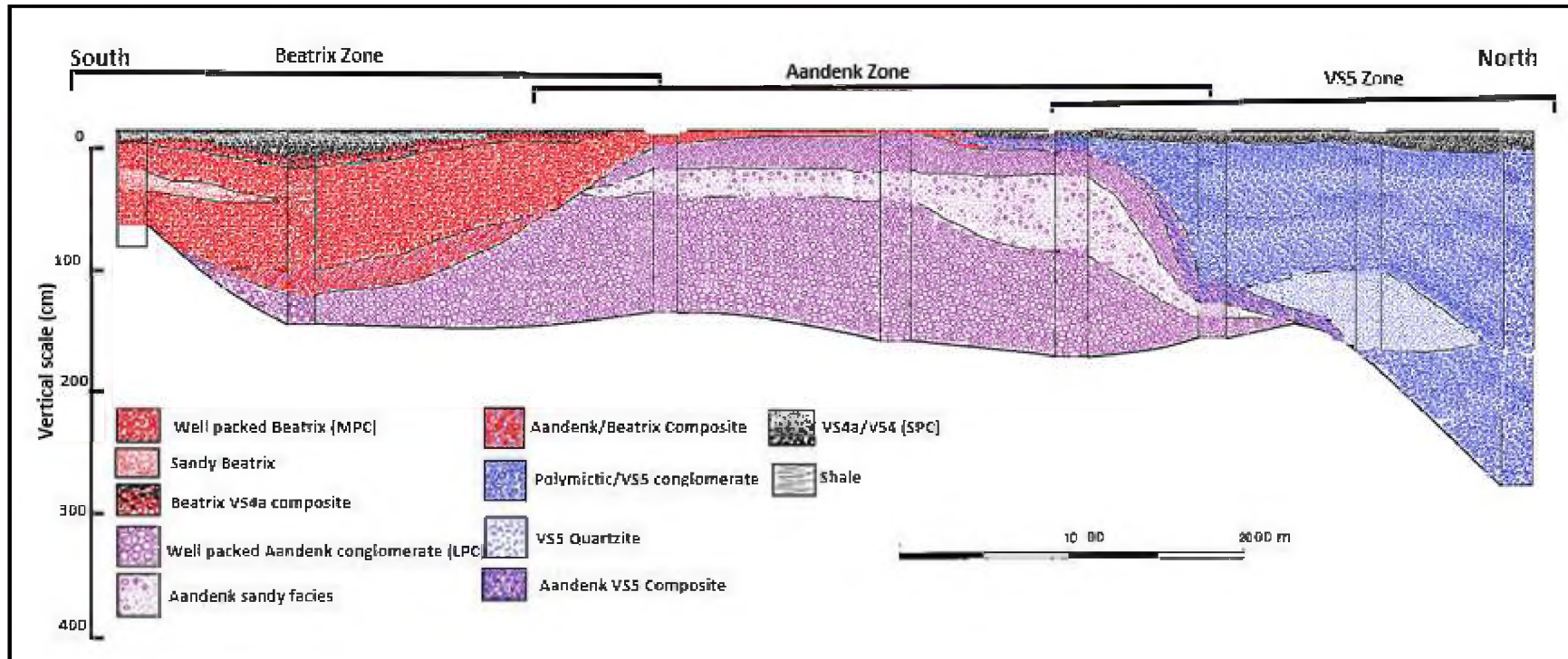


Figure 6.2: Detailed geological sections from south to north at the Beatrix No. 3 shaft showing the transition between the different reefs

Chapter 7

Summary and Conclusions

The Witwatersrand Basin remains the largest gold depository ever discovered and exploited in the history of gold mining and has accounted for about 38% of the world's total gold production. Although production has progressively declined from a high in 1970 (Viljoen, 2009), the basin still has potential to produce more than 16000 t of gold reserves and resources in the future.



Figure 7.1 South Africa gold production trend 1940-2012 showing a progressive decrease in gold production from 1970 to the present. Source: https://en.wikipedia.org/wiki/Mining_industry_of_South_Africa.

The Beatrix Mine is located in the south-western corner of the Welkom Goldfield at the southern edge of the Witwatersrand Basin and has historically targeted the Beatrix Reef as the major economic horizon for mining. Other reefs of economic importance in the Beatrix area include the Aandenk, Kalkoenkrans (KKR) Reefs as well as selective zones of the VS5 Reef. All of the placers mined at Beatrix Mine occur in the upper parts of the Central Rand Group of the Witwatersrand Supergroup.

The VS5 Reef constitutes the largest part of the unexploited resources in the Beatrix area and, if successfully converted into reserves, could replace the Beatrix and Aandenk Reefs which are nearing

exhaustion in the current mining areas and significantly extend the life of this mining district. The VS5 Reef will undoubtedly play a major role in gold production for Beatrix No. 3 Shaft in future.

The VS5 Reef is, however characterized by high variability in gold grade being uneconomic to marginal in certain areas and this limits its economic attractiveness. To mine the VS5 Reef economically and to maximize gold production from this reef, selective mining of economic zones is required. The recognition and delineation of these “pay zones” is the main objective of this project.

Stratigraphically the VS5 Reef occurs at an unconformity at the base of the Elsburg Formation overlying a footwall sequence changing from Main Formation to the south to the Kimberley Formation to the north and northwest of the mine lease area. Some important placers of the Welkom Goldfield (notably the Basal/Steyn Reefs) are missing in the Beatrix area due to erosional truncation causing onlapping of Formations towards the southern edge of the basin.

A significant correlation is evident between the sedimentology of the reefs and gold concentration that can be used as a tool to predict grades in unmined areas. Textural maturity of the conglomerates is by far the most important factor influencing gold distribution. Higher gold grades are associated with well packed, well-sorted, mature conglomerates which had been exposed to longer periods of reworking. Non-reworked poorly sorted, immature conglomerates are associated with low gold concentrations. In addition a strong positive correlation exists between gold tenor and conglomerates containing large, vein-quartz pebbles.

This study in conjunction with observations by Beatrix Mine geologists, has recognized three broad zones of VS5 Reef facies in the Beatrix Mine lease area based on sedimentology and gold content namely:

- (i) **Immature VS5 zone** – Stretches from the northwestern parts (No.4 Shaft) through the northern parts of No. 3 Shaft towards the south east in the adjacent Joel Mine. It comprises poorly packed and poorly sorted immature polymictic conglomerate with associated pebbly quartzites. This zone type has poor gold concentrations and is generally not economically exploitable under current (late 2015) economic conditions.
- (ii) **Sub-mature (Transitional) VS5 zone**- This zone covers most of the current mining faces at Beatrix No. 3 Shaft (zone 51), and formed by the reworking of the underlying Aandenk Reef by the barren VS5 material during deposition, accompanied by scavenging of the underlying gold. The Transitional VS5 facies is more mature compared to the immature facies. In some localized areas the VS5 has completely reworked the Aandenk Reef and in

other areas some pockets of un-reworked Aandenk Reef are preserved. Grades in the sub-mature VS5 ranges from marginal to economic gold concentrations. Mineralization occurs in scours surfaces as well as around large quartz pebbles.

- (iii) **Beatrix Reef facies** – In the past this reef has been described as a separate placer to the VS5, but new evidence from mining faces indicates that the Beatrix and VS5 Reefs occur at the same stratigraphic horizon and could have been deposited by the same depositional system as different facies in different environments. The VS5 Reef represents a less reworked proximal facies and the Beatrix Reef the highly reworked distal facies of an alluvial fan. The Beatrix Reef is associated with higher gold concentrations than the Sub-mature VS5. It occurs towards the south and southeast of the mine area. Mineralization in the Beatrix Reef is consistent and is a function of channel width and conglomerate packing.

The VS5 Reef has been deposited in a fluvial system transgressing from an alluvial fan dominated by debris flow deposits, to a braided river environment characterized by gravel channel deposits and sandbars. The sediment sources were from the west and north and comprised of diverse rock types including shales, lavas and quartzites resulting in a polymictic deposit. The abrupt change from polymictic VS5 to oligomictic Beatrix facies within a short distance reflects the role of reworking of the sediments by fluvial and or marine processes. A continuous washing of the Beatrix Reef by waves could have resulted in removal of non-durable pebbles leaving behind durable quartz pebbles and heavy minerals.

Structurally the Beatrix Mine area is consistent with regional structures dominated by north-south trending faults resulting in hosts and graben structures. The western boundary is marked by an overturned fold referred to as the western margin structure and the eastern side is bounded by the De Bron fault. Major faults with throws up to 100m occur in the mine area affecting mining layout and designs. Minor faults with a north south orientation as well as younger dykes and sills displaces reef in the area causing mining and safety problems. Faults running subparallel to crosscuts are common and cause problems to mining designs and layouts.

To economically mine a gold placer having highly variable grades like the VS5, a proper strategy has to be designed and implemented. Based on the findings of this research, the following conclusions are made for future mining of the VS5;

- The Immature VS5 facies should be avoided as the grade (both in terms of g/t and cmg/t) of this facies is critically low for economic extraction (average grades of 0.2 g/t).
- Selective mining in the Sub-mature (Transitional) VS5 facies zone is recommended. The lateral and vertical value distribution in the Sub-mature VS5 varies locally with higher gold concentrations associated with the bottom 1m to 1.5 m which represent the zone of mixing (reworking) of Aandenk materials. This bottom well developed part of the VS5 and the pockets of preserved Aandenk should be targeted in areas where it can be easily identified. This is critical in areas where the channel widths are in excess of 3.5m and mining full channel is not possible or lowers the grade. However, although the general trend shows that the sub-mature VS5 is bottom loaded it can be very erratic and locally changes into top-loaded within short distances therefore the grade controllers and geologists has to be vigilant in monitoring and advising of this change.
- No major grade problems is associated with the Beatrix facies except for extremely thin reefs or waste-on-contact areas, therefore thicker well packed conglomerates should be targeted.
- In the B-West block where the vertical distribution of gold tend to be spread all over the channel, full channel cut is recommended where possible and in very high channel the bottom 2m will provide the highest grade in average.
- A full gold deportment study on the VS5 should be undertaken to ascertain the metallurgical characteristics of the reef.

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Appendices

Appendix 1

Surface borehole data

BH ID	XTP	YTP	Conglomerate (cm)	Value (cmg/t)	Grade (g/t)	LPS	minimum % Non-durables
744	-25255.5	-26467.2	34	477	6.35	45	0
876	-25558.8	-24397.1	15	110	5.56	40	0
1125	-25033.6	-25104.8	43	503	17.29		0
1171	-26104.4	-26072.5	100	64	2.76	50	10
1415	-18013.6	-23530.2	226	287	1.22	45	60
DBH10	-16216.8	-17350.3	252	265	1.16	46	20
DBH13	-16810.8	-16585.2	677	539	1.15	52	12
DBH14	-18685.8	-20759.5	232	108	0.43	72	75
DBH15	-16699.8	-17970.4	261	1094	4.41	51	40
DBH16	-16834.8	-19820.4	21	340	5.61	41	5
DBH17	-15184.8	-16100.3	55	334	3.49	41	2
DBH2	-15543.8	-18745.5	195	389	3.95	51	0
DBH3	-16207.8	-19746.5	18	38	1.53	16	20
DBH4	-17521.8	-19710.5	192	384	1.79	36	5
DBH6	-16377.7	-18759.9	158	44	0.98	36	0
DBH8	-17642.9	-20498	223	168	0.91	45	50
DBH9	-17760.8	-17550.3	158	540	3.02	52	20
DC5	-23831.6	-26240.8	55	1389	21.57	41	0
DGR1	-21652.7	-24261.7	135	858	5.73	33	0
DPM1	-19128.7	-21943.4	216	341	1.65	57	50
DPM2	-17907.5	-21899.1	120	135	1.13	37	30
DR12	-22352.9	-21355.6	214	443	2.70	66	10
DR13	-23199.7	-23391.4	14	219	4.82	46	0
DR6	-18463.4	-16221.1	115	27	0.84	24	0
DR7	-23591.9	-20924.2	248	186	0.64	71	50
DR8	-23337.7	-24079.6	22	1090	25.12	47	0
DR9	-23923.1	-23090	24	420	12.21	34	0
DRH1	-22221	-23370.5	16	86	3.91	45	0
DRH2	-22555.9	-24195.3	17	187	9.35	50	0
DVP1	-24289.6	-25472.8	10	428	26.58	47	2
DVP2	-23330.7	-25512.4	25	735	13.95	53	5
DVP3	-24338	-26645.9	12	297	7.98	58	0
DWN4	-15767.9	-20682.5	84	117	1.61	27	5
DWN5	-16562.8	-21698.6	213	539	2.58	72	15
DWN6	-16696.8	-20729.5	114	115	1.36	34	40
DWN9	-15843	-21463.1	18	270	12.74	52	2
DWV1	-20269.7	-22399.7	218	295	1.41	48	40
DWV10	-21412.7	-20941.6	422	1102	3.26	72	30
DWV11	-21833.6	-21991.7	225	1028	4.30		50
DWV2	-18495.8	-19644.5	76	298	3.67	82	0
DWV3	-18714.8	-18666.4	31	93	2.19	35	2
DWV4	-19218.7	-19100.5	6	16	0.96	28	5
DWV5	-20517.3	-20221.6	290	1238	3.73	62	45
DWV6	-19673.7	-19809.5	182	40	0.20	42	60
DWV7	-20887.7	-21477.6	230	128	0.76	53	50
DWV8	-19983.7	-21248.6	281	247	0.90	75	40
DWV9	-21474.5	-22874.6	352	76	0.32		65

HAK10	-19030.8	-11044	462	46	0.21	66	35
HAK11	-16856.3	-15084.5	267	52	0.31	56	20
HAK12	-19473.7	-13680.1	138	635	4.13	65	35
HAK13	-16157.1	-14376.5	138	80	0.53	34	5
HAK14	-18060.6	-13960.5	111	93	0.94	55	7
HAK15	-17437.8	-12703	240	68	0.16	65	15
HAK17	-18194.2	-15017.3	188	225	1.15	60	50
HAK18	-17006.8	-13658.1	372	193	0.50	49	30
HAK19	-19153.7	-14638.8	352	648	1.82	65	70
HAK7	-19331.7	-10071.9	305	18	0.34	55	40
HAK9	-20578.7	-13283.1	54	61	0.70	67	3
JDR15	-18926.1	-16807.6	141	1108	8.39	42	17
JDR16	-21201.7	-18133.9	124	110	0.38	43	80
JDR19	-19031.7	-16336.6	18	138	1.22	51	15
JDR20	-17795.7	-15698	230	451	1.42	47	20
JDR22	-21057.5	-19394.4	400	654	1.52	77	60
JDR23	-20269.1	-18437.1	204	156	0.55	48	65
JDR7	-19824.4	-16678.8	10	99	0.65	46	40
JDR8	-18116.3	-16926.1	225	148	0.83	29	55
JS1	-19238.6	-22193.5	85	75	0.62	38	35
LB11	-16038.8	-25936.8	220	136	1.07	48	50
LB4	-17455.8	-25264.8	54	1028	13.22	41	50
LB5	-19018.8	-26521.8	85	1112	7.14	42	0
LB7	-17023.8	-26248.8	105	1004	4.45	41	0
LB9	-16302.3	-24582.9	228	223	0.99	38	60
LF3	-18214.7	-27707.9	41	2263	27.94	50	0
MS2	-19081.2	-23534.4	47	1788	7.84	30	
MS3	-19948.7	-24090.7	131	233	5.12	35	2
MS4	-18352.1	-23223.6	15	1038	5.99	42	10
MS5	-20453.5	-23913.8	198	412	18.64	40	12
SR11	-21400.6	-15654.5	15	112	0.44	23	15
SR12	-22913.7	-17571.1	518	44	0.07	54	70
SR16	-19184.6	-15733.7	5	176	5.04	26	0
SR2	-22836.7	-15990.6	16	24	0.10	43	60
SR9	-22308	-14937.2	51	66	1.46	35	15
ST11	-24262.7	-18969.3	241	118	0.99	63	60
ST15	-23305.6	-19257.7	383	27	0.22	76	85
ST22	-24444.6	-20966.6	682	164	1.32	86	30
ST26	-22416.5	-18926.8	388	446	3.74	54	50
ZP1	-20380.9	-22644.6	110	389	2.95	33	35

Appendix 2

Underground borehole data

BH ID	XTP	YTP	ZTP	Conglomerate (cm)	Value (cmg/t)	Grade (g/t)
BNC1282	-23648.7	-19370.4	143.2	343.3	788	2.30
BNC1620	-23413.5	-19351.1	145.6	180.3	82	0.45
BNC3043	-23101.2	-19735	189.1	141.2	334	2.37
BNC3752	-23198.2	-20507.7	109.2	148.1	1909	12.89
BNP1295	-23657	-19410	151	180.6	438	2.43
BNP1346	-23757.9	-19727.5	166.3	274.5	953	3.47
BNP1437E	-23718.7	-19702.2	156.2	887.9	3327	3.75
BNP1562	-23432.5	-19291.8	107.5	327.5	114	0.35
BNP1778	-23676	-19951	172.2	24.5	38	1.57
BNP2135	-23324.1	-19512.8	157.8	184.2	1240	6.73
BNP2169	-23377	-19533.5	164.4	93.7	698	7.45
BNP2170	-23354.2	-19518.1	161.6	163.2	974	5.97
BNP2171	-23392.4	-19543.9	164.5	162.4	1267	7.80
BNP2214	-23767.2	-19300.9	142	130.0	236	1.81
BNP2259	-23701.6	-19264.2	127.7	258.9	526	2.03
BNP2297	-23429.6	-19581.8	169.9	114.5	373	3.26
BNP2298	-23470.9	-19608.3	171.2	327.7	554	1.69
BNP2366	-23620.7	-19210.5	118.5	176.5	523	2.97
BNP2387	-23297.4	-19697.5	180.1	215.2	418	1.94
BNP2398	-23285.2	-19651.6	167.2	272.2	608	2.23
BNP2424	-23290.3	-19679.6	175.8	172.9	361	2.09
BNP2433	-23226.2	-19753.5	176.6	163.0	381	2.34
BNP2510	-23620.6	-19072.4	98.6	197.0	162	0.82
BNP2620	-23328	-19697.7	182.5	265.6	546	2.06
BNP2626	-23540.2	-19655.2	194.4	436.5	1997	4.58
BNP2676	-23255.5	-19640.8	171.3	170.0	861	5.07
BNP2677	-23272.9	-19643.3	168.9	78.9	312	3.95
BNP2707	-23222.6	-19613.4	193.8	253.1	872	3.45
BNP2720	-23216.6	-19622	162	194.0	617	3.18
BNP2735	-23361.7	-19318.4	130.6	334.5	1070	3.20
BNP2760	-23544	-19768.4	179.8	206.7	130	0.63
BNP2761	-23248.6	-19813.5	175.2	339.6	379	1.12
BNP2795	-23299.7	-19783.3	179.9	66.7	445	6.68
BNP2833	23274.3	-19317.8	129.7	181.3	5456	30.10
BNP2847	-23551.2	-19350.8	125	161.4	1303	8.08
BNP2879	-23165.1	-19751	176.9	107.4	14	0.13
BNP2896	-23226.5	-19367.5	119.5	102.4	86	0.84
BNP2898	-23177.7	-19761.8	168.3	143.8	273	1.90
BNP2923	-23263.6	-19790.7	173.6	110.6	50	0.46

BNP2928	-23672.5	-19321.7	129	178.2	1355	7.60
BNP2930	-23213.4	-19282.5	112.9	270.1	467	1.73
BNP2947	-23158.6	-19310.5	105.4	44.0	121	2.74
BNP2958	-23628	-19657.5	205.2	303.3	1748	5.76
BNP2998	-23174.2	-19751.5	178.3	207.7	556	2.68
BNP3000	-23564.4	-19615.6	196	366.5	2996	8.18
BNP3058	-23130.7	-19742.8	172.3	63.2	536	8.48
BNP3072	-23512.6	-19134.5	90.2	238.7	356	1.49
BNP3100	-23248.3	-19893.1	189.2	133.4	472	3.54
BNP3121	-23476.2	-19083	86	146.6	1436	9.80
BNP3126	-23430	-19232	100.8	166.1	343	2.07
BNP3156	-23490.9	-19103.2	87.6	167.1	1080	6.46
BNP3202	-23399.1	-18982.6	63	228.6	2351	10.28
BNP3212	-23174.4	-19451.6	128.4	149.9	64	0.42
BNP3213	-23131.2	-19419.6	117.6	133.3	266	2.00
BNP3229	-23105.2	-19818.4	119.9	145.7	22	0.15
BNP3230	-23160.7	-19863	180.1	143.9	285	1.98
BNP3244	-23559.7	-19008.2	78.4	232.0	31	0.14
BNP3259	-23136.4	-20006.8	191.6	198.0	56	0.28
BNP3262	-23192.4	-19885.6	185.3	146.8	458	3.12
BNP3263	-23187.1	-19864.8	182.3	234.9	1092	4.65
BNP3298	-23101.1	-19982.1	182.8	239.9	361	1.51
BNP3302	-23210.2	-19900	185.6	101.0	522	5.17
BNP3366	-23049.4	-19952.5	167.5	152.3	525	3.45
BNP3367	-23086.4	-19382.5	107.8	174.3	241	1.38
BNP3387	-23532.3	-20066.8	214.3	156.8	1070	6.83
BNP3392	-23044	-19941.1	169.2	255.6	184	0.72
BNP3397	-23528.6	-19556.9	103.5	255.6	528	2.07
BNP3410	-23013.4	-19919.5	163.1	193.0	902	4.67
BNP3427	-22996	-19903	164.2	79.9	32	0.41
BNP3428	-23020.8	-19839.5	165.9	127.1	131	1.03
BNP3440	-22988.4	-19897.4	167.1	40.7	47	1.16
BNP3441	-23564.4	-19554.2	180.2	225.2	958	4.26
BNP3445	-23070.8	-19722	163.7	196.4	374	1.91
BNP3448	-23467.7	-20082.3	200	129.7	2830	21.82
BNP3485	-23077.5	-19740.6	167.8	179.0	328	1.83
BNP3492	-23152.8	-20026.7	198.1	86.8	131	1.51
BNP3494	-23500.6	-19504	178.3	230.5	573	2.49
BNP3544	-23464	-19723	186.7	488.8	3092	6.33
BNP3545	-23514.1	-19528	177.5	324.7	452	1.39

BNP3549	-23420.4	-20281.8	144.1	102.4	2503	24.44
BNP3562	-23372.6	-19658.6	177.8	289.4	178	0.62
BNP3568	-23598.7	-18893.6	69.4	61.1	74	1.21
BNP3582	-23655.5	-21429.4	63.9	218.2	815	3.73
BNP3592	-23375.6	-19663.8	190.3	481.7	828	1.72
BNP3600	-23421.2	-20361.2	133	167.3	3650	21.82
BNP3607	-23677	-21436.6	70.3	171.1	90	0.53
BNP3608	-23629.1	-21432.4	61.5	166.2	59	0.36
BNP3609	-23439	-19706.6	185.3	189.2	1065	5.63
BNP3610	-23473.7	-19770.1	199.2	283.6	1258	4.44
BNP3616	-23289.3	-20277.2	121.1	240.8	781	3.24
BNP3616A	-23346.7	-20272.8	130.3	186.7	1821	9.76
BNP3624	-23707.9	-21413.2	74.2	193.2	243	1.26
BNP3629	-23703.9	-21399.3	74.1	109.9	80	0.73
BNP3631	-23388.7	-20415.3	125.3	128.5	137	1.06
BNP3652	-23451.2	-19740.5	186.3	287.6	512	1.78
BNP3665	-24310.3	-22054.7	181.4	48.6	301	6.20
BNP3712	-23551.5	-21221.8	56.9	158.5	466	2.94
BNP3723	-23299.2	-20457.9	128.4	244.0	1620	6.64
BNP3771	23495.8	-20462.7	141.3	22.2	42	1.88
BNP3786	-23350.2	-20534.5	130.4	187.8	547	2.91
BNP3787	-23280.6	-20576.4	109.4	258.5	1199	4.64
BNP3794	-23685.8	-18791.1	64.6	47.5	219	4.61
BNP3825	-23256.9	-20557.8	114.4	307.2	265	0.86
BNP3826	-23867.4	-20579.7	114.6	256.3	240	0.94
BNP3849	-23222	-20586.8	106.1	19.3	37	1.91
BNP3866	-23445.6	-20488	150	22.6	85	3.75
BNP3886	-23505.1	-20531.6	157.61	156.6	265	1.69
BNP3960	-23751.8	-21656.7	74.8	229.3	48	0.21
BNP3963	-23210.8	-20605.9	149.8	172.2	163	0.95
BNP3991	-23443.2	-21244.4	53.4	482.0	317	0.66
BNP4002	-23632.1	-20645	161.7	243.6	167	0.68
BNP4016	-23445.8	-20623.5	140.9	247.1	806	3.26
BNP4075	-23585.2	-20652.3	158.8	120.3	170	1.41
BNP4106	-23484	-21039.4	2.6	330.8	2074	6.27
BNP4133	-23637	-20635.5	160.3	117.5	1376	11.71
BNP4134	-23655.4	-20643.8	160.9	108.0	294	2.72
BNP4134A	-23649.7	-20630.8	150.3	30.3	791	26.11
NL5	-23460	-20627.8	141.8	225.4	424	1.88
NL5-D2	-23508.8	-20632.1	146.6	131.4	1435	10.91