BENEFICIATION OF WITWATERSRAND TYPE GOLD ORES BY MEANS OF OPTICAL SORTING

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A dissertation submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, in fulfilment of the requirements for the degree of Masters of Science in Engineering

Johannesburg, June 2012

DECLARATION

I declare that this dissertation is my own unaided work. It is being submitted for the Degree of Masters of Science in Engineering to the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other university

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Signed:

Date: this…………day of…………………………year…………

ABSTRACT

Automated optical- and radiometric sorting plants treating Witwatersrand gold ore were operational in the 1970's and 80's with limited success on run of mine applications. Since then sensor based sorting technology has evolved significantly in its detection capabilities and throughput capacities of the sorting machines. Over the last 8 years some gold mines have shown renewed interest in this beneficiation technology in particular to recover misplaced reef from surface waste rock dumps.

This research comprises two case studies to prove the effectiveness and viability of optical sorting of Witwatersrand type conglomerate ores.

The first case study deals with recovering gold reef from surface rock dumps (SRD) at Kloof Gold Mine. Over a period from 2003 to 2010 various test work campaigns and pilot plant work was carried out proving both the technical and economic viability of optical sorting. Typically the grade of a SRD ranges between 0.5 g/t to 1.0 g/t of gold. Optical sorting achieved product grades of between 1g/t and 5 g/t at a mass recovery of between 5% to 30% of feed. In 2011 a 100 t/h optical sorter plant was successfully installed at the mine as part of a stand-alone process plant for treating surface rock dump material.

The second case study deals with testing waste rock sorting from run of mine ore at Central Rand Gold (CRG). The ore body can only be mined with 30% to 60% waste dilution which makes it an interesting application for coarse rock pre-beneficiation using sensor based sorting.

In both case studies the gold-bearing quartz conglomerate reef could be effectively separated from waste rock by optical sorting techniques.

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LIST OF TERMS AND ABBREVIATIONS

CCD	Charge Coupled Device
CIP	Carbon in Pulp
CRG	Central Rand Gold Limited
CS1	Case study 1
CS2	Case study 2
Gold Fields	Gold mining group Gold Fields Limited
Mintek	South Africa's national mineral research organisation
MR	Main reef
MRL	Main reef leader
PRO Secondary COLOR	Optical sorter type provided by CommodasUltrasort (Pty) Ltd
ROD	Run of dump
ROM	Run of mine
RTZ	Rio Tinto Zinc
SPH	Saldanha Plant Hire
SRD	Surface Rock Dump
VCR	Ventersdorp Contact Reef

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1 INTRODUCTION

In general the mining industry worldwide is continuously facing new challenges. These include:

- Decreasing grade and increasing depth of deposits
- Cyclical commodity markets
- Increasing costs especially energy and steel
- Mill feed - typically highly diluted
- Increasing hauling distances from mine to process plant
- Stricter environmental legislation to reduce carbon footprint and improve tailings disposal
- Water scarcity
- Rehabilitation of waste rock dumps

The gold mines operating on the Witwatersrand ore body face exactly the challenges listed above. Lower grade resources have to be mined at ever increasing depths. Complex hoisting systems of keeping waste rock and reef separate are not always in place, and if they are, they may not be effective. The amount of waste dilution varies from mine to mine and depends on a number of factors:

- The reef channel width compared to the actual mined stoping width. For example, the thin Carbon Leader Reef which consists of a single conglomerate band with a thickness of between 0.02m and 0.25m. Using conventional mining methods a stoping width at best of 0.8m can be achieved resulting in about 70% waste rock dilution.
- Geological disturbances within the ore body such as faults, dykes
- The amount of on-reef development such as strike or dip gullies, winzes and travelling ways. The rock from these operations contains a mixture of gold reef and waste rock.
- Hanging- and footwall scaling.

Consequently this barren waste rock is milled in the plant, costing energy, water and gold recovery.

The largest cost component and energy consumption in mineral processing is comminution i.e. the crushing and milling of the ore to micron size particles to liberate the minerals for extraction. Considerable cost could therefore be saved if waste rock could be removed from the process as early as possible. The need for innovation, particularly in present times of high input costs, low commodity prices and water shortages as well as total environmental footprint, is significant.

There are two main areas of research which show great potential for optical waste rock sorting from Witwatersrand ore: Surface rock dump (SRD) treatment and run-of-mine (ROM) sorting.

As described in Section 3, the two scenarios will be tested: SRD treatment and ROM pre-concentration. In both cases the aim of the research was to test to what extent optical sorting can effectively separate gold conglomerate reef from waste rock.

The current research seeks to re-instigate the sorting process for gold ore recovery focusing primarily on the state-of-art optical sorting technology such as has been developed over the past ten years through the work of the author and his colleagues as referenced. The sorting equipment used during this research was a PRO Secondary COLOR sorter.

The long-term aim of this research is to develop and establish a sustainable pre-concentration process which can apply to other operations which are mining the Wits-basin.

2 LITERATURE SURVEY

Mining activities around the Witwatersrand complex have been going on for over 120 years. The tabular conglomerate reefs are mined and hoisted to surface. No matter how carefully the mining operation of the reef is done, there has been and will always be waste rock diluting the grade of the run of mine ore going to the mill and gold processing plant. This waste rock stems from shaft sinking and development operations as well as hanging- and footwall contamination from the stopes. A range of benefits could be achieved if such waste rock were removed as early as possible in the process stream.

Beneficiation in its simplest form by means of hand sorting has been part of mineral processing ever since mining started thousands of years ago. Many papers and articles have been published on the topic of sorting particularly from the 1970's onwards.

2.1 The History of Optical Sorting on Witwatersrand Ores

Reef picking or hand sorting is probably the oldest form of pre-concentration of mineral-bearing ores. Ever since gold mining started on the Witwatersrand on a commercial scale in the 1890's, hand picking to remove waste rocks from the ore stream or reef picking from the waste stream was practiced before further gold processing. Even nowadays DRDGold [1], for example, have used reef picking at their Blyvoor operation to recover gold reef from waste rock dumps.

Both Schaffler [2] and Bosch [3] describe ore sorting as the rejection of a barren portion of ore or the acceptance of a gold-rich portion for further treatment. This can either be achieved by manual sorting, based on the visual appearance of the material, or with mechanised ore-sorting equipment, which relies on bulk ore properties such as optical appearance, (i.e. colour or photometric properties) or radioactivity. Ore sorting has been applied with considerable success to the Witwatersrand pebble-quartz conglomerate ores.

During the 1970's and mid-1980's a number of sorting plants were installed and operated on some Wits-Basin gold mines. The company Ore Sorters of the Rio Tinto-Zinc Group (RTZ) did most of the pioneering work. In 1972 the first production sorter plant was commissioned at Doornfontein Gold Mining Company Limited which is part of the Gold Fields Group as described by Keys *et al* [11]. A further upgraded sorter was installed at West Driefontein Gold Mining Company Limited. This was the first sorter installed in South Africa operating in a run-of-mine mode as written by Barton *et al* [12].

Marsden *et al* [4] describes a relationship between gold and uranium in some Witwatersrand ores, related to a particular reef which had been exploited by using radiometric sorting to selectively pre-concentrate coarse gold- (and uranium) bearing rock from waste rock. In the 1970's and 1980's radiometric sorters were used at Buffelsfontein Gold Mine.

Hand–sorting of ore, based on human visual examination of mineral-bearing ore versus barren waste rock is by no means new. As per Murray [21] a number of mines have tried hand-picking gold ore, for example, at Buffelsfontein Gold Mine and also at Kloof Gold Mine. Particularly in the finer size ranges of -50mm hand picking is labour intensive making it difficult to produce adequate tonnages.

Other pre-concentration methods such as density separation techniques have not worked for this application where most of the rock types of both ore and waste are quartzitic and thus have a similar specific gravity.

2.2 Optical Sorting Technology

According to Wills [5] electronic ore sorting equipment was first introduced in the late 1940's. The following description is still valid: "Ore sorting involves the appraisal of individual particles and the rejection of those particles that do not warrant further treatment" Wills [5]. The sorting process can be divided into four interactive sub-processes - Salter *et al* [6]:

1. Particle presentation;
2. Particle examination;
3. Data analysis;
4. Particle separation.

Feed preparation is most critical for optical sorters due the importance of surface characteristics and physical size of the particles as most sorters need a 3:1 or 2:1 ratio between the largest and smallest particle to be efficient. The washing of the pre-screen sorter feed is therefore of paramount importance. In cases where clay is present causing smudging of the rock, trommel-screen scrubbers are advisable. Once the particles have been properly prepared for sorting they are then presented to the sensor. To operate efficiently the sensor must be able to analyse each single particle separately. As a result, feed rate and the materials handling methods are the critical components in this process.

Sorters incorporating conveyor belts or chutes are the most common methods used - Wotruba [7]. Both have their advantages and disadvantages:

- A chute sorter is a compact design with a small foot-print. This design allows the installation of two cameras which enable the free-falling material to be scanned from two sides. This provides the best surface scan coverage of every rock surface. In valuable minerals such as gold ore this can be critical in optimising recovery. The ideal size range for chute type sorters is -250mm +20mm. The particles at this size range travel more or less at the same speed, as the resistance of the chute does not affect the travelling speed. Finer material of -20mm tends to slide unevenly down the chute causing mis-timing on the ejection of the particles. The throughput of chute sorters is limited to the material size, gravity which limits the speed, the specific gravity of the material, and the width of the machine (standard sorters are 1 200mm wide). Mineral liberation is also an important factor to consider when deciding on the suitable size range. The throughput of the most common size -80mm +20mm is about 70 to 90 tons per hour.

- Belt sorters are more complex in their design and construction. The transfer of feed material from the vibratory feeders onto the conveyor belt is critical. To be able to achieve stable particles on the sorter belt the feed material must have close to the same speed as the conveyor. Higher throughputs can be achieved by speeding up the conveyor. In some applications 5 m/s sorter belts speed are in operation. Fine material is more suitable on belt sorters where up to 2 mm particles are in operation both in gemstone and in recycling applications.

Various sensors are nowadays used in sensor based sorting applications. The following acquisition methods are currently available - Wotruba [7]:

- Optical sensors for visible light,
- Optical sensors for the detection of weak visible (high sensitivity sensors, mainly used for fluorescent minerals),
- Infrared sensors,
- X-ray sensors,
- Metal detectors
- LIF (Laser-induced fluorescence) sensors and
- LIBS (Laser-induced breakdown spectrometry) sensors.

In the 1970's some Witwatersrand gold ores were beneficiated by RTZ Photometric Ore Sorters. The sensing system comprised of a helium neon laser light source, an octagonal mirror drum, and a photomultiplier assembly in which a lens system, field stop, polarising filter, and red-light sensitive photomultiplier tube were fitted. The Photometric Sorter separated the rocks into two categories according to the reflectance properties. The product had rock which had white or grey quartz pebbles in a darker surrounding matrix. The reject waste rocks were either quartzite ranging from light green through to olive green to nearly black or tuff. - Keys et al [11]. Essentially this sensing system focusses different shades of black and white to sort the ore into quartz-conglomerate reef and waste.

In recent years rapid advances have been made in charge-couple device technology particularly in combination with digital imaging. High-speed colour line-scan cameras together with rapidly advancing computing technology provide far more options and greater flexibility in optical sorting applications than the original black and white photometric sorting technology used in the 1970's.

In optical sorting applications transmitted light is used to detect transparent particles or colour and brightness properties of light reflected from the particle surfaces of opaque particles. Two CCD line scan cameras provide data in three colour channels; namely the primary colours red, green and blue. Each colour channel has a resolution of 10 Bits with the result that up to 1 billion different colour and brightness differences can be measured.

The colour sensing system scans the surfaces of the particles of the feed stream over its entire width. The feed stream falling at 1.5 m/sec on a 1.2 m wide chute provides a scanning rate with an adequate resolution. The sorting principle is illustrated in Figure 1 with a description of the sorting process listed in Table1.

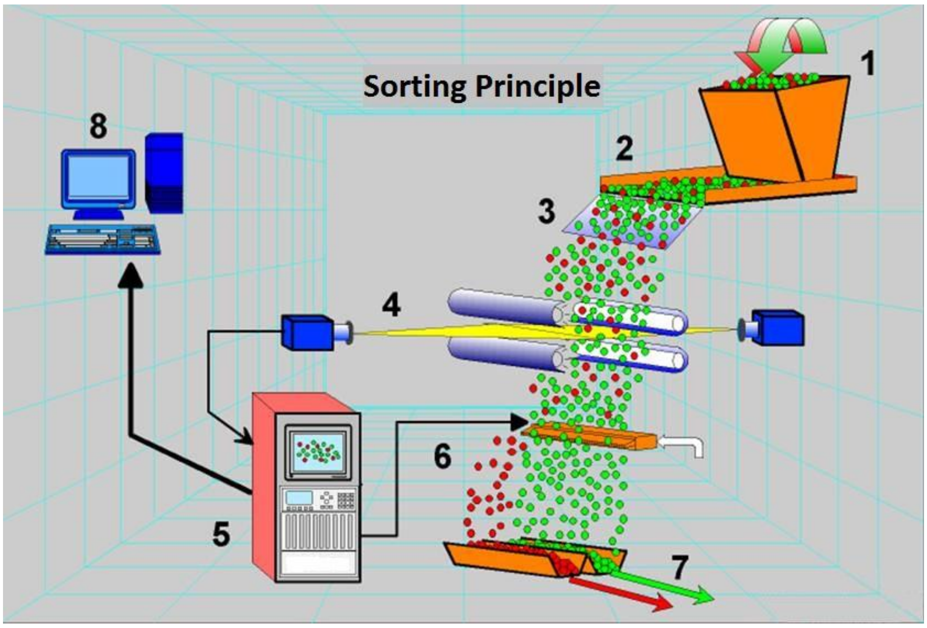


Figure 1. Optical sorting principle

Table 1. Description of processes detailed in Figure 1

1.	Material fed into feed hopper.
2.	Separation of particles on vibratory feeder.
3.	Transition to free-fall zone.
4.	Scanning of feed material by high-resolution optical sensor system.
5.	Image evaluation by rapid parallel processor technology.
6.	Product ejection by means compressed air impulses through solenoid valves.
7.	Removal of separated product and reject streams.
8.	Field bus network interface

The optical sorter used in this project was equipped with two cameras which enables the best image coverage of the surfaces of each particle. Camera 1 is placed directly under the feeder and camera 2 on the opposite side of the sorting chamber. The detection zone where the image scanning takes place is several centimetres beneath the end of feed chute. Here the particles are illuminated by four separate fluorescent lamps providing a diffuse light. The cameras scan against a blue background which is integrated into the lamps on either side. The new sorter model used for the test work in 2010 was equipped with an up-graded line-scan camera model as well as newly designed LED light modules which provide improved light stability resulting in better quality imaging.

The camera scans more than 2000 pixels per line and at a line scan rate of about 1000 lines per second. Each pixel is processed with a colour depth of 30 bits, 10 bit for each basic channel red, green and blue. Depending on the calibration, a pixel represents an area of approx. 0.5 mm^2.

The images are captured by the image processing hardware memory in real time and can be transferred to a PC and stored on the hard disc for off-line evaluation.

The colour classification and evaluation of sorting results can be simulated on a PC using the same data processing software as the high-speed processor of the sorter. The images data sets for each type of material are plotted on a colour graphic showing the distribution of the colour classes for each material type.

Individual particles in the feed stream are deflected by compressed air forced through a bank of air solenoid valves. These valves are controlled by semi-conductor switches. Up to 256 valves can be controlled by one sorter with switch cycles of less than 10 milliseconds. The sorter's processor is programmed such that factors such as gravitational speed, valve cycle time, object size and orientation will trigger the right valve/s at the right time to deflect the targeted particle over the splitter plate.

In order to define product colours and brightness the sorter's statistical analysis tool is able to distinguish and evaluate the frequency of individual colours by evaluating the images of the different types of particles.

The initial red, green, blue colour model is converted to a YUV model shown in Figure 2. Each particle type or, in this project's case, each rock type will be plotted on this YUV model as a 'colour cloud'. Thus a specific particle or rock type with the most frequent or dominant colour values will determine the boundaries of that colour class or cloud.

The triangle of the YUV colour model consists of 512 000 values (colour differences) which are derived from the basic red, green and blue with brightness as an independent variable. This creates a two dimensional colour space (UV) with brightness (Y) as an independent variable for additional analysis.

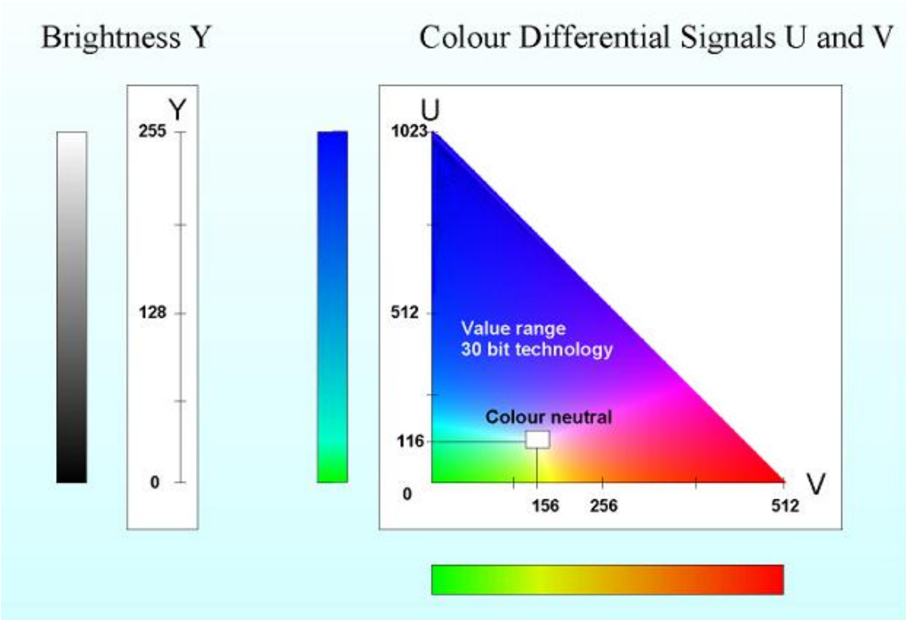


Figure 2. YUV Colour Model

2.3 Recent Advances

Optical and other sensor based sorting techniques for materials have experienced rapid advances in Europe over the last 10 years, primarily in the waste re-cycling industry. Highly effective sensor sorters have been developed for this purpose. Only very recently have such sophisticated sensors begun to be adapted for mineral sorting applications. Wotruba [7] in his paper "Sensor Sorting Technology – is the minerals industry missing a chance?" published in 2006 initiated this approach. In this paper the author presents the case for sorting minerals and ores and compares them to the sorting of various wastes including tin from plastics and many other discarded materials using the new sensor sorting technologies.

Harbeck *et al* [8] published statistical and practical evaluations of the new developments in sensor based sorting. These investigations included a variety of mineral applications using different sensors such as cameras, x-ray fluorescence, x-ray transmission, Near Infra-Red and electro-magnetic methods. In 2009, *von Ketelhodt et al* [9] compiled a paper showing a variety of practical mineral sorting applications and the latest development on sensor based sorting mechanisms for mineral processing plant design.

Pokrajcic *et al* [13] highlighted the importance of pre-concentration for gangue rejection at coarse particle size as an energy and cost saving process for resources of ever-diminishing grades. Keys *et al* [11] describe the first mechanised sorting application on Witwatersrand ores. The Rio Tinto-Zinc (RTZ) Group developed and operated its first full-size photometric sorter (Model 13) pilot plant between 1969 and 1973 on a Gold Fields mine.

A further paper by Barton *et al* [12], gives a review of the development and design of the follow-up RTZ Model 16 photometric sorter plant at West Driefontein Gold Mine. The operating and test results show similarities with the results shown in this research.

Three other references also show previous sorting applications that are directly related to the research topic of optical sorting of Witwatersrand gold ores, namely,

- *Schaffler* [2], describing combined radiometric-optical sorter and sorting at Buffelsfontein gold mine, and
- *Wheeler* [20], development of a model for the simulation of the radiometric sorting of gold and uranium ores

The investigations reported in these references refer mainly to sorting applications at Buffelsfontein Gold Mine that were in operation in the 1980's. Wheeler [20] describes that "…a 2 % inefficiency causes the sorter reject grades to rise above the plant residue values, thus undermining the entire profitability of sorting as a unit process……owing to high blasting inefficiencies, unacceptable reject grades were produced and the sorters were subsequently shut down".

A range of other literature is referred to throughout this document when relevant to specific sections.

3 EXPERIMENTAL PROCEDURES

In this chapter two case studies are presented illustrating the manner in which optical sorting will be tested.

3.1 Case Study 1: SRD Sorting at Gold Fields Limited

In 2002 Gold Fields had embarked on optical sorting test work on waste rock dump material from their Driefontein and Beatrix gold mining operations. The focus shifted to the SRD treatment of the Kloof Gold Mine during 2003.

3.1.1 Gold Fields Limited – Mining operations

Gold Fields Limited (Gold Fields) is a global group mainly focussed on gold mining with operations in South Africa as well as West Africa, Australasia and South America. According to the Gold Fields website [14] the South African region has a declared attributable resource of 228.3 million ounces which currently accounts for 80 % of the Group's gold equivalent resource and reserve base. The South African mines Driefontein, Kloof, Beatrix, and South Deep produce the bulk of the group's gold.

The Kloof Gold Mine, which is located 60 kilometres west of Johannesburg, near Westonaria in the Gauteng province of South Africa, has produced more than 70 million ounces of gold during its 75-year life and was, in its heyday, known as the richest gold mine in the world. While this mine is now in the autumn of its life, it still has a massive probable 77.5 million ounces of gold. Kloof is a large, well-established intermediate to ultra-deep-level gold mine with its lowest working level some 3,350 meters below surface. Geologically Kloof is located on the main north-western rim of the Witwatersrand Basin and exploits auriferous palaeoplacers (reefs), namely the Ventersdorp Contact Reef (VCR) that constitutes 85 % of the underground Mineral Reserve ounces, the Middelvlei Reef, 11 %, and 2 % from the Kloof Reef (KR). The illustration in Figure 3 shows a typical mine layout such as Kloof which is operating in the West Wits Line. Kloof consists of five producing shaft systems and two gold plants of which Plant No. 1 processes surface material while Plant No. 2 process underground ore.

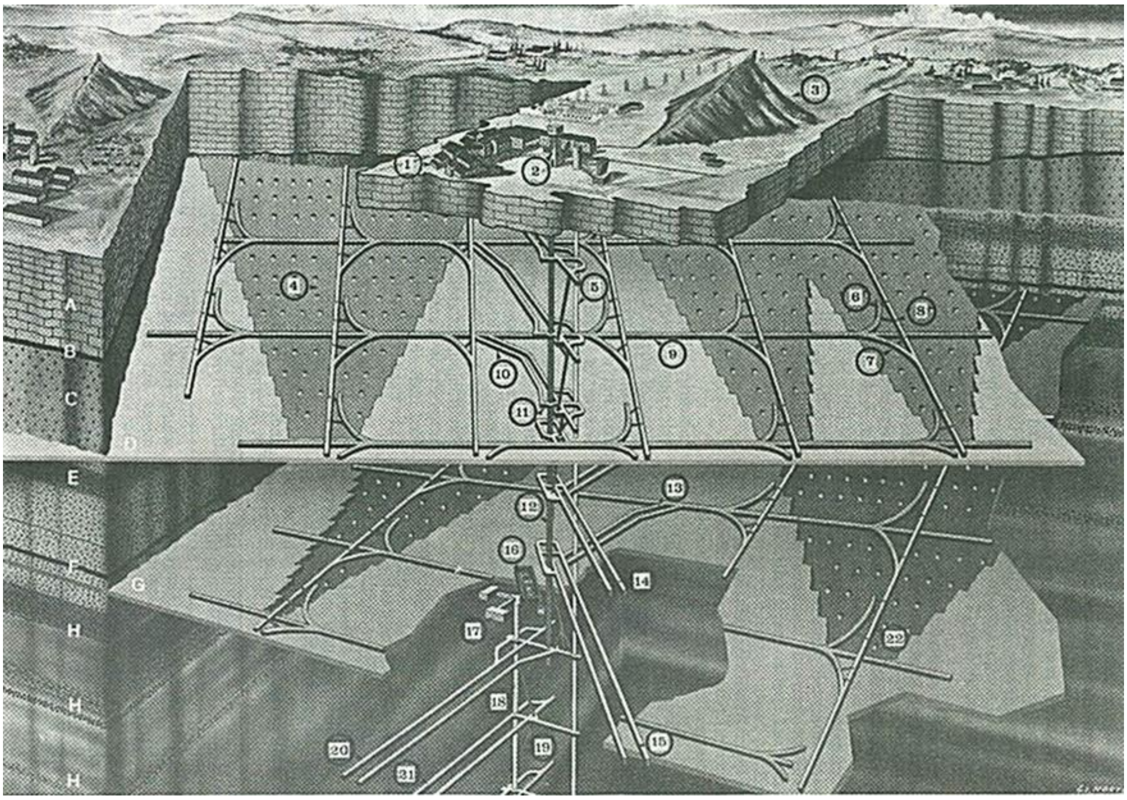


Figure 3. Typical mine on West Wits Line showing: rock formations: (A) Dolomite. (B) Black Reef Series. (C) Ventersdorp Lava. (D) Ventersdorp Contact Reef (VCR). (E) Kimberly Shale

Figure 3 by Coetzee [15] also illustrates the complex infrastructure of a deep-level mine with a series of shafts, drives, ore-passes, stopes and other underground excavations. It is logistically almost impossible to keep the gold-bearing reef separate from all other waste rock which is hoisted from underground. All the gold mines on the Witwatersrand will therefore have waste rock dumps containing conglomerate reef.

3.1.2 Surface rock dumps at Gold Fields

Over the years the Gold Fields' mines in South Africa have produced many low grade or waste surface rock dumps (SRD's) that have accumulated since operations began. In some instances these SRD's are being selectively re-processed through existing operations where surplus capacity exists. At Kloof for example excess capacity at No. 1 Plant is utilized to re-process SRD material in conjunction with underground ore. With the exception of a pre-screening step as shown in Figure 4 no other upgrading of the SRD material is generally undertaken. While these SRD's offer a significant opportunity to Gold Fields to realize added gold production, they also represent a significant liability as the sites ultimately require rehabilitation. Currently the Gold Fields group has over 50 million tons SRD at a grade of about 0.5 g/t within its South African operations. At a recovery of 85% this represents about 22 tons of gold.

This is an on-going issue as the SRD's are currently being generated at a rate of approximately 1t per 4t reef mined; from a Gold Fields operations perspective this amounts to 250 000 tons per month.

The current cost of re-processing of SRD's is relatively high so the net profitability is a direct factor of grade and gold price. Grade may vary between 0.3g/t and 1g/t after pre-screening.

Gold Fields have operated dedicated plants for SRD reprocessing but they are generally older and in less than ideal states of repair, with limited life spans in the absence of major capital reinvestment. The SRD's situated near plants have largely been depleted resulting in greater transportation distances as well as increased pressure on the transportation infrastructure.

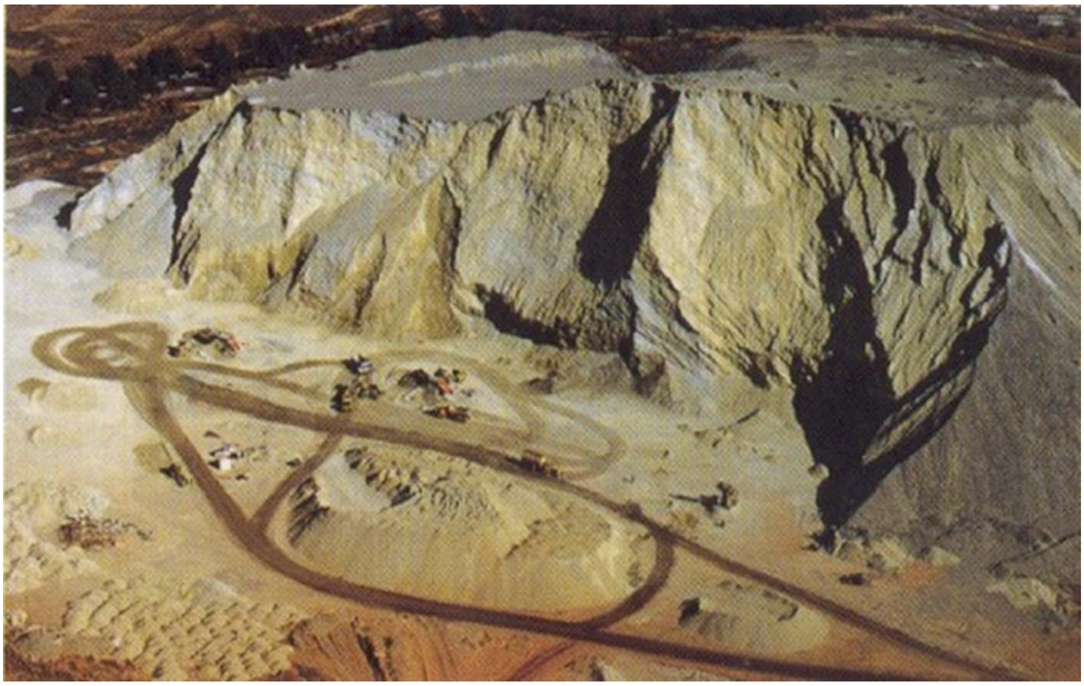


Figure 4. Typical SRD screening operation using mobile screening equipment

3.1.3 Full-scale dump treatment plant

As described by Da Silva [16] Gold Fields is in the process of developing a stand-alone solution to its SRD liability, while being able to generate a substantial return on its investment. The project envisages treating the group’s entire SRD holistically, to produce pebbles for milling, industrial aggregate, backfill for underground operations and a gold product resulting in a positive cash flow and allowing for the ultimate rehabilitation of the former SRD sites.

The heart of the process is an optical ore sorting system together with the “Python” gravity processing plant as supplied by Gekko Systems. Mobile rock recovery and screening equipment will be deployed on the SRD to produce a -50mm size feed to the plant. The schematic process flow as proposed by Da Silva [16] is shown in Figure 5.

The Gekko System consists of a Vertical Shaft Impactor (VSI) which produces a -3.35mm size the Inline Pressure Jig (IPJ). The IPJ reduces the mas pull recovery to 20%. The -1.14mm material is fed to a Flash Float Circuit. Both the IPJ and the Flash Float concentrates are pumped directly to the Kloof No 1 plant for the final gold recovery - Korzynski [22] in the conventional method of leaching.

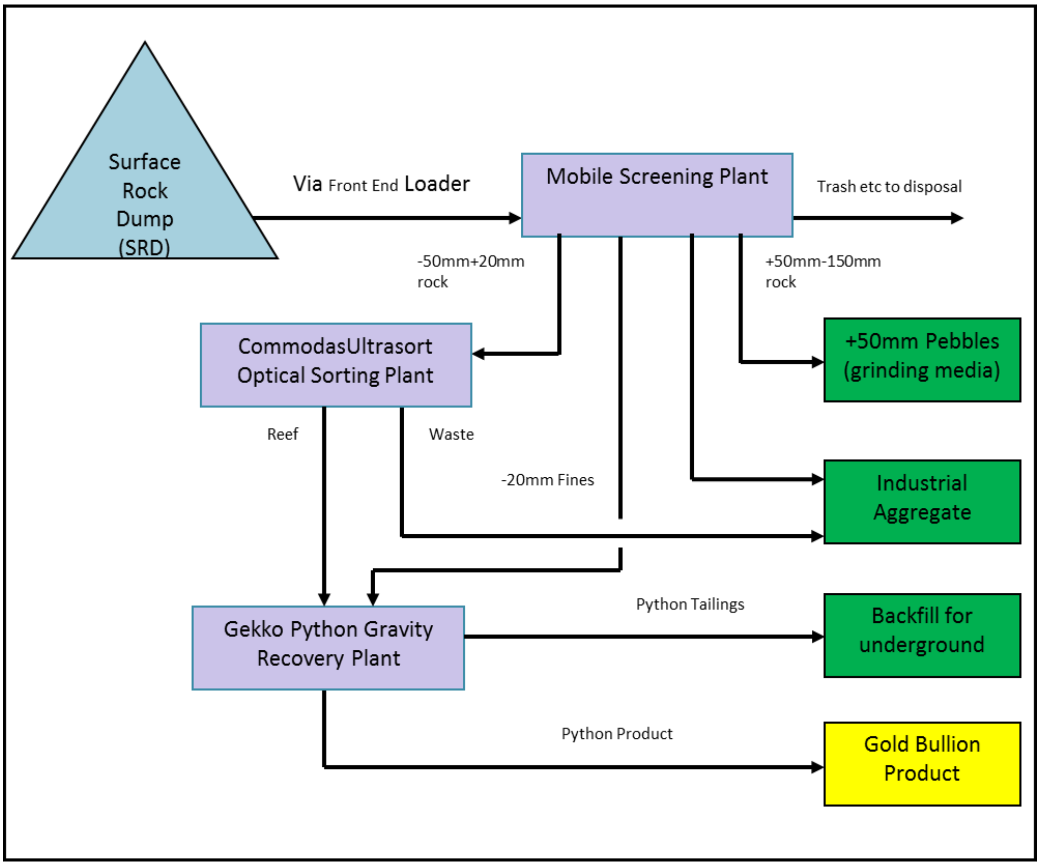


Figure 5. Proposed flow diagram for SRD treatment

Test work and pilot work with Gold Fields SRD material has been on-going since 2003. All this work and its results are in Section 4.1.

3.1.4 Test materials

All samples from Kloof Gold Mine were provided from the No: 1 Plant SRD. A series of procedures for sampling and preparation were undertaken over a 7 year period spanning from 2003 to 2009. A number of samples from various sources were taken and tested. This included:

- Initial grab sample test in 2003 consisting of:
    - Small sample for rock type analysis
    - Synthetically compiled sample
    - Random bulk sample (½ ton sample)

  - Bulk sample (6 ton)
- Bulk testing using a pilot plant during 2003 – 2004
- Comprehensive bulk sample tests in 2009.

(see Section 4.1 for further detail)

Each sample was prepared in the same manner for optical sorting i.e. screening into suitable sorting size fractions which varied e.g. (-80mm +50mm or -50mm +20mm); and washing to remove dust which provides clean surfaces of the particles which are exposed to the camera detection system of the optical sorter.

3.1.5 Equipment

For the test work and the pilot plant an optical sorter type 'PRO Secondary COLOR' was used which was provided by CommodasUltrasort (Pty) Ltd.

The test plant was set-up at Mintek, Randburg for sorting test work on the SRD material as well as the ROM material from CRG. Mintek services such as mineralogy, feed preparation and assaying were used when necessary.

For the pilot plant operation the sorter was moved to Kloof Gold Mine's waste dump. The earth moving and plant feeding operation was done by a crushing and screening sub-contractor.

3.1.6 Data gathering/analysis

The following data was collected:

- Assay values of different rock types – Mintek lab and Super Laboratory Services (Pty) Ltd.
- Mass of samples of feed, reject and accept fractions were weighed at Mintek
- Size distributions were conducted by the standard screening procedures at Mintek

- Feed rates were determined by weight meters on the feed and waste belts
- Mass rejection rates were determined by the optical sorter statistical module. These figures were checked with physically weighed mass balances of the product and waste fractions
- Costs and revenues were recorded by the contracting parties

Data analysis from test work is presented in tables and graphs showing assay values, mass balance and size distributions.

The following data analysis from bulk tests on the pilot plant are shown in Section 4:

- Assay values, mass balance and size distributions are presented in tables and graphs.
- Average values and trends
- Cost and revenues were evaluated and presented in table and graph formats

3.2 Case Study 2: ROM Sorting at Central Rand Gold Limited

The second case study is aimed at upgrading ROM ore which is mined in the old workings of the central rand mines.

3.2.1 Central Rand Gold Limited (CRG) – Mining operations

Chadwick [17] wrote: “CRG is revisiting some of the great mining areas of South Africa’s Central Rand Goldfield. Simply put, it is going back under Johannesburg to extract some gold reefs that the old miners of the early decades of the 1900s ignored as being too low grade. Today they are above the average gold grades being mined in many parts of the world.”

CRG have commissioned Snowden [18] to undertake a Competent Persons Report which includes optical sorting as part of the overall process. The CRG mineral rights are underlain by rocks of the Central Rand Group within the upper part of the Witwatersrand Supergroup (Wits). The Central Rand Group comprises a 7 km thick sequence of quartz-rich sediments within which there are three principal sedimentary sequences of quartz pebble reefs namely the Main, Bird, and Kimberley reefs. Within these reefs, heavy minerals, including gold and pyrite, have been concentrated to a greater or lesser extent. CRG has large contiguous mining and prospecting rights of over 40km of strike. This relates to a resource base of 35.6 million ounces of gold. Figures 6 and 7 taken from Snowden [18] illustrate the geological formations and the gold-bearing reefs that form part of CRG resource.

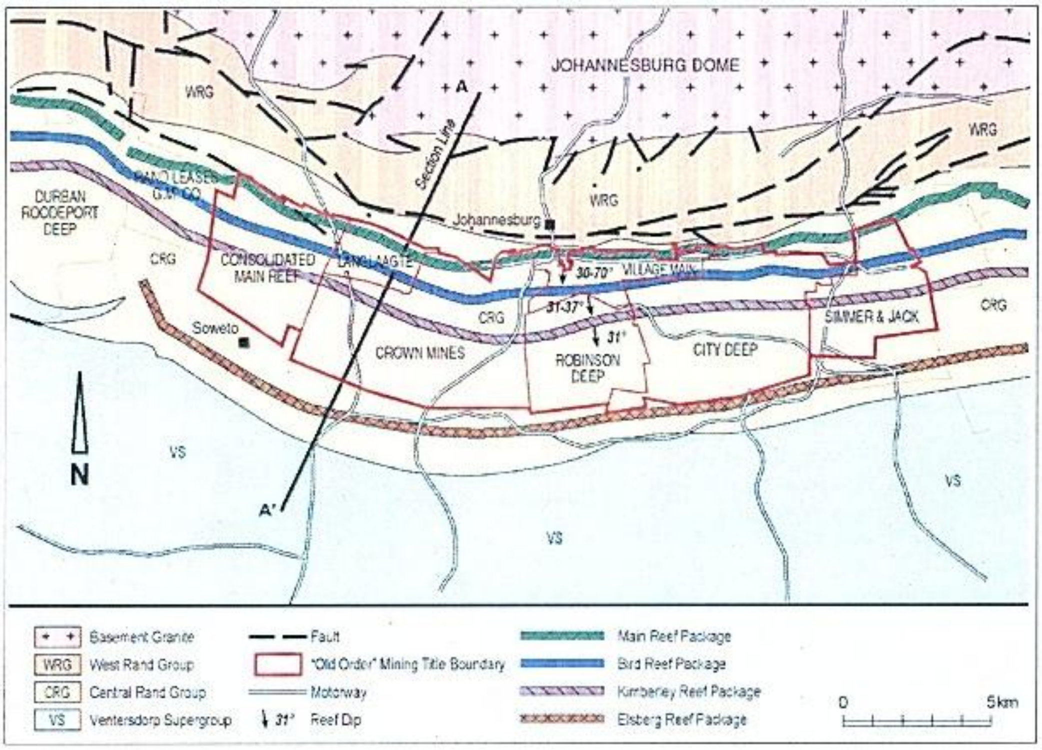


Figure 6. Geological map of the Central Rand project and surrounding area

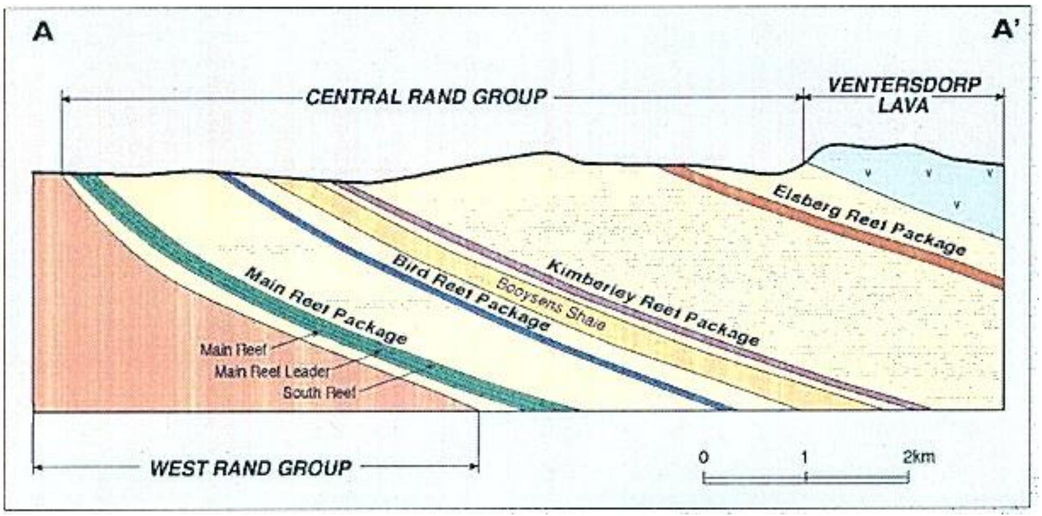


Figure 7. Geological section A-A (see Figure 6) showing the south-dipping quartz-pebble reefs within the Central Rand Group (looking east)

3.2.2 Waste rock dilution at Central Rand Gold

In the early days of gold mining in Johannesburg, the high grade Main Reef Leader (MRL) was mined out in most places. The lower grade Main Reef (MR) 5 g/t to 13 g/t which is lying 1 to 1,5m below the MRL is still intact. At today's gold price levels mining the main reef has become very attractive. The CRG Investor & Analyst Roadshow [19] shows in the diagram in Figure 8 the MR in relation to the MRL.

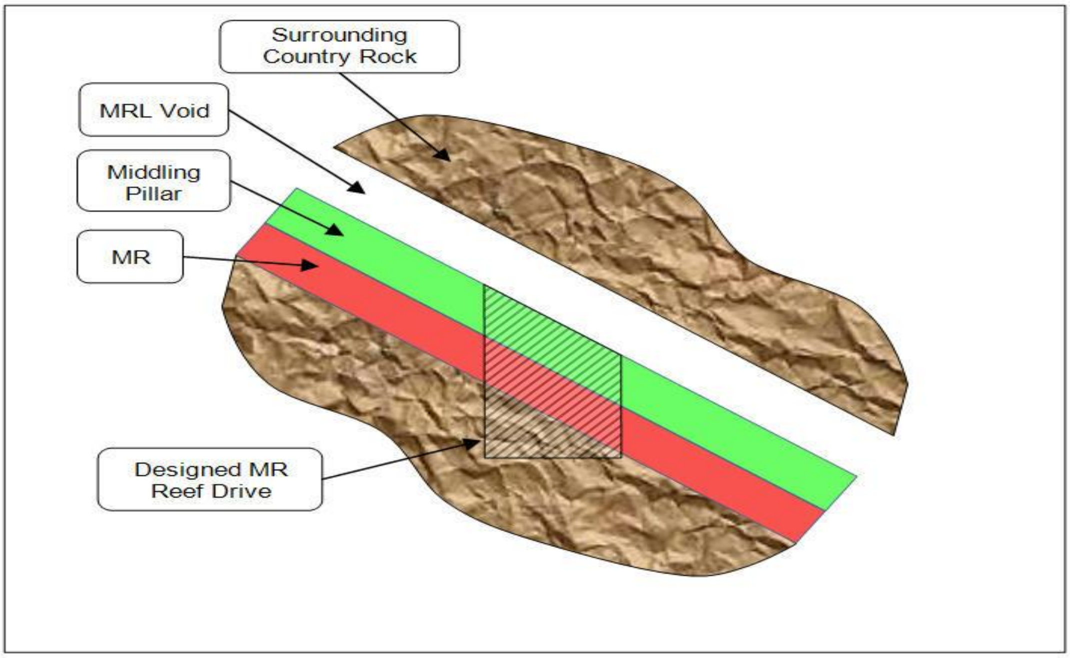


Figure 8. Schematic Diagram of Main Reef (MR) and Main Reef Leader (MRL)

The picture in Figure 9 illustrates the pebble matrix of the Main Reef.

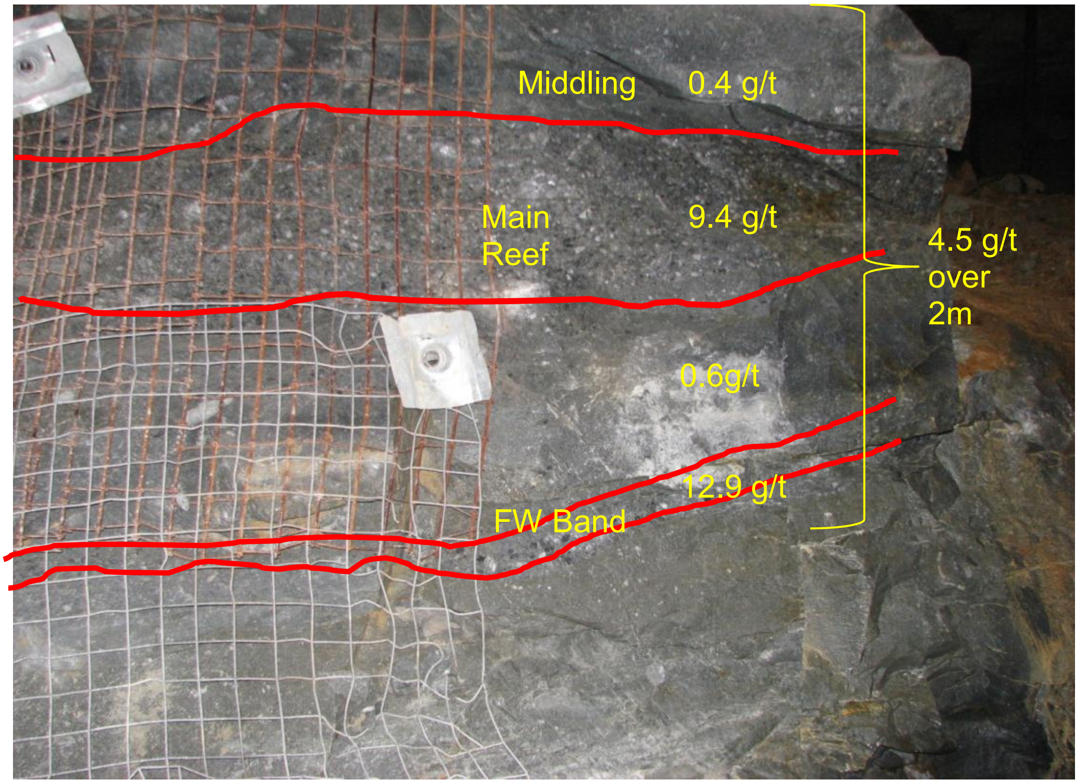


Figure 9. Main Reef

CRG has tested and proven a highly mechanised mining method for their underground operations. It is estimated that about 50% of the scheduled mine production will be waste rock termed ‘dilution’, which is mined concurrently with the Main Reef. The dilution stems mainly from the parting and middling between the MR and the MRL as well as reef drives which provide the required space for the mechanised mining equipment.

3.2.3 Ore pre-concentration

The Carbon in Pulp (CIP) plant will have a capacity of 250,000 tons per annum feed tonnage. In order to maximise the grade to the CIP plant, the following beneficiation stages will include crushing, screening, ore sorting and froth flotation. Ore sorting will be a key component in the process to treat the low-grade diluted run-of-mine (ROM).

4 RESULTS

This chapter presents the results of the performance of test work undertaken in the two case studies.

The initial programme and results of Case Study 1 on the SRD at Kloof Gold Mine led to further bulk test work as well as to Case Study 2, the ROM sorting application at CRG. The Kloof project had been on-going since 2003. Initial optical test work results gave enough confidence to the Kloof management team to commence with a pilot plant to gather production results starting in September 2003 until June 2004. The low gold grades in the SRD and the low gold price at the time of ±$390 per ounce were the reasons to stop the project. During 2009 Gold Fields Limited restarted this programme, this time with a much improved gold price, the focus was a holistic approach to develop a process to treat the group's entire SRD. In February 2009 renewed samples were taken from the SRD and tested on the latest optical sorter test facility at Mintek.

As part of a comprehensive mining and operational feasibility study CRG embarked on optical sorting test work in February 2009 which was finalised during 2010.See Gant Chart in Table 2 which illustrates the length of time required to prove the success of new technology.

Table 2. Gant Chart showing progress mile-stones of the project

Schedule for Masters of Science Project: Beneficiation of Witwatersrand type gold ores by means of optical sorting

Year	2003												2004						2005 - 2008				2009								2010											
Month	01	02	03	04	05	06	07	08	09	10	11	12	01	02	03	04	05	06					05	06	07	08	09	10	11	12	01	02	03	04	05	06	07	08	09	10	11	12
Task																																										
Gold Fields:																																										
Rock type analys	↔	↔																																								
Synthetical compiled sample test			↔	↔																																						
Random bulk sample (½ ton sample)					↔	↔																																				
Bulk sample (6 ton)							↔	↔																																		
Pilot plant during 2003 – 2004									↔	↔	↔	↔	↔	↔	↔	↔	↔	↔																								
New comprehensive bulk sample tests																							↔	↔	↔	↔	↔															
Installation of sorting plant																																							↔	↔	↔	↔
Central Rand Gold:																																										
Phase 1: ROM 30t sample																											↔	↔	↔	↔												
Phase 2: Waste/ore ratio test work																																↔	↔									
Installatrion of sorting plant																																							↔	↔	↔	↔

4.1 Case Study 1: SRD Sorting at Kloof, Gold Fields

Test work and pilot plant work carried out on the Kloof SRD is divided into 3 phases:

- SRD - Initial grab sample test in 2003

  This consisted of the following test runs:
  - Rock type analysis
  - Synthetically compiled sample sorting test
  - Random bulk sample (½ ton sample)
  - Bulk sample (6 ton)
- SRD - Pilot plant during 2003 – 2004
- SRD - Comprehensive bulk sample tests in 2009.

4.1.1 SRD - Initial grab sample test (2003)

Preliminary test on small sample

The results for this test were obtained from the test report by Bergmann [10]. The material supplied for the test work comprised of seven samples of the most common rock types found in the dump as well as a 1/2ton randomly selected bulk sample. The random sample was taken from the <75mm >30mm stockpile using a front-end loader. The various rock type samples were used to formulate a sorting program as well as to emulate a sweetened synthetic feed. The various rock type samples found on Kloof's SRD are shown in Figure 10 (also refer to Appendix A Figure 42 to 47 for detailed images).

Figure 10. Kloof– gold-bearing reef types and waste rock types

Table 3 shows the Au grades of the seven rock types. Note that the dolomite, lava, green and grey quartzite were assigned the same grade since these samples were identified as waste and were submitted as a single sample.

Table 3. Gold head grades of the various rock types

Rock type	Au (g/t)
VCR	14.50
Cobble	3.70
Marginal	0.55
Dolomite	<0.08
Lava	<0.08
Green Quartz	<0.08
Grey Quartz	<0.08

Prior to submitting the rock types for assaying, the classified rocks were used to establish a sorting algorithm and a synthetic feed for optimising the optical sorter.

Program set-up and design

Classification of the most common rock types:

- VCR
- Cobble
- Marginal reef
- Dolomite
- Lava
- Green quartzite
- Grey quartzite

Line scan images were then taken of each rock type, after which the colour and brightness were analysed, thus allowing distinct colour classes to be defined. The dolomite, lava, green and grey quartz were defined as waste and given the “accept” function in the program.

The VCR, which was in the minority, was defined as the product and given the “reject” function in the program. The cobble and marginal reef were also included in the VCR colour cloud. All particles defined as product in the feed stream would then be rejected by the sorter to the product stream.

Figure 11 shows the classification of the different colour classes in the designed program.

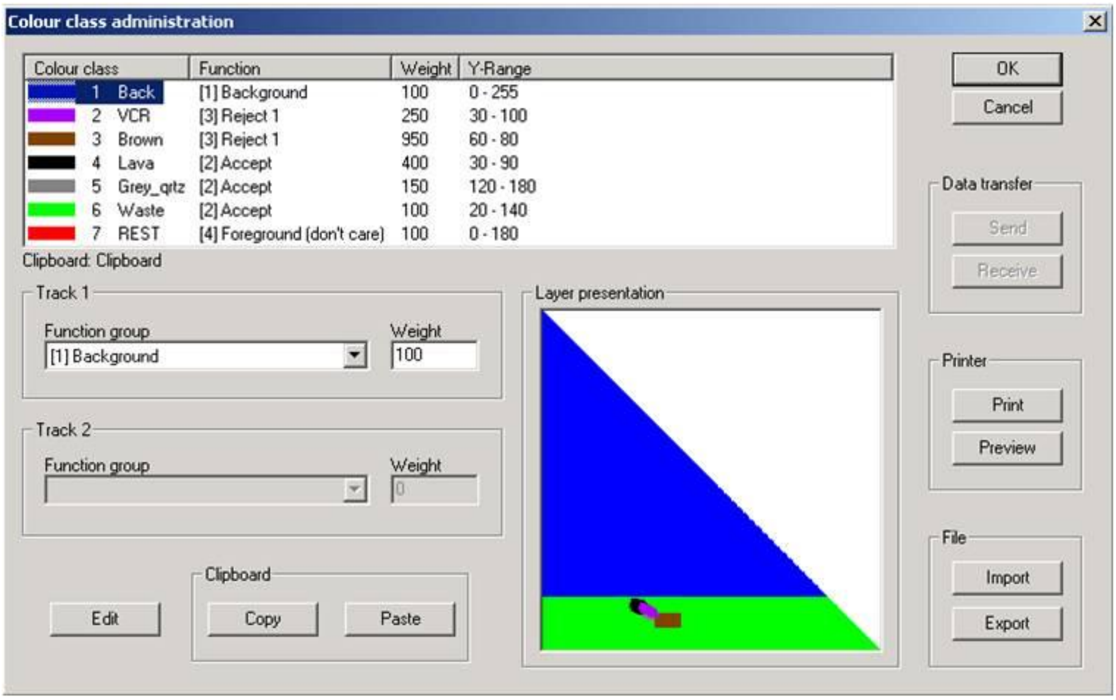


Figure 11. Sorting Program with colour classes

The different colour classes were defined and are listed in Table 4:

Table 4. Kloof SRD colour classes

1.	BG (background):	“Back“	(background colour)
2.	RE (reject):	“VCR“	(VCR, cobble & marginal reef)
3.	RE (reject):	“Brown”	(Oxidized reef)
4.	AC (accept):	“Lava”	(Lava and dolomite)
5.	AC (accept):	“Grey_qrtz”	(Grey quartz)
6.	AC (accept):	“Waste”	(Green quartz)
7.	FGDC (foreground)	“REST”	(All other undefined pixels)

In Appendix B simulation images shown in Figure 48 to 54 are all based on the program as per Figure 11.

The focus of the test work was to maximise VCR recovery as well as maximising waste rejection. One distinct colour used in the sorting algorithm was rusty-brown which is related to the oxidised sulphide which is associated with the gold reefs.

Method of sorting:

Figure 12 shows the flow diagram for a single-pass sorting method. The aim of the single-pass method was to obtain maximum VCR recovery to the concentrate stream with small to moderate dilution by waste particles.

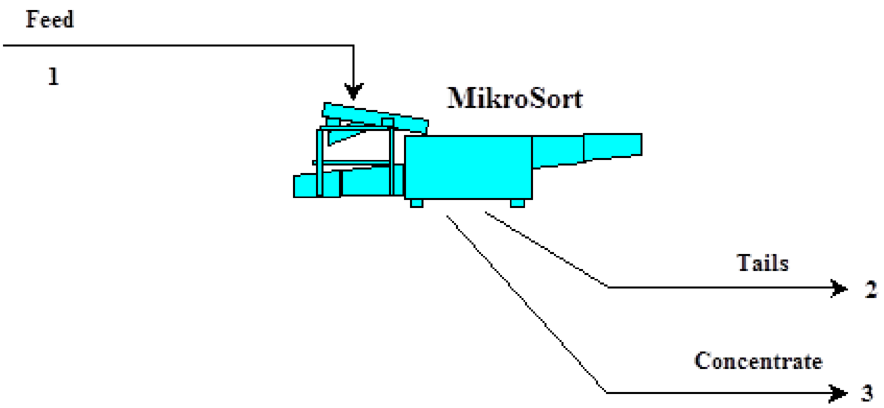


Figure 12. Flow diagram for a single-pass sorting method

Images of sorted material

The images that follow illustrate the sorting of the bulk sample and the resulting fractions reporting to the concentrate and discard streams. Figure 13 shows the waste in the product stream (A) relative to the waste in the discard stream (B).

Figure 13. Hand sorted waste in the product stream (A) and discard stream (B)

Figure 14 show close-up images of the waste in the both the concentrate and discard streams respectively.

Figure 14. Waste in the concentrate (left) and waste in discard stream (right)

Figure 15 shows the reef that was hand sorted from the concentrate stream. The VCR is labelled “A” and the cobble reef labelled “B”

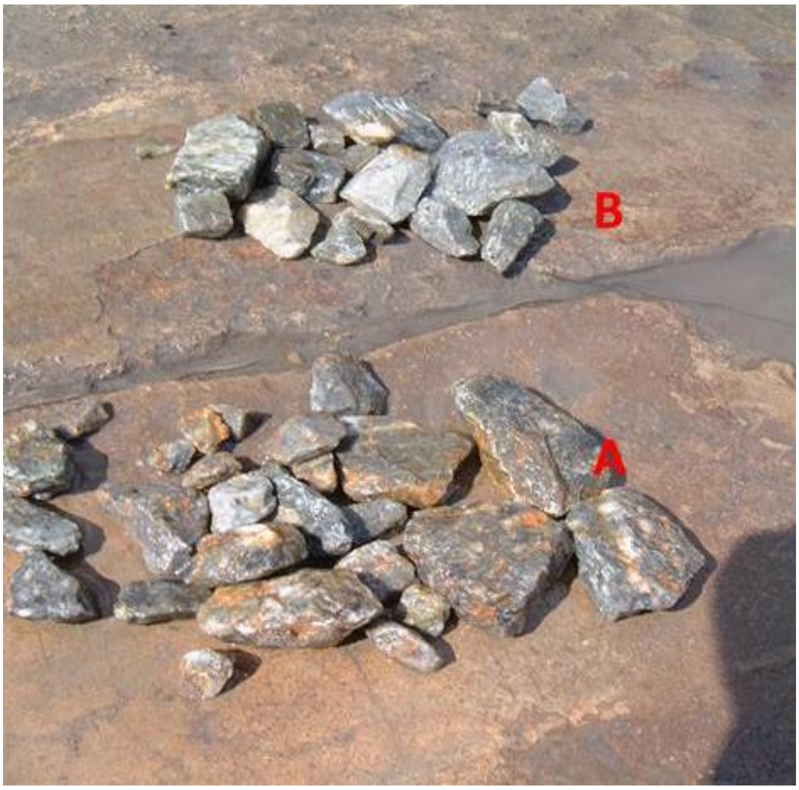


Figure 15. Gold reef detected by the optical sorter

Figure 16 shows the misplaced reef in the discard stream: 3 x VCR and 7 x cobble rocks were not detected in a single pass.

Figure 16. Gold reef not detected by the optical sorter

There are a host of factors influencing the accuracy of the sorter:

- Orientation
- Valve failure
- Material bouncing off the chute
- Splitter plate position
- Insufficient compressed air
- Muddy surfaces of the particle masking the true colours
- Over feeding the sorter with material falling through the sorter in excess of a mono layer
- Camera focus
- Calibration of the camera
- Defective light conditions
- Sorting algorithm
- Defective background lights of the detection zone
- Insufficient screening – excess fines masking the surface properties of the particles

- Excess water on the particles causing spray clouds in the detection zone masking the objects from the line scan camera in the detection zone

During this test work all the conditions were kept constant and the tests were conducted in a short period of time. It can therefore safely be assumed that the only factors affecting misplaced reef were orientation.

The misplaced reef particles were reprocessed or rescanned in the optical sorter and it was noted that certain rocks were detected. Detection of these rocks depended on the orientation of the particles within the detection zone of the sorter. Thus two-sided viewing of the falling monolayer stream will improve the recovery. Note that the particles detected in the second pass were not added to the concentrate stream, thus ensuring that the results remain conservative.

Once the machine was optimised, a test was conducted using the synthetic feed (refer to Figure 12). The resulting product streams were then hand sorted into the various rock types. Note that the Au distribution was based on the head grades per rock type as shown in Table 3. Table 5 shows the Au grades as well as overall mass and Au distribution.

Figures 17 and 18 shows the mass and Au distribution of the various rock types within the feed, discard and concentrate streams.

Table 5. Rock Classification results of optical sorter streams - mass and Au distributions (synthetic feed)

Stream Number	Stream description	VCR		Cobble		Marginal		Dolomite		Lava		Green Quartz		Grey Quartz		Total	
		Mass (%)	Au (%)	Mass (%)	Au (%)	Mass (%)	Au (%)	Mass (%)	Au (%)	Mass (%)	Au (%)	Mass (%)	Au (%)	Mass (%)	Au (%)	Mass (%)	Au (%)
1	Feed	8.8	71.9	11.4	23.9	2.3	0.7	12.7	0.6	29.3	1.3	17.8	0.8	17.7	0.8	100.0	100.0
2	Waste (Accept Class)	0.3	2.3	10.3	21.5	0.0	0.0	10.7	0.5	29.3	1.3	16.4	0.7	14.4	0.7	81.4	27.0
3	Concentrate (Reject Class)	8.5	69.6	1.1	2.4	2.3	0.7	2.0	0.1	0.0	0.0	1.4	0.1	3.2	0.1	18.6	73.0

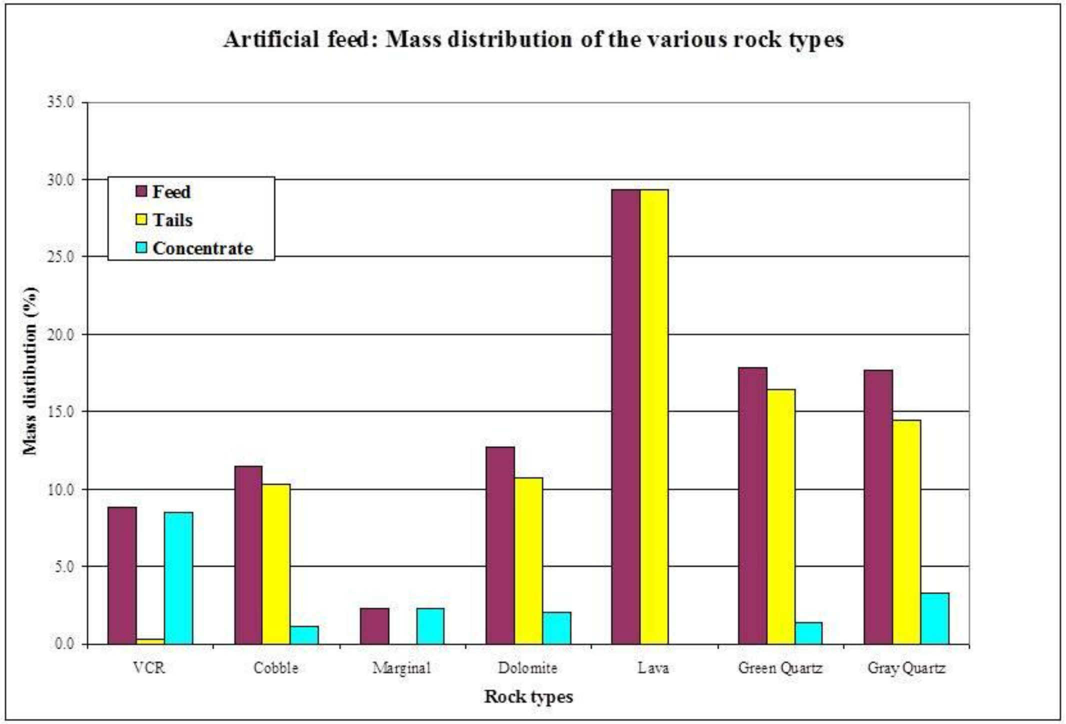


Figure 17. Rock type mass distribution in the feed, discard and concentrate streams (synthetic feed)

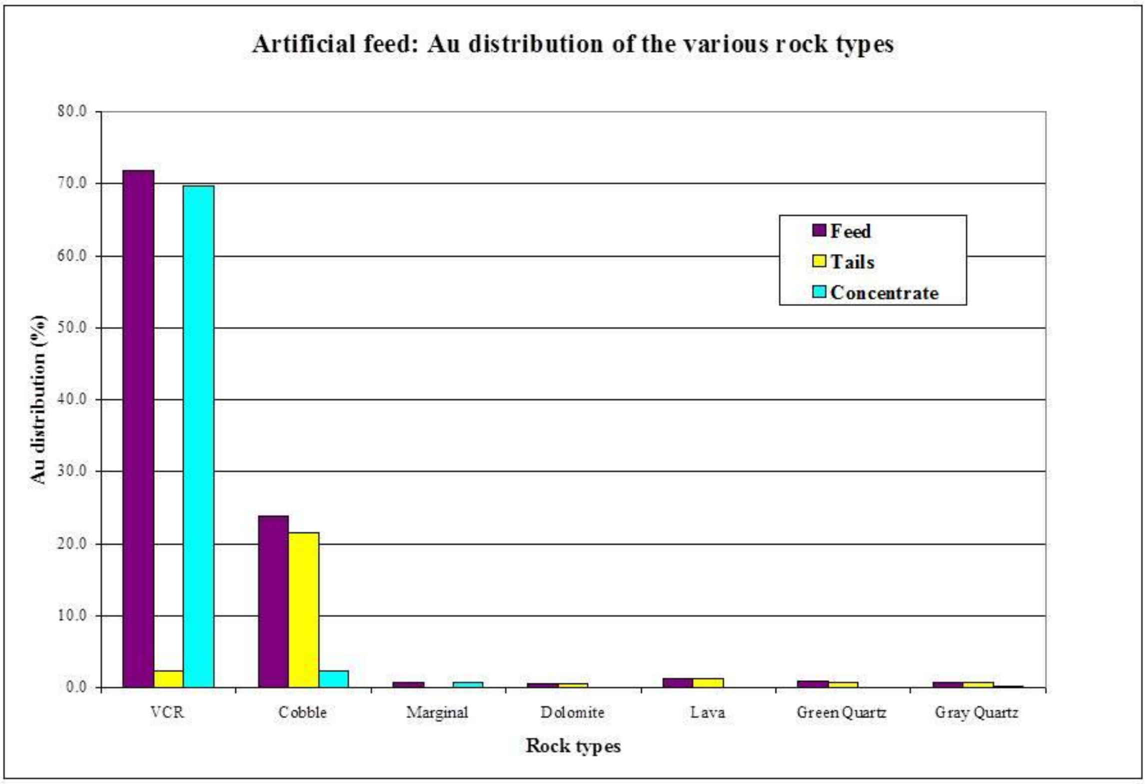


Figure 18. Au distribution vs. rock types in feed, waste and concentrate (synthetic feed)

The synthetic feed's head grade was calculated to be 1.77g/t and is higher than that expected in the actual dump. The discard stream comprised of 81% of the synthetic feed mass to the sorter, which was calculated to be 0.59g/t. The Au lost to tailings amounts to 27% of the optical sorter feed. The cobble reef contributed 21% to the loss of Au in the tailings. The results are summarised in Table 6.

Table 6. Optical sorter results for the synthetic feed

Stream Number	Stream description	Mass (%)	Au (g/t)	% Au Recovery
1	Feed	100.0	1.77	100.0
2	Waste (Accept Class)	81.4	0.59	27.0
3	Concentrate (Reject Class)	18.6	6.95	73.0

97%, 10% and 100% of the VCR, cobble and marginal reef in the sort feed reported to the concentrate resulting in a calculated grade of 6.95g/t. Only 9% of the waste in the feed to the sorter reported to the concentrate stream, the majority of which being the grey quartzite.

Only 10% recovery of cobble reef is very low considering the relatively good grades. According to the geologist cobble reef was only a small portion of the gold ore mined at Kloof GM. It must also be remembered that this is an artificial sample made up of all the different rock types found on the SDR. It is particularly difficult to distinguish between cobble reef and the grey waste rock types such as lava, Western Area and Alberts formation and grey quartzite particles. The main objective was to recover all or most VCR particles. Changing the sorting algorithm to recover more cobble reef has the effect that more grey waste reports to the product stream. This resulted in a mass recovery to product of over 50% which defeats the objective of this sorting application, namely recovering most gold out of a SRD at a low mass yield to concentrate.

If gold recovery is the main objective, then selective waste rejection can be applied where the sorter would be set to detect and remove waste rock types which are distinctly different from all other rock types. In this case green quartzite and dark grey or black dolomite represent only about 30% of the grab sample.

Random sample

The 1/2ton random bulk sample (random sample) was screened at 25mm and 75mm, and the resulting fractions weighed. The –75+25mm fraction was then sent for optical sorting.

Figure 19 shows the flow diagram of both the feed preparation and the optical sorting. Table 7 shows the Au grades and mass distributions, note that the -25mm and +75mm were not submitted for assaying, however it was noted that there was no VCR or cobble reef in the +75mm material. The mass of the bulk sample was 555kg.

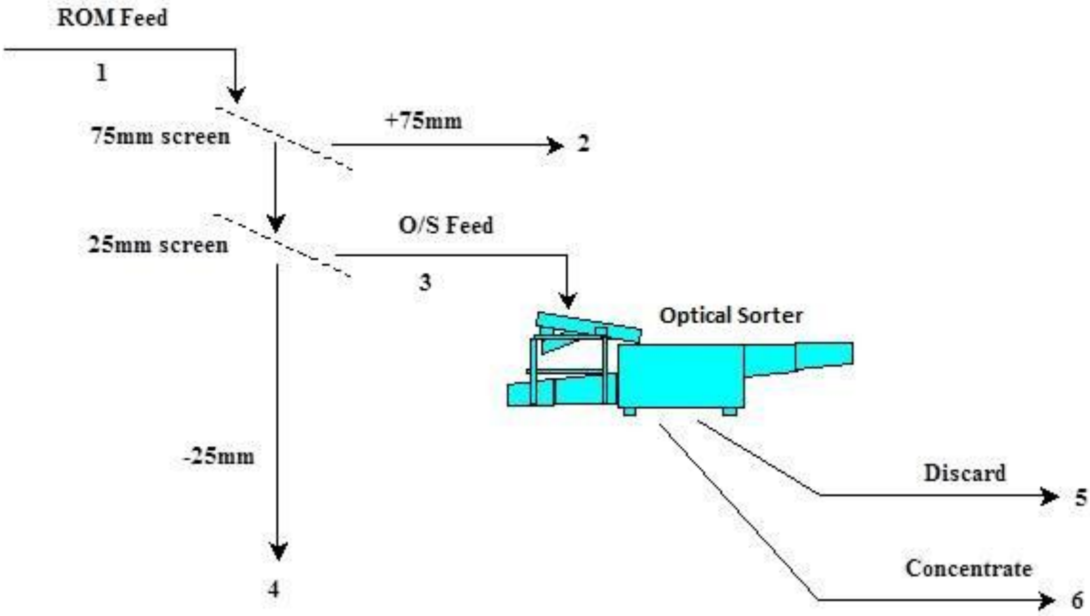


Figure 19. Flow diagram of the randomly selected bulk sample

Table 7. Au grades and mass distribution of the bulk sample

Stream Number	Stream description	Mass (%)	Au (g/t)
1	ROM Feed	100	-
2	+75mm	22.3	-
3	-75+25mm O/S Feed	75.9	0.27
4	-25mm	1.9	-
5	-75+25mm O/S Discard	62.2	0.08
6	-75+25mm O/S Concentrate	13.6	1.14

O/S = optical sorter

The sorter product streams were hand sorted into three rock types, namely, VCR, cobble and waste. The marginal reef was classified as waste. The three rock types per stream were submitted separately for assaying. The mass and Au distribution for the rock types in each stream are listed in Table 8. Figures 20 and 21 shows the mass and Au distribution of the various rock types within the feed, discard and concentrate streams.

Table 8. Rock Classification results of optical sorter streams - Au grades, mass and Au distributions (random sample)

Stream Number	Stream description	VCR			Cobble			Waste			Total		
		Mass (%)	Au (g/t)	Au (%)	Mass (%)	Au (g/t)	Au (%)	Mass (%)	Au (g/t)	Au (%)	Mass (%)	Au (g/t)	Au (%)
4	Feed	1.2	9.90	43.7	1.2	3.98	17.9	97.6	0.11	38.4	100.0	0.27	100.0
5	Waste (Accept Class)	0.2	0.16	0.1	0.3	0.51	0.6	81.5	0.08	23.9	82.0	0.08	24.7
6	Concentrate (Reject Class)	1.0	12.4	43.6	0.9	5.30	17.3	16.1	0.25	14.5	18.0	1.14	75.3

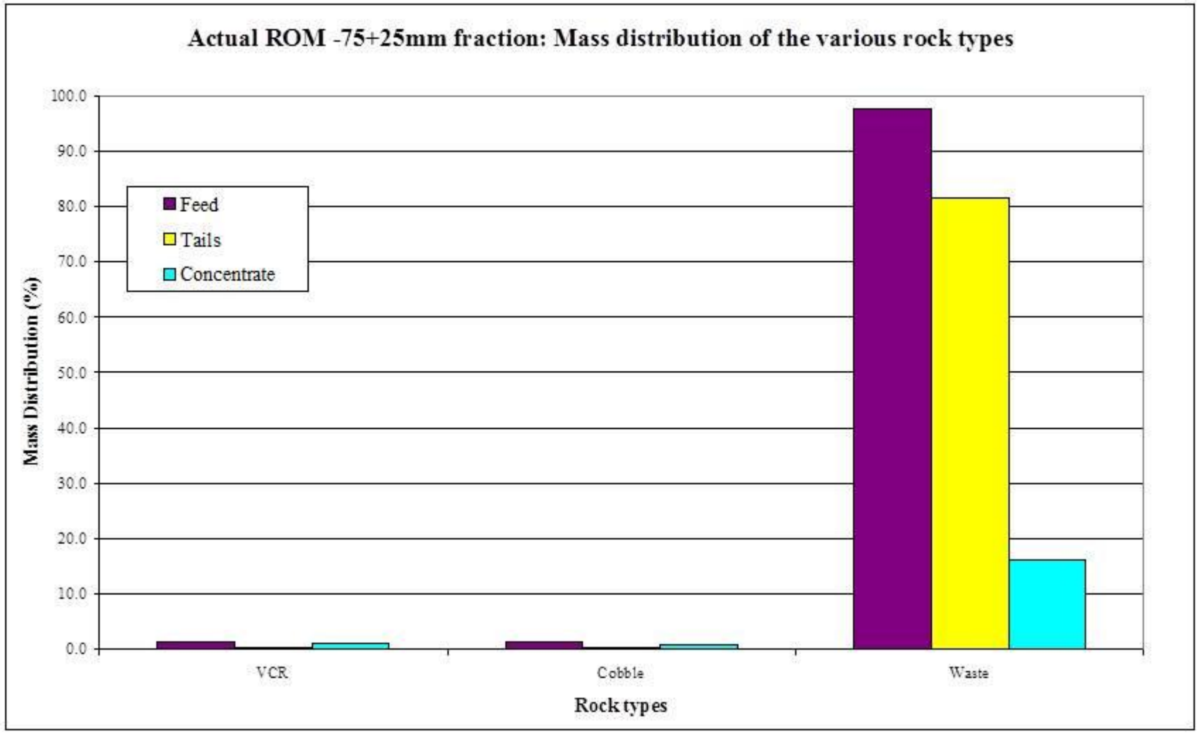


Figure 20. Rock type mass distribution in the feed, discard and concentrate streams (random sample)

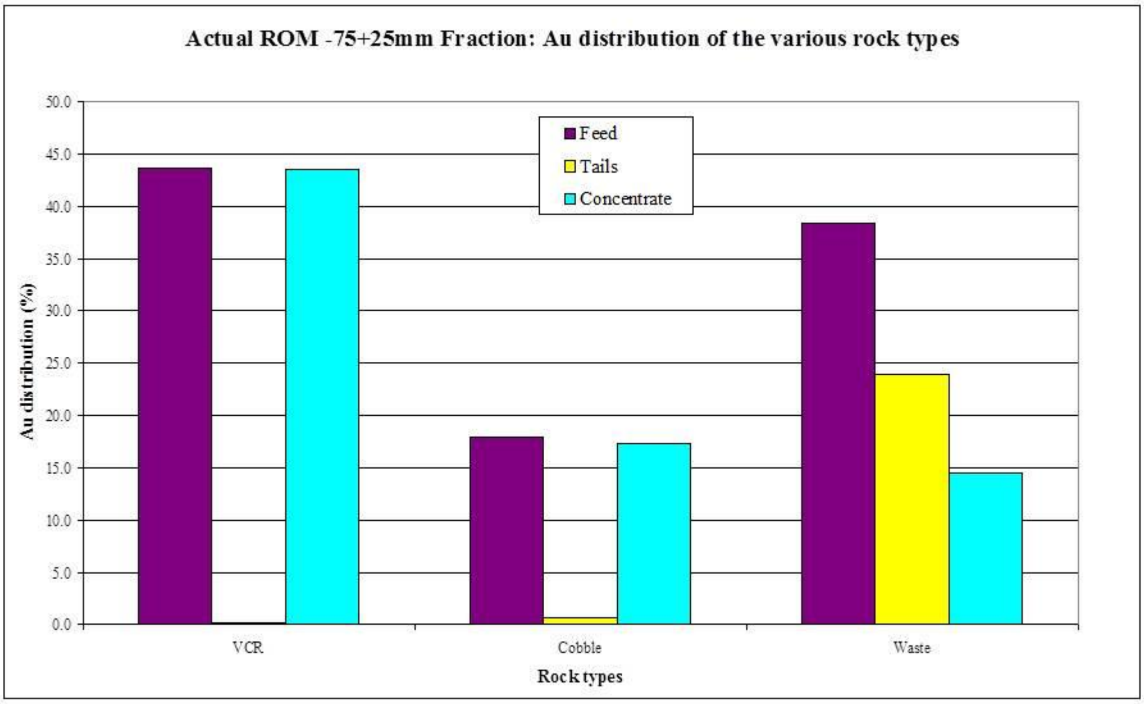


Figure 21. Au distribution vs. rock types in feed, waste and concentrate (random sample)

The results in Table 7 show that the –75+25mm random sample's head grade was calculated to be 0.27g/t. The discard stream comprised of 82% of the feed mass to the sorter, which was calculated to be 0.08g/t. The Au lost to tailings amounts to 24.7% of the optical sorter feed. The VCR and cobble reef contributed 0.7% to the loss, where the waste contributed 23.9%.

Although 20% by mass of the VCR in the feed to the sorter reported to the waste, the grade of this material was 0.16g/t. Similarly; the cobble reef was also upgraded.

Waste in the concentrate stream assayed higher than that in the discard stream. This can be partly attributed to the marginal reef that was incorporated in defining waste and should report to the concentrate stream since its colour cloud forms part of the VCR cloud. Waste with an oxide layer was also rejected to the concentrate stream and it is expected that this contains some value.

Bulk test work on 6 t sample

After the successful test conducted on the ½ ton random sample a 6 ton sample was collected at the Kloof SRD and tested on the optical sorter test centre at Mintek to establish both the head grade and the reproducibility of the first tests.

Table 9 shows the results of a single stage of sorting in which both VCR and Cobble was recovered.

Table 9. Optical sorter results on 6 ton bulk sample

Stream description	Mass (%)	Au (g/t)	% Au Recovery
Feed	100.0	0.24	100.0
Single stage concentrate	13.5	1.06	59.9
Single stage discard	86.5	0.11	40.1

Recovering both VCR and Cobble resulted in a 13.5% mass-concentration to reef product, which assayed at 1.06g/t Au. The discard contained 0.12g/t Au and this amounts to 40.1% of the gold in the feed to the sorter. A representative sample of the fines adhering to the coarse feed material was assayed at 0.98g/t.

4.1.2 SRD - Pilot plant operation (2003 – 2004)

The primary focus of this campaign was to evaluate the economic viability of optically sorting the +16mm size fractions that were produced at Kloof's rock dumps. This material was generated by a sub-contracted screening operation of the waste dumps to recover the -16mm fraction, which has sufficient gold content of ±1.0 g/t to be processed further by the mine's No. 1 Plant.

In order to evaluate the sorting option, two issues were investigated:

- The range of variability of the head grade in the +16mm fractions.
- The throughput and efficiency of the test sorter in order to specify a large-scale plant performance.

A pilot optical sorting plant was brought onto site from September 2003 until June 2004. This period can be divided into 2 phases:

- Phase 1 from September 2003 until February 2004 the plant was operated in its initial design and construction. After the first week of commissioning using one day shift only, the capacity was increased to be operational on a 3 shift basis during the week and one shift on Saturdays.
- Phase 2 – after the completion of the first phase a detailed evaluation was completed in terms of production performance, gold recoveries and profitability of the operation. After a period of repairs and maintenance and modifications the sorter ran for an additional month at a 3 shift capacity.

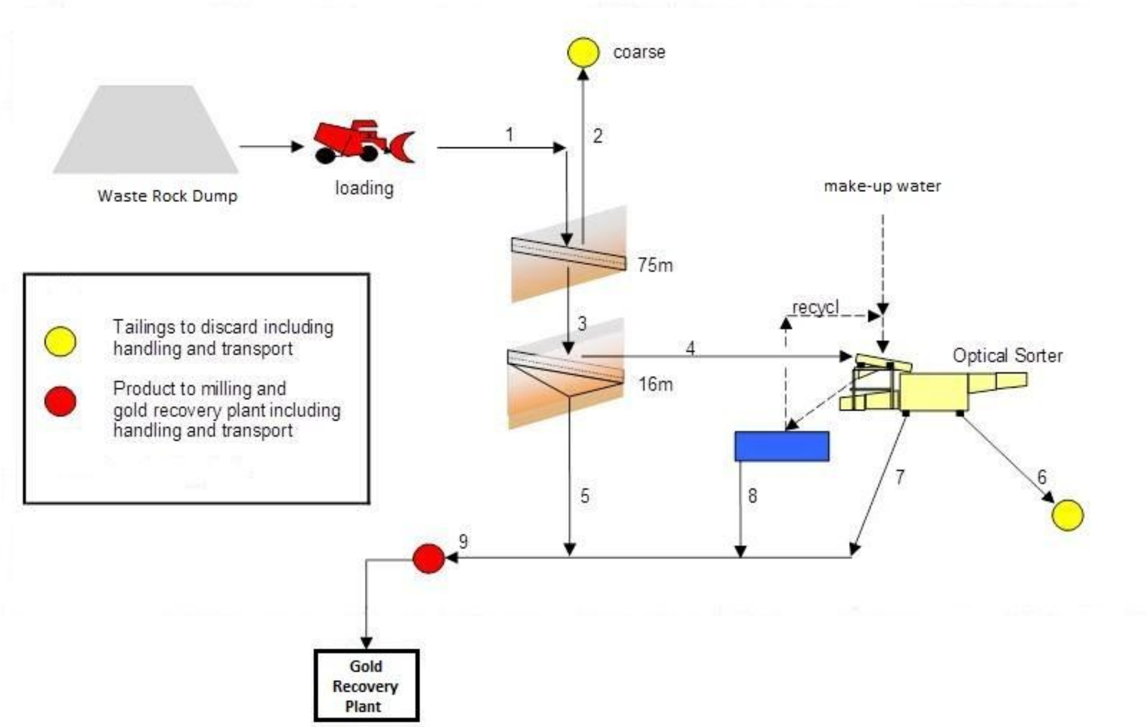


Figure 22. Flow sheet of optical sorter pilot plant at Kloof Gold Mine

Description of operation and plant

Figure 22 illustrates the layout of the plant and its operation. From this diagram the following will be noted:

- The feed to the sorting plant was contracted to Saldanha Plant Hire (SPH) who were operating the dump screen at 16mm to produce a supplementary feed to the mine's No. 1 process plant (1) (see Figure 22).

- The mobile screening operation produced:
    - oversize +75mm fraction was discarded and redumped on the waste stockpile (2)
    - a middling fraction -75mm + 16mm (3)
    - fines fraction -16mm (5) which is the supplement feed to the No. 1 process plant
- The plant includes a feed hopper with a variable speed feeder, conveyors, washing screen and water recirculation sump, sorter, power generator and loading and hauling equipment for feed, product and waste handling.
- Site establishment took approximately one week, including wet commissioning of all equipment.
- The sorter feed (4) was loaded directly into a feed hopper equipped with an oversize grizzly and a variable speed feeder.
- The water circulation system around the sorter initially consisted of a waste skip overflowing into a portable metal sump. The degritted water was circulated to the washing screen by means of a submersible pump. Intermittently, the skip will be drained and the fines will be collected and sampled for analysis.
- During the first month of operation it was established that this skip-water-treatment system was inadequate to handle the large volumes of slimes that were washed off the feed material. A conical settling tank including a flocculation system was installed. A sludge pump underneath the cone transferred the slimes to a slimes dam close to the sorter plant. Later the dry slimes were dug up and added to the sorter product (8).
- 4 operators were employed and trained for this project. Production was run with one operator per shift.
- In order to accommodate the dual purpose of treating sufficiently large bulk samples and to obtain performance data, the 8hr day shifts were run on a single sorting algorithm. This effectively fixed

the mass-concentration and throughput for that shift. As a rule feed to the plant came from a single source/area from the dump.

- The sorter product (7) and waste (6) was sampled intermittently during the shift, and then combined to form one composite product sample (1 ton) and one composite tailing sample (1 ton) per day.
- During the course of the period the product and tailings samples were kept in 1 ton bags and transported to Mintek where they were crushed, sub-sampled, pulverized and analysed for gold content. The 1 ton samples were transported weekly to Mintek to minimize cost of transport and setup of crusher facilities at Mintek.
- Kloof took control samples to confirm the assay results.
- The waste (6) produced by the sorting process was loaded and redumped onto the waste stockpile.
- The product (7) from all the sorter runs was stockpiled separately before being taken to the Kloof gold plant for further processing.
- The total products (9) from the waste rock dump operation are fines -16mm (5), sorted reef (7) as well as slimes (8)

Figure 23 presents a picture of the containerised optical sorter pilot plant in operation on the SRD at Kloof.

Figure 23. Optical sorter pilot plant at Kloof Gold Mine

Figure 24 shows images of the sorter product and discard fractions after optical sorting.

Figure 24. Optical sorter product (left) and sorter discard (right)

Production data and operational results

During the period of operation a total of approximately 110 000 tons was processed through the optical sorter. The results are shown in tables 10 and 11 below:

Table 10. Operating data – plant tonnages and availability

Period	Days of Operation	Feed Rate Tons/Hrs	Total Throughput (ton)	Conc (ton)	Slimes product (ton)	Total product (ton)	Total waste (ton)	Available Hours per day	Availability (hours)	Total Downtime (hours)	Overall Availability (%)
Sep/Oct 2003	24	67	12 526	743	251	994	11 532	366	186	180	50.85%
Nov/Dec 2003	32	68	27 657	1 428	553	1 981	25 676	622	406	216	65.29%
Jan 2004	22	83	29 185	1 442	584	2 026	27 159	446	353	93	79.08%
Feb 2004	17	74	20 995	530	420	950	20 045	348	283	65	81.44%
Jun 2004	13	82	19 321	522	386	908	18 412	284	236	48	83.10%
Total	108	75	109 683	4 665	2 194	6 859	102 824	2066	1464	602	70.88%

The operating data reflects the learning curve during the first months of this pilot plant operation. Initially the water treatment circuit was totally inadequate for the amount of fines that had to be washed off the sorter feed material. Dirty wash water caused a range of complications within the sorter such as blocked valves, muddy glass on the lighting system which all affected the sorter’s efficiency. Consequently the frequent stoppages resulted in a plant availability of only 50%. After having installed a conical settling tank with a flocculate dosage system the wash water quality stabalised which improved the plant availability to over 80%. Other factors that affected the plant availability were Compressor failure due to excessive dust and material handling.

Table 11. Operating data – grades and recovery

Period	Head grade Au (g/t)	Conc Grade Au (g/t)	Slimes Grade Au (g/t)	Total product grade Au (g/t)	Tailings Grade Au (g/t)	Recovery (%)	Yield (%)
Sep/Oct 2003	0.32	3.06	1.41	2.65	0.12	69.55%	7.93%
Nov/Dec 2003	0.30	3.42	1.40	2.86	0.11	71.28%	7.16%
Jan 2004	0.29	3.40	1.40	2.82	0.10	71.72%	6.94%
Feb 2004	0.25	5.00	1.40	3.41	0.10	70.33%	4.53%
Jun 2004	0.27	5.76	1.50	3.89	0.08	68.45%	2.78%
Total	0.29	4.13	1.42	3.12	0.10	70.27%	5.87%

This pilot operation proved that an upgrade from the average feed grade of 0.29 g/t the optical sorter could produce a product of 4.13 g/t showing a 14-fold grade improvement. The average yield to product was at a low 5.87% which produced a gold recovery of 70.27%. This means that only the small gold bearing fraction will be sent to the mill for further treatment. The remaining waste stream had gold losses of about 0.1 g/t and was discarded on the waste stock pile.

Viability

The profitability calculations for 2004 were based on the low gold price average of approximately $380/oz and at a rate of exchange of ZAR 6.50 = USD 1.00 which results in a gold value ZAR 80/g. The calculation in Table 12 shows that this pilot plant operation was unprofitable with a loss of R66 040 per month. The project was subsequently stopped.

Table 12. Profitability calculation of pilot plant (2004)

Income

Feedrate	(t/hr)	82,1
Mass percent to sorter concentrate	(%)	2,78
Value of gold	(R/g)	80,0
Days worked per month		20,0
Hours worked per day		20,2
Head grade of feed	(g/t)	0,26
Sorter tail flowrate	(t/hr)	78,2
Sorter tail grade	(g/t)	0,09
Sorter concentrate flowrate	(t/hr)	2,24
Sorter concentrate grade	(g/t)	5,46
Fines flowrate	(t/hr)	1,64
Fines grade	(g/t)	1,50
Overall concentrate flowrate	(t/hr)	3,88
Overall concentrate grade	(g/t)	3,79

Value of product per ton feed	(R/t)	14,31
Value of product per day	(R/day)	23.726

Profit/day	(R/day)	(3.302)
Profit per month	(R/month)	(66.040)

Tons of feed processed per day	(t/day)	1658,218
Tons of Sorted product needed per day	(t/day)	45
Tons of Fines needed per day	(t/day)	33
Total tons of product needed per day	(t/day)	78

Costs

Depreciation (60mnths)	(R/month)	111.667	(R/day)	5.583
Stannic finance cost	(R/month)	53.000	(R/day)	2.650
Operating cost (SPH)	(R/t)	6,5	(R/day)	10.778
Accommodation and S&T	(R/month)	9.200	(R/day)	460
Kloof processing/transport	(R/t)	35	(R/day)	2.742
Salaries	(R/month)	26.880	(R/day)	1.344
Assays	(R/month)	15.000	(R/day)	750
Maintenance	(R/month)	50.000	(R/day)	2.500
Hire of ablution	(R/month)	400	(R/day)	20
Hire of office	(R/month)	4.000	(R/day)	200
Total			(R/day)	27.028

Total cost per ton feed	(R/t)	16,30
Total costs per day	(R/day)	27.028

Fixed cost	(R/day)	8.233	depreciation and Stannic
Variable cost	(R/t)	11,33	rest

Sorter Gold recovery	(%)	56,3
Fines Gold recovery	(%)	11,3
Overall Gold recovery	(%)	67,6

These results relate to a relatively small-scale pilot plant. A full-scale production plant treating over 400 t/h ROD material will have a reduced cost per ton ratio as economies of scale take effect. The layout of a large-scale SRD treatment plant is illustrated in Figure 25. The operation would produce three product streams i.e. the -16mm fines, the wash-water slimes and the sorter concentrate would be treated for gold extraction at the mine's process plant.

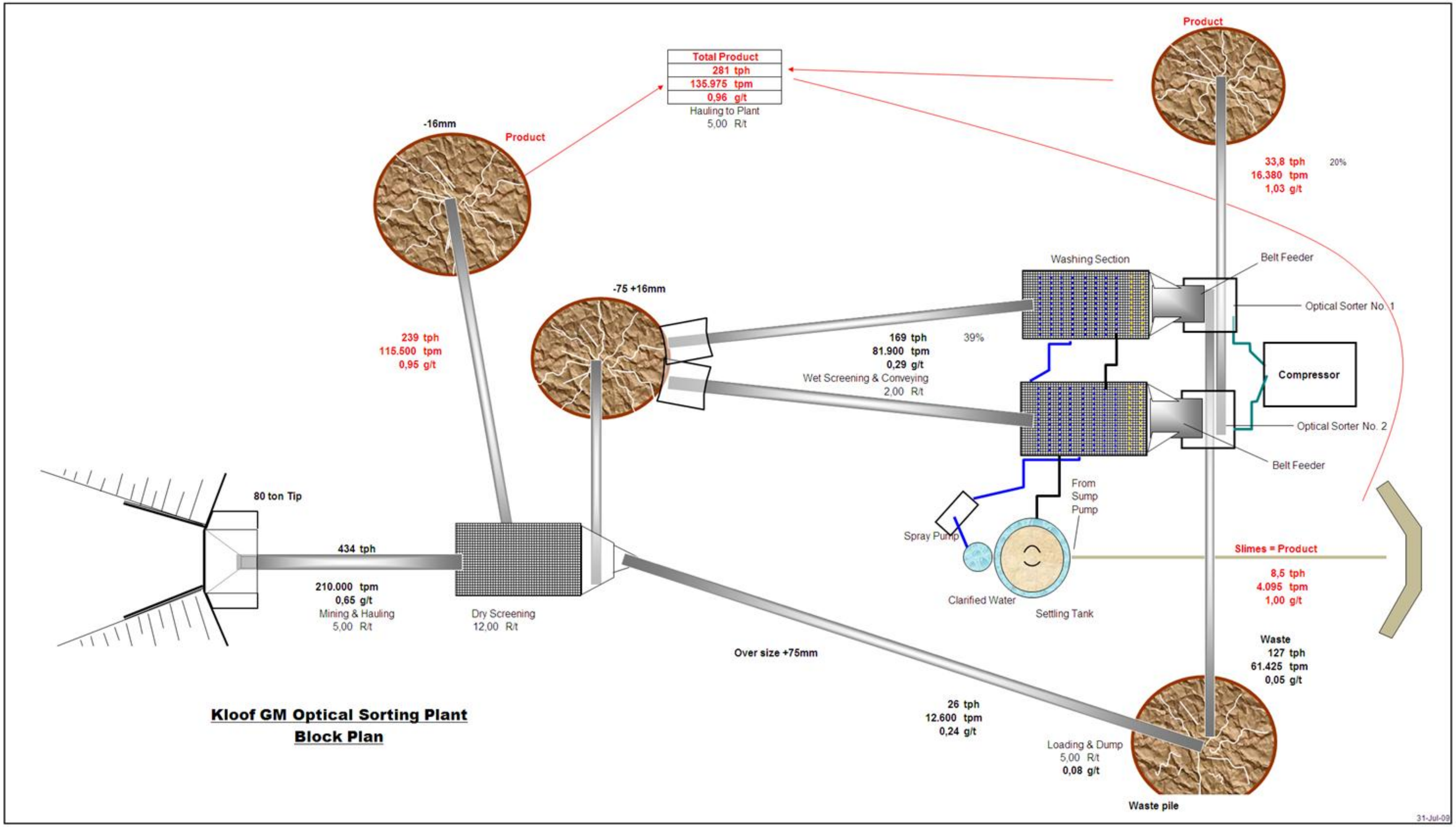


Figure 25. Block Plan of a Full-Scale SRD Treatment Plant

Four years after the pilot work was discontinued the price of gold improved significantly from about $400 per ounce in 2004 to between $800 to $1000 per ounce in 2008. The results achieved during the pilot plant operation were used to calculate various gold price scenarios to obtain an understanding of the break-even and profitability of such a plant.

In Table 13 the variables shown in yellow were used to calculate the different scenario summaries in Table 14.

Table 13. Variables used for scenario calculations

g/ounce		31.1
gold price $/ounce		800
R/$ exchange rate		8.0
Life of plant for financing	months	60
R/Euro exchange rate		12.0
Gold price	R/g	206
Total value in feed	R/month	14 295 820

Overall dump head grade	g/t	0.650
Run of Dump feed rate	t/month	210 000

Table 14. Scenario results

Scenarios	Variable Price of Gold R/g	Run of Dump (g/t)	<16mm Product (g/t)	Sorter Feed (g/t)	Sorter Product incl wash-fines (g/t)	Combined Product g/t	<16mm gold Recovery/ month (kg)	Sorted gold & slimes Recovered/ month (kg)	Sorting only Profit/Loss (R million)	Sorting only Payback Period (months)	Recovery Total gold per month (kg)	Screen & Sort Operation profit/Loss (R million)	Payback Period Screen & Sort (months)
Gold Price	180	0,65	0,95	0,29	1,03	0,96	103,92	19,97	1,40	19	123,89	11,45	2
Gold Price	200	0,65	0,95	0,29	1,03	0,96	103,92	19,97	1,80	14	123,89	13,92	2
Base Case $850/oz R8/$1	219	0,65	0,95	0,29	1,03	0,96	103,92	19,97	2,18	12	123,89	16,24	2
Gold Price	240	0,65	0,95	0,29	1,03	0,96	103,92	19,97	2,60	10	123,89	18,88	1
Gold Price	250	0,65	0,95	0,29	1,03	0,96	103,92	19,97	2,80	9	123,89	20,12	1

The majority of the value in SRD treatment is in the fines -16mm fraction. This has therefore been the main reason why many Witwatersrand gold mines were only screening and blending the fines into the ROM for further gold recovery. However, as shown in the calculations in Table 14 a sorted gold reef concentrate of the -80 +20mm fraction will also contribute to the financial viability, especially at the high gold price levels of today.

4.1.3 Kloof SRD - Comprehensive bulk sample tests (2009)

With the increase in demand for gold and the much improved gold price, Gold Fields have shown renewed interest in treating their group's entire SRD holistically.

In May 2009 Kloof Gold mine sent a 45t of SRD sample to Mintek for optical sorting test work on the CommodasUltrasort PRO Secondary COL sorting plant, pictured in Figure 26.

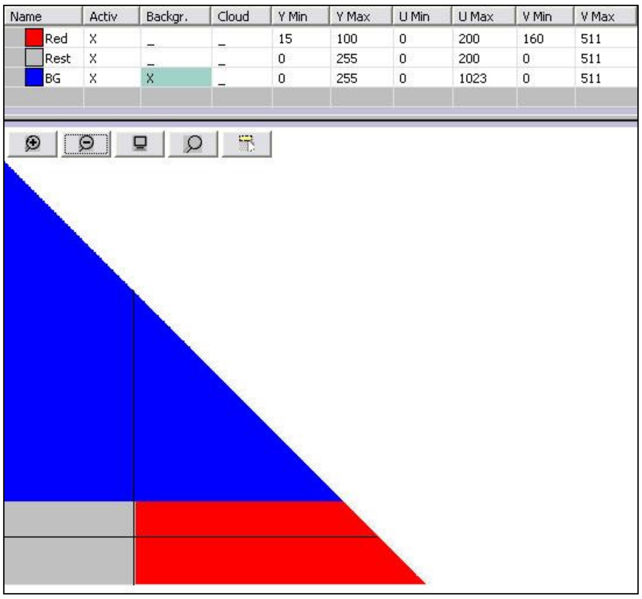
Figure 26. Optical sorter product (left) and sorter discard (right)

Feed preparation

The sample consisted of one coarse sample and two batches of finer samples. The samples were screened at 78mm, 50mm and 20mm. The resulting mass balances -78+50mm 33t, two samples -50+20mm each 10t.

Sorter set-up

The sorter was adjusted using small samples of a few rocks each of the coarse and fine dark Reef, light Reef, Lava waste and Quartz waste. These rock types were scanned on both cameras on the optical sorter (examples are shown in Appendix B). A colour model (see Figure 27) was set-up with a “Red” colour class representing Reef material. The boundaries of the “Red” colour class were fine-tuned by simulating the scanned images in the software by increasing “Red” content in reef particles and reducing it in waste particles.



Name	Activ	Backgr.	Cloud	Y Min	Y Max	U Min	U Max	V Min	V Max
Red	X	_	_	15	100	0	200	160	511
Rest	X	_	_	0	255	0	200	0	511
BG	X	X	_	0	255	0	1023	0	511

Figure 27. Colour model for coarse and fines sorting

A 1 ton set-up sample was used to optimise the optical sorter programme. Concentrate was defined as having a certain percentage of the “Red” colour class. This “Red” percentage was varied to produce different mass concentrations. By running the set-up sample continuously on the sorter’s close circuit and adjusting the percentages for both cameras (Side 1 & Side 2), the following settings were established to produce a high (~30%), a medium (~15%) and a low (~8%) mass-concentration to product. In Appendix D Figures 55 to 62 show simulation images of snap shots of the different SRD rock types.

Test runs

Using the "Low", "Medium", and "High" settings, equal masses of subsamples were used to run each setting. The test work flow-sheets are shown in Figures 28 and 29. Each sub-sample was processed separately. The feed rate was set to 50t/h for the fines fraction and 75t/h for the coarse fraction.

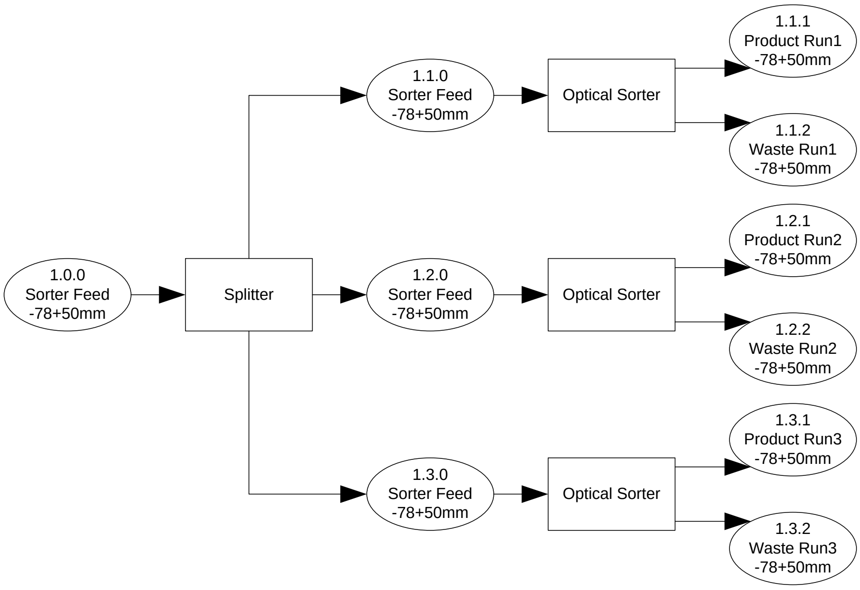


Figure 28. Flow sheet for coarse fractions

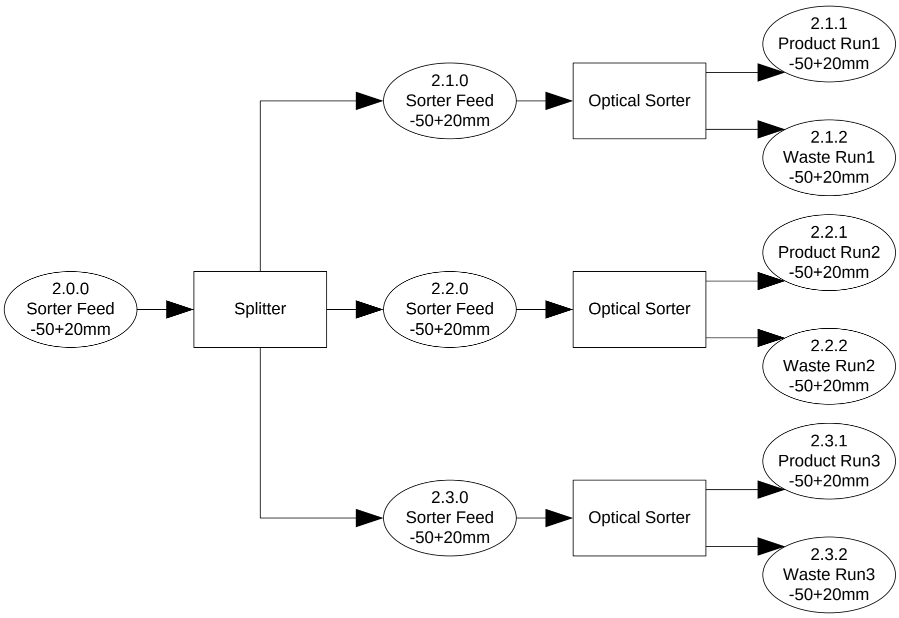


Figure 29. Flow sheet for fine fractions

Sample preparation

The waste and product fractions of the sorting process were separately prepared for assaying. At the first stage they were all crushed in a jaw crusher down to -25mm. The tailings were blended and sub-sampled to produce a 1 ton -25mm sub-sample for each run. In the next sample preparation stage the complete concentrate samples and the sub-sampled tailings samples were crushed to -6mm. All -6mm samples were then blended again and sub-sampled to make-up 60kg sub-samples for each run. These were then crushed through a high-pressure-grinding-roll to produce a -2mm fraction. The 60kg sub-samples at -2mm were blended, riffle split with a 5kg sub-sample and subjected to further rotary splitting. This resulted in a 100g sub-sample which was taken for pulverising. Finally the pulverised sub-samples were submitted for fire assaying.

Test work results

Table 15 illustrates the combined runs for each size fraction and sorter setting. The individual test runs are found in detail in Appendix C, Tables 21 to 26 .

Table 15. Optical Sorting Results

Feed Size	Sorter Setting	Feed Mass [kg]	Conc Mass [kg]	Tails Mass [kg]	Conc Masspull	Calc. Head Grade [g/t]	Conc Grade [g/t]	Tails Grade [g/t]	Au Recovery
-78+50mm	Low Masspull	11,213	935	10,278	8.3%	0.19	1.45	<0.08	62.2%
	Medium Masspull	9,749	1,319	8,430	13.5%	0.18	0.66	0.10	50.8%
	High Masspull	12,165	3,397	8,768	27.9%	0.33	0.82	0.15	68.7%
-50+20mm	Low Masspull	4,186	487	3,699	11.6%	0.43	2.53	0.16	68.2%
	Medium Masspull	3,052	551	2,501	18.1%	0.26	1.07	<0.08	74.6%
	High Masspull	3,115	923	2,192	29.6%	0.54	1.49	0.14	82.3%

The highest product grade for the coarse fraction was achieved at the lowest mass-extraction setting of 8.3%. This was assayed at 1.45g/t. The tailings grade at this setting was <0.08g/t. The highest product grade for the fines fraction was also achieved at the low mass-extraction setting of 11.6% with a value of 2.53g/t. The highest recoveries for both the fines and the coarse fraction were achieved at the high mass-extraction setting with 82.3% and 68.7% respectively.

The diagram in Figure 30 illustrates product grade and recovery in relation to the mass-extraction.

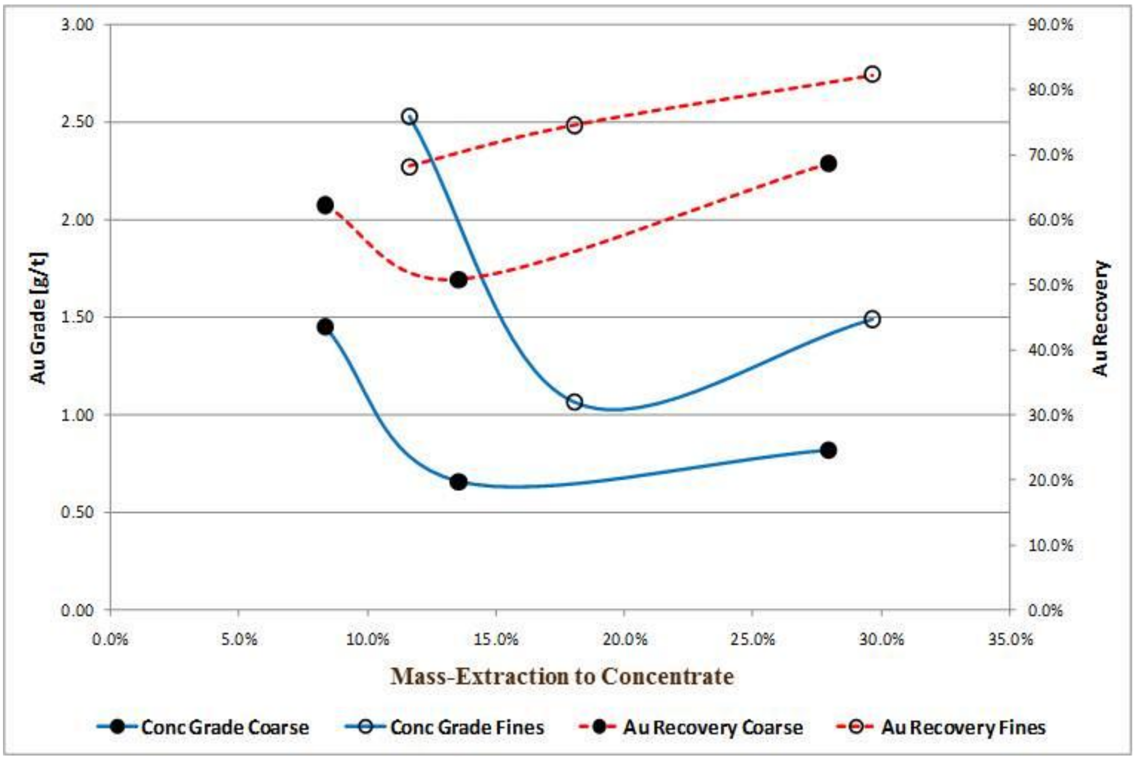


Figure 30. Au grade and recovery vs. mass-extraction

The results correspond to the production data which were achieved during the half year pilot plant operation in 2003/04 where ~110,000t were treated in total at an average weighted mass-extraction of 5.87% and an average product grade of 4.13g/t in a size range of -75mm +16mm. These results have also shown that the coarser material contains less gold than the fines.

Size vs. gold grade

Up to this point in time the test work was focussed on the effectiveness of optical sorting on the -75mm +16mm size range. When looking at the viability of installing such an optical sorting plant into an existing mining operation, the gold-grade per size range distribution needs to be considered.

Gold Fields therefore completed a comprehensive size and grade distribution analysis as shown in Figure 31. This clearly shows that the gold grade in the +50mm size range drops below to 0.3 g/t.

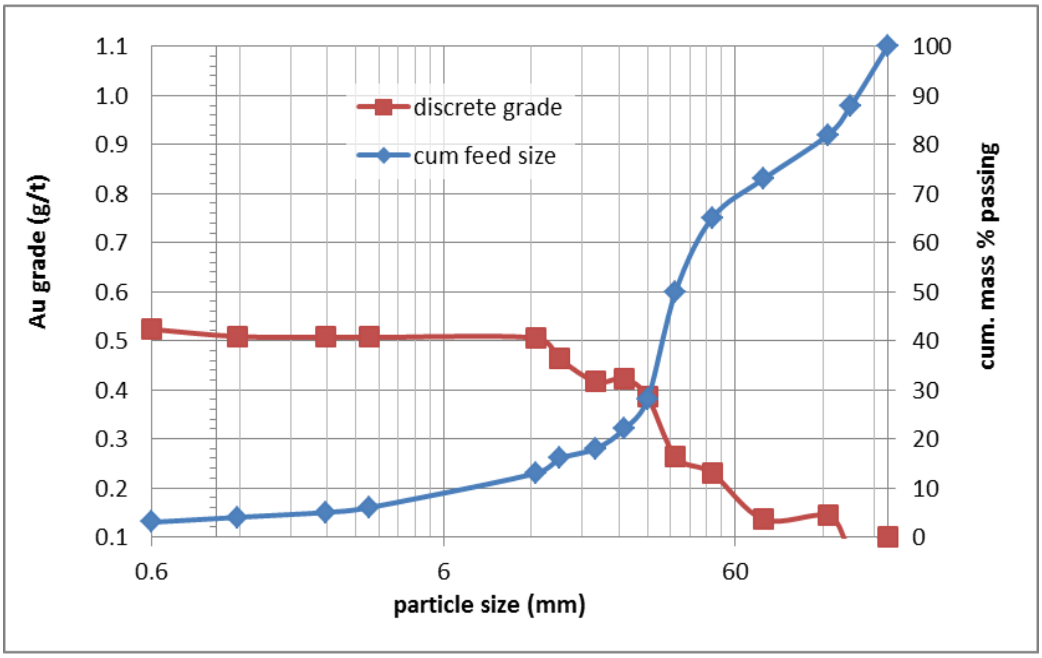


Figure 31. Au grade and size distribution

This raises the question of whether it is worth the effort to treat the coarse +50mm size fraction to gain more gold recovery.

The evaluation shown in Table 16 shows the detailed size distribution and gold distribution data. The summary shows the average values for the different size ranges:

+50mm contains the least gold at an average of 0.14 g/t at 35% mass,

-50mm +20mm contains on average 0.64 g/t at 47% mass and,

-20mm contains the highest gold concentration at 0.98 g/t at 18% mass.

By only treating the -50mm ROD material 91% of the gold contained in the SRD will have a chance of recovery, firstly by the optical sorter of the -50mm +20mm fraction and secondly by the traditional gold plant treating the sorter concentrate plus the -20mm fines fraction.

Table 16. Size and Au grade distribution of Kloof SRD

Size Fraction - Au Grade Evaluation								
Size mm	Discrete %	Cum % Passing	g/t Discrete	Au g	% Au	Au cum g/t	Section Au Cum g/t	% cum
+150	12	100	0.10	0.0120	2.3%	0.1	0.10	12
-150+125	6	88	0.04	0.0024	0.5%	0.08	0.08	18
-125+75	9	82	0.27	0.0243	4.6%	0.14	0.14	27
-75+50	8	73	0.11	0.0088	1.7%	0.14	0.14	35
-50+37.5	15	65	0.45	0.0675	12.9%	0.23	0.45	15
-37.5+30	22	50	0.34	0.0748	14.3%	0.26	0.38	37
-30+25	6	28	1.85	0.1110	21.2%	0.39	0.59	43
-25+20	4	22	1.15	0.0460	8.8%	0.42	0.64	47
-20+15	2	18	0.16	0.0032	0.6%	0.42	0.16	2
-15+12.5	3	16	1.75	0.0525	10.0%	0.46	1.11	5
-12.5+3.35	7	13	1.04	0.0728	13.9%	0.51	1.07	12
-3.35+2.36	1	6	0.62	0.0062	1.2%	0.51	1.04	14
-2.36+1.18	1	5	0.56	0.0056	1.1%	0.51	1.00	14
-1.18+0.6	1	4	0.63	0.0063	1.2%	0.51	0.98	15
-0.6	3	3	1.00	0.0300	5.7%	0.52	0.98	18
	100		0.52	0.5234	100%			

Summary				
Size mm	Au g	% Au	Au g/t	% cum
+50	0.0475	9%	0.14	35
-50+20	0.2993	57%	0.64	47
-20	0.1766	34%	0.98	18
Total	**0.5234**	**100%**	**0.52**	**100**

On the basis of this grade distribution and the test results, Gold Fields decided to implement optical sorting for the -50 +20mm size range only. The sorting plant shown in Figure 32 was installed and commissioned early in 2011. The coarse +50mm will be discarded, used as mill-grinding media or sold as aggregate.

Figure 32. Kloof plant showing two parallel optical sorters

4.2 Case Study 2: ROM Sorting at CRG

Test work for the CRG ROM sorting application was conducted in two phases:

- Phase 1: Optical sorting on ROM sample in two size fraction
- Phase 2: Optical sorting of ROM at different waste-reef ratios

4.2.1 Phase 1 - ROM 30t sample

In November 2009 CRG Gold mine sent a 30t run of mine sample to Mintek (as shown in Figure 33) for optical sorting test work.

Figure 33. 30t bulk sample offloading at Mintek

The bulk sample was then screened at 106mm, 75mm, 50mm and 20mm. The resulting fractions -75+50mm (5.7t) and -50+20mm (9.2t) were used for optical sorting test work (see Table 17).

Table 17. Screening results showing size distribution of ROM sample

Size [mm]	Mass			
	Retained [kg]	Retained [%]	Cum retained [%]	Cum passing [%]
106	307	1.1%	1.1%	98.9%
75	2,103	7.6%	8.7%	91.3%
50	5,713	20.6%	29.4%	70.6%
20	9,225	33.3%	62.7%	37.3%
-20	10,325	37.3%	100.0%	0.0%
Total	**27,673**	**100.0%**		

A 1 ton set-up sample was used to optimise the optical sorter programme. For the sorting algorithm several different colour classes were set up, representing red material (oxidised Main Reef Leader), pebble material (Main Reef) and all remaining colours. Concentrate was defined as having a certain percentage of the red and pebble colour classes. This percentage was varied to produce different mass fractions to concentrate during the set-up. It was decided to use a fixed sorting algorithm which will produce about a 15% mass concentrate in the final reef products for both size fractions.

For the test runs the feed rate was set at ~40t/h for the fines fraction (-50+20mm) and ~60t/h for the coarse fraction (-75+50mm).

The flow sheet in Figure 34 illustrates the optical sorting test work procedure.

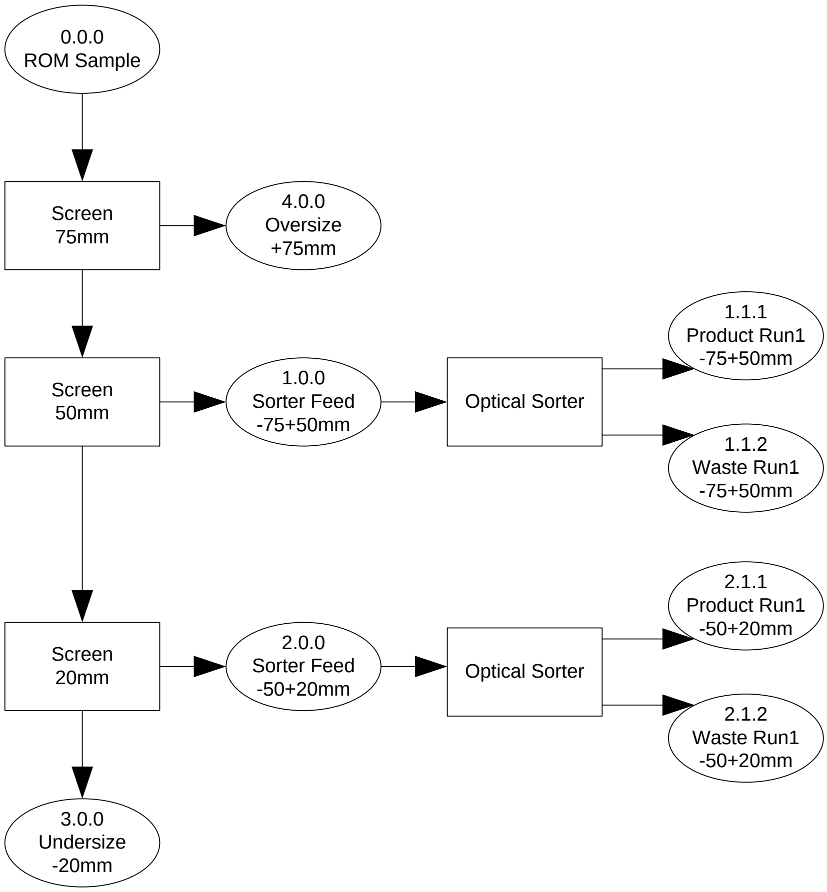


Figure 34. Optical sorting test work flow sheet

The resulting sorted products were separately prepared for assaying as described in Section 4.1.3 *Sample preparation*.

Test work results

Table 18 illustrates the results of the combined runs for each size fraction.

Table 18. Optical sorting results on CRG ROM sample

Feed Size	Feed Mass [kg]	Conc Mass [kg]	Tails Mass [kg]	Conc Masspull	Calc. Head Grade [g/t]	Conc Grade [g/t]	Tails Grade [g/t]	Au Recovery
-75+50mm	5,582	810	4,772	14.5%	0.47	1.71	0.26	52.7%
-50+20mm	4,343	742	3,601	17.1%	0.67	1.67	0.46	42.8%

Figures 35 and 36 show images of the concentrate Main Reef fraction containing predominately pebble quarzites. The colours of tailings fraction is mainly grey.

Figure 35. -50+20mm concentrate

Figure 36. -50+20mm tailings

The assay results show good recognition and differentiation of gold reef and waste material. The sorter improved the gold grade in the coarse fraction by a factor of 3.6 and in the fines fraction of 2.5. In both size fractions the mass was reduced to below 20% of the feed.

4.2.2 Phase 2 - Optical sorting of ROM at different waste-reef ratios

Following the results of the large low-grade sample a second series of test work was conducted on higher grade material. The objective was to beneficiate three different 5 ton samples with different waste-reef ratios in the size fraction -75+50mm on an optical sorter. In February 2010 CRG delivered -75+50mm ROM material which was hand sorted into reef and waste. The reef and waste was then blended at Mintek into 3 sets of samples according to Table 19.

The samples were artificially compiled by hand picking and mixing/blending reef and waste into the following ore/waste ratios.

Table 19. Optical sorting samples of different waste-reef ratios

Bulk Sample Testwork					
Test No.	Reef (t)	Waste (t)	Total (t)	Ore:Waste Ratio	Size Fraction
1	2.50	2.50	5.00	1:1	-75mm +50mm
2	1.67	3.33	5.00	1:2	-75mm +50mm
3	1.25	3.75	5.00	1:3	-75mm +50mm

The optical sorter algorithm of the previous test work was used as a basis to separate reef and waste in the different samples. The sorting algorithm was based on the reef having bright spots in form of pebbles. These were identified by a brightness setting and a filter enhancing large bright spots (pebbles) as opposed to random small bright spots. Concentrate was then defined as having a certain percentage of the bright (pebble) colour class. The washing screen was turned on for the test runs to present material with a clean surface to the detection system. The procedure of the three test runs is illustrated in the flow sheet in Figure 37.

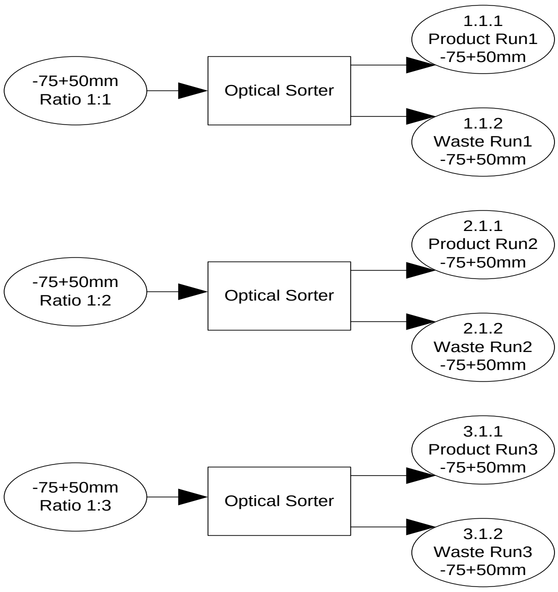


Figure 37. Test work flow sheet for 3 ratio samples

The resulting sorter products were hand sorted as illustrated in Figure 38 (further images of the bulk sample waste ratio test work are shown in Appendix E Figures 63 to 68) to determine:

- The amount of misplaced reef in the waste fraction (or low-grade fraction)
- The amount of waste diluting the reef concentrate fraction (or high-grade fraction)

Figure 38. Evaluation of sorted fractions by hand sorting

Table 20 summarises the results (refer to Appendix F, Table 27 for detailed results) of the combined runs for the three mixed ratios:

Table 20. Optical sorting results of different waste-reef ratios

Ratio	Stream	Total [kg]	Reef [kg]	Waste [kg]	Reef Content	Waste Content	Reef Recovery	Mass Distribution	Stream Grade [g/t]	Reef Grade [g/t]	Gold Content [g]
1:1	Concentrate	2,048	1,310	738	64.0%	36.0%	77.6%	57.7%	2.6	4.0	5.2
	Tailings	1,501	379	1,122	25.2%	74.8%	22.4%	42.3%	1.0	4.0	1.5
	Feed	3,549	1,689	1,860	47.6%	52.4%			1.9	4.0	6.8

Ratio	Stream	Total [kg]	Reef [kg]	Waste [kg]	Reef Content	Waste Content	Reef Recovery	Mass Distribution	Stream Grade [g/t]	Reef Grade [g/t]	Gold Content [g]
1:2	Concentrate	1,204	554	650	46.0%	54.0%	77.7%	53.0%	1.8	4.0	2.2
	Tailings	1,068	159	909	14.9%	85.1%	22.3%	47.0%	0.6	4.0	0.6
	Feed	2,272	713	1,559	31.4%	68.6%			1.3	4.0	2.9

Ratio	Stream	Total [kg]	Reef [kg]	Waste [kg]	Reef Content	Waste Content	Reef Recovery	Mass Distribution	Stream Grade [g/t]	Reef Grade [g/t]	Gold Content [g]
1:3	Concentrate	2,101	1,282	819	61.0%	39.0%	85.1%	53.7%	2.4	4.0	5.1
	Tailings	1,809	224	1,585	12.4%	87.6%	14.9%	46.3%	0.5	4.0	0.9
	Feed	3,910	1,506	2,404	38.5%	61.5%			1.5	4.0	6.0

The results show the following trends and observations:

- The test work shows that run of mine ore can be upgraded to a higher reef content. The lower the reef content in the feed, the more favourable the upgrade ratio becomes. This is also reflected in the calculated concentrate and tailings grades.
- Reef recoveries lie between 77% and 85% at mass-concentrations between 53% and 58% to the high-grade fraction.

Sorting plant at CRG

On the basis of the test results, the decision was made to implement optical sorting for the -75 +20mm size range ROM material. The sorting plant shown in Figure 38 was installed and commissioned early 2011.

Figure 39. Containerised ROM optical sorter plant at CRG

Optimisation of optical sorter detection and ejection during the commissioning of the plant at CRG is illustrated in Figure 39 and 40.

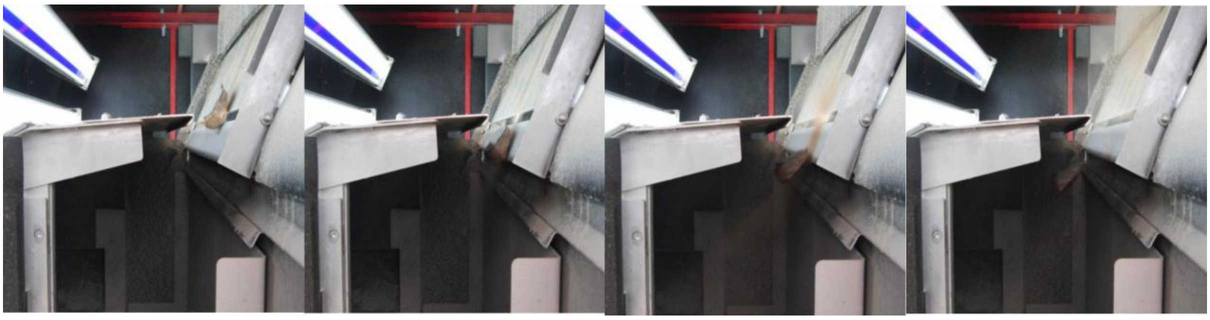


Figure 40. Picture sequence showing optical detection and ejection of gold-bearing Witwatersrand ore at CRG

The sequence of images in Figures 39 and 40 show the ejection of gold reef particles from a stream of typical run of mine feed material. The sorter operates at 50tph on feed material which is sized within the range -50mm +20mm.

Figure 41. Picture sequence showing ejection of gold-bearing Witwatersrand ore over the sorter's splitter plate

5 DISCUSSION AND CONCLUSION

The results of these two studies show that sensor based sorting, in this case optical sorting, is an effective technology for coarse rock beneficiation of Witwatersrand type gold ores.

In Case Study 1 at Gold Fields' Kloof Gold Mine the following results were achieved in a range of test work and pilot plant campaigns:

- The sorting algorithm focuses on recovering rocks with sulphide inclusions (mainly pyrite) which are closely linked to the gold,
- the run of dump feed grade to the sorter was improved at least three-fold,
- extraction rate to the concentrate was less than 10% of the feed stream,
- the mill feed to the gold processing plant which is a blending of the -20mm fines and the sorter concentrate will have a significantly higher grade than if the entire dump were to be treated,
- only the +20mm -50mm gold-bearing ore and the higher grade fines now need to be milled,
- the sorted barren waste with most of the sulphides removed can now be used as aggregate or stockpiled,
- the economic viability of an optical sorting plant was proven.

The Gold Fields SRD stand-alone treatment plant, with a 100 t/h optical sorting plant as a core component, was commissioned in 2011. This first installation could be the blue-print for other mining groups to follow when rehabilitating the vast volumes of SRD along the perimeter of the Witwatersrand-basin.

Case Study 2 deals with a problematic CRG ore deposit which contains high levels of waste rock dilution in the ROM when mining different reef horizons of the old mines of the Central Rand. The test work showed the following optical sorting results:

- Effective waste rock removal from the ROM ore at different levels of waste dilution at recoveries between 75% and 85%.
- This will provide a higher grade feed to the mill at a reduced feed rate.
- Effectively only the gold-bearing ore is now being milled and processed, saving energy and process costs when producing the same amount of gold.

A 70 t/h optical sorting plant was commissioned in 2011 to treat ROM ore. CRG has mining and mineral rights over a distance of 40 km which generates considerable transport and infrastructure cost. An important of this research has shown that de-centralised sorting plants close to the mining areas will help reduce material handling and transport cost by removing the waste rock early in the process stream.

6 RECOMMENDATION

These case studies and other advances made in recent years have opened up new opportunities in beneficiating coarse rock fractions. These include:

6.1 Underground Sorting on Witwatersrand Mines

The most obvious application would be underground pre-concentration. Most of the South African gold mines are deep level mines at over 2000 m below surface. Underground pre-concentration using sensor based sorting technologies are being investigated. The advantages will be significant if waste rock can be separated effectively underground. This will reduce the hoisting costs as only gold-bearing reef will be transported to surface. The results and experience gained from this optical sorting test work can play an important role in such research.

6.2 Other Mineral Applications

The rapid advancements in sensor technologies will be influencing future flow sheets of beneficiation plants. Traditional coarse rock beneficiating technologies such as dense medium separation or magnetic separation are limited in their application. A whole range of sensors, which are now available, make use of the entire electromagnetic spectrum to differentiate between mineral-bearing and barren particles. The most promising sensor is the newly developed X-Ray Transmission (XRT) sensor which is able to discriminate between barren and mineralised rocks without the use of water and at low operating cost. Many new applications have been tested and are being implemented in the market. These include:

- Chrome ore sorting using the dry XRT sorting process
- Dry coal de-stoning using XRT sorting

6.3 Other Gold Applications

6.3.1 Radiometric Sorting

Radiometric sorting of Witwatersrand type gold ore have in the past been used to beneficiate ROM ore as described by Schaffler [2]. Recent comprehensive rock-by-rock scanning test work of all available type sensors of waste dump material in the Vaal River gold field operations have shown that radiometric could potentially be used to treat the coarse +80mm size fraction. A combination of radiometric and colour sorting should be investigated further.

6.3.2 Gold Price Sensitivity for Low-Grade Gold Resources

During the long period of this research a wide range of fluctuation in the gold price was experienced; from as low as $390 per ounce to over $1900 per ounce. At very high gold price levels beneficiation of low grade deposits such as SRD, mining companies will tend to rather mill the entire dump even at gold grades of less than 0.5 g/t than spend the effort of beneficiation i.e. sorting. The risk of gold recovery losses is higher than the extra cost of milling large low-grade volumes.

6.3.3 Sulphide Gold Deposits

Sulphide type gold deposits such as TGME in the Pilgrim's Rest area and Navachab Gold Mine in Namibia (also poly-metallic deposits such as silver mining areas in Mexico) show great potential for XRT sorting. The XRT sensor can detect various concentration levels sulphides contained within a rock (size -60mm +10mm) varying from massive sulphides to disseminated sulphides. Test work for this dry beneficiation process has shown excellent results.

We are facing a future with ever increasing demand for resources which are fast diminishing. Low grade and difficult ore bodies will need to be treated cost-effectively. Integrating new dry separation technologies with state-of-the-art traditional mineral processing practices also requires innovative and ‘out-of-the-box’ thinking. We need the vision to integrate new technologies so that we can face and master new challenges in saving water, energy and costs.

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APPENDICES

A. KLOOF SRD - INITIAL GRAB SAMPLE TEST (2003)

The images, which follow, are digital images of the various rock types from Kloof SRD

Figure 42. VCR reef

Figure 43. Cobble reef

Figure 44. Marginal reef

Figure 45. Dolomite

Figure 46. **Lava, Western area and Alberts formation**

Figure 47. **Foot wall, Elsburg and Kimberly quartzite (green and grey quartz)**

B. SIMULATION IMAGES OF SRD ROCK TYPES AT KLOOF

The simulation images, which follow, are all based on the program as per Figure 11. The entire product is set to reject (red numbers) and all the waste is set to accept (green numbers).

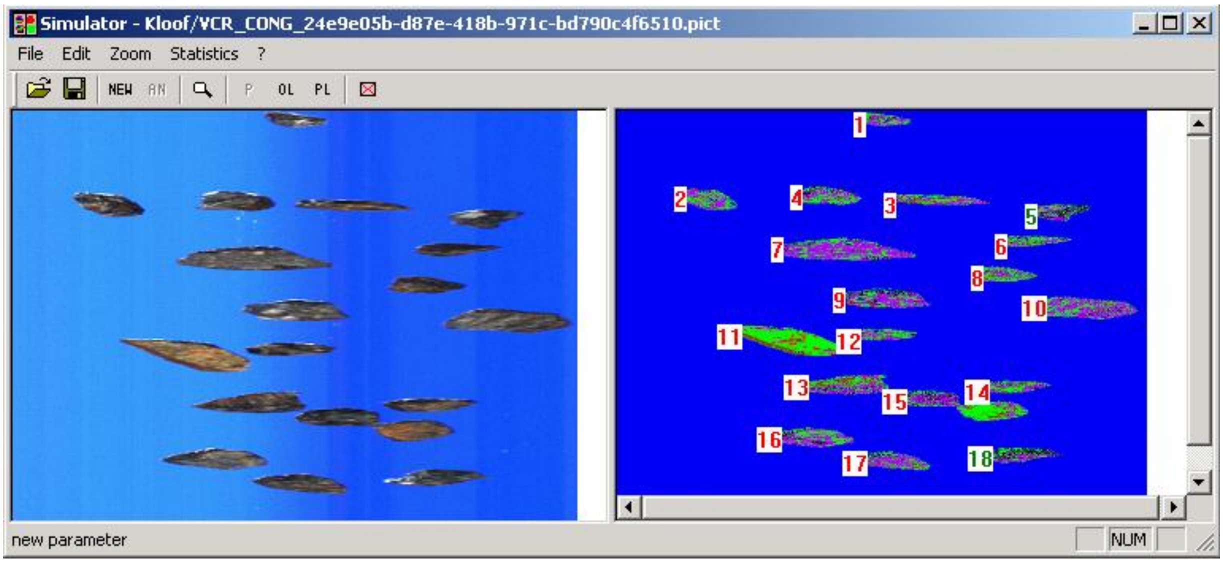

Figure 48. VCR reef (Simulation)

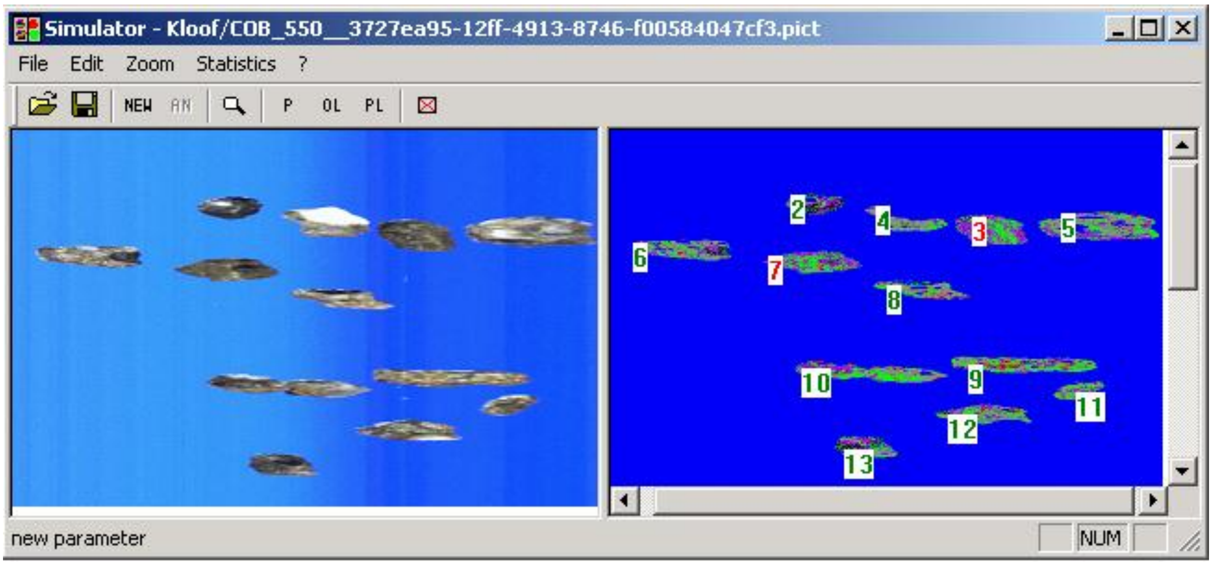

Figure 49. Cobble reef (Simulation)

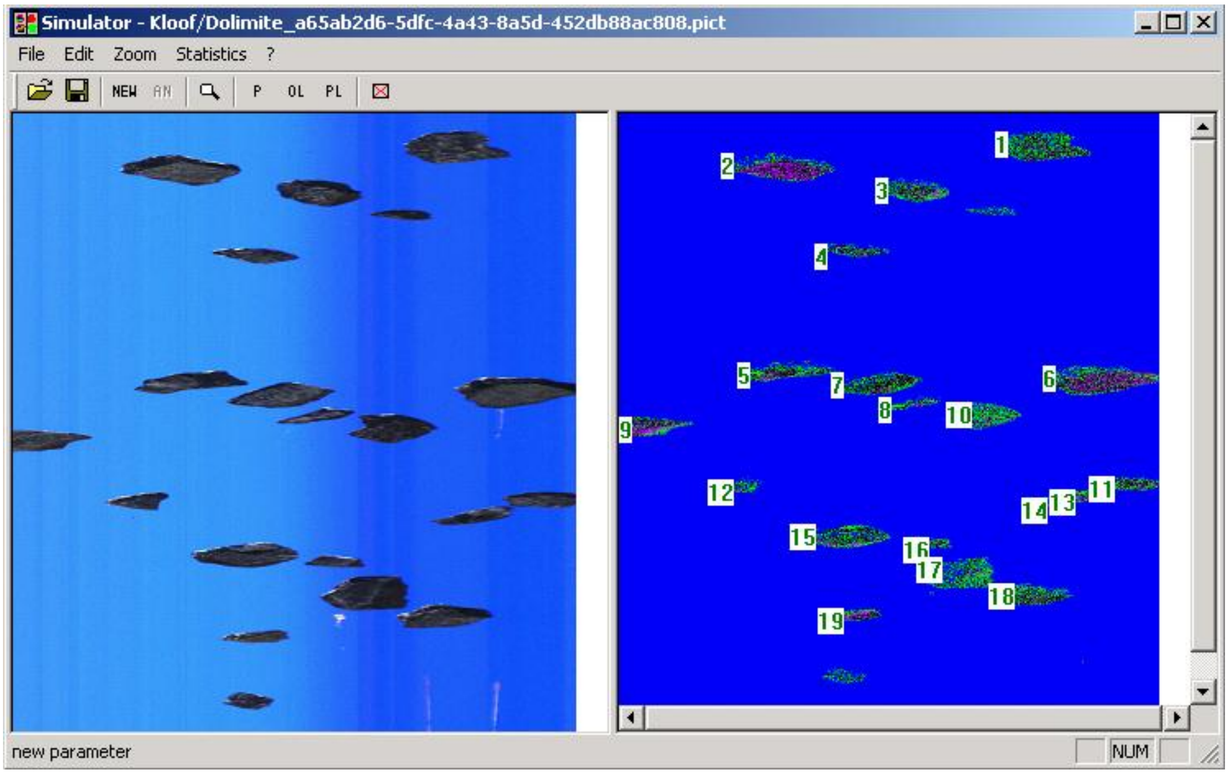

Figure 50. Dolomite (Simulation)

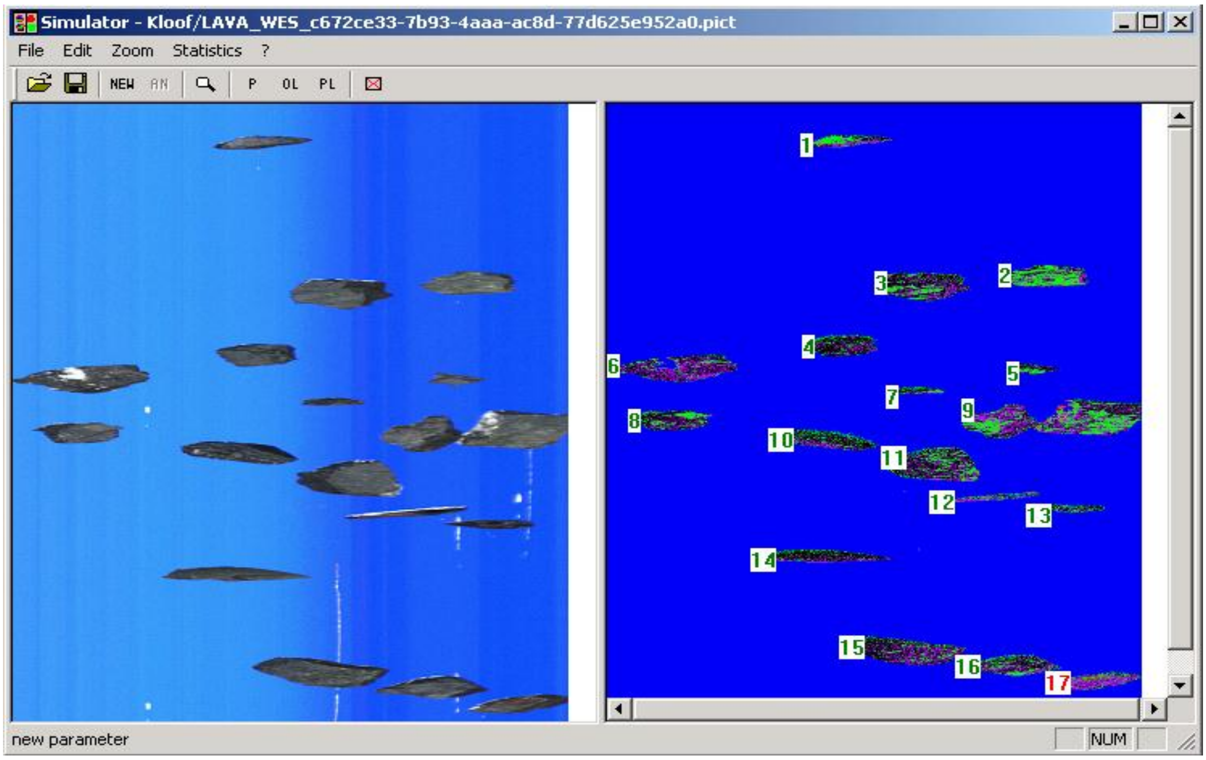

Figure 51. Lava (Simulation)

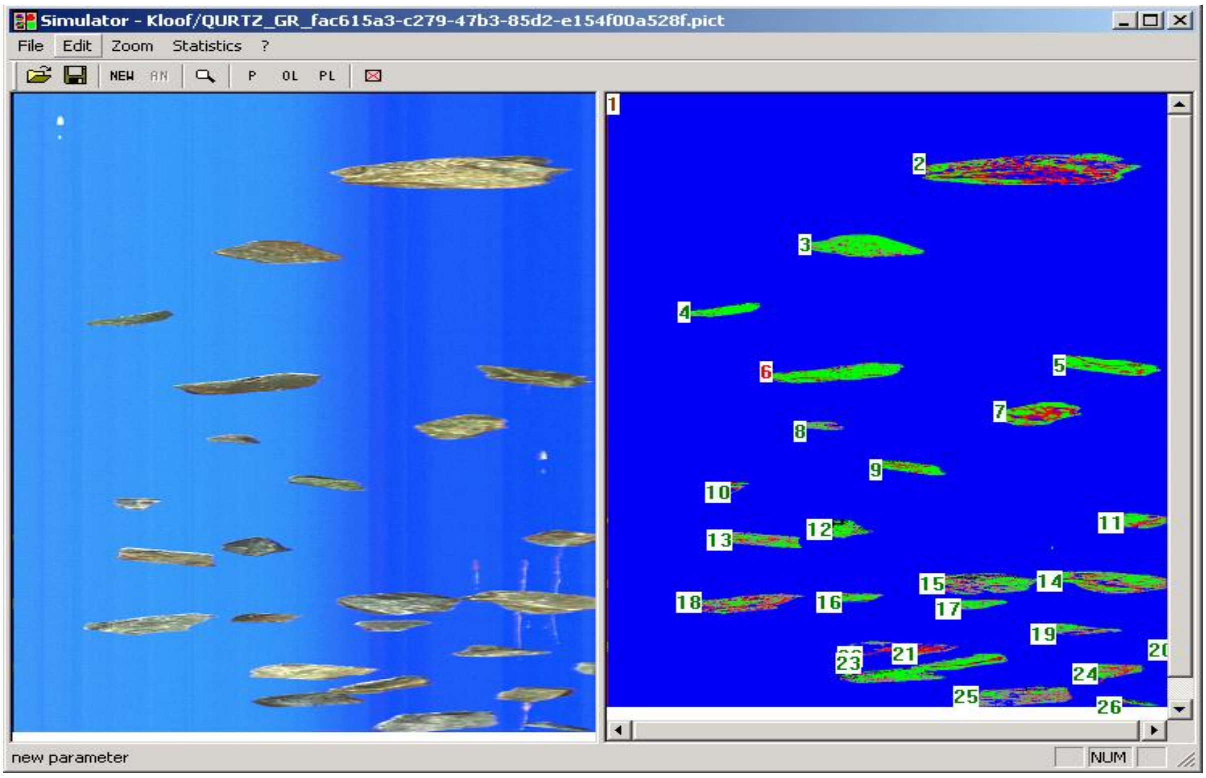

Figure 52. Green quartzite (Simulation)

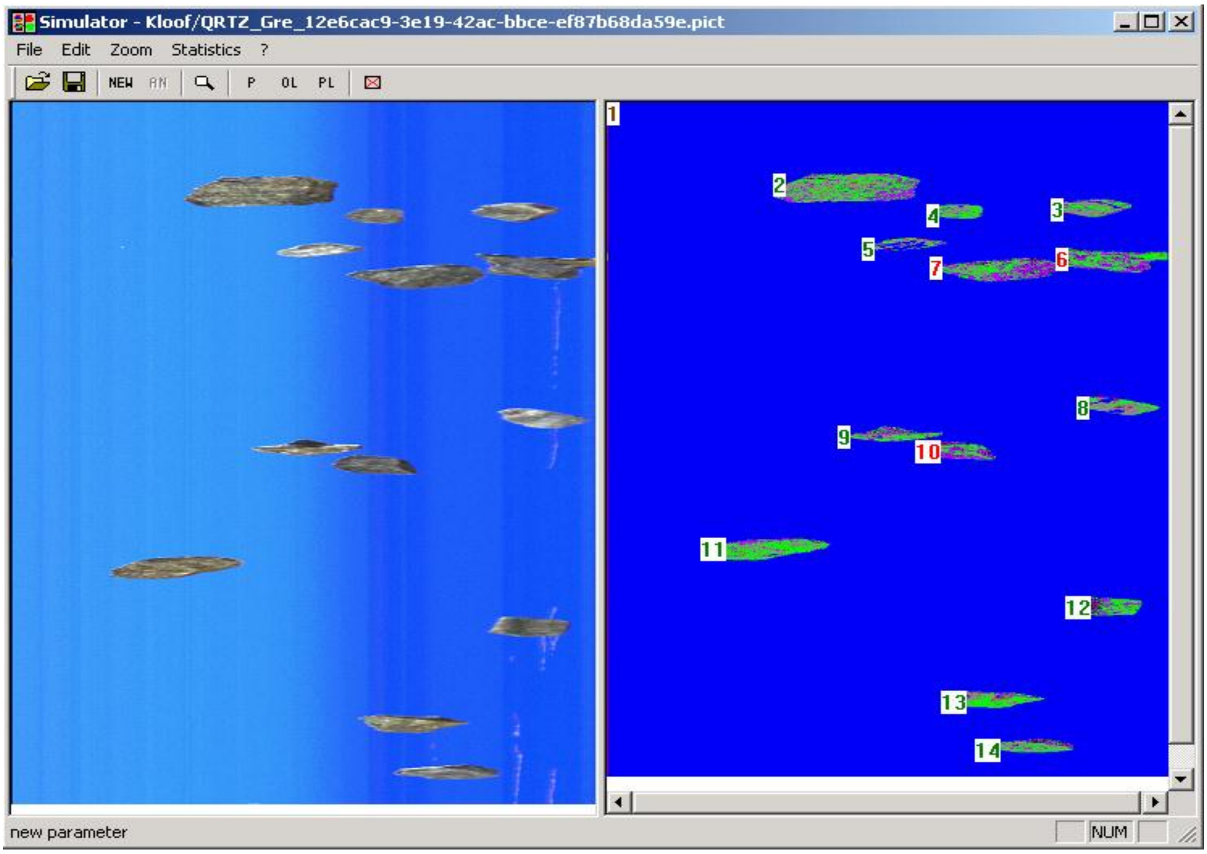

Figure 53. Grey quartzite (Simulation)

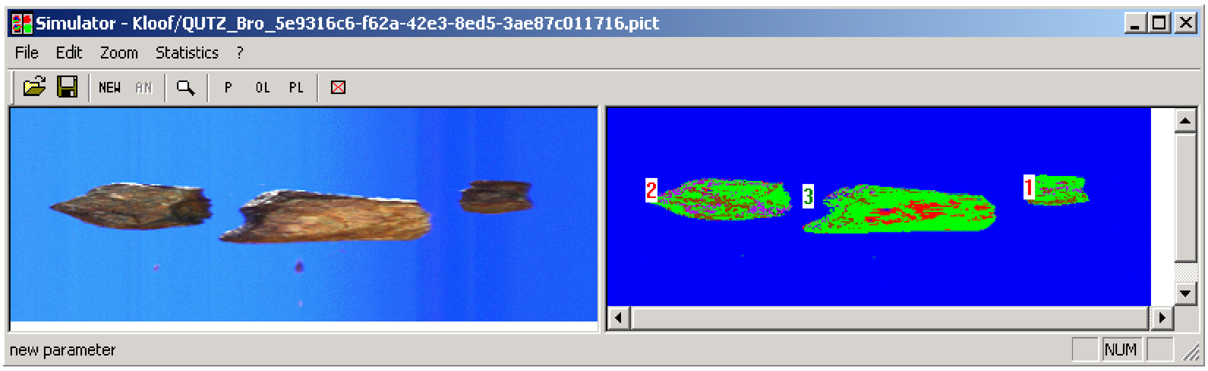

Figure 54. Foot wall (Simulation)

C. KLOOF SRD - BULK SAMPLE TESTS RESULTS (2009)

The following Tables show the test work results achieved for the Kloof SRD waste rock optical sorting in 2009.

Table 21. Kloof SRD test results on low mass-pull (coarse fraction)

Low Mass Pull Coarse										
			Setting		Mass [kg]				Mass Distribution	
Run	Date	Size Range [mm]	Side 1	Side 2	Feed	Tails	Conc	Total	Tails	Conc
KLO-004	08.05.2009	**-78+50**	38%	45%	1,337	1,207	130	1,337	90.3%	9.7%
KLO-005	08.05.2009	**-78+50**	38%	45%	1,224	1,066	158	1,224	87.1%	12.9%
KLO-010	11.05.2009	**-78+50**	38%	45%	684	619	65	684	90.5%	9.5%
KLO-011	11.05.2009	**-78+50**	38%	45%	906	821	85	906	90.6%	9.4%
KLO-015	11.05.2009	**-78+50**	38%	45%	1,024	935	89	1,024	91.3%	8.7%
KLO-017	12.05.2009	**-78+50**	38%	45%	964	899	65	964	93.3%	6.7%
KLO-020	13.05.2009	**-78+50**	38%	45%	939	881	58	939	93.8%	6.2%
KLO-022	13.05.2009	**-78+50**	38%	45%	991	946	45	991	95.5%	4.5%
KLO-028	19.05.2009	**-78+50**	38%	45%	1,132	1,072	60	1,132	94.7%	5.3%
KLO-029	19.05.2009	**-78+50**	38%	45%	1,102	1,017	85	1,102	92.3%	7.7%
KLO-032	19.05.2009	**-78+50**	38%	45%	910	815	95	910	89.6%	10.4%
					11,213	**10,278**	**935**	**11,213**	**91.7%**	**8.3%**

Table 22. Kloof SRD test results on medium mass-pull (coarse fraction)

Medium Mass Pull Coarse										
			Setting		Mass [kg]				Mass Distribution	
Run	Date	Size Range [mm]	Side 1	Side 2	Feed	Tails	Conc	Total	Tails	Conc
KLO-003	08.05.2009	**-78+50**	33%	39%	1,338	1,143	181	1,324	86.3%	13.7%
KLO-006	08.05.2009	**-78+50**	33%	39%	1,255	1,060	195	1,255	84.5%	15.5%
KLO-009	11.05.2009	**-78+50**	33%	39%	397	342	55	397	86.1%	13.9%
KLO-012	11.05.2009	**-78+50**	33%	39%	994	852	142	994	85.7%	14.3%
KLO-013	11.05.2009	**-78+50**	33%	39%	1,071	916	155	1,071	85.5%	14.5%
KLO-018	12.05.2009	**-78+50**	33%	39%	780	695	85	780	89.1%	10.9%
KLO-021	13.05.2009	**-78+50**	33%	39%	1,019	872	147	1,019	85.6%	14.4%
KLO-026	14.05.2009	**-78+50**	33%	39%	1,010	882	128	1,010	87.3%	12.7%
KLO-027	15.05.2009	**-78+50**	33%	39%	1,063	944	119	1,063	88.8%	11.2%
KLO-031	19.05.2009	**-78+50**	33%	39%	836	724	112	836	86.6%	13.4%
					9,763	**8,430**	**1,319**	**9,749**	**86.5%**	**13.5%**

Table 23. Kloof SRD test results on high mass-pull (coarse fraction)

High Mass Pull Coarse										
			Setting		Mass [kg]				Mass Distribution	
Run	Date	Size Range [mm]	Side 1	Side 2	Feed	Tails	Conc	Total	Tails	Conc
KLO-002	08.05.2009	**-78+50**	25%	30%	1,261	864	398	1,262	68.5%	31.5%
KLO-007	08.05.2009	**-78+50**	25%	30%	1,270	886	384	1,270	69.8%	30.2%
KLO-008	08.05.2009	**-78+50**	25%	30%	1,189	834	355	1,189	70.1%	29.9%
KLO-014	11.05.2009	**-78+50**	25%	30%	1,355	1,004	351	1,355	74.1%	25.9%
KLO-016	12.05.2009	**-78+50**	25%	30%	996	717	279	996	72.0%	28.0%
KLO-019	12.05.2009	**-78+50**	25%	30%	1,284	868	416	1,284	67.6%	32.4%
KLO-023	14.05.2009	**-78+50**	25%	30%	1,280	992	288	1,280	77.5%	22.5%
KLO-024	14.05.2009	**-78+50**	25%	30%	1,226	902	324	1,226	73.6%	26.4%
KLO-025	14.05.2009	**-78+50**	25%	30%	1,213	886	327	1,213	73.0%	27.0%
KLO-030	19.05.2009	**-78+50**	25%	30%	1,090	815	275	1,090	74.8%	25.2%
					12,164	**8,768**	**3,397**	**12,165**	**72.1%**	**27.9%**

Table 24. Kloof SRD test results on low mass-pull (fine fraction)

Low Mass Pull Fines										
			Setting		Mass [kg]				Mass Distribution	
Run	Date	Size Range [mm]	Side 1	Side 2	Feed	Tails	Conc	Total	Tails	Conc
KLO-035	22.05.2009	**-50+20**	38%	50%	1,102	964	138	1,102	87.5%	12.5%
KLO-037	22.05.2009	**-50+20**	38%	50%	1,240	1,090	150	1,240	87.9%	12.1%
KLO-040	22.05.2009	**-50+20**	38%	50%	772	680	92	772	88.1%	11.9%
KLO-042	22.05.2009	**-50+20**	38%	50%	1,072	965	107	1,072	90.0%	10.0%
					4,186	**3,699**	**487**	**4,186**	**88.4%**	**11.6%**

Table 25. Kloof SRD test results on medium mass-pull (fine fraction)

Medium Mass Pull Fines										
			Setting		Mass [kg]				Mass Distribution	
Run	Date	Size Range [mm]	Side 1	Side 2	Feed	Tails	Conc	Total	Tails	Conc
KLO-036	22.05.2009	**-50+20**	28%	37%	929	791	138	929	85.1%	14.9%
KLO-038	22.05.2009	**-50+20**	28%	37%	1,086	880	206	1,086	81.0%	19.0%
KLO-041	22.05.2009	**-50+20**	28%	37%	493	405	88	493	82.2%	17.8%
KLO-043	22.05.2009	**-50+20**	28%	37%	544	425	119	544	78.1%	21.9%
					3,052	**2,501**	**551**	**3,052**	**81.9%**	**18.1%**

Table 26. Kloof SRD test results on high mass-pull (fine fraction)

High Mass Pull Fines										
			Setting		Mass [kg]				Mass Distribution	
Run	Date	Size Range [mm]	Side 1	Side 2	Feed	Tails	Conc	Total	Tails	Conc
KLO-033	22.05.2009	**-50+20**	22%	29%	1,073	773	300	1,073	72.0%	28.0%
KLO-034	22.05.2009	**-50+20**	22%	29%	1,011	713	298	1,011	70.5%	29.5%
KLO-039	22.05.2009	**-50+20**	22%	29%	1,031	706	325	1,031	68.5%	31.5%
					3,115	**2,192**	**923**	**3,115**	**70.4%**	**29.6%**

D. KLOOF SRD - SCANNED AND SIMULATED IMAGES (2009)

The following simulation images show snap shots of the different SRD rock types.

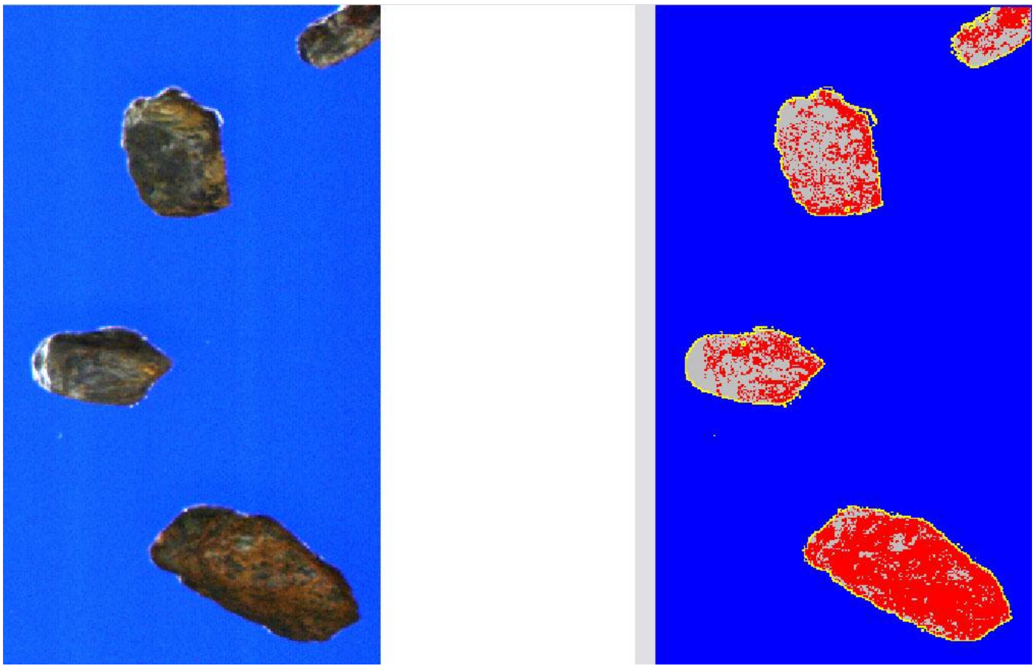

Figure 55. Dark Reef (-50+20mm)

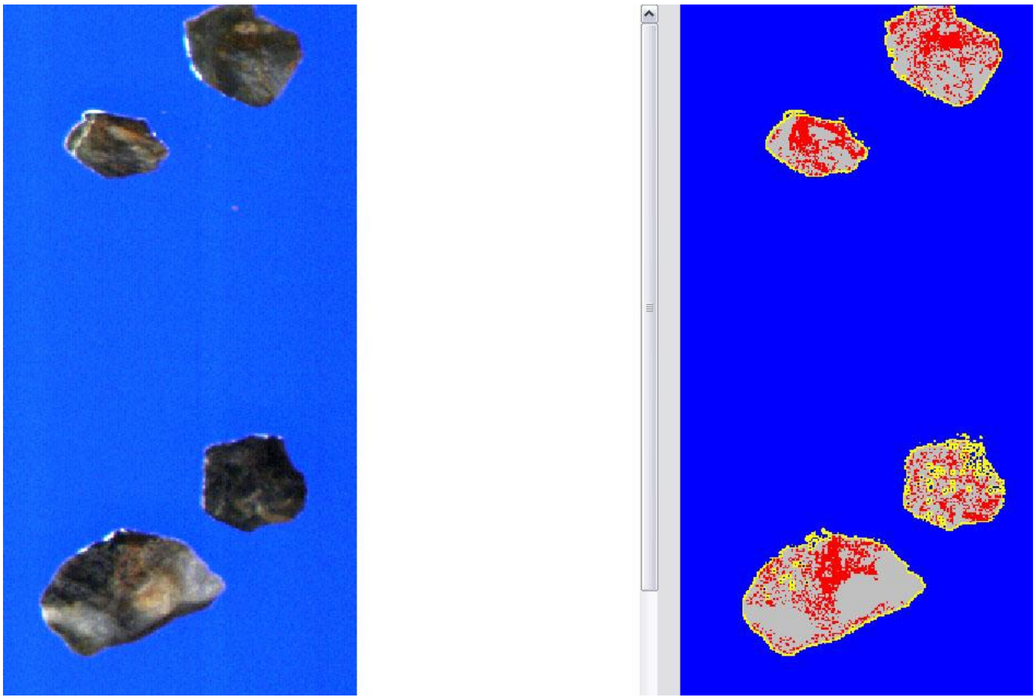

Figure 56. Light Reef (-50+20mm)

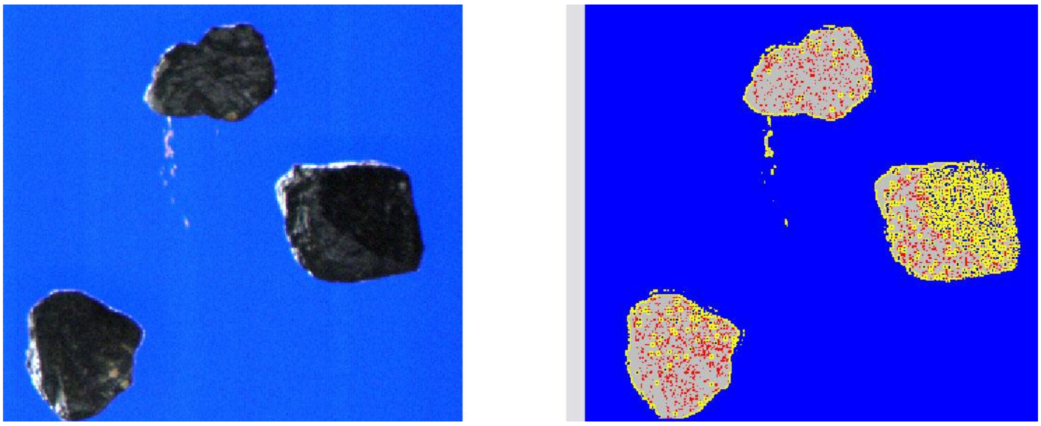

Figure 57. Laval waste (-50+20mm)

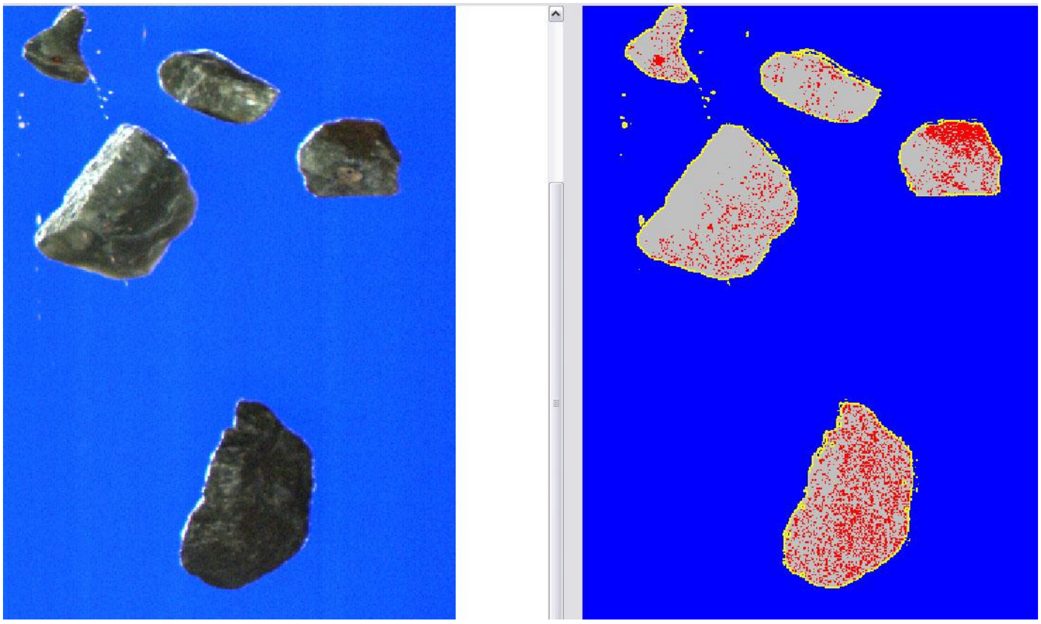

Figure 58. Quartz waste (-50+20mm)

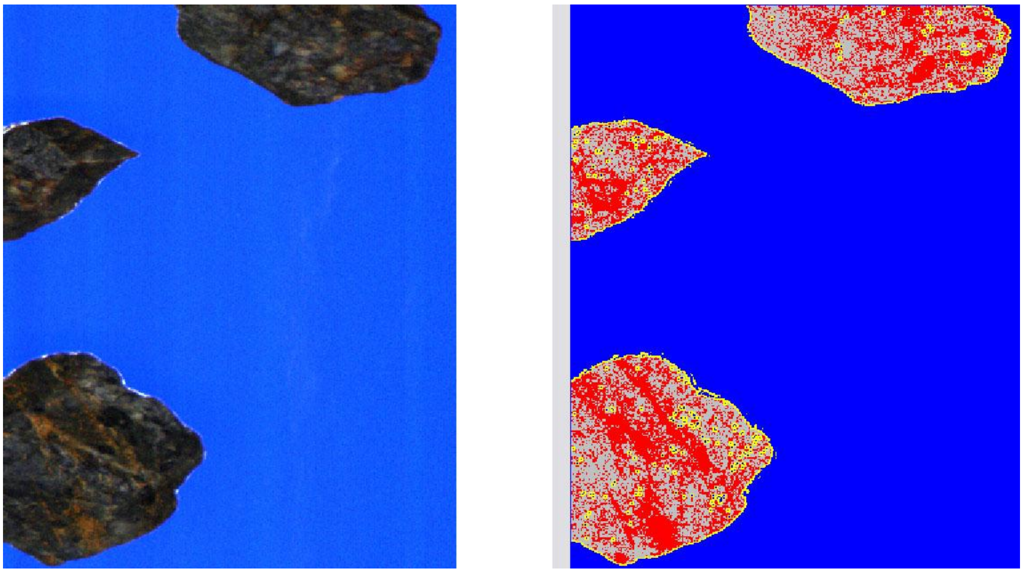

Figure 59. Dark Reef (-78+50mm)

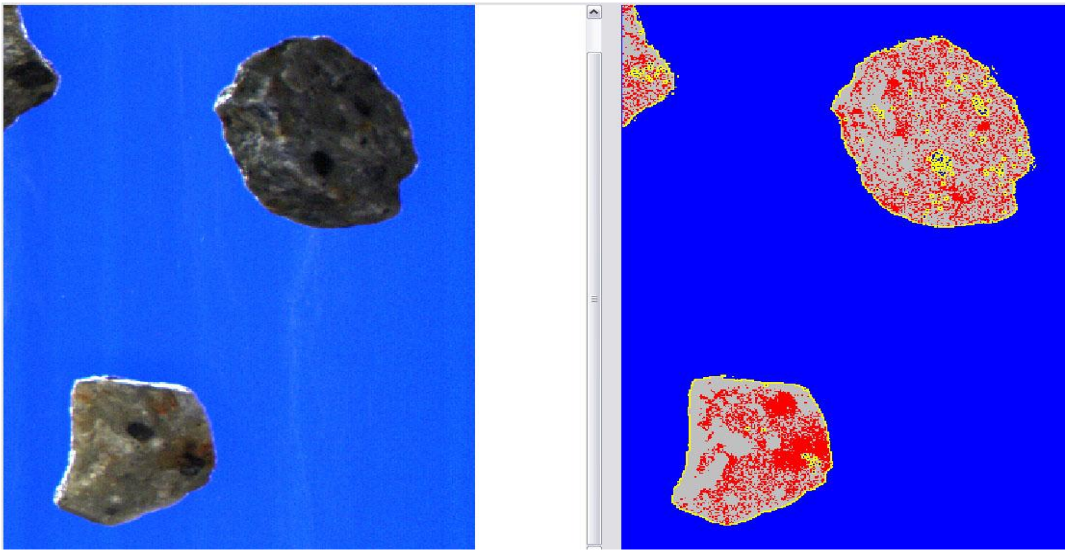

Figure 60. Light Reef (-78+50mm)

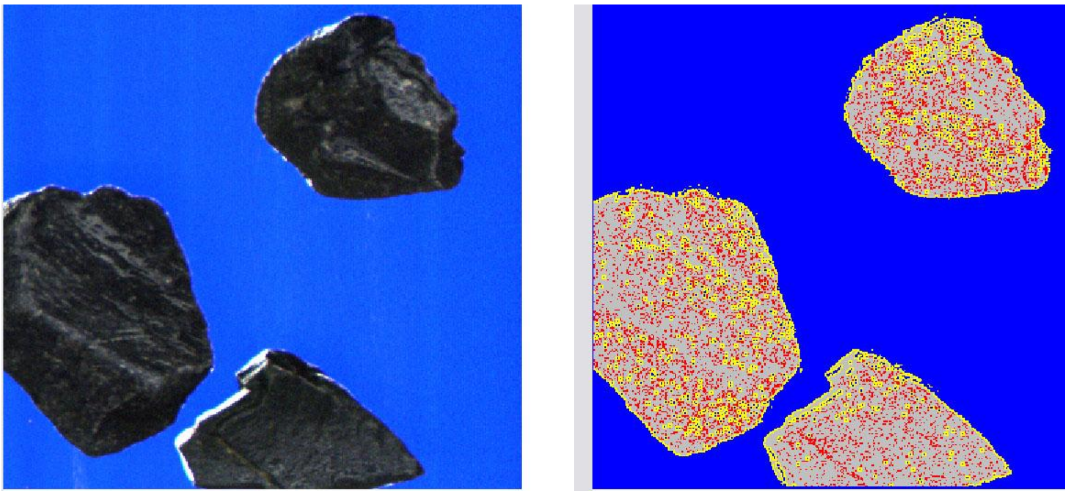

Figure 61. Lava waste (-78+50mm)

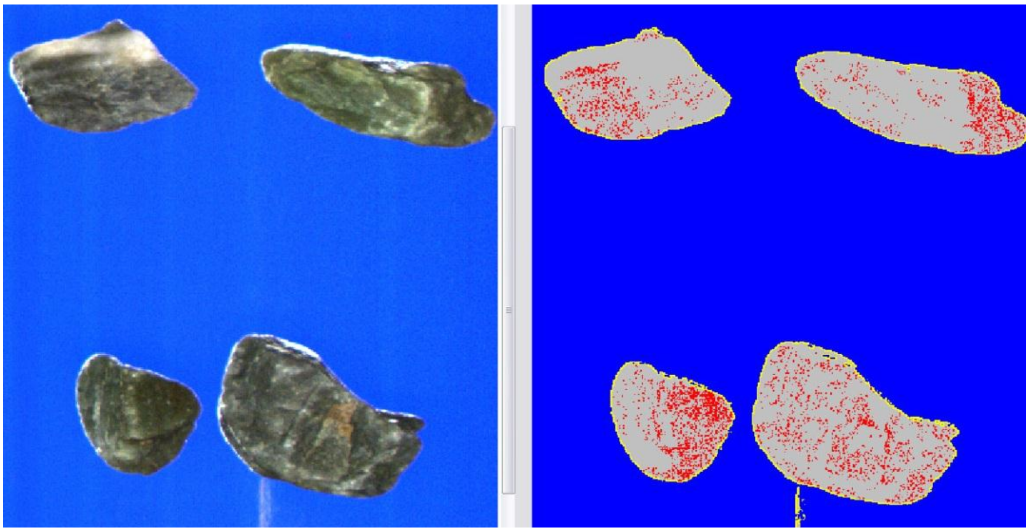

Figure 62. Quartz waste (-78+50mm)

E. CRG TEST WORK ON ROM SAMPLE

The following product images show the concentrate and tailings fractions achieved during the CRG test work.

Figure 63. Ratio 1:1 concentrate

Figure 64. Ratio 1:1 tailings

Figure 65. Ratio 1:2 concentrate

Figure 66. Ratio 1:2 tailings

Figure 67. Ratio 1:3 Concentrate

Figure 68. Ratio 1:3 tailings

F. CRG OPTICAL SORTING RESULTS

The Tables, which follow, are all the CRG test work results for the different waste/reef ratio mixes.

Table 27. CRG ROM test results on different waste-reef ratios

Run	Date	Size Range	Setting		Tailings				Concentrate				Feed	Mass Distribution	
			Side 1	Side 2	Total	Reef	Waste	Reef Content	Total	Reef	Waste	Waste Content		Tails	Conc
		[mm]			kg	kg	kg	%	kg	kg	kg	%	kg	%	%
CRG-001/ratio 1:1	09.03.2010	-75+50	3%	3%	480	107	373	22%	819	493	326	40%	1,299	37.0%	63.0%
CRG-002/ratio 1:1	08.05.2009	-75+50	3%	3%	441	124	317	28%	504	336	168	33%	945	46.7%	53.3%
CRG-004/ratio 1:1	08.05.2009	-75+50	6%	6%	580	148	432	26%	725	481	244	34%	1,305	44.4%	55.6%
Total					1,501	379	1,122	25%	2,048	1,310	738	36%	3,549	42.3%	57.7%

Run	Date	Size Range	Setting		Tailings				Concentrate				Feed	Mass Distribution	
			Side 1	Side 2	Total	Reef	Waste	Reef Content	Total	Reef	Waste	Waste Content		Tails	Conc
		[mm]			kg	kg	kg	%	kg	kg	kg	%	kg	%	%
CRG-001/ratio 1:2	09.03.2010	-75+50	5%	5%	541	69	472	13%	645	288	357	55%	1,186	45.6%	54.4%
CRG-002/ratio 1:2	08.05.2009	-75+50	5%	5%	527	90	437	17%	559	266	293	52%	1,086	48.5%	51.5%
Total					1,068	159	909	15%	1,204	554	650	54%	2,272	47.0%	53.0%

Run	Date	Size Range	Setting		Tailings				Concentrate				Feed	Mass Distribution	
			Side 1	Side 2	Total	Reef	Waste	Reef Content	Total	Reef	Waste	Waste Content		Tails	Conc
		[mm]			kg	kg	kg	%	kg	kg	kg	%	kg	%	%
CRG-001/ratio 1:3	09.03.2010	-75+50	6%	6%	399	33	366	8%	496	330	166	33%	895	44.6%	55.4%
CRG-002/ratio 1:3	08.05.2009	-75+50	6%	6%	429	48	381	11%	508	315	193	38%	937	45.8%	54.2%
CRG-003/ratio 1:3	08.05.2009	-75+50	6%	6%	490	63	427	13%	527	303	224	43%	1,017	48.2%	51.8%
CRG-004/ratio 1:3	08.05.2009	-75+50	6%	6%	491	80	411	16%	570	334	236	41%	1,061	46.3%	53.7%
Total					1,809	224	1,585	12%	2,101	1,282	819	39%	3,910	46.3%	53.7%