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OPTICAL SORTING OF WITWATERSRAND GOLD ORES: AN UPDATE – WASTE ROCK DUMP SORTING AT GOLD FIELDS; RUN-OF-MINE SORTING AT CENTRAL RAND GOLD

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ABSTRACT

Automated optical- and radiometric sorting plants treating Witwatersrand gold ore have already been operational in the 1970's and 80's with limited success. 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. Acid mine drainage from these waste dumps are an environmental liability. Ever since the discovery of the Witwatersrand basin in 1886 the mining activities have produced over 1 500 Million Ounces (Moz) of gold from the world's largest gold resource and along with it hundreds of millions tonnes of surface waste rock dumps. These waste dumps contain gold at a grade of between 0.5 g/t to 1.0 g/t.

A pilot plant incorporating screening and optical sorting has proven to recover most gold-bearing rocks which are associated with acid-causing iron pyrites. At today's gold prices such operations are not only economically viable with attractive returns on investment but they also rehabiltate these dump sites.

Mining narrow tabular conglomerate reefs especially those of less than 1m in channel width, it is inevitable that there will always be waste rock diluting the grade of the run of mine ore going to the mill and gold processing plant. A range of cost and processing benefits are achieved by removing waste rock with optical sorting as early as possible in the process stream.

This paper describes two separate gold ore sorting applications: one at Goldfield's Kloof Gold Mine, a waste rock dump application; and the second at Central Rand Gold, a run of mine application. In both cases the the gold-bearing quartz conglomerate reef is separated from waste rock by optical sorting.

INTRODUCTION

Witwatersrand Gold Ores

The origin of the Witwatersrand Basin shown in Figure 1 can best be described as an enormous inland sea with many rivers and braided streams feeding it from its vast margins. Gold deposits in the hinterland are thought to have been eroded by these feeder river systems and the gold essentially dumped into the Witwatersrand sea in the form of pebble bed conglomerates.

Ever since its discovery in 1886 the mining activities have been ongoing for over 120 years. Over 1 500 Million Ounces (M oz) of gold has been produced from the world's largest gold resource.

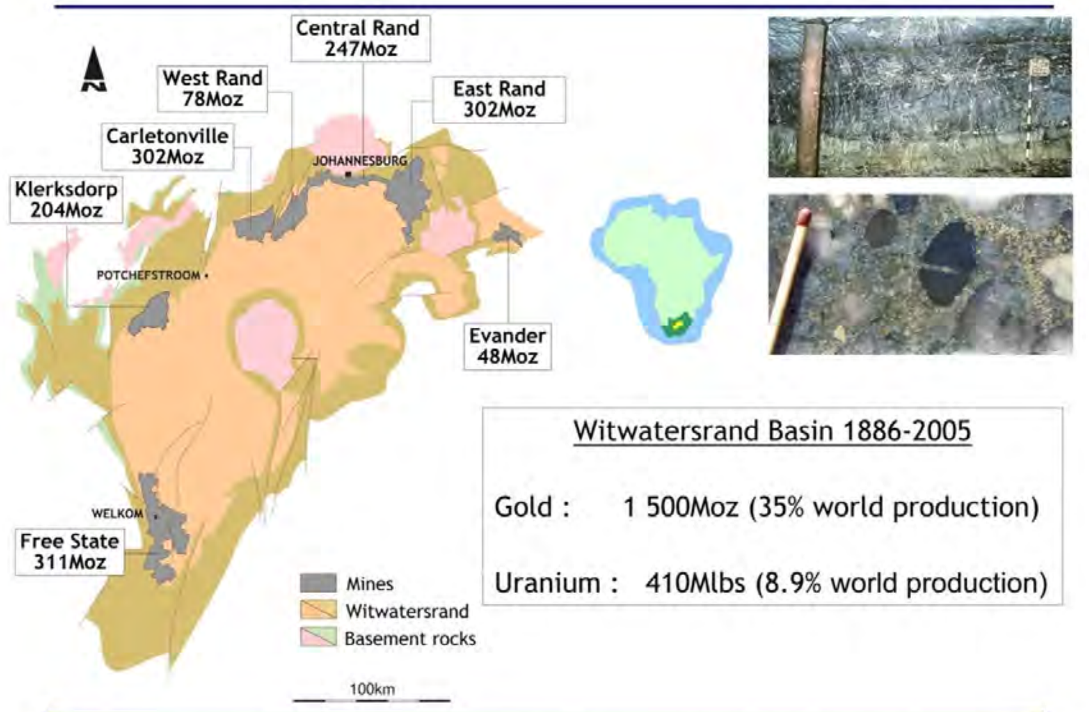

Figure 1: Witwatersrand Basin[1]

The Witwatersrand ore bodies are tabular conglomerate reefs ranging in width from a few centimetres to 3 – 4 meters. Mining narrow reefs especially those of less than 1m in channel width it is inevitable that there 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.

This paper describes two separate gold ore sorting applications; one at Goldfield's Kloof Gold Mine (Kloof) and the second at Central Rand Gold (CRG). In both cases the gold-bearing quartz conglomerate reef is separated from waste rock by optical sorting.

Optical Sorting Technology

The paper "Photometric sorting of ore on a South African gold mine" (Keys N.J., Gordon R.J., Peverett N.F., 1974)[2] describes the first mechanised sorting application on Witwatersrand ores. The Rio Tinto-Zinc (RTZ) Group developed and operated its first full-size photometric sorter pilot plant between 1969 and 1973 on a Gold Fields mine. Ore sorting itself is not a new concept, with hand sorting being one of the first methods of minerals processing. Electronic ore sorting equipment was first produced in the late 1940's (Wills 1992)[3]. "Ore Sorting involves the appraisal of individual particles and the rejection of those particles that do not warrant further treatment" (Wills 1992)[3]. Salter and Wyatt (1991)[4] divided the sorting process into four interactive sub-processes:

- Particle presentation

- Particle examination
- Data analysis
- Particle separation

Feed preparation is more critical for 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. 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, 2006)[5].

The different colour and brightness criteria used in the two gold applications will be described later. The detection and accurate ejection of a particle is shown in the sequence of high-speed camera images in Figure 2. The falling the particle is scanned by two cameras in the detection zone. In this case the image of the gold-bearing particle correlates to the pre-set colour/brightness class of typical gold reef. The high-speed processor thus triggers the correctly positioned selenoid valve/s to deflect the particle with a pulse of compressed air.

Figure 2: Picture sequence showing optical detection and ejection of gold-bearing Witwatersrand ore

The sequence of images shown in Figure 3 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 3: Picture sequence showing ejection of gold-bearing Witwatersrand ore over the sorter's splitter plate

Both Kloof and CRG have installed the CommodasUltrasort PRO Tertiary COLOR Sorter which has a feed presentation by free fall chute and a working width of 1,200mm. Two cameras are installed to detect un-liberated material effectively. To ensure correct feed presentation in a mono-layer a vibrating feeder is included in circuit.

Other components of the sorter are the free fall chute, splitter plate and separation chamber which is protected with heavy duty lining. The matching of the camera and lens system gives highest degree of sharpness and colour depth. The lighting system consists of high powered LEDs which are stabilized with a water cooling system. 224 air valves are installed to separate the reef material from waste. The image in Figure 4 illustrates the PRO Tertiary COLOR sorter.

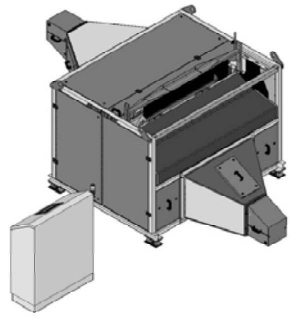

Figure 4: CommodasUltrasort PRO Tertiary COLOR Sorter

GOLD WASTE ROCK DUMP SORTING AT GOLD FIELDS' KLOOF GOLD MINE

Gold Fields

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[6] the South Africa region has a declared attributable resource of 228.3 million ounces which currently accounts for 80 per cent 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.

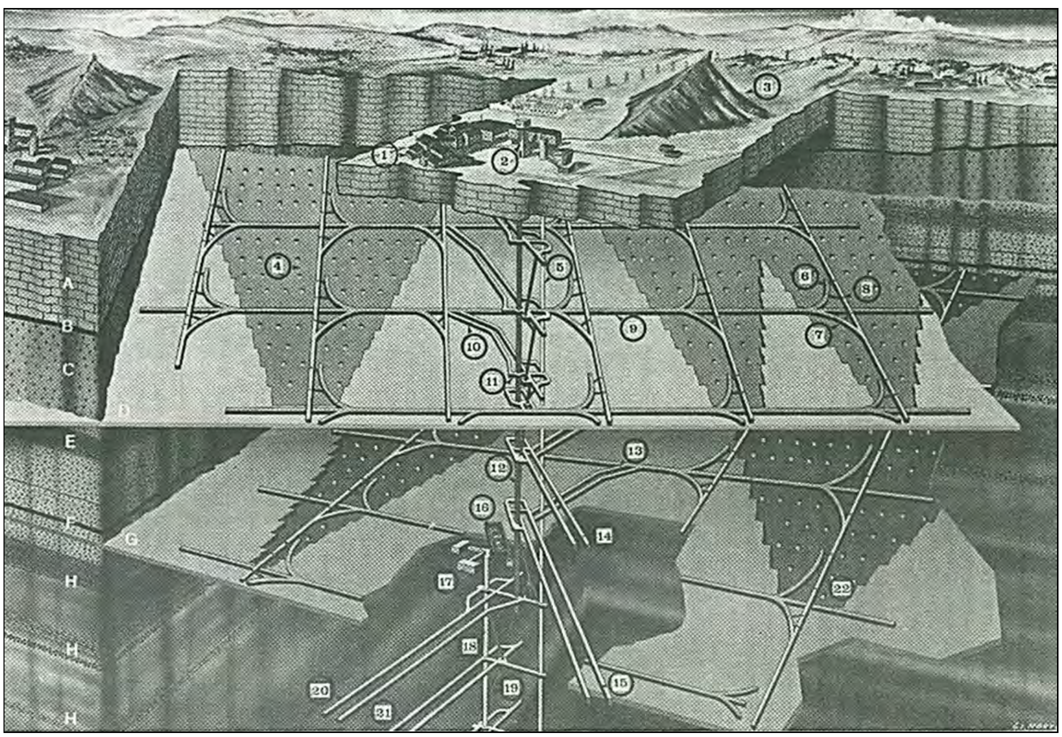

Figure 5 Typical mine on West Wits Line showing: rock formations: (A) Dolomite. (B) Black Reef Series. (C) Ventersdorp Lava. (D) Ventersdorp Contact Reef (VCR). (E) Kimberly Shale[7]

The Kloof Gold Mine, which is located 60 kilometers 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 late summer of its life, it still has a massive 77.9 million ounces of gold Mineral Resources. 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 per cent of the underground Mineral Reserve ounces, the Middelvlei Reef (MR), 11 per cent, and two per cent from the Kloof Reef (KR). The illustration in

Figure 5 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 1 Plant processes surface material while 2 Plant processes underground ore.

Surface Rock Dumps

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 reprocessed through existing operations where surplus capacity exists. At Kloof for example excess capacity at No. 1 Plant is utilized to reprocess SRD material in conjunction with underground ore. With the exception of a pre-screening step as shown in Figure 6 no other upgrading of the 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 SDR 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 ongoing 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 tpm.

The current cost of reprocessing 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 prescreening.

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 6: Typical SRD screening operation using mobile screening equipment

Test Work and Pilot Plant Operation 2003/2004

Intense optical sorting test work and a six month pilot plant operation was done during 2003/2004. The paper "Viability of Optical Sorting of Gold Waste Rock Dumps"[8] describes the test work and the operation of that pilot plant in detail. Some of the most important information from that project which is relevant to this paper is described below:

The various rock type samples found on Kloof's SRD are shown in Figure 7.

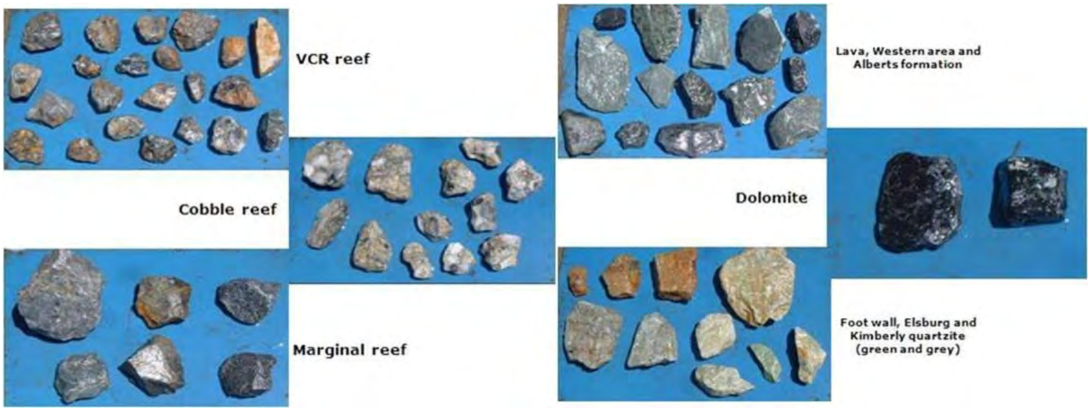

Figure 7: Kloof Gold Mine – gold-bearing reef types and waste rock types

The different gold grades of the seven rock types are shown in Table 1.

Table 1: Gold head grades of the various rock types

Rock types	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

Successful initial test work on a bulk sample proved the potential of this technology for a SRD sorting application. During the period September 2003 to June 2004 a pilot plant (Figure 8) was operated with the primary objective of evaluating the economic viability of optical sorting of the +16mm size fraction that was produced at Kloof's SRD. A sub-contracted screening operation was already in progress on the SRD to recover the -16mm fraction which has sufficient gold content to be processed further by the mine's No. 1 plant. The sorter feed material was the -75mm +16mm fraction. The coarse +75mm size range was discarded as it contained too little gold.

Figure 8: Optical sorter pilot plant at Kloof Gold Mine

During the period of operation a total of close to 110 000 tons was processed through the optical sorter. Some of the gold grade and recovery results are shown in Table 2 below:

Table 2: Operating data – grades and recovery

Period	Head grade (g/t)	Conc Grade (g/t)	Slimes Grade (g/t)	Total product grade (g/t)	Tailings Grade (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 still 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 negligible gold losses and can be discarded or used as aggregate.

Unfortunately in 2004 the low Gold price of about $380/oz made this operation unprofitable and the project was stopped. Over the last 2 to 3 years the price of gold has improved dramatically to levels above $1 400/oz. This has led to the parties re-evaluating these results under current price levels. The results have shown that SDR's can be effectively rehabilitated and gold-bearing reef recovered as a profitable operation.

Test Work 2009

In view of the recent improvement in the gold price Gold Fields embarked on a new series of bulk tests using the latest optical sorting technology. These tests were also conducted to confirm the results achieved during the pilot plant phase in 2003/2004.

A 45t SRD bulk sample was tested at the CommodasUltrasort optical sorting test facility at Mintek shown in Figure 9.

Figure 9: Optical sorting test center at Mintek

To establish the sorter's sorting algorithm for sorting, small samples of coarse and fine dark Reef, light Reef, Lava waste and Quartz waste were scanned in on both cameras in the optical sorter. Examples are shown in Figures 10 and 11.

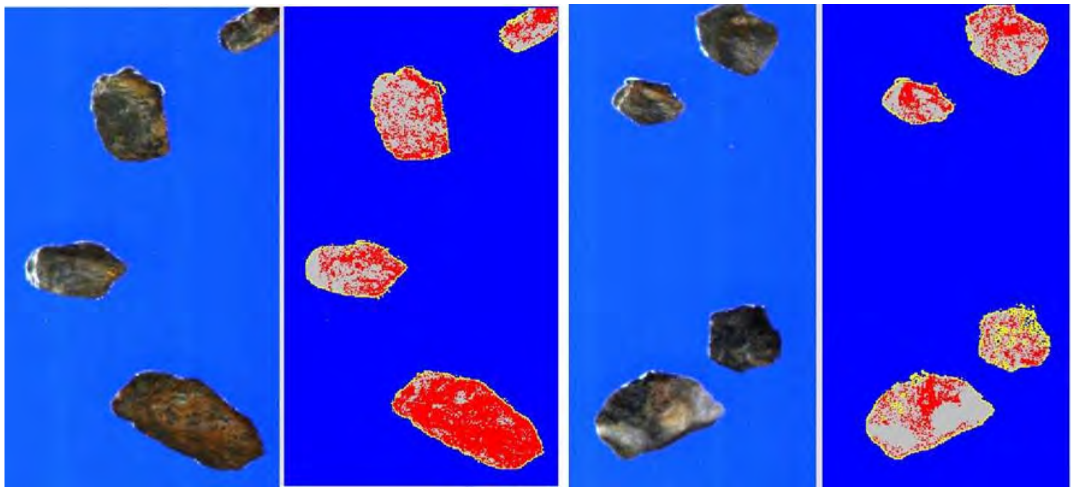

Figure 10: Scanned images of dark reef (left) and light reef (right)

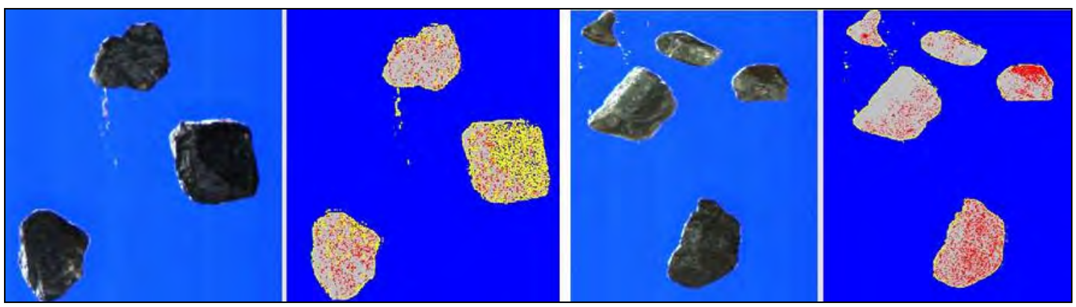

Figure 11: Scanned images of laval waste (left) and quartz waste (right)

After capturing these scanned images a colour model (Figure 12) was established 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.

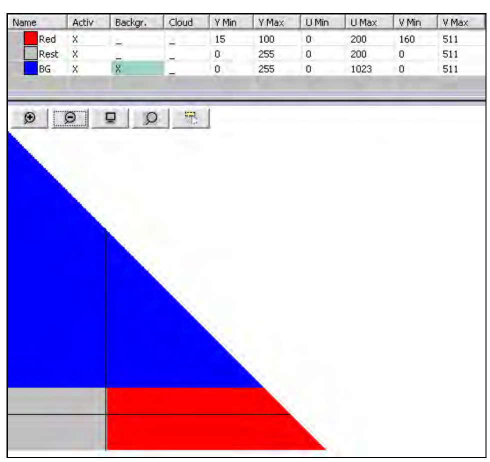

Figure 12: Colour model defining: reef = red; waste=grey; Background=blue

The sample was then fed to the sorter at different settings. The concentrate was defined as having a certain percentage of the “Red” colour class. This percentage for both cameras (Side 1 & Side 2) was varied to produce different mass extractions to concentrate: a high (~30%), a medium (~15%) and a low (~8%) mass extraction.
Table 3 illustrates the combined runs for each size fraction and sorter setting.

Table 3: Kloof bulk test work sorting

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 13 illustrates product grade and recovery in relation to the mass-extractionl.

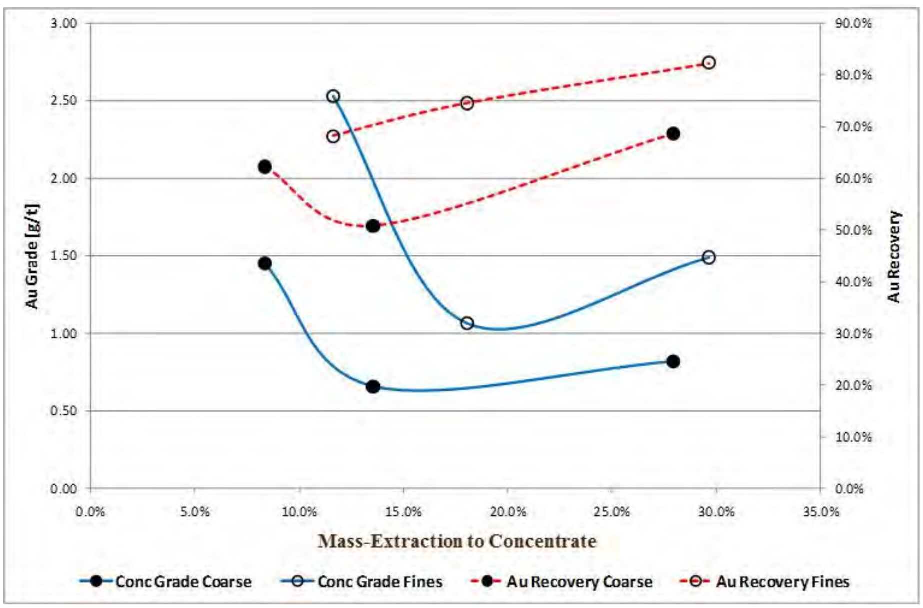

Figure 13: Au grade and recovery vs. mass-extraction

The results correspond to the production data which was 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 grade than the fines. Gold Fields therefore completed a comprehensive size and grade distribution analysis which concluded that the +50mm size fraction contains a gold of less than 0.2g/t. The grade in the size range -50mm +20mm was about 0.4 g/t. On the basis of this grade and the test results, Gold Fields decided to implement optical sorting for the -50 +20mm size range only. The coarse +50mm will either be discarded, used as mill-grinding media or sold as aggregate.

Full-Scale Dump Treatment Plant

Gold Fields has now developed a successful standalone solution to the SRD liability, while being able to generate a substantial return on its investment. The project envisages treating of 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 cashflow and allowing for the ultimate rehabilitation of the former SRD site[9].

The heart of the process is the CommodasUltrasort 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 is shown in Figure 14.

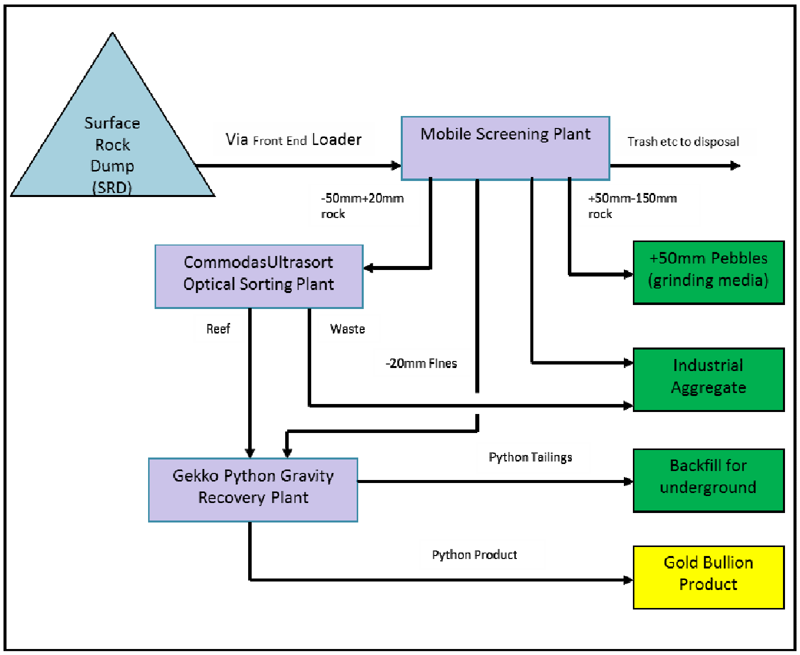

Figure 14: Flow diagram for SRD treatment[9]

The first full-scale production plant was delivered and installed in early 2011. The plant is installed adjacent to the No. 1 plant. The No. 1 Shaft SDR (20 million tons) is in close proximity to the sorter plant will produce the feed material to the plant.

CommodasUltrasort supplied the optical sorter plant consisting (see pictures in Figures 15 and 16) of the following components:

- 2 PRO Tertiary COLOR Sorters (a third Sorter will be supplied after the initial operating phase) including:
    - Dual camera 1,200mm working width sorter
    - Vibrating feeder with dewatering screen deck
    - LED powered lighting
    - Control cabinet with PLC interface
- 5kW extraction fan
- Operating platform, walkways, stairs, railing and grating
- Containerised 75kW compressor station

Other components such as feed bin, conveyors, transfer chutes etc were supplied and installed by different sub-contractors.

Figure 15: Installed optical sorter showing feed arrangement, dust extraction and chiller

Figure 16: Kloof plant showing two parallel optical sorters (third sorter to be installed at later stage)

At the time of writing this paper the sorting plant is still in its commissioning phase. Results on gold recovery and performance are not yet available.

RUN OF MINE SORTING AT CENTRAL RAND GOLD

At the ALTA 2010 conference, the paper "Sensor Based Sorting – Gold Applications"(10) was presented which describes the waste dilution challenges at Central Rand Gold (CRG) in detail. The paper also describes the test work and its results leading to CRG purchasing a containerised optical sorter plant which was installed in early 2011.

This section focuses on the new optical sorting plant and its integration into the CRG process.

Central Rand Gold

Chadwick wrote in an article published in International Mining, January 2011[11]: "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 to undertake a Competent Persons Report which includes optical sorting as part of the overall process[12]. 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 17 and 18 illustrate the geological formations and the gold-bearing reefs that form part of CRG resource.

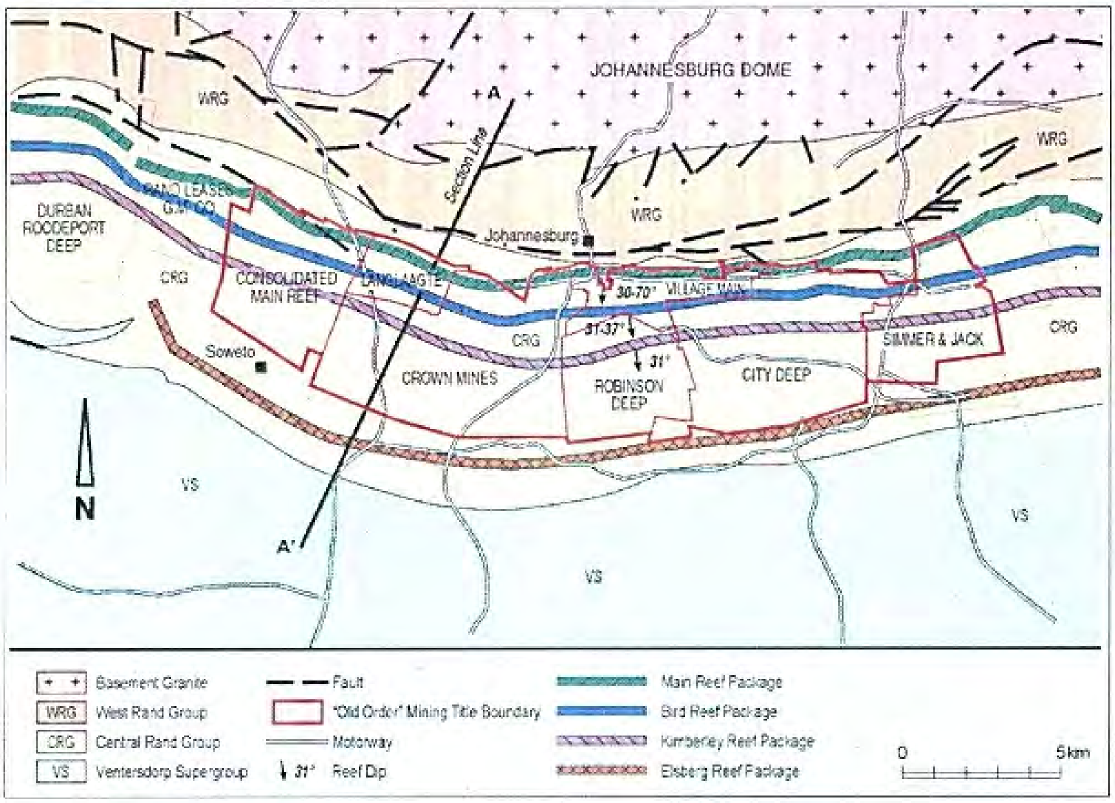

Figure 17: Geological map of the Central Rand project and surrounding area[12]

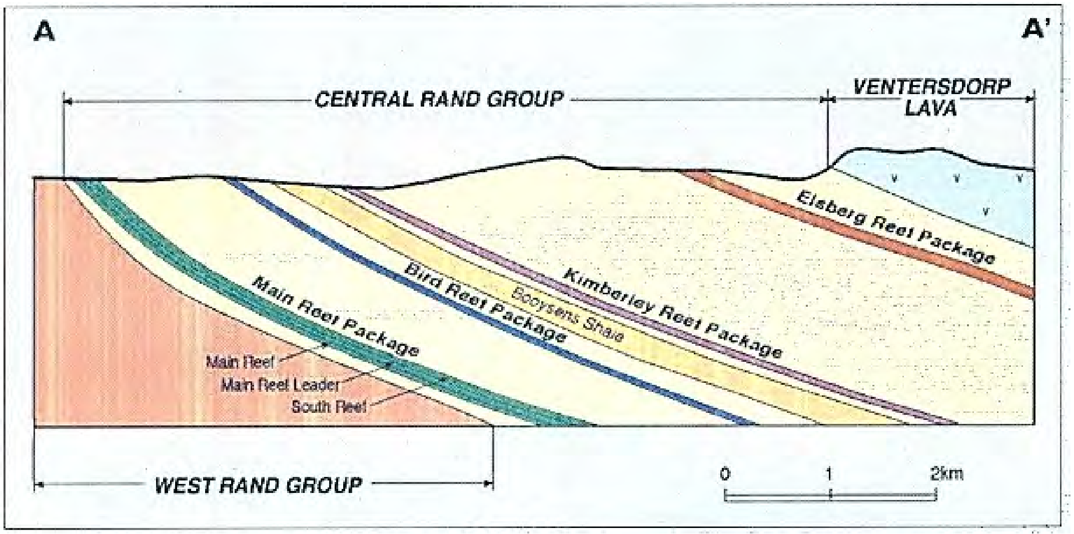

Figure 18: Geological section A-A (see Figure 4) showing the south-dipping quartz-pebble reefs within the Central Rand Group (looking east)[12]

Waste Rock Dilution at Central Rand Gold[13]

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 diagram in Figure 19 shows the MR in relation to the MRL.

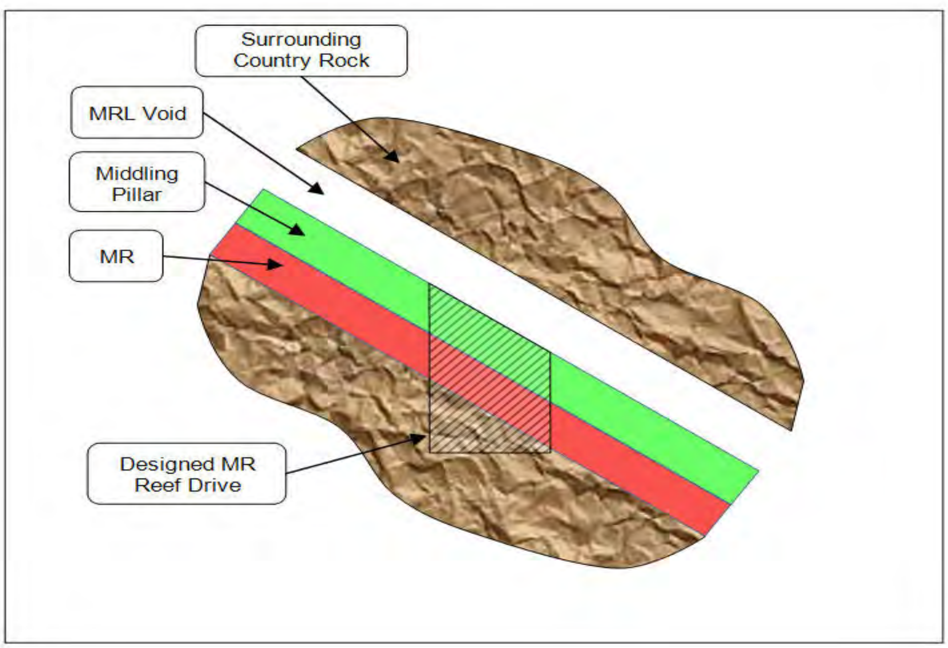

Figure 19: Schematic Diagram of Main Reef (MR) and Main Reef Leader (MRL)[13]

The picture in Figure 20 illustrates the pebble matrix of the Main Reef.

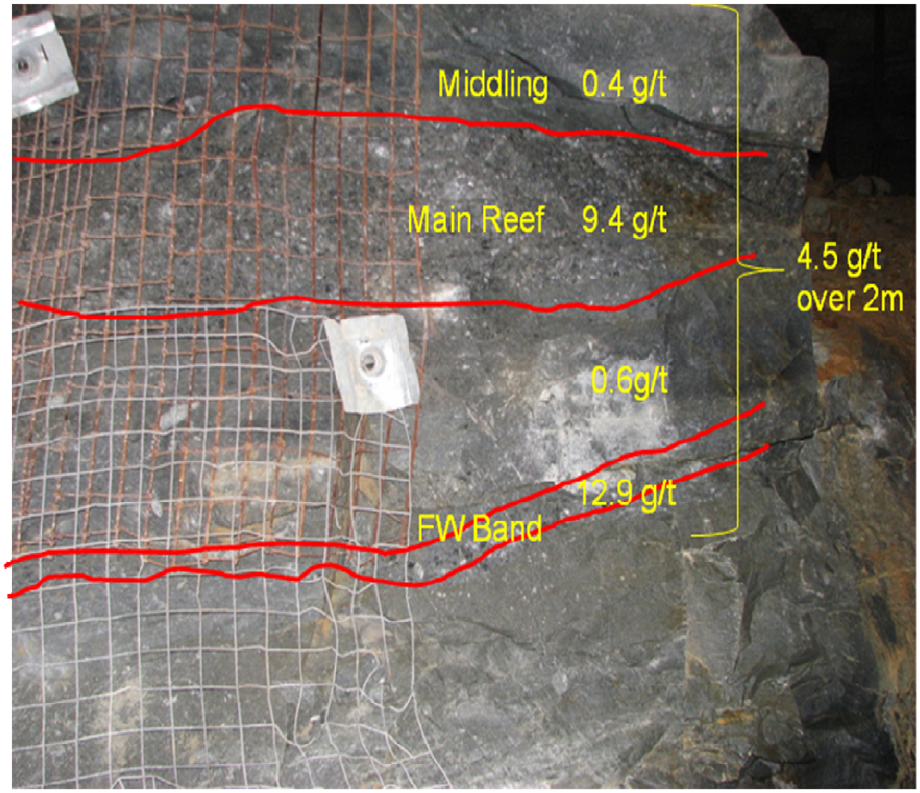

Figure 20: Main Reef[13]

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 provides the required space for the mechanised mining equipment.

Ore Beneficiation at CRG[12]

The Carbon in Pulp (CIP) plant will have a capacity of 250,000 tpa 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. The low-grade diluted run-of-mine (ROM) will be beneficiated in the following manner:

- The ROM is crushed to -75mm.
- The crushed product is screened into -75mm +25mm; -25mm +4mm; -4mm +1mm, and -1mm.
- The -75mm +25mm size fraction is fed (at 50 to 70 tph) to the optical sorter to separate the high grade reef and waste.
- The high grade sorter product is crushed and recycled to the wet screen.
- The low grade barren waste is discarded from the plant and sold as aggregate.
- The -25mm +4mm fraction is crushed to -4mm and recycled to the wet screen.
- The -4mm +1mm size fraction is ground to -250 micron and fed to the flotation plant to upgrade this material which is fed to the CIP plant.
- Tailing from the flotation plant is then dewatered and stored in a tailings dam or deposited in open pits as part of the mine rehabilitation programme or stored underground in allocated voids.

Expected Sorting Results

The CommodasUltrasort containerised sorter shown in Figure 21 has been commissioned during March 2011.

Figure 21: CommodasUltrasort containerised PRO Secondary COLOR sorting plant at CRG

Many areas of the plant are still in the process of being modified and expanded, therefore no continuous operational results can be reported to date. It is expected that the sorter will be fed diluted ore in a ratio of 3:1. The test results in Table 4 show that 85% of the reef is recovered.

Table 4: Optical sorting results of the combined runs for the three mixed 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]
	Concentrate	2,048	1,310	738	64.0%	36.0%	77.6%	57.7%	2.6	4.0	5.2
1:1	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]
	Concentrate	1,204	554	650	46.0%	54.0%	77.7%	53.0%	1.8	4.0	2.2
1:2	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]
	Concentrate	2,101	1,282	819	61.0%	39.0%	85.1%	53.7%	2.4	4.0	5.1
1:3	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

CONCLUSION

Both Central Rand Gold (CRG) and Gold Fields' Kloof Mine are examples of mines facing the challenge of treating low-grade gold deposits and still making it an economically viable operation.

At CRG the nature of their deposit and mining method inherently will have a waste dilution of 3:1. The optical sorting plant will remove most of the waste and double the grade to the mill. Only the gold-bearing reef is now crushed and milled which improves the restricted capacity of the CIP plant.

Gold Fields have launched a project to develop a concept to treat the groups Surface Rock Dumps (SRD). The first plant has been installed and the operation thereof has commenced to prove this standalone solution to deal with the SRD liability, while being able to generate a substantial return on its investment. A key component of this plant is the optical sorter treating the -50mm +20mm run of dump material. The sorting algorithm can be varied to produce different mass-extractions and product grades as required. A mass-extraction of 30% to the concentrate will result in a three-fold grade improvement from 0.5g/t to 1.5g/t with a recovery rate of about 80%.

The mining and mineral processing industry is facing increasing challenges such as lower grade ore reserves, high energy cost, water shortages and increasing environmental legislation. The advanced sensor based sorting technology will provide part of the solution by its ability to remove barren waste from mineral-bearing rock at an early stage in the mineral extraction process.

At CRG and Kloof optical sorting is effectively used to upgrade the mill-feed at minimal losses.

Mill the ounces, not the waste!

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