

The life, death and revival of the central Rand Goldfield

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Introduction

South Africa has produced more than a third of the total gold mined throughout history and remains a major although, until recently, no longer the largest producer of gold. South African gold production peaked in 1970 with an output of 1 000 t, a major component of the western world's gold production, with the development of the country's economy having been based largely on this mineral wealth. The costs and difficulties of increasingly deep-level mining, coupled with increasing labour costs and the low gold price until relatively recently, have seen production fall steadily since then, with the closure of many mines including those of the Central Rand Goldfield in the mid seventies. Thus in 1998, only 464 t were produced, with 342 tons being produced in 2004. In 2006, 275 tons of gold were produced and after more than 100 years was the last year as the world's largest gold producer. In 2008 gold production was 221 tons, making South Africa the third largest gold producer after China (292 t) and the USA (234 t).

Gold production would have been lower if it had not been for massive tailings dam retreatment operations that started in the late seventies, including in the Central Rand Goldfield. Mining of a remaining deep and lower grade shallow resources has now also become a major focus and has recently lead to a rebirth of reef mining on the Central Rand Goldfield.

Gold in the Witwatersrand basin

South Africa's gold production is centred overwhelmingly on the Witwatersrand Basin, a 350 km arcuate basin that stretches to the east and west of Johannesburg, and southwards into the Free State, and which comprises seven major discrete gold fields (Figure 1).

The gold (and uranium) deposits of the Witwatersrand Basin (Figure 1) form one of the greatest metallogenic provinces of the world with more than 98 per cent of the primary gold recovered in South Africa having been won from mining operations in the Basin. After more than 122 years of mining in the Basin, following the discovery of gold on the farm Langlaagte (immediately to the SW of the city of Johannesburg) in 1886, over 50 000 t of the precious metal have been recovered from generally narrow (1 m thick) gold-bearing pebble layers (conglomerate reefs) within the Witwatersrand Basin from depths down to 4 000 m (Figures 1 to 4). Remarkably, the Witwatersrand Gold Field probably still contains about 35 000 tons of gold or almost 45 per cent of the world's known gold resources. This resource is still six times that of the resource contained in the world's second largest gold field. Challenges, however, face the gold mining industry with most of the gold resource being at depths between 2.5 and 5 km with the remaining shallow resources being of lower grade (Figure 1). This applies also to the Central Rand goldfield.

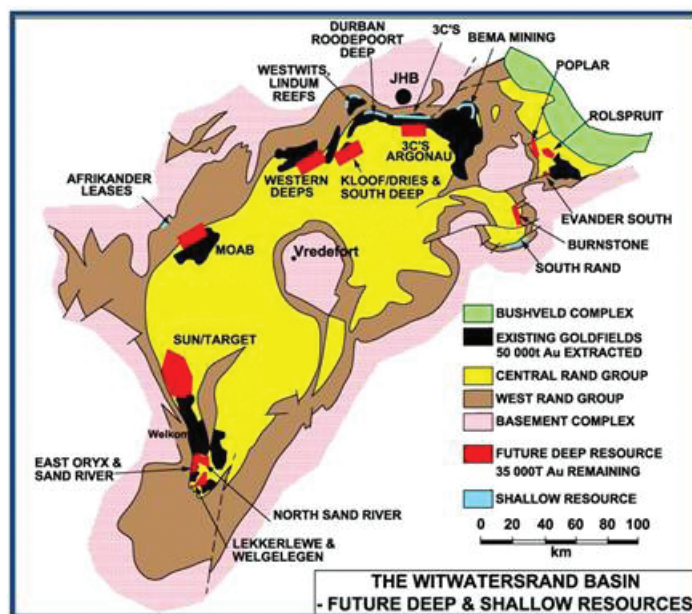


Figure 1. Major geological features of the Witwatersrand basin stripped of younger cover and showing major goldfields and main remaining deep and shallow gold resource

Geology of the Witwatersrand Basin

The Witwatersrand Basin is underlain by an Archaean granite-greenstone Basement dated at greater than 3 100 million years and is overlain, unconformably, by rocks of the Ventersdorp Group of lavas and sediments dated at 2 700 million years. Younger Transvaal (2600 Ma) and Karoo (280 Ma) Supergroups overlie the above. The lowermost West Rand Group, which forms the lower part of the Witwatersrand sedimentary successions, consists largely of quartzite and shale (Figure 2).

The Central Rand Group, which hosts the gold mineralization, unconformably overlies the West Rand Group and attains a maximum thickness of 2880 m. In the Vredefort area the domical structure in the centre of the basin is thought to have been caused by a meteorite strike at about 2 000 million years ago (Figure 1). The Central Rand Group lithologies are characterized by quartzite and conglomerate which dominate over shale. Gold-bearing conglomerates dominated in the lower part of the Central Rand Group succession where they are associated with basin wide unconformities (Pretorius, 1976) (Figures 5 and 6).

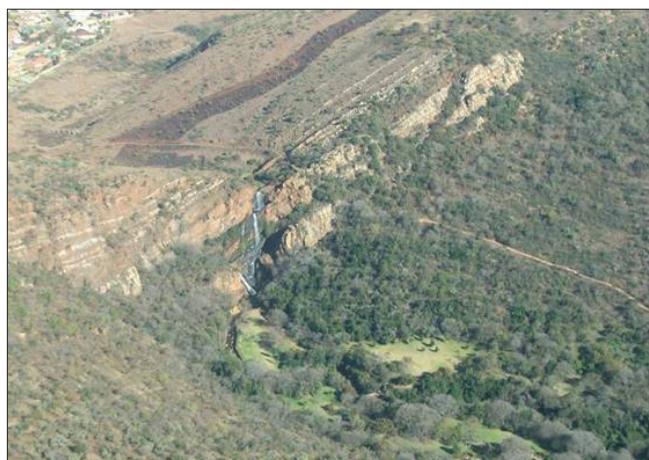


Figure 2. The Witwatersrand (White ridge of Waters) as epitomized by the Orange Grove quartzite at the base of the basin and the Witpoortjie waterfall



Figure 3. Discovery site of the Main Reef and Main Reef Leader reefs at Langlaagte, shortly after discovery in 1886 and as it is today

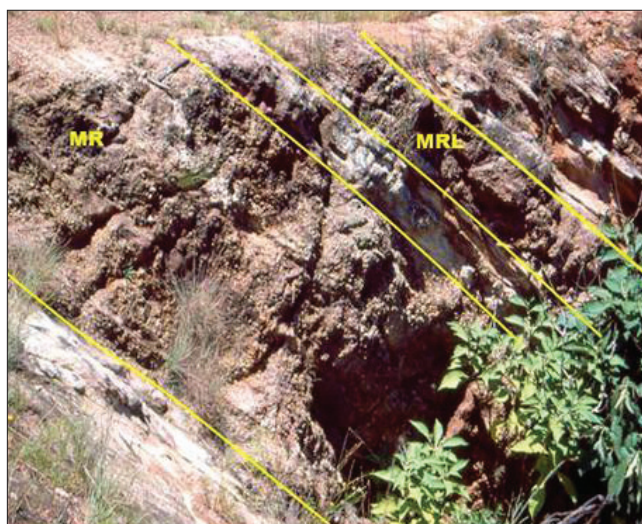


Figure 4. Outcrop of the Main Reef and Main Reef Leader reefs at the discovery site

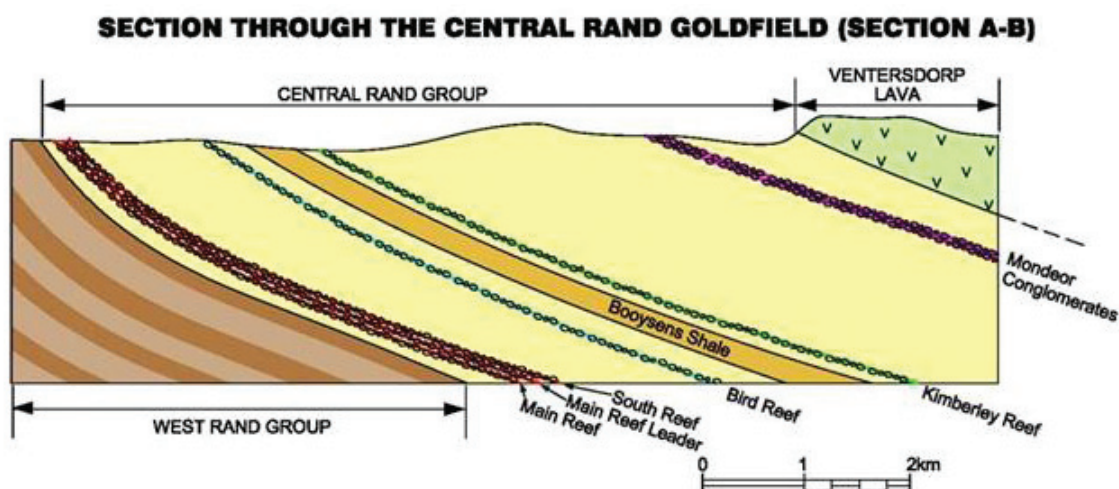


Figure 5. Geological section through the gold-bearing conglomerates of the Central Rand Group

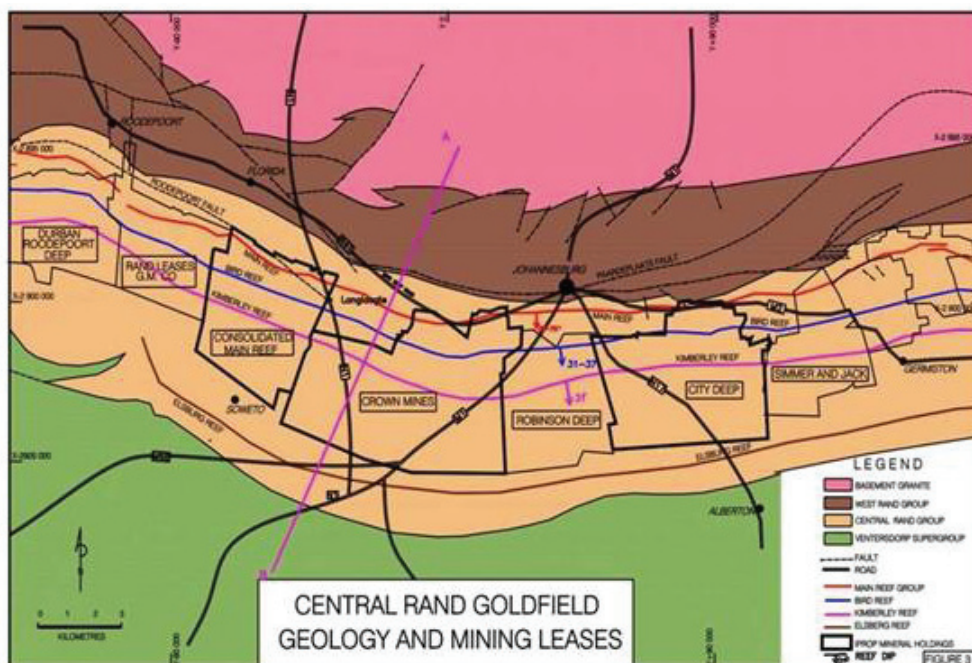


Figure 6. Geology of the Central Rand showing position of main gold-bearing conglomerates and mining lease areas

Discovery of gold and the early history of the Central Rand

The discovery of the Central Rand goldfield and the Witwatersrand goldfield was made in 1886 by prospectors George Harrison and George Walker (Figure 3). Before this time there was considerable prospecting and mining activity in the region but this was mainly focused on traditional gold-bearing quartz vein lode deposits and shear zones in Basement, Witwatersrand and Transvaal basin rocks. Examples include the Confidence Reef mine on the Rietfontein fault and Kromdraai and Blaauwbank Mines. The presence of gold in conglomerates had been made earlier by the Struben brothers but the discovery of the economically important Main Reef and Main Reef Leader on the farm Langlaagte, goes to Harrison and Walker.

The first phase of activity on the Witwatersrand goldfield consisted of individual prospectors and diggers working for their own account or in small partnerships. The Ferreira Company Syndicate formed in 1887 by Col. Ignatius Ferreira, C. Hanan and the Barber brothers (after whom the town of Barberton was named) mined from outcrop immediately south of the city of Johannesburg, is an example of one of these. They produced 365 ounces of gold during the first year of operation and one of the old Ferreira mine stopes is still preserved as a museum of early mining in the basement of the new Standard Bank Building, 5 Simmonds Street Johannesburg. The second phase was followed by the first of two consolidation periods in which individual or small consortium ownership gave way to amalgamation and the listing of joint stock companies as a means of raising the capital necessary for further intensive development of the mining field. This created a very lively trade in claims and shares and the formation of an open air street Stock Exchange in an area cordoned off by chains.

The earliest mining activities were concentrated along and adjacent to the outcrop, but drilling proved that the reefs extended not only over a great strike length, but also down-dip, with their gold values persisting. An early death

of the fledgling goldfield loomed in the late eighteen eighties when it became evident that gold could not be extracted from unoxidized ore below about 35 m. In 1890, however, MacArthur-Forrest discovered the cyanidation process which successfully overcame the problems of treating the refractory pyritic ore from deeper levels and gave a huge boost to the goldfield. The major companies, headed by Eckstein's Corner House and Rhodes and Rudd's Gold Fields of South Africa, as well as others as documented for example by Lang 1986 and Handley 2004, began to acquire large blocks of ground some distance south of the outcrop where the reef lay at depth. Confidence in the continuity of reefs at depth was afforded by the drilling of a number of pioneering deep boreholes. The first relatively deep exploration borehole, drilled by the American geologist J.S. Curtis at the Village Main Reef Mine in 1890, intersected the Main Reef at a depth of 177 m. Several others followed, the most ambitious of which was the Turffontein East borehole, drilled in 1901. Situated more than 2.5 km south of the outcrop, it intersected the reef at a vertical depth of 1 489 m, an engineering feat unparalleled at the time.

Based on the remarkable lateral as well as depth continuity of the reefs, numerous incline and then vertical shafts were sunk. Ultimately, there were three generations of deep-level shafts sunk from surface to exploit the reefs at ever-increasing depths, the earliest ones being wooden framed. The third generation 14 shaft of Crown mines now facilitates the underground tourist visit at Gold Reef City which showcases the story of gold and the city of Johannesburg, South Africa's premier city, founded on the Central Rand goldfield (Figure 7).

Conglomerate reefs

The three principal auriferous conglomerate units in the Central Rand Gold Field are the Main Reef, Main Reef Leader and South Reef, which occur at the base of the Johannesburg Subgroup (Figure 5). The overlying Bird and

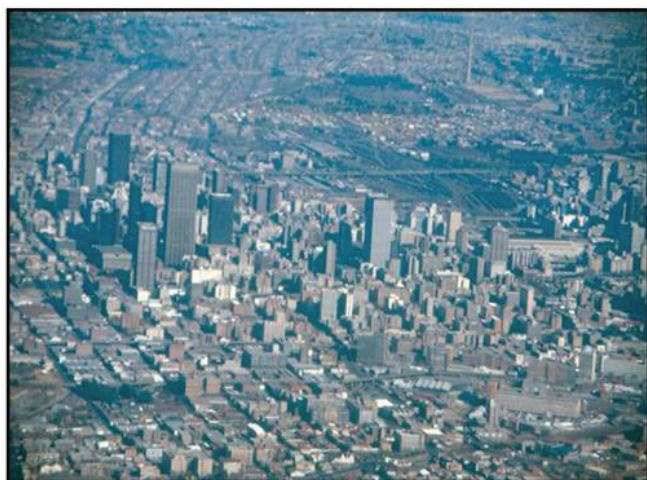


Figure 7. City of Johannesburg, South Africa's premier city, founded on the Central Rand goldfield

Kimberley reef were also locally important and thus up to 5 major conglomerate layers were mined at various places at various times on the Central Rand. The lowermost Main Reef is generally a poorly sorted conglomerate with pebbles typically up to 5 cm in diameter, with occasional boulder-filled channels. The overlying Main Reef Leader was the most prolific gold producer on the Central Rand. It is relatively thin, averaging about 40 cm in thickness but often containing grades above 50 g/t. It is better sorted and graded than the Main Reef, with pebbles on average being coarser, up to 8 mm in diameter. The reef is often dark in colour, due mainly to chlorite in the footwall. The South Reef is the most persistent of the conglomerate layers, but is slightly lower grade than the Main Reef Leader. It is less well sorted than the other two reefs and generally occurs as a number of individual pebble bands with arenaceous partings.

Most of the gold in the Central Rand reefs occurs as submicroscopic crystalline grains within pyrite, the latter being in part of detrital origin. A smaller, but indeterminate proportion of gold occurs as rounded or flattened flakes, of a detrital nature. Nevertheless, a crude correlation exists between the degree of pebble sorting/packing and the overall gold grade, suggesting that sedimentological parameters played a role in the original concentration of gold. Redistribution of gold is also suggested.

Mining methods used

The generally narrow reefs and hence narrow mining widths, availability of cheap labour, moderate dip of the reefs and great depths of most mines, led to the development of a very specific mining method, known as breast stoping on the Central Rand and Witwatersrand Basin in general (Figure 8). In this method, development is kept in the footwall of the reef and a raise is cut between ends. From this raise gullies are cut at a 45° angle to the raise and the stope developed in a Christmas tree manner. The stopes advance by jackleg drilling and blasting of a 2 m length of stope on each shift. Ore is scraped out from the advancing face along the gully using mechanical scrapers and the stope is cleaned carefully, often using high pressure jets, as much gold is contained in fines in the cracks in the

floor of the stope. The scraper transfers the ore to footwall boxholes whence it is trammed to the main ore pass and the primary underground crusher. If the stope takes in more than one level then it is known as a longwall. The hangingwall of the advancing stope is supported by hydraulic props, later reinforced by timber packs.

Mechanized mining of narrow stopes is not easy and mechanization has been most successful in wide stopes, such as those in the Elsburg reefs on the West Rand, which are often 2 m or thicker.

A major consideration at great depths is rock stability. The quartzites have considerable strength and deform in a brittle manner, causing rockbursts (explosive disintegration of rock). These events cause disruption to production and are a major cause of fatal accidents. Rockburst frequency can be reduced by backfilling of stopes and careful monitoring of stress build-ups.

Crown mines

Crown Mines Limited, the flagship of the Central Rand Mine was founded in 1909 by the amalgamation of seven existing mining properties, including the original Crown and Robinson Mines. It was for many years the world's largest single producer of gold. The surface area of the property covered more than 42 square kilometers, and over 1 600 km of underground development were excavated. When mining ceased in 1977, the deepest workings extended to 3 000 m below surface, and 6.2 km down dip on the Main Reef Leader. During its life, the mine produced more than 1 400 tons of gold.

It has been estimated that from the start of operation in 1886 to 1993, a total of 7 617 t (245 Moz) of gold was produced from the Central Rand Goldfield (Sanders *et al.*, 1994), although production may have been considerably more probably up to 300 Moz if early unrecorded sources are included.

In the early 1960s there were still 8 large operating mines in the Central Rand, including Durban Roodepoort Deep, Rand Leases, Crown Mines, Robinson Deep, Consolidated Main Reef Mines and Estates, Village Main Reef, City Deep and Simmer and Jack, as well as at least a dozen small workings (Pretorius, 1964) (Figure 6). Most of these mines ceased operation in the mid to late 1970s with a substantial deep resource and relatively low grade shallow resource still in place.

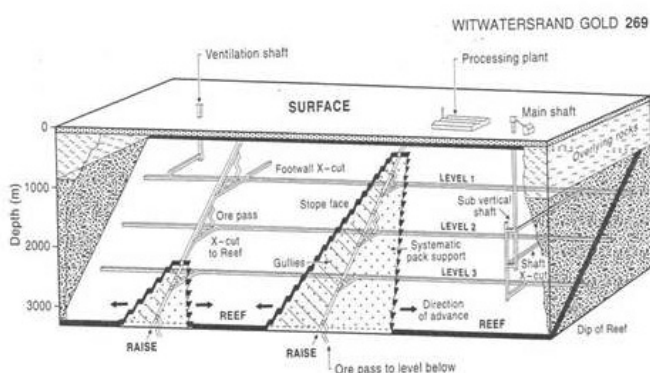


Figure 8. Mining method used for extracting narrow reef Witwatersrand conglomerate reefs

Reclamation of gold-bearing tailings dumps

Towards the end of the seventies at about the time of the Central Rand Mine closures it was realized that a valuable resource of gold and other commodities was present in the tailings dumps of the Witwatersrand mines and in 1978 the East Rand Gold company (ERGO) started producing gold, uranium and pyrite from re-treated dumps. A similar programme of gold recovery commenced at about the same time on the Central Rand on slimes dams averaging about 0.4 g/t gold and sand dumps averaging about 0.6 g/t (Figures 9 and 10). This process, which is ongoing, was made possible because of a somewhat higher gold price and improved extraction technology such as the use of the carbon in leach and carbon in resin processes. Mining of gold tailings dams is both profitable and removes a major environmental hazard as tailings from reprocessing are consolidated onto 3 low grade existing dumps with tailings being be disposed of in accordance with present environmental standards. In the Central Rand, processing plants are situated on Crown Mines and City Deep and roughly 350 kg of gold is produced monthly from about 480 000 t/m comprising 360 000 t sand and 120 000 tons of slimes. Disposal takes place on 3 large, low grade dumps straddling the N1 highway on Crown Mines in the Soweto area.

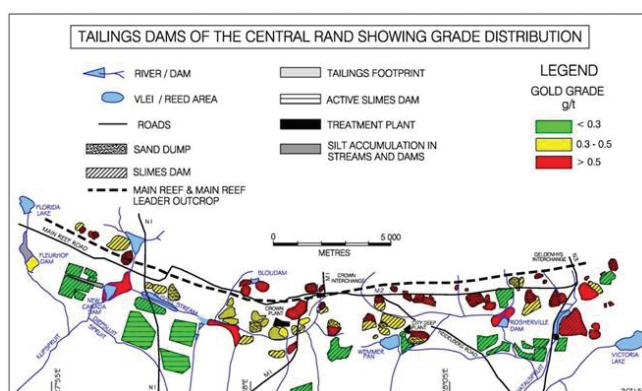


Figure 9. Gold values in tailings dams of the Central Rand

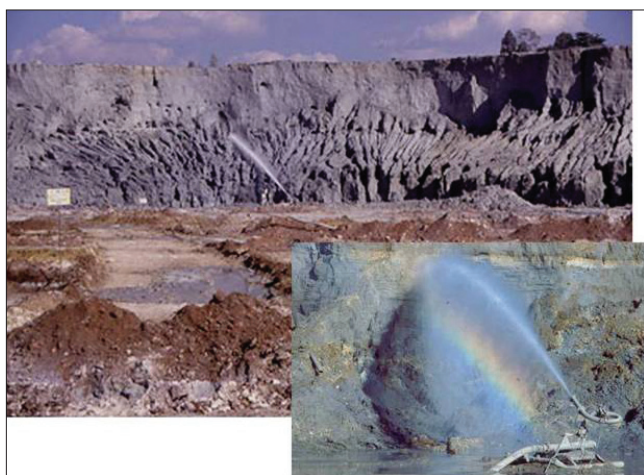


Figure 10. Reclamation of a slimes dam by water jet monitoring

Environmental impacts of mining on the Central Rand

Mining activities on the Central Rand goldfield in the past have left a legacy which has negatively affected the surrounding environment and nearby communities. Virtually all mining on the Central Rand has been underground with surface features including infrastructure in the form of shaft complexes, processing plant and residential development. Impacts have included ground sterilization and building restrictions on shallow undermined areas. Rock dumps have been created from waste rock. The above have had same impact, but by far the most important environmental impact has been the generation of numerous large slimes dams and sand dumps. Due to original inadequate design, subsequent poor management, neglect or present activity (status), these have been subjected to varying degrees of water and wind erosion, which have resulted in widespread pollution. The Central Rand area just south of Johannesburg is one of the areas most directly affected by the impact of mine tailings due to their age, high population densities and commercial developments in their vicinities as well as the presence of numerous streams of the upper Kliprivier catchment.

Dust was a major problem on the Central Rand until the early sixties after which time most tailings dumps had been completely covered by vegetation following a very successful programme initiated by the Chamber of Mines which largely solved the dust problem.

Due to earlier wind and water erosion as well as oxidating of the contained pyrite and other sulphides in the tailings, extensive pollution of the upper headwater streams and dams of the Kliprivier drainage has taken place from the earliest days of mining. Water quality studies now show widespread AMD, high salt loads and heavy metal contamination throughout the area.

Re-exposure of dumps during reprocessing as well as sites of deposition, have reactivated the dust and water pollution problems. Of particular concern to local communities is the resurgence of dust pollution. Dust fallout from active dumps is of particular concern to local communities living close to tailings dams, especially where no or inadequate mitigation measures have been applied to mine tailings management.

After reclamation of a tailings dam, bare soil with variable amounts of remnant tailings, often remains on the footprint. As a result of oxidation of this material, footprints invariably generate AMD in the form of ferrous and ferric sulphates as well as iron hydroxides and phytotoxic heavy metals such as Co, Ni, Cu and Zn. Paddocks are normally laid out on the footprints to prevent possible water run-off to the surrounding environment. Liming is applied where vegetation cover can be established. Once a proper clean-up has been undertaken, tailings footprints become valuable sites for a range of property developments (Figure 11).

Remaining deep and lower grade shallow gold resource

As a result of a number of studies carried out since the closure of the Central Rand mines and in particular studies carried out at the University of the Witwatersrand over the last 10 years, a substantial remaining gold resource has been defined in the defunct Central Rand Goldfield. The mining of this resource has lead to the rebirth of the goldfield where mining first began 123 years ago.



Figure 11. Central Rand area with tailings dump footprints

From old assay plans, a large amount of data for reef thickness in centimetres, together with percentage internal quartzite, gold values in g/t and gold content in cm g/t, were used as the basis for reef modelling of the Main Reef Leader, Main Reef, Bird Reef and Kimberley reefs.

From these data, the main channels which carried sediment into the depositional basin to form the various conglomerate reefs (reflected by areas of thicker reef and a greater amount of internal quartzite) were delineated. Interpretations showed that in many instances, gold was concentrated both within, and more particularly, on the edges of the palaeo-channels in better sorted and reworked regions. The presence of such higher grade zones or paystreaks is a feature recognized and documented by Reynecke in 1927 but apparently never used for production planning purposes on the Central Rand

From the modelling of the Main Reef Leader three main entry points emerged, and these fed sediment into the Central Rand depositional basin to form large, coalescing fans that now constitute the Main Reef Leader. Twelve discrete channels with associated ore shoots have been defined with a major cluster emanating from an entry point (feeder site), on the north side of the Robinson Deep (now Village Main) mine, and extending to the southwest, south and southeast. The most robust channel on the Main Reef Leader trends to the southeast of the major central entry point and is persistent for a considerable distance (over 6 km) down dip. Two subsidiary entry points were also defined, one on CMR and one on Simmer and Jack mines (Figure 12) Structural features also appear to have had some control on the SE trending channels and payshoots in particular. A sedimentological model was thus created on which an evaluation could be based and this revealed the presence of a remaining multimillion ounce gold resource on the Main Reef Leader. (Viljoen *et al.*, 1998 and Viljoen and Viljoen, 2004). Other sedimentological parameters support the positions of the main and secondary entry points of reef material for the Main Reef Leader.

Similar studies were carried out on the other lower grade reefs of the Central Rand including the Main Reef which Bird Reef and Kimberley Reefs, which are more channelized and lower grade than the Main Reef Leader. A major ESE trending ore shoot on the Main Reef is present on Rand Leases and extends through the lower levels of CMR and Crown Mines. A major SW trending ore shoot extends across the northern part of City Deep and onto Robinson Deep. It appears to be closely associated with a well bedded pyritic quartzite footwall channel which is also

goldbearing. Numerous generally smaller, N-S trending ore shoots are present in shallower areas across the whole Central Rand (Viljoen and Viljoen, 2004).

It was concluded that modelling of Witwatersrand ore shoots based on old mine plans is possible and gives a good indication of the size, content and direction of the main distributory channels as well as of the extent and gold content of associated ore shoots. The portrayal of the ore shoot patterns in relation to stoped areas has shown the location of a considerable remaining resource of potentially mineable gold. The exercise has thus added huge value to historical mine data of otherwise limited use and has revived interest in a final phase of both opencast and underground mining of a multi-million ounce gold resource on the Central Rand Goldfield.

An old decline shaft on the Kimberley Reef on Crown Mines shown in Figure 13; examples of ore shoot modelling on the Kimberley Reef and Main Reef are shown in Figures 14 to 16.

Rebirth of mining on the Central Rand Goldfield

Based on the resource modelling and portrayal of remaining gold value distribution patterns discussed above, a company called Rand Quest Syndicate started acquiring mineral rights to the whole Central Rand area in 2004. Further

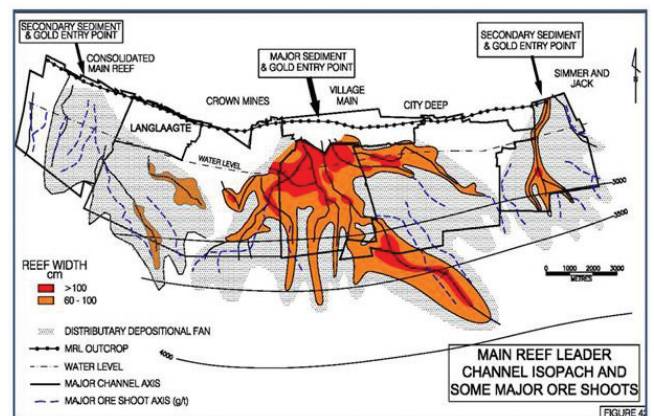


Figure 12. Sedimentary channels and related ore shoots on the Main Reef Leader of the Central Rand

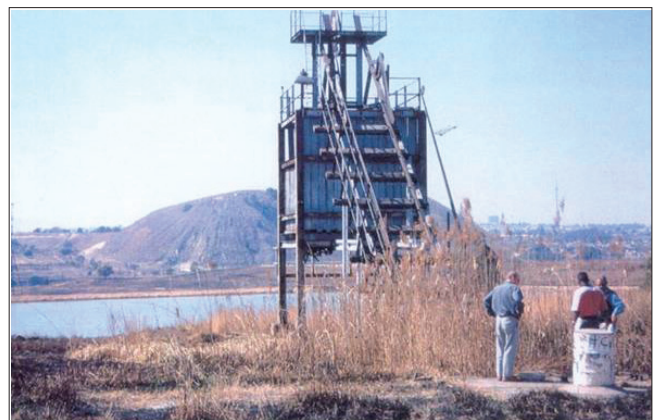


Figure 13. Old decline shaft on the Kimberley Reef on Crown Mines

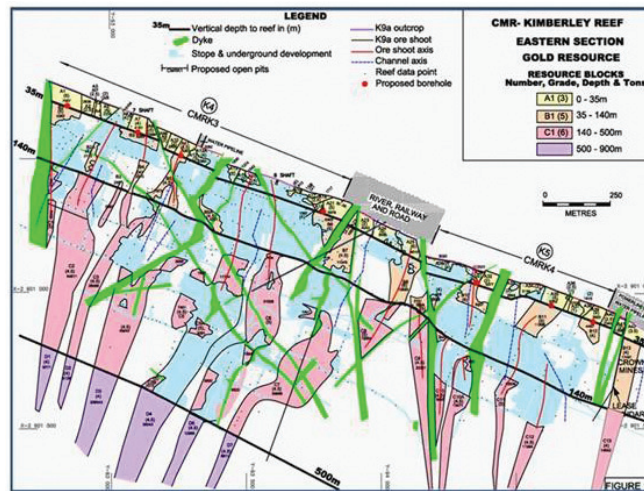


Figure 14. Modelling of ore shoot on the Kimberley Reef on CMR mine

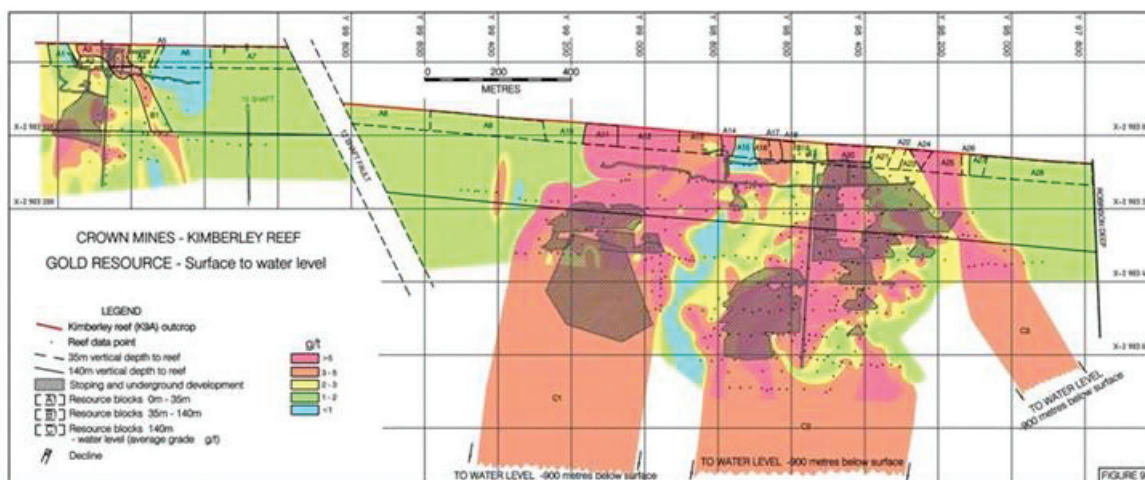


Figure 15. Modelling of ore shoots on the Kimberley Reef on Crown Mines at Gold Reef City

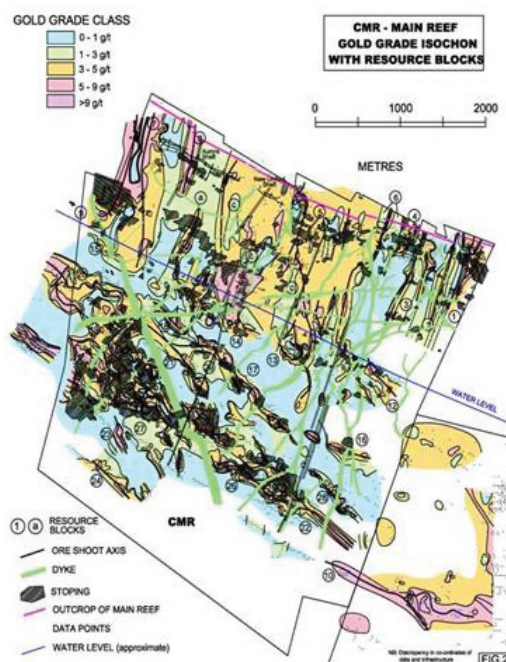


Figure 16. Modelling of ore shoots in relation to stoping on the Main Reef of CMR in the area where mining operations of Central Rand Gold have commenced

evaluation followed by exploration drilling took place and a project area 40 km in length and extending from west of CMR through CMR, Crown Mines Langlaagte Village Main, Robinson Reefs, City Deep and Simmer and Jack lease areas was amalgamated. Based on these assets and projected remaining gold resource, a company called Central Rand Gold was listed in November 2007 on the London and Johannesburg stock exchange. Further drilling and trenching leading to trial mining and metallurgical testing took place and continues at present. An example of shallow open pit mining of the Kimberley Reef on Lindum Reefs Mine on the West Rand is given in Figure 17.

A decline on CMR to exploit the Main Reef should allow for reef development to start shortly and to test the proposed mining and metallurgical methodologies. Mining will combine narrow reef mining practices with high productivity mechanized mining methods and will focus initially on accessing higher grade ore shoots. In the metallurgical process use will be made of a gravity concentrator flotation cells to produce a flotation to recover the gravity recoverable gold with the concentrate tail passing through concentrate. The two concentrate streams will be processed in a carbon-in-leach circuit to recover the gold by electrowinning and smelting. After appropriate cyanide neutralization, flotation and C/L tailings will be disposed of in the underground voids.

Should the planned mining and metallurgical methodology prove to be successful, production will be stepped up to exploit the huge low to medium grade gold resource that is still present on the Central Rand Goldfield and a rebirth of one of the world's greatest gold fields will have taken place 123 year after mining began and roughly 30 years since large scale underground mining ceased.

References

- CAMDEN-SMITH, P.M. The Geology and Valuation of the Main Reef on Crown Mines. Unpublished company report. 1993.
- HANDLEY, J.R.F. *Historic Overview of the Witwatersrand Goldfields*. Handley, Howick. 2004.
- LANG, J. Bullion Johannesburg. Jonathan Ball Pub. 1986.



Figure 17. Example of successful shallow, open pit mining at the Kimberley Reefs of Lindum Reefs Mine on the West Rand

- PRETORIUS, D.A. Gold and uranium in quartz pebble conglomerates. *Economic Geology 75th anniversary* vol. 1981. p. 117–138.
- REINECKE, L. The location of payable ore bodies in the Gold-bearing Reefs of the Witwatersrand, *Trans. Geol. Soc. S. Afri.* vol. 30, 1927. pp. 89–120.
- VILJOEN, R.P. Petrographic and Mineragraphic Aspects of the Main Reef and Main Reef Leader of the Main Bird Series. Witwatersrand System. unpubl. MSc thesis. Univ. of the Witwatersrand. 1963. 193 pp.
- VILJOEN M.J., VILJOEN, R.P., and ZHAO, B. Evaluation of a Remaining Gold Resource on the 3C's Mines, Central Rand. Unpub. Report. 1998.
- VILJOEN, M.J. and VILJOEN, R.P. Sedimentary Distributory Channels and Payshoots of the Conglomerate Reefs of the Central Rand Goldfield. Unpub. Report. 2004.



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Morris Viljoen is an emeritus professor of mining geology in the School of Geosciences at the University of the Witwatersrand. After a career in exploration and mining geology with JCI, he was appointed to the Chair of Mining Geology at Wits in 1991, a position he retired from in 2003. He has wide interests ranging from gold, platinum and base metal deposit geology, to remote sensing environmental geology and geoheritage and he has authored or co-authored over 60 papers on these topics.

While at Wits, he started a project together with Professor Richard Viljoen and students, of modeling and re-evaluation of the remaining gold resource in the defunct Central Rand Goldfield, making use of old mine plans. This study attracted attention of investors and in November 2007, led to the listing of The Central Rand Gold Company on the London and Johannesburg stock exchanges and the re-birth of reef mining, where the greatest goldfield on earth was discovered 123 years ago.