Rehabilitation of Tailings Dams on the Central Rand; Johannesburg

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Abstract

Underground mining on the Central Rand goldfield of the Witwatersrand basin south of Johannesburg has led to a number of environmental impacts of which the establishment of tailings dams is the most important. These mining residue deposits are impacting negatively on the environment and on social and economic development of the area. This is because of pollution and sterilization of land covered by the tailings dams. Different technologies have been used to ameliorate the impact of the huge volumes of tailings material. Of these, vegetation cover is the most important and requires a variety of preparatory steps including leaching, liming and chemical amelioration. Rock cladding of tailings dams has also been used to a limited extent on the Central Rand, while other applications used during the early 1960's have included covering tailings dams surfaces with substances such as molasses, salt, hygroscopic materials and sludge from black vlei soil. Most of these methods have not provided a permanent solution to tailings dam rehabilitation and this has led to the formation of the Gauteng Mining Pollution Forum which will investigate rehabilitation by the removing of the tailings causing problems to communities and the environment and the establishment of a new super dump(s). This will complement the current elimination of tailings dams as part of the reprocessing of the gold-bearing dumps. The end results will be a few, well managed super dumps and open up large areas of prime land for development.

Introduction

The discovery of gold in the Central Rand Goldfield in 1886 led to the establishment of the world's greatest goldfield, the Witwatersrand, from which nearly 50 000 tons of gold have been produced. This gold bonanza has contributed enormously to the economic development of South Africa. The gold mining activity however has left a legacy of environmental problems, the major impacts being air (dust pollution), surface and ground water pollution and the sterilization of land for development.

These impacts are mainly associated with the establishment of numerous tailings dams during mining operations. To date approximately 240 tailings dams covering an area of 44 000 hectares, are registered in the Witwatersrand goldfield of which 70 are in the Central Rand. When mining ceased on the Central Rand in the mid-seventies there was little environmental legislation in place that required mining companies to rehabilitate and manage their tailings dams, and only limited rehabilitation was undertaken. This has led to the current environmental problems experienced from tailings dams.

Attempts to rehabilitate tailings dams started in the sixties by the Chamber of Mines of South Africa who experimented with various methods of dump rehabilitation. This led to an extensive programme of vegetative covering of tailings dams conducted by most of the mining companies.

With a large population concentration and growth in and around the Central Rand, many people are still being exposed to the impacts of tailings dams in particular and there is an increasing public awareness of environmental issues which has led to pressure on the mining industry and government to put in place appropriate rehabilitation measures.

The main focus at present is to extract the remaining gold from the tailings dams. Gold values range from about 0.4 g/t to 1 g/t with lower grade and non-viable dumps now being reclaimed by the Gauteng Mining Pollution Forum (GMPF) under the Department of Agriculture, Conservation, Environment and Land Affairs.

This joint reclamation programme will eventually solve the problem associated with tailings dams, since this will lead to the establishment of a few, consolidated, well managed tailings dams away from population centres and managed under current strict environmental standards.

The Central Rand

The Central Rand goldfield extends for a distance of 45 km, in an east-west direction centered on the city of Johannesburg (figure 1) This area represents the upturned and exposed northern rim of the 350 km x 160 km Witwatersrand sedimentary basin laid down between 2900 million and 2800 million years ago on a granite-greenstone basement. The lowermost sedimentary strata of the West Rand Group comprises shales and quartzites and is overlain by quartzites and conglomerates of the Central Rand Group. The latter sediments were deposited under fluvial conditions and contain the important palaeoplacer conglomeratic, gold-bearing reefs. In the Central Rand these comprise the closely associated Main Reef, Main Reef Leader and South Reef, the Bird Reef, Kimberley Reef and Elsburg Reef (figure 1). The highest grade and most extensively mined reefs were the Main Reef Leader and South Reefs. These were frequently less than a metre in thickness and carried grades often in excess of 50 g/t. Only the Elsburg Reefs have not been mined. Mineralization consists largely of gold bearing, often rounded pyrite which attests to deposition in an anoxygenic environment

Tailings dam deposits

Huge volumes of ore have been mined from the reefs of the Central Rand with mining taking place to depths of about 3000m below surface. Good gold values were still present but inadequate shaft systems led to the mines becoming uneconomic. During the early days of mining, ore from underground was brought to surface, where it was crushed, milled and gold was recovered using the mercury amalgam method. The tailings were deposited on sand and slimes dumps. From 1921 the cyanide process was introduced as a process of recovering gold from unoxidised sulphidic ores. The cyanide process required a finer milling of the ore and led to the establishment of exclusively slimes dams. Thus two kinds of tailings disposal dams, sand dumps and slimes dams were formed. Sand dumps are heaps of coarser, sand grain size materials while slimes dams are built up of more finely ground material, which settles from suspension in water to form horizontal slime layers within the dumps.

Quartz pebble and sand dominate and therefore SiO_2- rich silicates, iron sulphides and zircon. Heavy minerals in matrix are dominated by pyrite. Others include chromite, zircon, leucoxine, gersdorfite. Other sulphide minerals which occur in less abundance include Ni, Co, Cu, Zn and Pb sulphides in the form of galena, sphalerite, gersdorfite, cobaltite, limnite, chalcopyrite, carbon, phyllosilicate (chloritoid and sericite) (Viljoen, 1963 (table 1).
The following heavy elements are present in tailings dams Viz. manganese, cobalt, copper, nickel, zinc and vanadium and vanadium-rich rutile (Mphephu, 2001).

Both these kinds of tailings dams pose different conditions for rehabilitation e.g. Slimes dams were prone to wind erosion on the top, but with little from the side surfaces which usually become hardened by secondary oxidation salts termed efflorescence. Tailings dams cover a total of 11 000 hectares, slimes dams 6 800 hectares and sand dumps 4 200 hectares on the Central Witwatersrand goldfield (Groves, 1974).

Environmental impacts and rehabilitation technologies

Although all mining on the Central Rand has been underground, one of the major impacts of early mining resulted from the establishment of mine tailings, which neutralized thousands of hectares of land. Seventy tailings dams have been identified on the Central Rand, which due to poor management and neglect have been subjected to varying degrees of water and wind erosion. Environmental impacts range from water pollution (acid mine drainage derived from oxidation of sulphides, mainly pyrite, and the heavy metals in the mine tailings (table 1)); air pollution in the form of airborne dust from unrehabilitated, partially rehabilitated and reprocessed mine tailings, and the sterilization of appreciable tracts of land where mine tailings are located.

Rehabilitation technology

The tailings dams consist mainly of quartzitic material, derived from the quartz pebble conglomerates. The main concern is to stabilize the mine dumps from water and wind erosion. Different methods have been experimented with and the most documented and mostly widely used method is vegetation cover. Other methods experimented with include spraying of dump surfaces with various substances such as molasses, salt and hygroscopic material, but these have had little success. Sludge made from black vlei soil was used with success and this was practiced for many years on sand dumps (Grange, 1974). The main objective of a rehabilitation method or combination of rehabilitation methods is for it to have little or no maintenance in the long-term.

Vegetation

The proper establishment of vegetative cover depends mainly on the selection of plant species that will grow, spread and thrive under the hostile conditions provided by the nature of dump material. The revegetation of tailings dams requires some preparatory measures prior to vegetating. This is because the tailings dams are quartzitic (siliceous) and acid generating on the surface and lack organic nutrients for plants to grow and are thus totally inappropriate for vegetation growth.

The preparatory measures include altering these conditions by using methods such as liming and leaching.

Liming

The main aim of liming is to raise the pH of tailings dam material to 5.0 or higher since this is where a wide range of plant communities can survive. The pH value of the material near the surface of the tailing dams materials varies from dump to dump and place to place, depending on how much pyrite is present and the extent to which oxidation has occurred. Liming has been found to have a limitation on tailings dams with very low acidity (Grange, 1973).

Leaching

The slimes deposited are alkaline in nature, but because of the surface oxidation of pyrite in varying amounts, gradually become acidic in the surface layers of the dump. Acidification occurs to a depth of 2m to 5m below the surface (James et al, 1965). The acids on the surface of the tailings dams need to be leached out from the root zone of plants and this can be achieved by an extremely fine spray of water, which forms a mist over the surface and retards evaporation. To be effective the rate of deposition of water must not exceed the rate at which it can infiltrate into the slimes. The approach used and still in use on the Central Rand is by means of fine jets surmounted by striker plates (James, 1966).

Leaching increases the pH, and during the process acid water moves down. However, if the spraying stops, the water, as a result of evaporation and capillary action, rises up again triggering oxidation. This upward movement can be prevented by control of the spraying time.

It has been found that leaching and liming efficiency depends on the dump material pH and pyrite concentration. For example if the pH is greater than 3.5 and the pyrite concentration is less than 3000 ppm, liming is needed before planting. If the pH is less than 3.5 and pyrite concentration less than 4000 ppm leaching should be undertaken.

If the pH is less than 3.5 and pyrite concentration is over 4000 ppm, the material should be left to lie fallow for further natural oxidation as it is uneconomic to undertake both leaching and liming (Grange, 1973).

Windbreaks

The process of rehabilitation during early years needed the establishment of windbreaks in the form of cut stems of reeds. This was to prevent vegetation being buried by sand since most of the tailings dams had steep slopes. The area was divided into small paddocks whose size is determined by the slope of the ground (James, 1966). The wind breaks afford the protection for the seedlings until they have grown and become stable. This method is no longer in use, since now the tailings dams are contoured and organic matter in the form of fertilizers added before vegetation.

Chemical amelioration method –Envirogreen method.

This method was developed by the Company Envirogreen and involves turning the tailings materials into a medium favourable for plant growth by addressing the chemical, physical and biological deficiencies of the media. This is done by applying lime and fertilizer to the surface of tailings dams to a depth of 300mm.

To further improve the organic matter, fast-growing annuals and legumes are included in the seed mixture to produce plant debris after a short time (Van Deventer, 2002). Vegetative covering has been used extensively in the Central Rand, but there has been little success to in stabilizing the sides of tailings dams with slopes of more than 50^0 (Blight et al, 2001).

Rock cladding

Rock cladding has been used in a few instances in the Central Rand. Failures are however associated with rock cladding which include slump structures and erosion which takes place underneath the cladding leading to instability and collapse. Erosion is caused by leveling and compaction prior to rock cladding, which reduces infiltration capacity and results in total surface run-off. Rock cladding however if properly laid, enhances the stability of the slopes and dust can be curbed to some extent. The Central Rand tailings dams situation, therefore will probably require that the vegetation method and rock cladding be combined to stabilize tailings dams. Rock cladding should in general be limited to tailings dams with slopes of more than 50^0, since this is where vegetation is not effective.

Reclamation of tailings dams

Gold price and in particular the Rand price of gold, together with improvements in extraction technology (e.g. the carbon in leach and carbon in resin process) have made it possible for many mine tailings to be processed for their residual gold. For over two decades and starting shortly after the closure of the Central Rand mines in the late seventies, tailings with gold contents of between 0.4 to 0.8 g/t have been reprocessed. The extraction of gold has resulted in a profitable venture while at the same time removing a major environmental hazards as new mine dumps from processing have to be disposed of in accordance with present environmental standards.

On the Central Rand uranium minerals are not and important constituent of the reefs mined and uranium was never extracted, therefore the concentration of radionucliides is low. Land has thus been opened for development in areas where there are no shallow underground workings and where radioactive contaminated soil is not a factor.

On the Central Rand, Crown Gold Recoveries, which is part of the Durban Roodepoort Deep (DRD) group, has reclaimed more than 130-million tons of mine tailings. The reprocessed tailings have been redeposited at three superdump localities (on the top of existing dumps) adjacent to the Nasrec road at Crown Mines (figure 2). Mine dumps with cut –off grades of 0.45 g/t residual gold and a recovery of 80 % are currently being reprocessed.

Reclamation of mine tailings, if properly undertaken with an end-use in mind, can lead to the preparation of valuable and strategically placed land for productive uses with a major benefit to the population and the environment.

Gauteng mining pollution forum (GMPF).

After long, persistent complaints from residents affected by dust from tailings dams which have also involved court battles, the government under the Department of Agriculture, Conservation, Environment and Land Affairs formed the Gauteng Mining Pollution Forum with the aim of relocating low grade (<0.4.5 g/t Au) and particularly environmentally troublesome dumps to a new site and establishing a new, super tailings dam. This option will release land for development and eliminate multiple sources of pollution. The new dump(s) will be planned from the start with knowledge that has been acquired over recent years to mitigate pollution and prevent any failures.

Even though this option is costly, it will have a long-term benefit on the area. This method will also be complemented by the fact that some of the tailings dams still have gold in them, and if the gold price goes high enough even those with currently uneconomical gold content will be processed profitably. Removal of tailings dams will be prioritized so that dumps close to residential areas for example should receive priority and land that could be in demand for use will be prioritized first.

Tailings dams footprint rehabilitation and development

It is of importance that remaining tailings materials are removed completely to prevent further acid and salt generation immediately after reclamation. The current requirements are for paddocks to be laid out on the footprints to prevent possible water run-off to the surrounding environment. Treatment of topsoil such as liming should be applied where vegetation cover can be established to prevent the migration of contaminants as an interim measure before land can be prepared for other uses. This treatment of land should depend on envisaged future land use. This means that rehabilitation and final cleaning should be done to satisfy the final land use envisaged.

Conclusion

The rehabilitation of tailings dams both in the form of reclamation of gold-bearing tailings and removal of tailings dams as part of the Gauteng Mining Pollution Forum will benefit greatly from recently acquired knowledge. Technology has been developing from early mining rehabilitation to the present technology and will successfully improve the environmental, economical and social conditions that have been impeded by the present status of old tailings dams.

Socially, this will bring major benefits which will include improvement in public health and safety and government liability for health hazards associated with mine dumps. Environmental benefits will include the elimination of multiple pollution sources and economic improvement will be realized by using the land currently occupied by tailings dams for productive use such as industrial development. The new consolidated tailings dams that will be created will be planned so that they will have minimal impact on the environment as a result of utilizing skills acquired by studying old mine tailings.

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Table 1: Average chemical composition of gold tailings dams samples from the Central Rand

Tailings dams samples trace elements

Elements	Rb	Sr	Y	Zr	Nb	Co	Ni	Cu	Zn	V	Cr	Ba
Units	ppm	ppm	ppm	Ppm	ppm	ppm	Ppm	ppm	ppm	ppm	ppm	ppm
Ave. content	16	30	11	232	10	14	27	9	24	34	215	85

Tailings dams samples major elements

Elements	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI
Units	%	%	%	%	%	%	%	%	%	%	%
Ave.content	85.14	0.48	6.00	3.90	0.07	0.28	0.05	0.17	0.43	0.04	3.71

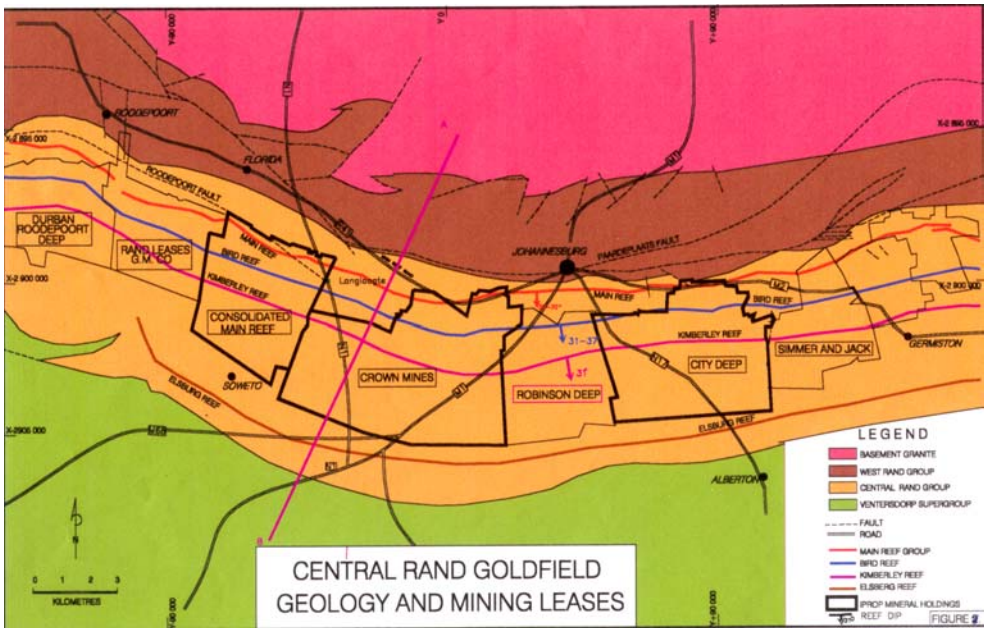

Figure 1. Central Rand goldfield in location, geology and mining leases.

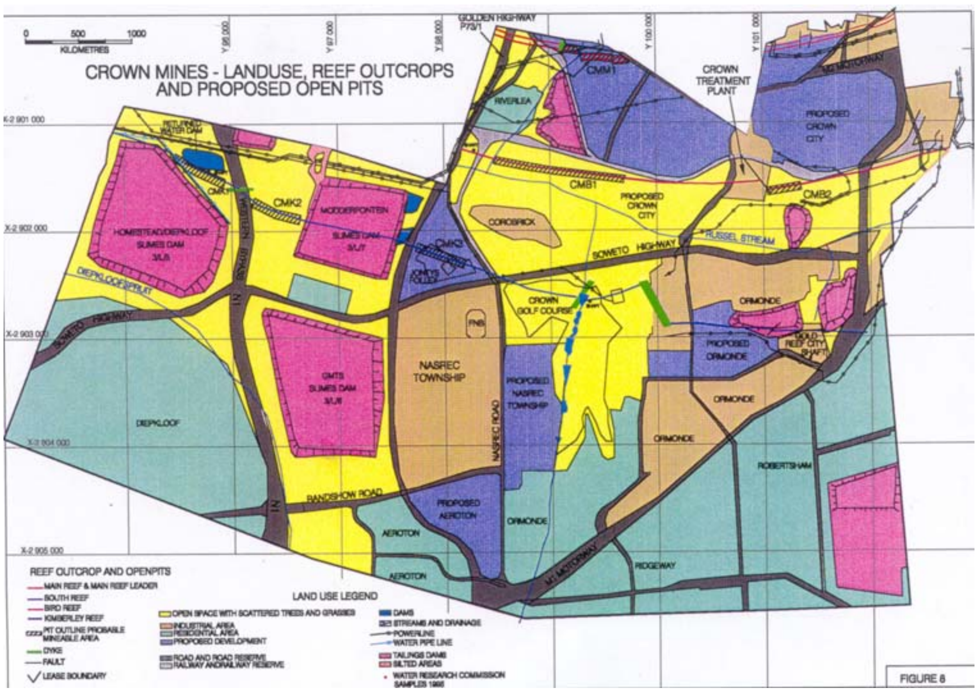

Figure 2. Land use plan of Crown Mines showing active slimes dams and other infrastructures (roads)