The residue waste disposal facility for Iscor's Hillendale project in KwaZulu-Natal

by J.R.G. Williamson*

Synopsis

The Mining Division of Iscor, an integrated minerals and metals company, has recently completed a feasibility study for the establishment of a new heavy minerals mine and smelter in the Richards Bay area of KwaZulu-Natal, South Africa. The mine will produce a heavy mineral concentrate containing ilmenite, zircon, rutile and leucoxene which will be beneficiated at a central processing complex close to Empangeni. The ilmenite will be smelted to produce high-grade titania slag and pig iron for export.

The ancient dune containing the mineral deposit is located some distance inland of the coastal dunes, and the sands contain a high proportion of extremely fine material which must be extracted ahead of the gravity separation process.

Of the 56 million tonnes to be mined annually over the ten-year life of the mine approximately 23,4%—a total of 13,1 million tonnes of minus 45 micron residue fines—will have to be disposed of in a containment facility. The origin of the fine material is from the weathering of amphibole minerals. The remaining coarse sands will be returned to the mined area to re-create the original dune configuration.

A number of options for the disposal of the residue fines have been examined and specialised laboratory tests undertaken to determine the deposition behaviour of the fines.

The final solution involved the use of a 'sub-aerial' technique for deposition of fine material in a disposal facility. The resulting arrangement will adequately meet technical and environmental criteria. Upon closure after 10 years of operation, the surface of the disposal facility will be returned to sugar cane cultivation

The paper refers to the various options considered and describes the problems associated with competent disposal of the residue fines and the development details of the final disposal facility.

Introduction

The Hillendale heavy mineral deposit to be mined by Iscor, commencing in 1998, lies in an ancient dune situated adjacent to the Mhlatuze river, to the eastern (coastal) side of the N2 highway and about 7 km from the coast. Approximately 56,1 million tonnes of material will have been moved by hydraulic mining methods to recover 2,6 million tonnes of ilmenite, zircon, rutile and leucoxene and 53,5 million tonnes of residue sands over the ten-year life of the mine.

The ancient dune formation in which the heavy minerals are contained lies inland from the coast, and there is a high proportion of extremely fine material in the residue sands, namely 23,4% or nearly 13,1 million tonnes of minus 45 micron silty clay resulting from the weathering of amphibole minerals. These extremely fine particles must be separated from the process stream ahead of the primary wet plant to improve the efficiency of the gravity separation process.

One of the critical factors associated with the project feasibility study was the achievement of a technically sound and environmentally acceptable way of disposing of the 13,1 million tonnes of minus 45 micron material, concurrent with the return to the mining area of the 40,4 million tonnes of plus 45 micron residue.

Previous work

Prior to Iscor's acquisition of the mineral rights to the Hillendale deposit in 1994, Shell S.A. undertook much valuable work in determining the properties and behaviour of the residue fines and studied various options for disposal. Iscor reviewed this work, took account of the conclusions, and extended the laboratory and pilot plant studies. Testing was taken to the stage where satisfactory results could be achieved in the separation process and slimes thickening, and conceptual design of the disposal facility could begin.

Some of the primary characteristics of the minus 45 micron fines determined by Iscor and by previous workers can be summarized as follows.

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General behaviour

- Shear action on the slurried fines causes a deterioration in settling characteristics of the solids.
- High flocculant dosages are needed to achieve effective settling of solids.
- The characteristics of the slurried fines change with time-ageing.
- Beached slurried fines display 'mud flow' characteristics, i.e. there is little or no segregation of particles as the slurry flows onto the beach.
- Slimes alone and slimes/sand mixes exhibit excessively high slump characteristics, even at high solids concentration.
- Deposited beach slopes derived from tests range from 1:70 to 1:120.

Mineralogy of fines

Primary minerals are
* quartz
* kaolinite
* chlorite
* haematite.

Geotechnical properties of slimes/sand

Shear strength	ϕ_1'	=	±28°
	c_1'	=	±0,5 t/m^2
Permeability	k	=	10^{-6} to 10^{-8} cm/s
SG of solids	S	=	2,8
In-situ dry density of deposited fines	ρ	=	800–900 kg/m^3.

Disposal options

Initial studies by Shell S.A. identified the disposal of the minus 45 micron fines as being an obstacle to the success of the project.

Subsequently various alternative options for disposal of the residue fines were considered by Iscor, as follows:

- High-density placement in bunded areas
- Low-density storage in conventional valley dams
- Disposal by conventional tailings dam techniques (gold, platinum, copper)
- Back-mixing with residue sand and use of mix for dune rehabilitation
- Chemical binders to solidify the waste
- Pumping out to sea
- Agricultural usage (spray onto lands)
- Dewatering by
  - filtration
  - centrifuge
  - furnace drying
  - high-rate thickener.

Upon investigation, each of these was found to have unacceptable technical and/or environmental drawbacks. In particular, conventional tailings disposal techniques as used in the South African gold, platinum and copper industries were found generally to be inappropriate for the disposal of the extreme fines at Hillendale. The scope of this paper, however, does not permit discussion of each of the considered alternatives.

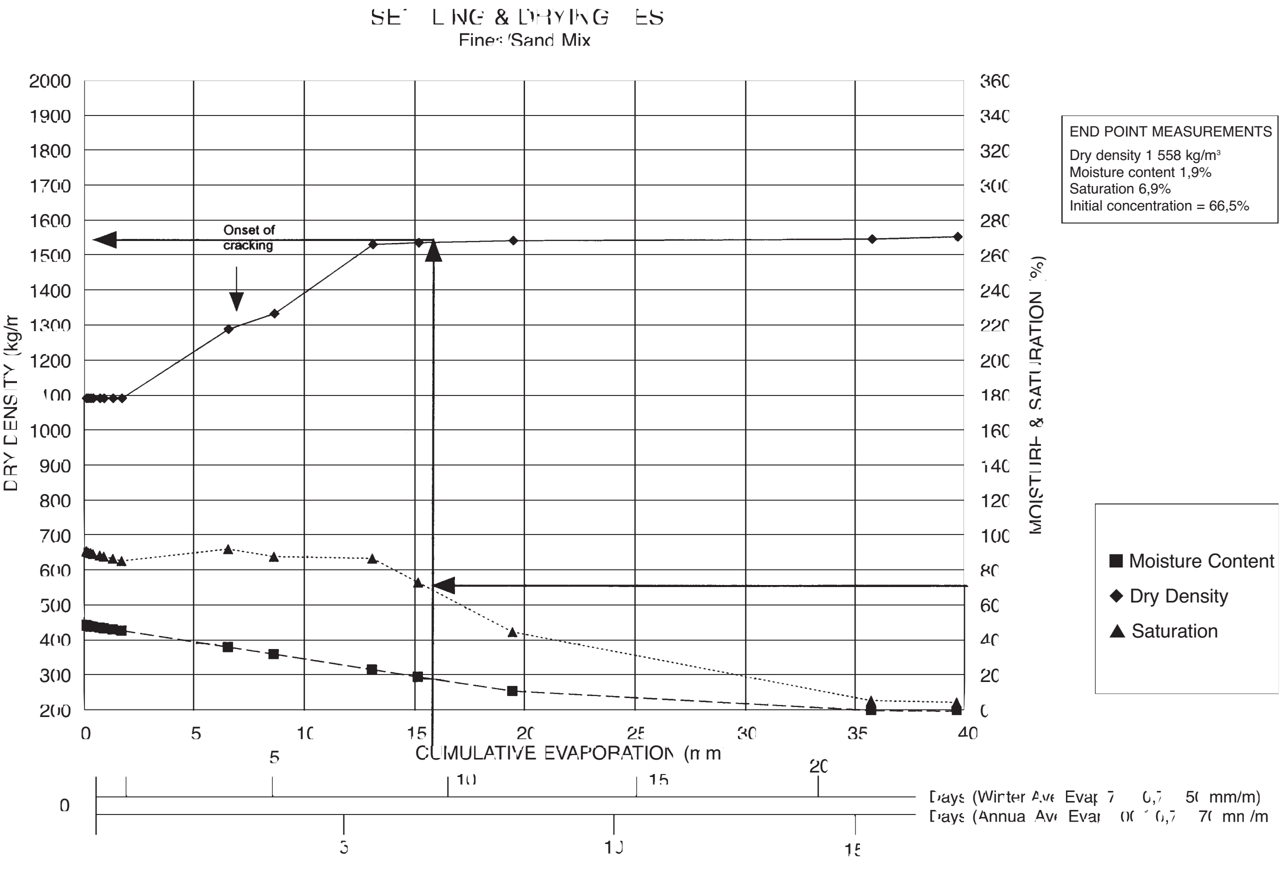

Figure 1—Typical laboratory test results of Hillendale mine residue disposal dam[1]

After a review of alternatives, the only residue disposal technique found to satisfy technical and environmental parameters was 'sub-aerial' deposition in carefully controlled layers in an appropriately sized residue disposal dam, as described more fully in the balance of the paper. Deposition of the fines by this method onto the beaches of the residue disposal area will lead to an acceptably dried and consolidated deposit that can ultimately be returned to agricultural use.

Laboratory tests

Specific laboratory testing was undertaken to determine the parameters for placement of the fines. The tests were specifically designed to determine the evaporation drying characteristics of the residue material so as to achieve the required dried, partially saturated, consolidated deposit.

The following were the results and conclusions.

(a) In order to achieve homogeneous drying and consolidation, the material must be fed onto the disposal area in thin layers and allowed to dry and consolidate for a defined minimum period before the next layer can be deposited.

(b) The tests demonstrated that the addition of sand to the fine-fraction residue significantly improves the achievable dry density of the deposit. This in turn reduces the required volume and base area of the residue disposal facility. Typical laboratory test results for a fines/sand mix are shown in Figure 1.

(c) The achievable dry density of a fines/sand mix, as derived from the tests using the reduction of saturation to 70% as a design criteria, is 1 300 to 1 500 kg/m^3, depending on the proportion of sand in the mix.

(d) The drying-cycle time will vary from about 6 to 10 days depending on the season of the year.

Achievable dry densities at the same degree of saturation for the fines without the addition of sand were significantly lower, and drying-cycle times longer.

The design drying-cycle time is derived by converting the laboratory evaporation rate to the Richards Bay evaporation rate, suitably modified to take account of beach evaporation, depression of the winter evaporation rate and retention of rainfall within the residue pores.

Site selection

Various disposal sites in the general vicinity of the mine had been investigated for some of the alternative residue disposal options referred to in the previous section.

The site selection was made on the basis of the following criteria:

- adequate size (100 ha)
- technical acceptability
- environmental acceptability
- exposure to flooding
- accessibility from the mine site.

A site on the Mhlatuze flood plain immediately to the east of the N2 freeway and adjacent to the mine site was finally chosen as shown in Figure 2.

Mhlatuze river hydrology

Two of the most crucial factors determining the acceptability of a site were:

- susceptibility of the residue disposal dam to flooding by the Mhlatuze river during extreme conditions
- potential influence of the residue dam on floodwater levels and on the velocity and direction of the floodwaters.

A detailed hydrological assessment of the Mhlatuze river was therefore undertaken to determine maximum river discharges and corresponding water surface profiles for various flood return periods.

The Regional Maximum Flood (RMF)—an event of roughly 200-year return period—was estimated to peak at 10 000 m^3/s, i.e. well in excess of the Domoina flood of 1984 and the even more extreme floods of 1987.

Encroachment of the residue dam into the flood plain was found to raise the RMF water surface elevation by less than 0,5 m at the maximum point, and to increase velocities by at most 0,4 m/s. In any event the average velocity would not exceed 2,0 m/s and this would be unlikely to cause erosion of the grassed embankment slopes.

The compacted earthfill perimeter starter wall would be raised to a crest level at least 0,7 m above the 1:100-year flood level, thus ensuring a low risk that the river flood would encroach into the storage area or against the outer surfaces of the deposited residue once the dam rises above the starter wall level.

Disposal facility features

Method of residue disposal

As noted previously, it was desired to develop a residue deposit that would be stable in both short and long term and which could be rehabilitated after mine closure for use as agricultural land, i.e. to return the site to its original land use.

To satisfy these objectives, the deposition procedure must be carefully monitored and controlled throughout the mining period to ensure compliance. Essentially, the residue must be placed in such a way that the material will dry out and consolidate to acceptable densities after placement. This can be accomplished by the 'sub-aerial' method of deposition.

The 'sub-aerial' technique essentially breaks the main delivered slurry flows into a series of small streams which are discharged gently onto the beach of the disposal dam using perforated 'drop bar' pipes or 'spray bars' to dissipate flow energy. The solid particles are thereby encouraged to settle out 'sub-aerially' on the beach rather than in the supernatant pool, where deposited densities would be extremely low. The thickness of each deposited layer is held to an allowable maximum so as to ensure that drying and consolidation takes place throughout the thickness of the layer. The layer is allowed to dry for a specified cycle time before the next layer may be deposited. The deposition technique described here is a refinement of the commonly used 'spigot' system and has been developed over a period of many years by Knight Piésold in Australia, Canada and the USA and successfully used with fine tailings under these controlled conditions. The outer perimeter wall can then be economically and safely raised by the upstream technique.

The laboratory tests showed that the dried *in-situ* densities

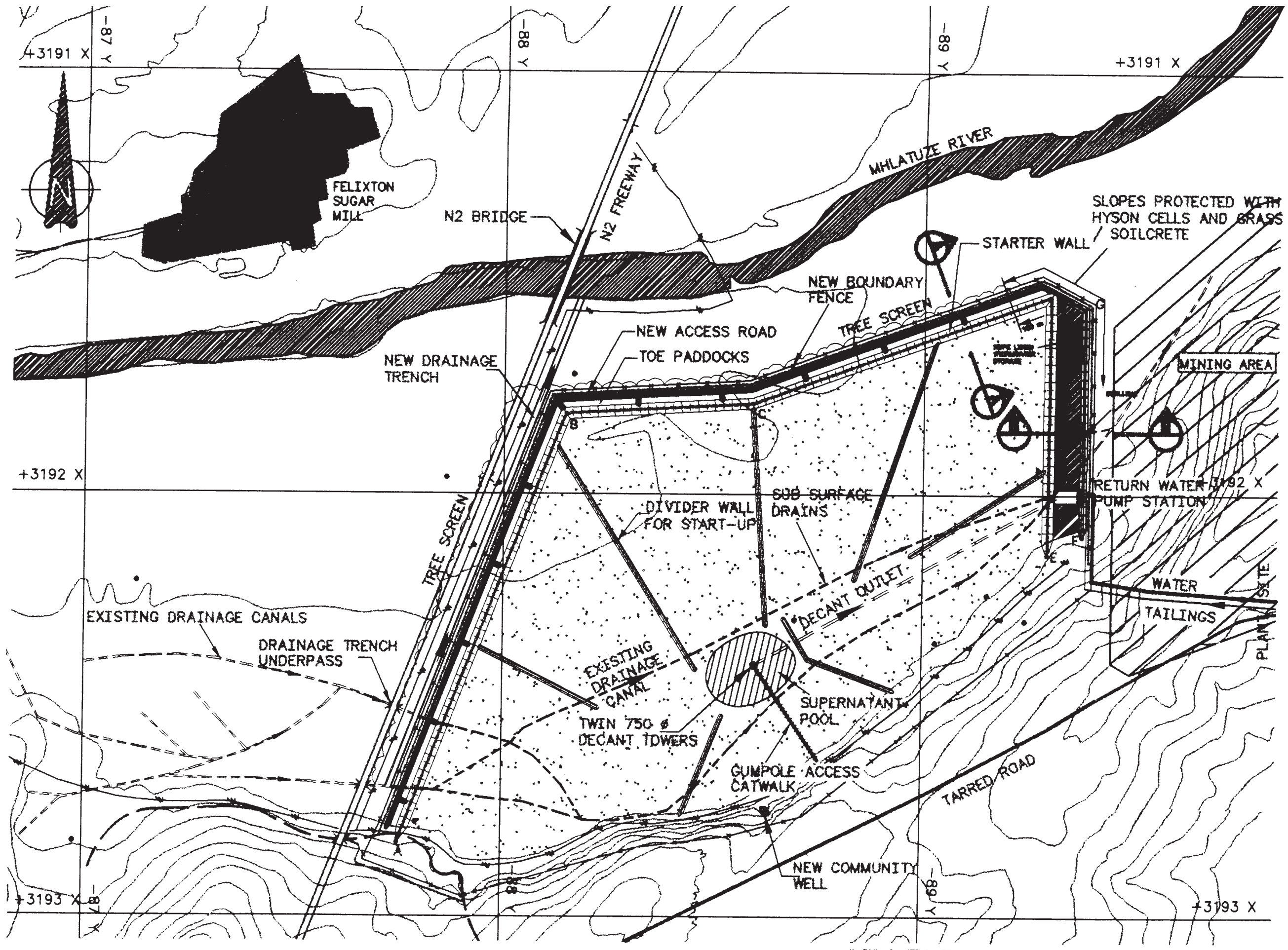

Figure 2— Hillendale mine residue disposal dam plan

can be significantly enhanced by the introduction of sand to the residue fines and this principle has been adopted in the final design.

Delivery of the residue slurry to the dam will be achieved in a 300 mm diameter main pipeline positioned around the perimeter of the dam, fitted in turn with 300 mm diameter branch pipelines at intervals from which the small 100 mm diameter perforated drop bar pipes or spray bars will discharge onto the beaches of the dams.

The residue material will initially be placed behind a 5 m high perimeter starter wall of compacted earthfill. Once filling has risen to the crest of the starter wall, the outer impoundment will be formed of dried residue material from the upper reaches of the beach as is conventionally done on many South African platinum and copper tailings dams. The total impoundment will ultimately rise to 15 m above existing ground level.

Stormwater management

The surface area of the residue dam is large (100 ha) and the large quantity of rain intercepted must be carefully removed. As the dam butts against a hillside it will also be necessary either to divert hill-slope runoff away from the dam, or to include this runoff in the total to be handled in the dam. The latter option has been adopted as the hill-slope runoff volume is relatively small.

Depth/capacity calculations show that as the peripheral impoundment rises there will always be about 3×10^6 m^3 of temporary storage available within the bowl formed by the beach material. Stormwater runoff calculations showed that the temporary storage capacity would be sufficient to cater for the runoff derived from the probable maximum precipitation while still allowing sufficient statutory freeboard required to accommodate the 1:100-year, 24-hour storm.

The operating principle would be to keep the water stored in the dam to an absolute minimum at all times. Excess stormwater would therefore be removed by gravity over a period of a few days by way of a decant facility.

In order to take advantage of captured stormwater for use in the plant, thereby reducing the need to purchase fresh water, a stormwater storage reservoir is to be provided outside the perimeter of the dam.

Pre-deposition works

The following pre-deposition works for the 100 ha dam will ensure safe, efficient and environmentally acceptable standards for the residue disposal to follow. The cross-section in Figure 3 and the plan in Figure 2 partially illustrates the arrangement.

(a) *Perimeter earthfill starter wall*—3 km long, 5 m high

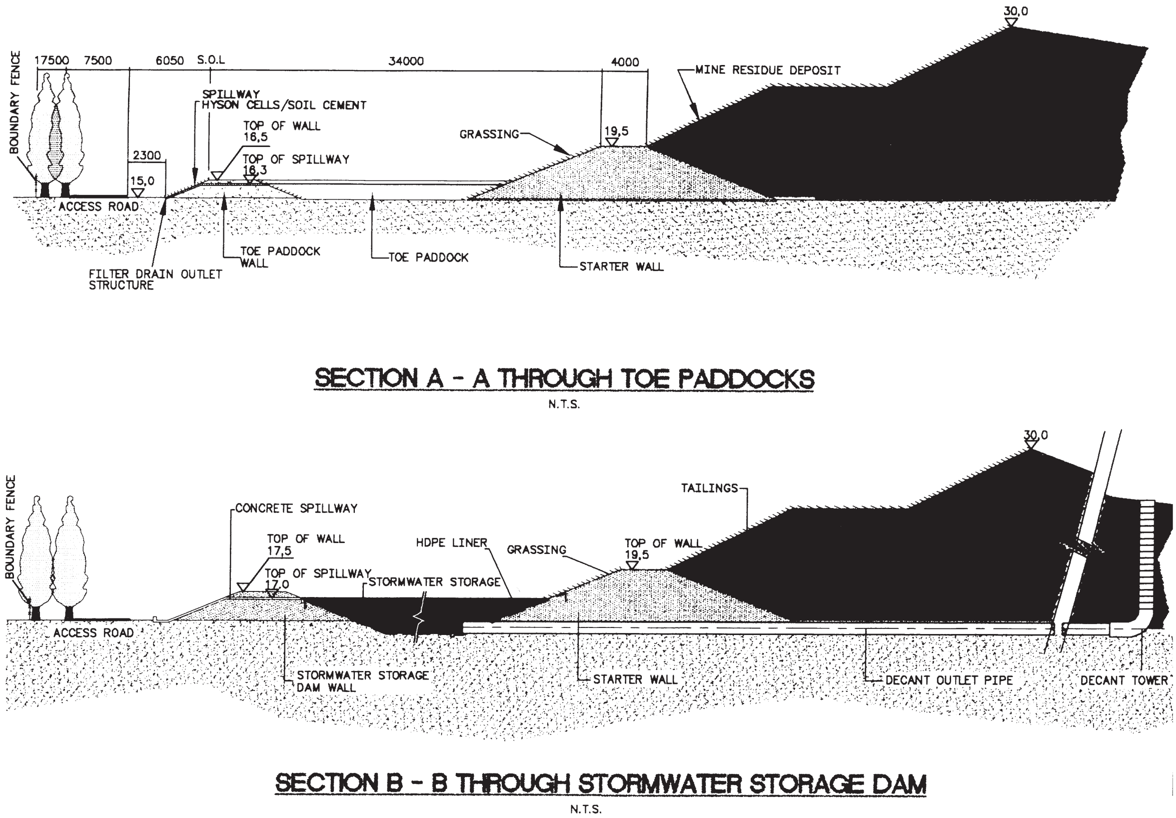

Figure 3—Cross-section of the Hillendale mine residue disposal dam

and constructed to a level above the 1:100-year river flood level. The outer slope will be grassed to with stand runoff and flood erosion.

(b) *Small internal divider walls* to contain initial deposition in controlled zones so as to limit initial seepage and facilitate formation of early beaches.

(c) *Gravity decant* comprising two 800 mm diameter horizontal outlet pipes for two associated stackable-ring decant towers that will be raised to follow the rise of the deposited material.

(d) *Access walkway* to the decant towers.

(e) *Perimeter filter drains* to control seepage and the phreatic surface.

(f) *'Agricultural' filter drains,* formed within the existing drainage canals that traverse the site, to facilitate their drainage.

(g) *Perimeter toe paddocks* to intercept material eroded from the outer faces of the embankment.

(h) *Toe collector drain* to receive discharge from the filter drains.

(i) *Perimeter access road and security fence.*

(j) *Tailings slurry delivery pipework.*

The pipework will comprise:

- a delivery main from the process plant, plus a standby main
- a delivery main around the dam perimeter
- full diameter branch lines at intervals, allowing selection of delivery to any desired zone of the dam
- small diameter valved spigots off the branch lines, each fitted with a perforated drop bar pipe for discharge of slurry onto the beach of the dam.

Environmental aspects

Careful consideration has been given to possible adverse environmental impacts of the residue dam.

Visual impacts

The dam will be visible from the N2 freeway. To mitigate this impact, general screening will be provided by trees planted around the perimeter of the dam. More specifically, screening trees will be planted along the N2 embankment to shut out the view of the facility from the freeway.

Seepage

The site is underlain by permeable alluvial silts and sands. The sub-aerial deposition technique, which achieves effective drying and consolidation of each deposited layer before the next layer is added, serves to limit any seepage to the foundation through the beach zones which comprise at least 95% of the wetted area.

Furthermore, the permeability of the residue material itself is extremely low so that once the base area of the dam has been covered by residue, seepage from the supernatant pond area will be minimal.

Erosion by wind and rain

Windblown material from the outer surfaces of the impoundment will be controlled by an ongoing grassing programme. Sediment associated with storm runoff from the outer walls will be trapped in the toe paddocks.

Although the internal beaches of the deposit will be exposed, and thus vulnerable to wind erosion, pilot plant trials have shown that once the deposit has partially dried and consolidated, the cohesive surface is still sufficiently moist to obviate wind erosion. The zone of beach that is under active deposition will be wet and therefore not subject to wind erosion.

Solids eroded from the beaches will mostly report in suspension in the supernatant pool. Some will settle and the rest will pass through the decant system to the stormwater storage pond where further settling will take place.

Conclusions

The successful disposal of the minus 45 micron fine residue from the Hillendale mine site has posed a technical challenge to those wishing to develop the deposit.

By developing a clear understanding of the behavioural characteristics of the fine residue under disposal conditions and by extensive examination of all potential disposal options and methods, a residue disposal technique has been developed that will result in a stable and competent deposit that can be rehabilitated on closure of the site.

Furthermore, hydraulic and hydrologic calculations show that the residue disposal dam will have no significant influence on the Mhlatuze river floodwaters and that the floodwaters will not prejudice the safety and integrity of the dam.

It is concluded that the derived solution to the fine residue disposal requirement has allowed the mining venture at Hillendale to proceed with confidence.

Acknowledgements

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Change of management at De Beers Mines*

Alan Smith, General Manager of De Beers' Central Mines in Kimberley, has been appointed Chief Operating Officer of Free State Consolidated Gold Mines (Freegold), with effect from 1st October 1997.

De Beers is pleased to announce that Richard Molyneux, currently General Manager of Namaqualand Mines, will succeed Mr Smith.

Mr Molyneux (48) joined De Beers in 1971 as an exploration geologist in the then Northern Cape and Western Transvaal. He was the Junior Technical Assistant to the Consulting Geologist from 1973 to 1974 and was involved in further exploration work in Swaziland and the Northern Transvaal in 1974 and 1975.

In 1976, he was appointed Resident Geologist at Premier Mine and became the Chief Geologist at Namaqualand Mines in 1983. Mr Molyneux was promoted to General Manager of Namaqualand Mines in March 1995.

An announcement with regard to Mr Molyneux's successor will be made in due course. ◆

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