Phase II: Continuous improvement of geometallurgy at Namakwa Sands Mine

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Geometallurgy is broadly considered as a combination of geological and processing information that forms part of a predictive mining and metallurgical process model. This concept works at improving production management by optimisation of mining and processing activities. These are the key drivers for the value of ore being exploited. Namakwa Sands is currently in the second phase of geometallurgical studies. Phase 1 continued from the ore characterisation studies of the Namakwa Sands deposit, where the geological domain characterisation conducted indicated that the distinctive geological domains exhibit variability and different processing behaviours (such as hardness, settling, gravity separation, magnetic separation, coating removal, and electrostatic separation), which drives metallurgical performances of the processing plants to produce the respective products (i.e., zircon, rutile, and titanium feedstocks).

Phase 1 geometallurgy was aimed to develop and assess the methodology to characterise the various ore types using a 'mini-bulk analysis' approach. The mini-bulk approach retrieves run-of-mine samples of over 300 kilograms, taken at regular, widely spaced, intervals which are used to run the beneficiation simulation. The minibulk samples are treated in a designed pilot plant mimicking the current Namakwa Sands beneficiation process to gather a vast array of data for geometallurgical modelling purposes. Phase 2 geometallurgy aims to calibrate the designed pilot plant from a simulation of actual processing performance for metallurgical forecasting and production planning.

The generated geometallurgy data model will be used for the mineral resource-technology matching (throughput efficiency and mineral recoveries) for timeous and effective intervention during geometallurgical excursions and mineral production.

INTRODUCTION

Tronox Mineral Sands is a subsidiary of Tronox Holdings PLC and is expanding as a leading global producer of titanium dioxide.

Namakwa Sands, one of the Tronox Mineral Sands mines, is located on the west coast of South Africa in the Western Cape Province. The northern operations consist of two mines, two primary concentration plants (PCP), and a secondary concentration plant (SCP) at Brand-se-Baai, approximately 400 km northwest of Cape Town, and a mineral separation plant (MSP), located 52 km south of the mine. The southern operations consist of the administrative headquarters, the smelting complex with two furnaces, and export facilities near Saldanha Bay, about 300 km from the MSP (Figure 1).

Namakwa Sands is currently improving a conventional approach to model its heavy mineral sands deposit to quantitatively predict the quality of concentrates and metallurgical performance, such as metallurgical recoveries and throughput, using a geometallurgical concept. Geometallurgy is broadly considered as a combination of geological and processing information which forms part of a predictive mining and metallurgical process model for improving production management (Lishchuk, *et al.*, 2015) by optimisation of mining and processing activities, which are the key drivers for the value of ore being mined.

Previous geological domain characterisation studies conducted on the Namakwa Sands orebody have indicated that the distinctive geological domains exhibit different processing behaviours (such as hardness, settling, gravity separation, magnetic separation, coating removal, and electrostatic separation) (Rozendaal & Philander, 2008).

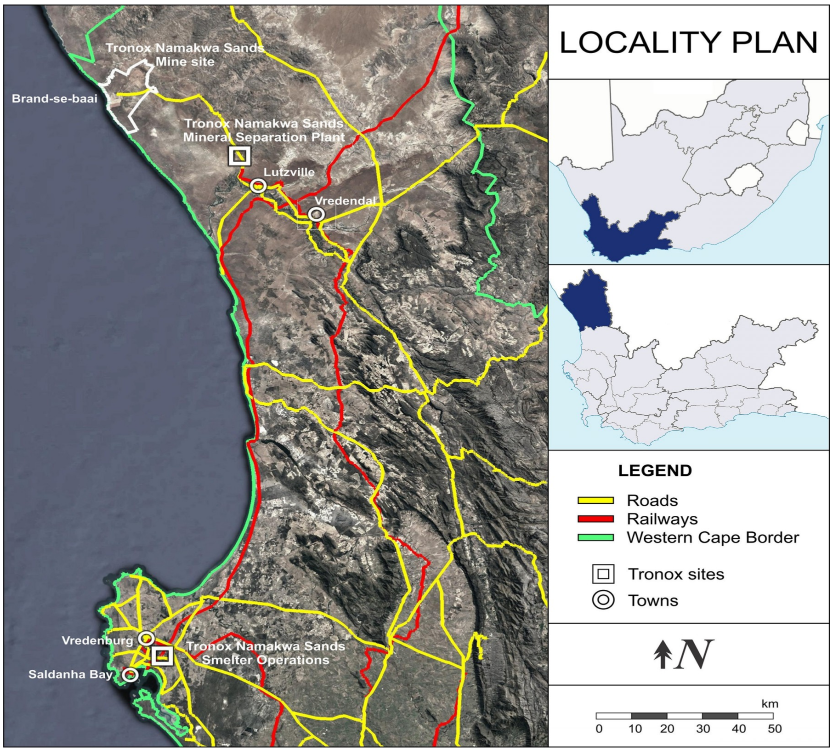


Figure 1. Tronox Namakwa Sands operation showing the mine site (Brand se Baai), where the mine, the primary concentration plants and the secondary concentration plant are located; the mineral separation plant (Koekenaap and smelter (Vredenburg) (Tronox Namakwa Sands, 2022).

These processing behaviours have a direct influence on the final product grade and recovery and thus have a significant impact on the overall Tronoxbusiness. Therefore, the ore characterisation improvement study is aimed at assessing the robustness of the methodology and further characterising the varieties of ore types using a 'minibulk' approach. The minibulk approach is a process of retrieving run-of-mine samples of over 300 kg mass, taken at regular, though widely spaced, intervals which are used to run the process beneficiation simulation. These bulk samples are taken well ahead of the current mining operation to enable in-time interpretation and comparison with plant behaviour. Routinely, the mineral processing plants (PCP, SCP and MSP) sample critical mineral streams and run minibulk projects and integrated automated mineralogy and petrography data through quantitative evaluation of materials by scanning electron microscopy (QEMSCAN) campaigns. The data is later stored in a database called optimisation metallurgy (OPMET) data. The simulation results will be calibrated to give information on the actual processing performance using the OPMET data. The results of this comparative study will be used as inputs into the budget systems, and to create a model linking the ore blend to the geological domain characterisation.

BACKGROUND

The Namakwa Sands heavy mineral assemblages originated from weathering of Pre-Cambrian age metamorphic rocks of the Namaqualand Metamorphic Complex and Van Rhynsdorp Group. The heavy mineral assemblages found in the orebody reflect medium to high pressure and temperature conditions (Philander & Rozendaal, 2007). Distinctive minerals found in this deposit are ilmenite, rutile, zircon, and leucoxene - the so-called valuable heavy minerals (VHM), including several non-valuable minerals such as haematite, garnet, pyroxenes, amphiboles, and quartz. Fluvial systems concentrated and transported the heavy minerals to the coast, where mineral concentration and distribution by the longshore current factors further enriched the heavy minerals in the sands.

The heavy-mineral-barren, white to buff fine-grained unconsolidated sands, referred to as Other Sands, are the oldest sediments and unconformably overlie the bedrock. The strandline which is the so-called 'sweet' ore because of its enriched heavy mineral content, represents sea level standstills at 20 and 35 metres above mean sea level (mamsl) and lies directly on the bedrock or on Other Sands (Rozendaal and Philander, 2008). This heavy-mineral-enriched ore type constitutes only 2% of the orebody. The strandline ore type is overlain by the most dominant ore type, a thick package of yellow-orange reworked marine and aeolian quartzofeldspathic sand, collectively named the Orange Feldspathic Sand (OFS). OFS constitutes over 70% of the orebody, overlie by a duricrust or dorbank layer. Dorbank (DOR) is formed by the cementation of sands of the feldspar and quartz-richaeolian beds. The surface is covered by a thin layer of loose and free-flowing sand called red aeolian sand (RAS).

Using a grade geological model, a mine plan schedule is drawn to give the forecast zircon grade for both the East Mine and the West Mine. Dry mining is performed in a load-and-haul operation. The mineral-bearing sands are mined using front-end loaders and hydraulic excavators and dumped onto a conveyor belt system that runs behind the mining face at two mining areas called the East Mine and West Mine. The East Mine is currently targeting the surface deposit, consisting of loose and free-flowing sand (RAS) ranging from 1 to 4 m in thickness. The RAS has elevated concentrations of ilmenite and zircon and is strongly depleted in gangue minerals like garnet and pyroxenes. The West Mine targets the deeper horizons below the RAS, which consist of the OFS. The harder feldspathic material extends up to 35 m below the surface. For the East Mine operation, the ore feeds into a grizzly that sieves out vegetation, and for the West Mine operation, the ore feeds into a crusher to reduce it to 20 mm. Ultimately in both mines, the ore is then conveyed to the plant for mineral processing, starting from PCP, SCP to MSP.

The PCP uses screening and wet gravity separation techniques to upgrade the material to a heavy mineral concentrate (HMC) of specific zircon grade, for further processing at the secondary processing stage. The feed preparation circuit is designed to liberate VHM contained in the ore. The spirals separate the heavy minerals from the lighter minerals by means of density separation. Particle characteristics relating to size, shape and specific density govern the hydraulic behaviour in a spiral system. The higher density of a mineral improves the recovery performance during mineral processing (Philander and Rozendaal, 2008). Thus, zircon and ilmenite, both with a density of 4.7 g/cm3, have higher recoverability than rutile (density of 4.2 g/cm3), followed by leucoxene (density of 3.8 g/cm3). The SCP receives HMC from the PCP and separates this material by magnetic separation into a magnetic concentrate of a specific ilmenite grade, and a nonmagnetic concentrate of a specific zircon grade. The magnetic separation circuit comprises drum magnets to remove the magnetite from the feed to the wet high-intensity magnetic separator (WHIMS), which separates magnetic from nonmagnetic material. The product is upgraded by spirals. The WHIMS efficiency depends on the garnet content, grain size distribution, and magnetic susceptibility of the material being processed.

The MSP stage is aimed at beneficiating the concentrates using dry magnetic separators and (mainly) electrostatic separators. Prior to treating the nonmagnetic concentrate, the dry feed is subjected to a high-temperature contact acid leach to remove surface iron coatings which improve the subsequent electrostatic separation, using high-tension rolls. It is then passed through the wet gravity separator to remove quartz and other lighter minerals, followed by platen electrostatic machines, which separate the non-conductive minerals such as zircon, kyanite, staurolite, quartz, and monazite from conductive minerals such as rutile, leucoxene, and residual ilmenite to recover valuable zircon and rutile. The magnetic concentrate upgrades the magnetic concentrate to recover ilmenite using electrostatic separation. The efficiency of this stage depends on the purity of the minerals (absence of coatings, inclusions). Mineral recovery is the most important factor in producing a quality product with specifications that meet market requirements.

The previous geometallurgical programme at Namakwa Sands showed that the different geological ore types have different processing behaviours (Rozendaal & Philander, 2008). The follow-up geometallurgy programme is aimed at linking the orebody in terms of its geometallurgical characterisation (geology, mineralogy, and metallurgical process performance), to help build a robust geometallurgical model that will be linked to the overall production and related financial planning and forecasting.

GEOLOGICAL MINIBULK SAMPLING POINTS

The orebody consists of different geological zones which have been classified vertically as previously mentioned in the background section (i.e., RAS, DOR, OFS, Other Sands, strandline). For short-term mine planning purposes, locality names are used to further divide the different areas in the orebody laterally. The East Mine focuses its mining operation on the RAS ore type as previously stated, where local names are used for short-term mine planning and blending purposes to consider remote mining and conventional mining methods. The following locality names are used for the East Mine, Houtkraal, Joetsie, Langlaagte, Rietfontein and Soutpan (Figure 2). The mine plan utilised for the minibulk sampling of the East Mine was only focused on the locality names, Joetsie and Langlaagte, as observed with the sampling points in Figure 2. The West Mine focuses on lithologies that lie below the RAS ore type which defines the vertical ore characterisation zones. For the purpose of the short-term mine planning and blending in the West Mine, the orebody has been laterally divided into different pits based on local names: West Pit, East Pit, Centre Pit and North Pit (Figure 2). These pits have variations in the proportion of the hard material or the duricrust layer. The mine plan utilised for the minibulk sampling in the West Mine constituted all the mining pits as observed with the sampling points in Figure 2. However, not all mining pits were represented in all four quarters as depicted in the minibulk sampling locality map.

METHODOLOGY

This paper is put together using the geometallurgy campaigns which occur in three phases of development, to be able to consider the minibulk simulation for the life of mine (LOM) modelling (Table 1). In each phase, representative mini-bulk samples are retrieved from the mine representing the short-term section business mine plan. The samples are taken through the PCPs at a ratio of 2:1, as per the actual feeding philosophy. The mine plan takes into consideration that the blending of the different ore types is also represented to achieve the mine production targets. The mine production targets are the zircon grade and ore tonnage, and the mineral processing targets are based on the spiral rougher zircon grade, concentration grade and concentration recovery.

The Namakwa Sands geometallurgy progress is currently in phase 2 part 2; phase 1 and phase 2 part 1 have since been successfully completed as per their objectives. Phase 1 was presented in 2018 at the geometallurgy conference (Tshivhase & Philander, 2018). The major focus of the results reporting and discussion in this article will be focused on the latest milestone results which are phase 2 part 1. An update will be given in the future for phase 2 part 2 which is yet to be concluded to date.

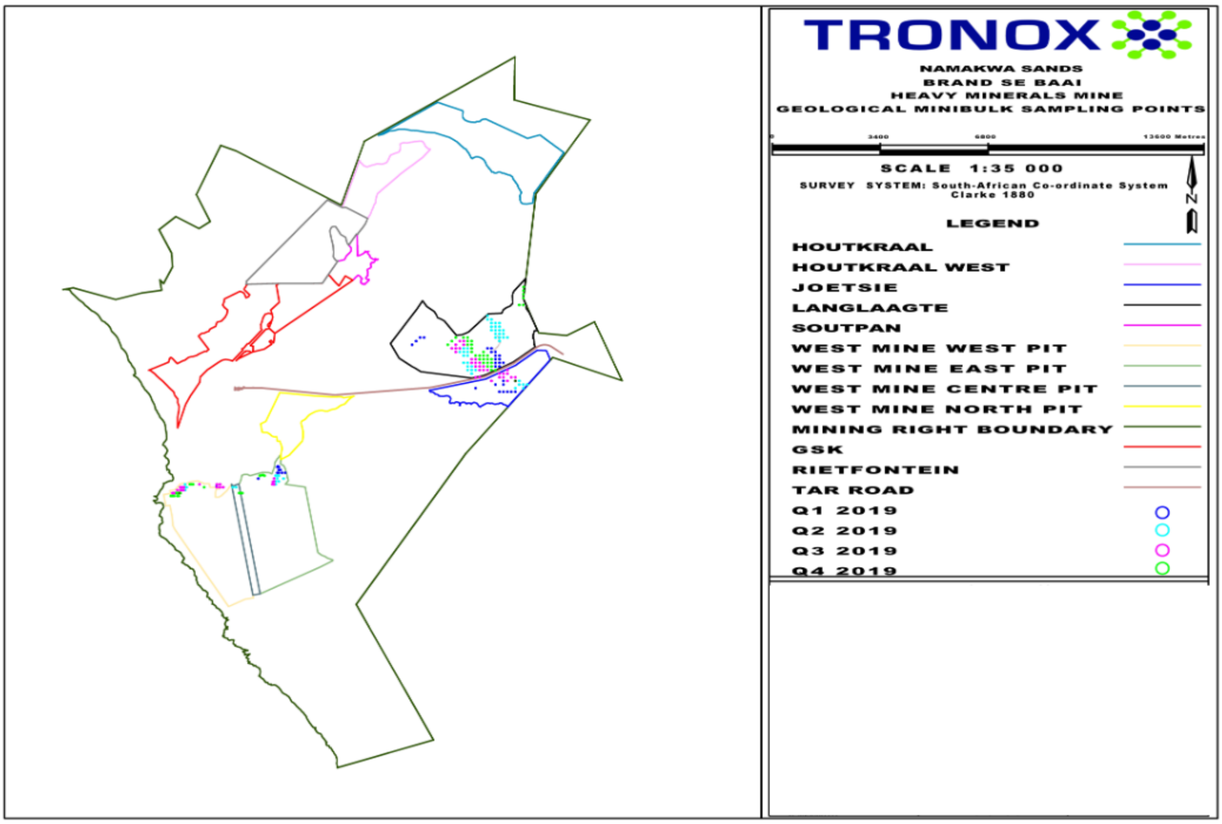


Figure 2. Minibulk sampling locality map.

Table I. Namakwa Sands geometallurgy programme showing the objectives of each geometallurgy phase

	Ore characterisation studies	**Phase 1 (Evaluation)**	**Phase 2 (Part 1: Calibration)**	**Phase 2 (Part 2: Calibration)**	**Phase 3 (LOM rollout)**
Objective	To define the geological domain of the Namakwa Sands deposit and the distinctive processing behaviours of the various geology units	Assess the robustness and potential of the methodology to characterise a variety of ore types	Calibrate test simulation to actual processing performance – inputs into the budget system (PCP to SCP)	Establish the calibration of the simulation to actual processing performance – inputs into the budget system (PCP to MSP)	Create a model to link blended ore to domain characterization
Sample suite	LOM	Quarterly mine blend, control samples (SCP concentrate, and duplicates)	2019-2020 Mine schedule, control samples, and duplicates	2022-2024 Mine schedule	Geological domains, and sub-domains based on a sectioned in business plan intervals

The mini-bulk samples are treated in a pilot circuit in order to gather a vast array of data for geometallurgical modelling. A pilot circuit is designed to simulate the current Namakwa Sands process chain (liberation, spirals, WHIMS, spirals, attrition scrub, magnetic and electrostatic cleaning) in the simplest manner (Figure 3). The pilot circuit is also designed in correlation with the actual plant feed rates. The objective of the pilot circuit is to produce semi-final products in order to provide a clear picture of the ore processing behaviour. The following assessment of the ore was conducted:

- Liberation – how much energy is required to free mineral particles.
- Clay residue – how the suspension particle fines settle and establish their classification.
- Gravity separation – how efficiently a concentrate is extracted from the groundmass of ore and recovery loss established.
- Particle sizing – to establish the particle size distribution quantification.
- Magnetic separation – how efficiently the non-magnetics are separated from magnetics and recovery loss established.
- Surface cleaning – how efficiently the impurities are removed from particles.
- Non-magnetics surface cleaning – how efficiently surface impurities are removed from non-magnetic particles.
- Non-magnetics gravity separation – how efficiently a concentrate is extracted and recovery loss established.
- Non-magnetics electrostatic separation – how efficiently zircon is separated from rutile and recovery loss established.
- Magnetics electrostatic separation – how easily ilmenite is separated from garnet and recovery loss established.

X-ray fluorescence (XRF) is used to determine the elemental composition of the head feeds, product fractions and some processing streams within the flowsheet. Bulk mineralogy analysis (BMA) and particle mineralogy analysis (PMA) were performed on the HMC product fractions using quantitative evaluation of minerals by scanning electron microscopy (QEMSCAN). The HMC product from the primary process was fractionated into magnetics and non-magnetics using Carpco fractionation. This method works by separating the total heavy minerals (THM) according to the different magnetic susceptibilities, exploiting either paramagnetic or diamagnetic properties, producing magnetics and non-magnetics. The Carpco products (magnetics and non-magnetics) were analysed for BMA, PMA, and XRF assays for reconciliation purposes, with the final products that are produced at different stages in the process flow.

The overall database generated after the minibulk simulation proved to be very complex in drawing the optimum value of the whole study. It is important to note that the study does not only focus on reporting the major relationships that were under testing but also develops means to understand other relationships that the data generated. The OPMET data (as previously stated, are the actual production averages obtained from the analysed bulk samples collected from the plant product streams) will be used as a comparative grade and recovery measurement with the minibulk simulation database. This will be done in further phases of the geometallurgical campaigns.

The simulated minibulk samples are derived from a section business mine plan. This is done without taking into consideration the uncertainties brought by dynamic changes that may arise during the actual operation of the mine. Dynamic changes may result in abrupt changes that are accommodated on the delivery of the mine plan to consistently get the mineral processing plant running without stopping. Such dynamic changes may include equipment breakdown (not only in the mining operation, but also in the mineral processing plants), inclement weather conditions that result in only mining certain blocks and or stockpiles, variability of the grade distribution of the orebody, and other factors. As a result, the greatest value of this approach of comparing the actual production performance and the minibulk simulation lies in the relative similarities, which are more important than the absolute differences.

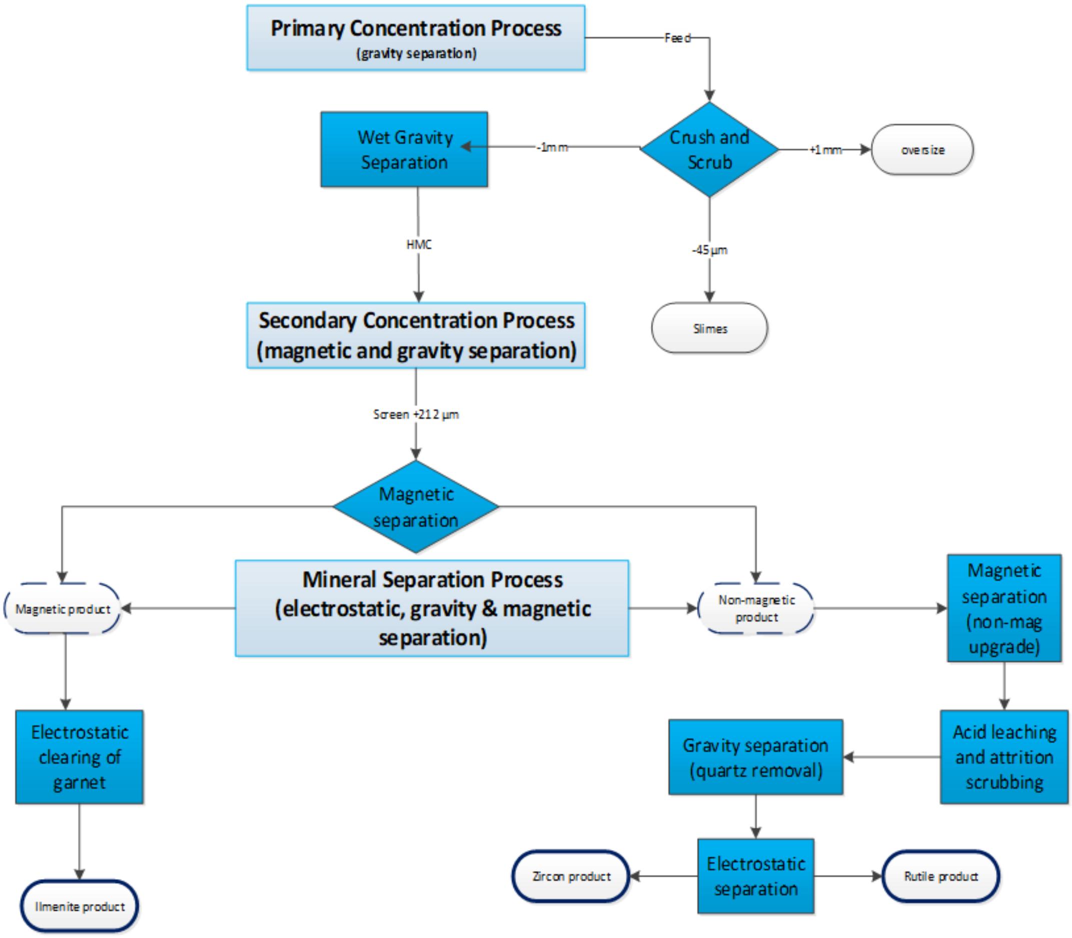


Figure 3. Simplified mineral processing concentration processes mimicking the Namakwa Sands process. flow.

MINIBULK SIMULATION AND ACTUAL PRODUCTION PERFORMANCE: PRIMARY CONCENTRATION PLANT

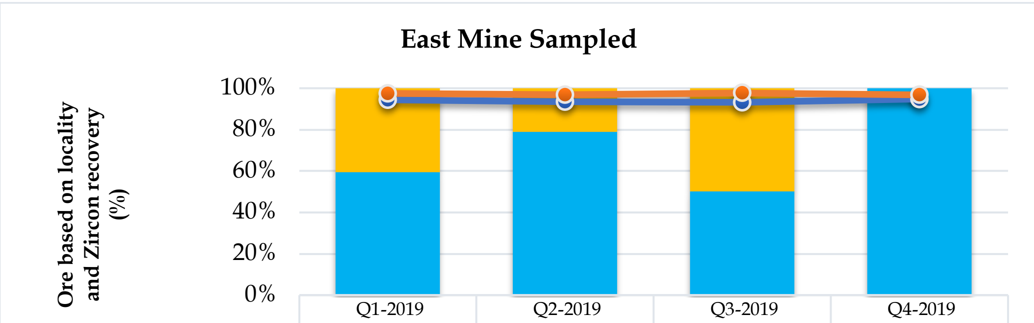
The minibulk simulation sampling campaign is based on the section business mine plan composed of different geological ore types; therefore the mineralogical assemblage will also vary. Previous ore characterisation studies gave an insight into the mineralogical recovery factors, which helped predict the plant process performance of the ore types that beneficiate better. These factors are driven by geological properties such as clay content or undersize particles (-45 µm particles), mineral texture (shape and size), gangue content, hardness, and mineral purity. East Mine plan is generated based on one ore type, RAS which is free-flowing and uniform in terms of its composition. The West Mine plan consists of different ore types that are semi-consolidated and cemented as compared to the free-flowing sand (RAS). The different ore types lie in different elevations and contain variability when it comes to their respective geological properties.

Based on the mine plan subdivided into local names for the different quarters of 2019, the East Mine minibulk samples are blended as per the proportions specified in Figure 4. Locality names Joetsie and Langlaagte were scheduled for quarters 1 to 3 and only Langlaagte for quarters 4 (Figure 4). The mineral processing consistency and uniformity of the RAS ore type mined in the East Mine are observed in Figure 4. This ore type characterisation is drawn from the comparison between the simulated versus the actual production zircon recovery for the different quarters, which are almost a flat line, regardless of the varying proportions of the RAS ore blend based on locality. The West Mine blends based on the pit boundaries as observed in Figure 5 show a similar relationship. However, there is an observation that quarter 4 had a much higher zircon recovery for both simulated and actual, which is due to its blend composition of the balance of more West Pit (which is associated with higher grades), followed by Centre Pit then the East Pit. It is evident that when there is a reduction proportion blending of the West Pit, the recoveries also decrease as observed for the other quarters. This draws the relationship that the PCP West is more driven by grade to generate higher recoveries.

The West Mine is largely affected by dynamic changes that occur in the mine, as compared to the East Mine operation. There is also a hypothesis that these dynamic changes affect the recoveries at the PCP stage of mineral separation. These dynamic changes were noted during the execution of this project, as a point of follow-up study. The dynamic changes are inclusive and not limited to the following:

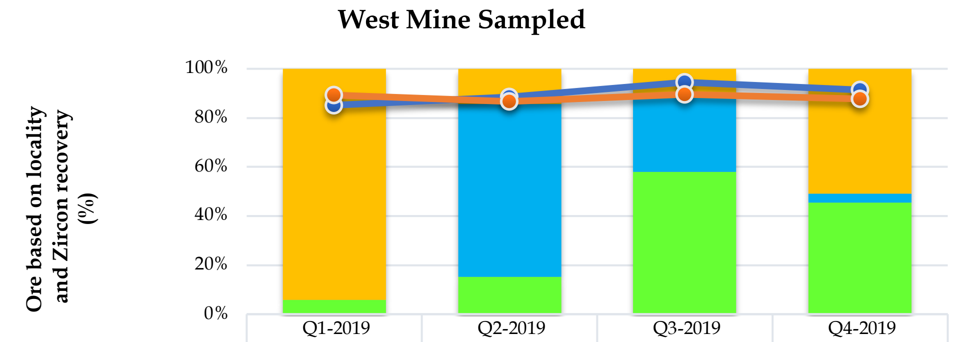
- Elevation changes during mining - some areas included in the mine plan lie deeper in the orebody, and unfortunately, the minibulk sampling method did not permit access. For sample representations of material deeper in the ground, a depletion from the geology model was conducted to review the ore types that are included in those layers and elevation. And then the samples were simulated based on the areas in the pit that were opened with the same ore types, and it was expected to give inconsistency in the data, because the ore types can also possess some elevation variability, regardless of the overall composition that defines the ore types.
- Another dynamic change - the inconsistency in the actual production mine blending affected by breakdowns, and weather conditions which potentially affect the overall blend sent to the plant during the execution of the 2019 mine plan. And this can be traced to the mineral processing plants in terms of their performance, including breakdowns that also take place in different functions of the mineral plants.

The whole purpose of the phase 2 minibulk campaign is to be able to generate respective products that can be accounted for in terms of the actual environment processing targets. The next section will explain the SCP portion of this article, which then leads to the conclusion and recommendations.



	Q1-2019	Q2-2019	Q3-2019	Q4-2019
Goeraap	0%	0%	0%	0%
Houtkraal	0%	0%	0%	0%
Soutpan	0%	0%	0%	0%
Joetsie	41%	21%	50%	0%
Langlaagte	59%	79%	50%	100%
Zircon Rec_Simulated	95%	94%	93%	95%
Zircon Rec_Actual	98%	97%	98%	97%

Figure 4. East Mine minibulk sampled localities with their percentage ratios versus the simulated and production zircon recoveries.



	Q1-2019	Q2-2019	Q3-2019	Q4-2019
East Pit	94%	14%	10%	51%
Centre Pit	0%	70%	32%	4%
West Pit	6%	15%	58%	45%
Zircon Rec_Simulated	85%	89%	95%	91%
Zircon Rec_Actual	89%	87%	90%	88%

Figure 5. West Mine minibulk sampled pit boundaries with their percentage ratios versus the simulated and production zircon recoveries.

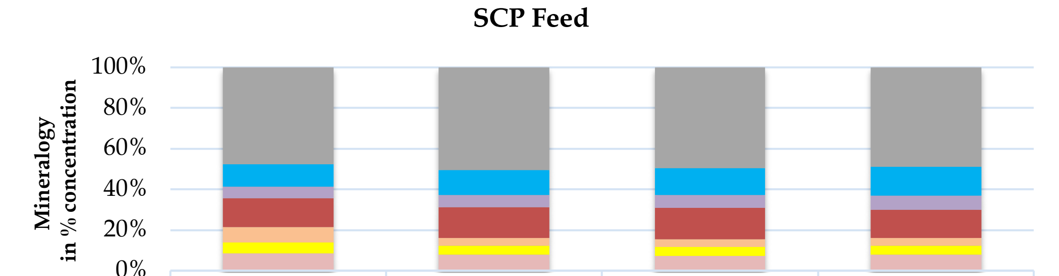
MINIBULK SIMULATION AND ACTUAL PRODUCTION PERFORMANCE: SECONDARY CONCENTRATION PLANT

The SCP feed chemistry was generated using the QEMSCAN BMA analysis of the combined PCP East and PCP West concentrate blend at a ratio of 2:1, after the concentrate upgrade at the PCP stage. The valuable minerals reported are zircon, rutile, and ilmenite. The major gangue-reported minerals are almandine, pyroxene, quartz, and iron oxides. From these gangue minerals, the magnetic and paramagnetic minerals such as garnets (i.e., amandine) have a big negative impact on SCP processing as they compete with the valuables for mineral processing and recovery because the separation is driven by magnetism to separate the magnetic from the non-magnetic minerals.

The SCP has a zircon and ilmenite grade lock on the production of the final product for the non-magnetic and magnetic concentrates respectively. A grade lock is a concentration quality specification. For all four quarters, the feed quality was more or less the same in terms of the mineralogy (Figure 6), with similar observations for the final SCP ilmenite, zircon, and rutile grade concentration (Figure 7). However, there are differences in performance in generating the final SCP mineral recoveries (Figure 7). This indicates that there is another metallurgical attribute playing a role during the mineral separation process in recovering the valuable minerals, and that is most likely the liberation of the minerals in the different concentration blend samples.

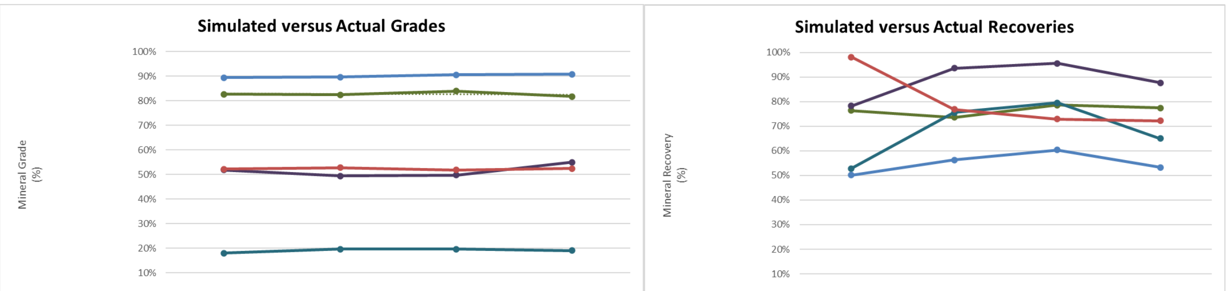
The simulation captured the three main SCP mineral products, zircon, ilmenite, and rutile. Due to the application of the grade lock on the actual production performance, only ilmenite and zircon will be used in the comparison with the simulated results. For all four blended samples, the simulated and actual SCP final product is very similar for the zircon and ilmenite concentration grades. The mineral recoveries are very inconsistent when compared to the actual production environment. The pattern of general inconsistency in the mineral recovery has since been observed in the actual production environment based on mine historical data that is not in the public domain. As previously stated, the effect might be due to the level of mineral liberation as a metallurgical attribute that affects mineral recovery at the SCP stage, as well as the concentration of the competing gangue minerals such as garnets during the magnetic separation.

With very minimal data points a grade and recovery graph has been plotted (Figure 8). The theoretical relationship that can be depicted in such a graph is that there is a maximum recovery of minerals at a given grade, meaning that the grade can reach a specific threshold and the recovery starts to decline or remain consistent. Figure 8 for the simulated grade recovery graph deduces this relationship very well for the zircon and ilmenite, and rutile does not necessarily follow the same concept. This might be due to the design of the SCP grade recovery philosophy to get maximum input where a grade lock is applied in the individual processing circuit for only zircon and ilmenite respectively, and not for the rutile mineral. The actual SCP grade recovery graph (Figure 8) however does not show this relationship clearly as there is less plant control in real-time during the mineral processing flowsheet in the actual environment. Such control is the ability to account for concentration quality and mineral liberation in various stages within the SCP circuit. The control samples only focus on concentration quality which is taken ahead of sample reporting turnaround time, and it has also been historically captured to be the case as compared to simulated data studies, and due to the mineral liberation phenomena, driving the mineral recovery.



	Q1-2019	Q2-2019	Q3-2019	Q4-2019
ilmenite	41,3	43,5	43,1	41,7
zircon	9,41	10,65	11,42	12,17
rutile	4,9	5,2	5,4	5,7
almandine	12,3	12,8	13,5	11,9
pyroxene	6,6	3,5	3,4	3,3
quartz	4,7	3,6	3,8	3,6
Fe-oxides	7,2	6,9	6,3	6,7

Figure 6. Secondary concentration process feed mineralogy.



	Q1-2019	Q2-2019	Q3-2019	Q4-2019
Ilmenite Grade_Simulated	83%	82%	84%	82%
Zircon Grade_Simulated	52%	49%	50%	55%
Rutile Grade_Simulated	18%	20%	20%	19%
Ilmenite Grade_Actual	89%	90%	91%	91%
Zircon Grade_Actual	52%	53%	52%	52%

	Q1-2019	Q2-2019	Q3-2019	Q4-2019
Ilmenite Rec_Simulated	76%	74%	79%	77%
Zircon Rec_Simulated	78%	94%	96%	88%
Rutile Rec_Simulated	53%	76%	80%	65%
Ilemite Rec_Actual	50%	56%	60%	53%
Zircon Rec_Actual	98%	77%	73%	72%

Figure 7. Secondary concentration process simulated vs actual product grades and recoveries.

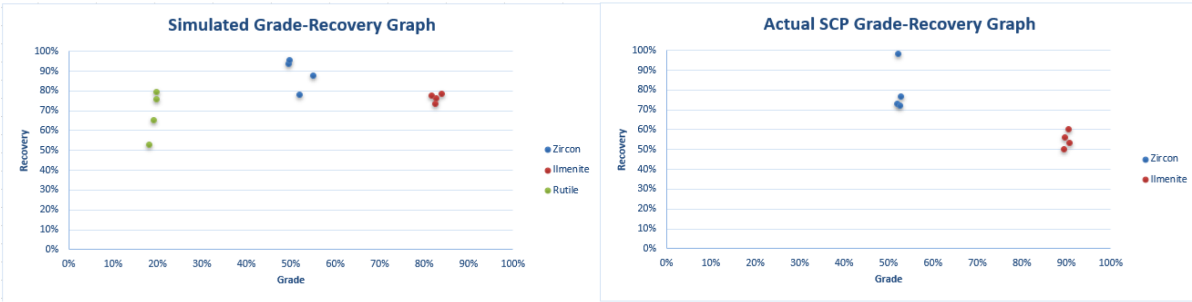


Figure 8. Simulated and SCP actual grade and recovery graphs.

CONCLUSION

The minibulk ore characterisation approach produced acceptable results inclusive of the comparison between the actual production environment for PCP and SCP processes and the processing simulation based on different mining blends. The PCP data gave a good correlation for both simulated and actual production zircon recoveries, which means mineral processing is not necessarily dependent on material blending. The SCP gave the same trend for the final mineral production grades; however the mineral recovery is different, looking at simulated results versus the actual production environment. This inconsistent recovery behaviour has been historically captured and observed for this mineral processing stage. It is apparent that it is independent of the ore blend sent for processing, where metallurgists struggle with capturing a direct trend for the overall mineral recovery at the SCP stage. The zircon mineral recovery is consistent for the simulated versus actual. datasets. Unfortunately, the minibulk simulation cannot capture the uncertainty brought in by the dynamic changes of the mining operation such as breakdowns, grade variability etc. This leads to changing the plan to be able to deliver consistent material, tonnages, and grades to the plant. Dynamic changes also take place in mineral processing, and they are still not as well explored for this study. The overall study managed to develop a methodology to characterise ROM samples into concentrate at different stages of the mineral processing, therefore geometallurgical modelling is possible for the future of the Namakwa Sands mine.

RECOMMENDATION

Minimal data was used to draw various relations including the grade and recovery graph. For further data calibration, the rest of the minibulk campaigns should be integrated into a joint database for publication. The effect of dynamic changes is not significantly captured in the simulation data and the actual production recoveries for this test study, considering the different mine plan blends to the PCP to SCP simulation and the actual production in this study. Further investigation can be explored to test the hypothesis that dynamic changes have some level of impact on mineral processing performance. This can also include LOM consideration for the minibulk sampling approach that will cater for the variability of the ore at depth and not rely on sampling simulation, and sample areas as per the mine plan in real-time. Investigate further the mineral liberation metallurgical characterisation and the impact it has on the final recovery of the SCP valuables. This investigation can also be extended to understand the relationship between mineral liberation and the recovery of the ilmenite since the results were relatively different for the simulated vs actual, and the inconsistency has been generally noted to be the case in the actual production environment.

Finalising the calibration will enable geometallurgical modelling of the orebody, and address uncertainties that lie with the current forecasting issues that arise in mineral processing when there is no geometallurgical data in making decisions. Since the minibulk simulation generates big data, and the focus currently is on relationships that are known, it will be best to incorporate operations research techniques and tools to manage the data optimally. This can potentially derive other relationships within the data that can help improve the simulation as well as make development improvements in the actual mineral processing environment. Such tools are not limited to applying global optimisation models that use a heuristic algorithm to find an optimal solution. Examples of heuristic algorithms are hybrid and simulated annealing algorithms, which are commonly used for mineral processing problems and handling complex data.

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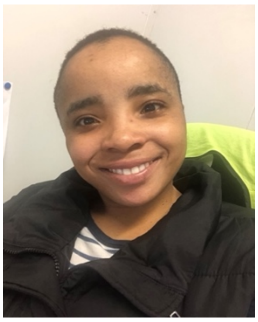

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KD Tshivhase has over 9 years of experience working in heavy mineral sand open pit mines as a geologist at Tronox South Africa (Namakwa Sands and KZN Sands), specializing in geometallurgy and process solutions, ore characterization, mineralogical studies and conducting MRM technology development-based research. She has been in serval geology roles throughout her career development; from a graduate geologist, project geologist to now a senior geologist. She also had job shadowing and acting position capacities such as senior exploration geologist and resource estimation geologist. She is also affiliated with SACNASP (South African Council for Natural Scientists) as a professional natural scientist.