Geometallurgy Conference 2025

Future-Ready Geometallurgy: Trusted Data, Advanced Tools, Smarter Decisions

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Abstract Book

14-15 October 2025

Glenburn Lodge and Spa, Muldersdrift

THE SOUTHERN AFRICAN INSTITUTE OF MINING AND METALLURGY JOHANNESBURG 2025

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FOREWORD

It is with great enthusiasm that the organising committee welcomes you to the third SAIMM Geometallurgy Conference. This year's theme, *Future-Ready Geometallurgy*, explores strategies for generating trustworthy data through the steady application of machine learning, novel sensors, digital twins, and Industry 4.0 technologies in mining. While geometallurgy is now widely recognised as a refined, multidisciplinary approach to enhancing the value of ore deposits, it is critical that practitioners have access to reliable data and innovative tools to enable its success. These empower the industry to make more timely and informed decisions in mine planning and metallurgical plant optimisation.

We are delighted to welcome two keynote presentations by international experts in the field: Wendy Ware (Datarock, Australia) and Adam Johnston (Transmin Metallurgical Consultants, UK). Both will also lead concurrent pre-conference workshops. In addition, we look forward to a diverse range of papers presented by contributors from both academia and industry. These will explore key themes including sampling, standardised reporting methods, geostatistics, data integration, smart workflows, predictive modelling, and a variety of project and operational geometallurgy case studies. The conference programme concludes with a post-conference field trip to Mintek, South Africa's national mineral research and technology organisation. This full-day visit will offer an in-depth look at Mintek's various divisions and facilities that support the mining industry. As the organising committee, we hope this conference provides each of you with a valuable platform for learning, engagement, and networking, and that it sparks innovative research and development in geometallurgy.

We extend our sincere thanks and appreciation to the keynote presenters, authors, reviewers, exhibitors, and sponsors for generously sharing their time, resources, and expertise to make this conference possible. We also gratefully acknowledge the contributions of the Mineralogical Association of South Africa and the Geological Society of South Africa in supporting the organisation and promotion of the event. Special thanks go to Gugu Charlie and her team at the SAIMM for their outstanding coordination and management of the conference.

On behalf of the Organising Committee:

Professor Megan Becker (MSAIMM, FGSSA)

Conference Chair

Contents

Page No

Conference Chairperson's CV's 1

Keynote Presenters CV 2

The geomet shift – A decision-first approach for the future of mining
W. Ware 4

Reducing processing and cost risks for new processing plants through effective design simulation
S.K. Edwards, N.C. Steenkamp 5

Data-driven delineation of geometallurgical domains in porphyry copper systems
T. Mombe, G.T. Nwaila 7

Are variational gaussian processes the missing link in predictive geometallurgy?
G.T. Nwaila, Í.G. Gonçalves 8

Establishing QAQC protocols for reliable geometallurgical modelling in bulk commodities
L. Tafur 10

A guideline for representative geometallurgical sampling
T. Scott 12

Mineralogy as a predictor of comminution behavior for Merensky Reef low-grade Ores
V. Notole, G.T. Nwaila, M. Safari, S. Ndlovu 13

Further development of geometallurgical proxies to predict A*b of the cemented hard layers in a mineral sands deposit
S. Mgoduka, A. van der Westhuizen, M. Becker 15

Addressing the elephant in the room: Integrating diamond breakage into Kimberlite geometallurgy
S. Burness, S. Bremner, M. Becker, G.H. Howarth, A.N. Mainza 16

Advancing geometallurgical modelling with machine learning: Recovery and comminution hardness estimation at Mogalakwena Platinum mine
C.N. Govender, T. Scott 17

Differentiation of iron oxides using modern automated scanning electron microscopy
K. Youlton, L. Vonopartis, S. Poelinca, R. Harrison 19

The role of mineralogy in geometallurgy
M. Becker 20

Is it time to rethink gold tailings characterisation using real time portable and automated characterisation technologies?
X.C. Simelane, S. Ndlovu, G.T. Nwaila 21

Maximising throughput of ore characterisation by means of automated mineralogy
M. Dosbaba 23

Contents

Page No

Communicating uncertainty in geometallurgical models
A. Johnston 25

Deportment of gold in historical Witwatersrand tailings: Implications for geometallurgy
S. Chingwaru, B.P. von der Heyden, M. Tadie 26

Development of beneficiation processes for low-grade manganese ores for the ferroalloy industry
D.A. Barrett, M. Tadie, B.P. von der Heyden, R. Cromarty 27

Hydrometallurgical pretreatments for the enhancement of magnetic separation of ferruginous manganese tailings
E. Olivier, M. Tadie, B.P. von der Heyden, P. van Wyk 28

Geometallurgy in the Kalahari Copper Belt, Ngami district Botswana
J.K. Mangwiro, A. Bayani, K. Kgotlele, R. Situmorang, G. Mosanga,M. Babusi 29

Linking mineralogy to comminution behaviour in the Kalahari manganese field
M. Tadie, B.P. von der Heyden, P. Mathebula, L. van Eeden 31

Understanding the economic importance and scientific significance of oceanic Fe-Mn crusts
A. Menzies, P. Josso 32

Textural Implications of iron ore beneficiation outcomes based on jigging – a case study
K. Netshikulwe, E.R. Manjengwa, B.P. von der Heyden 33

Geometallurgy learnings from First Quantum Minerals' Zambian Operations
L. Little, A. Kottgen, M. Chibesa, P. Ogilvie 34

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Conference Chairperson

Megan Becker

Researcher
University of Cape Town

Professor Megan Becker is a researcher at the Centre for Minerals Research within the Department of Chemical Engineering at the University of Cape Town (UCT). She holds degrees in Geological Sciences (UCT) and Metallurgical Engineering (UP). Her research focuses on using mineralogical insights to better understand, optimize, and predict key processes in the mining industry—considering both technical and environmental factors.

To date, she has supervised nearly 50 postgraduate students and published over 100 peer-reviewed papers. Professor Becker is a fellow of the Geological Society of South Africa and a member of the South African Institute for Mining and Metallurgy. She currently serves as the Chairperson of the committee organising of the SAIMM Geometallurgy Conference, and is a member of the technical committee organising the next International Mineral Processing Conference taking place in Cape Town in Sept 2026, as well as a consultant for the Minerals Engineering International Process Mineralogy Conference series

Keynote Presenters

Wendy Ware

Geomet Advisor & Business Development Manager
Datarock

Wendy Ware is a geoscientist and systems thinker with over 20 years of experience in the mining industry. Currently at Datarock, she works across geoscience and business development, helping mining companies make better, faster decisions through integrated, data-informed geomet workflows. Her work spans the full mining value chain—from exploration and design through to operations and closure—and focuses on turning rock data into timely insight. Wendy has led multi-disciplinary teams across a wide range of commodities and regions, always with an eye on practical outcomes that support operational and strategic decisions. In her keynote, Wendy challenges traditional views of geometallurgy, proposing a shift toward connected systems that are decision-ready by default—supporting an industry under growing pressure to deliver value with speed, clarity, and confidence.

Adam Johnston

Chief Metallurgist
Transmin Metallurgical Consultants

Graduate of Western Australian School of Mines with extensive experience in plant audits, process optimization, and testwork supervision across global operations. A Fellow of AusIMM and Chartered Professional (Metallurgy), with over 30 years of expertise in metallurgical process engineering and consulting. As Chief Metallurgist for Transmin Metallurgical Consultants in the UK and Peru, led numerous world-class projects including Mina Justa and Constancia. Creator of the industry-leading Cancha geometallurgy software.

The geomet shift – A decision-first approach for the future of mining

W. Ware
Datarock, Australia

In a mining industry under pressure to be faster, leaner, and more transparent, the role of geometallurgy (Geomet) is evolving. It is no longer just about understanding ore — it is about enabling better decisions, earlier. This keynote explores how Geomet can drive industry transformation when reimagined as a future-ready system — one that delivers the right insight about the rocks, at the right time, to support decisions in mine design, planning, ore control, and processing.

Through the lens of a structured and integrated framework, the paper presents a practical and forward-thinking view of how drilling, sensing, testing, modelling, prediction and reconciliation can be organised into a responsive, connected ecosystem — a system of systems. The message is simple but urgent: value is eroded or lost when decisions are delayed. To transform mining, we must design Geomet systems that are decision-ready by default—timely, scalable, and deeply integrated across the value chain.

Reducing processing and cost risks for new processing plants through effective design simulation

S.K. Edwards[1], N.C. Steenkamp[2]
[1]SKEmet Pty Ltd
[2]GeoScience Professional

Mineral deposits are increasingly becoming lower grade and mineralogically complex. This poses significant cost implications, specifically in the small and junior mining operational space. The geometallurgical program aims to reduce uncertainty on the processing requirements by defining elements such as mineralogy, grain size, hardness and reagent responsiveness. Exploration results often become disconnected from the prospectivity once metallurgical variability has indicated the extent of recovery losses, higher reagent consumption and equipment wear. Discovery of these issues too late in the study phase could result in costly design changes, such as additional mills, slurry agglomerators or reagent recovery systems. These design and cost risks can be prevented or mitigated by undertaking process simulation during the concept phase and identify and optimise aspects related to optimised grind size, flotation reagents, leach times and ore blending parameters, ultimately maximising recoveries, while optimising reagent consumption and power demand.

Using a premium simulation software package, METSIM®, the processing challenges with today's complex ores can be addressed. METSIM® can predict the response of a system to a set of conditions and inputs with which it is presented. The following approach demonstrates how the synergy between predictive analytics and process simulation within METSIM® facilitates a holistic view of mining operations. The proposed process flow sheet is re-created in METSIM®, entering in drill-core mineralogy and chemical analysis results, process plant design criteria and required equipment specifications. The model is run, and the ore is digitally fed through each section of the flow sheet. This results in the most cost-effective mineralogical recoveries for the given process conditions. Discard and vented streams are then digitally processed enabling the development of sustainable processing strategies. The proposed mine block model and the mining sequence are then imported into a dynamic model to review the effect of the Life-of-Mine (LoM) on the process plant. By putting these models together in METSIM®, we can create more accurate and flexible resource plans that help mining companies make better decisions. This approach not only helps improve mining's effectiveness but also aims to protect the environment, setting a good example for the future of mining.

Samantha Kay Edwards

Senior Process Engineer
SKEmet Pty Ltd

Samantha is a qualified and experienced process engineer with commissioning, operational and design experience; she has spent the past 20 years as a Process Engineer focussing within the EPCM space. She has recently moved away from EPCMs and now owns her own consulting company, SKEmet (Pty) Ltd, which specialises in Junior mining and process plant optimization utilizing premium simulation software.

SKEmet (Pty) Ltd delivers comprehensive process engineering solutions, including multi-disciplinary detailed plant design, mechanical equipment sizing and procurement, process control, cost estimation, and technical evaluations. Under Samantha's leadership, these services are meticulously tailored to meet each of her client's specific needs, ensuring the delivery of accurate and dependable solutions within tight project timelines. This enables clients to make informed financial decisions with confidence. Samantha leverages the capabilities of METSIM®, a robust process modelling software, to perform accurate mass and energy balances across complex systems, reinforcing the reliability of SKEmet's engineering outcomes.

Furthermore, Samantha holds a Postgraduate Diploma in Business Administration from the WITS Business School, she leverages on the ability to identify her client's needs, engage with technical experts and perform strategic planning according to identified needs. Samantha retains a keen appreciation and understanding of the identification, development and management of business opportunities.

This diversified combination of technical and business dexterity has stood her in good stead as a professional of exceptional value, providing the capability and necessary technical capacity to bid for and deliver on sector specific projects and tender solutions.

Data-driven delineation of geometallurgical domains in porphyry copper systems

T. Mombe, G.T Nwaila
University of the Witwatersrand, South Africa

Partitioning an orebody into geospatially coherent domains supports stationarity and improves the reliability of resource estimates and metallurgical forecasts. Geological bodies exhibiting consistent statistical properties are considered stationary domains, though such conditions are rarely uniform throughout a deposit. Conventional domaining is predominantly based on lithological or ore grade interpretations, which often overlook subtle yet economically substantial variations in mineralogical, geochemical, and metallurgical attributes that increase uncertainty in recovery predictions. Unsupervised clustering techniques have been increasingly adopted to define stationary domains more effectively.

This paper presents a machine learning framework applied to a porphyry copper dataset, which includes several geochemical variables (Cu, Fe, Au, Ag) and processing variables (Bond Work Index, Recovery). A customised signed-distance function was employed to optimise variable weights through hyperparameter tuning. This adaptive weighting ensured that variables most influential in defining coherent domains were emphasised, preventing high-variance features from overshadowing lower-variance but informative attributes. Pairwise distances computed using the customised metric underwent multidimensional scaling to embed samples in a lower-dimensional space. K-Means clustering applied in this space subsequently partitioned the transformed data into four candidate domains. Cluster validity was evaluated using silhouette scores and Davies–Bouldin indices, guiding the selection of optimal domains. Principal Component Analysis within each domain validated internal consistency and revealed dominant compositional patterns, with the first three components accounting for over 70% of the variance. Results demonstrate that this workflow yields domains with reduced internal variability while maintaining geological plausibility. The identified domains (potassic, phyllic, argillic and propylitic) align with established porphyry copper deposit alteration zones.

Accurate delineation of geospatial domains enables reliable geometallurgical block estimates and improves confidence intervals in process models. Domains with consistent metallurgical response inform blending strategies, milling response and recovery planning. Automating weighting and clustering reduces reliance on subjective decisions and ensures reproducibility across datasets. The resulting framework links orebody heterogeneity with processing behaviour, informing mine planning and design. A data-driven domaining approach thereby addresses key industry challenges of heterogeneity and non-stationarity and demonstrates how advanced analytics can improve value extraction.

Tariro Mombe
PhD Researcher
Wits Mining Institute

Tariro Mombe is a geoscientist and PhD researcher specialising in data-driven mineral resource management. Her expertise spans geometallurgy, resource estimation, and machine learning, with a focus on improving digital workflows that support real-time mine optimisation. She holds a Master of Science (MSc) in Geology from the University of the Witwatersrand, where she applied machine learning techniques to predict in-situ gold grades in the Witwatersrand Basin. She is currently based at the Wits Mining Institute, where her research centres on developing a machine learning–based metal accounting system. This work integrates geological, spatial, and process data to support real-time tracking of material movement and composition – thereby improving how resources, particularly critical raw materials, are monitored, managed, and reconciled. Her broader interests lie in using AI and automation to drive efficiency and sustainability across the mining value chain.

Are variational gaussian processes the missing link in predictive geometallurgy?

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The Assen iron ore deposit, located ~50 km northwest of Pretoria within the Transvaal Supergroup's Penge Formation in South Africa, hosts a structurally complex banded iron formation (BIF) with multiple lithofacies, including high grade hematite (>60 % Fe), and lower grade BIF (<35 % Fe) whose compositions and densities vary due to supergene enrichment and dolerite intrusion influences. Traditional approaches to geometallurgical modelling often decouple lithology, grade, and density, leading to sub optimal resource estimation and processing design. In this paper we introduce an integrated, probabilistic framework using variational Gaussian processes (VGPs) to simultaneously model 3D lithological domains, multi element assays (e.g., Fe and proxy oxides such as SiO_2, CaO), and bulk density, with the aim of improving predictive accuracy and supporting iron ore processing decisions. Our workflow begins with implicit geological modelling, that is, drillhole logs are used to construct a continuous 3D representation of Assen's lithological architecture, honouring the spatial distributions of geodomains. These domains are then populated with assay data (Fe, SiO_2, CaO, Al_2O_3) and density measurements, properties known to both co-vary and influence extraction outcomes. A sparse variational Gaussian process model is implemented to jointly predict these variables, with multi-output kernels capturing covariance across attributes and lithofacies. Training leverages both spatial location and lithological domain as inputs, enabling the model to learn how geochemistry and density co-vary in space and by rock type. The VGP approach yields a dynamic 3-D geometallurgical block model together with internally consistent uncertainty estimates. Importantly, the learned covariance structure reveals systematic changes in density relative to ore properties. These relationships echo known supergene enrichment patterns at Assen and offer valuable insights for ore beneficiation, where impurity removal and concentrate grade depend on accurate spatial targeting. Bulk density modelling is often neglected in predictive geometallurgy, yet it is critical for mass balance, reserve estimation, and process plant design. By integrating density in the VGP framework, we derive 3D volumetric tonnage models under uncertainty, information essential to crushers, gravity circuits, or magnetic separation systems where feed density governs throughput and energy consumption. For instance, high density hematite zones near dolerite contacts may be prioritised for lump production, whereas lower-density BIF may be better suited to fines and grinding circuits. To translate these data-driven insights into metallurgical implications, we simulate two processing scenarios: a gravity-magnetic route targeting >60% Fe product for lump or sinter feed, and a beneficiation route for fines requiring removal of SiO□ and CaO. The VGP-based resource model informs feed control regimes by flagging zones with elevated impurity risks or density anomalies. This can significantly reduce the variability in plant feed, translating to stable product quality and lower operating costs. Ultimately, this paper showcases VGPs as a powerful tool for predictive geometallurgy, enabling integrated modelling of multiple variables across lithologies. The framework is extendable to other iron ore systems and commodity chains, paving the way for truly predictive, circular economy aligned mineral value chains.

Keywords: Variational Gaussian Processes, Predictive Geometallurgy, Iron Ore, Bulk Density Modelling, Supergene Enrichment, Implicit Geological Modelling

Glen Nwaila

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Glen Nwaila is an Associate Professor and Deputy Head of the School of Geosciences at the University of the Witwatersrand. He is also the Director of the African Research Centre for Ore Systems Science (CORES) and former Director of the Wits Mining Institute. Glen holds a PhD (University of Würzburg) and an MSc in Chemical Engineering (University of Cape Town) and is a Fellow of the Geological Society of South Africa (FGSSA). His work integrates geometallurgy, geostatistics and machine learning. He leads multi-partner collaborations with academia, government and industry.

Establishing QAQC protocols for reliable geometallurgical modelling in bulk commodities

L. Tafur
Kumba Iron Ore, South Africa

Quality Assurance and Quality Control (QAQC) is a well-established practice in geodata collection. However, geometallurgical test work represents a deviation from standard procedures in bulk commodities. To address this, a tailored suite of QAQC protocols was developed to support the Kumba geometallurgical workflow. These protocols are essential for ensuring the reliability and defensibility of geometallurgical models.

The on-site Kumba geometallurgical workflow is structured into three streams: drillhole-, sample-, and composite-level.

- Drillhole-level QAQC ensures spatial accuracy and logging consistency.
- Sample-level QAQC applies standard exploration practices, including Certified Reference Materials and duplicates. However, additional controls were introduced for samples submitted for hardness testing (e.g., UCS) to address specific test sensitivities.
- Composite-level QAQC required the development of new best practices to mitigate risks such as sample swaps, poor mass splitting, and chemical biases introduced during fragmentation.

Given the typically small size of geometallurgical datasets, each data point holds significant value. Data loss due to acquisition errors not only reduces dataset integrity but also wastes time and resources. A robust QAQC protocol, subject to regular audits, is therefore critical to minimise downstream data loss and uphold model quality.

Lorena Tafur

Specialist Resource Modelling Geologist
Kumba Iron Ore Ltd

Lorena Tafur is a Specialist Resource Modelling Geologist at Kumba Iron Ore.

After completing her Honours and Master's degrees in Geology at the University of Cape Town, Lorena joined Kumba in 2019 as a Professional in Training. During the graduate programme, she gained experience across Exploration, Database Management, and Geometallurgy.

In 2020, she presented her work on the initial interpretation of RhoVol data collected during the early stages of the Geometallurgy Campaign at Kolomela Mine. As this dataset had not been previously explored within Kumba's geometallurgical context, her efforts in quality control and preliminary analysis provided valuable insights that informed early approaches to managing feed variability to the UHDMS plant.

Her growing interest in Geometallurgy led to her appointment as the Geometallurgist at Kolomela Mine, where she played a key role in advancing the recognition of geometallurgy's value within the business.

In 2022, Lorena represented Kumba at the IOM3 Geometallurgy Conference in London, sharing insights from her work and contributing to the broader geomet community.

In 2024, she transitioned into Resource Modelling, with the goal of deepening her expertise in geological end-products critical to the mining value chain. In this role, she is responsible for delivering frequent and reliable geological model updates, while also leading improvements in modelling workflows to enhance efficiency and accuracy.

Lorena continues to maintain a strong interest in database management and on-site QAQC, ensuring high-quality data for geological modelling and decision-making.

A guideline for representative geometallurgical sampling

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Orebodies are inherently heterogeneous; with mineralogical, physical, and chemical characteristics varying significantly throughout the deposit. Effective geometallurgical programs aim to capture and quantify this variability through representative sampling and testwork. Building a geometallurgical program on a solid foundation of representative samples ensures that resulting metallurgical performance predictions are reliable and the geometallurgical program meets its objectives.

The Geometallurgy Subcommittee of the Global Mining Guidelines Group is drafting a guideline for representative sampling, aiming to provide clear, actionable guidance on geometallurgical sampling. This presentation will outline project progress thus far, explaining the basic principles of representative geometallurgical sampling, followed by a case study demonstrating the application of these principles. To ensure a robust, industry-accepted guideline, volunteers are welcome to provide feedback on the project, as well as offer future contributions.

Tricia Scott

Principal, Geomet Estimation
Anglo America

Tricia Scott is the Principal, Geomet Estimation at Anglo American, where she leads the development and delivery of spatial geometallurgical models. She began her career at Kumba Iron Ore, gaining experience across exploration, production geology, and geometallurgy, before moving to Anglo American Corporate in 2021. Since then, she has provided geometallurgical support to global operations, including platinum, iron ore, and copper, with a focus on model development and implementation.

Her geometallurgical experience spans from drill rig management, logging, sampling, and data collection through to model development and implementation. Tricia finds reward in working within multidisciplinary teams and in building models that support informed, value-driven decisions. She believes that in a rapidly changing mining industry, it is thorough ore body characterization and an appreciation of variability that provide the foundation for achieving business, environmental, and strategic goals.

Mineralogy as a predictor of comminution behaviour for Merensky Reef low-grade Ores

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Geometallurgical frameworks bring together spatially resolved measurements of ore characteristics and process design considerations. However, the variability of platinum group mineral (PGM) bearing ores such as the Merensky Reef of the Bushveld Complex complicates their application in economically viable mine-to-mill operations. This study aims to develop an integrated geometallurgical framework that combines mineralogical characterization, comminution testing, and machine learning to predict energy demand and liberation behaviour in complex, low-grade PGM ores. Understanding how mineralogical attributes govern comminution response is important for optimising energy consumption and improving liberation prior to downstream beneficiation. In this paper, we evaluated two low-grade PGM-bearing ore types (Ore A and Ore B) from the Merensky Reef by means of automated mineralogy (e.g. TIMA) and standardised laboratory milling tests. We maintained identical wet-milling conditions (i.e., use of chrome rods and fixed grinding duration) for both samples to ensure direct comparison of particle size distributions and grindability metrics. Ore B which is richer in sulphide (i.e., pentlandite, pyrrhotite and chalcopyrite) and secondary alteration phases (e.g., serpentine, chloride and talc) with finer grain sizes demonstrated a better comminution efficiency compared to the coarser, silicate-dominated Ore A. Notably, variations in plagioclase–pyroxene ratios (i.e., 1:2.44 and 1:1.68) and grain-boundary textures exerted a strong control on ore hardness and fracture behaviour, while liberation trends correlated closely with grain size and textural complexity. We developed a multi-scale, image-based approach to characterise mineral textures. TIMA BSE micrographs were processed using Local Binary Patterns (LBP) and contrast enhancement, then segmented by K-means clustering. Silhouette analysis confirmed two distinct textural clusters (K = 2) for PGE host minerals (i.e., isoferroplatinum and pyrrhotite), which were further validated via LBP-intensity scatter plots and cluster frequency distributions. To augment training data, we used Generative Adversarial Networks (GANs), improving the diversity of textural examples for Convolutional Neural Network (CNN) classification. A CNN trained on both original and GAN-enhanced datasets achieved over 90% accuracy in recognising mineral textures under limited sample availability. Comminution performance was modelled using Bond Work Index energy simulations. We applied a logistic liberation model as a function of P_{80} (grind size) and executed Monte Carlo simulations (n = 1000) to capture variability in feed size (F_{80}), median size (P_{50}) and grindability parameters. Results reveal that Ore A required ~ 16.2 kWh/t to achieve 50% liberation at P_{80} = 20 µm, whereas Ore B required about 15.5 kWh/t under the same conditions. Beyond this grind size, energy demand rose non-linearly, exhibiting diminishing returns in liberation gain. These results imply that automated mineralogical analysis, quantitative texture metrics and machine learning can forecast comminution behaviour, energy demand and liberation performance, providing a data-driven framework for mine-to-mill optimisation in complex, low-grade PGE systems.

Keywords: geometallurgy, mineralogy, comminution, machine learning, Bond Work Index, platinum group elements

Viwe Notole

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Viwe is a geoscientist with special interest in geometallurgy and geodata analysis, with two years of hands-on professional experience in mineral characterisation, mineral processing, geohydrology, database management, and geological data analysis. He has worked as a consultant junior geologist, conducting fieldwork that involved geological mapping, collection of geological and hydrogeological data, as well as overseeing borehole drilling and test-pumping activities. He served as intern mineralogist at Mintek, geohydrologist at Umvoto Africa, and a geologist at A&B Global Mining.

Viwe holds a B.Sc. in Geology and Chemistry, a B.Sc. Hons. in Geology, and an M.Sc. in Economic Geology (GeoMetallurgy) from the University of the Witwatersrand. He is currently completing his Ph.D. at the same university, with a focus on metal accounting, mineral processing, and machine learning.

Further development of geometallurgical proxies to predict A*b of the cemented hard layers in a mineral sands deposit

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The variations in the mineralogical properties of an orebody have a direct impact on the mining excavation rates and comminution throughput, and consequently, the profitability of a mine. This is the case for a local mineral sands mine. Mineral sands, which normally consist of unconsolidated sands, have cemented over time at this locality to form what are locally referred to as "cemented hard layers" or CHLs. A preliminary study by Sikushumane et al., (2025) on 43 samples aimed at quantifying the variability in hardness of these CHLs showed that MgO, SiO_2, LOI and Equotip HLS have statistically significant correlations to A*b. This study adds a further 48 samples to the database, which now show that in addition to the known vertical variability of the CHLs, lateral variability is also significant. New models linking XRF chemistry, mineralogy, and Equotip HLS with A*b are developed here, which also explore non-linear relationships for proxy development. Correlations to Bond Work Index are also explored. Consideration is also given to class-specific models or trends vs generic models of the CHLs. Ultimately, the result of this work could be embedded into the larger mine database to make more timely decisions for mine planning and plant optimisation.

Keywords: Cemented hard layers, A*b

Sibulele Mgoduka

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Sibulele Mgoduka is a Master of Science candidate in Geometallurgy at the University of Cape Town and holds a Bachelor of Science in Chemical Engineering, completed with First-Class Honours. Her research focuses on understanding ore hardness variability and developing predictive approaches to improve ore characterization and process performance, while her broader interests include tackling complex challenges, sustainability projects, and process optimization.

Addressing the elephant in the room: Integrating diamond breakage into Kimberlite geometallurgy

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Published accounts of existing geometallurgy programmes for kimberlites largely focus on the effects of ore variability on throughput, equipment performance, power and water consumption, and diamond yield (% recovery to DMS concentrate). But the value of kimberlite ore lies not in the host rock itself but in the discrete diamonds it contains. Since the central aim of geometallurgy is to anticipate and manage risks linked to ore variability, this raises an important question: why has relatively little emphasis been placed on factors unique to kimberlites? These include the role of indicator minerals in predicting grade, the diverse characteristics of diamonds that influence recovery, and the significant risks associated with diamond breakage during processing. To some extent, this has been driven by the proprietary practices within the industry.

Recent research at UCT investigates diamond breakage through two complementary approaches: detailed mineralogical characterisation of diamond parcels and controlled laboratory experiments using synthetic simulants embedded within kimberlite analogues to better understand breakage mechanisms. Natural geological breakage is unavoidable, with twin plane inversions, cleavage along (111) planes, and inclusions acting as primary controls. Mechanical processing can amplify breakage in two ways. First, surface damage occurs through attrition and abrasion, producing tram-line pits and chatter marks on diamond surfaces. Second, internal micro-fractures surrounding inclusions can propagate, leading to more extensive breakage. Simulant tests establish the energy thresholds at which unliberated or partially liberated diamonds are most at risk for severe breakage, highlighting processing stages that threaten diamond recovery. For example, scrubbing, screening, and transport are often linked to surface damage, while suboptimal crusher operation, such as running without proper interparticle crushing or choke feeding, can cause significant volume loss. These insights have led to a framework for characterising and classifying diamond breakage, linking stone properties with the unit operations that pose the highest risk.

Sara Burness

Lecturer
University of Cape Town

Dr. Sara Burness is a lecturer in the Department of Chemical Engineering at the University of Cape Town and is affiliated with the Centre for Minerals Research. Her research focuses on process mineralogy and geometallurgy across a variety of ore deposit types, with particular emphasis on diamond breakage and xenolith studies. She teaches applied mineralogy to undergraduates and process mineralogy and geometallurgy to fourth-year students. Sara holds a unique crossover position funded by the South African Minerals Qualification Authority, designed to bridge Chemical Engineering and Geological Sciences and promote interdisciplinary collaboration. She completed her PhD at the University of the Witwatersrand, investigating sulphur mobility and metallogeny in eclogite xenoliths associated with kimberlite volcanism.

Advancing geometallurgical modelling with machine learning: Recovery and comminution hardness estimation at Mogalakwena Platinum mine

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A key challenge in the integration of geometallurgical data into resource model estimation is the limited availability of high-resolution datasets. This constraint is largely due to the high costs and high sample mass requirements associated with conventional metallurgical testwork, which results in sparse data coverage across the orebody. Additionally, when working with sparse and heterogenous datasets conventional interpolation methods often struggle to capture the complex, non-linear relationships between primary geological attributes and metallurgical responses. To address this, machine learning (ML) offers a promising alternative by leveraging correlations between sparsely sampled geometallurgical data and more densely sampled geological data.

ML techniques have been incorporated into the Geometallurgical modelling workflows to predict plant recovery and comminution hardness parameters—Bond Ball Work Index (BWi) and Drop Weight Index (DWi) using geological assay and mineralogy data at Mogalakwena Platinum Mine. A supervised decision tree-based framework using XGBoost was developed, incorporating bulk modal mineralogy and major element oxide chemistry. The workflow included exploratory data analysis, multivariate imputation using Gaussian Mixture Models, and projection pursuit multivariate transformation for independent simulation of predictor variables. Model training involved hyperparameter optimization and iterative predictor selection, with XGBoost outperforming alternative methods in accuracy and generalization. Model performance was evaluated using five-fold cross-validation.

The DWi model (1044 samples) achieved an R^2 of 0.747 and RMSE of 0.839, while the BWi model (1061 samples) achieved an R^2 of 0.803 and RMSE of 0.928. Analysis of feature importance revealed mineralogical variables such as serpentine, chlorite, amphibole, and clinopyroxene as key contributors to hardness variability.

Recovery models were developed using a dataset of 183 bench-scale flotation test samples from a single pit location. Despite the relatively small sample size, machine learning models developed for Pt, Pd, Cu, and Ni recovery demonstrated strong predictive capability. The combined Pt and Pd (2E) recovery model achieved an R^2 of 0.835 and RMSE of 2.488 on the full dataset. Validation using withheld test data yielded an R^2 of 0.558 and RMSE of 4.314, indicating moderate generalization and highlighting the potential for overfitting. Expanding the training dataset would likely improve model robustness and predictive reliability. Feature importance analysis identified SiO_2, orthopyroxene, serpentine, and amphibole as key drivers of flotation performance, underscoring the critical role of mineralogical composition in recovery estimation. The final ML models were deployed across the block model, enabling high-resolution spatial predictions of metallurgical parameters.

The study demonstrates the application of machine learning to enhance spatial geometallurgical modelling, particularly within complex mineral systems such as the Platreef. By integrating geometallurgical variables into block models at Mogalakwena Mine, the operation has achieved more agile, data-informed decision-making across ore control, mine planning, and metallurgical forecasting and optimisation, delivering actionable insights and, importantly, unlocking additional value for the business.

Caillan Nicholas Govender

Specialist Geometallurgist
Valterra Platinum

I am a Geologist with over a decade of diverse experience spanning mine geology, minerals processing, and geometallurgy, across both underground and open-pit mining operations. I currently serve as a Specialist for Geometallurgical Modelling at Valterra Platinum, where I bring a multidisciplinary approach to ore characterisation, resource development and operational optimization. My expertise lies in enhancing ore control and metallurgical practices through the development of innovative rock characterization workflows and their integration into spatial models using rapid resource modelling techniques. These workflows are designed to improve value-based ore control, optimize mine planning and processing strategies, and support the assessment and implementation of emerging technologies in mining and processing environments.

I am passionate about leveraging geoscientific data to drive strategic decision-making, and I thrive in collaborative environments where technical excellence and innovation are key to unlocking resource value.

Differentiation of iron oxides using modern automated scanning electron microscopy

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Accurate differentiation between hematite and magnetite in mineralised systems is vital for interpreting alteration processes, fluid evolution, and ore-forming environments. However, their overlapping elemental signatures and similar backscattered electron response have historically proven problematic for differentiating these iron oxides using Automated Scanning Electron Microscopy (AutoSEM). While traditional AutoSEM workflows offer rapid and reproducible mineral identification, their capacity to distinguish between hematite and magnetite has been limited, often relying on bulk mineral classifications or complex post-processing.

Limited success has been achieved through highly tailored sample preparation procedures or by incorporating complementary analytical techniques, but these augmentations are time-consuming and not scalable for high-throughput exploration or geometallurgical studies. Consequently, the lack of rapid and reliable differentiation of these phases has hindered the use of AutoSEM in the derivation of iron oxide ratios as proxies for redox conditions, alteration intensity, and mineralisation style.

In this paper, we present a refined AutoSEM (TIMA) approach that enables consistent and reliable differentiation between hematite and magnetite. This is accomplished by a deposit-by-deposit adaptation of classification schemes and calibration of mineral definitions to account for subtle yet significant chemical differences. This includes adjusting elemental thresholds and subsequent elemental signatures to reflect fine-scale variations in Fe/O ratios and trace element incorporation, which influences phase discrimination. The application of this method across a suite of alteration and mineralisation assemblages demonstrates that hematite and magnetite can be reliably resolved using an AutoSEM, including cases of complex intergrowths or replacement textures. The improved phase resolution enables better interpretation of paragenesis, as hematite commonly replaces magnetite in late-stage oxidised conditions.

Therefore, we demonstrate that proper calibration of AutoSEM methods, beyond standardised workflows, can overcome previous limitations; ultimately unlocking the full potential of iron oxide mineralogy as a vector for alteration and mineralisation. The ability to distinguish hematite from magnetite at scale using oxide ratios can be used as a redox proxy to inform geological models and support exploration strategies for one of the largest mining industries.

Kirsten Leigh Youlton
HOD Mineralogy
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Dr Kirsten Youlton is a process mineralogist with over five years of experience in mineralogical investigations, project management, and cross-disciplinary collaboration in the mining and metals industry. She holds a PhD in Geosciences from the University of the Witwatersrand, with a focus on economic geology and metallurgy. Her expertise spans a wide range of commodities—including gold, copper, PGEs, and industrial materials—and she is proficient in advanced mineralogical techniques such as TIMA/QEMSCAN, XRD, SEM-EDS, and optical microscopy. Dr Youlton has held senior roles at SGS and Mintek, where she led high-value technical projects, managed mineralogical instrumentation, and mentored junior staff. She is a published geoscientist with a strong interest in data-driven process optimisation and interdisciplinary problem-solving within the mining sector.

The role of mineralogy in geometallurgy

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University of Cape Town, South Africa

Since the recognition of geometallurgy as a formal activity focused on managing ore variability to mitigate risk across the mining value chain, mineralogy has always been part of the conversation. But is mineralogy something we should measure because it's 'good to have', or can it deliver more value? Suppose we pose the theory statement that mineralogy is the 'blueprint' encapsulating all the primary properties of the rock (including the signatures of the ore-forming and any subsequent alteration processes). In that case, the blueprint will define the response to an applied process. But how should we reconcile things if we cannot prove our theory statement? This paper explores the 'mineralogical approach' to geometallurgy considering mineralogy through the lens of the mineral composition triad and mineral texture. It takes a practical approach to work through the considerations of sampling, mineralogical measurement accuracy, mineralogical measurement descriptors and response variance as factors that could be masking the mineralogical effects. The paper concludes with key take-home thoughts on where mineralogy should be applied to develop models of the necessary accuracy, dependent on the stage of geometallurgy in the mine's life.

Is it time to rethink gold tailings characterisation using real time portable and automated characterisation technologies?

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The Witwatersrand Basin, South Africa's most historically prolific gold-producing region, is home to hundreds of legacy tailings storage facilities (TSFs) that collectively represent one of the world's largest above-ground secondary gold resources. As the global mining sector shifts toward circular economy principles and urban mining strategies, these TSFs have re-emerged as critical targets for resource recovery, environmental remediation, and land revalorisation. However, current approaches to tailings evaluation often rely on outdated or labour-intensive sampling and characterisation protocols that do not fully capture the complex heterogeneity or latent value of these materials. This paper poses a fundamental question: Is it time to rethink how we sample and evaluate gold tailings, particularly using portable and automated technologies capable of real-time, spatially-resolved mineralogical and geochemical analysis? In this paper we present an integrated characterisation framework applied to selected TSFs in the Witwatersrand Basin, combining portable X-ray fluorescence (pXRF), quantitative X-ray diffraction (QXRD), and automated mineralogy via TESCAN Integrated Mineral Analyser (Tescan TIMA). This multi-instrument approach enables a rapid, non-destructive, and spatially aware analysis of tailings material, bridging the gap between field-based reconnaissance and laboratory-scale decision-making.

The pXRF provides near-instant elemental assays, including proxy signals for Au-bearing phases such as Fe, As, S, and trace metals (U, Th), while QXRD captures bulk mineralogical phases associated with gold entrapment and mineral weathering. TIMA, in turn, offers liberation, association, and grain size data critical to understanding gold deportment and materials processing potential. Field campaigns across two TSFs in the East and West Rand goldfields demonstrated that portable and automated instruments can reveal fine-scale variability in TSFs chemistry, lithological layering, and alteration halos, features often missed by conventional grid-based sampling. The pXRF provides near-instant elemental assays that support the identification of gold proxies in Witwatersrand tailings, including Fe and As associated with arsenian pyrite, Ni and Co indicative of Ni-Co pyrite phases, and U, Mo, Cu, Zn, and REEs (e.g., Ce, La, Nd) linked to uraniferous zones and heavy mineral bands. In parallel, the pXRF enables real-time screening of environmental hazard indicators, such as As, Pb, U, Th, Cr, and Mn, which are mobile under acid-generating or redox-altered conditions and pose ecotoxicological risks. pXRF-derived lithogeochemical signatures (e.g., Si, Al, K, Mg, Ca, Ti, P) and detrital provenance indicators (e.g. Zr, Hf, Th, Sc, Ce, Y) aid in interpreting the mineralogical fabric and sediment maturity of tailings material. Complementing this, QXRD captures the bulk mineralogical phases, including quartz, chlorite, muscovite, and secondary oxides, critical for understanding gold entrapment mechanisms, alteration processes, and long-term weathering behaviour. For instance, QXRD patterns indicated significant mineralogical transitions within decimetre intervals, reflecting depositional and diagenetic variation linked to upstream processing routes. TIMA analysis confirmed the association of residual gold with silicates and phosphate mineral phases (to a lesser extent with refractory pyrite), often below the detection limit of bulk assays, but with recoverable potential under alternative flowsheet design. Beyond analytical capabilities, the use of portable tools reduces turnaround time and cost per sample, enabling high-density data acquisition and near real-time geometallurgical modelling. This is particularly advantageous for informal or small-scale reprocessing projects seeking rapid techno-economic assessments. Our findings suggest that the integration of portable and automated characterisation tools offers not merely an operational upgrade but a conceptual rethinking of how we engage with TSFs as urban mineral systems. This paradigm shift has implications for resource classification, project feasibility, ESG compliance, and stakeholder engagement, especially in data-sparse or legacy mine environments. As the industry moves toward net-zero commitments and just transition frameworks, the ability to efficiently valorise historic tailings using advanced, low-footprint technologies could be central to unlocking sustainable economic opportunities from past waste. We conclude by proposing a hybrid workflow for tailings characterisation that merges in-field sensing with selective laboratory verification, thereby aligning mineral sampling strategies with the realities of modern circular mining.

Xolile Carol Simelane

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Ms. Simelane is a geoscientist who passionately specializes in economic geology and geometallurgy. She is currently pursuing a PhD degree in Geology at the university of the Witwatersrand. She holds a MSc in geology from the university of Johannesburg and a BSc Hons in geology from the university of KwaZulu-Natal (South Africa). She has extensive work experience in mining geology and geometallurgy within the gold mining industry with ambitions to expand this experience into other commodities (i.e. platinum, coal etc.) within the mining and metals industry. She has a keen interest in economic geology, process engineering, geometallurgy and environmental conservation. Her PhD project focuses on the valorisation of mine waste from the Witwatersrand goldfields using an approach that incorporates predictive geometallurgy and the application of alternative or eco-friendly reagents in gold recovery.

Maximising throughput of ore characterisation by means of automated mineralogy

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TESCAN, Czech Republic

Automated mineralogy is an established technology in modern metallurgy, enabling high-resolution, quantitative characterisation of ore mineralogy and microtextures. This method, primarily based on scanning electron microscopy (SEM) integrated with energy-dispersive X-ray spectroscopy (EDS) and advanced image analysis algorithms, provides insight into mineral associations, liberation, and grain size distribution. Its data-driven approach enables informed decision-making across exploration, process optimisation, and resource modelling.

Despite its robustness, there is considerable room for optimising the throughput of data acquisition and analysis. Throughput can be enhanced by adaptive measurement protocols, spectral summing algorithms, and leveraging software automation for intelligent segmentation and phase identification. Recent advancements in scripting interfaces have enabled batch processing workflows and improved detector efficiency, substantially reducing the time per analysed area while maintaining data quality.

An efficiency gain also lies in the shift from reliance on drill core scanning to the characterisation of homogenised powdered samples. While drill core scanning provides valuable spatial and structural information, its throughput (and applicable resolution) is limited due to sample heterogeneity, surface preparation variability, and the complexity of interpreting non-homogeneous textures. Powdered samples, on the other hand, offer a statistically robust and reproducible dataset. This approach allows for rapid, scalable assessment of mineralogical variability across large ore bodies and supports the development of predictive geometallurgical models.

One of the persistent challenges in ore processing is the presence of complex mineral textures, such as intergrowths, inclusions, and fine-grained associations that complicate liberation and separation. Automated mineralogy addresses these textural complexities by generating high-resolution compositional and morphological datasets. Metrics such as mineral association matrices, liberation indices, and grain boundary characteristics directly inform processing strategies. Furthermore, these datasets can be used to identify and quantify problematic textures that lead to processing inefficiencies, such as poor flotation performance or high grinding energy consumption.

Automated mineralogy enables a shift in ore characterisation by combining high-fidelity data with scalable, efficient workflows. By prioritisng powdered sample analysis and exploiting the full capabilities of automation and scripting, throughput can be significantly increased without sacrificing data integrity. This approach supports more agile and informed decision-making in ore processing and resource evaluation.
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Marek Dosbaba

Automated mineralogy specialist
TESCAN GROUP, a.s.

Marek Dosbaba has over 20 years of experience in applied geology, mineral characterization, and microanalytical instrumentation. After earning a master's from Masaryk University (Brno, Czech Republic), he held roles in surveying, exploration, and microanalysis, progressing to senior technical and leadership positions in industry. Since 2013, he has worked at TESCAN, where he is Product Marketing Manager for Microanalysis. His focus is on integrating automated mineralogy into analytical workflows, optimizing throughput, and enhancing usability. Marek has contributed to publications and conferences, especially in process mineralogy, rare-metal deposits, and SEM-based analytics. His fieldwork spans Central Asia and the Balkans, and he collaborates closely with R&D and TIMA development teams to align the tool with real-world ore characterization needs.

Communicating uncertainty in geometallurgical models

A. Johnston
Transmin Metallurgical Consultants, Peru

Geometallurgical modelling traditionally focuses on finding the ‘best fit’ model that produces single-value predictions for metallurgical responses in each block. However, this deterministic approach often fails to adequately capture the uncertainty that exists in complex ore bodies. This paper examines how the communication of uncertainty in geometallurgical models can significantly enhance risk management throughout the mining value chain. We demonstrate that simpler models with well-quantified uncertainty bounds often provide more value than complex models that appear more accurate but fail to represent prediction confidence. Through case studies we compare deterministic approaches with stochastic simulation techniques that generate probability distributions rather than single values. Results show that stochastic methods not only better represent the true nature of geometallurgical variability but also provide mining engineers and metallurgists with critical information for risk-informed decision making.

The research highlights how transparent communication of model uncertainty leads to improved mine planning, more realistic production forecasts, and better-informed capital investment decisions. By shifting focus from predictive precision to comprehensive risk characterisation, operations can develop more robust strategies for handling ore variability. This approach aligns perfectly with the themes of trusted data and smarter decisions, representing a significant step forward in making geometallurgy truly ‘future-ready.’

Deportment of gold in historical Witwatersrand tailings: Implications for geometallurgy

S. Chingwaru, B.P. von der Heyden, M. Tadie
Stellenbosch University, South Africa

The Witwatersrand Basin represents the world's largest gold province and contains over 53,000 tonnes of native gold primarily hosted within quartz pebble conglomerates. Secondary reprocessing of the Witwatersrand gold tailings, typically through conventional cyanide leaching, achieves only 30–50% recovery of the gold previously unrecovered by historical beneficiation. Consequently, an estimated 1325–1855 tonnes of refractory gold, together with approximately 30 million tonnes of sulfide-rich material, are discharged to the waste stream following secondary extraction. The mineralogical deportment of this residual or refractory gold remains poorly constrained. Analytical results reveal that 0.71–10.21 g/t of gold occurs within the heavy mineral concentrates, which consist predominantly of sulfides (35–76% and oxides (9–20%. Detailed in situ analyses indicate that the gold within these concentrates is mainly hosted in pyrite and arsenian pyrite, exhibiting grades ranging from 0.1 to 2,729 g/t. Considering that the Witwatersrand Goldfield is classically regarded as a native gold deposit, the identification of 'invisible' gold within detrital pyrite suggests a previously under-exploited resource and may, in part, account for the refractory nature of the 50–70% of gold remaining after secondary processing. Moreover, detailed characterisation of sulfide mineral chemistry, including the distribution of heavy metal contaminants, and its transformation during surficial oxidation provides critical insight into the geochemical mobility and environmental behaviour of these deleterious elements.

Bjorn von der Heyden

Associate Professor: Economic Geology
Stellenbosch University

Dr Bjorn von der Heyden completed his Ph.D. in geology at Stellenbosch University in 2013 and subsequently spent two years working as a geologist in the South African minerals sector for Exxaro Resources Ltd. He gained excellent exposures and experiences at Arnot underground coal mine, Grootegeluk open cast coal mine, the Research and Development Unit (Mineralogy section), and the Mayoko iron ore exploration project in the Republic of Congo.

In 2015, he returned to academia appointed as a lecturer in Economic Geology at Stellenbosch University (SU). He has worked on a number of research projects, both nationally and internationally (Namibia, Malawi, Tanzania), and has published on a wide variety of ore commodities including gold, diamonds, copper, cobalt, zinc, manganese, iron, and lithium-bearing pegmatites. He has developed fluid-inclusion microthermometry capabilities and hyperspectral core scanning facilities, bth currently housed at the Department of Earth Sciences at Stellenbosch University.

In 2020 he was promoted to Senior Lecturer, and then in 2025 to Associate Professor in Economic Geology. Dr von der Heyden was elected as a fellow of the Society of Economic Geologists in 2021 and starting from 2022 he fulfilled a position of co-Chair for the African Rainbow Minerals Chair in Geometallurgy. In this role, he places equal emphasis on generating and publishing exciting new science, and on providing high-quality education to the next generation of African earth scientists and geometallurgists.

His research interests include understanding the processes of ore mineralisation in hydrothermal, magmatic and chemical sedimentary sub-classes, and modelling the detailed geometallurgical characterisation of these deposits to facilitate enhanced efficiencies in downstream mining and processing of ore bodies. Bjorn has published 44 peer-reviewed research articles and will have graduated 55 post-graduate research students at the end of 2025. Many of these students have received national and international awards and recognition for their research endeavours. He sits on a number of committees and conference organising panels and has received several accolades for his efforts in teaching and learning.

Development of beneficiation processes for low-grade manganese ores for the ferroalloy industry

D.A. Barrett[1], M. Tadie[1], B.P. von der Heyden[1], R. Cromarty[2]

[1]Stellenbosch University, South Africa
[2]University of Pretoria, South Africa

Manganese is a key global resource primarily used in the steel industry for ferroalloy production. South Africa has the world's largest reserve of manganese, found in the Kalahari manganese field. Tailings from the Nchwaning mine, previously considered subeconomic, contain recoverable manganese but are penalised by elevated and complex iron content. To be used as high-quality ferroalloy feedstock, iron needs to be separated to achieve the target grade of 40 % Mn and a Mn/Fe ratio of 7.5. These tailings present a geometallurgical challenge due to their mineralogical variability. Iron is present both as discrete hematite and in solid solution within manganese minerals such as Bixbyite and Braunite II.

The mineralogical distribution influences process response during beneficiation. The solid solution of Fe in Mn minerals, in particular, complicates separation, as it has been shown to lead to the formation of mixed (Mn,Fe)O phases during conventional carbothermic roasting. Addressing this required a geometallurgical approach to develop a process that could separate the iron, regardless of its host phase. This study employed reductive roasting in a hydrogen rich atmosphere followed by magnetic separation. Hydrogen has a low carbon footprint and is sufficiently reducing to produce metallic iron that can be separated magnetically. Salt additives were investigated for their potential to improve the separability of Fe and Mn by promoting the formation of larger metallic Fe globules, especially from Fe initially locked within Mn mineral lattices.

A central composite design was employed in laboratory-scale experiments to optimise key response variables such as Mn grade, Mn/Fe ratio, and Mn recovery while minimising the number of experimental runs. Optical microscopy and SEM analysis of the reduced material revealed distinct metallurgical behaviour between iron liberated from hematite—forming larger globules—and iron reduced from Mn-hosted phases, which formed smaller globules (1–10 μm. The separation of these globules is expected to produce a non-magnetic, Mn-rich product with an upgraded Mn/Fe ratio and a secondary, Fe-rich magnetic fraction with residual Mn content. This approach provides a mineralogy-informed carbon-friendly beneficiation route that improves tailings recovery and supports the full utilisation of the orebody in line with geometallurgical principles.

Daniel Anthony Barrett
MEng (Chem) Candidate
Stellenbosch University

Daniel Barrett is currently pursuing a master's degree in chemical engineering, specialising in pyrometallurgy and extractive metallurgy. He graduated with a bachelor's degree in chemical engineering from Stellenbosch University in 2023, where he was awarded the SAiChE Silver Medal for best final-year student in the Department of Chemical Engineering. Daniel's ongoing project focuses on the green beneficiation of ferruginous manganese tailings from the Kalahari Manganese deposit.

Hydrometallurgical pretreatments for the enhancement of magnetic separation of ferruginous manganese tailings

E. Olivier, M. Tadie, B.P. von der Heyden, P. van Wyk
Stellenbosch University, South Africa

While local hydrothermal alteration has significantly enriched a fraction of the Kalahari Manganese Deposit (KMD) in manganese (Mn), it has also enriched the iron (Fe) concentration, resulting in ore that cannot be used to produce ferromanganese due to a low Mn/Fe ratio (< 3). This material is generally categorised as waste rock during geological modelling of orebodies, resulting in significant manganese tonnages remaining unmined. Towards maximising resource efficiency, a geometallurgical goal is to upgrade the Mn/Fe ratio during minerals processing, potentially via magnetic separation. The overlap between the magnetic susceptibilities of iron and manganese-bearing minerals in the KMD, however, presents a challenge. Roasting to liberate iron is often recommended as a pretreatment step, though this is associated with carbon emissions. Thus, further research on alternative methods such as hydrometallurgy is beneficial to potentially unlock value from this deposit by redefining the ferruginoused material as ore requiring upgrading and not simply waste. This study aims to adopt a mineralogical approach comparing two pretreatment methods for enhancing the magnetic separation of ferruginous manganese tailings and to suggest a flowsheet for effective resource utilisation that minimises waste. The first method utilises a two-stage process using oxalic acid to selectively leach iron and form humboldtine (FeC2O4•2H2O) on the surface of iron-bearing minerals in the first stage, followed by roasting to convert the humboldtine to highly ferromagnetic magnetite (Fe3O4). The second method involves the addition of the tailings into an alkaline medium containing ferrous (Fe2+) ions that attach to iron oxides at the particle surfaces to form magnetite directly. The preferential formation of magnetite on iron mineral surfaces allows for magnetic separation at a lower field strength, thus reducing the loss of manganese to the magnetic fraction.

Mineralogical investigations, lab-scale leaching experiments and thermodynamic modelling in HSC Chemistry were conducted to evaluate the use of the proposed treatment routes in the upgrading of KMD ore. Preliminary experiments have indicated that the oxalic acid method effectively enhances magnetic separation by allowing magnetic separation to take place at a lower field strength.

Edwin Olivier

Postgraduate Student (M.Eng Chemical)
Stellenbosch University

Edwin Olivier is currently pursuing a Master's Degree in Chemical Engineering, specialising in Hydrometallurgy and Extractive Metallurgy. He graduated with a Bachelor's Degree in Chemical Engineering from Stellenbosch University in 2023, where he was awarded the SAIMM prize for best mineral processing student in his third year. His master's project focuses on comparing two innovative hydrometallurgical methods to enhance the magnetic separability of iron from ferruginous tailings of the Kalahari Manganese deposit. His research seeks to unlock additional value from manganese deposits and enable more efficient utilisation of ore bodies.

Geometallurgy in the Kalahari Copper Belt, Ngami district Botswana

J.K. Mangwiro[1], A. Bayani[2], K. Kgotlele[2], R. Situmorang[2], G. Mosanga[2], M. Babusi[2]
[1]Fluor, South Africa
[2]MMG Khoemacau, Botswana

Zone 5 deposit is in the Kalahari Copperbelt and was developed between 2011 and 2019 as a main feed to the Boseto processing plant. The mineralogy of Zone 5 varies widely in the content of different copper sulfide species, which comprises primarily bornite, chalcopyrite and chalcocite with trace amounts of covellite. The orebody also contains arsenic and antimony bearing tennantite/enargite and tetrahedrite respectively. Minor galena, sphalerite, molybdenite, arsenopyrite and silver are also observed. The main gangue minerals are calcite and silicate minerals, primarily quartz, feldspars, muscovite and chlorite. The evaluation of the deposit was conducted by developing recovery and concentrate algorithms using sulfide mineralogy and considering gangue mineralogy. The latter influenced liberation as dictated by ore competency through the Bond Ball Work Index (BBWi). The BBWi correlated well with the alteration Index (Ai) as defined by (Ca/(Si+Ca+Al)). Ores associated with high quartz (silica) content and fine grained are associated with higher BBWi and poor sulfide liberation while ores with higher calcite (lower Ai) content are softer and had favourable sulphide liberation. A regrind mill is included in the circuit to improve liberation and the concentrate grade by lowering the silica levels to mitigate the effect of ore hardness variability.

A multilinear regression was used to develop the correlation between the copper recovery and sulfide mineralogy based on Cu:S ratios and metallurgical testwork results. The recovery equations were extended to the resource model by correlating copper to the dominant sulfide mineralogy as determined by the copper sulfur molar ratio shown in Table 1.

Table 1. Metallurgical Recoveries for Cu and Ag based on Predominant Mineral Domain

Cu:S Ratio		Dominant Mineralogy	Copper Recoveries 2020	Ag Recoveries 2020
From	To			
0.01	0.75	Chalcopyrite	86.12 + 0.56*% Cu	83.3
0.75	1.5	Bornite	86.42 + 0.56*% Cu	83.1
1.5	99	Chalcocite	88.85 +0 .56*% Cu	87.1

Silver recovery followed the Cu:S domains as it is hosted within the copper sulfides. Arsenic recovery correlated well with copper recovery.

The resulting equations were incorporated into the Zone 5 resource model, allowing short internal prediction of Cu and Ag recoveries. The copper recovery equation exhibited a high correlation coefficient of 0.97 and a standard error of 3.3%.The silver recovery for silver feed grade greater than 10g/t Ag showed a high correlation coefficient of 0.96 despite the high standard error of 5.1% due to the lower assay precision at lower feed grades. There was good agreement between predicted copper and actual recoveries from plant operational data which showed a standard error of ±5%. The BBWi correlations were validated with additional data which showed strong correlationship with the Zone 5 lithology. Production data trends of recovery, Cu:S ratio and Ai showed the influence of both gangue and sulfide mineralogy on concentrate grade and metal recoveries.

The concentrate grade prediction was closer at higher Cu:S ratios than at lower ratios. The copper concentrate grades were influenced by the copper sulfide mineralogy, non-sulfide gangue, the relative concentrations of lead to copper (Pb:Cu) and zinc to copper Zn:Cu and rougher concentrate liberation. The latter is influenced by the Cu:S ratio, Ai and regrind mill performance. There is scope to improve recovery and concentrate prediction accuracy by incorporating the impact of gangue mineralogy through Ai, lead and zinc effect.

John Mangwiro

Principal Engineer
Flour

John has over 30 years of experience in the mining industry with major and junior mining houses which include Anglo American; Rio Tinto, Blue Ridge, MMG and Umbono Capital. John has assumed executive and leadership roles in his career in the operation of plants; in conducting prefeasibility and feasibility studies; in the commissioning and startup of green and brown field operations in Africa. John worked at Palabora Copper (PC) for over 7 years with the first 4 years in the smelter for the upgrade study and the last 3 years in the concentrator where he led the underground transition study from 100,000 tpd to 60,000 tpd.

John has been involved in the design and optimisation of PGM concentrators on the Bushveld and Great Dyke complexes. He ws involved in the design and operation of the Blue Ridge concentrator and the Feasibililty of the Sheba Ridge where HPGR technology was evaluated. John has been involved in the recovery optimisation of Great Dyke PGM ores using high intensity shear conditioning (HIC). Johh worked as an owner metallurgist on the Lesego Platinum and Khoemacau project.

John has extensive base metal concentrator experience. John was the Lead process engineer on the Khoemacau Copper and Silver Project where he evaluated fine grinding, filtration, online analysers and fine floatation technology. He was responsible for the metallurgical testwork, plant design, commissioning, rampup and optimisation. He was involved is colloboration with MMG in the development of the geometallurgical model using multiple linear regression analysis, its validation and fine-tuning tuning during the operation.

John has extensive knowledge of coarse and fine particle floatation technologies which involve the hydrofloat and Jameson circuits for base and PGM concentrators. John is currently the lead processing engineer for the backfill project at Khoemacau. John is providing technical support for geometallurgy during the ramp up. John was the lead process engineer for the Khoemacau expansion project. He is geometallurgical consultant for the expansion deposit the MMG.
John worked on the feasibility of the copper, lead and zinc ore project South Africa where he was involved in the floatation testwork, plant design, evaluation of the DMS and provided input for CAPEX and OPEX during fund raising.

John commissioned Kolomela process plant and the automated laboratory successfully with characterisation of products. He has extensive experience in metallurgical processing of copper and associated by products (PGM); gold; Iron; PGM; Chrome; Manganese; Coal; Phosphate; Lead & Zinc; Magnetite; Uranium, Zirconia; Nickel. John participated in the development and assessment of tehcnology for fine chrome recovery and its economic assessment.

Linking mineralogy to comminution behaviour in the Kalahari manganese field

M. Tadie, B.P von der Heyden, P. Mathebula, L. van Eeden
Stellenbosch University, South Africa

The geometallurgical characterisation of manganese ores has advanced significantly, with a notable shift from traditional chemistry classifications to mineralogical classifications through X-ray diffraction (XRD) being introduced by the work of Chetty (2016). Furthermore, the work of von der Heyden et al., (2024) introduced textural relationships into classifying manganese ores. Building on such foundations the paper advances the geometallurgical processes by investigating whether manganese mineralogy can be used not only for classification, but also to quantitatively predict comminution behaviour for different ore types. The paper therefore presents an essential step in developing geometallurgical models that integrates processing response for manganese ores. Whilst high grade ores typically do not undergo further beneficiation than ore dressing before shipping to market, a future outlook that needs to be considered is the beneficiation of more complex lower grade manganese ores.

In an experimental geometallurgy approach, ore samples from the Kalahari manganese field were analysed using quantitative QXRD to determine mineralogical composition and subjected to comminution testing to measure uniaxial compressive strength (UCS), crushability index (CI), and Bond ball mill work index (BWI). These parameters served as proxies for breakage behaviour. Statistical analysis indicated variability in both mineralogy and comminution response, with correlations observed between breakage indices and the relative abundance of hausmannite, braunite, kutnohorite, and quartz. Specifically, higher hausmannite and braunite content were associated with increased rock strength and grinding resistance, while higher kutnohorite and quartz content generally corresponded to weaker, more friable samples.

These findings combined with the knowledge available in the literature confirm that texture, mineralogical composition, particularly the proportions of key manganese and gangue phases, can be used to predict breakage behaviour. The implication for geometallurgy of manganese ores is most significantly noted for mine planning, energy forecasting, and process optimisation in the further beneficiation of lower grade manganese ores.

Margreth Tadie

Co-Chair ARM Geometallurgical Research Chair
Stellenbosch University

Dr Margreth Tadie is the co-chair of the African Rainbow Minerals Research Chair in Geometallurgy at Stellenbosch University. A chemical engineer by training, she earned her PhD from the University of Cape Town with a specialization in froth flotation and has since built a research portfolio that integrates process mineralogy, process modelling, and the valorisation of tailings.

Her work bridges academic research and industrial application, with a focus on developing geometallurgical frameworks that enhance resource efficiency and support circular mining. Dr Tadie has collaborated with the PGM, gold, Iron and Manganese industries on flowsheet development and waste reprocessing and regularly consults on extractive metallurgy and geometallurgy projects.

She is a former Royal Society Future Leaders – African Independent Research (FLAIR) Fellow and a fellow of South Africa's Future Professors Programme. With over 38 peer-reviewed publications and leadership in interdisciplinary geometallurgical research, she is actively involved in shaping geometallurgy as a critical discipline for sustainable mining in Africa and beyond.

Understanding the economic importance and scientific significance of oceanic Fe-Mn crusts

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[2]British Geological Survey, U.K

Fe-Mn crusts, or ferromanganese crusts, are marine sedimentary mineral deposits primarily composed of iron and manganese oxides. These crusts are of both scientific and economic interest due to their unique chemical composition, which includes valuable metals like cobalt, nickel, copper, titanium, platinum, tellurium and rare earth elements. They form as thin layers on rock surfaces in the deep ocean ranging from 500 to 7,000 meters, particularly on seamounts, ridges, and plateaus, over millions of years through the direct precipitation of oxides from seawater and possible subsequent phosphatisation episodes. Firstly, Fe-Mn crusts are valuable for scientific research, as they act as an historical record of past ocean conditions. Their slow growth rate and ability to accumulate elements over long periods make them ideal for studying changes in the marine environment and the Earth's climate. Secondly, Fe-Mn crusts are of growing interest as a potential source of valuable metals, particularly nickel and cobalt, which are essential for emerging technologies. The high concentrations of various metals in Fe-Mn crusts, compared to land-based deposits, make them attractive for potential future mining operations. It should be noted that such potential as described here does not discuss the political nor environmental considerations, as this is a separate topic, albeit important and relevant. Nevertheless, microXRF is the ideal analytical tool for characterising and understanding the formation and economic potential of Fe-Mn crusts as it requires minimal sample preparation, has a small spot size, and the technique is sensitive to base metal elements, even at trace concentrations. To that end, numerous samples from a variety of locations from around the world have been analysed and their similarities and differences are discussed.

Andrew Menzies

Senior Applications Scientist
Bruker Nano Analytics

Andrew Menzies holds a Doctorate of Geochemistry from University of Cape Town (South Africa) and a Bachelors of Science and Bachelors of Commerce from University of Auckland (New Zealand). He has over 25 years professional experience working as a geologist involved in numerous projects around the world ranging from grassroots exploration, follow-up reconnaissance exploration, target evaluation, laboratory analysis, and consulting and project management. During this time he has used various analytical techniques and managed analytical laboratories. He was an academic (geochemistry) at Universidad Católica del Norte, (Antofagasta, Chile) from 2011 to 2018 teaching Geochemistry, and supervised numerous doctorate and masters students, and is an active member in numerous geological societies. He is currently employed as a senior application scientist at Bruker Nano Analytics. Research interests include ore deposit mineralogy and mineral processing; mantle geochemistry and the origin of diamonds; automated mineralogical analysis and applications, especially using micro-XRF and AMICS, and analytical standards preparation and evaluation.

Textural implications of iron ore beneficiation outcomes based on jigging – a case study

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Iron ore reserves are estimated at approximately 700 Mt across South Africa with an expected Life of Mine of about 13 years. To sustain our iron supply, alternative lower-grade deposits must be considered. The Blinkklip Breccia which comprises of banded iron formations, chert, and hematite clasts, has received little attention despite its potential. The complex textures of the deposit pose beneficiation challenges, therefore, understanding mineralogical and textural effects is essential. This paper assessed the potential of coarse particle jigging to beneficiate the low-grade Blinkklip Breccia and the influence of texture on outcomes. Four textural classes were identified: BK1 (hematite-rich), BK2 (silica-rich), BK3 (hematite–silica mix), and BK4 (matrix-supported hematite–silica mix). A hydraulic jig concentrator was commissioned and tested under optimised conditions. Results showed distinct textural controls on the recovery outcomes. BK1 achieved the highest recovery (71.6%), BK3 yielded 40.9%, BK2 28.8%, and BK4 only 19.7%. The lumpy fractions (+6.3 mm) were concentrated, while fines reported to tailings. Concentrate grades show that BK1 texture responded best, whereas silica-rich and matrix-supported textures showed poor recovery due to the mineral content and limited liberation. The paper concludes that coarse particle jigging alone is insufficient for the Blinkklip Breccia. Further size reduction and additional beneficiation steps must be considered. Mineralogy and texture play key roles in the breakage pattern, degree of liberation, and separation efficiency, and must be considered in geometallurgical evaluation of alternative iron ore deposits.

Khuliso Netshikulwe

Geology graduate: Drilling Assistant
African rainbow Minerals

I am a dedicated Earth Sciences professional with a Master of Science in Earth Sciences (Cum Laude) from Stellenbosch University, completed under the African Rainbow Minerals Geometallurgy Research Chair. My research focused on the mineralogy and beneficiation characteristics of the Blinkklip Breccia mineralized zone, exploring its implications for the economic extraction of iron ore resources. I hold a Bachelor of Science in Mining and Environmental Geology from the University of Venda, where I was recognized as the Most Promising Geologist. I have developed strong skills in mineralogical analysis, including mineral characterization, and geometallurgical test work. I have skills in 3D geological modelling using Leapfrog Geo, data visualization, and multivariate geochemical analysis. I am currently working within the Exploration and New Business department at African Rainbow Minerals. I am passionate about uncovering the stories told by rocks and minerals, and I strive to apply scientific precision and creative problem-solving to support innovative and sustainable practices in the minerals and Geometallurgy sectors.

Geometallurgy learnings from First Quantum Minerals' Zambian Operations

L. Little, A. Kottgen, M. Chibesa, P. Ogilvie
First Quantum Minerals Ltd, Zambia

Within the North-Western Province of Zambia, First Quantum Minerals has two copper mines (Kansanshi and Sentinel) and a nickel mine (Enterprise). Although there are some similarities between these deposits, they each have different geometallurgical challenges, which we have attempted to address using a variety of tools and technical approaches. Organisational structures and wiring have evolved over time, as we have tried and tested different ideas for managing operational and technical aspects of applying ore body knowledge to understand and improve process performance. To date, despite various challenges and limitations, 'Geomet' at First Quantum is delivering value, and we look forward to continuously improving both the quality of our interdisciplinary working relationships, and the detail and level of confidence afforded by our models. Key site learnings will be carried forward to other First Quantum Greenfields projects.

Dr Lucy Jane Little

Superintendent, Process Mineralogy and Geometallurgy
First Quantum Minerals Ltd.

Lucy has worked at Kansanshi since 2017, gradually making minor steps towards geometallurgy while focusing on process mineralogy and various minerals processing projects. In the last two years, she has worked on more ambitious geometallurgical projects, attempting to characterise and effectively predict and communicate the likely impacts of key ore variables on production over the medium to long term.

Axel Kottgen

Assistant General Manager
First Quantum Minerals Ltd.

Axel moved to Kansanshi as the Assistant General Manager in 2024 after his success as project manager for the Enterprise Nickel Project over the preceding few years. Axel is passionate about geometallurgy and promotes and supports interdisciplinary collaboration in both technical and operational spaces. He values the information and understanding provided by geometallurgical work for strategic decision making.