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Linking mineralogy to comminution behaviour in the Kalahari manganese field

Margreth Tadie, Bjorn von der Heyden, Louis van Eeden, Ivan Pardon Mathebula, Tobi Louw, Tinotenda Katsumbe

Geometallurgy Conference 2025

ARM African Rainbow Minerals GeoMetallurgy Research Chair

Overview of geometallurgy

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forward together sonke siya phambili saam vorentoe
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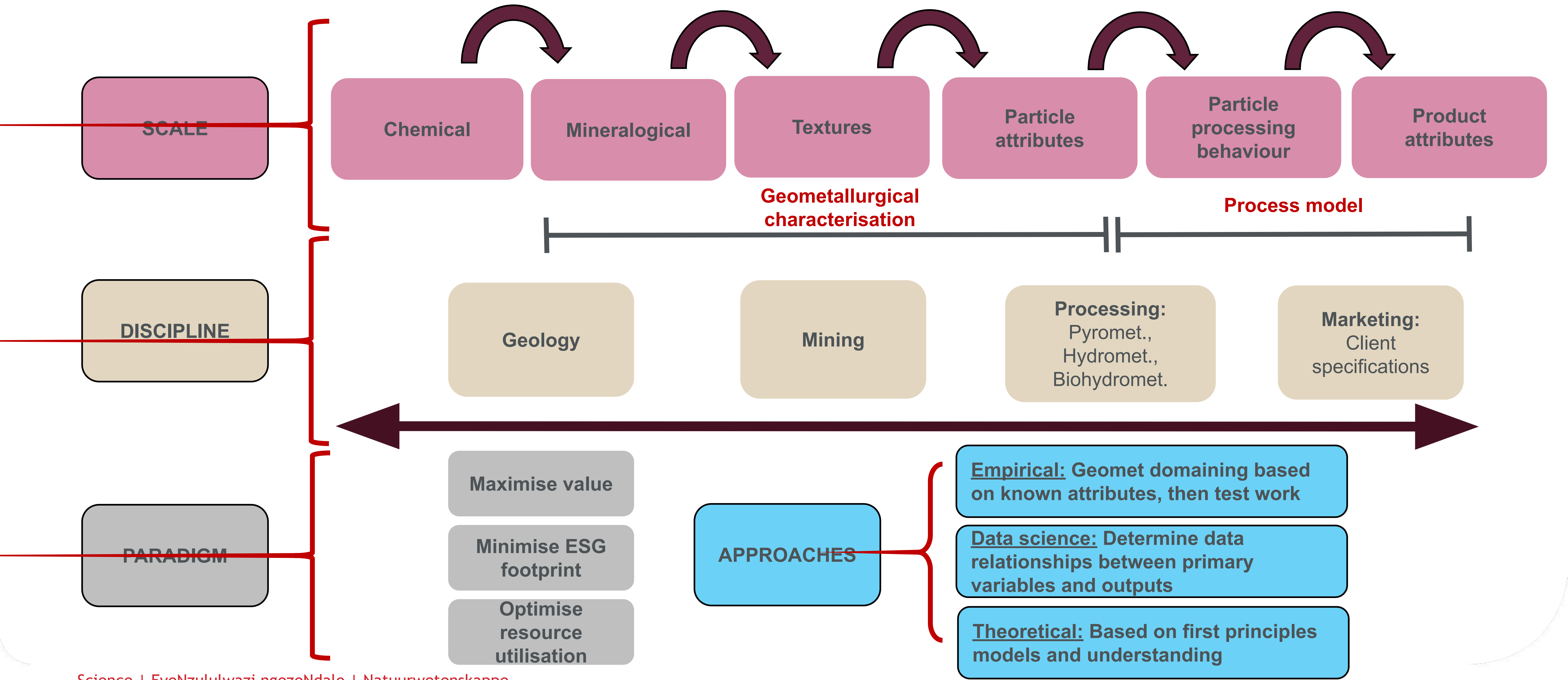

Overview of geometallurgy

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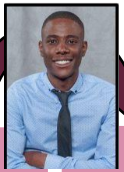
Part 1

Part 2

Part 3



SCALE

- Chemical
- Mineralogical
- Textures
- Particle attributes
- Particle processing behaviour
- Product attributes

Geometallurgical characterisation

Process model

DISCIPLINE

- **Geology**
- **Mining**
- **Processing:** Pyromet., Hydromet., Biohydromet.
- **Marketing:** Client specifications

PARADIGM

- Maximise value
- Minimise ESG footprint
- Optimise resource utilisation

APPROACHES

- **Empirical:** Geomet domaining based on known attributes, then test work
- **Data science:** Determine data relationships between primary variables and outputs
- **Theoretical:** Based on first principles models and understanding

Case study

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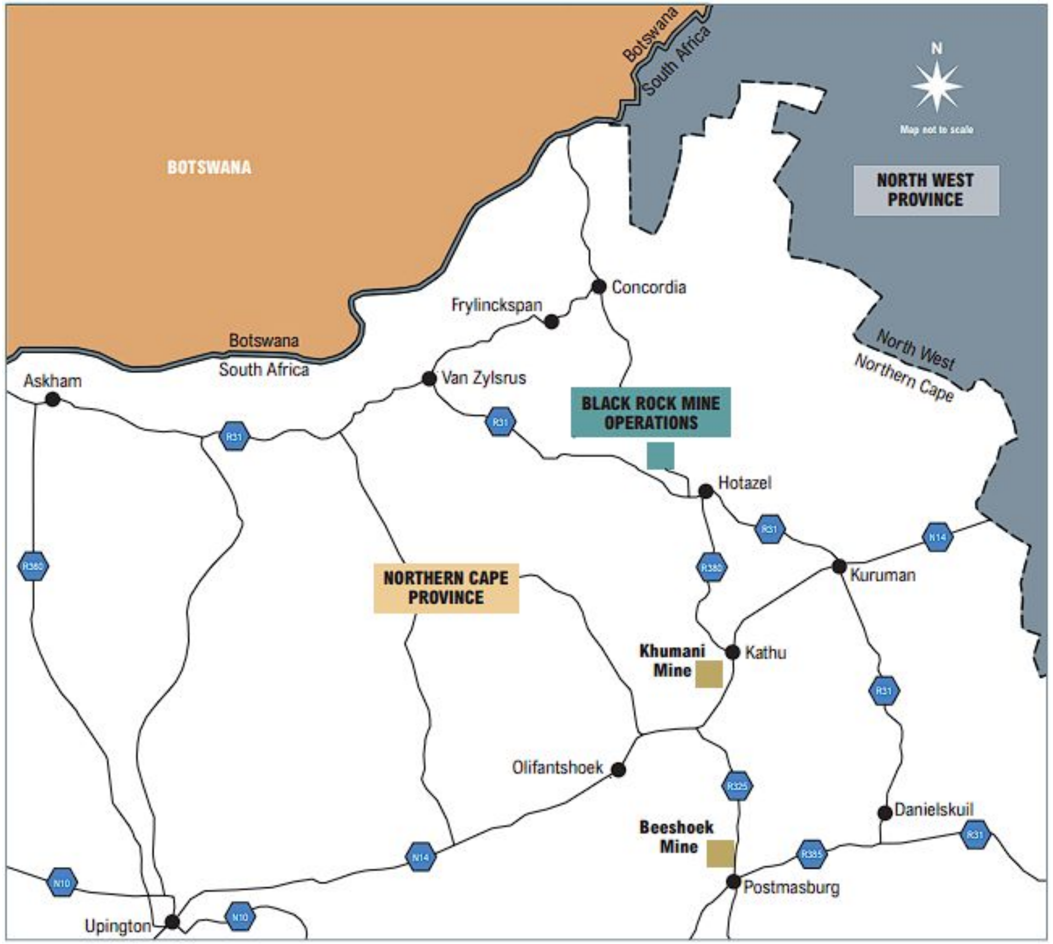
- BRMO is situated 60 km from Kuruman, Northern Cape.
- Transvaal Supergroup:
  - Griqualand West sub-Basin.
  - Hotazel Formation.
- Three Distinct Mn beds present.
  - Lowermost bed (seam1) is most economical.
- Low-Grade Ore (<36% Mn).
- High-Grade Ore (<42% Mn).
  - Hydrothermal Alteration.
- Mn mainly used in steel industry.
- Increased demand in Li Battery sector.



(ARM Resource and Reserves report, 2022)

Case study

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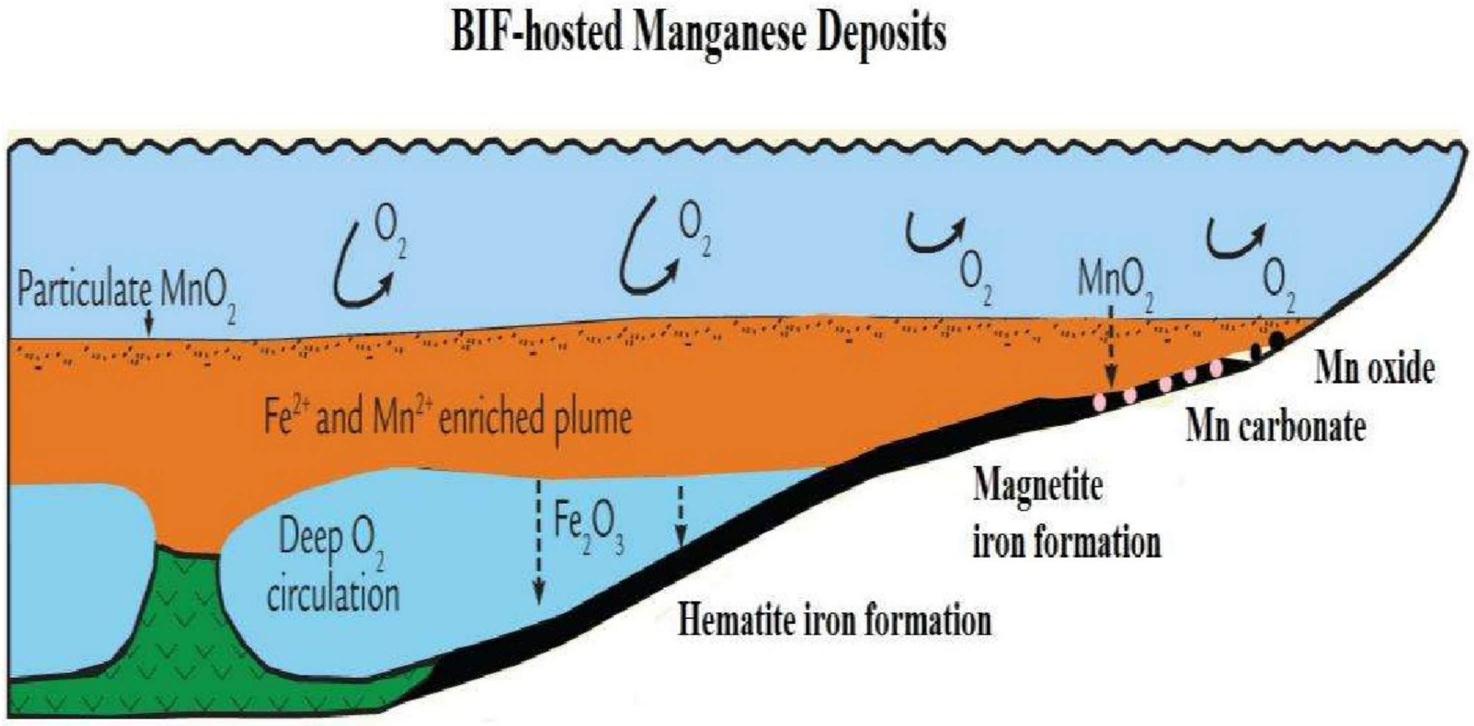

(Cairncross and Beukes, 2013)

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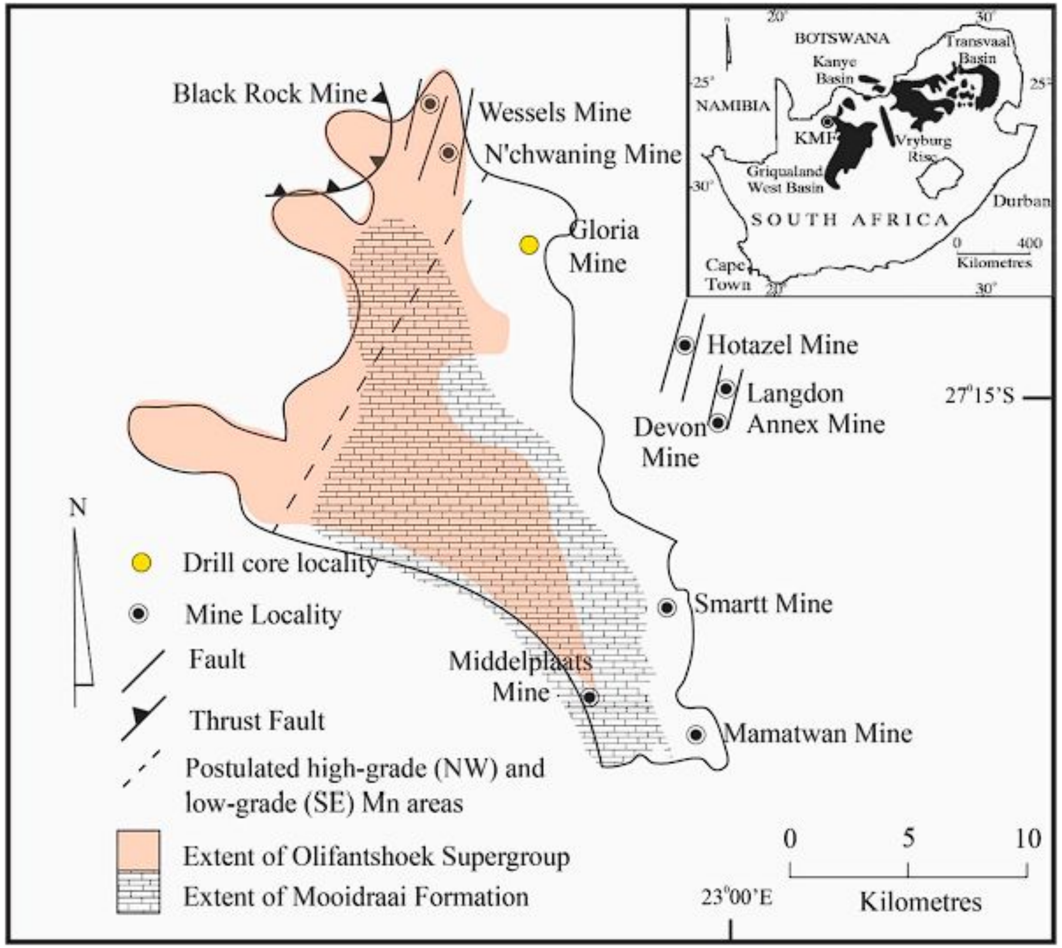

(Mhlanga, 2023)

Case study

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(Project Blue, 2022)

Study aim

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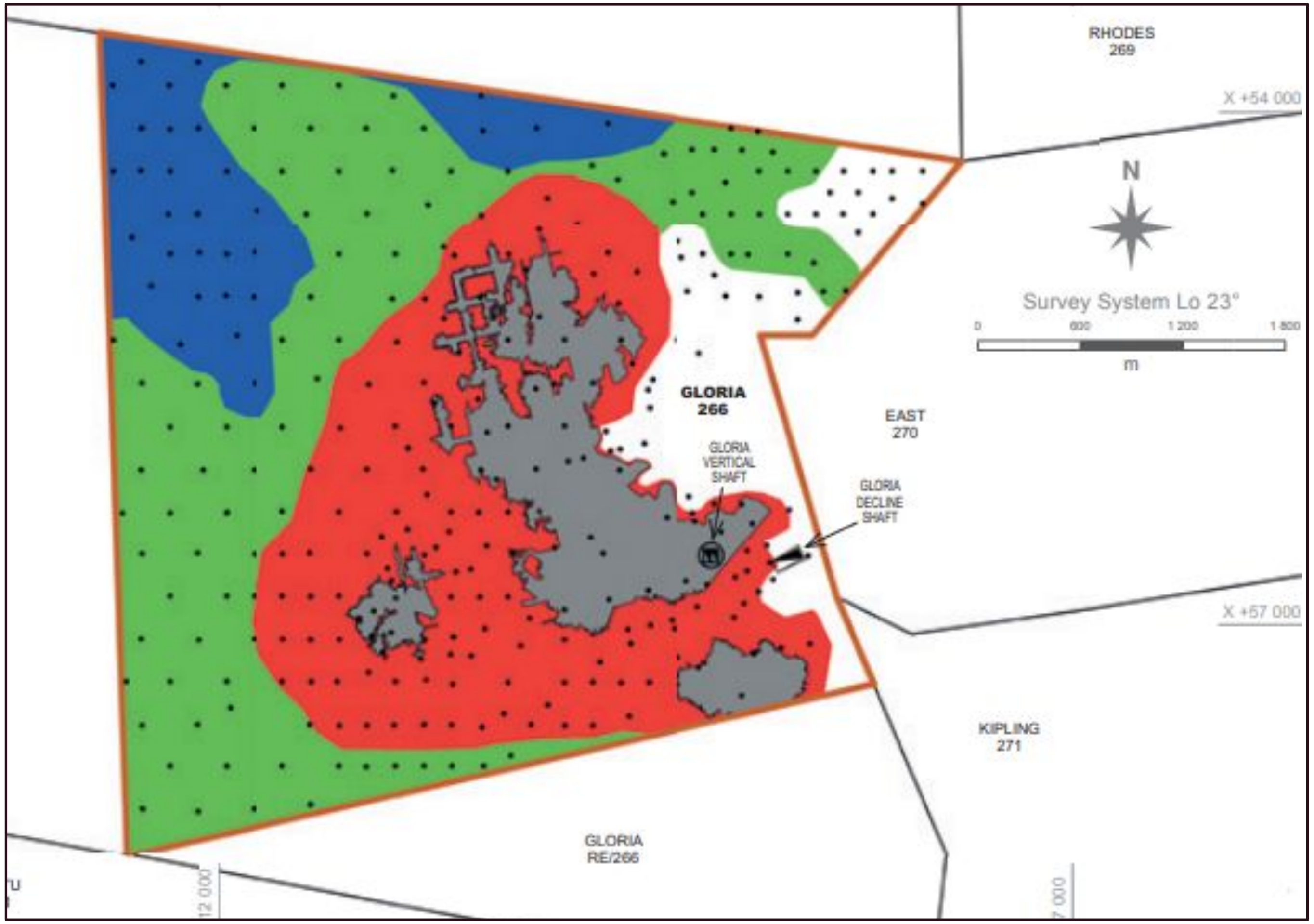
- Whole rock chemistry or bulk rock X-ray Fluorescence (XRF) data is readily available from e.g. resource and reserve drilling campaigns.
- Whole rock mineralogy data sets are much more sparse.
- Comminution data typically limited to dedicated test work campaigns.

Towards building a geometallurgical block model based primarily on available XRF data, can we determine the mathematical relationships that exist between chemistry, mineralogy, texture and comminution response?



(ARM Resource and Reserves report, 2022)

Typical methodology

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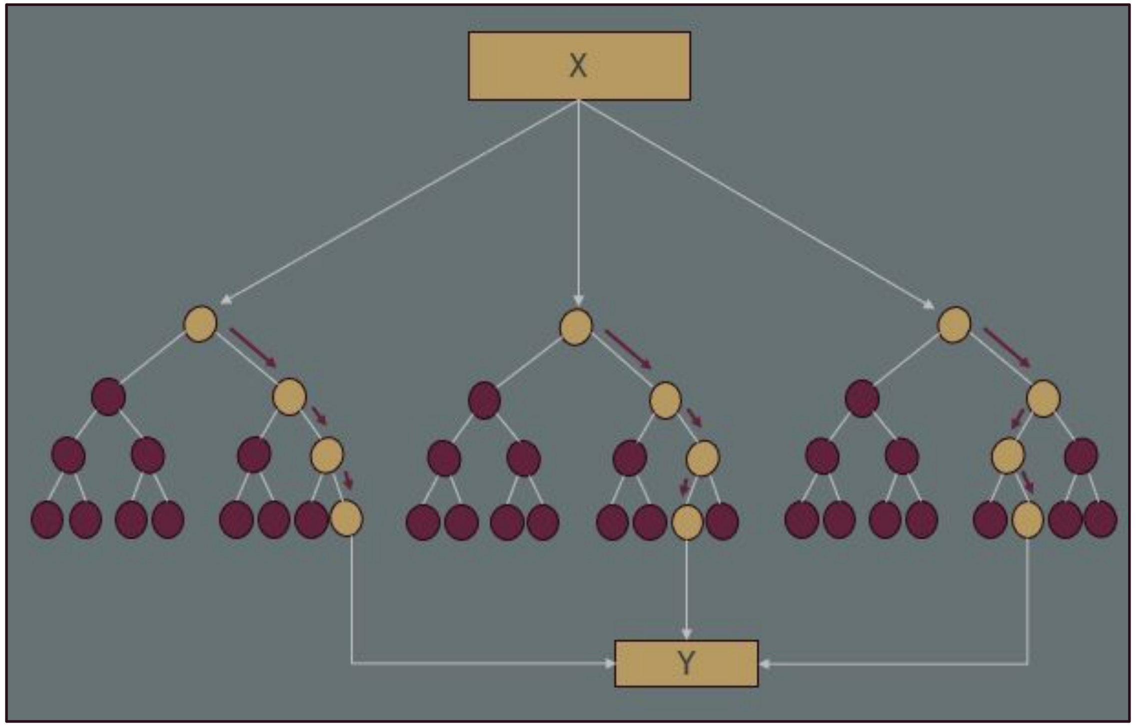

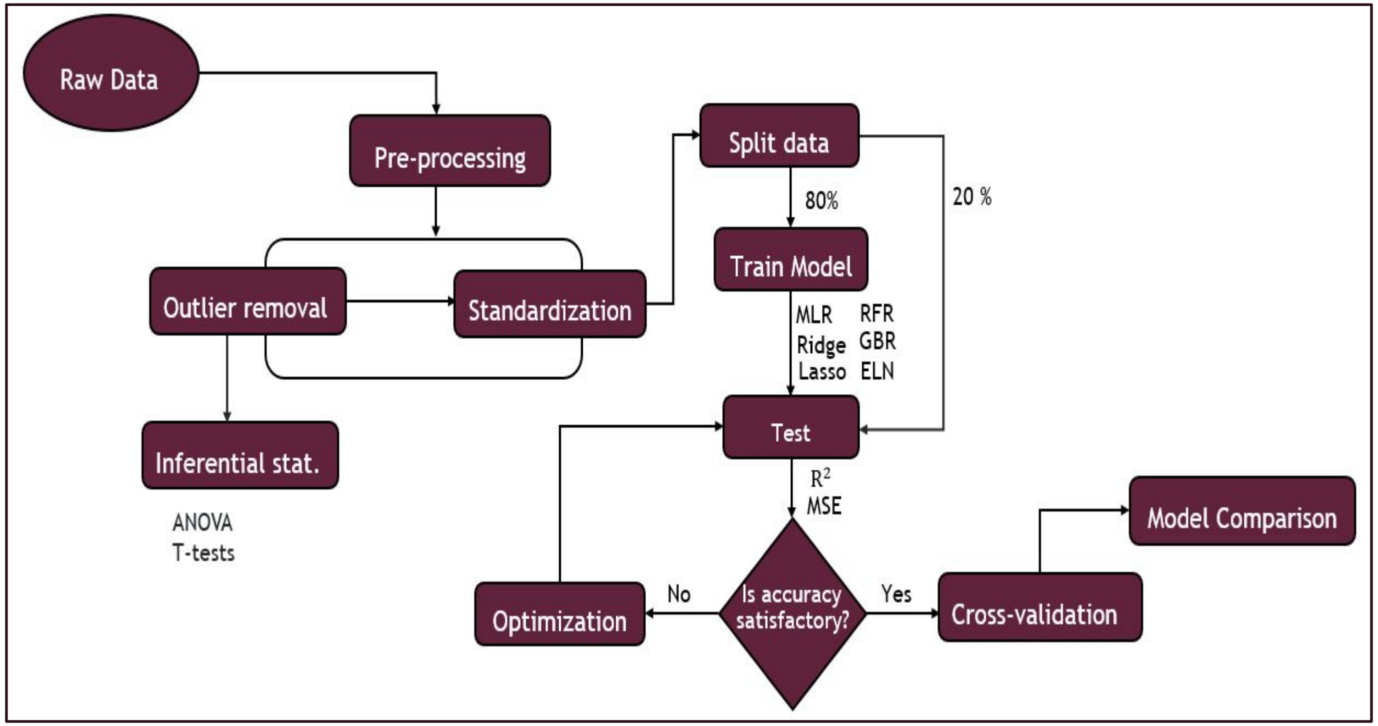

Various tree-based regression models were used map out relationships between the input variables and the variable being predicted.

80 % of the data was used for training the various models, 20 % used for testing.

Part 1: Decision tree, Random Forest Regression, Extra trees regression

Part 2: Random Forest Regression

Part 3: Multiple Linear regression (MLR), Ridge regression, Lasso regression, Elastic Net (ELN) regression, RFR, and Gradient Boosting regression (GBR)

Part 1: Chemistry to mineralogy

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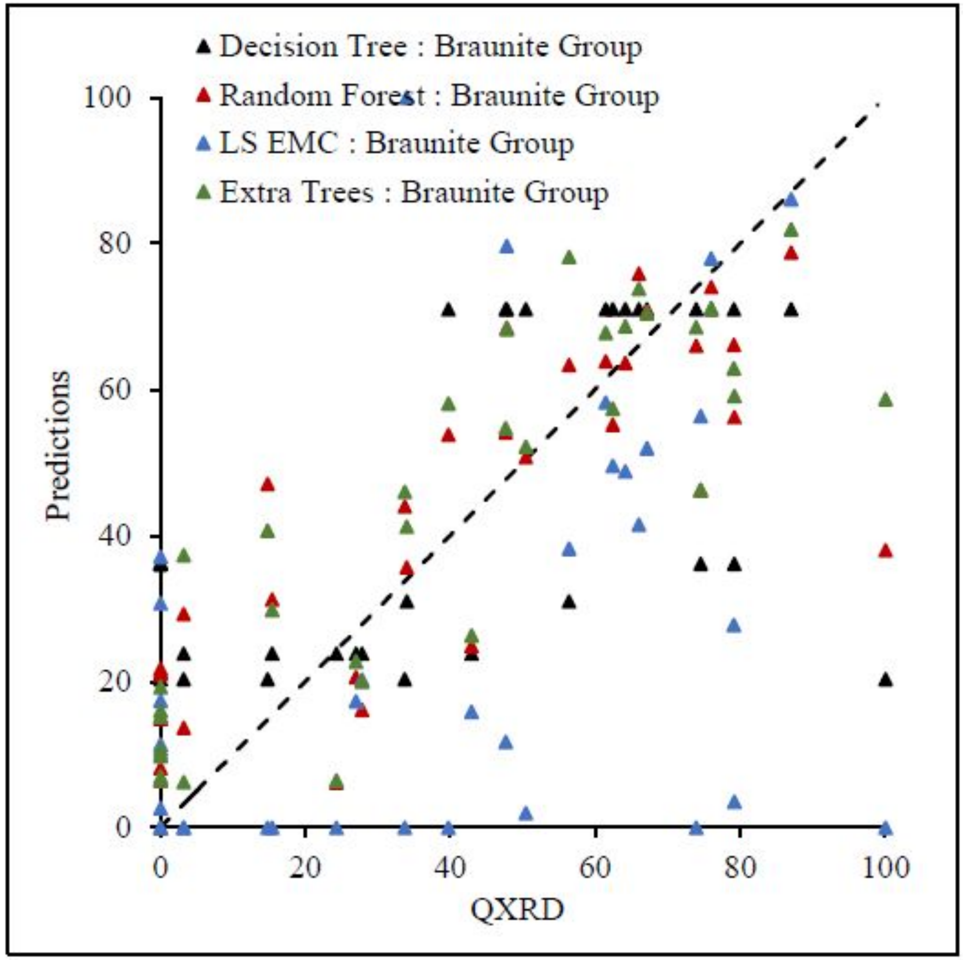
- Data collated from Chetty (2010) and Blignaut (2017), comprised whole rock mineralogy (XRD), whole rock chemistry (XRF) and mineral chemistry (EPMA).

Conducted in two parts:

- Performance of machine learning approaches compared against the more traditional Least Squares Element-to-minerals conversion (mineral groupings/categorisations followed methodologies of Cupido (2021)).
- Performance of ML approaches predicting full mineralogy (i.e., uncategorised)



Part 1: Chemistry to mineralogy

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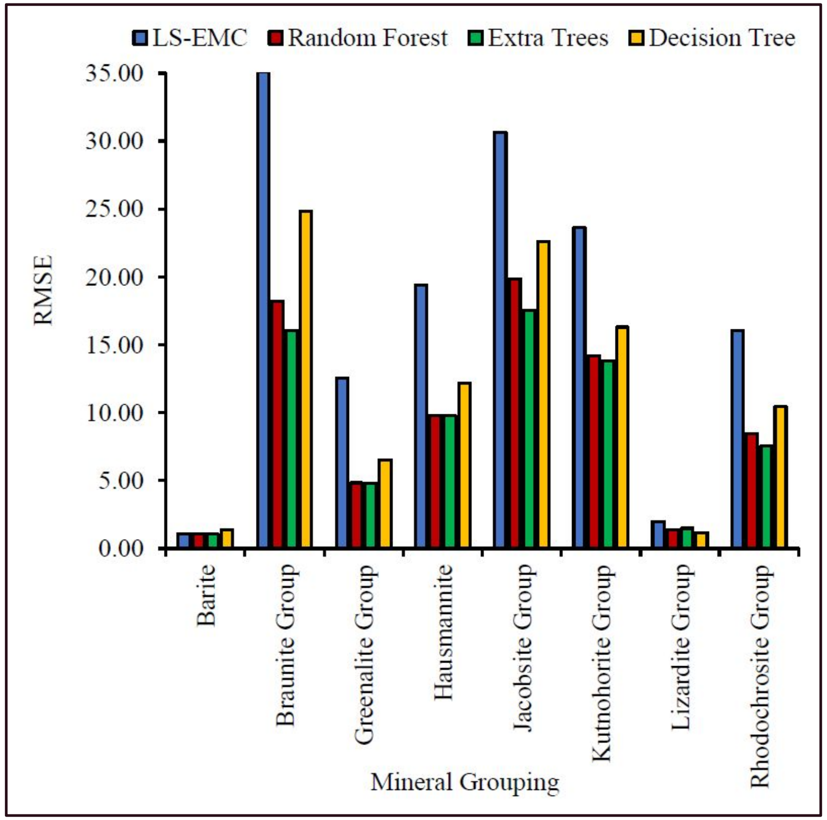
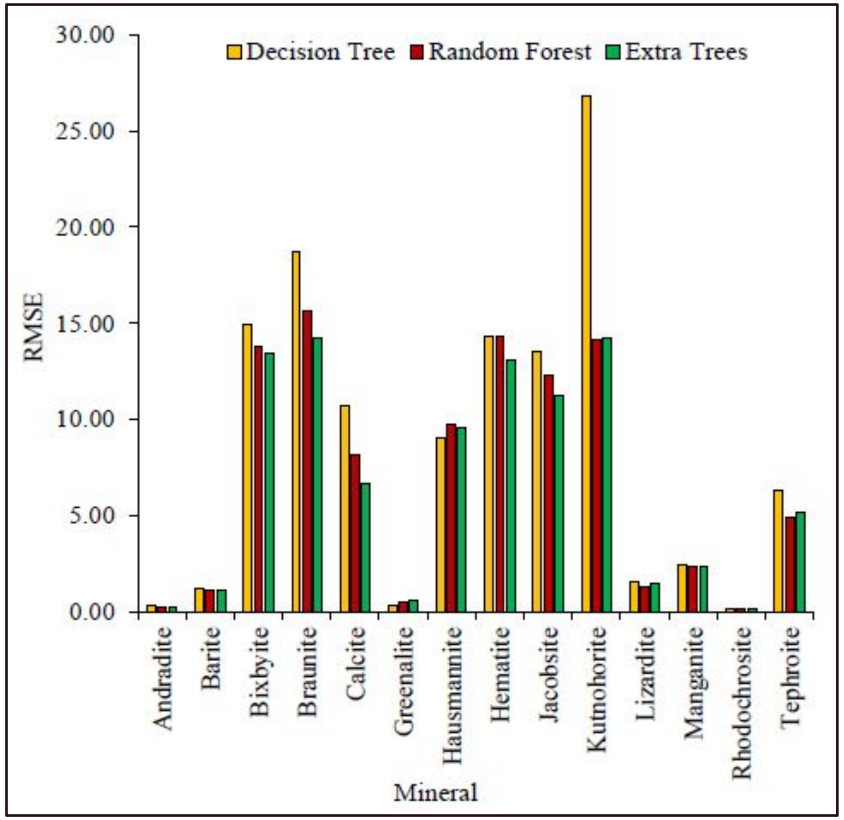


In classifying the data into categorized mineral groups, the extra trees regressor outperformed the other models including the traditional Least squares elements-to-minerals conversion approach.



The extra-trees classifier also showed improved performance in predicting the unclassified minerals, producing the best estimates for nine of the thirteen minerals evaluated.

Part 2: Chemistry to texture

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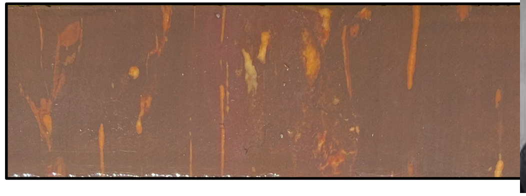
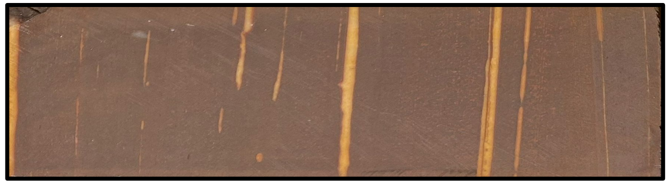
Hematite Lutite



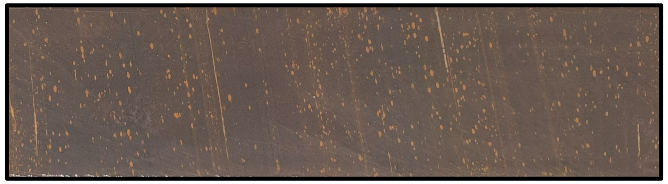
Red-brownish colour in hand specimen and generally consists of a very fine-grained matrix, with carbonate lenses dispersed throughout the ore, in low abundance.

Transitional



Colours that ranges from brown to purple in hand specimen.
This textural domain signifies the shift from a predominantly Fe-rich hematite lutite into the more Mn-rich, underlying ore bed.

Ovoidal



Forms part of the unaltered ore, displaying a brown to black matrix with an abundance of carbonate ovoids.

Laminated

Forms part of the unaltered ore, displaying a brown to black matrix with an abundance of carbonate laminae.

Massive

Forms part of the altered ore, contains only a small number of ovoids, laminae and lenticles, most of which has almost been completely replaced by hausmannite or other minor oxide minerals.

Part 2: Chemistry to texture

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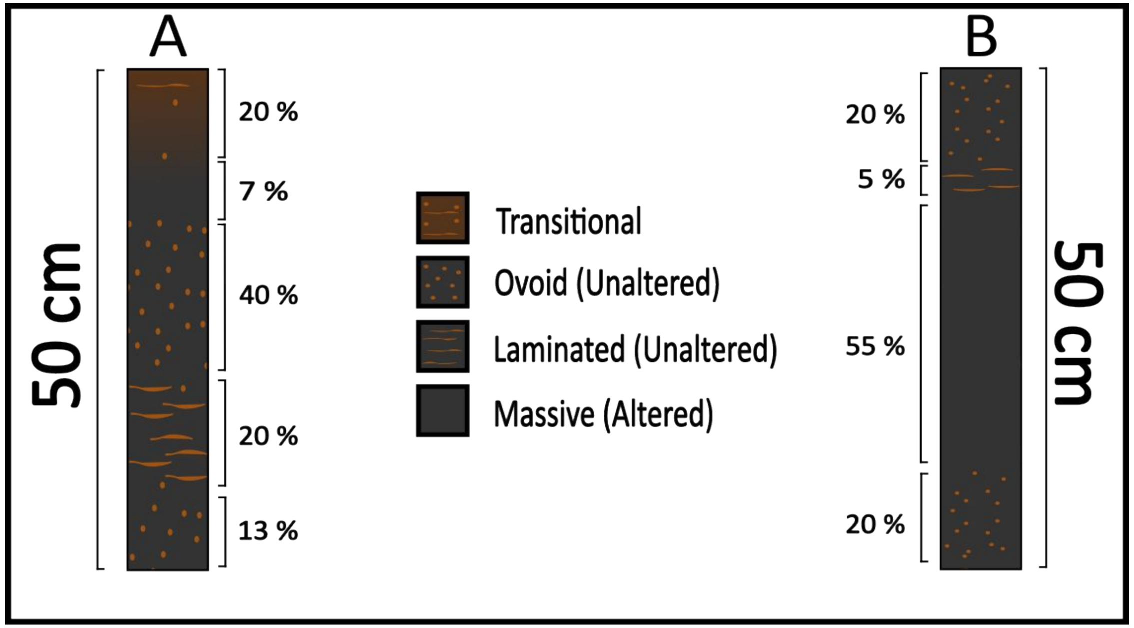

	Depth From	Depth To	Ovoid	Laminated	Massive	Transitional	Hem - Lutite
A	430	430.5	53	20	7	20	0
B	430.5	431	40	5	55	0	0

MN	Ovoid	Laminae	Massive	Transitional	Hlutite	Predicted_Mn	Residuals
31,6	40	40	20	0	0	30,83843847	-0,76156
34,06	10	50	40	0	0	33,48226132	-0,57774
33,03	40	15	45	0	0	33,16519567	0,135196
36,05	30	0	70	0	0	35,62004675	-0,42995
32,77	80	0	20	0	0	30,72778984	-2,04221
33,18	30	40	30	0	0	32,78657463	-0,39343
38,73	20	20	60	0	0	36,16047841	-2,56952
34,54	30	20	50	0	0	35,05962866	0,519629
36,73	10	0	90	0	0	37,64238617	0,912386
36,16	5	0	95	0	0	39,69859563	3,538596

Whole rock chemistry values reported for 50 cm core intervals. Need for weighted averaging.

Part 2: Chemistry to texture

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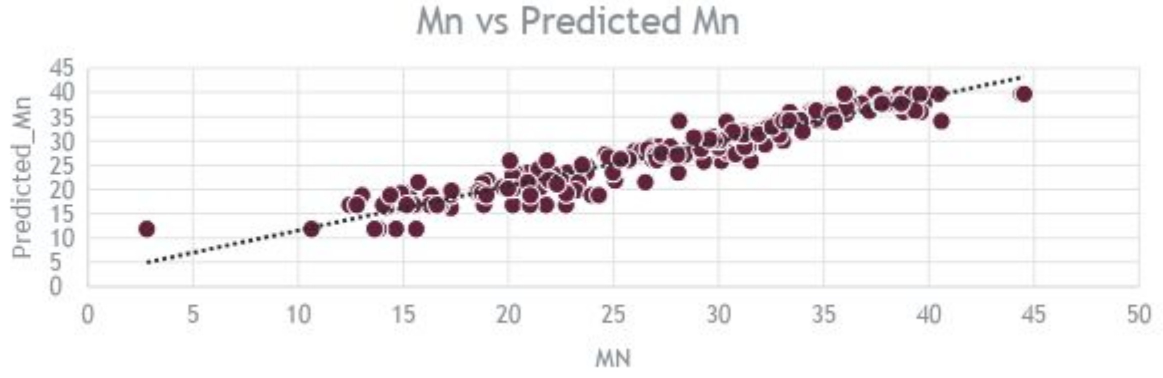

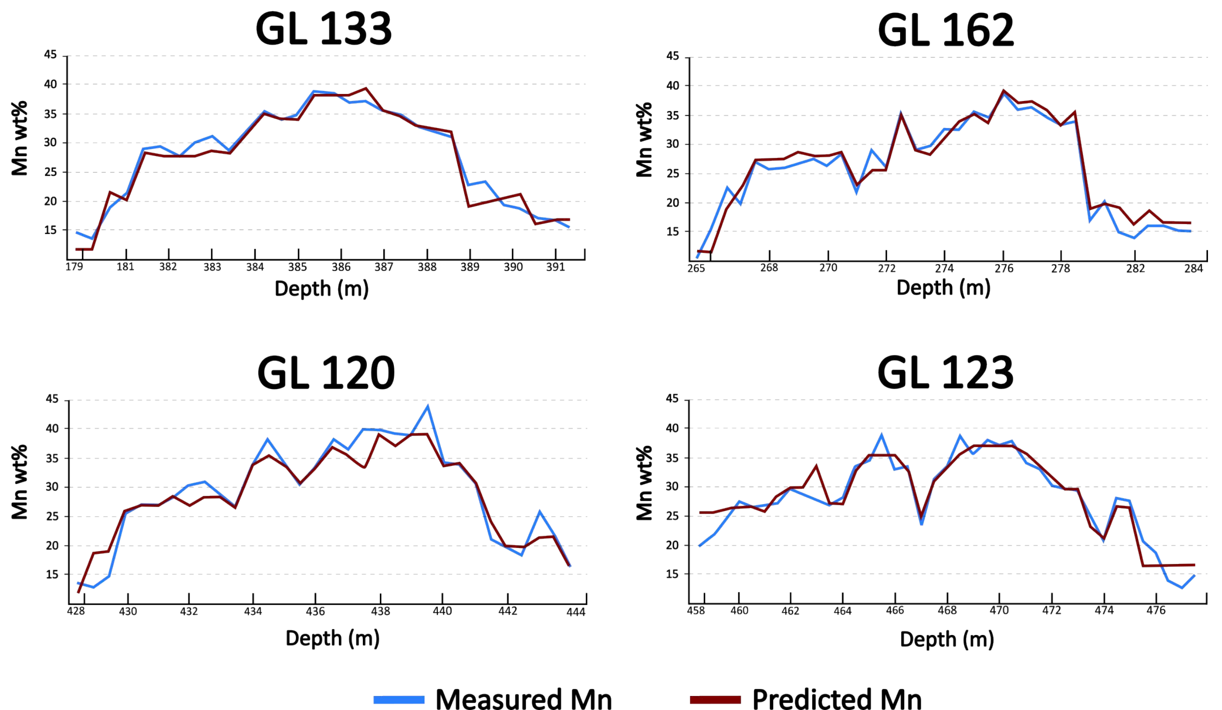

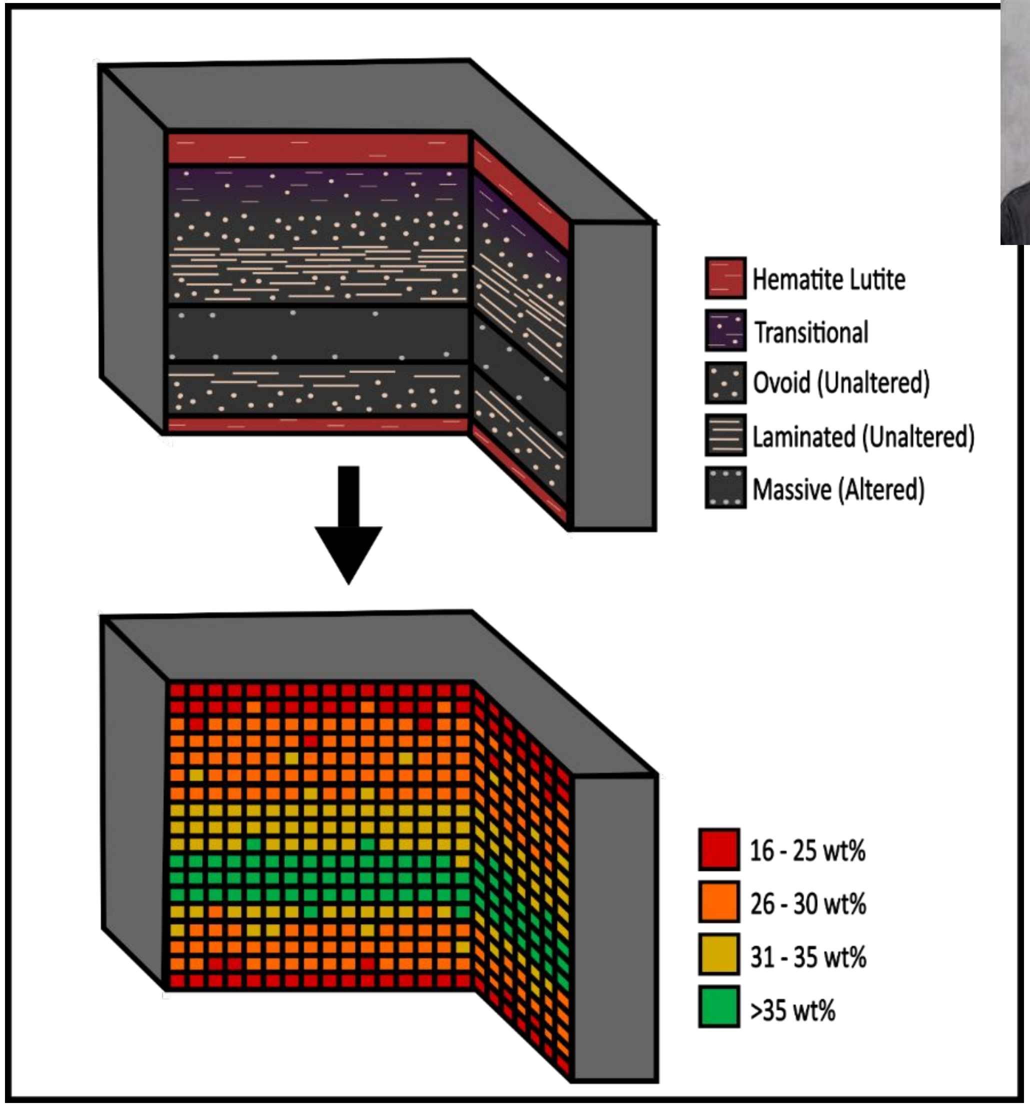

Part 3: Mineralogy to comminution

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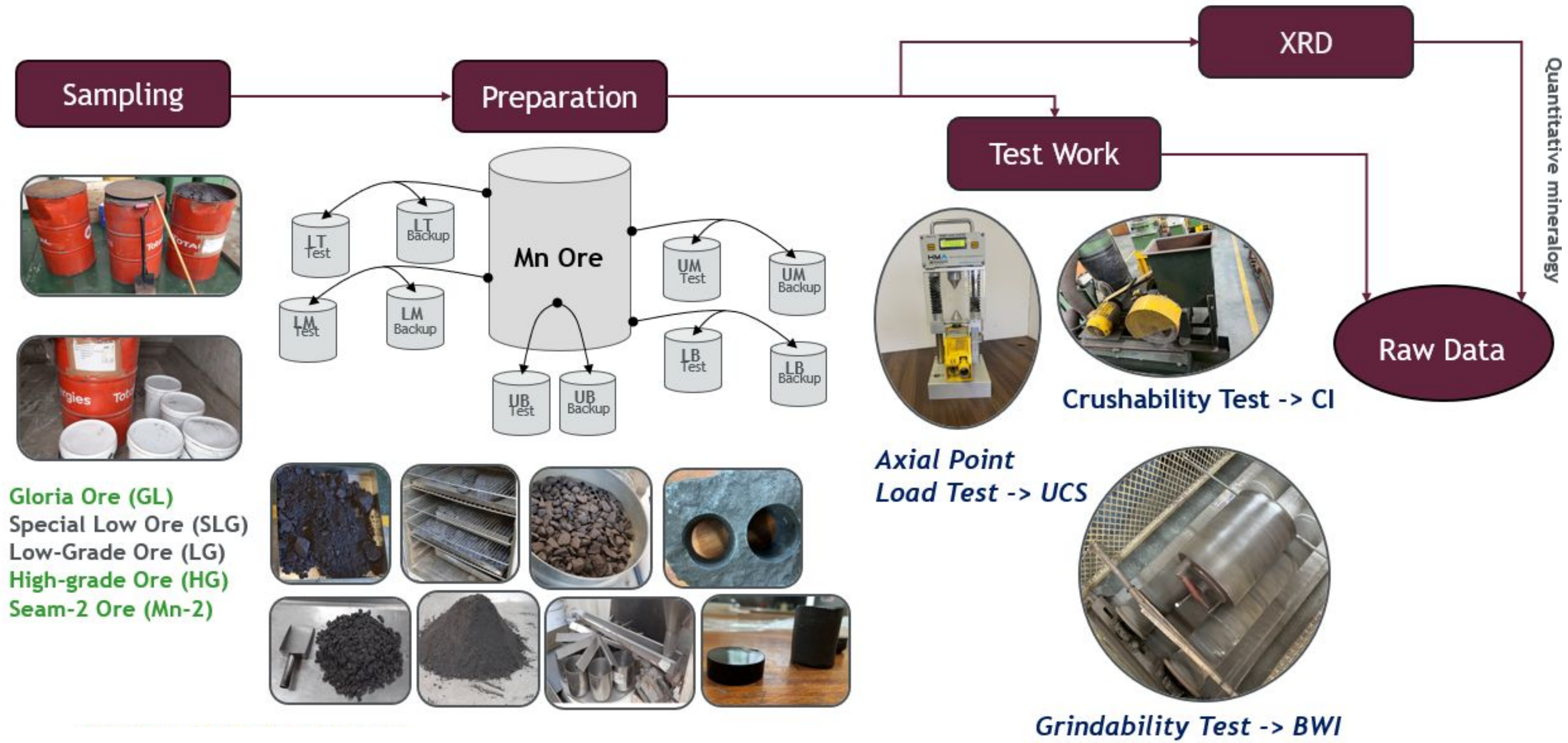

Part 3: Mineralogy to comminution

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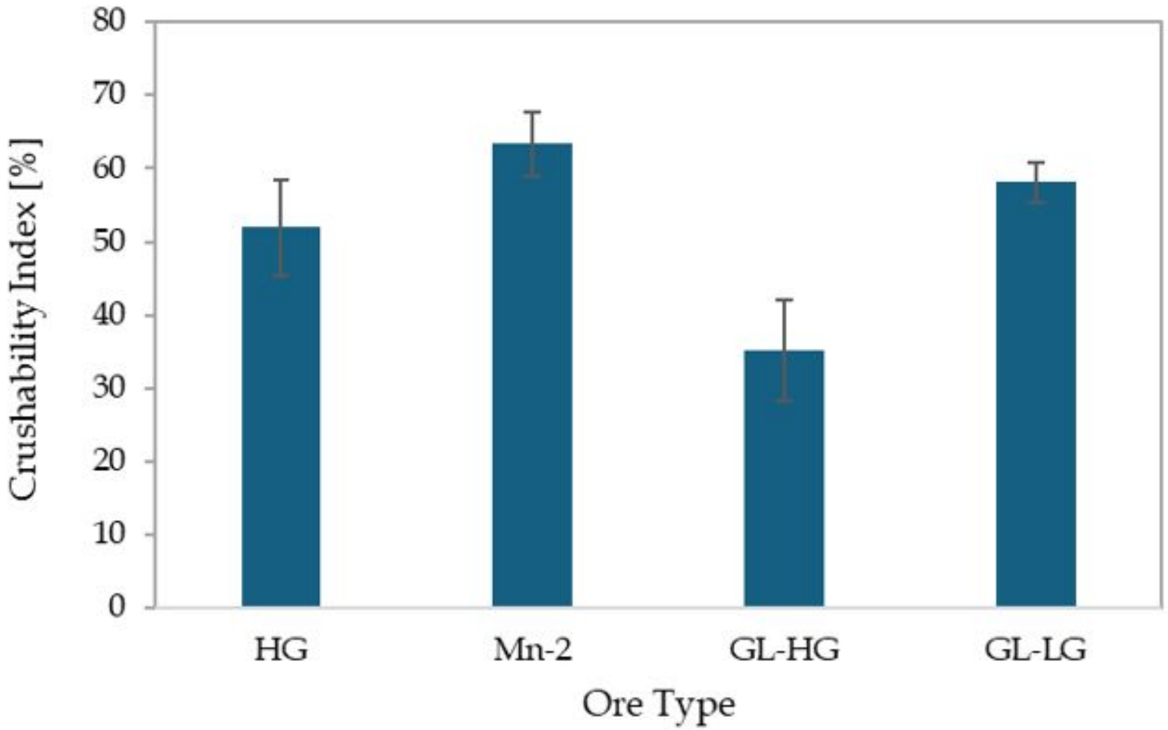
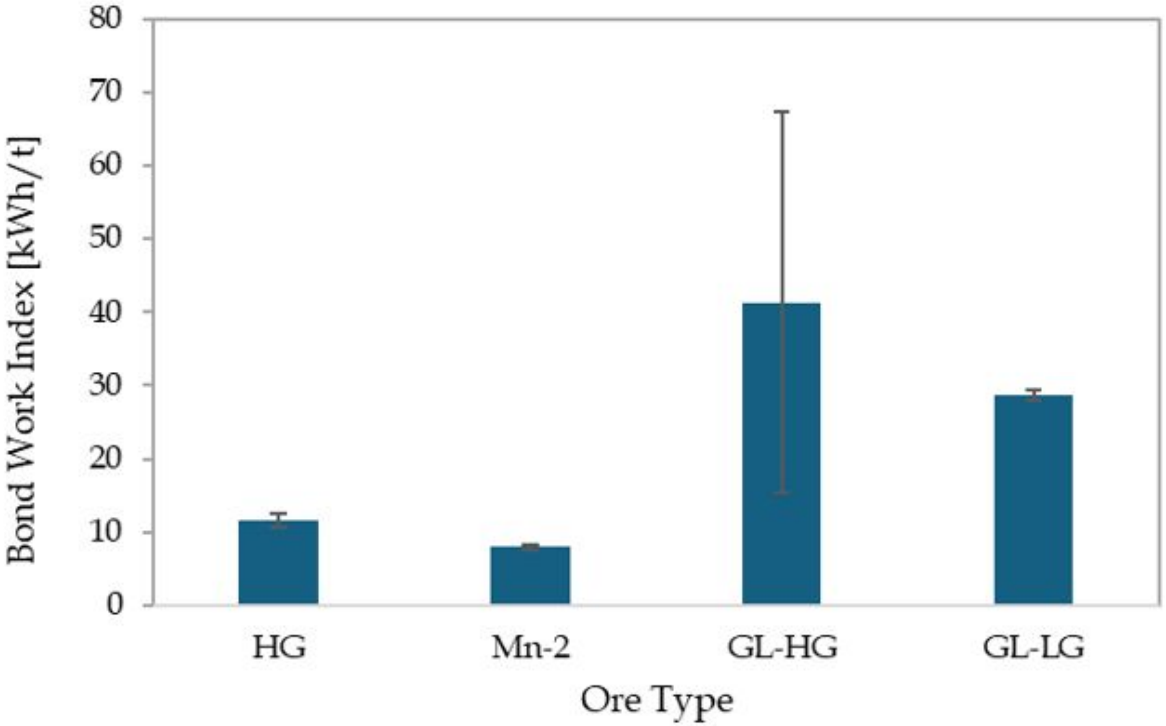
- Comminution indices showed variable response between the different ore types.
- Some surprising results, viz. Gloria ores with high bond work index, yet low crushability





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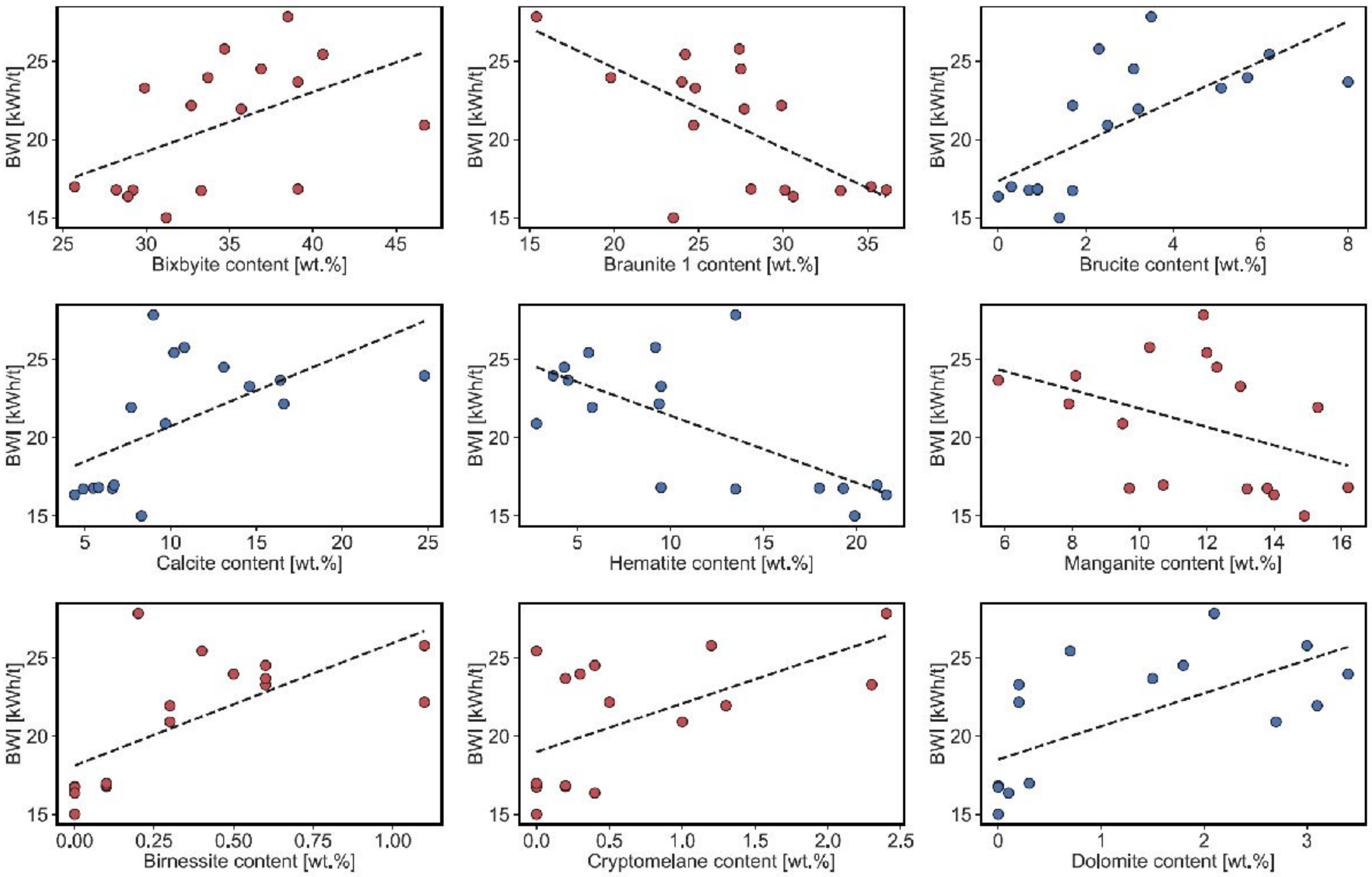

- Samples with higher contents of manganite, hematite, and braunite 1 showed lower BWI values, suggesting that increase in these minerals due to their hardness or brittleness may enhance breakage.
- Minerals such as bixbyite, kutnohorite, calcite, and dolomite which are softer mineral was generally associated with increased grinding resistance.
- Infer that other physical properties possibly influenced breakage behaviour. e.g., texture, rheology, size distributions, cleavage planes…

Part 3: Mineralogy to comminution

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Crushability Index results:

Index	Actual	Model predictions					
#	CI [%]	MLR	Ridge	Lasso	ELN	RFR	GBR
1	67.0	65.2	63.9	64.1	64.1	64.9	63.5
2	55.0	59.9	59.1	58.7	59.0	59.0	59.4
3	60.3	60.4	60.2	61.2	60.4	60.3	59.7
4	53.7	53.0	52.9	55.9	53.5	54.1	54.8
RMSE		**2.6**	**2.6**	**2.8**	**2.4**	$\boxed{\textbf{2.3}}$	$\boxed{\textbf{3.0}}$
		0.74	**0.75**	**0.70**	**0.79**	$\boxed{\textbf{0.81}}$	$\boxed{\textbf{0.67}}$

- Good predictive performance
- Random Forest Regression model shows highest accuracy: RMSE =2.3 %, R^2=0.81.
- Gradient Boost Regression model shows lowest, yet comparable, accuracy: RMSE =3 %, R^2=0.67.

Part 3: Mineralogy to comminution

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Bond Work Index results:

Index #	BWI [kWh/t]	Model predictions					
		MLR	Ridge	Lasso	ELN	RFR	GBR
1	25.8	23.4	24.1	24.4	24.4	24.6	25.8
2	23.7	26.1	23.9	24.2	23.9	24.0	23.7
3	22.2	18.8	21.8	20.9	21.4	20.4	17.7
4	16.4	15.1	16.9	16.8	16.9	16.5	16.4
RMSE		**2.49**	**0.90**	**1.01**	**0.86**	**0.96**	**1.38**
		0.49	**0.93**	**0.92**	**0.94**	**0.92**	**0.84**

- Elastic Net regression model shows highest predictive accuracy: RMSE =0.86 kWh/t, R^2=0.94.
- Multiple Linear Regression model shows lowest, yet still comparable, accuracy: RMSE = 2.49 kWh/t, R^2= 0.49.
- Comminution indices could be accuracy predicted from mineralogy…

Further work

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- Textural evaluations from core scanning data.
- Hyperspectral scanner: SWIR + RGB.
- Intermediate scale measurements, with continuous data.
- Case study at a porphyry system in British Columbia
- Complement existing technologies at e.g., Wits, UCT.

Thank you
Enkosi
Dankie

Photo by Stefan Els

Conclusion

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M.Sc.

Part 1

Part 2

Part 3

SCALE

Chemical | Mineralogical | Textures | Particle attributes | Particle processing behaviour | Product attributes

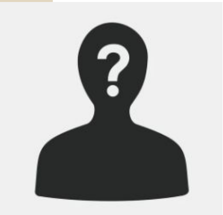
Geometallurgical characterisation

Process model

DISCIPLINE

Geology | Mining | **Processing:** Pyromet., Hydromet., Biohydromet. | **Marketing:** Client specifications

Ph.D.



PARADIGM

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APPROACHES

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ACHES

<u>Empirical:</u> Geomet domaining based on known attributes, then test work

<u>Data science:</u> Determine data relationships between primary variables and outputs

<u>Theoretical:</u> Based on first principles models and understanding

Apply now

Master's and doctoral research in geometallurgy at Stellenbosch University

The African Rainbow Minerals (ARM) Chair in Geometallurgy, housed at Stellenbosch University's (SU) Departments of Process Engineering and Earth Sciences, invite candidates to apply for master's and doctoral research in this exciting and interdisciplinary field.

This Research Chair, sponsored by the minerals industry, represents a research unit at SU that focuses on understanding and modelling ore deposits from their discovery through mining, to ultimately their beneficiation response. This collaborative research partnership couples geological and minerals processing skillsets with world-class analytical facilities housed at SU.

Student projects will cover a range of subtopics within the field of geometallurgy, including themes such as ore body characterization, a meta-analysis of existing datasets, ore body and geometallurgical modelling, process modelling and optimization. Student projects will involve a component of field/mining industry exposure. Supervision and project oversight will be provided by Drs Margreth Tadie and Bjorn von der Heyden, an assigned post-doctoral researcher, and an industry-based engineer.

How to apply

Applicants must submit a single pdf document comprising a cover letter, and comprehensive CV including three professional references.

Applications and enquiries should be emailed to both Dr Von der Heyden (bvon@sun.ac.za) and Dr Tadie (mtadie@sun.ac.za) by **22 November 2024**.

Stellenbosch University reserves the right not to fill the position.

Requirements

Applicants should hold the relevant degree qualifications to meet SU's entry requirements. Preference will be given to applicants from the fields of geology, earth sciences, chemical engineering, extractive metallurgy, mining engineering, mathematics, data science, or a related field. Applicants must be fluent in English and possess excellent written communication skills.

Applications will be evaluated by both SU and African Rainbow Minerals. Students are expected to complete their degrees within the typical SU degree timeframe, i.e. two years for an MEng/MSc and three years for a PhD.

These positions are open to South African citizens only.

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