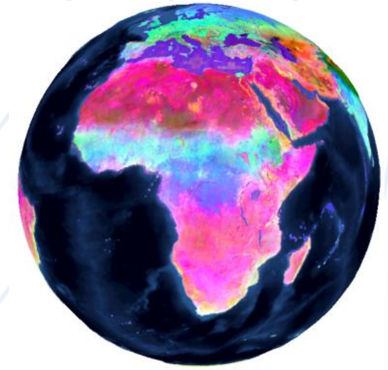
Geometallurgy Conference 2025
Future-Ready Geometallurgy: Trusted Data, Advanced Tools, Smarter Decisions

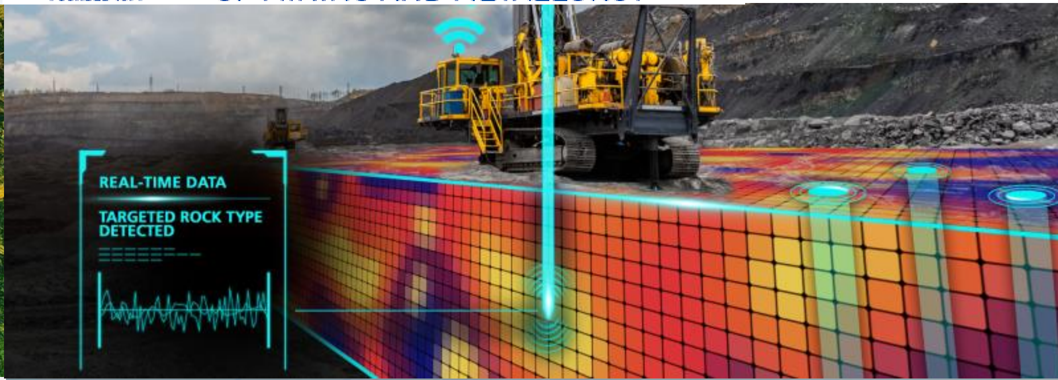
WITS GEOSCIENCES — 120 Years of Teaching & Research

CORES — THE AFRICAN RESEARCH CENTRE FOR ORE SYSTEMS SCIENCE — EST. 1957 AS EGRI

SAIMM — THE SOUTHERN AFRICAN INSTITUTE OF MINING AND METALLURGY — CAPACI OCCASIO — FOUNDED 1894

unipampa — Universidade Federal do Pampa



Are Variational Gaussian Processes the Missing Link in Predictive Geometallurgy?

Prof. Glen Nwaila

Director of the African Research Centre for Ore System Science (CORES) |University of the Witwatersrand | Email: glen.nwaila@wits.ac.za | Website: www.glennwaila.com

Prof. Ítalo Gomes Gonçalves

Geological Modelling Laboratory | Federal University of Pampa – Caçapava do Sul – RS – Brazil

Compartments limit adoption of Geomet

- Mining doesn’t run on a value chain; it runs on islands (i.e., compartments/segmented disciplines).
- Every arrow here is a hand-off where uncertainty dies and a spreadsheet is born.
- We export a number; the next team imports a fact.
- Today I’ll show a way to keep uncertainty alive across the chain.

Toward Coherent Predictive Geometallurgy

Statistics

"Discipline that concerns the collection, organisation, analysis, **interpretation**, and presentation of **data**."

Geostatistics

"Branch of statistics **focusing on spatial** or spatiotemporal datasets."

Machine learning

"Field of study in artificial intelligence concerned with the development and study of statistical algorithms that can **learn from** and generalise to unseen **data** and thus perform tasks **without explicit instructions**."

We need a name to unify the new discipline!

- Geo-machine intelligence?
- Spatio-temporal big data analytics?
- Geostatistical learning?
- Geodata Intelligence?

Fog of War

- Your model is a scout, not an oracle!
- The question isn't *what* it reveals, it's *how far that revelation is reliable*.
- Spatial awareness: We need to know how far we can trust it.

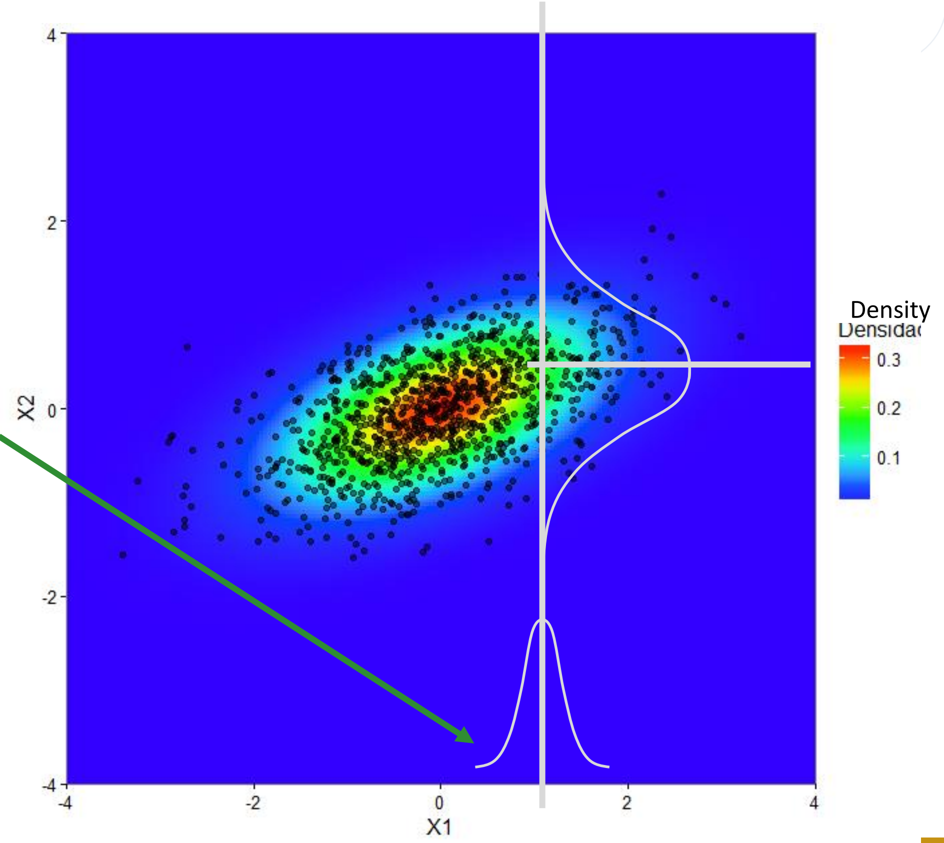
Variational Gaussian Processes (VGP): Calibrated Uncertainty at Deposit Scale

Given a noisy observation of x_1, we update our belief about x_2 : the mean shifts towards what x_1 suggests, and the variance shrinks; both by amounts determined by correlation and noise.

$$p(x_2|x_1) = \mathcal{N}\left(\underbrace{\frac{\sigma_1\sigma_2\rho_{12}}{\sigma_1^2+\Lambda}(x_1-\mu_1)}_{\text{Conditional Mean}} + \mu_2,\ \sigma_2^2\underbrace{\left(1-\frac{\sigma_1^2\rho_{12}^2}{\sigma_1^2+\Lambda}\right)}_{\text{Conditional Uncertainty}}\right)$$

Uncertainty

- If **one value is known**, it can be used to obtain **the conditional distribution** for the other.
- If one value is only **approximately known**, it is still able to provide some information.



Gonçalves, Í. G., & Wellmann, F. (2025).

Case study: Assen Fe Deposit (South Africa)

Reality in BIF deposits

- Heterogeneous chemistry/texture/density across domains.
- Blend stability, energy use, and spec risk vary spatially.

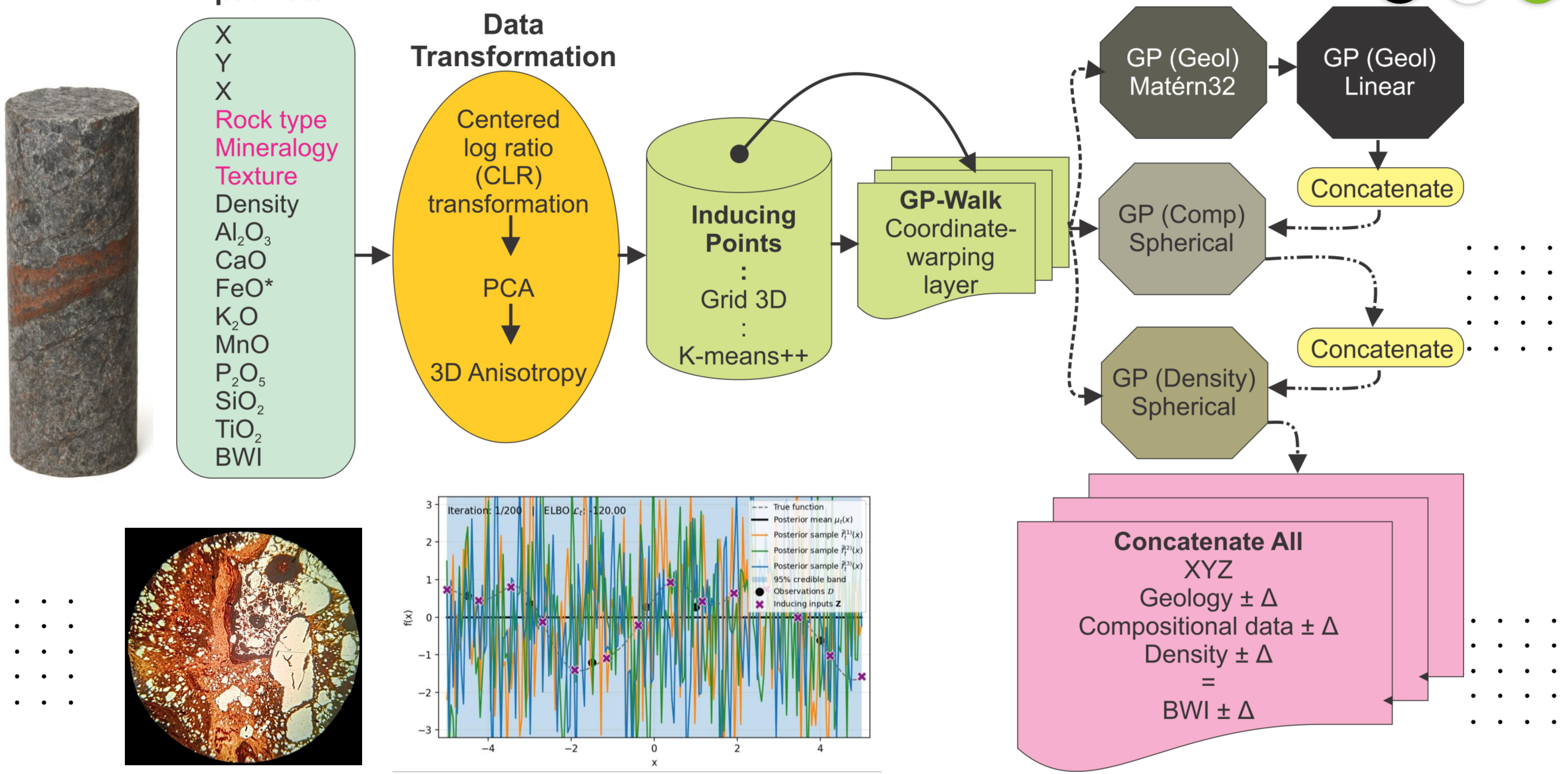
Why classical GP/co-kriging fall short

- With 30,000 samples and 5 outputs, **standard GP and co-kriging is about 10^{13} FLOPs,** while a **variational GP lands near 10^{10}**. That's roughly **a 1000-fold** saving versus exact GP.

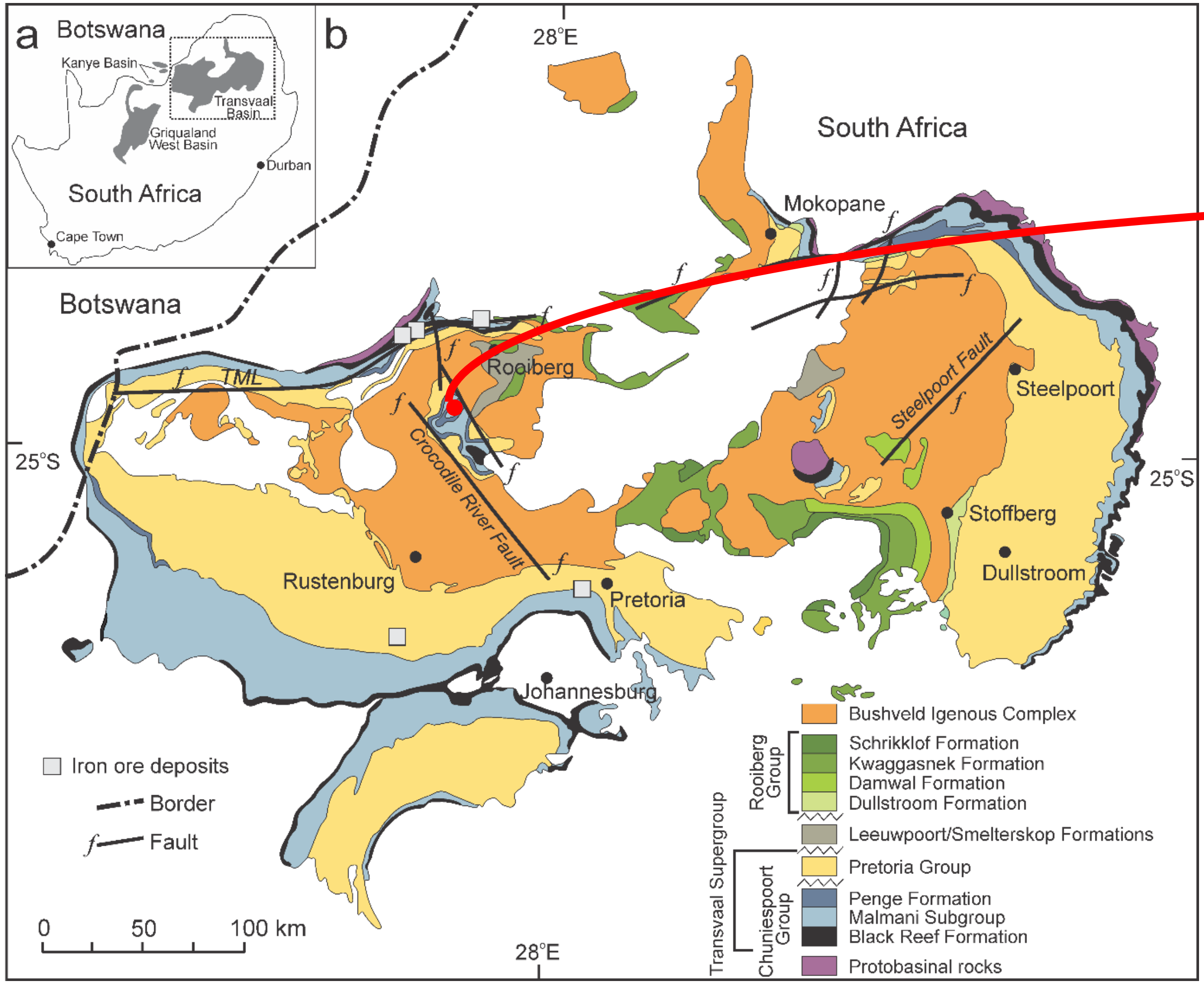
Testable question

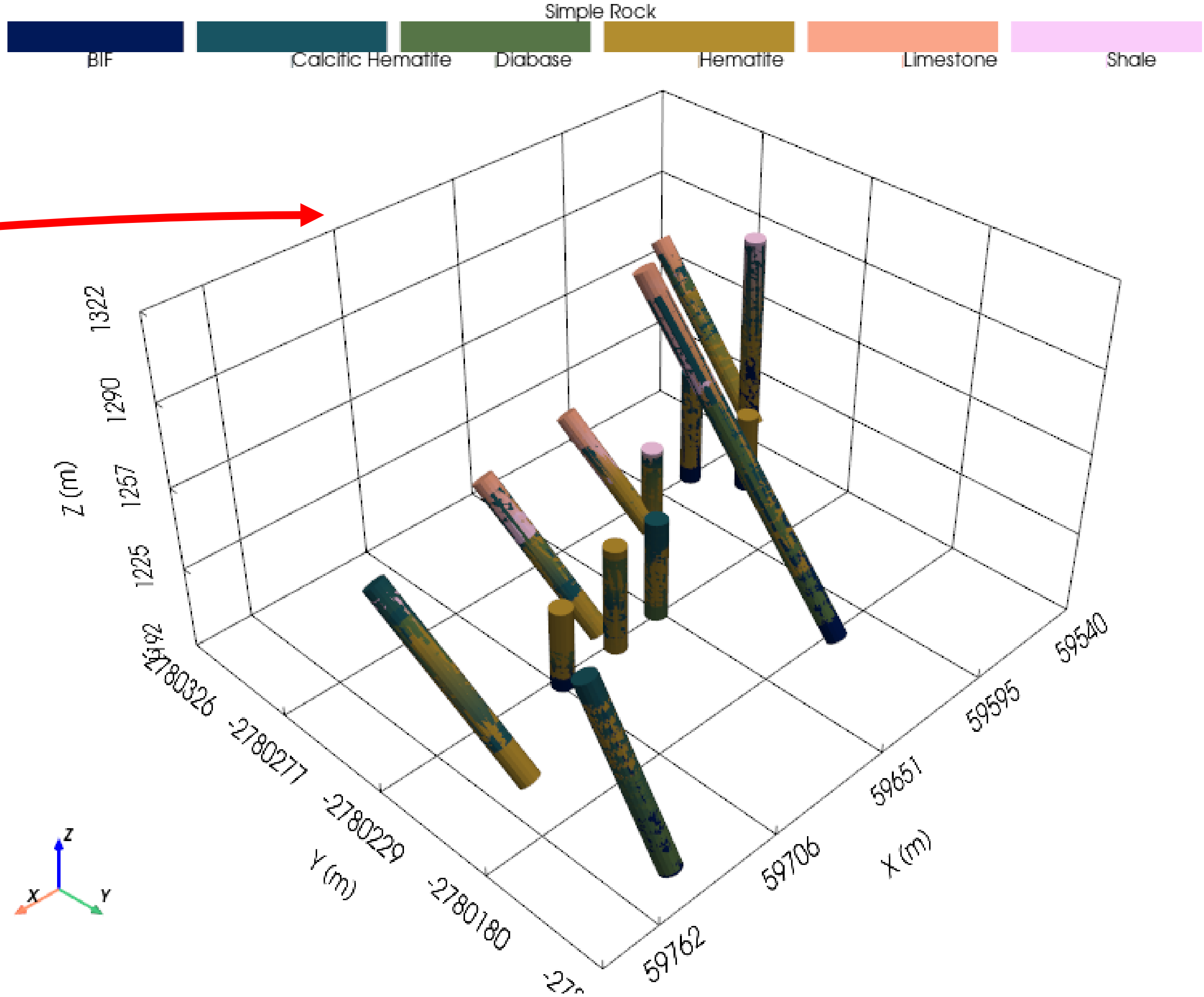
- Can a scalable, compositionally coherent VGP support rock classification, multi-element prediction, density estimate and energy decisions?

How the VGP geometallurgy pipeline works

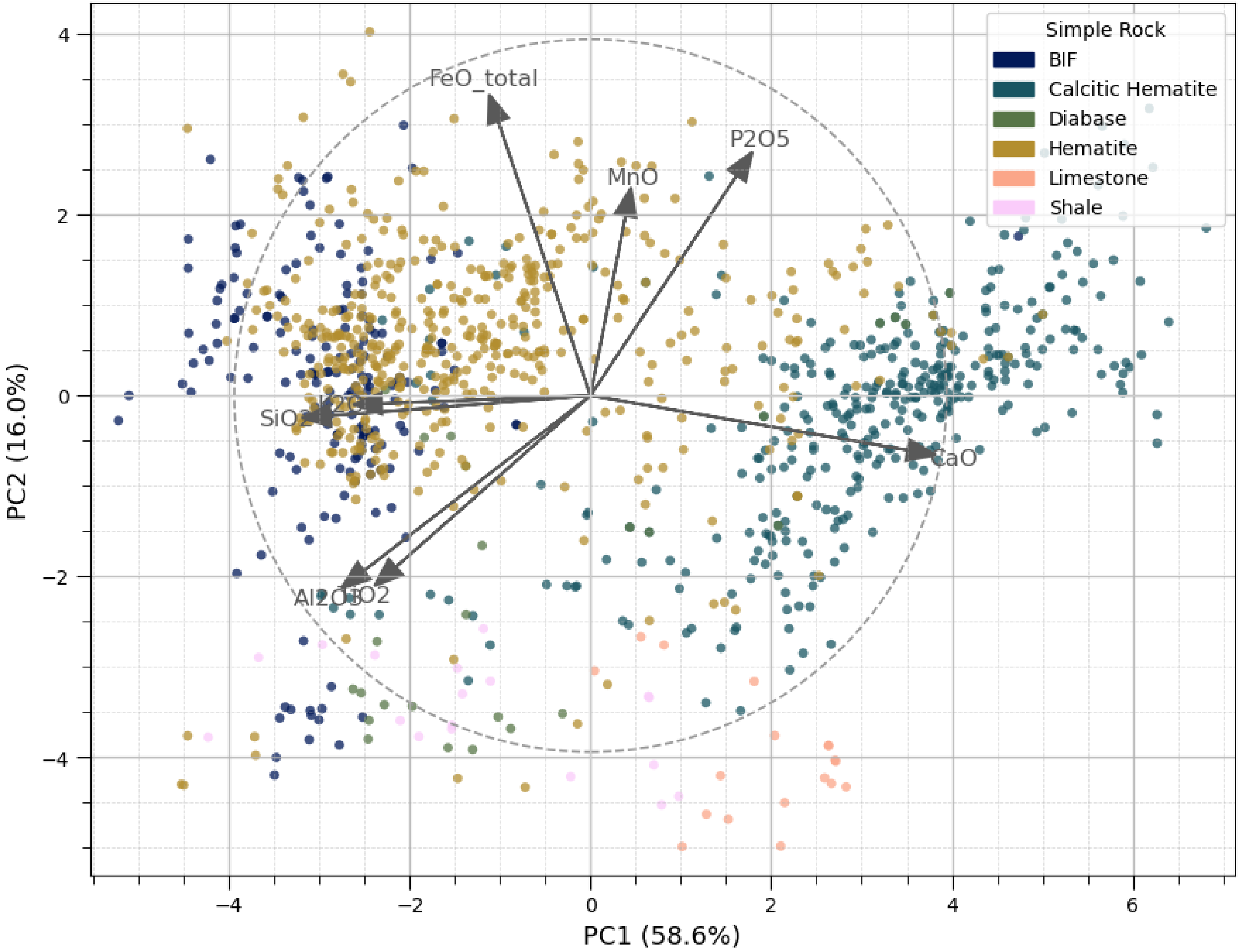


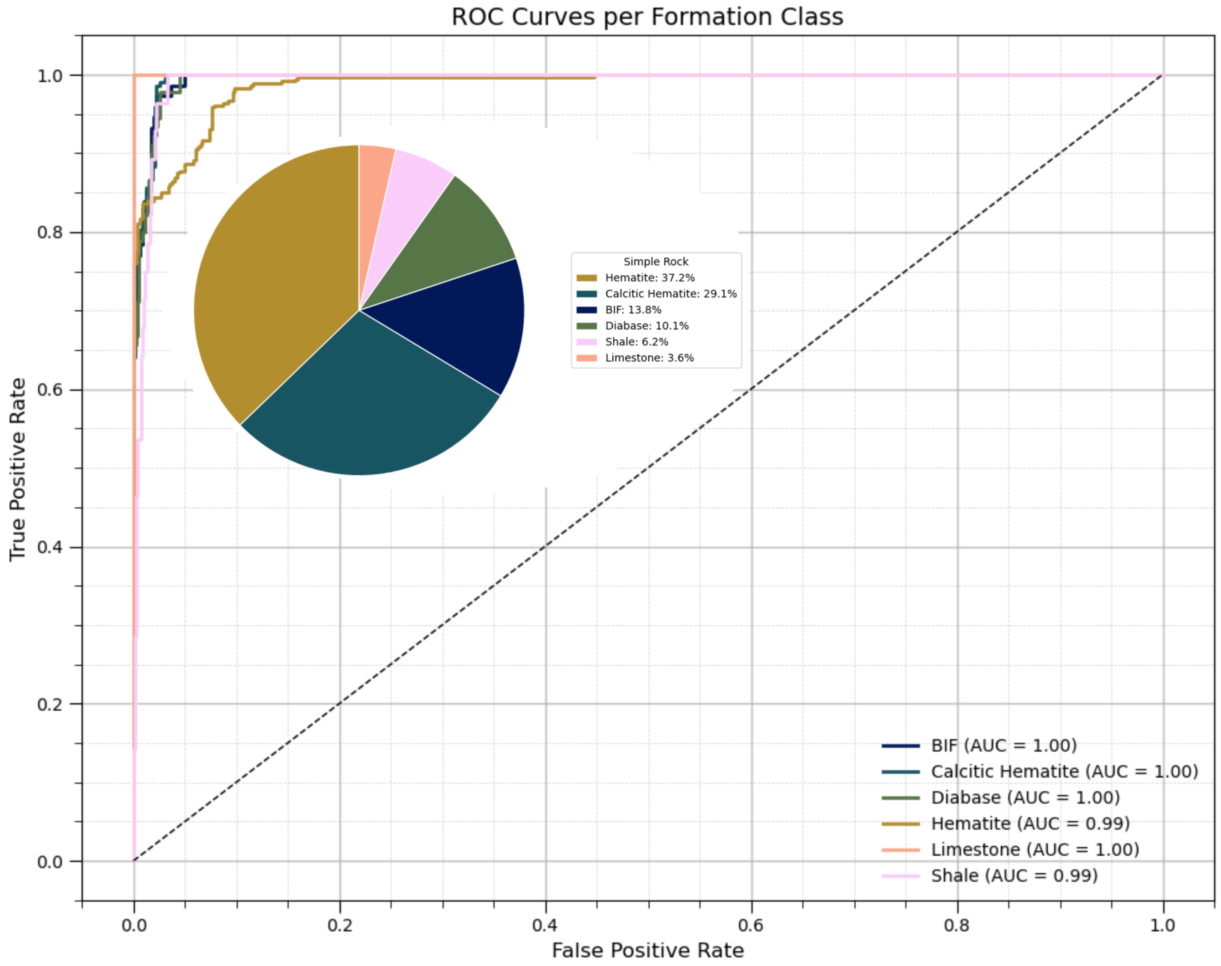
Implicit Geological Modelling



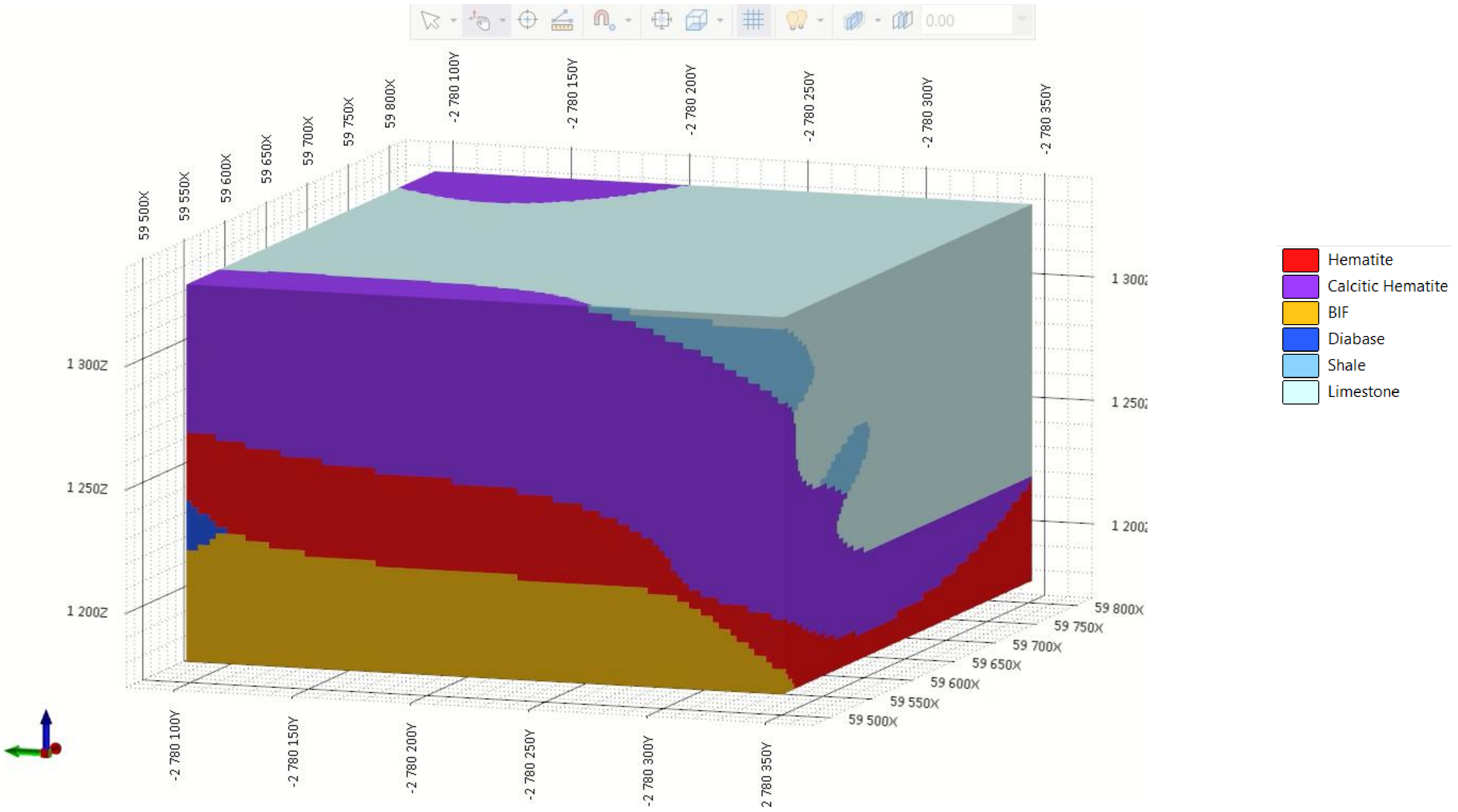


Implicit Geological Modelling



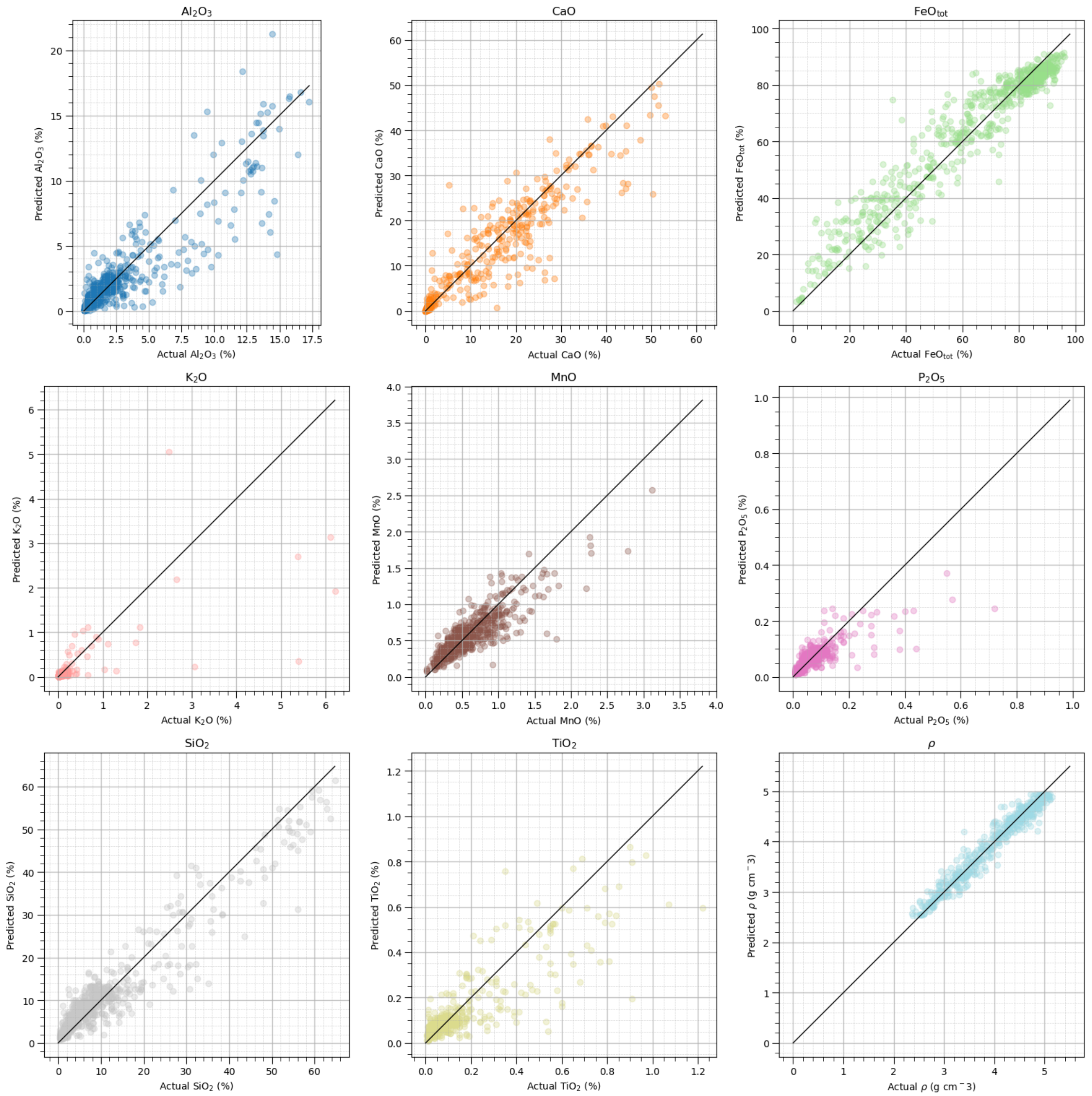


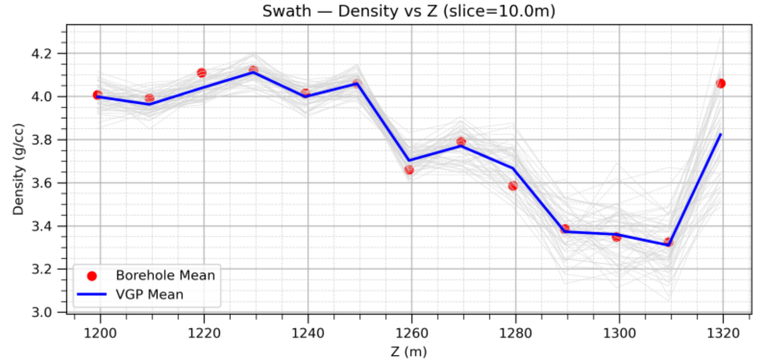
Implicit Geological Modelling



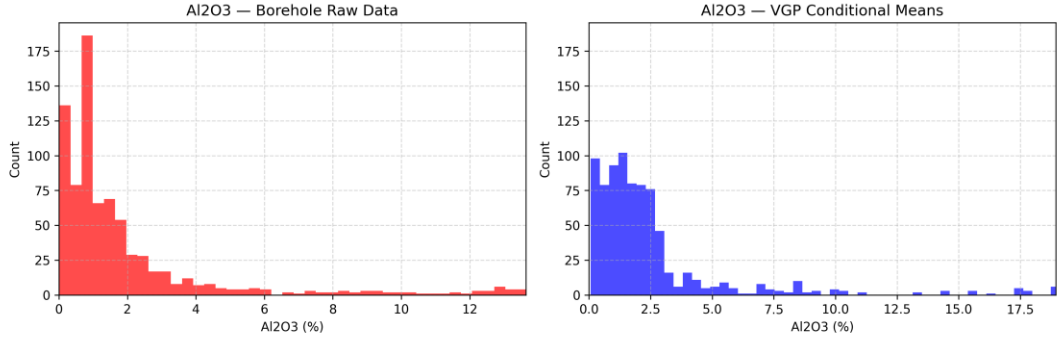
Setting calibrated business rules

Actual Versus VGP Prediction

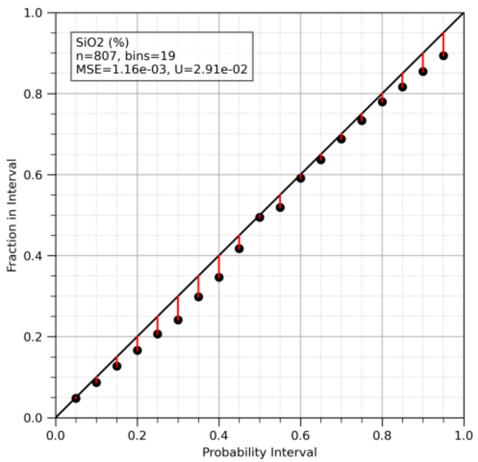




Swath Plots



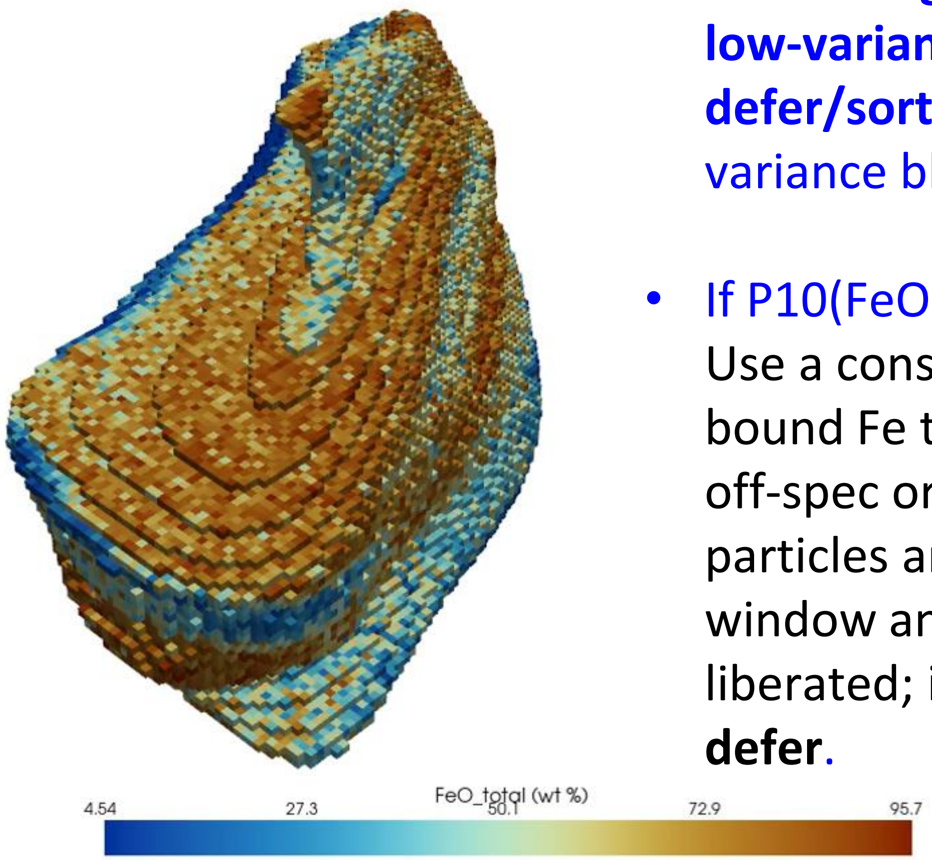
PDFs



- **X-axis (probability/coverage asked for):** target/nominal coverage of your predictive interval (e.g., 0.7 ⇒ “70% should contain the truth”).
- **Y-axis (probability/coverage achieved):** empirical fraction of cases where the truth actually fell inside those intervals for each bin.
- **45° Line:** on line = calibrated; below = under-coverage/over-confident; above = over-coverage/conservative.

FeO_{total} Uncertainty Quantification

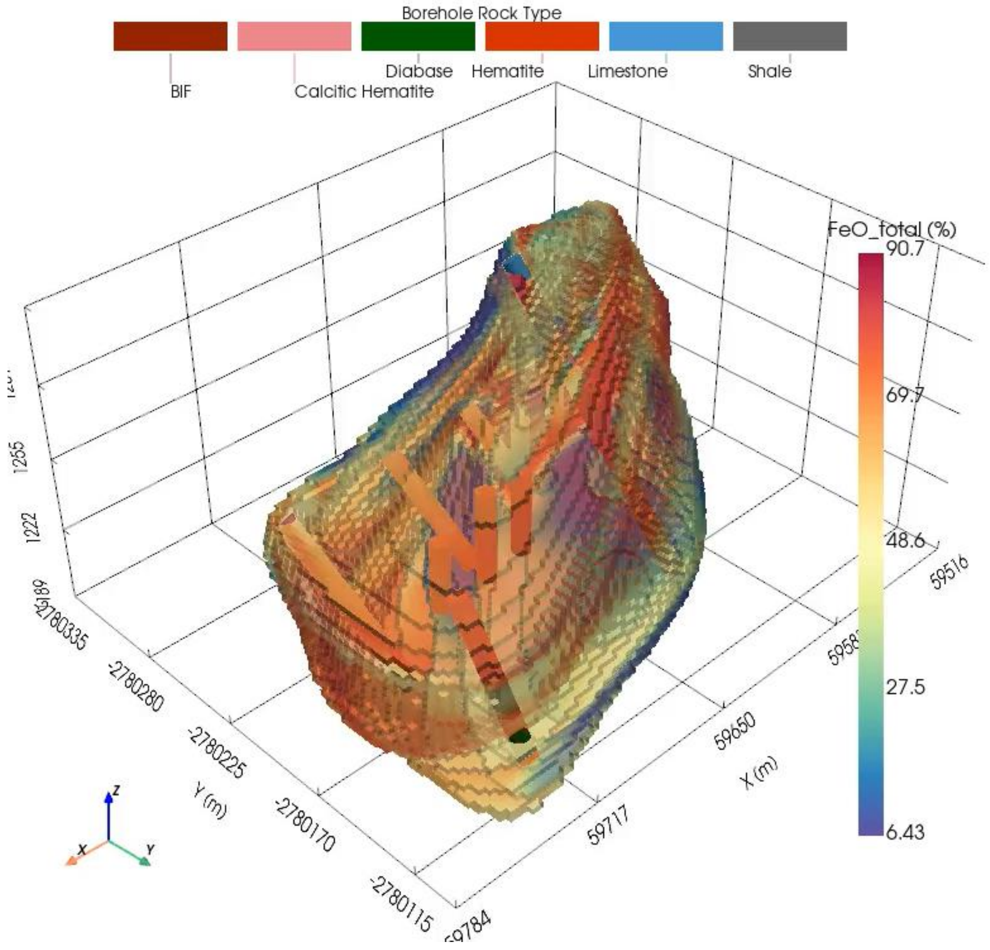
Multiple VGP Realisations



- **Scheduling:** advance **high-Fe, low-variance** blocks; **defer/sort** low-Fe or high-variance blocks.

- If P10(FeO_{total}) ≥ Fe min → Use a conservative lower-bound Fe to schedule; send off-spec ore to **jig/DMS** when particles are in the right size window and sufficiently liberated; if not, **stockpile or defer**.

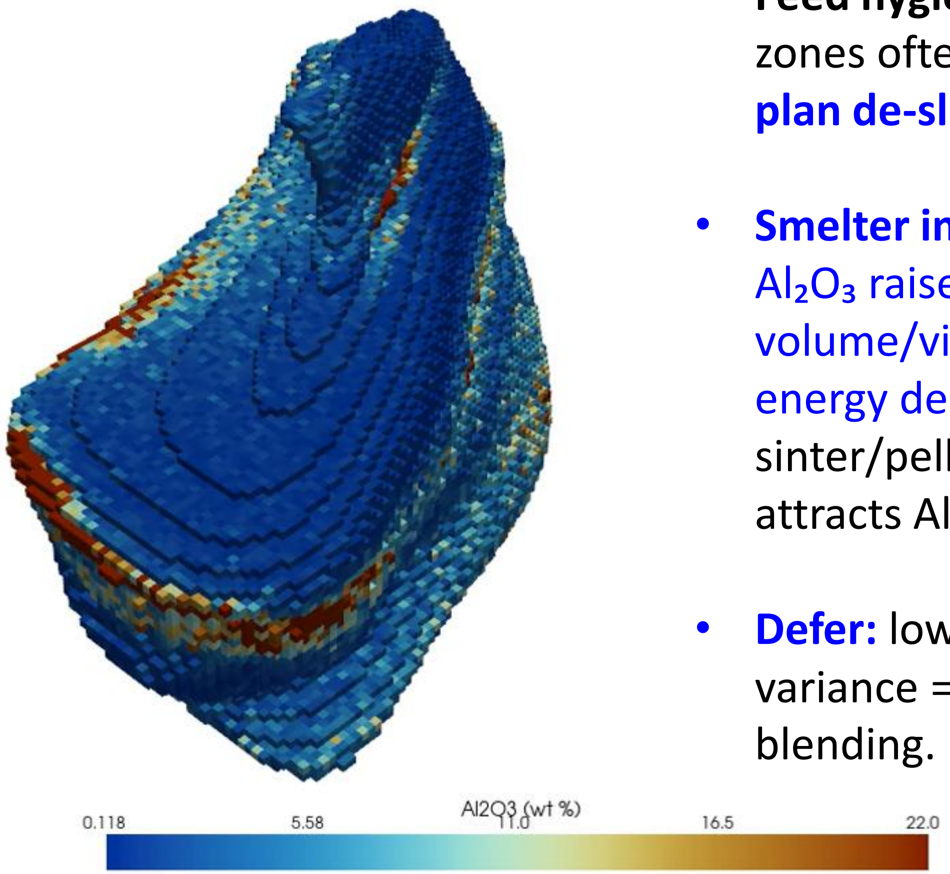
VGP Final Model



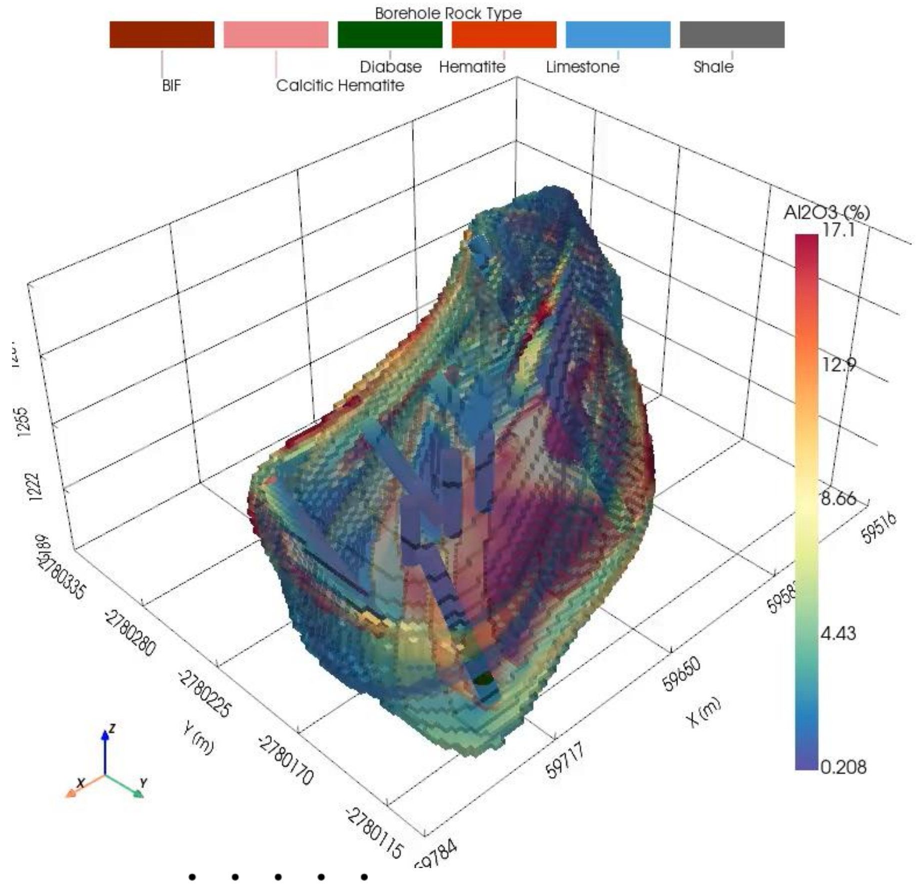
Al_2O_3 Uncertainty Quantification

Multiple VGP Realisations

VGP Final Model

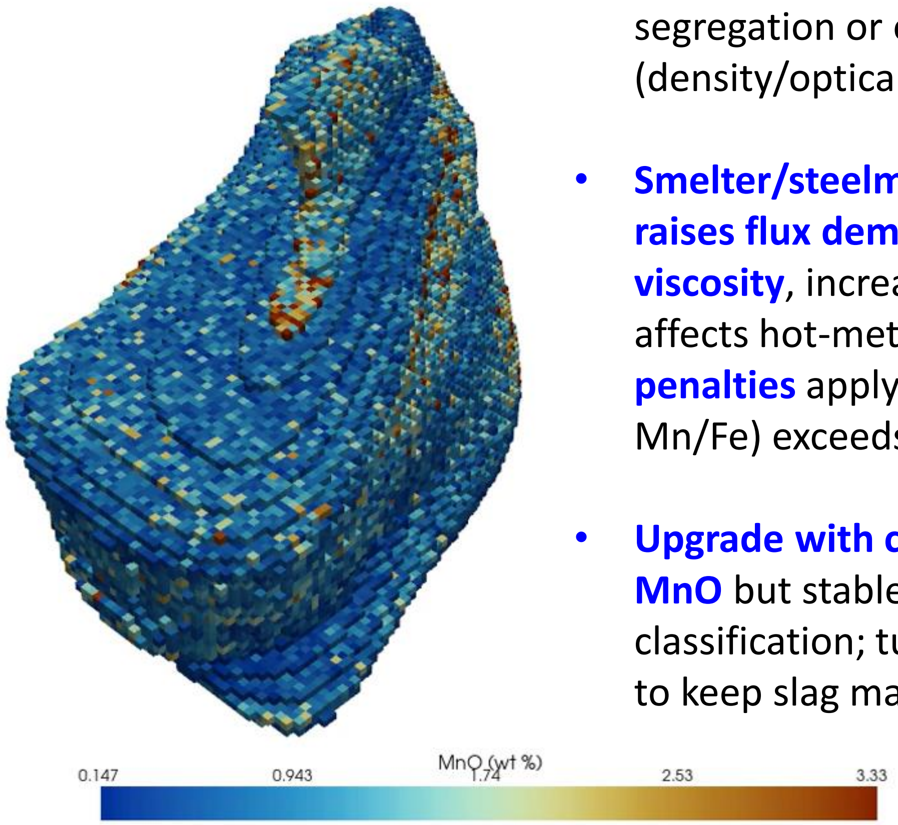


- **Feed hygiene:** high-variance zones often = clays/kaolinite; **plan de-sliming at source**.
- **Smelter implication:** High Al_2O_3 raises slag volume/viscosity, lifts flux and energy demand, affect sinter/pellet quality, and attracts Al_2O_3 penalties.
- **Defer:** low Fe + high Al_2O_3 variance ⇒ park or drill before blending.



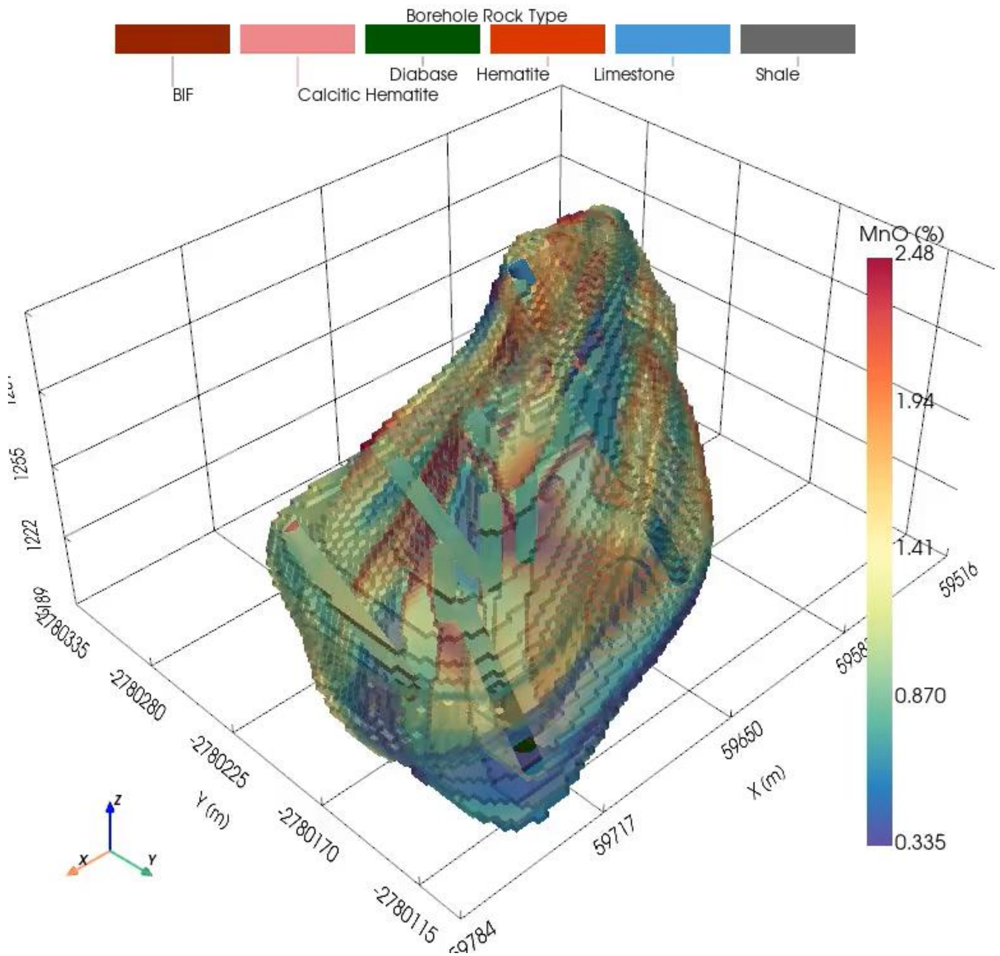
MnO Uncertainty Quantification

Multiple VGP Realisations



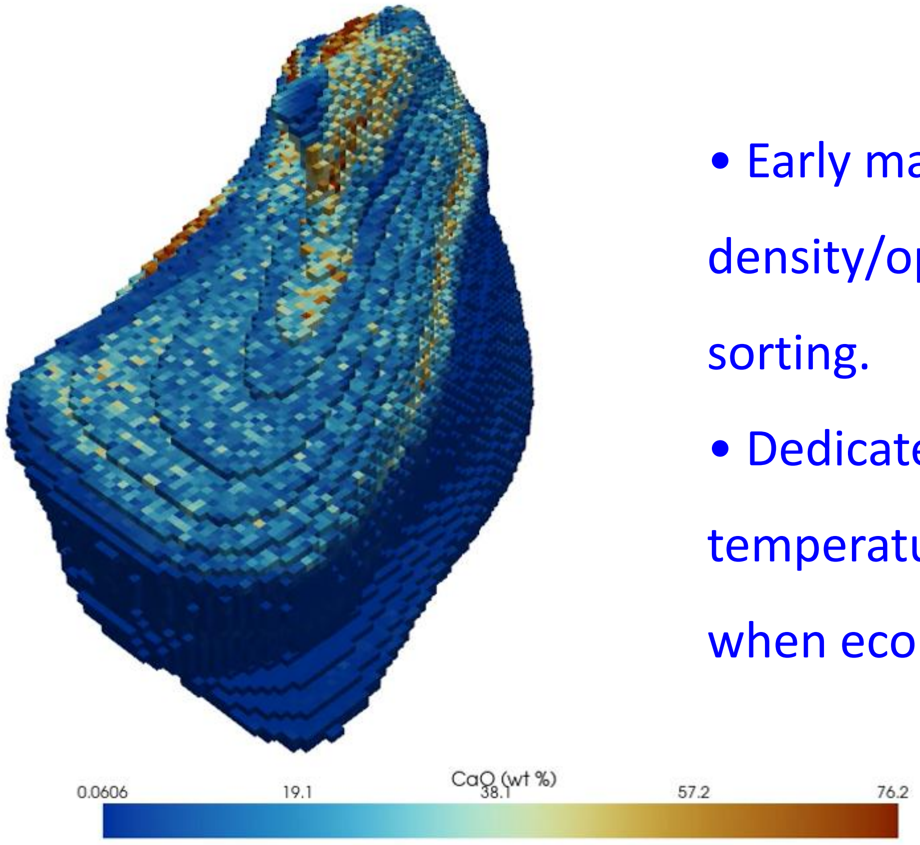
- Map streaks of high MnO for segregation or ore sorting (density/optical/X-ray).
- **Smelter/steelmaking:** High MnO **raises flux demand and slag viscosity**, increases **energy/coke**, affects hot-metal quality; **contract penalties** apply once MnO (or Mn/Fe) exceeds product limits.
- **Upgrade with controls: Moderate MnO** but stable ⇒ magnetics + classification; tune **basicity (CaO)** to keep slag manageable.

VGP Final Model



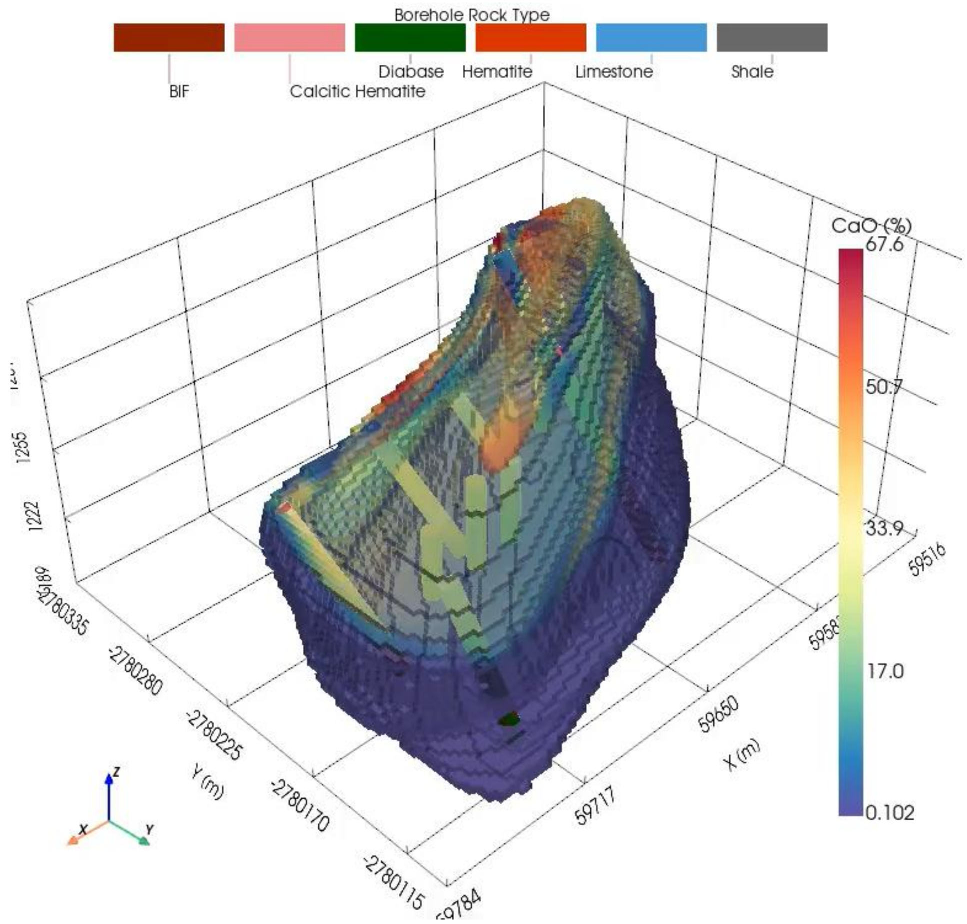
CaO Uncertainty Quantification

Multiple VGP Realisations



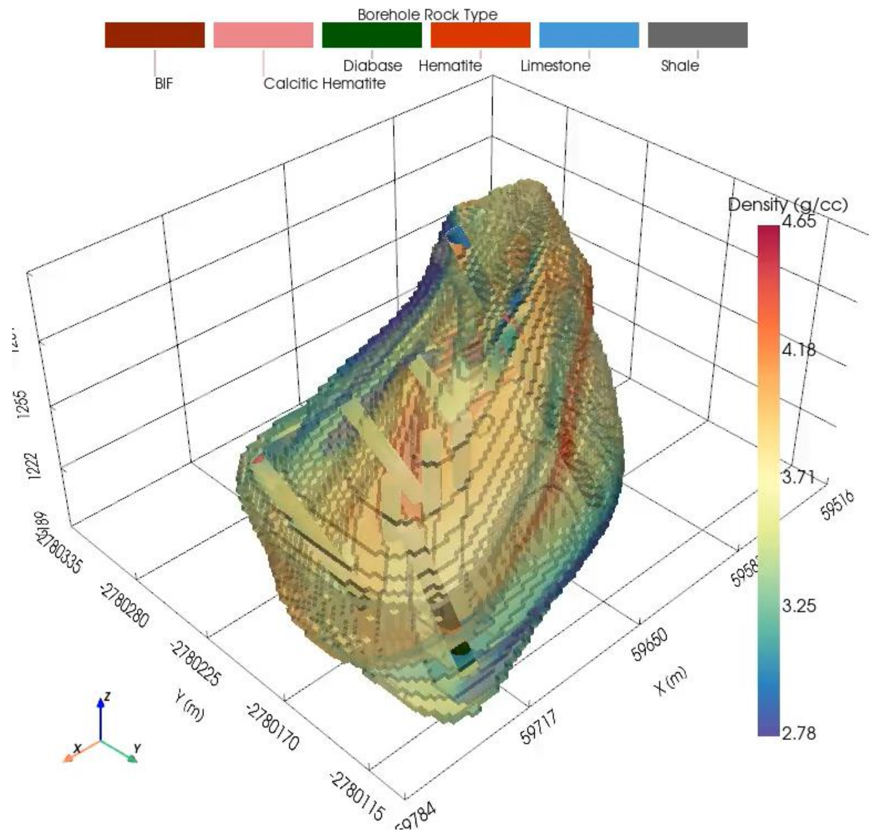
- Early mass rejection via density/optical/X-ray sorting.
- Dedicated low-temperature calcination when economic.

VGP Final Model

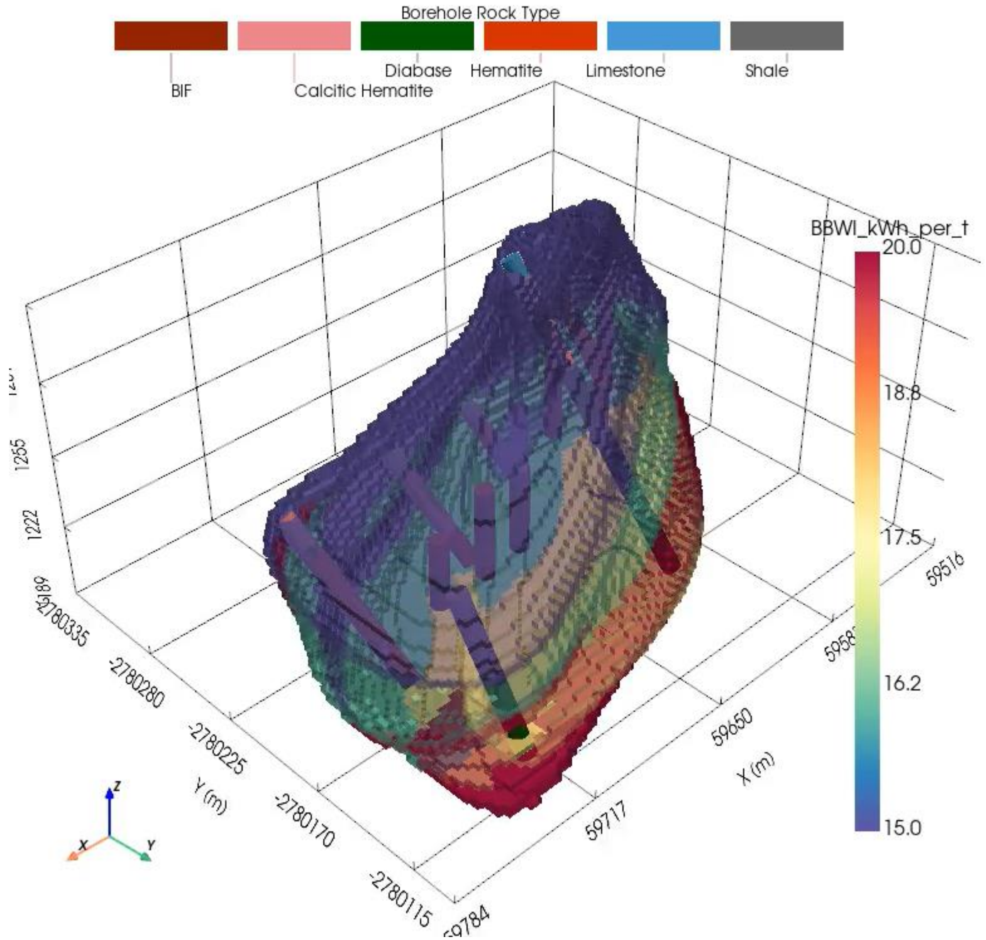


Density and BWI

Specific Gravity (t/m³)



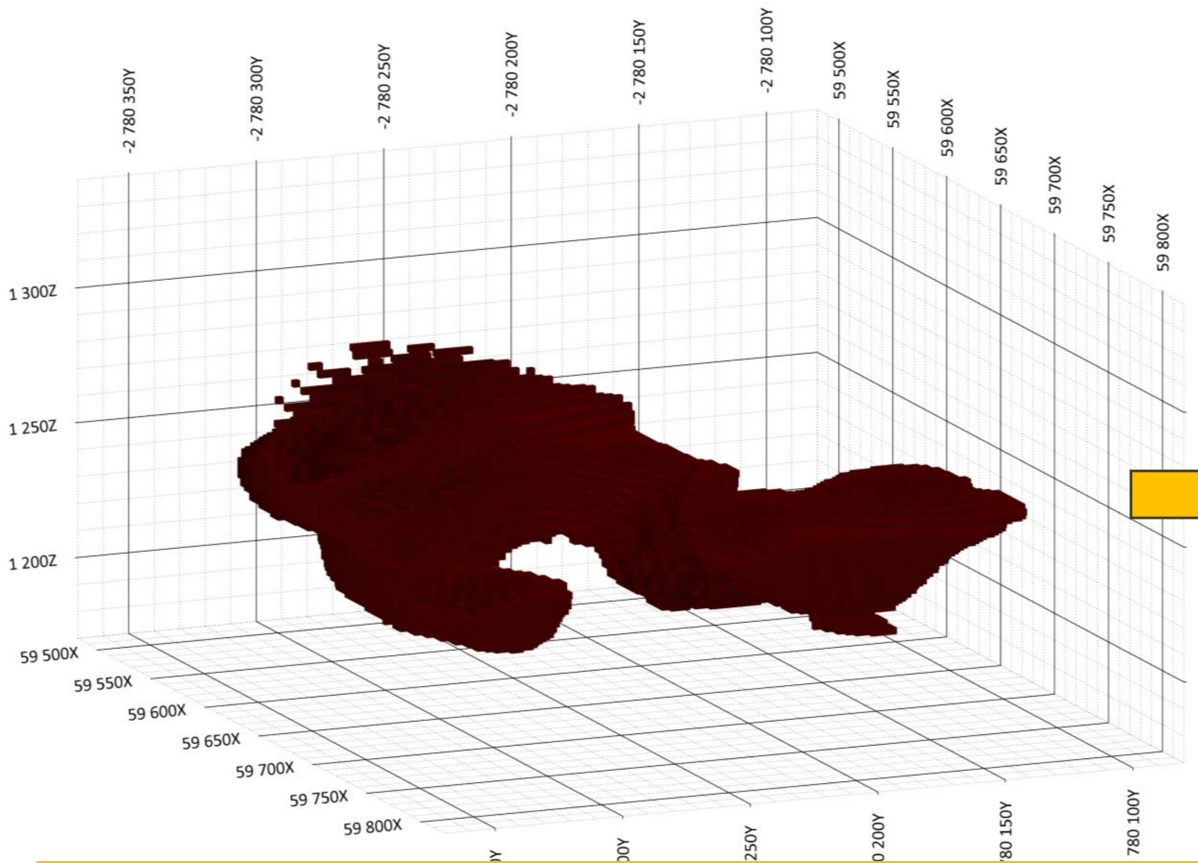
Bond Work Index (kWh/t)



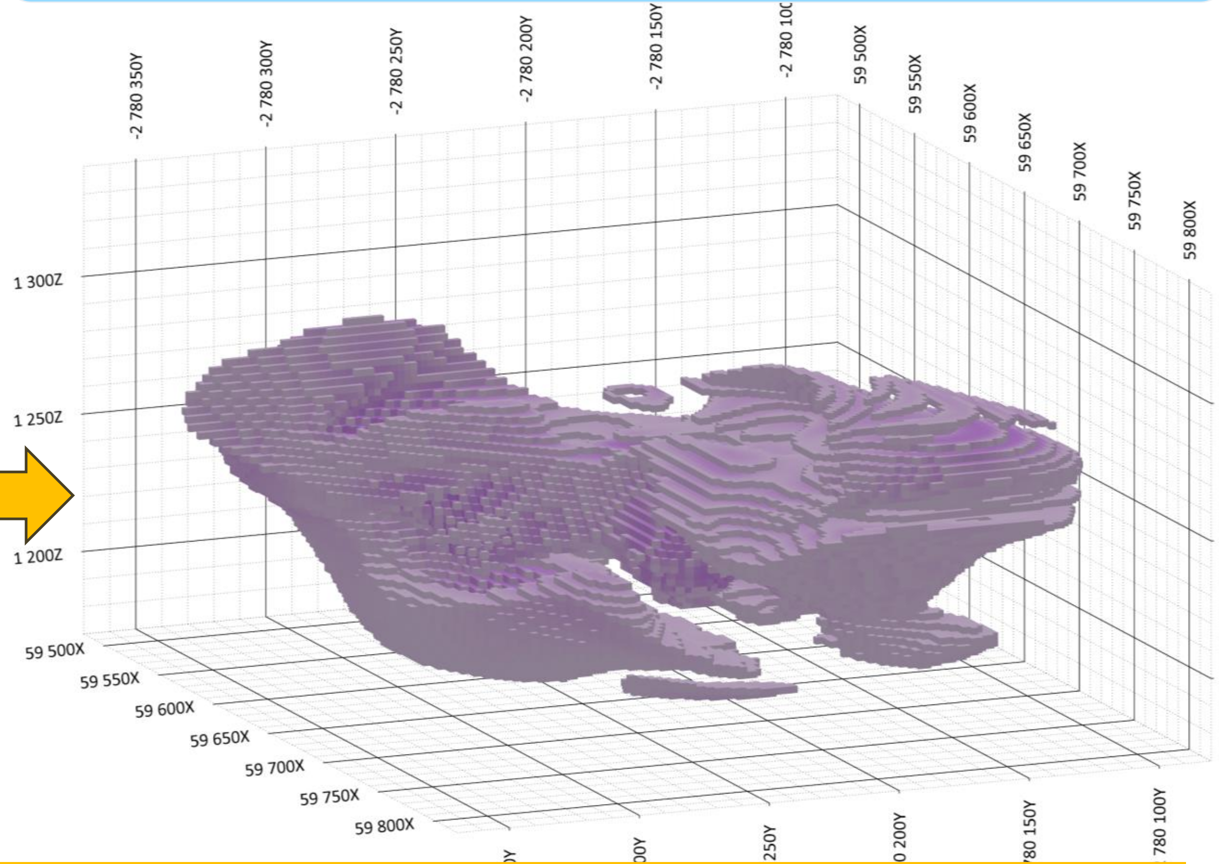
- Higher SG tracks hematite; lower SG marks siliceous/carbonate/clay zones.
- High BWI correlates with **silica-rich BIF**; lower BWI aligns with **massive hematite**.
- **Route guardrails:** Require **Fe P10 ≥ Fe min, SiO_2 P90 ≤ cap, Al_2O_3 P90 ≤ cap, BWI P90 ≤ energy cap** for premium blend; otherwise **upgrade (sort/float)** or **defer**.

Value proposition: Minimise uncertainty upstream; reduce cost downstream

Filter Mineral Reserves for Mine Planning

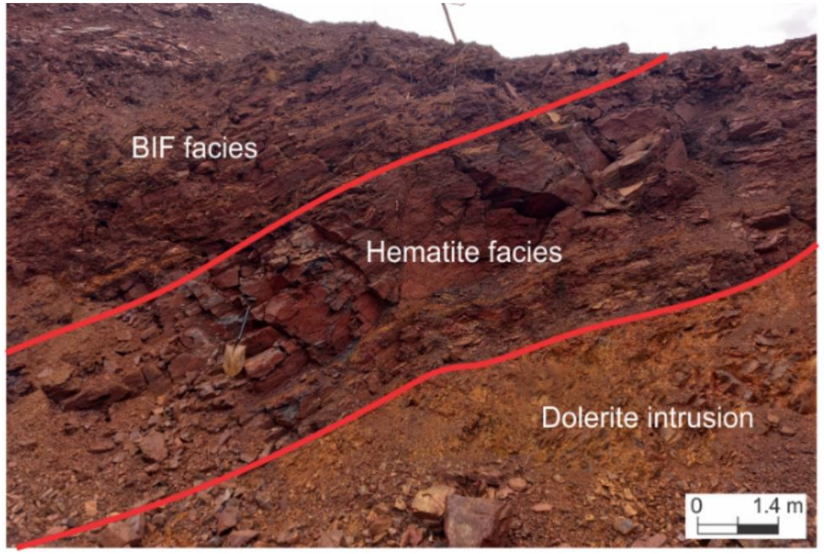


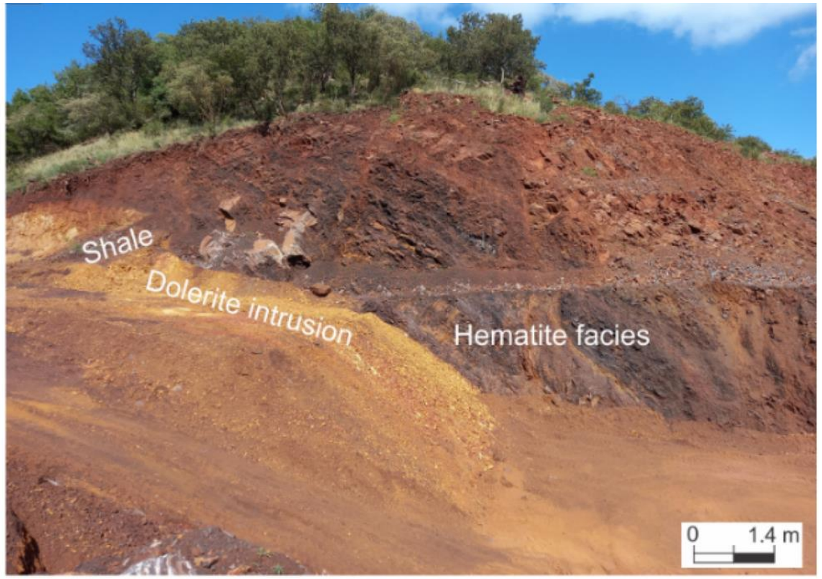
Design the Mine based on Geomet Model



Turn compliant tonnes into executable tonnes: filter by geomet constraints, then design to the ore's behaviour.

Key Takeaways





1. Variational Gaussian Processes give calibrated ranges, not just single numbers, so blending, routing, and drilling are set to a risk matrix, *not hope*.

2. Multi-element/oxides are modelled coherently with geology making downstream *slag, blend, and spec checks trustworthy*.

3. Simple rules on Fe, Al_2O_3, MnO, density, and BWI turn maps into actions: tighten or relax envelopes, route to jig/DMS when size–liberation allow, sort early, or defer..

4. Fewer surprises: Using conservative percentiles for grade and energy cuts penalties, sizes equipment sensibly, reduces blend volatility, and focuses drilling where it most lowers risk.

Thank You

SCIENTIA ET LABORE

WITS GEOSCIENCES

120 Years of Teaching & Research

CORES

THE AFRICAN RESEARCH CENTRE FOR ORE SYSTEMS SCIENCE

EST. 1957 AS EGRI

micromine

origin & beyond