

STRATUM AI

PHOSPHATE CASE STUDY

AI-driven reconciliation of primary crusher feed grade cutting daily forecast error by 27% for P_2O_5, 75% for SiO_2, and 73% for CaO at a sedimentary phosphate mine in Saudi Arabia.

CASE OVERVIEW

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CONTEXT & CHALLENGE

- ~150k m blast hole assays, ~60k m drill hole assays, plus daily ore routing and segregation records
- Kriging systematically failed to predict effective grade at the primary crusher
- Ignored lag time, silica segregation, and sand blending

AI APPROACH

Three independent XGBoost models predict each block's effective post-crusher grade, aggregated daily and embedded directly into the mine's planning spreadsheet.

VALUE DELIVERED

Higher-confidence resource model, cut daily forecast error by 27% (P_2O_5), 75% (SiO_2), 73% (CaO) vs. kriging — no change to the existing planning workflow.

DEPOSIT

OPEN PIT

Sedimentary phosphorite deposit,
Al Khabra region, northern Saudi Arabia

P
Phosphate



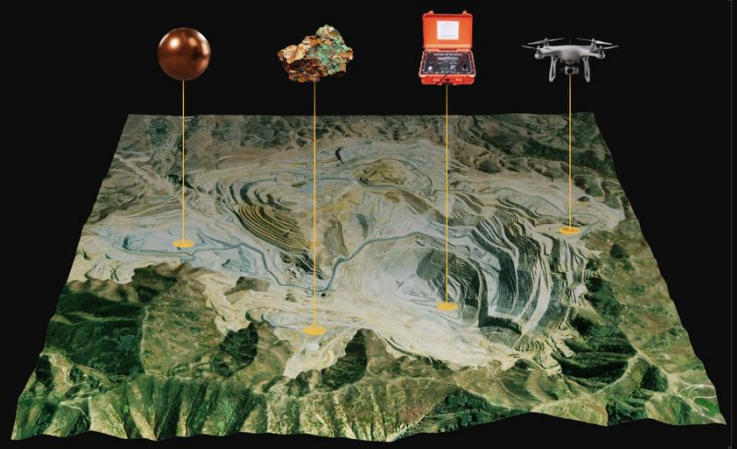
*AI-driven reconciliation prevented **23,396 t of additional P_2O_5** from being misrouted at the primary crusher (≈US$11.2M). SiO_2 and CaO error reductions (-75%, -73%) deliver additional operational value not quantified here.

APPLIED METHODOLOGY

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1 INPUT
Existing data

Historical, multichannel, and other unstructured data



We leverage all available data —such as metallurgy, geochemistry, geophysics, and sensor data— together with the full historical dataset of the mine

2 PROCESSING
Saige Deep Learning

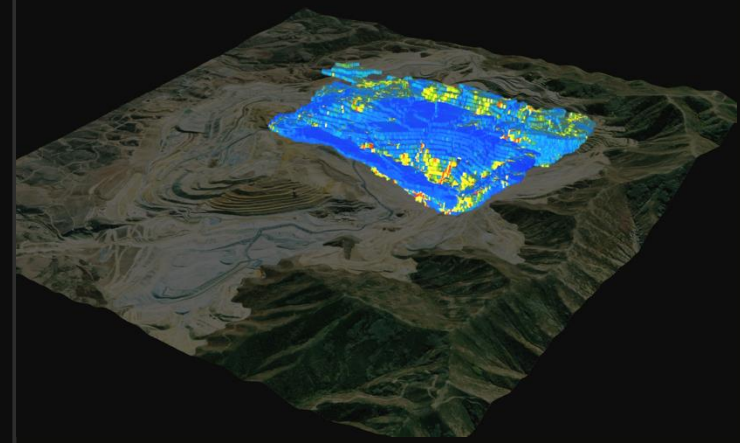
AI-driven analysis and integration of complex patterns



Our AI model learns geological patterns from historical data, using a neural network trained on high-density datasets to model multivariate relationships in lower-density environments.

3 OUTPUT
AI predictive model

More accurate and comprehensive identification of mineral deposits



Identifies previously unrecognized mineralized areas, improves definition in zones with low data density, and enables continuously updated resource models that guide companies toward the most profitable locations for mineral extraction.

CORE ARCHITECTURE

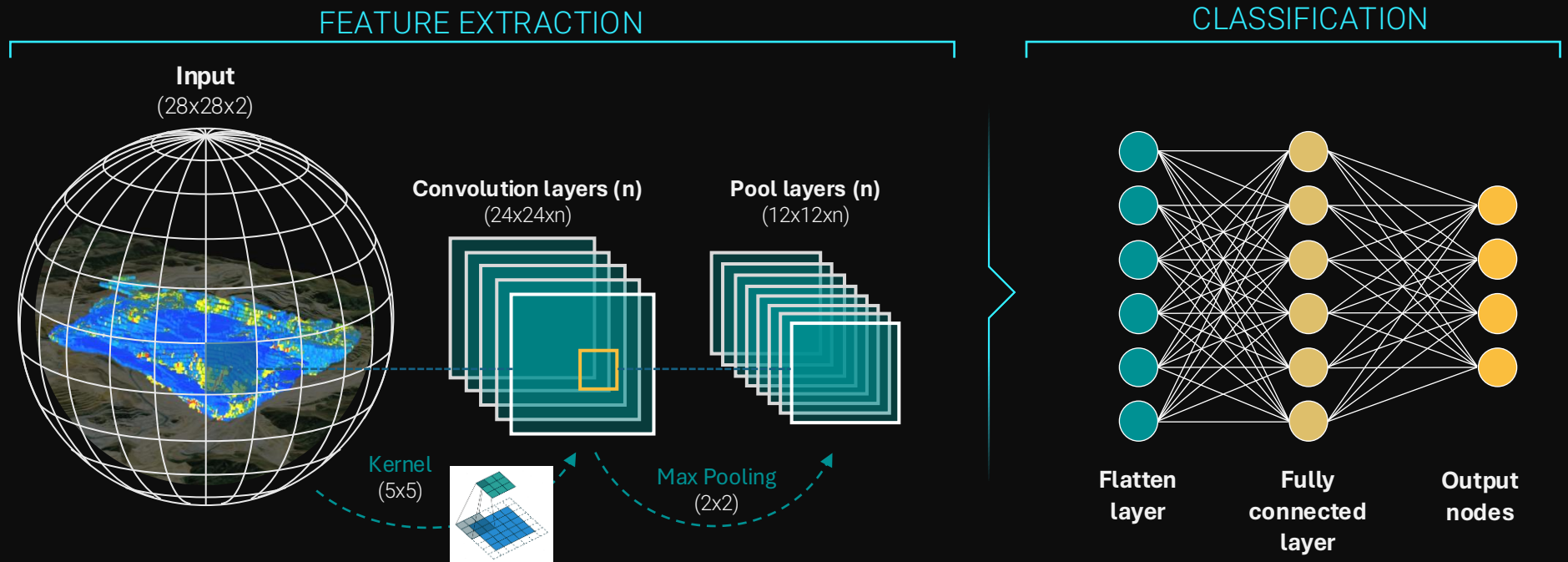
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SAIGE

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Geospatial Estimator

CONVOLUTIONAL NEURAL NETWORK

Deep learning algorithm that successfully captures spatial dependencies in an image through the application of relevant filters. Stratum AI model is based on this architecture, adapting it to the unique challenges of mining data.



HISTORICAL MODEL VALIDATION

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Prior to the 2025 operational application, Stratum AI worked with the mine on an earlier modelling study to evaluate whether SAIGE could better capture the complex geometry and grade distribution of the phosphate deposit.

The study provided early evidence that SAIGE could:

- **Better constrain complex seam geometries**, including variations in thickness and elevation.
- **Identify marginal and waste zones** that were less clearly represented by traditional Kriging.
- Better distinguish economic from uneconomic material, particularly where thin seams and lower P_2O_5 grades increased the risk of dilution and misclassification.
- **Capture spatially continuous patterns** that were subsequently observed in areas mined during 2022–2023.

These early results demonstrated SAIGE's potential to improve geological representation and provided the foundation for its subsequent operational application.

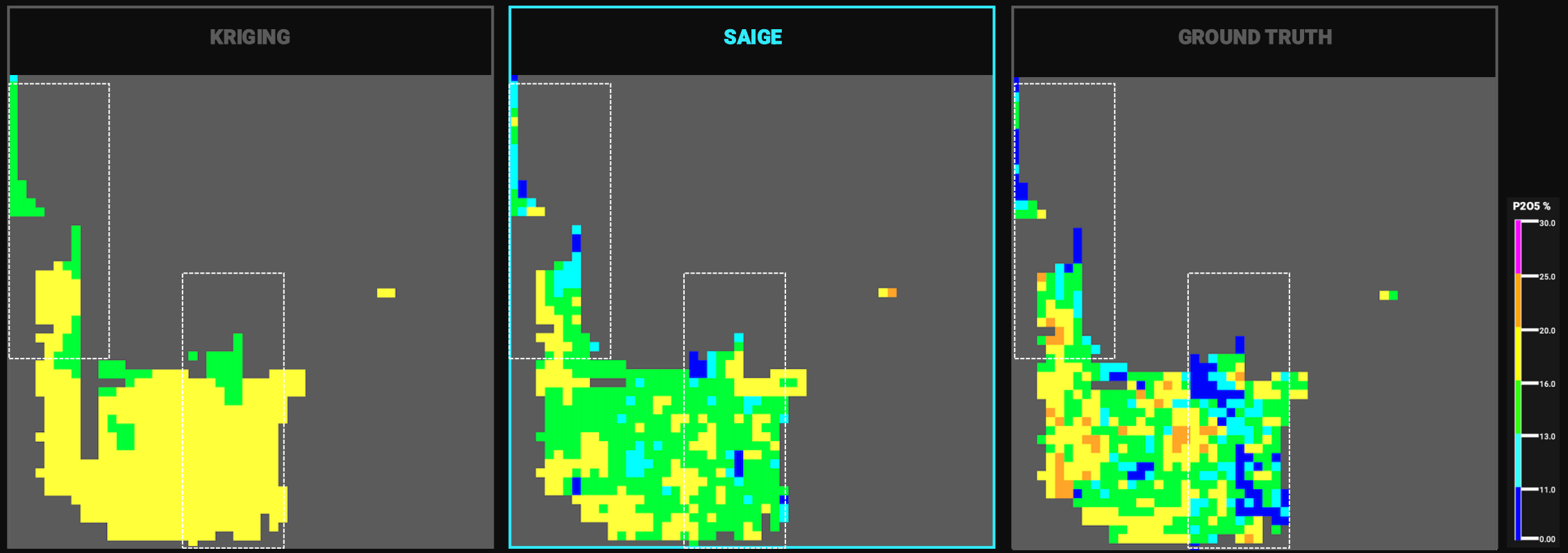
EARLY VALIDATION PH2

BENCH VIEW

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Compared with the traditional model, SAIGE more accurately identified two large, mostly continuous zones of marginal material mined in **2022–2023**, characterized by lower P_2O_5 grades and/or thinner-than-expected PH2 seams.

Block Size
50 x 50 x 5 m



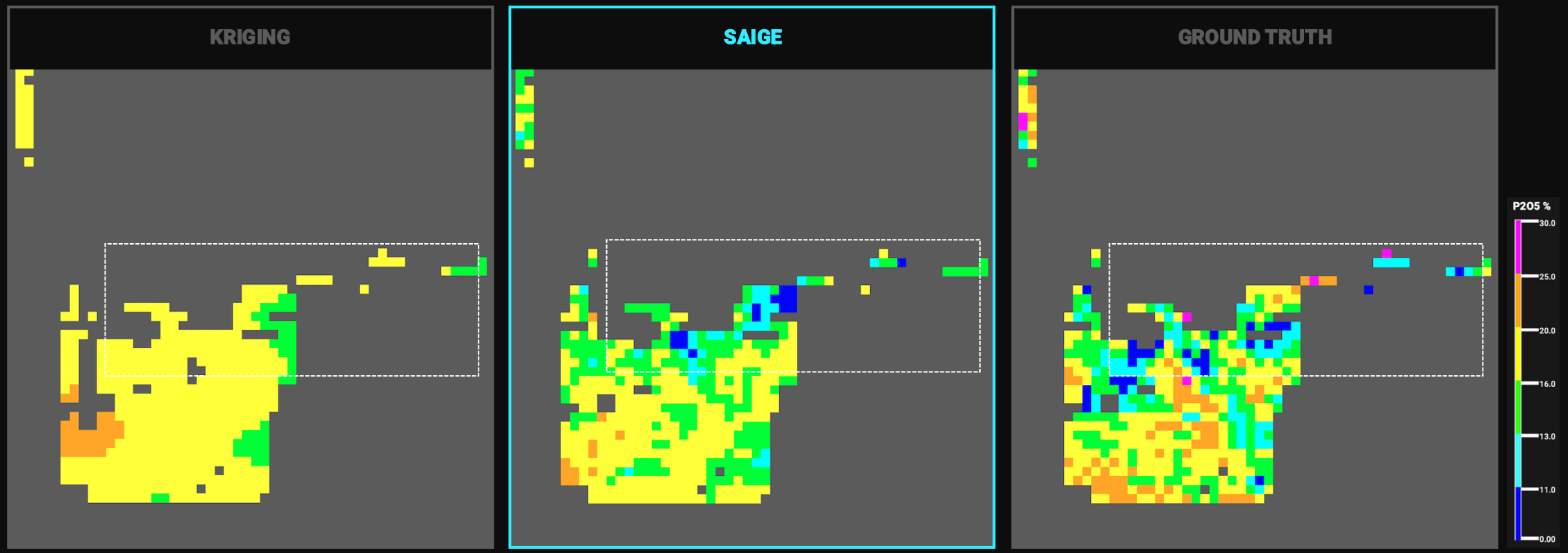
EARLY VALIDATION PH3

BENCH VIEW

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The SAIGE model more accurately identified a large, mostly continuous zone of marginal material mined in 2022–2023, associated with lower P_2O_5 grades and/or thinner-than-expected PH3 seams, resulting in increased dilution.

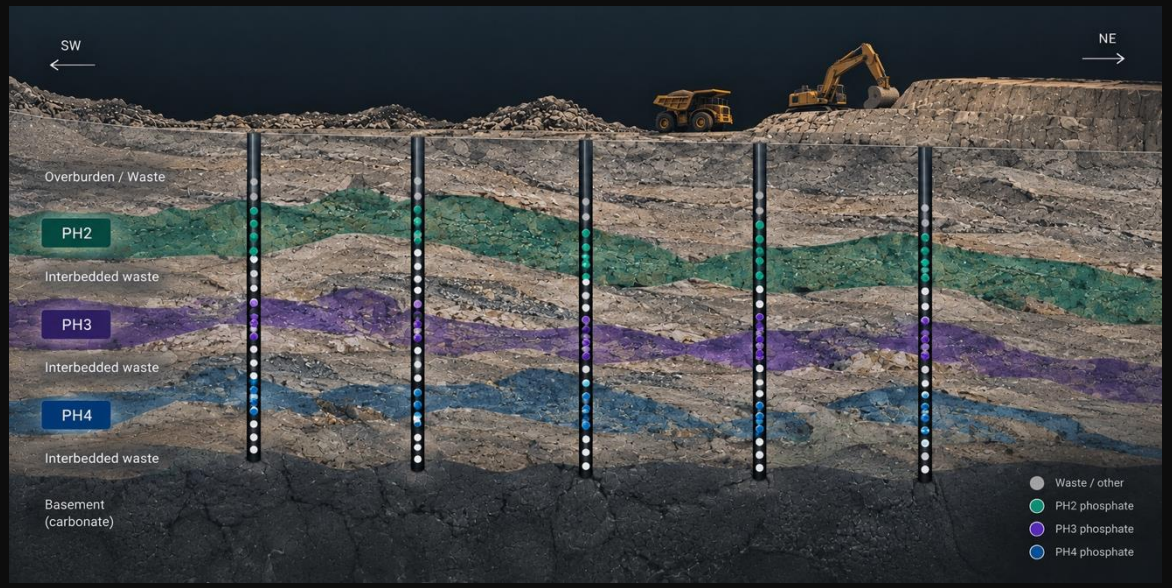
Block Size
50 x 50 x 5 m



2025 OPERATIONAL VALIDATION

THE RECONCILATION CHALLENGE

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COMPLEX STRATIFORM GEOLOGY

Sedimentary phosphate is distributed across multiple seams (PH2, PH3 and PH4) separated by waste layers, with increasing silica intercalation and grade variability in the deeper seams

Ore is drilled on a 5m x 5m blast hole grid, blasted, then cleaned: dark silica-rich fragments are manually segregated, sand is blended back at a variable daily rate, and 5-6 blocks are fed to the crusher across two shifts per day, generating one composite daily lab assay.

WHY KRIGING FAILS?

The baseline, a tonnage-weighted average of kriging block grades, ignores cleaning, blending and lag time entirely. This is a **structural bias,** not a data quality problem: kriging under-predicted **SiO2 by -5.9%** on average and over-predicted **CaO by +3.5%.**

THE STRUCTURAL CHALLENGE

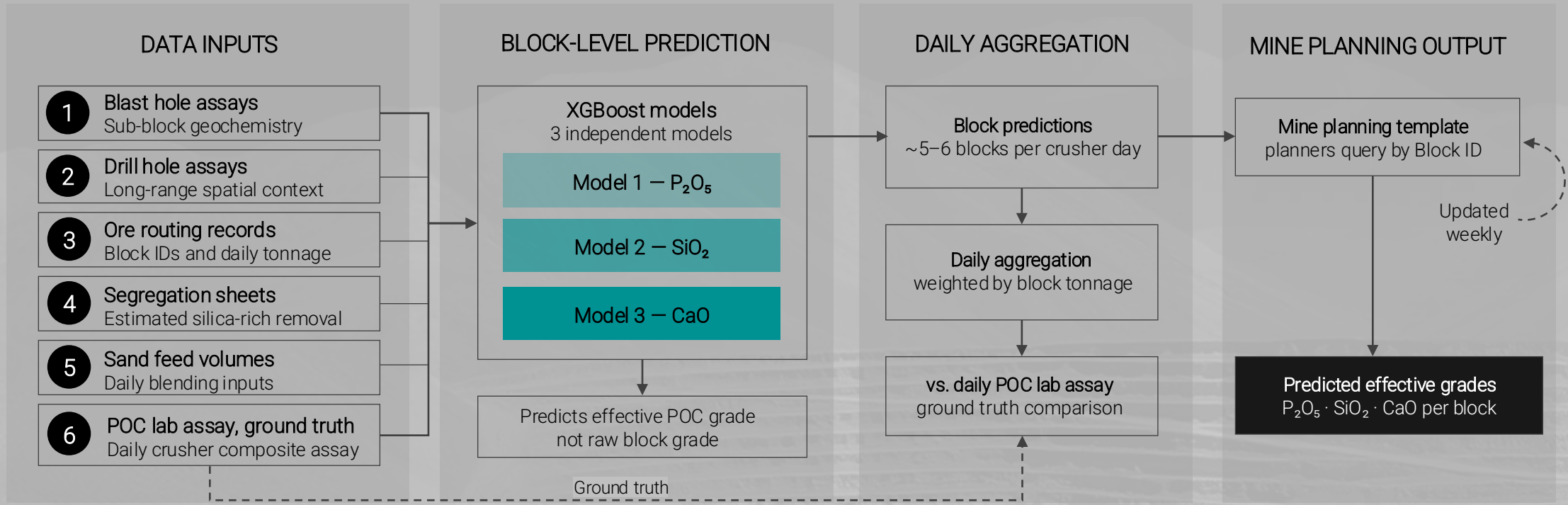
Five to six blocks contribute to one composite daily assay, and a block may be split across days: a many-to-one mapping problem. Simple averaging of block grades before modelling was found to underperform, collapsing individual block behaviour.

Note: SiO2 hardness approaches 250 MPa; the color-sensor ore sorter loses accuracy above 15% dark silica by volume. Only one of six mills can process high-CaO material.

MODELLING WORKFLOW

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From multi-source data to mine planning inputs through block-level prediction and daily aggregation.



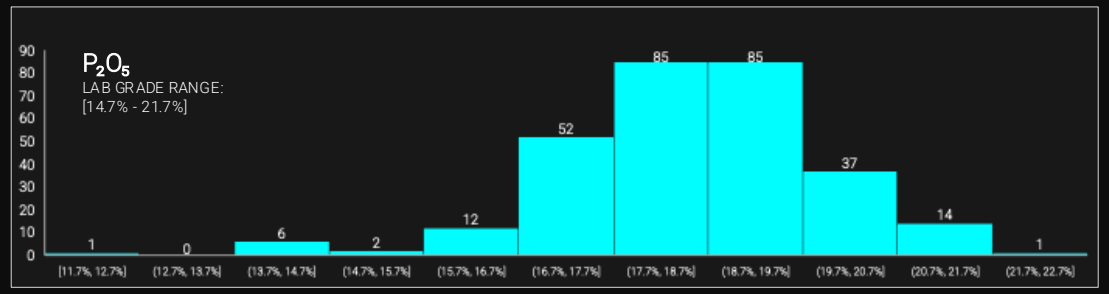
EVALUATION — 292 OPERATING DAYS (JAN–NOV 2025)

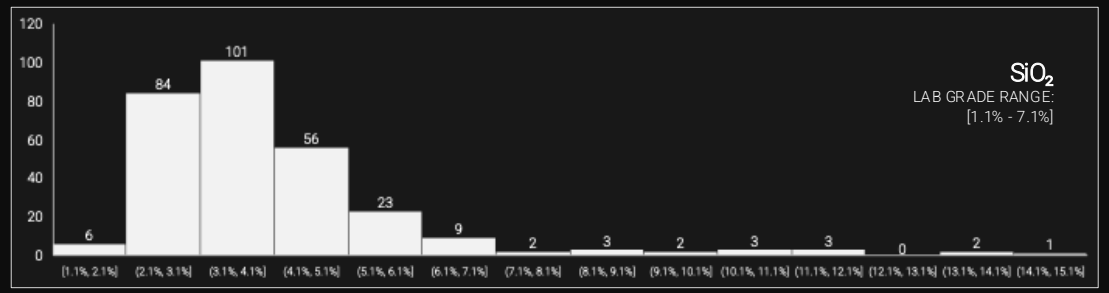
P_2O_5 MAE	SiO_2 MAE	CaO MAE
−27% daily , −44% monthly	−75% daily, −82% monthly	−73% daily, −80% monthly

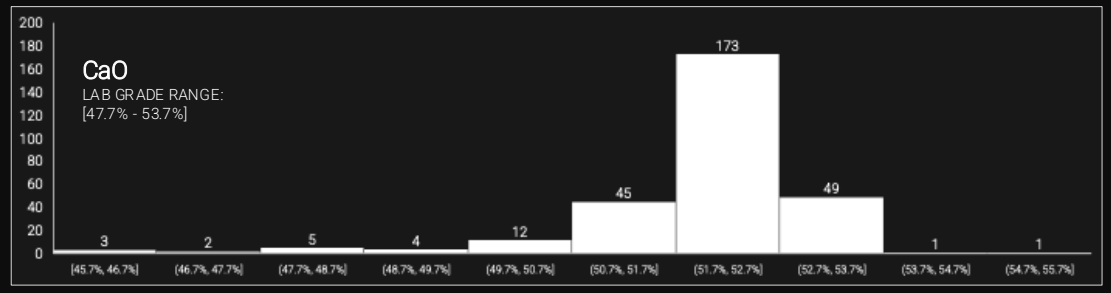
RECONCILIATION METHOD

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LAB GRADE RANGES







TECHNICAL NOTE

Reconciliation Method

- **Ground truth:** POC laboratory assays were used as the reference to evaluate how closely each model reproduced the actual crusher feed grade.
- **Aggregation:** AI and Kriging block-level predictions were tonnage-weighted and aggregated into daily, weekly, and monthly grades to enable comparison at different time scales.
- **Error measurement:** For each period, predicted grades were compared with the corresponding POC laboratory result. MAE (Mean Absolute Error) represents the average absolute difference between predicted and actual grades, preventing positive and negative deviations from canceling each other out.
- **AI relative improvement:** Measures the percentage reduction in MAE achieved by the AI model compared with Kriging. A higher positive value indicates a larger reduction in prediction error: (Kriging MAE − AI MAE) / Kriging MAE × 100.

SAIGE MODEL RESULTS - 2025

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P_2O_5 RESULTS

Tight Bounds (−0.42/+0.49pp) /Loose Bounds (-2.80/+1.74pp)

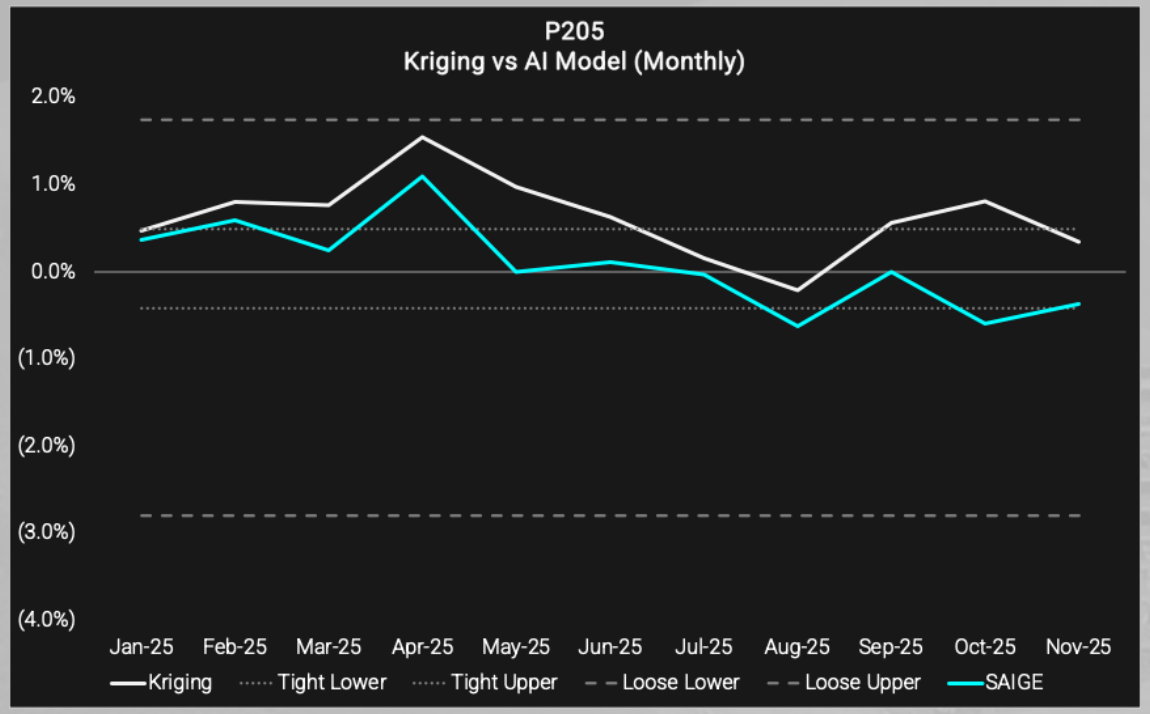
27% Daily MAE reduction

SAIGE 26/46 Weeks in tight bounds

KRIGING 15/46

Monthly Grade Reconciliation

AI Model vs. Kriging vs. POC Lab Assays (Ground Truth)



LAB assays vs Model Predictions	Kriging 2025	SAIGE 2025	MAE Improvement
Daily Dev. (MAE)	1.32%	0.97%	26.6%
Weekly Dev. (MAE)	0.96%	0.58%	39.7%
Monthly Dev. (MAE)	0.66%	0.37%	44.4%

Results

P_2O_5 is the most stable element under cleaning operations, as it is less affected by visual segregation than SiO_2 or CaO. Model performance further improves at coarser time resolutions, with weekly MAE reduced by 40%. Most importantly, the AI model prevented an estimated 23,396 t of additional P_2O_5 from being misrouted compared with Kriging (28,763 t vs. 5,367 t), representing an estimated value impact of ~US$11M* over the evaluation period.

** Note: Indicative value based on additional P_2O_5 correctly routed, assumed recovery, and benchmark phosphate product value. Excludes processing costs and price variability.*

SAIGE MODEL RESULTS - 2025

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SiO_2 RESULTS

Tight Bounds (-0.57/+0.83pp) /Loose Bounds (-2.65/+4.08pp)

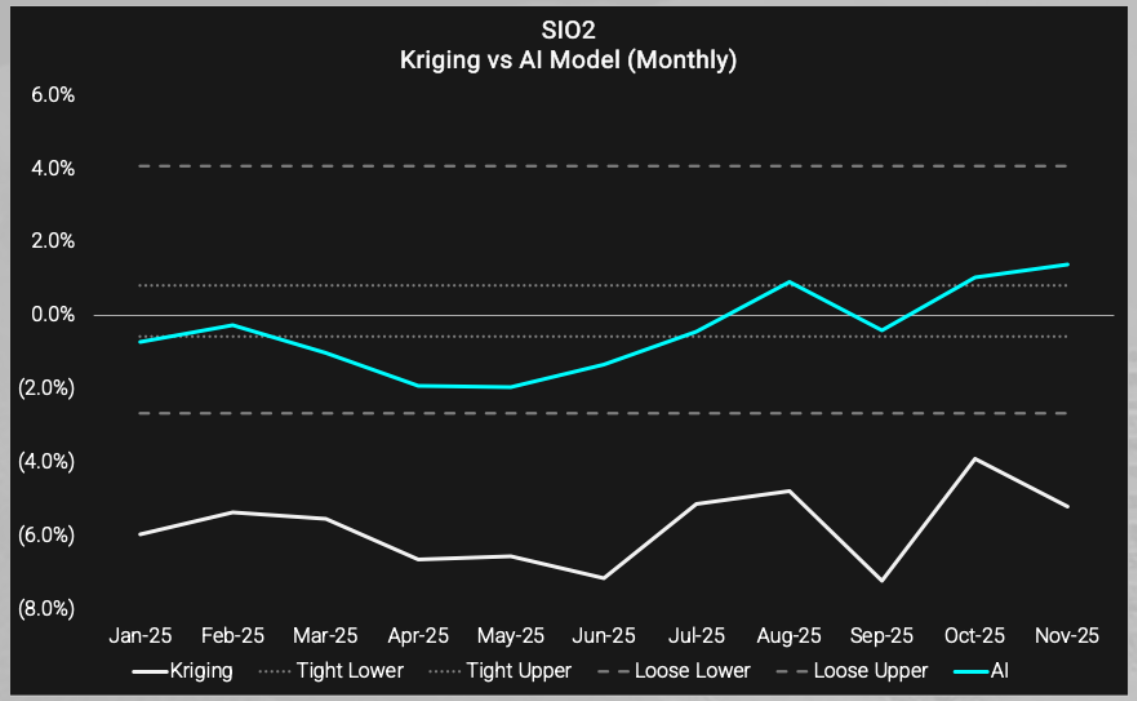
75% Daily MAE reduction

SAIGE 19/46 Weeks in tight bounds

KRIGING 0/46

Monthly Grade Reconciliation

AI Model vs. Kriging vs. POC Lab Assays (Ground Truth)



LAB assays vs Model Predictions	Kriging 2025	SAIGE 2025	MAE Improvement
Daily Dev. (MAE)	6.06%	1.05%	75.3%
Weekly Dev. (MAE)	5.81%	1.20%	79.3%
Monthly Dev. (MAE)	5.77%	1.03%	82.1%

Results

Kriging showed a severe, structural under-prediction — it cannot account for the cleaning that removes silica before it reaches the crusher. At monthly resolution kriging achieved 0 of 11 months within loose bounds; the AI model achieved 11 of 11, with monthly MAE improving 82% (5.77 → 1.03% SiO2).

SAIGE MODEL RESULTS - 2025

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CaO RESULTS

Tight Bounds (-0.57/+0.96pp) /Loose Bounds (-2.09/+2.96pp)

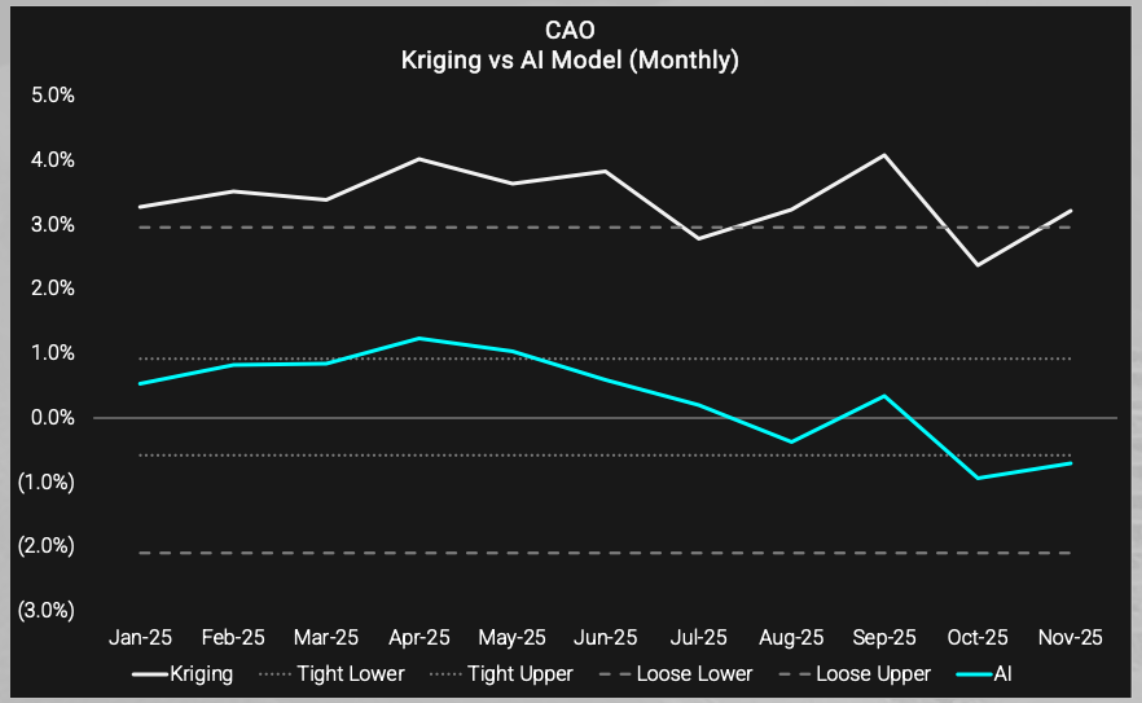
73% Daily MAE reduction

SAIGE 29/46 Weeks in tight bounds

KRIGING 0/46

Monthly Grade Reconciliation

AI Model vs. Kriging vs. POC Lab Assays (Ground Truth)



LAB assays vs Model Predictions	Kriging 2025	SAIGE 2025	MAE Improvement
Daily Dev. (MAE)	3.53%	0.96%	72.8%
Weekly Dev. (MAE)	3.39%	0.79%	78.6%
Monthly Dev. (MAE)	3.40%	0.70%	79.5%

Results

Only one of the site's six mills can process high-CaO material — exceeding its capacity cuts throughput directly. Kriging consistently over-predicted CaO; the AI model corrected this bias and lifted monthly loose-bound compliance from 18% to 100% of months, with monthly MAE improving 80% (3.40 → 0.70% CaO).

SAIGE MODEL RESULTS - 2025

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	P_2O_5		SiO_2		CaO	
Metric	Kriging	SAIGE	Kriging	SAIGE	Kriging	SAIGE
Daily MAE (%)	1.32	**0.97**	6.06	**1.50**	3.53	**0.96**
Daily MAE improvement	—	**27%**	—	**75%**	—	**73%**
Mean bias (%)	+0.62	**+0.11**	-5.90	**-0.59**	+3.46	**+0.43**
Weeks within tight bounds / 54	15	**26**	0	**19**	0	**29**
Weeks within loose bounds /54	40	**45**	1	**43**	11	**46**
Months within tight bounds /11	4	**7**	0	**3**	0	**7**
Months within loose bounds /11	11	**11**	0	**11**	2	**11**

Key Takeaway
The AI model consistently outperformed Kriging across all three elements and time scales. Performance strengthened at coarser aggregation as systematic Kriging biases were reduced. From Jan–Nov 2025, P_2O_5 misrouting fell from 28,763 t to 5,367 t—an 81% reduction (23,396 t).

SAIGE MODEL OPERATIONAL RESULTS

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P_2O_5	SiO_2	CaO
-27%	**-75%**	**-73%**
daily MAE	**daily MAE**	**daily MAE**
-44% monthly · 26/54 weeks in tight bounds	-82% monthly · 11/11 months in loose bounds	-80% monthly · 7/11 months in tight bounds

OPERATIONAL DEPLOYMENT

Model outputs were embedded directly into the site's existing mine planning spreadsheet, linked to each block ID. Planners query any feeding scenario and immediately see expected P2O5, SiO2 and CaO at the crusher — no change to the existing planning workflow or software environment.

Models are updated weekly ahead of the site's twice-weekly feeding-scenario planning cycle, and the approach is transferable to any phosphate operation where cleaning, segregation or blending causes block grade to diverge from crusher-feed composition.



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PHOSPHATE CASE STUDY

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