Assessing SWIR and MWIR Hyperspectral Imaging for Rapid Estimation of P2O5 Distribution in Sedimentary Phosphate Drill Cores

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Abstract

Sedimentary phosphate rocks are crucial for global food security, contributing to over 90% of the fertilizer industry's needs. However, their exploration and mining face significant challenges due to substantial horizontal and vertical variations in phosphorus concentrations within the strata. Traditional characterization methods are time-consuming and costly, requiring complex sample preparation, which often limits the spatial resolution of measurements across the ore body. On the other hand, infrared hyperspectral core scanning has emerged as a proven technique for rapid characterization of mineral assemblages along drill cores, which by leveraging advanced machine learning algorithms, offers a powerful tool for predicting geochemical variations. In this context, our study aims to assess the ability of hyperspectral infrared imagery to rapidly quantify the distribution of P_2O_5 in phosphate drill cores using a non-destructive methodology. For this, a ~65-meter drill core from the phosphatic series of Ben Guerir (Morocco) was analyzed. P_2O_5 measurements were acquired using a Thermo Fisher XL5 portable XRF (pXRF), and hyperspectral images were collected using a SPECIM SisuROCK core-scanner with SWIR (1000–2500 nm) and MWIR (2700–5200 nm) cameras. To predict P_2O_5 concentrations from infrared spectra recorded in hyperspectral imagery, we explored a direct method, using high-performing machine learning algorithms trained on a ~5-meter drill core dataset. When applied to the whole drill core dataset, the machine learning algorithms—Random Forest Regressor, KernelRidge Regressor, Gradient Boosting, Support Vector Regressor, and K-Nearest Neighbors—reported good predictive performance with strong correlations of 79%, 62.1%, 69.4%, 60.3%, and 68.7% in the SWIR region and 82.5%, 83.6%, 80.7%, 82.3%, and 85.1% in the MWIR region, respectively. Direct estimation of P_2O_5 using the Support Victor Regression model on MWIR imagery thus represents a more effective approach, offering significant potential for P_2O_5 chemical mapping and improved phosphorus resource estimation with a low mean absolute error of 3.07. Further improvements could be achieved by employing a larger training dataset and deep learning algorithms.

Objective: The main goal of this study is to evaluate infrared hyperspectral core scanning at estimating P2O5 consentrations through a non-destructive approach based on integrating spectral and geochemical information in machine learning models.

Introduction

- Sedimentary phosphate rocks are a major source of phosphorus; however, their mining faces increasing challenges due to significant lateral and vertical variations within deposits. Traditional exploration methods struggle to capture these variations at high resolution and over large areas, making the process costly and uncertain, especially during the early stages of exploration.
- With advancements in sensor technologies, computational power, and automation, drill core scanning has emerged as a promising tool for mineral exploration. In this study, we adopt an integrated approach to evaluate the potential of drill core scanning in addressing a key challenge in sedimentary phosphate mining—tracing geochemical variations of elements of interest, particularly P_2O_5 at high coverage and reduced time.

Methodology

1 Infrared Core Imaging

Collect hyperspectral digital twin of drill core in SWIR and MWIR ranges.

2 X-Ray Core Profiling for P2O5

- Collect **330 measurement points along drill core using Portable XRF.**
- Collect an additional 100 points focused on a single core box.

3 Models Building

- Use Core box 100's spectral and respective geochemical datapoints to train 5 Regression models: **Random Forest, Ridge, K-Nearest Network, Gradient Boosting, and Support Vector Regressor**

4 P2O5 Estimation and Mapping

- Use each built model to Predict P2O5 Concentrations along the whole drill core.
- Use Best Performing Model to Extract P2O5 concentration map from training core box.

5 Models Evaluation

Evaluate Models performances for P2O5 tracing compared to PXRF Measured Concentrations.

Results (1/2)

***Table 1**. Accuracy metrics for the different machine learning models used in SWIR and MWIR ranges. MAE: Mean Absolute Error, MedAE: Median Absolute Error, CCC: Concordance Correlation Coefficient, CI: Confidence Interval.*

	Model	Spearman	Pearson	Kendall	R2	MAE	MedAE	CCC	CI at 95%	P-values
SWIR	RF	0.787	0.778	0.580	0.565	3.932	3.255	0.722	[0.675, 0.763]	0.000
	Ridge	0.621	0.505	0.444	0.136	5.116	3.949	0.49	[0.415, 0.567]	0.000
	KNN	0.687	0.691	0.498	0.446	4.120	2.921	0.677	[0.614, 0.737]	0.000
	GB	0.694	0.685	0.495	0.425	4.480	3.437	0.646	[0.581, 0.705]	0.000
	SVR (L)	0.603	0.459	0.429	0.13	5.408	4.321	0.414	[0.351, 0.474]	0.000

	Model	Spearman	Pearson	Kendall	R2	MAE	MedAE	CCC	CI at 95%	P-values
MWIR	RF	0.825	0.825	0.621	0.681	3.295	2.546	0.809	[0.771, 0.841]	0.000
	Ridge	0.836	0.822	0.645	0.655	3.396	2.757	0.771	[0.729, 0.806]	0.000
	KNN	0.823	0.822	0.623	0.652	3.41	2.761	0.808	[0.769, 0.838]	0.000
	GB	0.807	0.809	0.6	0.651	3.464	2.778	0.801	[0.762, 0.834]	0.000
	SVR (P)	0.8513	0.851	0.656	0.718	3.0726	2.6493	0.828	[0.793, 0.858]	0.000

- Models' evaluation reported better predictive performance in the MWIR region compared to SWIR, with a +80% agreement, and explaining around 70% of the variations *(Table 1.)*.
- Support Victor Regression metrics in MWIR show as the best performing of the used models, offering significant potential for P_2O_5 chemical profiling and mapping (*Figure 1.*).
- This approach displays a good potential use for geochemical mapping drill cores directly from their corresponding hyperspectral data.
- The overall calculated errors are relatively low however, they suggest adopting model performance improvement to reduce outliers' effect.

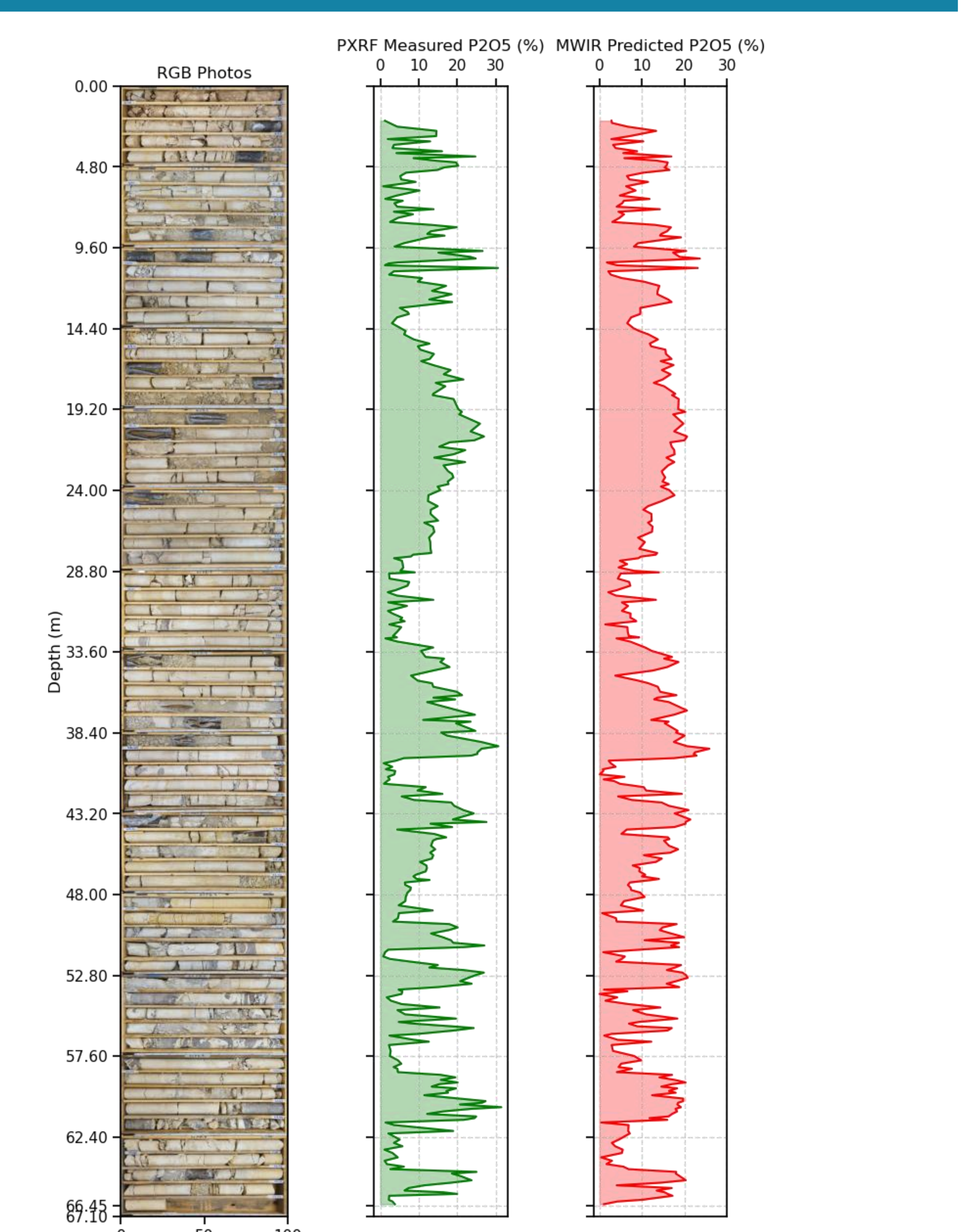

***Figure 1.** Hyperspectral Core scanning and pXRF data integration results. From left to right: RGB image of studied drill core. Geochemical variations of P_2O_5 measured using Portable X-ray Fluorescence (PXRF) compared to Support Vector Regressor prediction in MWIR range.*

Results (2/2)

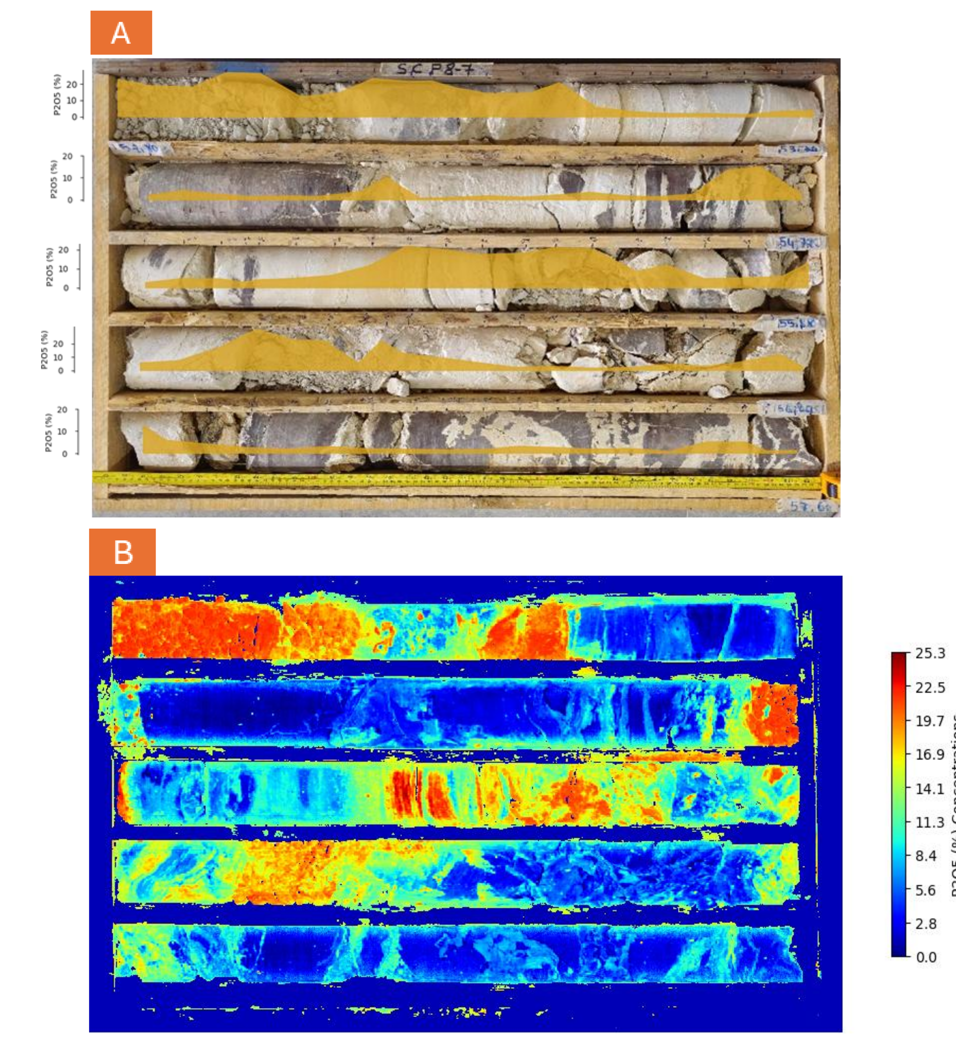

***Figure 2.** P_2O_5 profile along the training sedimentary phosphate core box using PXRF (A), compared to predicted map of P_2O_5 using Support Vecrtor regressor (B).*

Conclusion

- Drill core Scanning showcases an increasing potential for fast and cost-effective acquisition of several physical and chemical parameters along drill cores.
- Integrating infrared core imaging in MWIR range, X-Ray Fluorescence, and Machine learning techniques, through this non-destructive approach, was able to successfully trace P2O5 variations at millimetric scale along ~65-meter sedimentary phosphates drill core. Thus, unlocking a path for high coverage, high-resolution, and non-destructive geochemical mapping/tracing.
- Although the reported strong performances, but effects related to sample size and outliers were limiting accurate estimation. Therefore, further improvements are required for better results.

References

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