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Multimodal SWIR–MWIR Hyperspectral Core Imaging Fusion for Rapid Sedimentary Phosphate Grade and Quality Assessments

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Traditional geochemical characterization of sedimentary phosphate drill cores often relies on time-consuming, discontinuous-sampling, destructive, and costly techniques. Consequently, rapid analytical techniques, even when associated with relatively lower precision, become attractive alternatives for the mining industry. In this context, infrared hyperspectral imaging has emerged as a technology of growing interest, providing several operational advantages. It has been successfully tested across multiple mineral deposits, particularly for its potential in predictive mineralogical mapping and characterization. However, its applications to phosphate deposits remain limited. In this study, we focus on a particularly underexplored aspect of phosphate drill cores: extracting geochemical information from infrared hyperspectral imagery and exploring the contribution of multi-sensor data fusion to enhanced prediction accuracy. A multi-stage, multimodal workflow integrating SWIR-MWIR hyperspectral core scanning and machine learning was developed to predict P_2O_5, MgO, and CaO concentrations, enabling rapid, non-destructive assessment of sedimentary phosphate grade and quality. To ensure consistent spatial alignment and achieve proper co-registration of the SWIR and MWIR hypercubes, we evaluated a range of image registration strategies, including area-based methods, feature-based methods, and manual landmark-based registration. The predicted concentrations from this workflow were evaluated against both portable and laboratory XRF measurements, showing strong agreement and a reliable, semi-quantitative assessment of phosphate grade and quality (**R^2=74-93%, MAE=5.3-1.67%**). By combining SWIR and MWIR spectra, the data fusion approach achieved higher prediction accuracies than models relying on either sensor individually. Layer-based visualization and mapping enable geologists and mining engineers to interpret continuous spatial variations, providing decision-making insights for resource-grade assessment and early-stage team communication across the entire phosphate mining value chain.



