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EnMap hyperspectral data in geological investigations: Evaluation for lithological and hydrothermal alteration mapping in Neoproterozoic rocks

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ABSTRACT

This study conducted a rigorous evaluation of Environmental Mapping and Analysis Program (EnMap) data in geological applications, specifically focusing on lithological and hydrothermal alteration mapping. This research represents one of the earliest attempts to apply EnMap data for such purposes, and the first to integrate EnMap and airborne geophysical data for geological mapping over the entire Arabian Nubian Shield. To ensure a comprehensive appraisal, we selected a study area characterized by complex Precambrian rocks, including igneous, metamorphic, and sedimentary formations, alongside structural intricacies and hydrothermal activities. Our study utilized various image-processing techniques, including principal component analysis (PCA), Uniform Manifold Approximation and Projection (UMAP), Sequential Maximum Angle Convex Cone (SMACC) end-member analysis, and spectral resampling. These techniques successfully discriminated ophiolitic serpentinite, volcaniclastic metasediments (as part of the ophiolitic mélange matrix), metavolcanics, metagabbro-diorite, *syn*-orogenic granite, post-orogenic granite, Nubian sandstone, and Wadi deposits. Additionally, they revealed the prevalence of OH-bearing minerals and iron oxides as the primary hydrothermal alteration products within the study area. By correlating the findings with USGS spectral libraries and airborne geophysical data, we determined the efficacy of EnMap data in these applications. Our findings were further validated through multiscale observations, field investigations, petrographic analyses, and scanning electron microscopy-energy-dispersive X-ray spectroscopy (SEM-EDX). In addition to endorsing the use of the UMAP algorithm and EnMap data for future applications, this study highlights key alteration zones that could serve as potential targets for future gold exploration, alongside insights into bauxite ore occurrences.

1. Introduction

Over the last few years, significant investments have been directed towards the deployment of hyperspectral satellite systems dedicated to Earth observation and monitoring. The Environmental Mapping and Analysis Program (EnMAP), a recently launched German hyperspectral satellite, is anticipated to facilitate various environmental and geological applications through spectral enhancements compared to previous hyperspectral satellites. The EnMAP satellite has emerged as one of the main hyperspectral resources since its launch in 2022, and has been extensively utilized in various applications, including LULC mapping (Lekka et al., 2024) and methane mapping (Roger et al., 2024) by the scientific community across diverse disciplines, such as soil, forests, agriculture, urban, natural hazards, geology, and more (Storch et al., 2023). Hyperspectral sensors that capture data across numerous narrow, adjacent bands have electromagnetic spectra spanning wavelengths that

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