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A multi-scale remote sensing approach for mineral exploration: An example from the Lofdal carbonatite-hosted REE deposit, Namibia

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The demand for critical raw materials, such as Rare Earth Elements (REEs), has risen over the past decade due to their increasing use in consumer electronics as well as in industry (e.g., solar panels and wind turbines). Of all the critical elements, REEs have the highest supply risk for Europe. However, both production and recycling have a high environmental impact due to inefficient use of chemicals. Thus, purely recycling REEs is not sustainable over time. We therefore suggest a renewed focus on innovative and responsible exploration of REE deposits. Conventional mineral exploration methods can be limited by financial costs, field accessibility, area size and climate as well as public acceptance. To tackle these problems, we propose a multi-scale, multi-source remote sensing workflow. Multi-scale remote sensing is particularly beneficial in inaccessible and remote areas, because we can accomplish a systematic, dense and generally non-invasive survey. Our developed approach starts off with a satellite regional reconnaissance followed by high resolution airborne-based mapping to refine the area of interest. We then use Unmanned Aerial Systems (UAS)-based data for detailed mapping. Lithological mapping is performed on the satellite and airborne-based data. Robust spectral analysis methods such as band ratios and minimum wavelength mapping are used to discriminate between lithologies. A light-weight, hyperspectral camera is attached to the UAS to capture data for the detailed geological mapping. An in-house, python-based toolbox (MEPHySTo) is used to correct for radiometric and geometric distortions in the UAS-based hyperspectral data. End-member modelling and classification techniques are used as a basis for rapid and accurate lithological mapping. An important part in the workflow is validating the UAS-based hyperspectral data by geological field work. In-situ spectroscopic and XRF analyses are performed and field samples are taken back to the laboratory for further geochemical analyses. Additionally, we use RGB images taken by the UAS to produce Digital Elevation Models (DEMs) through Structure-from-Motion Multi-Vision-Stereo (SfM-MVS) photogrammetry. The integration of topographical data with hyperspectral allow us to extract information on both lithology and structures. Image processing techniques are used to extract linear features such as dykes and fault scarps from DEMs. We prove that the multi-scale approach allows us to define promising areas that are further refined using UAS-based surveying. We further argue that the addition of UAS-based hyperspectral data together with topographical information can improve the accuracy of field mapping in mineral exploration. UAS-based measurements can supplement and direct geological observation relatively quickly in the field and therefore allow better integration with in-situ ground investigations. Our approach was tested on the Lofdal carbonatite-hosted REE deposit in Central Namibia. The target area is in a remote environment and is characterized by rugged terrains and harsh vegetation, making it difficultly accessible. Previous exploration of the area confirms the occurrence of REEs in structurally controlled carbonatite dykes, making it ideal to show-case our method.