IGARSS 2023 - 2023 IEEE International Geoscience and Remote Sensing Symposium | 979-8-3503-2010-7/23/$31.00 ©2023 IEEE | DOI: 10.1109/IGARSS52108.2023.10281698

A LCT PEGMATITE SPECTRAL LIBRARY OF THE ALDEIA SPODUMENE DEPOSIT: CONTRIBUTES TO MINERAL EXPLORATION

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ABSTRACT

Several methodologies can be employed in the prospection of Lithium (Li) in hard-rock (pegmatites). Spectrometry analysis, a Remote Sensing (RS) technique, can be applied to understand the surface spectral response of a sample, both to identify the rock-forming or alteration minerals in its composition and to validate the data collected *in situ* (by sensors onboard satellites/drones, for example). This paper aims to make available for public use the information acquired on the spectral composition of rock samples from the Barroso pegmatite field in Portugal, within the scope of the INOVMINERAL4.0 project. As a result, a spectral library was created with 47 spectra, collected from 11 different samples. All data is made available in a universal format, thus contributing to open science, corroborating the validation of local spectral data, and stimulating the creation of other databases, in other locations.

Index Terms — *Reflectance spectroscopy, LCT pegmatite, Spodumene, Lithium, Mineral Exploration*

1. INTRODUCTION

Reflectance spectroscopy is a method for analyzing absorption features and understanding the composition of the rock, either in the field or the laboratory [1,2]. The United States Geological Survey - USGS [3] and ECOSTRESS [4] libraries provide some reference spectral curves, however, their focus is not providing spectra for all Li minerals [1]. Considering the European Commission's environmental measures that have resulted in an increasing demand for Li and other critical materials [5], coupled with the need for new geological exploration technologies to discover and evaluate possible European deposits, this study focuses on the Aldeia Li-Cs-Ta (LCT) pegmatite dykes, located in the Barroso-Alvão pegmatite field. The objective of this paper is: (i) present a methodology for obtaining reflectance spectral data on rock samples, culminating in the construction and availability of a spectral library that can be used as laboratory validation of field data; and (ii) compare the spectra obtained with a Landsat 9 image, evaluating the potential use of RS for mineral exploration. The work presented is within the scope of the project INOVMINERAL4.0 whose overall objective is the innovation and reorientation of the industrial models that sustain the Mineral Resources Sector, through the development of advanced technologies, new products and software (https://inovmineral.pt/).

2. STUDY AREA

The aplite-pegmatite dykes of the Barroso-Alvão pegmatite field were classified by Martins [6] and Dias [7] using the concepts of Černý & Ercit [8] classification as belonging to the LCT family, subdivided into the complex type, spodumene sub-type, and petalite sub-type. The Li mineralization at the Barroso pegmatite field, which involves the Aldeia pegmatite (and others), occurs predominantly in the form of spodumene-bearing pegmatites, which are hosted by metapelites and mica schists. The Aldeia pegmatite dyke corresponds to a moderately west dipping tabular body defined over an area of 250 m N-S with a dip extent of 340 m [9]. The pegmatite is also exposed in a quarry in the central portion of the mine where the geometry of the main pegmatite is visible, allowing for remote sensors to acquire its spectral signature. Although there are other pegmatites in the surroundings of Aldeia, in this work we focused on the aforementioned region and the Li pegmatites.

3. DATA ACQUISITION, AND DATA PROCESSING

A total of 11 samples were collected on a field campaign, performed on the Canedo-Covas Mining Lease Application, integrated in Savannah Resources PLC Barroso Lithium Project.. The samples were dried at 50°C in a muffle furnace for 24 hours. The spectral data were collected on different faces of each sample, considering the visible changes in its composition.

The ASD FieldSpec® 4 spectroradiometer was used for data acquisition, with a wavelength range of 300 to 2500 nm, and a rapid data collection time of 0.2 seconds per spectrum. In each analyzed sample point, an average of five measurements was performed with the ASD ViewSpec Pro™ software [10] to increase the signal-to-noise ratio, totaling 47 final (raw) spectra in the end. Moreover, for each analysis point, a photographic record was made together with a description of its characteristics. Finally, each spectrum was submitted to a quality check through visual inspection using the SpectraGryph software [11] and was subsequently processed with a Python routine to remove the continuum and extract the absorption features [1]. All results were inputted into the spectral library and the database was generated [12].

4. SATELLITE IMAGE PROCESSING

In this study, the new and recently available Landsat 9 data were selected to assess the potential of this space dataset for mineral exploration in general, and for pegmatite exploration. With a radiometric resolution of 14 bits, Landsat 9 can differentiate 16,384 shades of grey, allowing the sensors to detect more subtle differences on the Earth's surface. This radiometric improvement can make Landsat 9 a powerful tool for lithological studies, with images collected since October 31, 2021. Being a satellite that has been operating for a short time, there are not many Landsat 9 images covering the study area. Among the available images, the one with less cloud cover was chosen for download. The image was pre-processed using the Semi-Automatic Classification Plugin (SCP) plugin (version 7.10.6), available in the QGIS software (version 3.22.1). The atmospheric correction method used was the Dark Object Subtraction 1 algorithm [13]. First, the main absorptions and reflectance peaks were identified and analyzed. After that, the main absorptions and reflectance features were compared with the spectral range of the Landsat 9 satellite bands of the product acquired on 2022/01/28. Only the most significant spectrum of each sample was used in the analysis, totaling 10 spectra selected. Principal Component Analysis (PCA) [13] was chosen as an RS method that complements the spectral library data and can validate information obtained *in situ*. The bands used in this method were selected according to their spectral response and compared to the rock samples from Aldeia pegmatite. As the selective PCA on a two-band subset achieved the best results in previous studies [14-15], in this work PCA was tested with the following two-band subsets: (i) PCA of bands 3 and 7; (ii) PCA of bands 6 and 7; and (iii) PC of bands 4 and 7.

4. DATA

The generated/processed products were organized in the spectral library, making various analyzes possible, both on the raw spectrum and continuum removed spectra to identify the main absorption and reflectance bands. The database was intended to be freely used by researchers and industry professionals alike, as well as by any other mining or exploration stakeholder [16]. The data was stored in a database, namely a .accdb Access format (Microsoft 365), which holds files with different files (jpeg, .pdf, .txt and .png) as attachments. The database can be later connected to a geographic information system. A first analytical approach was carried out based on the coloration of the sample, which allows inferring possible mineralogical compositions. This methodological systematization ensures that the available data resultant from this study is corroborated through different validation sources, minimizing the analytical subjectivity, and allowing the user to complement his studies with new analysis criteria, if necessary (Figure 1).

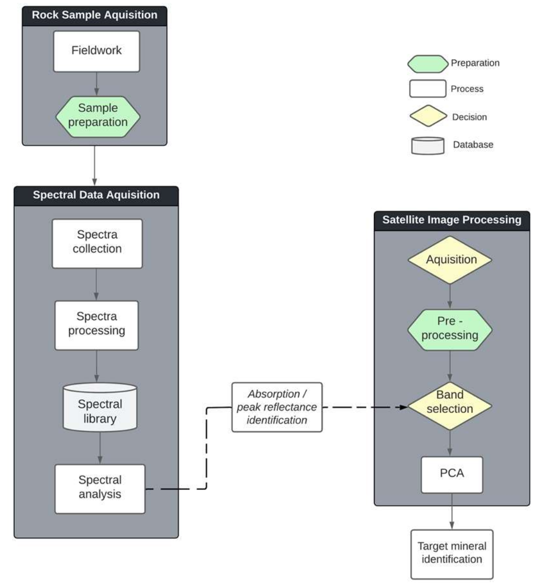

Figure 1. Methodology Workflow, with methodological processes and their integration for the identification of target minerals.

5. PRELIMINARY RESULTS AND DISCUSSION

In the created library it is possible to access several files, including: (i) a photograph of the location where the spectrum was collected within the sample; (ii) the (raw) collected spectra consisting of the spectra for each sample; (iii) the processed spectra, consisting of the continuum removed files; (iv) the extracted spectra absorptions, corresponding only to the most prominent (deep) features, resulting in 173 files with the different absorption bands of the samples. Figure 2 shows an example of the graphical products available in the spectral library for consultation and analysis.

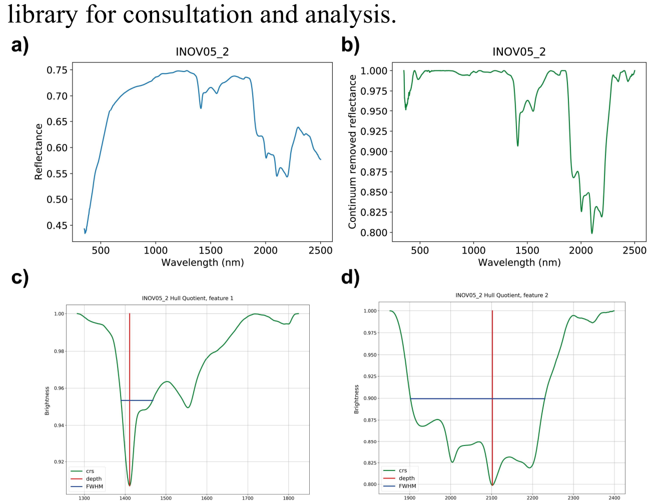

Figure 2. Example of the graphical products of the spectra INOV5_2, available in the spectral library, for consultation and analysis: a) Raw_spectra; b) Processed_spectra; c) and d) Spectra_absortions, with different wavelengths and depths.

All 47 spectra were processed and analyzed to identify the most prominent absorption features and identify the correspondent spectral mineralogy through comparison with the literature available information [1. 17-18].
The most representative spectra of each class were selected. All spectra of Figure 3 have one AlOH absorption feature around 2190 nm and two features around 2340 nm and 2440 nm, typical of the white mica group minerals, namely, muscovite and illite. It is the presence of the AlOH secondary absorptions that, together with the symmetry and sharpness of the main AlOH absorption and absence of water feature, are decisive for the distinction of these minerals. The spectrum INOV09_03 has two iron features (680 nm and 880 nm), in addition to a reflectance peak at ~730 nm, indicating the possible presence of hematite in this sample (Figure 3 a).

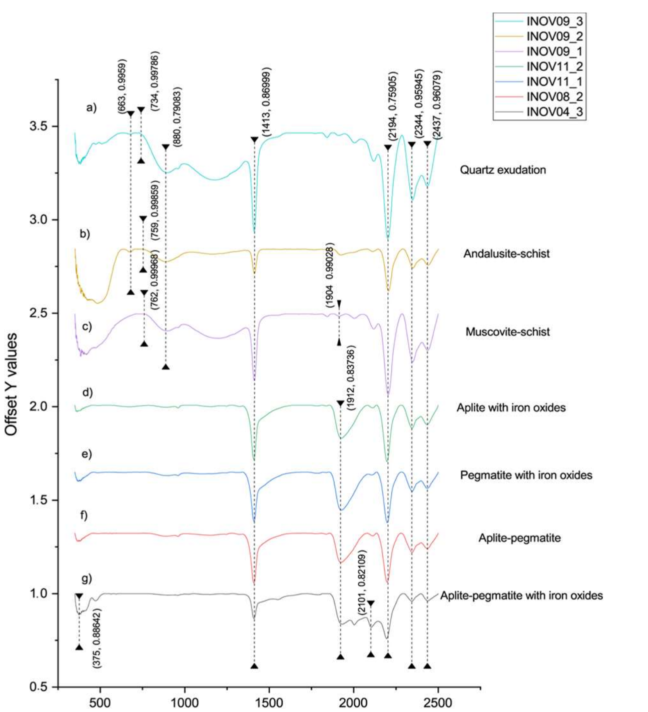

Figure 3. Diagnostic absorptions of the spectra of each class: a) Quartz exudation; b) Andalusite-schist; c) Muscovite-schist; d) Aplite with iron oxides; e) Pegmatite with iron oxides; f) Aplite-pegmatite and g) Aplite-pegmatite with iron oxides.

Similarly, the spectrum INOV09_2 has the same absorptions and reflectance peak diagnostic of the presence of hematite (Figure 3 b). The spectrum INOV09_01(Figure 3 c), also has diagnostic absorption features and reflectance peaks that indicate the presence of hematite in the VNIR region. The weak to absent water absorption (~1904 nm) that together with the AlOH absorption (~2194) and the double AlOH secondary absorptions at ~2340 nm and ~2430 nm, can confirm the presence of muscovite in this sample (Figure 3 a to c). Muscovite was expected in spectra b and c (Figure 3 b and c) since it is an important rock-constituent mineral of pelitic metasediments. The spectra INOV11_2 (Figure 3 d), INOV11_1 (Figure 3 e), INOV08_2 (Figure 3 f), and INOV04_3 (Figure 3 g) have a more pronounced, asymmetric water absorption shorter than the main AlOH absorption that, together with the double ALOH secondaries at ~2340 nm and ~2430 nm, indicate the presence of illite.
A comparison was made between the built spectral library and the Landsat 9 spectral resolution, using three Aplite-Pegmatite representative spectra as examples. It was observed that the laboratory spectra have three main absorption features located around 1400 nm, 1925 nm, and 2200 nm. This last absorption feature around 2200 nm is the most prominent, as it is the only one covered by a Landsat 9 band (band 7, SWIR 2). Regarding the reflectance peaks, the most relevant band is band 6 (SWIR 1), which covers a faint reflectance peak occurring around 1600 nm. Band 3 (Green) and band 4 (Red), also match the high reflectance regions.
Therefore, bands 3, 4, 6, and 7 were selected and assigned in the method described in the following steps. The tested PCA two-band subsets highlight the pixels of Aplite-Pegmatite with high values which are represented in bright white color. The other elements of the study area like vegetation and water are represented in shades of grey, but could be easily masked through index computation. Density slice highlighted the pixels with higher values in red color.
PCA 6,7 was able to identify the other mining areas of the Barroso-Alvão pegmatite field, namely Lousas, NOA, and Alijó. Those are known LCT-pegmatite targets within a radius of 10 km of the Aldeia deposit. But the method was not successful in identifying the area of the Aldeia pegmatite. PCA 3,7 and 4,7 obtained very similar results and highlighted the known pegmatites in the study area including the Aldeia pegmatite. Both were able to identify four of nine known pegmatite points, totaling 44.4% of accuracy. False positives occur on some roads and in urban areas for all PCA tested, but PCA 3,7 has fewer false positives (Figure 4).

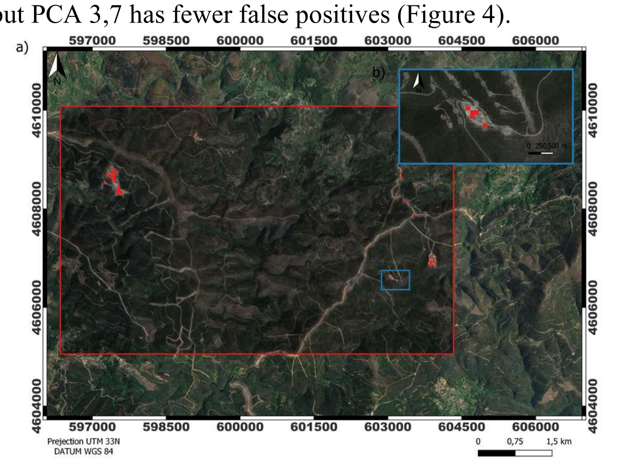

Figure 4. Result for PCA 3,7. a) The Aldeia mining area is highlighted by the blue rectangle. The pixels of Aplite-Pegmatite are highlighted in red, showing that the method was accurate in other known target locations apart from the training area (e.g. Lousas, NOA and Alijó). b) Aldeia mining area in focus.

It is noteworthy that the spatial resolution of 30 m in the Landsat 9 data was a limitation in this study. This was already identified and discussed in previous studies [19], as well as possible approaches to migitate this limitation and segregate more effectively the target signature through spectral unmixing [20]. For smaller study areas, as the one presented in this work, with limited variation in land use and land cover classes, spectral mixing at pixel level might not occur in large scale. However, for larger areas with greater heterogeneity, it is recommended to the aforementioned methodologies.

6. CONCLUSION

To validate the mining data obtained in the field, a successful methodology was proposed to structure the data into a spectral library, with freely available public access data that can even serve as a source of validation in new scientific studies. This approach was the result of the identification of the absence of spectral libraries for this particular purpose.

The available spectra allow the user to establish a relationship between the expected theoretical spectral curve and the empirical data obtained, which can favor more assertive prospecting processes through the selection of key satellite bands. This comparison allowed validation of the data acquired in the field and by new satellite sensors in a small known area, evaluating the ability to identify these minerals by RS. It is expected that the proposed methodology will be applied to new larger areas of study, enabling the inclusion of complementary techniques/algorithms (such as deep learning) and contributing to meeting the needs for available data on LCT pegmatite prospecting.

ACKNOWLEDGMENTS

The authors acknowledge the support provided by Portuguese National Funds through the FCT – Fundação para a Ciência e a Tecnologia, I.P. (Portugal) projects UIDB/04683/2020 and UIDP/04683/2020 (Institute of Earth Sciences); through ANI and COMPETE 2020 as well as European funds through the European Regional Development Fund (ERDF) with POCI-01-0247-FEDER-046083 INOVMINERAL project. The authors also thank Savannah Resources PLC for access to the Aldeia pegmatite and for providing the samples used in this study. Cátia Rodrigues de Almeida and Douglas Santos were financially supported by Portuguese national funds through FCT (Grant: PRT/BD/153518/2021, Grant: UI/BD/154412/2023, respectively).

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