Special Conference Edition, April, 2022

http://dx.doi.org/10.4314/bajopas.v13i1.32S

Bayero Journal of Pure and Applied Sciences, 13(1): 198 - 203
ISSN 2006 – 6996

SPATIAL MAPPING OF PEROVSKITE USING MINERAL RATIO INDEX: A CASE STUDY OF HAWAL MASSIF, MICHIKA, NORTH-EASTERN NIGERIA

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ABSTRACT

Perovskite, a very vital resource for cleaned solar energy generation, occurs naturally in igneous rocks as titanium oxide minerals in layered massif intrusions within the magmatic igneous formation. It occurs in association with some oxides and hydroxides such as ilmenite. In this work, we developed a Perovskite mineral ratio index model for spatial mapping of the mineral based on its spectral reflection characteristics. The work is necessitated by the need for the development of an optical remote sensing tool for the survey of perovskite –bearing ilmenite, within the Precambrian basement terrain. The ratio index was used to map a portion of Hawal massif of Michika, Northeastern Nigeria. The area is a basement formation between the foot of the Mandara Mountain and the Gongola Basin believed to be rich in Perovskite mineral resources based on its geologic setting. Landsat-8 Operational Land Imager and Thermal Infrared Sensor (OLI/TIRS) satellite image of the study area was acquired and processed using the developed ratio index. The results indicate a high concentration of Perovskite-bearing minerals in a small central portion of the area. Comparative analysis of the results with the geologic map of the area indicates that Perovskite bearing zones correspond to major faults and fracture regions of the formation. The regions are therefore considered as alteration zones associated with kimberlite emplacement deposit since Perovskite also occurs as groundmass kimberlite. The work is therefore a move toward exploration and effective exploitation of this useful renewable energy generating resource.

Keywords: Hawal Massif, Michika, Mineral Index, Perovskite,

INTRODUCTION

Perovskite is a calcium titanate mineral with the chemical formula $CaTiO_3$ which occurs as brilliant black cubes in many massif igneous rocks in association with pegmatite, and in metamorphic contact zones. It also occurs in chlorite or talc schists found in altered limestone as an accessory mineral in massif igneous rocks (Chakhmouradian and Mitchell, 1998). Structurally, Perovskite is orthorhombic pseudo cubic resembling distorted cube (John *et al.,* 2019). Perovskite is an unremarkable oxide mineral discovered in 1839 on the basis of its versatile crystalline structure. The crystalline nature of perovskite enables it to accommodate wide varieties of cations such as high-temperature superconductors, organic and inorganic hybrid perovskite solar cells with high power conversion efficiency (Fu *et al.*, 2015), nano-particle display narrow band photoluminescence useful in optoelectronics (Zhao and Zhu, 2016). It is also used as a solid oxide fuel cell where it serves as oxygen ion conductors separating anode and cathode (Sunarso *et al.,* 2017). Perovskite is therefore an economically important solid mineral resource and remains attractive for solid mineral prospectors due to its growing industrial values.

Remote sensing technology plays a significant role in the geologic mapping of solid mineral resources, providing a unique opportunity for large scale regional surface characteristics of land form. These include lithological mapping (Langford, 2015), environmental mapping (Jensen, 2006), predicting forest fire characteristics (Maffei *et al.*, 2021) among others. Several remote sensing techniques which involve image analysis and processing techniques can be used to extract information from remotely sensed spectral data for possible mineral deposit detection (Liu *et al.,* 2017). Optical remote sensing data are records of the electromagnetic reflective radiance of the target surface exposed to the sunlight, at a few microns of wavelength. For geologic application, high spectral resolution covering the components that are sensitive to spectral characteristics of the minerals such as Short Wave Infrared (SWIR) is very necessary. Hence the Landsat-8 Operational Land Imager (OLI)/Thermal Infrared Sensor (TIRS) dataset is an important tool for identifying hydrothermal alteration on the earth's surface which has the potentiality of indicating ore deposits (Pour and Hashim, 2015; Xu *et al.*, 2018, Shi *et al*, 2018). The Landsat 8 OLI/TIRS is latest version of landsat system. The system has two main sensors, the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS). The OLI has nine spectral bands (bands 1 to 9). They include seven bands in the visible-near infrared (VNIR) range (four bands: B1(0.45–0.52 μm), B2(0.52–0.60 μm), B3(0.63–0.69 μm) and B4(0.76–0.90 μm), shortwave infrared (SWIR), range (two bands: B5(1.55–1.75 μm) and B7(2.08–2.35 μm) and thermal infrared (TIR) region (one band: B6 (10.4–12.5 μm) of the electromagnetic spectrum (USGS, 2019). The nine bands of OLI sensor can be uniquely arranged to extract useful information about the surface such as the surface spectral signature which will subsequently be used to map features like geological formation, and lithologic sequences.

While band combinations may not be sufficient in identifying land cover features, enhanced processes such as feature extraction and band ratio indices are found to be very effective in geological and mineral identification (Pour and Hashim, 2015; Imbroane *et al.*, 2007). Band ratio index is developed based on the identification of high reflection peaks and absorption troughs from the spectral signature of the material. The procedure involves differencing and band ratio operations based on the information obtained from the spectral signature of the mineral type as recorded using the image spectroscopy technique (Calvin *et al.*, 2015; Mia and Fujimtsu, 2013). Details of SGS spectral library of different solid minerals for remote sensing application were compiled by Kokaly *et al*. (2017).

In this work, we developed a mineral ratio index for perovskite –bearing mineral based on its reflection spectral signature obtained from the United State Geological Survey (USGS) Spectral Library. The developed ratio index was used to map the spatial distribution of the mineral resource in an area that is geologically observed to be favourable for the occurrences of the mineral.

MATERIALS AND METHODS

Different mineral and rock types have specific spectral signature determined by their respective reflection peak and absorption trough. The effectiveness of the application of the spectral signature in spatial mapping of the mineral is however dependent on the nature and the level of vegetation cover of the study area (Grebby *et al.*, 2014). To this extent, the effectiveness of mineral ratio index in spatial mapping of mineral deposit is determined by the nature of the study area.

Study area

The study area covers the entire Michika Local Government Area (LGA) of Adamawa state, northeastern Nigeria geographically located within latitudes 10°25′N to 10°50′N and longitudes 13° 15′E to 13°30′E. (Figure 1).

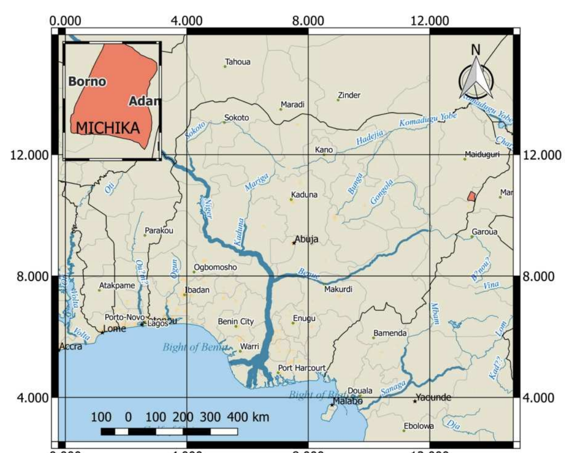

Figure1. Map of Nigeria showing the study area (Digitized from Google Earth)

The entire LGA is geologically located within the Precambrian Hawal Massif, situated between the Cameroon Highland and the Benue Trough. The area is bounded by the Chad Basin in the north and northwest, Gongola arm of the Upper Benue Trough in the southwest and south respectively. The area is underlain by the massif igneous rocks consisting of Basalt, Porphyritic Biotite Granite, Medium to coarse-grained Granite, Migmatite Granite, Banded Gneiss and, crush Braccia catalasite and Mylonite along a fault zone (Muhammed and Muhammed, 2017). The topography of the area is characterized by outcrops of granitic rocks from the underlying extensive crystalline basement complex (Mohammed and Mohammed, 2017)

Perovskite occurs in massif igneous rocks as an accessory mineral in alkaline massif rocks in the form of either kimberlite (Nkere *et al.*, 2019) or carbonate in association with titanite, ilmenite or magnetite rocks (Chakhmouradian and Mitchell, 1998). It also occurs in altered blocks of limestone, talc shists and alkaline and other titanium–bearing oxides which are also associated with igneous rocks such as granites and pegmatite. These basement complex rocks were described by Ibrahim *et al.* (2019) as the dominant petrographic composition of the study area.

Surface geology and earth materials are mapped based on the material mapping technique which involves searching an input image for the presence of a specific material of interest based on the spectrum of the material. The result is a grey-scale map image of a portion of the covered area with spectrum similar to that of the material. The digital number (DN) values of the output image therefore, give an estimate of the concentration of the material in the study area (Liu *et al.*, 2017). Material mapping is practically accomplished using multispectral algebraic operations. There are infinite numbers of band computations derivable from the spectral signature of the material of interest. The most common operation is the band ratio index which can be derived based on the visual observation of the reflection spectrum of the target mineral. The most popular ratio indices include Normalized Difference Vegetation Index (NDVI), iron oxide index, clay mineral index etc. They are all derived based on the ratio of the differences between the bands corresponding to reflection peaks and absorption troughs as visualized in the spectral signature.

In this work, the spectral signature of perovskite-bearing minerals available in the study area, the ilmenite, was obtained from the United States Geological Survey (USGS) Spectral Library as shown in Figure 2.

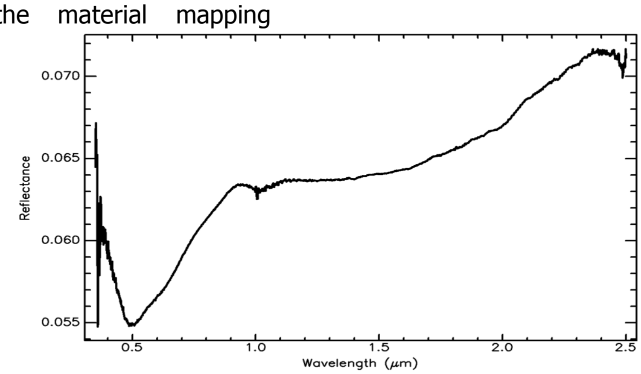

Figure 2. Laboratory spectrum of perovskite- bearing ilmenite (Kokaly *et al.,* 2017). Reflection peak and trough are identifiable at 2.4 μm and 0.5 μm respectively.

It can be observed from the figure that the reflection peak occurs at a wavelength of 2.4 μm which corresponds to band 7, (short wavelength infra red-2) of the Landsat 8 OLI/TIRS data. The absorption trough on the other hand, occurs at 0.5 μm wavelength, which corresponds to band 2 (blue) of the same data. The significant difference between these two bands regarded as SWIR edge, gives a unique spectral property capable of discriminating between the perovskite bearing minerals from other background land covers (Liu and Mason, 2009). Thus a different index of the mineral can be expressed with respect to OLI/TIRS data, the Normalized Perovskite Index (NPI) as

$$NPI = \frac{SWIR2 - RED}{SWIR2 + RED} = \frac{Band7 - band2}{band7 + Band2} \quad (1)$$

The above mineral index can be enhanced using ratio index by subtracting the background information, leading to Perovskite Radio Index (PRI) expressed as

$$PRI = \frac{Band7 - Min(Band7)}{Band2 - Min(Band2) + 1} \quad (2)$$

where the Min(Band7) and Min(Band2 are the lowest Digital Number (DN) within the respective bands. The subtraction of the lowest DN from each of the bands is to remove the added constants of the atmospheric scattering effect to improve the signal to noise ratio. The value of 1 is added to avoid zero value of the denominator.

A cloud-free level 1T (terrain-corrected) Landsat-8 image (LC81850542018340LGN00) of the study area was obtained from the US Geological Survey Earth Resources Observation and Science Center (http://earthexplorer.usgs.gov) on 6th December 2019. The image map projection is Universal Transverse Mercator Zone 33N (polar stereographic for Antarctica) from the WGS 84 datum. The image was processed with Environment for Visualizing Images (ENVI) version 5.3 software. This involves the conversion of the DN into surface reflectance using the internal average relative reflection method (Kruse, 1988). The technique is described as very effective in mineralogical mapping. Based on the reflectance spectrum of the mineral of interest, an RGB colour combination image was produced using bands 2,4 and 7 in which band 2 is placed in blue ($0.450 - 0.515\mu m$), band 4 in red ($0.630 - 0.680\mu m$) and band 7 short wave infrared-2 ($2.10 - 2.30\mu m$). The required band ratio was calculated based on equation 2 using the band math function of the software.

RESULTS AND DISCUSSION

The band ratio derived from the reflection spectrum enables identification and mapping of perovskite – bearing mineral in grey-scale binary image. The map is a vector map with a DN values ranging from 0, representing the absence of the mineral, to 1 representing the region for its possible occurrence. The PRI map is shown in Fig. 3.

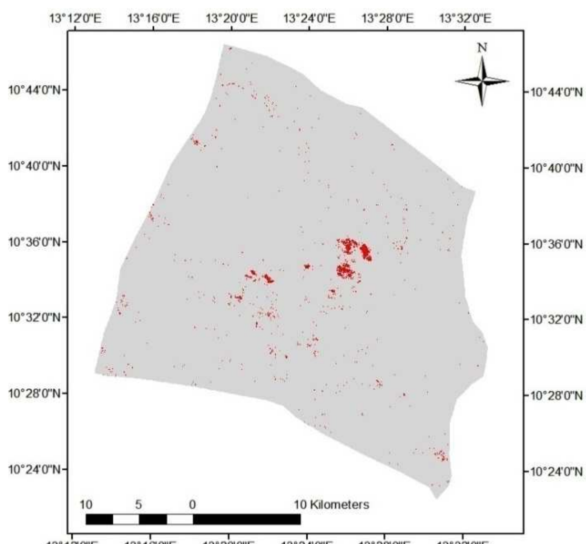

Figure 3. PRI map of the study area, indicating the regions of possible occurrence of perovskite mineral.

The highlighted regions of the map are regions of possible occurrences of perovskite. The regions relatively occupied a small portion of the study area, mainly concentrated at the centre of the area. Comparative study of the resulting map with the geologic and mineral resource map of the area developed by the Nigeria Geological Survey Agency (NGSA) indicates that the highlighted areas coincide with the regions associated with deposits of titanites, talc and magnetite (NGSA, 2007). These are associated with perovskite as mentioned earlier. The finding, therefore, confirms the relationship of the mineral with its various form of occurrence particularly talc schist which occurs in association with perovskite in alkaline massif igneous rocks and the association of perovskite with titaniferous magnetite, and magnesian ilmenite in ultramassif rocks (Chakhnouradian and Mitchell, 1998). This study demonstrates the importance and advantages of Landsat 8 OLI/TIRS data in mapping minerals associated with perovskite. The data reveals significant information about the presence of minerals associated with perovskite in any geological formation and can therefore be used as a reconnaissance survey for the mineral resource.

CONCLUSION

This work is a reconnaissance survey and mapping of perovskite –associated mineral deposits conducted within a formation of a geologic setting that is potentially conducive for the occurrence of the resource. The work involves the application of the band ratio index of Landsat 8 OLI/TIRS data formulated based on the laboratory measurement of the reflection spectrum of the mineral. Comparative analysis of the results with a compiled mineral resource map of the study area revealed that the two are relatively in good agreement. The perovskite – bearing oxide minerals relatively coincide with the location of the highlighted regions of the map. We therefore, recommend detailed survey and sample analysis within the identified locations using powerful and effective spectroscopic techniques such as Raman spectroscopy to exploit this economically viable resource.

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