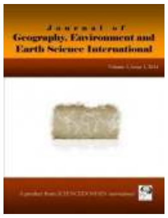

Journal of Geography, Environment and Earth Science International
9(4): 1-14, 2017; Article no.JGEESI.31847
ISSN: 2454-7352

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Mapping of Hydrothermally Altered Rocks for Mineral Targeting in Jos Plateau and Its Environs North Central Nigeria Using Aster Image

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Authors' contributions

This work was carried out in collaboration between all authors. The data for the work was sourced and analyzed by author JOO. The interpolation and rasterization was carried out by authors JOO and AAO. Supervision was done by authors SOM and ENG. The paper was coordinated by authors SOM and HAS. The manuscript was done and edited by author JOO. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JGEESI/2017/31847
Editor(s):
(1) Pere Serra Ruiz, Department of Geography, Universitat Autònoma de Barcelona, Spain.
Reviewers:
(1) Amin Beiranvand Pour, Korea Polar Research Institute (KOPRI) Songdomirae-ro,Yeonsu-gu, Republic of Korea.
(2) Lorna T. Enerva, Polytechnic University of the Philippines, Philippines.
(3) Pavel Kepezhinskas, Kimberlitt AS, Norway.
Complete Peer review History: http://www.sciencedomain.org/review-history/18658

Original Research Article

Received 27th January 2017
Accepted 27th March 2017
Published 15th April 2017

ABSTRACT

ASTER short wave infrared (SWIR) bands have been known to be suitable for mapping hydrous silicates and carbonates. The occurrence of certain mineral groups and specific minerals which include; kaolinite, alunite, illite, muscovite, montmorillonite, chlorite, calcite, dolomite, serpentine, and others, have been predicted using the SWIR bands. The aim of this research is to investigate the presence of hydrothermal alteration minerals and their relationship with the tin mineralisation in the study area using ASTER satellite imagery and other data sets.

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The study area falls within parts of Naraguta Sheet 188, which is part of the younger granite province of Jos Plateau in north central Nigeria. False-color composite (FCC), band ratios, principal component analysis (PCA), methods, were used to process the ASTER data. The (SWIR468) image of the Jos plateau and environs, shows a general sight of alteration, a compound band ratio of RGB (2/1, 4/9, 3/2) was applied, where the bright yellow color represents the presence of hydrothermal alteration in the study area. A colour composite of (-PC4 (1234), PC4 (1346), 3/2) was also used where green and yellow color show hydrothermal alteration in the study area. The following band compositions were transformed using PCA to discriminate phyllosilicates which are the main features of alteration. For Alunite, (bands 1, 3, 5, and 7), Ilit (bands 1, 3, 5, and 6), Kaolinte and Smectit (bands 1, 4, 6, and 9), Kaolinte (bands 1, 4, 6, and 7). The results of the study shows the relationship of the Tin rich younger granite complexes of parts of Jos Plateau and their association with the hydrothermally altered rocks, where Kaolinite, Alunite Biotite Muscovite and Illite where identified using ASTER data.

Keywords: Hydrothermal alteration; ASTER SWIR; band ratio; principal component analysis.

1. INTRODUCTION

Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Visible Near Infrared (VNIR), Short Wave Infrared (SWIR) and Thermal Infrared (TIR) scanners where launched aboard Terra Sat platform 1999, since 2000 the multispectral imagery has provided enhanced spectral and spatial information when compared to LANDSAT. ASTER images have been used effectively in identification of minerals and surface geological mapping at very good mapping scales. NASA Jet Propulsion Laboratory has shown that VNIR data are sensitive to the presence of iron oxide minerals; the shortwave infrared (SWIR) bands of ASTER are good for mapping hydrous silicates and carbonate layers in volcanic environments. The occurrence of certain mineral groups and specific minerals which include; alunite, kaolinite, illite, montmorillonite, muscovite, chlorite, calcite, serpentine, dolomite, and others, have been predicted using the SWIR bands. The TIR data are sensitive to differences in silica-bearing rocks, either in the presence of or in the absence of the other mineral constituents. Although ASTER has its limitation in mapping and differentiating between FeO_2 and Fe minerals, this is because the visible and near-infrared (VNIR) bandwidth is narrow [1-4].

New methods are been continuously developed for mapping different rock types, remote sensing geology has yielded positive results in this area. Hydrothermal alteration in rocks has attracted considerable attention because of their potential to host mineralization, and the fact that they can be easily differentiated by their unique spectral characteristics using remote sensing techniques [5-8].

Where there are shallow intrusions into igneous environment, thermal perturbations is produced in the fluid-rich area of the rocks of the upper crust, this generates hydrothermal systems in which thermal energy is dispersed to the surrounding by convective fluid circulation and heat conduction [9-11]. Permeability property of a rock plays a fundamental role in the control of convective fluid motion, other associated chemical and the alteration of minerals [11].

The hydrothermal alteration pattern in tin-tungsten ore systems is essentially identical to copper porphyry systems of Cordilleran type [12]. The high concentrations of boron and/or fluorine in Sn-W systems result, however, in the additional and specific alteration components of tourmaline and fluorite ± topaz. Fig. 1. Below is a typical alteration sequence. In the following figure, the temporal sequence which comprise potassic, sodic, sericitic and argillic stages which have variable proportions locally, are been compared in parallel by mineral sequence of structurally controlled tin mineralization, where the early phase is associated with feldspar while later phases, muscovite or chlorite dominate [13].

Jos Plateau Nigeria is known for its tin mineralization, the tin occurrence is associated with the Jurassic younger granite intrusions, the Biotite granites are known to host most of the tin mineneralisation. These intrusions through the injection of hot magmatic fluids during their emplacements resulted in the hydrothermal alteration of the rocks of the region, the mineral assemblage of the rocks of the Jos plateau are similar to the alteration pattern described in Fig. 1. By using remote sensing techniques these alteration zones which occur at regional scales can be detected. In this research, ASTER satellite imagery data covering Jos Plateau

(Parts of Naraguta Sheet 188) was processed to map spectral signatures associated with the hydrothermal alterations using various image processing techniques.

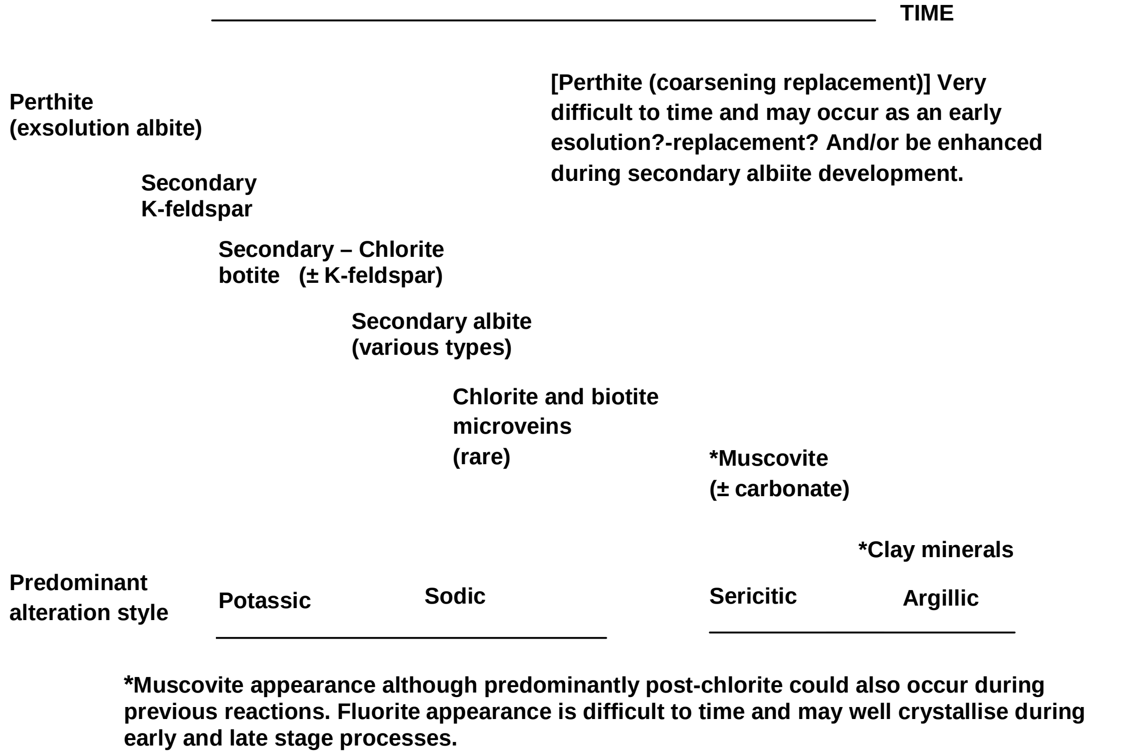

Fig. 1. Timing of main alteration minerals in incipient pervasive alteration of tin granites in the Herberton tin field, Tasmania, Australia. (Pollard and Taylor 1986)

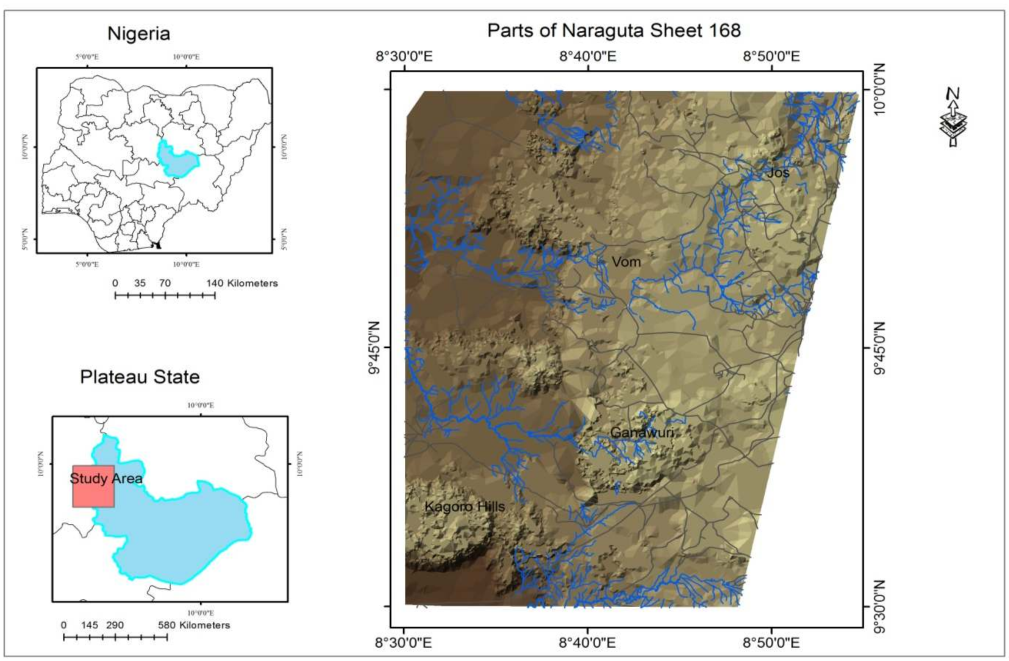

Fig. 2. Map of study area showing parts of Jos Plateau and Envinrons

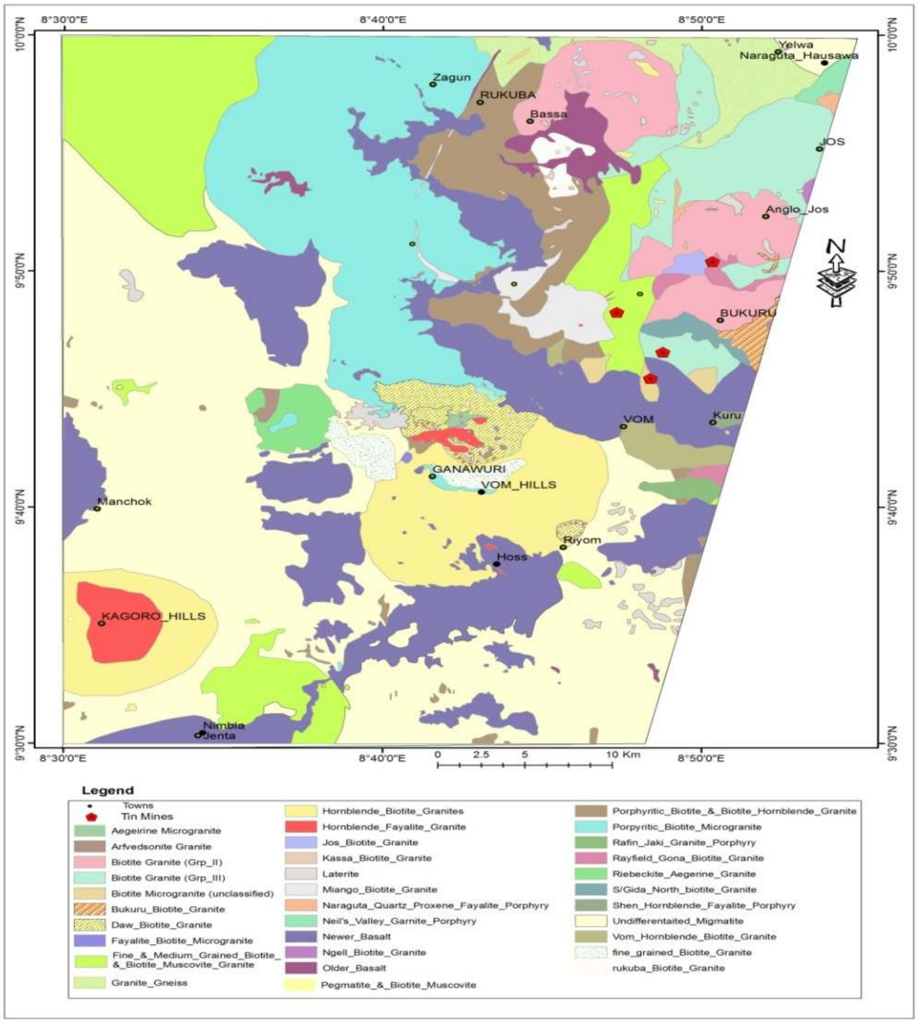

Fig. 3. Geology map of parts of parts of Jos Plateau

The aim of this study is to carry out a regional investigation of the study area for the presence of hydrothermal alteration minerals and the relationship with the tin mineralization using ASTER satellite imagery and other regional data sets, and linking the spatial distribution of the minerals to the factors that control their distribution.

1.1 Study Area

The area covers mostly, parts of Naraguta Sheet 188, located on the Jos Plateau which is in the north central part of Nigeria. Jos – Plateau measures approximately 104 km (65 miles) from the Northern axis to the Southern end, and 80 km (50 miles) from eastern flank to the Western tip, covering a total area about 8,600 km^2. The Jos Plateau has steep escarpment edges with a descent of about 600 m to the surrounding plains. The Southern part of Jos Plateau is in the Benue Lowlands extending towards the River Benue flood plain. The study area (Jos – Bukuru complex) lies between latitudes 8° 50′ N and 9° 00′N and longitude 9°45′E and 9°50′E. the area has an average elevation of about 1,150 metres above mean sea level and the highest peak some 20 km eastwards from Jos-Shere hill, rising to 1777 metres above mean sea level [14].

1.2 General Geological Setting

The geology of the Jos Plateau has been exhaustively earlier studied by Falconer in 1911 and 1921, MacLeod and other workers carried out further studies of the area in 1971. In recent times, researchers have continued to work on the younger granites of the Jos Plateau. The predominant rock types are mainly biotite-granite. Precambrian Basement migmatite-gneiss-quartzite complex has been reported to underlie about half of the entire State, in some places, the Precambrian to the late Paleozoic Pan-African granite (Older Granite), diorite, charnockite etc. have intruded the migmatite-gneiss-quartzite complex. On the other hand, the Basement Complex rocks are also intruded by the Jurassic anorogenic alkali Younger Granites that are associated with volcanic rocks such as basalts and rhyolites.

The volcanic rocks usually overly or cross-cut the Younger Granite as well as the Basement rocks. These volcanic rocks are believed to have been formed during the early Cenozoic (Tertiary) “Older Basalts” and Quaternary “Newer Basalts” [14-18]. The description of Macleod confirm the presence of minerals of economic importance such as tin and columbite which where extensively mined between 1902 and 1978.

2. METHODS AND MATERIALS

In carrying out this research, we attempted to detect the alteration zones and targeting key alteration minerals in Jos Plateau area using different image processing techniques on ASTER imagery data such as false colour composite, band ratios and Crosta method. Data analyses were carried out using ENVI 5.4, HypPy and ArcGIS 10.4 software. Available dataset used for the project include among others, the following; ASTER L1A Satellite imagery captured "2007-03-06", 1:100,000 Geological maps, 1:100,000 Topographic maps.

2.1 Data Processing

ASTER L1A data covering the study area, in hierarchical data format (HDF), captured "2007-03-06" was used for this research. ASTER L1A usually obtained as reconstructed data, are normally unprocessed instrument data that are at full resolution. The data streams are encoded with image data, radiometric coefficients, geometric coefficients and other auxiliary data. Atmospheric correction was carried out on the image using FLAASH module in ENVI software, this was used to accurately compensate for atmospheric effects. This technique of atmospheric correction using FLAASH, allows for retrieving spectral reflectance from hyperspectral and multispectral radiance images. FLAASH also corrects wavelengths in the visible through near-infrared (VNIR) and shortwave infrared regions (SWIR). The different bands were georeferenced and co-registered, before the data was atmospherically corrected using FLAASH. Georeferenced VNIR and SWIR datasets were combined afterwards using the Layer Stacking tool, the SWIR dataset were resample to 15 m resolution to match the resolution of the VNIR dataset. The geological and topographical maps covering the area of study were scanned, georeferenced and digitized using ArcGIS software.

Different methods of image processing techniques are available for the interpretation of spectral data set. Some of which are; Pseudocolor, false-color composite (FCC), band ratios, decoloration, principal component analysis (PCA), Tassel Caps (TC), normalized difference vegetation index (NDVI), and MNF, these techniques are important and are applied in the determination of alteration zones. In this research, some of these techniques were applied. According to Azizi et al. 2010, False-color composite (FCC) method of 468-color composite combination of red–green–blue (RGB) scheme was used to distinguishing alteration zones. In this color composite, propylitic alteration will appear as green, and a phyllic alteration zone with a large quantity of Al-OH minerals will appear as a pinkish color (Fig. 4), because in the b4 band, alunite, kaolinite, and white mica minerals exhibit more reflection than in the b6 and b8 bands [19]. Band ratio methods and Crosta method were also applied in this study for the detection of the alteration zones and targeting key alteration minerals around the Jos Plateau area.

2.2 False Colour Composite

The (SWIR468) image of the Jos plateau and environs, shows a general sight of alteration. These bands are highly sensitive to lithological and alteration variations and are in a region of the electromagnetic spectrum that the eye cannot perceive. This is therefore the recommended image for geological/alteration interpretation. Based on this image, magenta tones represent hydrothermal and propilitic alterations respectively (Fig. 4).

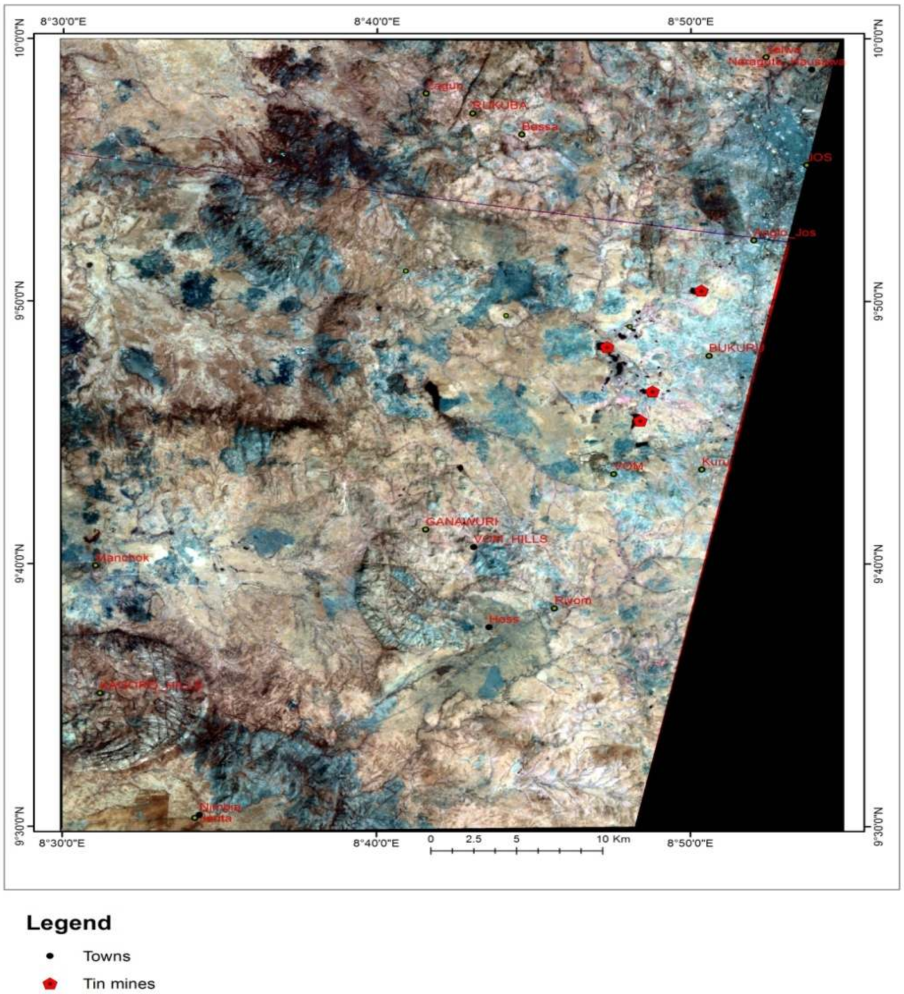

Fig. 4. 4,6,8, ASTER false colour composite of parts of Jos Plateau and environs

2.3 Band Ratio and Band Combination

Band ratioing is a very effective technique in mapping mineral assemblages and hydrothermal alteration, this technique combines different wavelengths in the different representative bands simultaneously, this simple procedure, reveals very useful information. Ratio images were prepared for identification and classification of hydrothermal alteration zones in the study area, the ratio images were created by dividing the Digital Number (DN) in one band by the corresponding DN in another band for each pixel. The image shown in Fig. 5 is a compound band ratio of RGB (2/1, 4/9, 3/2) [20], where the bright yellow color represents the presence of hydrothermal alteration in the study area see (Fig. 5).

2.4 Crosta Method

The principal component transformation is a multivariate statistical technique that selects uncorrelated linear combinations (eigenvector loadings) of variables in such a way that each successively extracted linear combination or principal component (PC) has a smaller variance [21]. The main aim of PC analysis is to remove redundancy in multispectral data. Principal component analysis is widely used for mapping of alteration in metallogenic provinces [22-25]. Crosta technique is also known as feature oriented principal component selection. Through the analysis of the eigenvector values it allows identification of the principal components that contain spectral information about specific minerals, as well as the contribution of each of the original bands to the components in relation

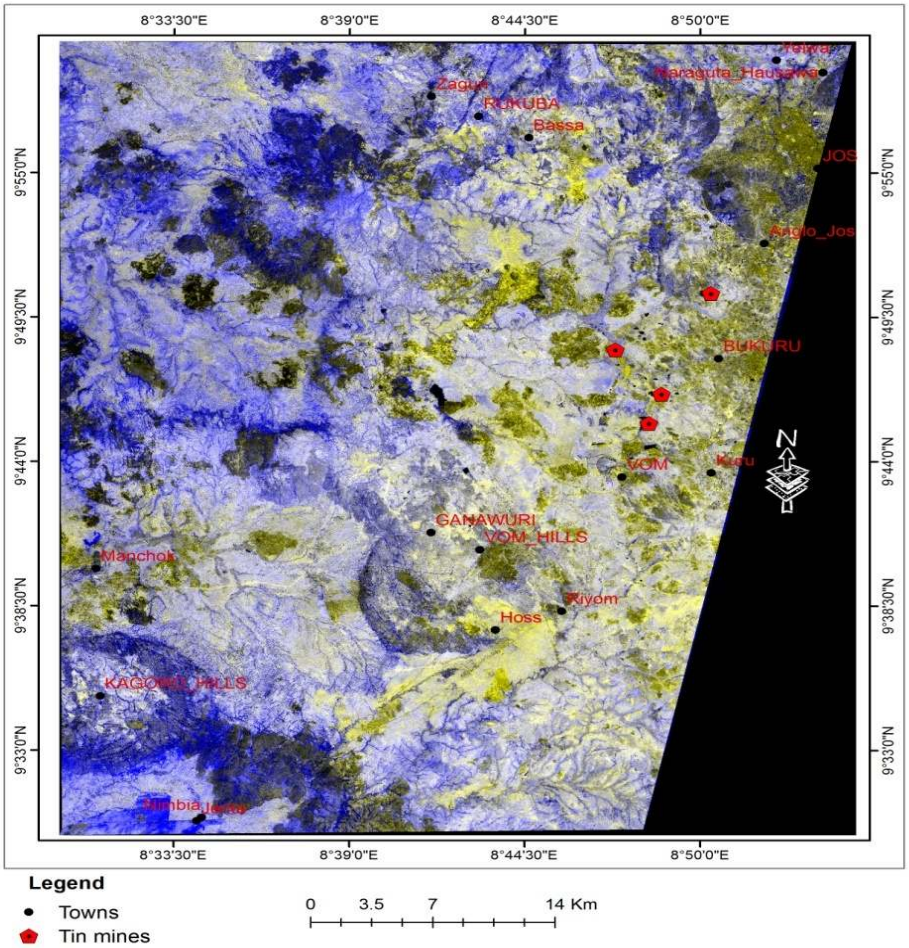

Fig. 5. Red-Green-Blues color composite of Ratio 2/1, 4/9, 3/2. Yellow color showing the Hydrothermal Regions

to the spectral response of the materials of interest. According to present experiences and previous studies and also geological structure of region, appropriate bands for PCA analysis can be recognized. For example, following band compositions can be used as a good material in Crosta method for discriminating phyllosilicates which are the main features of alteration. Alunite (bands 1, 3, 5, and 7), Illite (bands 1, 3, 5, and 6), Kaolinte and Smektit (bands 1, 4, 6, and 9), Kaolinte (bands 1, 4, 6, and 7) [3]. Bands 1, 4, 6 and 7, were selected for Kaolinite because it has highest reflectance values in bands 4 and 7 and high absorbs in bands 1and 6 [19] (Fig. 8).

3. RESULTS

PCA was applied to subsets of four ASTER bands, using an adaptation of the Crosta technique proposed by Loughlin [23]. The subsets were selected according to the position of characteristic spectral features of key alteration mineral endmembers (Table 3), in the VNIR and SWIR portions of the spectrum. After applying PCA, the eigenvector matrix used to calculate PCA for each subset was examined, to identify which PC contained the target (mineral) information. The criterion for the identification is the same proposed by Laughlin [23,26-33],: The PC that contains the target spectral information shows the highest eigenvector loadings from the ASTER bands, coinciding whit the target's most features, but with opposite signs (+ or -) [3]. For mapping Hydrothermal alteration zones, first determined zones include iron oxide and hydroxyl minerals by PCA methods. For recording Iron oxides bearing and hydroxyl bearing minerals in Jos Plateau region by Crosta method, bands 1, 2, 3, 4 (Fig. 6) and 1, 3, 4, 6 (Fig. 7) have been used. Tables 1 and 2 show the results of Principal Component Analysis for recording Iron oxide bearing minerals and hydroxyl bearing minerals respectively with the mentioned bands.

The eigenvector values for Table 1 shows that band 1 has the highest values in the matrix, therefore displays the highest index for the mineral under investigation.

Table 1. Results of principal component analysis of bands sets, comprising 1, 2, 3 and 4

Eigenvector	Band 1	Band 2	Band 3	Band 4
Band 1	0.383068	0.481672	0.788179	0.005007
Band 2	0.378438	0.696545	-0.609597	-0.000370
Band 3	-0.842637	0.531802	0.084546	-0.000681
Band 4	-0.002352	-0.001792	-0.004115	0.999987

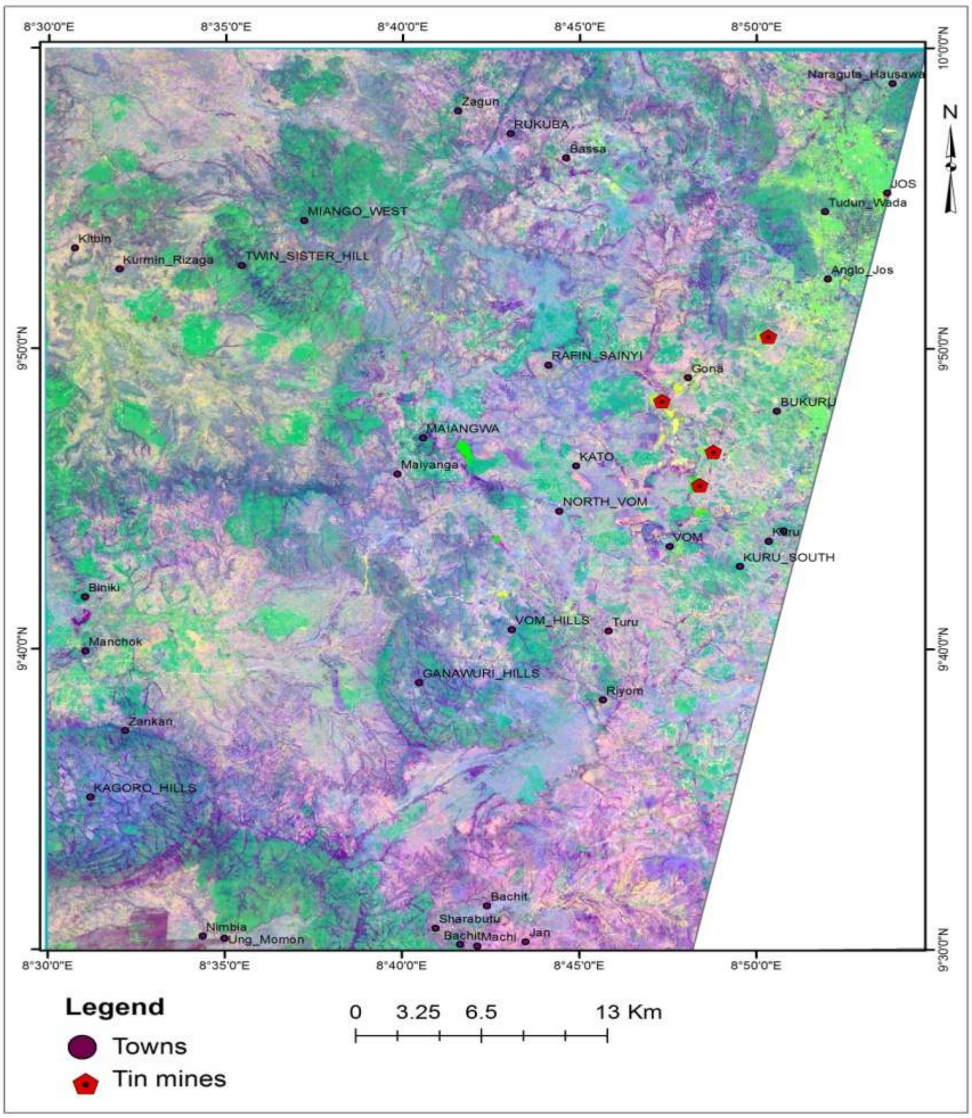

Fig. 6. Image of PC4 (1, 2, 3, 4) where greenish yellow pixels are related to iron oxide bearing minerals in Jos plateau area

Table 2. Results of principal component analysis of bands sets, comprising 1, 3, 4 and 6

Eigenvector	Band 1	Band 3	Band 4	Band 6	Eigenvalue
Band 1	0.343626	0.706767	0.004582	0.618369	0.019898
Band 3	0.002862	0.657688	-0.002119	-0.753282	0.000485
Band 4	0.939101	-0.260614	-0.003062	-0.223964	0.000117
Band 6	-0.001307	0.002643	-0.999983	0.005115	0.000000

Table 3. Alteration minerals and their respective ASTER bands

Alunite	Ilite	Kaolinite
1	1	1
3	3	4
5	5	6
7	6	7

Table 2 above shows the result of principal component analysis of bands 1, 3, 4, 6 showing hydroxyl bearing minerals respectively with the mentioned bands, band 1 has the highest eigenvector load, see Fig. 7.

The Table 3 shows the common alteration minerals and their respective band combinations in a principal component analysis.

3.1 Kaolinite

Recording Kaolinit for detection of advanced Argillic alteration in the study area is important. For this comprising bands 1, 4, 6 and 7 have been processed by Crosta method (Fig. 8). Table 4 shows principal component analysis results for recording kaolinite by applying band set, comprising bands 1, 4, 6 and 7. The fourth

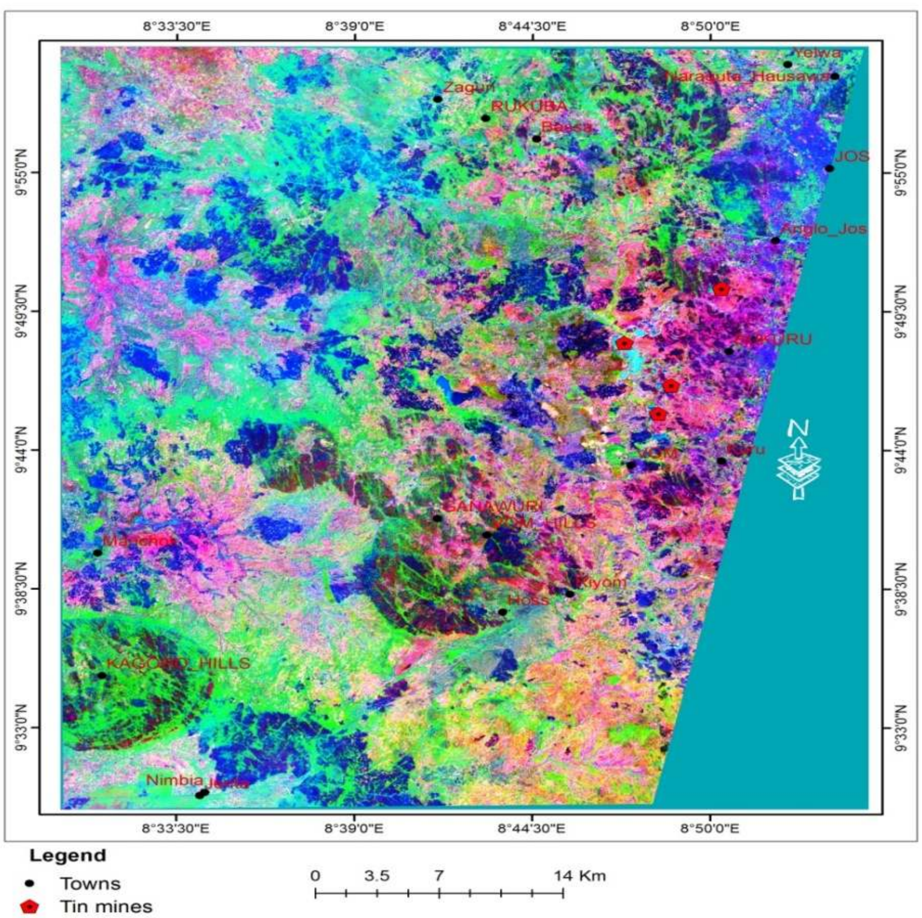

Fig. 7. Image of PC4 (1, 3, 4, 6) that green pixels are related to hydroxile bearing minerals in Jos plateau area

component has been chosen due to maximum difference between bands 6 and 7 in Table 4. Maroon color in Fig. 8 showing regions with abundance of kaolinite [3].

The Table 4 shows principal component analysis results for recording kaolinite by applying principal component analysis on band set comprising bands 1, 4, 6 and 7.

Table 4. Results of principal component analysis of comprising bands 1, 4, 6 and7

Eigenvector	Band 1	Band 4	Band 6	Band 7	Eigenvalue
Band 1	-0.357745	-0.004814	-0.662132	-0.658465	0.017917
Band 4	-0.933641	-0.000807	0.239987	0.265930	0.000184
Band 6	0.018070	-0.004808	-0.709891	0.704063	0.000047
Band 7	0.002388	-0.999977	0.006407	-0.000430	0.000000

Table 5. Results of principal component analysis of bands sets, comprising 1, 3, 5 and 7

Eigenvector	Band 1	Band 3	Band 5	Band 7	Eigenvalue
Band 1	0.292554	0.597196	0.528552	0.527638	0.027335
Band 3	0.109768	0.753219	-0.410874	-0.501791	0.000704
Band 5	0.942984	-0.262825	-0.203028	-0.021994	0.000118
Band 7	-0.114648	0.083313	-0.714559	0.685070	0.000036

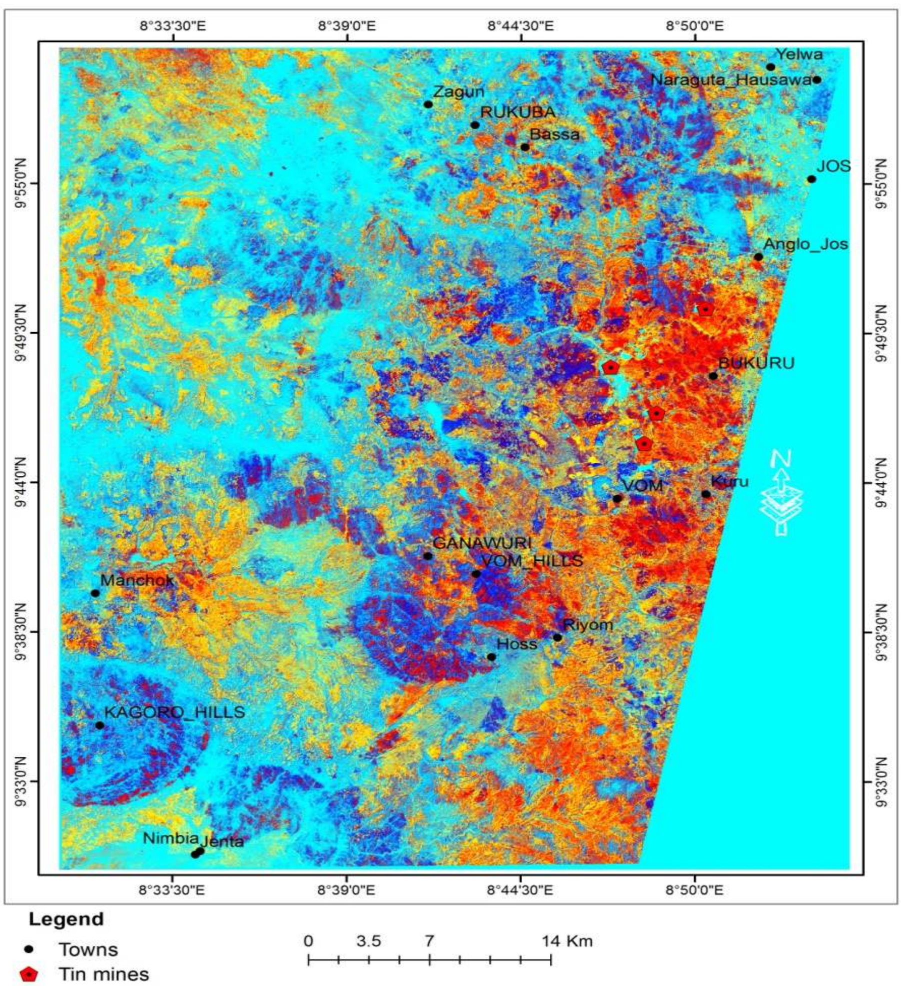

Fig. 8. PCA 1, 4, 6 and 7

3.2 Alunite

For recognition of alunite which is the index mineral of alunitization alteration, bands 1, 3, 5 and7 have been chosen to take part in principal component analysis. Table 5 showing principal component analysis for the mentioned bands set. The bands 5 and 7 has been selected for the maximum reflectance of Alunite in the band 7 and minimum reflectance in the band 5 that the most difference in the PC4 has been seen. Because of negative and high loading of PC4 from band 7, PC4 image is negated (by multiplying all pixels by -1) so that target material is displayed as purple color in the respective abundance image (Fig. 9) [3].

3.3 Illite

Illite is one of the important Argillic alteration minerals, for recording this mineral, we applied Croasta method by using the bands 1, 3, 5 and 6, in the resulting PCA image, illite is displayed in bright green pixels since it has the highest reflectance in this PCA combination (Fig. 10). Table 6 shows the results of eigenvector loading of principal component analysis of bands sets, comprising 1, 3, 5 and 6.

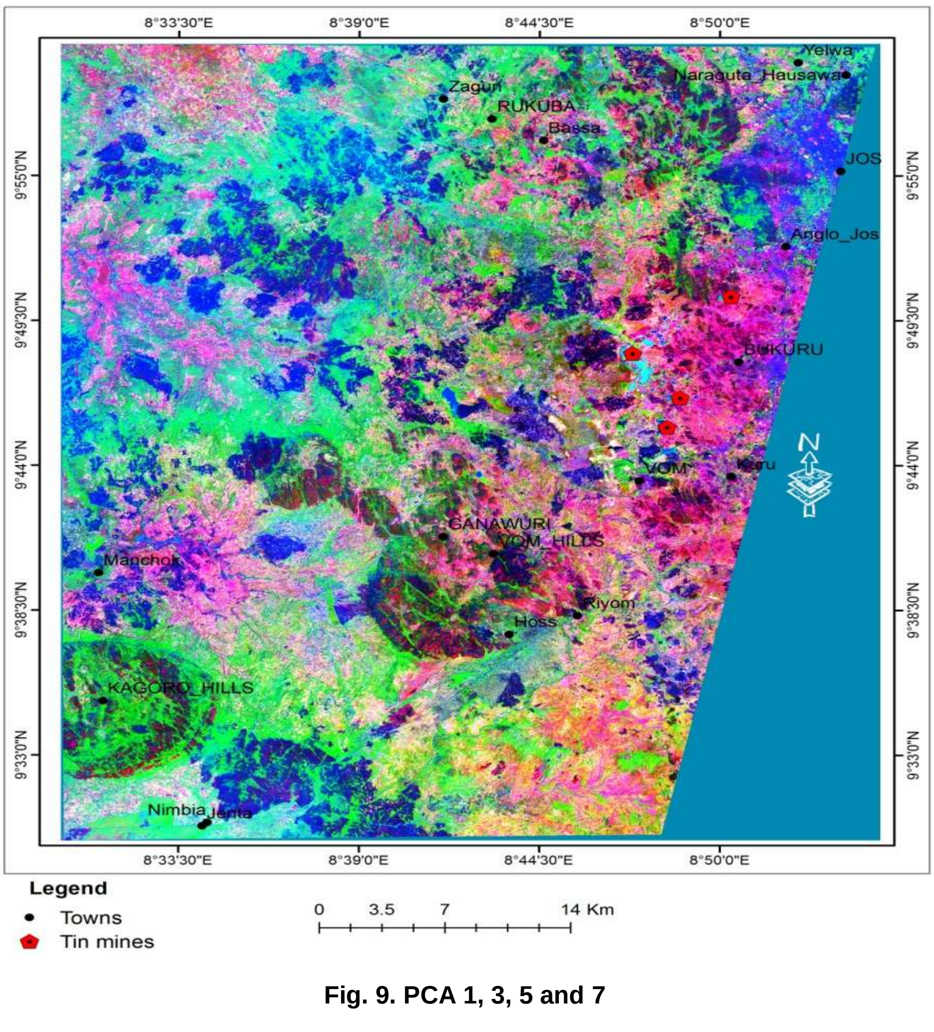

Fig. 9. PCA 1, 3, 5 and 7

Table 6. results of principal component analysis of bands sets, comprising 1,3,5 and 6

Eigenvector	Band 1	Band 3	Band 5	Band 6	Eigenvalue
Band 1	0.499068	0.496580	0.502288	0.502042	3.880710
Band 3	0.381696	0.609727	-0.484258	-0.498032	0.078486
Band 5	-0.777971	0.617695	0.085376	0.076969	0.036354
Band 6	-0.000820	0.009698	-0.711275	0.702847	0.004450

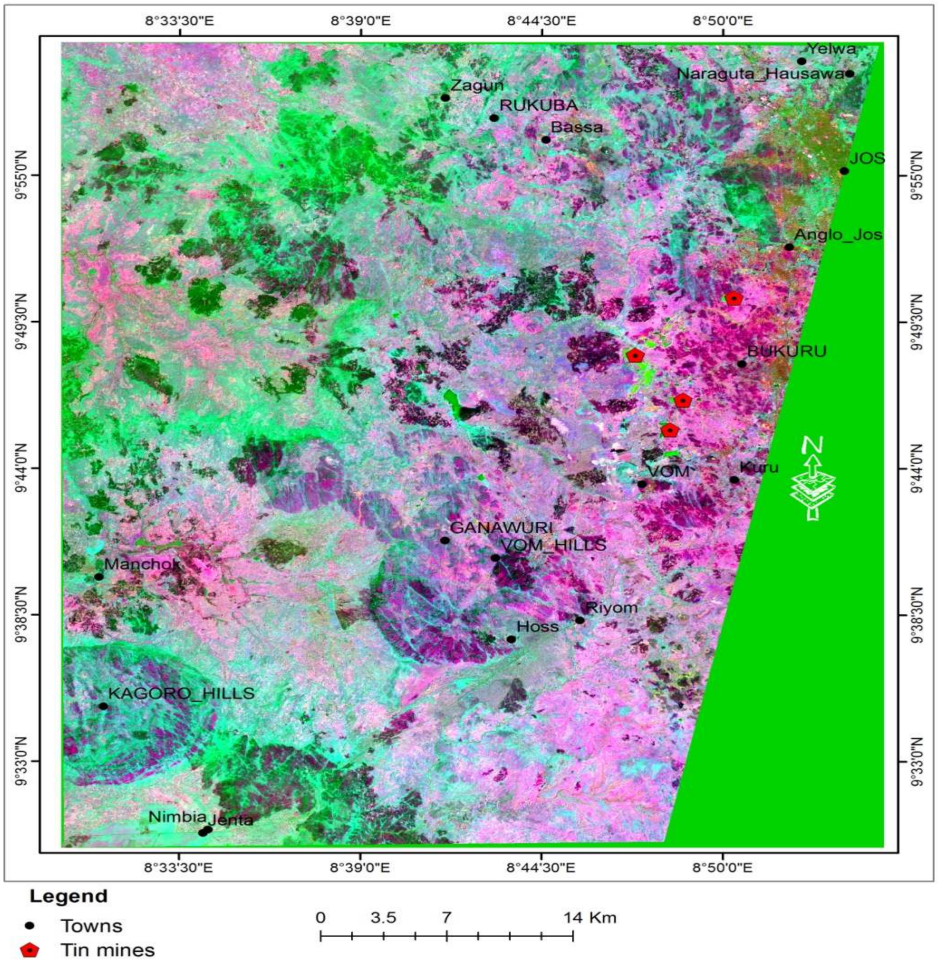

Fig. 10. PCA 1, 3, 5 and 6

The Table 6 shows the results of eigenvector loading of principal component analysis of bands sets, comprising 1, 3, 5 and 6.

4. CONCLUSION

Analysis of ASTER spectral reflectance data of parts of Jos Plateau and environs that was used for the research, gave a promising insight to the hydrothermally altered region of the study area and their mineral abundance. In this study carried out on the Tin rich younger granite complexes of parts of Jos Plateau, Kaolinite, Alunite Biotite Muscovite and Illite which are alteration index minerals where identified using ASTER data. The Tin mineralization in the study area is mainly within the biotite granites, which are seen to be associated with hydrothermal alteration zones in the study area. Results obtained from the study proved that PCA technique is a simple and fast method, and when applied on ASTER data can extract subtle mineralogy information in areas. The information generated from this research can be useful in exploration of Tin mineralization and other minerals associated with hydrothermal systems in parts of Jos Plateau and environs. Other methods that were used in this research such as band ratio and false color composite can also be used to improve accuracy of study and give a general view of mineral abundance of the areas. At the end of this study, the findings were checked with GPS points of known Tin mines which were laid over the final maps to check with the outputs from the Crosta techniques and band ratios, this showed good correlation between Tin occurrence and the highly altered region of the study area. These areas coincide with the regions of the Biotite and Muscovite Granites of the region, from the geology of the study area, the mineral assemblages can be compared to the pattern seen in Fig. 1.

The research effort has produced fairly reliable and accurate results and can therefore, be recommended for mineral exploration. However, it is important to note that spectral remote sensing is only one tool among many available to the explorer to target mineral deposits. Information from remote sensing must be integrated with all other available data such as geological, geophysical, geochemical, and radar, and interpreted within the context of a geologic model.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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