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Alteration mineral mapping using ETM+ and hyperion remote sensing data at Bau Gold Field, Sarawak, Malaysia

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Abstract. The area under investigation is the Bau gold mining district in the State of Sarawak, East Malaysia, on the island of Borneo. It has tropical climate with limited bedrock exposures. Bau is a gold field similar to Carlin style gold deposits. Geological analyses coupled with remote sensing data were used to detect hydrothermally altered rocks associated with gold mineralization. The Landsat Enhanced Thematic Mapper$^+$ (ETM$^+$) and Hyperion data were used to carry out mineral mapping of mineralized zones in the study area and surrounding terrain. Directed Principal Components Analysis (DPCA) transformation of four appropriate ETM+ band ratios were applied to produce DPC images, allowing the removal of the effects of vegetation from ETM+ data and the detection of separate mineral images at a regional scale. Linear Spectral Unmixing (LSU) was used to produce image maps of hydroxyl-bearing minerals using Hyperion data at a district scale. Results derived from the visible and near infrared and shortwave infrared bands of Hyperion represented iron oxide/hydroxide and clay minerals rich zones associated with the known gold prospects in the Bau district. The results show that the known gold prospects and potentially interesting areas are recognizable by the methods used, despite limited bedrock exposure in this region and the constraints imposed by the tropical environment. The approach used in this study can be more broadly applicable to provide an opportunity for detecting potentially interesting areas of gold mineralization using the ETM$^+$ and Hyperion data in the tropical/sub-tropical regions.

1. Introduction

In this study, the possibility of identifying hydrothermally altered rocks, faults and fractures associated with hydrothermal ore mineralization in the tropical environments is examined using the Landsat Enhanced Thematic Mapper $^+$ (ETM) and the Hyperion remote sensing data. Bau is a gold field with Carlin style gold deposits [1, 2]. Bau gold mining district in Sarawak province, eastern Malaysia, on the island of Borneo in Southeast Asia has been selected (Fig. 1). It is located between 1° 25′ N in longitude and 110° 10′ E in latitude in 25 km southwest of Kuching city, Sarawak. The climate of Bau is characterized by heavy but seasonal rainfall, uniform temperature, and high humidity.

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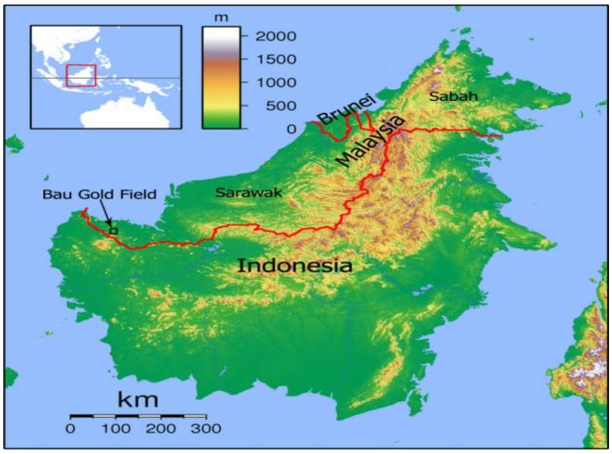


Figure 1. Location of the study area in Southeast Asia. The Bau gold mining district is on westernmost Borneo. It is located on the state of Sarawak which is part of Malaysia.

Gold was first discovered in the Bau gold field area in the 1870s, but there was very little production until 1909, and only about 22,000 ounces was produced through 1964. However, by 2008, mines in the Carlin Trend had produced over 70 million ounces of gold. To date, remote sensing study is not carried out in the Bau mining district to identify hydrothermally altered rocks and structure elements associated with ore mineralization for exploring potentially interesting areas of Carlin style gold mineralization. Therefore, this investigation attempted to acquire comprehensive and accurate information for exploring potentially interesting areas of gold mineralization using the integration of the ETM^+ and Hyperion remote sensing data.

2. Materials

Landsat Enhanced Thematic $Mapper^+$ (ETM^+) and the Hyperion data were used in this investigation. It was acquired during dry season with 5% cloud coverage on August 3, 1998 for the Bau mining district and surrounding areas. Hyperion scene was also obtained during dry season on August 28, 2004 for the Bau mining district. The images were pre-georeferenced to UTM zone 40 North projection using the WGS-84 datum.

3. Methods

Atmospheric correction was applied to ETM^+ and Hyperion data. The ETM^+ data were converted to reflectance using the Internal Average Relative Reflection (IARR) method. This algorithm is recommended for mineralogical mapping as a preferred calibration technique, which it does not necessitate to have the prior knowledge of samples that collected from the field. Desteriping of the Hyperion Level 1B data was accomplished before atmospheric correction. To correct the atmospheric effects, Atmospheric CORrection Now (ACORN) software was used to retrieve the surface reflectance [3].

To suppress and separate the erroneous effects of vegetation in hydrothermal alteration mapping and unveiling the lithology of the tropical terrain the principal components analysis (PCA) [4] was implemented on specific spectral indices of ETM^+ data. Vegetation index (band ratio of 4/3), clay minerals index (band ratio of 5/7), ferric iron oxide index (band ratio of 3/1), and ferrous iron oxide index (band ratio of 5/4) were used to generate PCA image components. The image eigenvectors and eigenvalues were obtained from PCA using covariance matrix on indices.

Linear spectral unmixing was applied on VNIR and SWIR bands of Hyperion for mapping iron oxide/hydroxide minerals and clay mineral assemblages associated with gold mineralization at district scale. This technique also known as sub-pixel sampling, or spectral mixture analysis, is a widely used procedure to determine the proportion of constituent materials within a pixel based on the materials' spectral characteristics [5].

4. Results and discussion

After analyzing the results of principal component analysis transformation for specific spectral indices of ETM^+ data, considering magnitude and sign of the eigenvector loadings and percentage of eigenvalues for selected spatial subset scene covering the Bau gold mining district, it is realized that the first principal component (PC1) accounts 81.23 percent of total eigenvalue, which is higher value among the PCA images in the scene. A PCA image with higher eigenvalue contains most of the spectral information in the scene. All of the eigenvector loadings for the PC1 are positive, thus the differentiation between materials (vegetation and alteration minerals) using the specific spectral indices in the PC1 image is unattainable [6,7].

Eigenvector loadings for the PC2 indicate that PC2 image has highest value of vegetation variations, which is statistically dominant in the image due to the high positive contribution from the vegetation index (0.730) and negative contribution for the specific hydrothermal mineral indices. The existence of vegetation within a pixel can reduce the 2.20 μm absorption depth related to AlOH/MgOH-content [6, 7].

PC3 image manifests desired information related to Al (OH)-bearing (clay) minerals with very squat disturbance of vegetation due to very low negative (contribution) eigenvector loadings for the vegetation index (-0.097) and very strong positive eigenvector loadings for the clay mineral index (0.870). Eigenvector loadings for ferric iron oxide index (3/1) and ferrous iron oxide index (5/4) are (-0.329) and (-0.352), respectively. Hence, the contribution of iron oxide minerals in the extracted spectral information from the PC3 image is very low.

Figure 2 indicates selected spatial subset scene covering the Bau gold mining district and surrounding terrains, hydrothermally altered rocks are especially marked in the scene by red color.

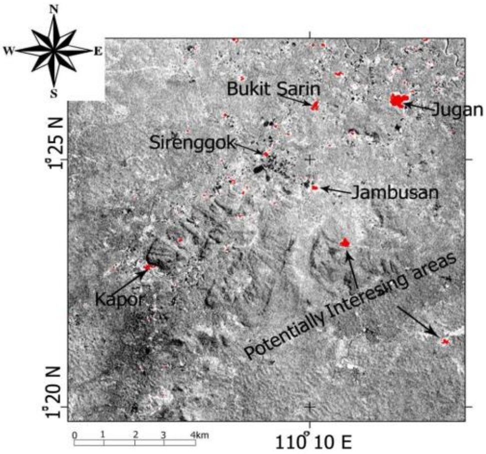


Figure 2. Selected spatial subset scene covering the Bau gold mining district and surrounding terrains, hydrothermally altered rocks (clay minerals) are indicated as red color.

It is evident that iron oxide minerals can be distinguished in the PC4 image (Fig 3).

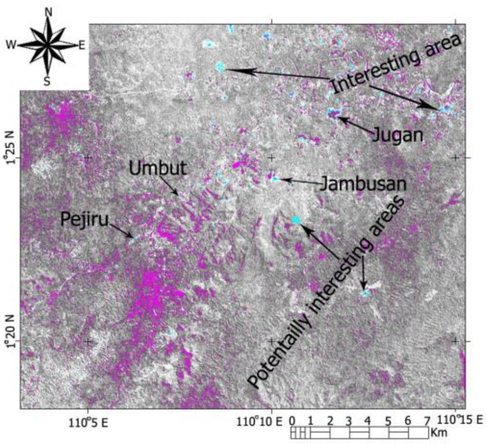
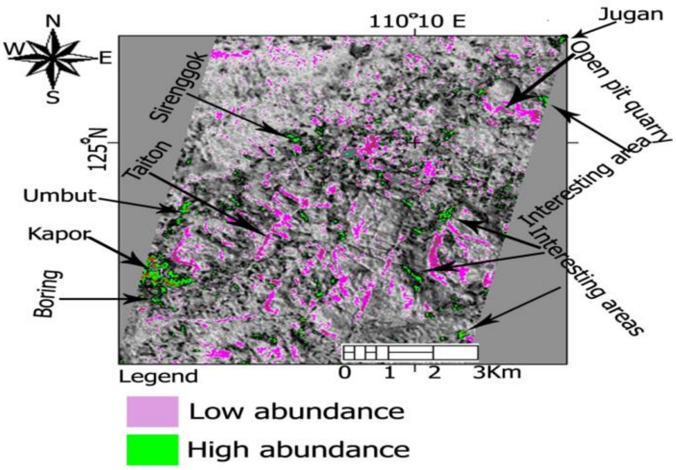


Figure 3. Selected spatial subset scene covering the Bau gold mining district and surrounding terrains, iron oxide minerals are indicated as blue (iron rich) and purple (iron fair) colors.

The linear spectral unmixing technique was applied to the selected spatial subset scene of the Hyperion covering the Bau gold mining district for detailed hydrothermal alteration mapping at district scale. Figure 4 shows image map of the selected spatial subset scene for first subset (VNIR), showing spectrally predominant iron oxide minerals as colored pixels that are overlaid on the gray-scale image background of Hyperion band 36. The abundance of iron oxide minerals is represented as green (high abundance) and purple pixels (low abundance) in the Bau subset scene (Fig. 4). Iron oxide concentrations are obviously associated with lineament structures and as well as known prospects in the Bau area. Figure 5 shows image map of the selected spatial subset scene for second subset (SWIR). Kaolinite-sericite abundance is illustrated as red (high abundance) and yellow (low abundance) pixels that are overlaid on the gray-scale image background of Hyperion band 205.



Figures 4. Image map of VNIR bands of Hyperion shows the abundance of iron oxide minerals in Bau gold mining district.

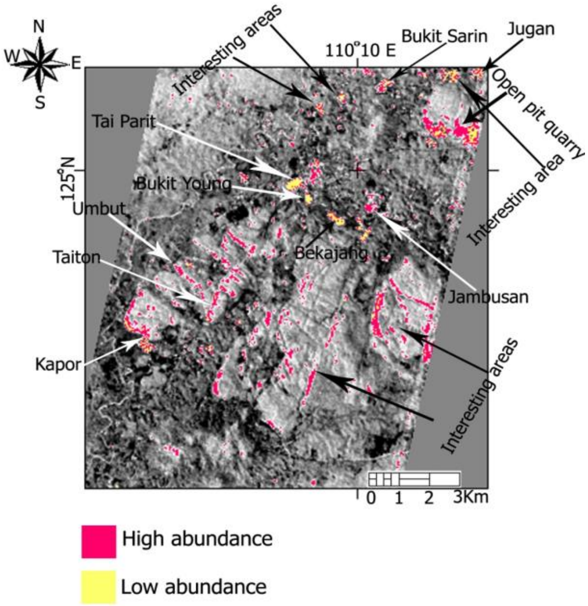


Figure 5. Image map of SWIR bands of Hyperion shows the abundance of clay minerals in Bau gold mining district.

5. Conclusions

The results presented in this study demonstrate the importance and advantages of the combined use of ETM^+ and the Hyperion remote sensing data in detecting potentially interesting areas of Carlin style gold mineralization in tropical/sub-tropical regions. Structurally controlled gold mineralization indicators, including iron oxides, clay minerals and faults and fractures in the Bau gold mining district have been detected using the remote sensing satellite data and the approach used in this investigation.

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