Alteration mineral mapping to identify primary tin potential using Landsat 8 images and geographic information system in Rimba Kulit Area, Southern of Bangka Island

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Abstract. Remote sensing data has been proven to provide geographic information such as geographic structures, land covers, lithologies and hydrothermal alteration minerals, as shown in previous researches. Nonetheless, in this research, Landsat 8 images as one of remote sensing images are utilized in hydrothermal alteration mineral mapping to identify primary tin which is located in Gadung village, Toboali sub-district, South Bangka District. This research is intended to identify the distribution of primary tin based on types and alteration mineralogy in the research area by using Landsat 8 images. Accordingly, the method employed in this research is defoliant method for each mineral: 4/3;2/1 band ratio for quartz identification, 4/3;6/5 band ratio for illite identification, 4/2;7/6 band ratio for chlorite identification, and 4/3;7/6 band ratio for iron oxide. Further, the observations of morphology, lithology and geological structures used 5/4;6/3;4/2 and 5/3;6/4;5/4 composite image combinations. Moreover, petrography, X-Ray Diffraction (XRD) and XRF analyses served as confirmation for the result of image interpretation. The composing lithology of the research area is generally composed of sandstone units, whereas alteration which develops is predominantly dominated by clay alteration (illite mineral) and sulphide dominance in hydrothermal solution. The primary tin mineralization developed in the research area is classified as oxide mineral characterized by the presence of wolframite, pyrite, arsenopyrite, and cassiterite, and deposited in big polymetallic veins, as well as allegedly influenced by NNW-SSE-trending main geological structure and associated to iron oxide mineral in form of goethite and hematite. Meanwhile, the type of tin mineralization developed in the research area in form of mineralization in ironstone or gossan units is the result of supergene process carried by cassiterite which associated with iron oxide minerals.

Keywords: Gadung village, polymetallic veins, primary tin gossan, Rimba Kulit location.

1. Introduction

The application of remote sensing technologies in geologic field has undergone a significant advancement, as a lot of geologists use remote sensing data to study geologic structures, lithologic boundaries, geohazard and mitigation identification, geomorphological processes, and landform and...
mineral exploration (Ali et al., 2012; Mshiu, 2011; Mulder et al., 2011; Rouskov et al., 2005; Tofani 2013; van der Meer et al., 2012, in [1]).

In remote sensing field, Landsat 8 satellite, one of natural resource satellites, is developed by the United States of America and launched on 11 February 2013 to refine the previous version (Landsat 7) by increasing the number of the channels, the lowest electromagnetic wave spectrum range that can be detected by the sensor and having the range of scan area of 170 km x 183 km. In the application of primary tin identification, Landsat 8 data is able to provide the data in the form of alteration mineral anomalies which is related to primary tin mineralization. Even though hydrothermally altered rocks have different mineralogy and spectrum compared to unaltered rocks, sometimes some rocks have spectrum similarities, and as the result, some mineralization identifications are not valid. In many cases, an interpreter of remote sensing data must rely on indirect clues, such as alteration zones, rocks, geologic structures, lineaments, oxide mineral, morphology, drainage, and related vegetation anomalies, because it is very rarely that primary tin mineralization can be directly identified only based on remote sensing data. In order to help the interpretation and analysis of Landsat 8 data in its relation to the primary tin mineralization, the group of alteration mineral in the research area has been mapped in four groups, namely:

1. Iron oxide (hematite, goethite, and jarosite)
2. Hydroxyl minerals (clay, mica, etc)
3. Chlorite
4. Silicification

In this perspective, Landsat 8 multispectral sensor is expected to give clues which are related to primary tin mineralization as well as be integrated into exploration models based on Geographic Information System (GIS) ([2]).

Hydrothermal alteration is a process where structure and mineral composition of rocks are changed because of heat circulation which mostly consists of water. This hydrothermal fluid also causes the concentration of certain elements, often form hydrothermal mineral deposit which is rich in mineral deposit. Alteration mineral mapping using remote sensing method is one of important geologic mapping activities, despite the fact that the use of remote sensing images cannot replace direct field observation or data taken from field survey and laboratory. However, these images can become valuable additional/complementary data for a more traditional methods and provide information that do not exist. From the technical side, remote sensing data have limitation in mineral exploration i.e. depth aspect, which the penetration reaches a couple of micrometer in near-infrared area up to a couple of centimeter in thermal infrared and several meters in microwave.

2. Literature Review

2.1. Landsat 8 images

Landsat 8 is an American-owned program which is built with the objective to continue and refine Landsat 7 launched on 11 February 2013. The characteristics of Landsat 8 are not much different than Landsat 7 (Figure 1), whether its resolutions (spatial, temporal, and spectral), correction method, flight altitude, or its sensor characteristic. However, there are only several additions as the perfecting points of Landsat 7 such as the number of channels, the lowest electromagnetic wave spectrum range that can be captured by the sensor and bit value (Digital Number value range) of each image pixel. As published by USGS, Landsat 8 satellite flies at 705 km above surface and has scan area of 170 km x 183 km.
2.2. Hydrothermal alteration mapping

The success key of Landsat data application to map the altered rock is Landsat images that has multiespectral to distinguish the earth surface objects. However, recently, the researchers from various fields including earth scientists use Landsat image data to map alteration mineral related to mineralization, as done by [4] who used 5/7:3/1:3/4 (RGB) TM wave ratio as a 5/7 TM ratio which resulted a satisfying value in delineating hydroxyl-bearing minerals, sulphate hydrate, and carbonate, 3/1 TM is used for limonite, using a combination with 3/4 TM to delineate vegetation. Further, [5] developed hydrothermal alteration identification method in densely-vegetated area and used Directed Principal Component Analysis (DPCA) [6]. [5] suggest using transformation principal component (PC) algorithm to 5/7 and 4/3 ratio wave; 5/7 is considered as the most effective wave ratio for alteration in arid and semi-arid environment, and 4/3 wave ratio is used as the image of vegetation. First PC contains contribution of dominant plants in both ratios; second PC contains contribution of altered minerals.

2.3. Image quality enhancing process

Image quality enhancing process is done after the geometric and radiometric corrections have been done to the raw images. As the type of image quality enhancing process, this research employed in band ratio method, showing the ability of band ratio method to enhance the spectrum response of different mineral and rocks ([7]; [8]; [9]; [10]). The followings are some of band ratios from Landsat image which are used by [11] in mapping the mineral as shown in Table 1.

| Alteration Mineral Mapping | Band ratio |
|---------------------------|------------|
| Quartz                    | 2/3 ; 7/1  |
| Alunite                   | 2/3 ; 5/1  |
| Illite                    | 4/2 ; 7/1  |
| Chlorite                  | 4/2 ; 5/1  |
| Epidote                   | 4/1 ; 5/7  |
| Limonite                  | 2/3 ; 5/7  |
It is suggested that band ratio of Landsat TM image for mineral mapping is 5/7 : 3/1 : 3/4 (RGB), where 5/7 band ratio yields a satisfying value in delineating hydroxyl-bearing mineral, sulphate hydrate and carbonate, 3/1 band ratio is used for limonite, while 3/4 band ratio delineates vegetation. [12] use 5/7 Landsat image band ratio to identify clay mineral, 5/4 band ratio for ferrous minerals (Fe^{2+}), and 3/1 band ratio for iron oxide.

3. Research Area
The research area is located in the administration of South Bangka Regency, Bangka Belitung Island Province with the area approximately 117.92 Km². The location can be accessed by using vehicles, with a distance of 138 Km from the center of province capital (Pangkalpinang) as shown in Figure 2, and it is a part of Tanjung Genting Formation and Granite Klabat Formation (Figure 3).
3.1. Geomorphology
Based on the analysis of topographic map (contour pattern and slope slant), Landsat 8 images as well as from the observation of morphological change, the geomorphological units of research area are grouped into denudational hill, fluvial plain and marine units (Figure 4).

3.1.1. Denudational hill units
Denudation hill units include strong eroded hills and weakly eroded hills. It has a relatively moderate slope slant (flat to hilly), i.e. around 2-20% with elevation around 25-140 m above the sea level (dpl). It is marked by the existence of contours with medium density, which represents relatively low hill elevation and the presence of big hills portrays morphological lineament because of the working endogenic process.

3.1.2. Fluvial plain units
The distribution of fluvial plains includes alluvial plains, having low elevation (0-2%), which is formed on elongated valleys due to the working geological structures.

3.1.3. Marine units
The distribution of marine units includes coastal alluvial plain which have slope slant between 3-7% with wavy relief.

4. Research Method
The images used in this research is Landsat 8 image based on the recording result on 23 September 2015. On this date, the cloud cover is 15.03% (based on information on metadata) which is above the recommended limit of 10%, however the research area is cloud free hence these images is feasible to be used. Landsat 8 images which is used is situated in screen number (column/row) 132/62 and 131/62 in Landsat 8 index data ([13]). Several processes of digital image processing are required in order to be used for interpreting and analyzing. Based on [14], digital image processing can be grouped into several stages; image restoration stage including geometric and radiometric refinement of the raw images, enhancement and sharpening of the corrected images, and lastly mosaic and cropping stage as well as making image combinations to improve the information that is needed.
4.1. Pre-processing
Geometry correction of 23 September 2015 recording Landsat 8 images does not need to be done again, because based on information from metadata it is 1T Level, meanwhile radiometric correction uses ToA correction which includes reflectance ToA and sun correction. Reflectance ToA correction is done by converting DN value to reflectance value. In this research, gain and offset values are acquired through satellite image metadata and conversion is done by using equation released by official web page of Landsat satellite images as follows:

Correction at Sensor Radiance

$$L_\lambda = M_L \cdot Q_{cal} + A_L$$  \hspace{1cm} (1)

Where:

- $L_\lambda$ = ToA radiance (Watt/m$^2$ x s rad x $\mu$m)
- $M_L$ = Gain sensor (radiance_multi_band_x, where x is the band number (taken from Landsat 8 metadata))
- $A_L$ = Offset sensor (radiance_add_band_x, where is is the band number (taken from Landsat 8 metadata))
- $Q_{cal}$ = Digital Number (DN) Value on the images

Correction at Sensor Reflectance

$$\rho_{\lambda'} = M_{\rho} \cdot Q_{cal} + A_{\rho}$$  \hspace{1cm} (2)

Where:

- $\rho_{\lambda'}$ = ToA reflectance, without correction for the sun angle
- $M_{\rho}$ = gain sensor (reflectance_multi_band_x, where x is the band number (taken from Landsat 8 metadata))
- $A_{\rho}$ = Offset sensor (reflectance_add_Band_x, where x is the band number (taken from Landsat 8 metadata))
- $Q_{cal}$ = Digital Number (DN) value on the image

TOA Reflectance with a Correction for the Sun Angle

$$\rho_\lambda = \frac{\rho_{\lambda'}}{\cos(\theta_{SE})} = \frac{\rho_{\lambda'}}{\sin(\theta_{SZ})}$$  \hspace{1cm} (3)

Where:

- $\rho_\lambda$ = ToA reflectance
- $\theta_{SE}$ = sun elevation (taken from metadata of the correction result at sensor reflectance for each band)
- $\theta_{SZ}$ = sun zenith angle; $\theta_{SZ} = 90^\circ - \theta_{SE}$

Atmospheric correction

Corrected DN = original-bias DN

5. Tools And Materials
The requirements during this research are divided into tools and material used during data collection, data processing and data analysis. Tools and materials used in this research are:
- GPS (Global Positioning System) navigation to determine the absolute coordinate in the field.
- Digital camera for documenting field data.
- Field notebook for noting down all field data
- Three scenes of Landsat 8 Images covering Bangka Island and be downloaded at [15] (path 124, Row 61; path 123, Row 61 dan Path 123 Row 62), recording on 23 September 2015.
- SRTM images (Shuttle Radar Topography Mission) 1 arc second 30 m covering Bangka Island and be downloaded at [16].
6. Result And Discussion

6.1. Lithologic control
Host rock in primary tin mineralization system occurred in the research area is metasedimentary rocks namely sandstones of which distributions almost cover all research area. However, primary tin mineralization in the research area is only dispersed on polymetallic veins, quartz veins which contains many metal elements. Oxidation process to the polymetallic veins resulting ironstones is firstly begun with the fracture process in the rocks, then it is filled with hydrothermal fluid hence quartz veins are formed with megacrystalline size. Further, the contact between hydrothermal fluid with host rock cause the occurrence of metal mineralization including tin ores and altered minerals such as clay minerals. The next stage is the transformation of mineral with sulfide elements into oxide minerals (goethite). Source rock of igneous rock as the source rock which brings tin mineralization is found in the research area (Figure 5).

Based on thin incision and XRD analysis on the sample in the research area, these oxidation stages are characterized by the forming of secondary mineral in the form of iron oxide minerals (goethite). The existence of these iron oxide minerals are constituent minerals of polymetallic veins as well as ironstones (gossan), whereas in the field polymetallic veins in characterized by the color of black.

6.2. Geologic Structure Control
Geologic structure found in the research area is shear joints. Based on the measurement on shear joint in the research area, there are two common joint direction i.e. N 330°E/84° and N 035°E/80° (Figure 6a). After analysis, the common strike in this area is obtained i.e. North-South (Figure 6b).
Figure 6. The position of shear joint in Rimba Kulit Location (a) and The analysis of shear joint common strike in Rimba Kulit location (b).

6.3. Research area alteration
Direct field observation and sampling on several research location is done to the altered minerals which is detected from the result of defoliant method analysis. Further, the XRD and thin incision of these samples are analyzed to discover the composition of the alteration mineral. The result of XRD analysis is used to determine the threshold from each detected alteration mineral. The PCA result of some minerals in the research area is presented as follows (Table 2):

Table 2. Statistics of Principal Component Analysis (PCA) result for quartz minerals.

| PCA | Eigenvalue (%) | Eigenvector |
|-----|----------------|-------------|
|     |                |             | Mineral kuarsa (silisifikasi) |
|     |                |             | 4/3 | 2/1 |
| PC1 | 81,2936        | 0,99297     | 0,11836 |
| PC2 | 18,7064        | -0,11836    | 0,99297 |

|     |                |             | Mineral goethit |
|     |                |             | 4/3 | 7/6 |
| PC1 | 65,3895        | 0,80717     | 0,59032 |
| PC2 | 34,6105        | -0,59032    | 0,80717 |

|     |                |             | Mineral ilit |
|     |                |             | 4/3 | 6/5 |
| PC1 | 64,7171        | 0,60921     | 0,79301 |
| PC2 | 35,2829        | 0,79301     | -0,60921 |

|     |                |             | Mineral klorit |
|     |                |             | 4/2 | 7/6 |
| PC1 | 84,8695        | 0,96868     | 0,24832 |
| PC2 | 15,1305        | -0,24832    | 0,96868 |

Table 3. Raster values on rock samples representing some minerals.

| No. | Sample Analysis | Threshold value |
|-----|-----------------|-----------------|
| 1   | 14,13a,13b,8a,8b| Thin section 1,3936,3682-1,436370666 |
|     | Goethite minerals |                 |
Based on the result of XRD as well as thin section analysis shown on Table 3, silicified minerals appear in samples 14, 13a, 13b, 8a, and 8b, goethite appear on samples 7, 25 and 62, illite minerals appear on samples 20, 35A, 35B and 38, and chlorite minerals appear on sample 49.1, 49.2, 54-c1 and 54c2.

By applying the threshold from pixel and histogram values shown on Table 3 on each alteration minerals, the distribution of alteration mineral occurred in the research area is obtained as presented in Figure 7.

**Table 3**

| Sample  | Analysis Method  | Reference Range (2θ) |
|---------|------------------|----------------------|
| 2       | XRD              | illite minerals      |
| 3       | XRD              | chlorite minerals    |
| 4       | Thin section     |                      |

**Figure 7.** Distribution of alteration mineral map in the research area.

**Conclusions**

1. Lithologies bearing primary tin mineralization in the research area is sandstone units in the polymetallic veins.
2. The complex geologic structures result in alteration and mineralization processes in the research area, which are classified into silicification, ironoxide, illite and chlorite with its distributions on valleys suspected to be valleys controlled by geologic structures.
3. The origin of primary tin deposit in the research area is controlled by geologic structures with WNW-ESE strikes which is characterized by the existence of polymetallic veins carrying mineralization of cassiterite on sandstone units. Meanwhile, mineralization on ironstones or gossans occurred as the result of oxidation process in those polymetallic veins. These oxidation processes are supergene processes happened on the surface of ground water level. In this stage, iron sulfide minerals will be oxidized and it will form iron layers composed over the goethite minerals.
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