Hydrothermal Alteration Mapping, Using the Crosta Technique: Case Study of the Kibi Goldfields Osino Concession, Ghana

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Abstract:
The interaction between high and low-temperature mineralisation fluids during mineral deposition creates signature features which serve as clues during mineral exploration. The results of these interactions are known as hydrothermal alteration and maybe in few centimetres or large kilometres wide, which are used in eliminating barren zones from mineralised ones. Hydrothermal alterations are in different forms with different characteristic mineralogical composition, whose response to electromagnetic waves can be used in deciphering them. This research made use of the Crosta Principal Component analysis Technique of reducing data dimensionality and mapping hydrothermal alterations through the analysis of the surface spectral response to various bands of the Landsat 7 ETM⁺ image covering the Kibi Goldfields, Osino concession of Ghana. Each mineral has a characteristic feature of degree reflectance and absorption of the various bands of the Landsat 7 ETM⁺. Signature response of surfaces (lithologies) to bands 4-5, 5-7 and 1-3 were used in mapping ferrous, hydroxyl and iron-oxide mineral alterations respectively. Hydroxyl alterations dominate the area due to the large coverage of clay-rich metasediments in the area. Again the area's gold mineralisation may be associated with pyrites which were revealed to be present in the iron-oxide- ferrous mineral alteration zones.

Keywords: Bands, Crosta Technique, GIS, Hydrothermal alteration, Principal Component Analysis, Remote sensing

I. Introduction
Mapping and delineation of mineralised zones in an area requires establishing the presence and absence of various mineralisation shreds of evidence (e.g. geophysical, geochemical, hydrothermal alteration, geomorphology etc.). Alterations caused by high mineral concentrated fluids of varying temperatures are known to have a good spatial correlation with gold mineralisation within the gold belts of Ghana [1]. Notably, the lode gold, oxide and sulphide ore deposition styles within the Ashanti belt which are suspected to have similarities with the less probed Kibi-winneba belt is noted for this feature [2].

Hydrothermally-altered rocks are lithologically anomalous groups of rocks, which resulted from the chemical attack of pre-existing rocks by hydrothermal fluids [3]. Thus, it refers to the mineralogical, textural, composition and colour changes in rock resulting from the interaction between rocks and high temperature, chemically potent ascending fluids. This process leads to the formation of mineral deposits, the replacement of existing minerals and even realignment of mineral grains. Alterations have a close spatial-temporal relationship with mineral deposits and are excellent guides to mineralisation in exploration [4]. It can vary considerably in extent, sometimes limited to a few centimetres to thick kilometres of halo around the ore body. It is usually of considerable exploration value, as it widens the drilling target. However, it may be challenging to differentiate alteration such as chloritisation from the effect of low grade regional/ contact metamorphism [4]. It is therefore very essential that the effects are identified to prevent a waste of a considerable degree of exploration effort.

However, remote sensing of the response (reflectance and absorption) from various minerals to various electromagnetic bands provide a means of analysing the spectral signatures of various minerals (hydrothermal alterations) and therefore, identifying what exists in a particular area [5]. The signatory response of various minerals to the bands of the Landsat ETM⁺ has led to the identification of different types of hydrothermal alterations (hydroxyl/clay minerals, iron-oxides, ferrous minerals) through a plethora of analysing techniques [6]-[8].

A. Crosta Technique
The Crosta technique is a methodology based on the selection of best Principal Components possessing an Eigenvector loading which depicts the reflectance and absorption signature of a particular material (rock, soil, vegetation etc.) within a satellite image [9]. The fulcrum of this approach is its ability to highlight the target surface as bright or dark pixels within the relevant principal component image. This requires that a Principal Component Analysis (PCA) is carried out on the spectral bands recorded in the satellite images.

Principal Component Analysis is a mathematical dimensionality or data reduction procedure which reduces the dependency/correlation of variables into a number of less correlated variable which is known as Principal Components (PC) [7]. This multivariate statistical technique selects
uncorrelated linear combinations (Eigenvector loadings) of variables with each successively produced principal component layer having a smaller variation [10]. Here, multispectral band images are treated as variables and carried through the analysis with the outcomes being highly influenced by the spatial abundance and distribution of the various surficial materials and the image statistics [7]. Thus the Digital Numbers (DN) recorded on the image for each band captured depends on the reflectance or absorption characteristics of the surface under study with respect to each spectral band (Figure 1).

The distribution and density of the DN values control the resulting Eigenvectors loadings and their signs after the principal component analysis. Depending on the sign (+/-) and value of these Eigenvectors assigned to a Principal Component layer, decisions are made on which Principal Component better displays a particular feature (rock, hydrothermal alteration, minerals, soil, vegetation etc.) in the remotely sensed image’s dark pixels or bright pixels [7] (Loughlin, 1991). The Crosta technique is a powerful Remote Sensing (RS) image analysis method which has been used in the delineation of various hydrothermally altered zones [6], [12]-[13].

II. Materials and Method
A. Study area
Kibi Goldfields is located within 46 square kilometres Osino concession, which is centred on the UTM coordinates, 775,738 East and 698,593 North (WGS 84 Zone 30N datum). This area has an undulating topography with elevation range between 180 and 450 m above the sea level, characterised by steep sloping ridges and undulating mountain side hills, dominated by the prominent, NNE-SSW trending Atewa Range that is about 50 km long and 10-15km wide.

It is situated on the east of Akim, Kraboa Districts, eastern flank of Atewa Range along the headwaters of Birim River, Eastern Region of Ghana. Two asphalted secondary highways provide access to the Osino concession. Access to the study area is by driving northwest from Accra on the paved Accra-Kumasi Trunk Road which is the main national highway for approximately 80 km until the town of Kibi (Figure 2).

The Eastern region of Ghana experiences two (2) annual raining seasons with a mean annual rainfall of about 1,500 to 2,000mm for most of the area and 2,000mm in the highland areas. Temperatures vary within the range 30-35°C during daytime and 23-28°C in the evening [14].
of exploration activities. The most recent Kibi Greenstone Belt geology map (Figure 3) was based on regional geological survey traverses and airborne geophysics interpretation (aeromagnetic and radiometric).

The Kibi Belt being a typical Birimian greenstone belt that shares several litho-tectonic and metallogenic similarities with the prospective Ashanti and Sefwi belts clearly, hosts a significant resource of bedrock gold as evidenced by the extensive alluvial throughout the area [15]. However, the substantial bedrock sources of gold are yet to be discovered in the area, and this may be simply due to the lack of systematic exploration as well as due to the presence of extensive alluvial cover along the lower slope of the Atewa Range and in nearby valleys [15]. The deposit type targeted at the Osino concession consists of orogenic mesothermal gold mineralisation of classic Ashanti-type of gold occurrence.

C. Software

The research was undertaken with Landsat 7 ETM+ satellite images (from the date 26/12/2002) covering the study from the USGS earth explorer website. Other raster image analysis and principal component analysis were carried out using the ESRI ArcGIS software version 10.4.

D. Method

The hydrothermal alterations: chloritisation, sericitization, argillic, ankerite, silicification and calcite-magnetite-green schist facies are associated with gold mineralisation in the area [15]. These alterations were grouped into the hydroxyl (clays and micas), iron oxide or ferrous minerals alteration groups and extracted from the Landsat 7 ETM+ data applying the Crosta Technique [9] and [16] on the appropriate bands in a composite band layer.

A separate composite band image of bands ‘(1, 3, 4, 5, 7)of the Landsat 7 ETM+ data, proven to be resourceful in geological and mineralogical mapping [17] was made and used in delineating zones of the different forms of alterations through the analysis of the eigenvalues table generated after carrying out a principal component analysis on the 5-band composite. However, to be band specific and reduce variation in the principal components, two separate four (4)-band composite (composite band 1, 3, 4, 5 and composite band 1, 4, 5, 7) were made and carried through the principal component analysis to obtain a set of Eigenvalues.

However composite band 1,3,4,5 was best used to map ferrous mineral alteration, because the minerals with this alteration has high reflectance of ETM+ band 5 and absorption of the ETM+ band 4(Figure 1); hydroxyl minerals group were mapped using the 1,4,5,7 composite with attention to the high reflectance of ETM+ band 5 and absorption of the ETM+ band 7. Whereas the Iron-oxide alteration group were best delineated using the composite band 1, 3, 4, 5, 7 with attention to its spectral characteristics of high reflectance of ETM+ band 3 and absorption of ETM+ band 1.

Principal Component Analysis (PCA) using Principal component analyst tool of the Arc GIS software was carried out on each composite band image to improve visualisation and generate the Eigenvalues for analysis. With high reflectance due to specific material in a particular band, its Eigen loading due to that band should be of a high positive magnitude and high negative magnitude for its absorbed band. However, the converse may happen, therefore displaying the mapped alteration of a PC layer in dark pixels instead of the bright pixels in the convention above. In such situations, the PC layer is negated to display mapped alterations as bright pixels for better visualisation.

The best-selected layer for ferrous and iron-oxide alterations was stacked together as one layer for better display due to the similarity in their base element (iron). The selected alteration layers, based on the Eigen loadings, were analysed, integrated and displayed in bright Red-Green-Blue (RGB) assigning the mapped alteration; hydroxyl and ferrous + iron oxides to Red and Blue respectively to represent the final alteration map of the KGL concession.

III. Results and Discussion

A. Layer stacking

From the raster image scene covering most areas of the Kibi-Winneba belt and its surroundings, the area of study was subset using the KGL concession boundary and displayed in an RGB image showing the bands (4,5 and 7) Landsat 7 ETM+ (Figure 4).

![Figure 4. Composite band image of study area showing band 4, 5, 7)](image)

B. Principal Component Analysis (Crosta Technique)

Table 1 shows the results of the Principal Component Analysis carried out on the 5-band (1, 3, 4, 5, and 7) composite of Landsat 7 ETM+ image. From the table, the best-mapped alteration is the Iron oxide alterations which were displayed as dark pixels of PC 5. This is due to the high...
positive Eigenvalue of ETM$^+$ band 1 (0.94713) and the negative Eigenvalue of ETM$^+$ band 3 (-0.30600).

Table 1. Eigen value results from 5-band composite PCA

<table>
<thead>
<tr>
<th>ETM$^+$ LAYERS</th>
<th>PC1</th>
<th>PC2</th>
<th>PC3</th>
<th>PC4</th>
<th>PC5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band 1</td>
<td>0.08617</td>
<td>0.04298</td>
<td>0.17320</td>
<td>0.25235</td>
<td>0.94713</td>
</tr>
<tr>
<td>Band 3</td>
<td>0.29969</td>
<td>0.19988</td>
<td>0.70576</td>
<td>0.52773</td>
<td>0.30600</td>
</tr>
<tr>
<td>Band 4</td>
<td>0.10730</td>
<td>0.93781</td>
<td>0.30927</td>
<td>0.11531</td>
<td>0.00696</td>
</tr>
<tr>
<td>Band 5</td>
<td>0.71189</td>
<td>0.15288</td>
<td>0.56749</td>
<td>0.38043</td>
<td>0.05542</td>
</tr>
<tr>
<td>Band 7</td>
<td>0.62005</td>
<td>0.23524</td>
<td>0.23283</td>
<td>0.70696</td>
<td>0.07870</td>
</tr>
</tbody>
</table>

For better visualisation, the PC5 layer was negated to display the mapped iron oxide as bright pixels of the grey-scale image (Figure 5).

Figure 5. Iron oxide alteration in PC 5 (bright pixels)

The principal component analysis results from the 4-band (1, 3, 4, 5) composite best displayed the ferrous minerals alteration in the dark pixels of its Principal component (PC) layer 2, due to its high positive Eigenvalue (0.92188) of band 4 and a converse negative value (-0.17269) of the supposed to be reflected ETM$^+$ band 5 (Table 2).

Table 2. Eigenvector loadings for the 1, 3, 4, 5 band composite

<table>
<thead>
<tr>
<th>ETM$^+$ Layers</th>
<th>PC1</th>
<th>PC2</th>
<th>PC3</th>
<th>PC4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band 1</td>
<td>0.09634</td>
<td>-0.08274</td>
<td>0.21737</td>
<td>0.96779</td>
</tr>
<tr>
<td>Band 3</td>
<td>0.32436</td>
<td>-0.33684</td>
<td>0.84742</td>
<td>-0.25141</td>
</tr>
<tr>
<td>Band 4</td>
<td>0.29457</td>
<td>0.92188</td>
<td>0.25161</td>
<td>-0.00702</td>
</tr>
<tr>
<td>Band 5</td>
<td>0.89372</td>
<td>-0.17269</td>
<td>-0.41392</td>
<td>-0.01076</td>
</tr>
</tbody>
</table>

The PC 2 layer from the PCA on composite 1, 3, 4, 5 was negated to display the mapped ferrous mineral alterations as bright pixels (Figure 6).

Figure 6 Ferrous minerals alterations in 1,3,4,5 composite’s PC 2 (bright pixels)

The mapped iron-oxide and ferrous mineral alterations were summed up in greyscale to produce the iron oxide + ferrous minerals alteration map of the area (Figure 7).

Figure 7 Combination of Ferrous and Iron oxide alteration PCAs
Areas displaying the presence of iron oxide + ferrous minerals are underlined by metavolcanics and in areas surrounding the metavolcanic and metasedimentary geologic contact of the area (Figure 3). Some observed outcrops showed pyrites (Figure 10) and box-works of weathered pyrites (FeS) (Figure 11) which is an iron-based mineral, commonly used as pathfinder element for gold exploration in the volcanic gold belts of Ghana.

The hydroxyl alteration minerals were best displayed as dark pixels in the PC 3 layer of the PCA carried out on the ETM bands 1,4,5,7 composite (Table 3) with a negative Eigenvalue (-0.65168) for band 5 and a positive Eigenvalue (0.67829) for band 7. This was also negated to display the delineated hydroxyl alterations as bright pixels in a grey scale image (Figure 8).

<table>
<thead>
<tr>
<th>ETM Layers</th>
<th>PC1</th>
<th>PC2</th>
<th>PC3</th>
<th>PC4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band 1</td>
<td>0.08732</td>
<td>-0.04969</td>
<td>0.19464</td>
<td>0.97572</td>
</tr>
<tr>
<td>Band 4</td>
<td>0.14245</td>
<td>0.94972</td>
<td>0.27810</td>
<td>-0.01986</td>
</tr>
<tr>
<td>Band 5</td>
<td>0.75134</td>
<td>0.07953</td>
<td>-0.65168</td>
<td>0.06681</td>
</tr>
<tr>
<td>Band 7</td>
<td>0.63841</td>
<td>-0.29872</td>
<td>0.67829</td>
<td>-0.20766</td>
</tr>
</tbody>
</table>

Table 3. Eigenvector loadings for the 1,4,5,7 band composite

Areas dominated by the hydroxyl mineral alterations mapped are underlain by metasedimentary rock (eg. Greywacke and phyllite (Figure 3) which are known to be clay (e.g., illite) dominated rocks [18]. A ground truthing showed silica-rich, highly foliated greywacke SE of the metavolcanic-metasedimentary contact which has been highlighted by the Crosta technique as bearing hydroxyl (clay minerals) alterations.

The alterations identified were integrated into an RGB image representing the hydrothermal alteration map of the area. Figure 9 is an RGB composite image of the best highlighted hydrothermal alterations with Ferrous and iron oxides displayed as blues and the hydroxyls showing as red.

Figure 9 Hydrothermal alterations composite map of the Osino concession.

IV. CONCLUSION

From the analysis of Eigenvalues resulting from the principal component analysis conducted on selected bands of remotely sensed Landsat 7 ETM+ image, hydrothermal alterations (i.e. Hydroxyl, Ferrous and iron-oxide minerals) within the concession area mapped is dominated by hydroxyl alterations. This is evident in the extensive coverage of the area by high clay and micaceous lithologies. The ferrous and iron oxide mineral alteration is entirely concentrated in patches and well highlighted in areas surrounding the metavolcanic-metasedimentary contact. These zones have green-schist facie metavolcanics which had evidence of pyrites, limonites and box-works of pyrites. The Crosta technique is therefore deemed successful and effective a method in delineating hydrothermal alterations. This method can, thus, serve as a powerful tool during the early stages of mineral exploration.

V. REFERENCE


VI. APPENDIX

A. Images of encountered lithologies during ground-truthing

Figure 10. Metavolcanic with pyrite inclusions (circled red)

Figure 11. Quartz showing box-works of weathered pyrites
Figure 12. Highly silicified metagreywacke near the metavolcanic-metasedimentary contact

Figure 13. Metavolcanic underlying some areas suggesting ferrous minerals alteration, showing signs of rust