Remote Sensing Application in Geothermal Exploration: Case Study of Barrier Volcanic Complex, Kenya

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ABSTRACT

Kenya's vast geothermal energy resources have the potential of becoming a highly significant source of safe, secure, competitively-priced, emission free, renewable base load power supply for centuries to come. This potential combined with the evidence of risks posed by climate change is stimulating growth in development of geothermal energy. Recent significant improvements in the wavelength coverage, spectral resolution and quality of remote sensing imagery have lead to the extensive application of these data sets in geothermal exploration and site characterization. The traditional techniques in spectral and spatial analysis of imagery, coupled with new, high signal to noise data, allow their direct application to problems in geothermal energy exploration and development. High resolution thermal infrared remote sensing data can be used as a cost-effective tool to explore large areas for geothermal potential and pinpoint smaller target areas for further exploration using ground-based survey techniques. This work seeks to demonstrate and outline how airborne and spaceborne imagery can be used to map geothermal anomalous sites, mineralogy, geological features, thermal anomalies and hot spots over broad and inaccessible geothermal prospects regions within the Barrier volcanic complex in the Northern Kenya Rift. With clearly associated indicators, mineralogy, volcanic framework, geological formation, present and past geothermal activity, mapping can be conducted from different multi spectral and multi spatial satellite imagery. Remote sensing data can also be useful in identifying fault extensions not previously mapped by field Geologists. Future work will test these methods on new sites not yet producing power to confirm their predictive capabilities for new resources.

Introduction

Spectral identification of geothermal potential areas can be associated with various types of geological structures and hydrothermal alteration zones and minerals. Remote sensing techniques can be used in mapping of geological formations, hydrothermal alteration zones and other surface markers of geothermal activity. The extraction of information related to volcanology and geological formation from sub meter resolution satellite images from GeoEye can be used to map fault lines, fractures, eruption centers, lava flows and lineaments zones. The use of multi-spectral

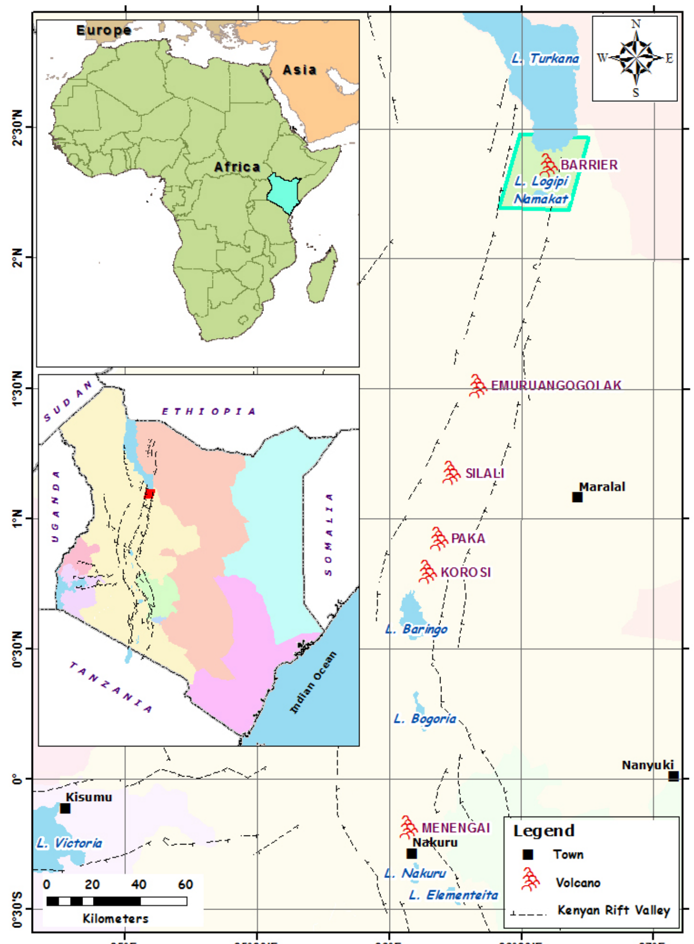

Figure 1. Location of Barrier Volcanic Complex.

imagery from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and Landsat Thematic Mapper (TM) multispectral sensors can be applied for mapping soil moisture anomalies, volcanic and fumarolic activity thermally active areas and ground water discharge areas for delineation of potential geothermal areas.

Digital image processing techniques such as band ratio and Principal Component Analysis (PCA) and/or Crosta method are instrumental in extraction of feature information from remotely sensed data (Crosta *et al.* 2003, Rowan *et al.* 2005). Hydrothermal alteration deposits are often produced by fluid flow processes that alter the mineralogy and the chemistry of the surface and subsurface rocks. Previous research has shown the reliability of multispectral data analysis in the field of alteration detection and thermal mapping of field anomalies. Hydrothermally altered host rocks (Rowan *et al.* 2006), are typically zonally distributed which can be used as indicators in geothermal exploration and characterization. By using remote sensing techniques, alteration mineral zones, volcanic activity and geological formations can be detected and mapped on a regional scale. In this research, processing was performed on the ASTER and GeoEye satellite imagery data of Barrier Volcanic Complex to map spectral signatures associated with the hydrothermal alteration, geological and volcanic formations. Different image processing techniques such as Principal Component Analysis (PCA), band ratio and false color composites (FCC) methods have been used in the analysis of the satellite images for Barrier Volcanic Complex. Finally the results will be checked by field study and ground truthing.

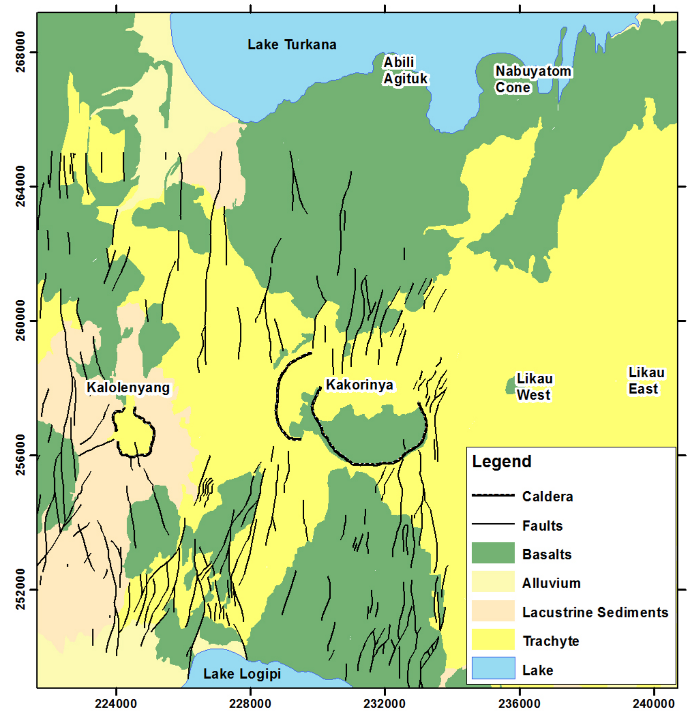

Figure 2. Geology of Barrier Volcanic Complex.

Geology of Barrier Volcanic Complex

Barrier Volcanic Complex(BVC) composite structure is composed of four distinct volcanic centres namely; Kolalolenyang, Kakorinya, Likaiu West and Likaiu East. They are composed of a wide spectrum of lava types including trachytes and basalts (Figure 2). Trachytic pyroclastic deposits cover much of the western slopes of Kakorinya and the summit area of Likaiu west. Basalts on the other hand forms the base of the complex with the oldest basalts exposed in the rift margins. The rocks are young towards the inner trough from the rift margins indicating active volcanism in the centre. There are phonolites which are older than the recent basalts and are exposed within Kakorinya caldera.Pyroclastics cover most parts of the western side of Kakorinya while spots of alluvium are scattered within this area. The latest eruption in the area was in 1921; erupted material was scoria basalts of Teleki cone,(Omenda, 2000).

Methodology

The ASTER spectral range was selected for detecting hydrothermal alteration zone and mineralogy spectral reflectance. The ASTER sensor consists of three separate subsystems with a total of 14 bands. The VNIR subsystem obtains optical images, with a spatial resolution of 15 m. The SWIR subsystem also scans optical images with six bands, with a spatial resolution of 30 m. The TIR subsystem obtains optical images of five bands with a spatial resolution of 90 m (Table 1, Fujisada, 1995). The GeoEye Image used comprised of four bands in the blue, green, red near infrared bands of the electromagnetic spectrum at 0.50m resolution and a swath width of 15.2km (Table 2, GeoEye, 2011). In this study detection and delineation of alteration and thermal active zones was done by targeting key alteration minerals in Barrier Volcanic Complex. Application of different image processing methods on ASTER imagery data such as false color composites, band ratio

Table 1. ASTER Data Characteristics (Modified after Fujisada, 1995).

Characteristics	VNIR		SWIR		TIR	
Spectral range	Band 01	0.52–0.60 µm	Band 04	1.600–1.700 µm	Band 10	8.125–8.475 µm
	Band 02	0.63–0.69 µm	Band 05	2.145–2.185 µm	Band 11	8.475–8.825 µm
	Band 03N	0.78–0.86 µm	Band 06	2.185–2.225 µm	Band 12	8.925–9.275 µm
	Band03B	0.78–0.86 µm	Band 07	2.235–2.285 µm	Band 13	10.25–10.95 µm
			Band 08	2.295–2.365 µm	Band 14	10.95–11.65 µm
			Band 09	2.360–2.430 µm		
Radiometric	8 bits		8 bits		12 bits	
Ground Resolution	15m		30m		90m	
Swath Width	60 km					

Table 2. GeoEye Data Characteristics.

Characteristics	Blue	Green	Red	Near Infrared
Spectral range	0.45 – 0.51 µm	0.51 – 0.58 µm	0.655 – 0.690 µm	0.780 – 0.920 µm
Radiometric	8 bits			
Ground Resolution	0.5 m			
Swath Width	15.2 km			

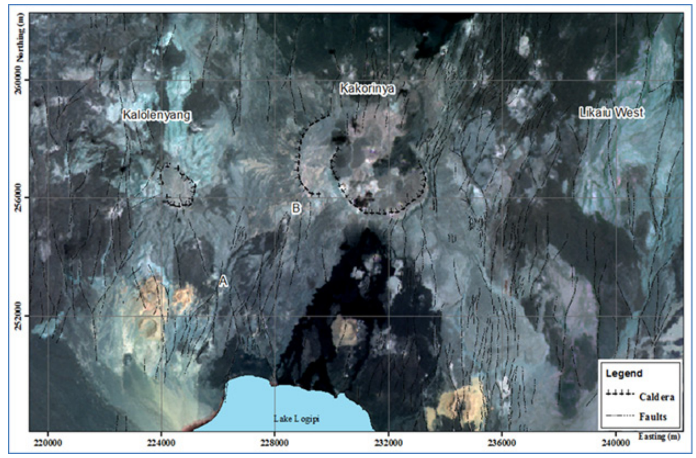

Figure 3. Red-Green-Blue Color Composite of Bands 4, 6 and 8, ASTER imagery.

methods and principal component analysis was carried out. The volcanic and geological formation was mapped using knowledge based classifiers based on the surface expressions in the high resolution imagery (GeoEye). During the study, data analyses were carried out using ENVI 4.7 and ArcGIS 10 software. Future work will include validation of these methods by field work.

Band Combination and Band Ratio Transformation Analysis

Multiple wavelength sampling is very important for identification of features and different types of land cover. Despite the large ASTER bandwidths, the instrument is useful in mapping mineral suites (Rowan *et al.* 2003). A color composite of separate multispectral bands with blue, green, red, (RGB) colors is the most often shown form. Figure 3 is a false color composite (SWIR bands 468) image of the Barrier area highlighting a site of hydrothermal alteration in light tones versus dark areas as regions with young basaltic lava. 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 display for geological and/or alteration interpretation (Pty Ltd, A.B.N 2011).

The high resolution satellite imagery (GeoEye) was used for mapping of faults and other geological formations. Figure 5 and 6 above shows some of the faults that were interpreted and mapped from the GeoEye imagery. Also the high resolution satellite imagery gave an interim method for checking the ASTER imagery analysis and hydrothermal mapping (via linked displays of the analysis results from ASTER and the GeoEye image in ENVI 4.7 software).

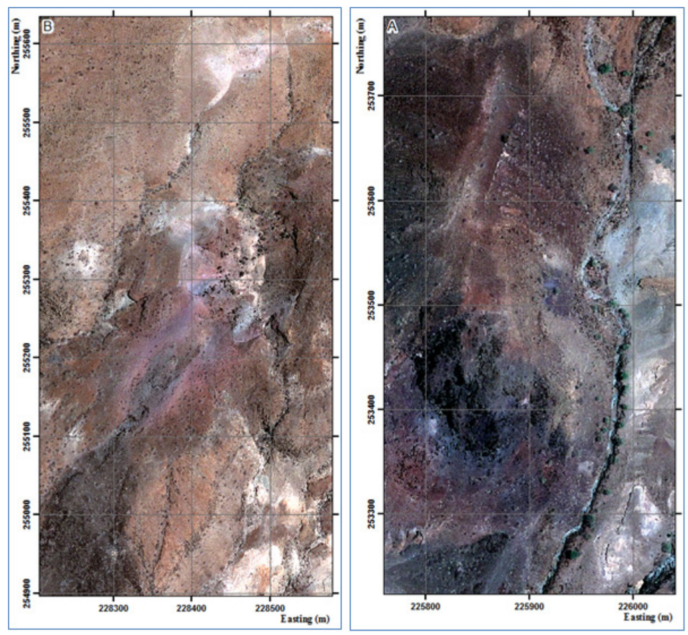

Figure 4. Hydrothermal alteration zones and hot ground corresponding to areas A and B in Figure 3 from GeoEye satellite imagery of the Barrier Volcanic Complex.

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 (John and Xiuping, 2006, Abrams *et. Al*, 1997, Kratt, 2005). The main aim of PC analysis is to remove redundancy in multispectral data. Principal component analysis is widely used for mapping of hydrothermal alteration (Loughlin, 1991). The Crosta technique is also known as feature oriented principal component selection. Through the analysis of the eigenvector values it allows

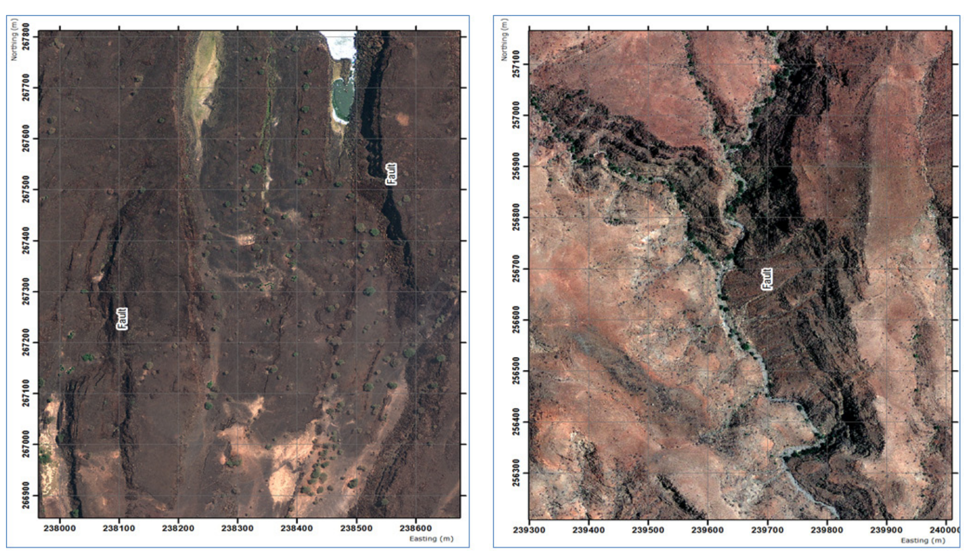

Figure 5. Faults mapped from GeoEye satellite image.

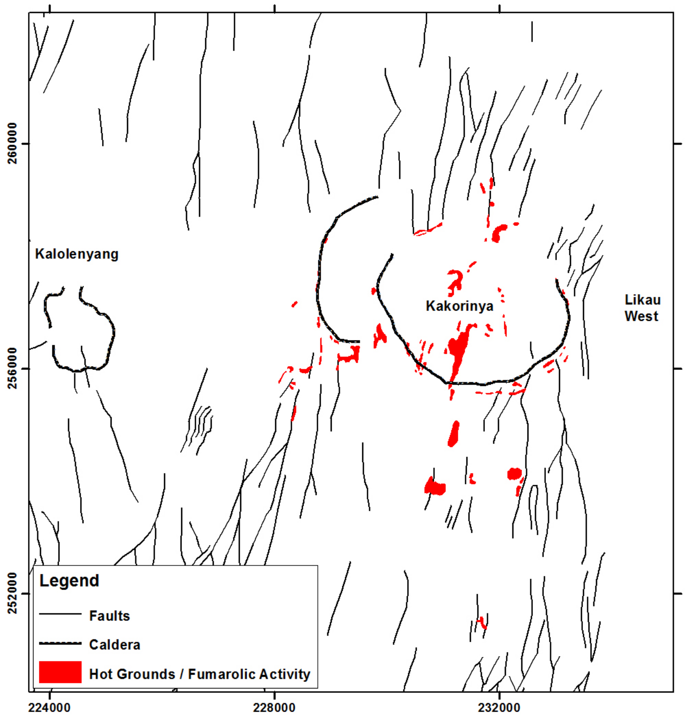

Figure 6. Features mapped from GeoEye Satellite Image.

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

PCA	Band 1	Band 3	Band 5	Band 7
PC 1	0.72	0.46	0.36	0.36
PC 2	0.52	0.11	-0.50	-0.68
PC 3	-0.45	0.88	-0.09	-0.13
PC 4	0.05	0.04	-0.78	0.62

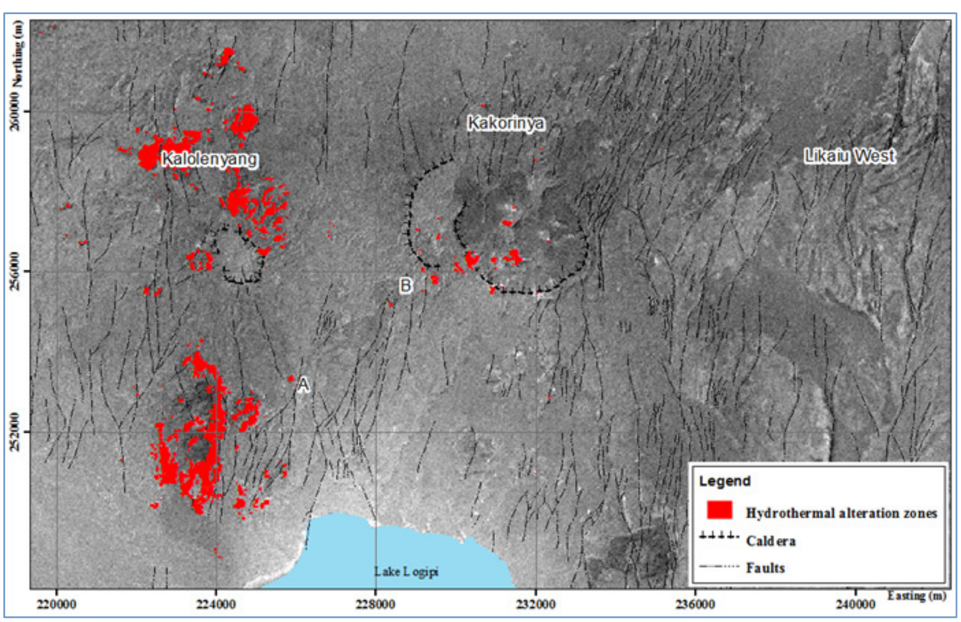

Figure 7. Image of PC4 (1357) in which red pixels are related to presence of Alunite

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 to the spectral response of the materials of interest. This technique indicates whether the materials are represented as bright or dark pixels in the principal components according to the magnitude and sign of the eigenvector loadings. This technique can be applied on four, six or more selected bands of ASTER data (Crosta and Moore, 1989; Rutz-Armenta and Prol-Ledesma, 1998, Martini *et. al*, 2003).

Hydrothermal alteration mineral endmember identification can be done by applying principal component analysis (PCA) and an adaptation of the Crosta technique on ASTER bands. For recognition of alunite (an index mineral of alunitic alteration) PC analysis of bands 1, 3, 5 and 7 was computed. Table 2 shows the PC's for the mentioned band set. Bands 5 and 7 were selected for the maximum reflectance of alunite in band 7 and minimum reflectance in band 5 respectively. The difference is depicted in PC4 based on the negative and positive eigenvector loadings (Figure 7).

Discussion

The high resolution satellite imagery was successfully used in mapping of faults, fractures, altered ground and areas perceived as hot ground with manifestations of fumarolic activity. Areas mapped as hydrothermal alteration in figure 3 are 'ground truthed' using the high-resolution GeoEye imagery. Distinct zones of alteration are clearly visible (Figure 4) as are potential fault zones seen as lineaments in figure 5. Comparison of the results obtained from the high resolution GeoEye data and the ASTER imagery, indicate that altered areas are mapped well with high resolution GeoEye imagery whereas actual alteration mineralogy was mapped better using band ratio and PCA techniques. This preliminary result indicates that multi-spectral, satellite-based mineral alteration and fault mapping may be a viable prospecting tool for regional geothermal exploration. Field verification will be carried out to ground truth and check the methodologies applied. Additionally, future spectral and thermal emittance analysis will be carried out for land surface temperature mapping.

Conclusion and Recommendations

PCA and Crosta technique is useful in mapping of the different hydrothermal alteration zones as well as the associated alteration minerals Spectral analysis of thermal emittance data in the TIR bands and co-registration to the VNIR/SWIR bands of ASTER data can be useful in mapping and giving estimates of surface emissivity whereas high resolution images are very useful in geological mapping of surface expressions and markers of geothermal activity.

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