
RESEARCH ARTICLE

Mapping evaporite minerals and associated sediments in Lake Magadi, Kenya, using Hyperspectral Hyperion data

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Abstract: Hyperion hyperspectral (VNIR-SWIR) satellite image data was used to map the spatial distribution of mineral precipitates at Lake Magadi area, in the southernmost part of the eastern Kenya rift, Kenya. Mapping was coupled with laboratory analysis, including visible near-infrared diffuse reflectance spectroscopy (VNIR) measurements and X-ray diffraction for selected rock and soil samples. The VNIR spectral responses of 92 rock and soil samples including trona, chert, diatomite, basalt/trachyte, erionite, Green bed and High Magadi bed were studied and identified. The spectral signatures of Chert samples show the broad Si-OH absorption feature at 2.2 μm while, Green bed, High Magadi bed and diatomite exhibit carbonate absorption feature at 2.35 μm with broad Si-OH absorption feature at 2.2 μm . Trona exhibits six common absorption features at 1.50, 1.74, 1.94, 2.03, 2.22 and 2.39 μm . These characteristics spectral absorption features together with the general shape of the spectral curve are used to identify the surface minerals of the area. In the mapping of different stages of evaporites and other surface minerals using Hyperion data, various image processing techniques including, the Minimum Noise Fraction (MNF), Pixel Purity Index (PPI) and Mixture Tuned Matched Filtering (MTMF) were applied. These spectral mapping methods coupled with geochemical knowledge of the area substantially improved the existing geological knowledge and enhanced the capability to derive substantial information related to the distribution and formation of precipitates and evaporites in the area.

Keywords: *Hyperion, Reflectance spectroscopy, X-ray Diffraction, Surface mineral mapping, Remote sensing*

Introduction

The Lake Magadi, in the southernmost part of the eastern Kenya rift, is one of the most interesting places to study lacustrine evaporitic sedimentation processes and their mineral reactions in the world. The area is characterized by a trona precipitating saline lake, which is fed by alkaline hot springs (at the perimeter of the basin), hydrothermal alteration and

chertification process (Behr and Röhricht, 2000, Surdam and Eugster, 1976, Warren, 2006). Mineral formation in the area and their reactions have been studied in the field by looking at their spatial distribution with age of the formation (Behr and Röhricht, 2000, Eugster, 1967, Eugster, 1969) and in the laboratory by changing physical and chemical

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factors similar to the present and past conditions of the area (Beneke and Lagaly, 1983, Fletcher, 1987, Wang, Wang et al., 2006) and cited since 1960s in geological literature (Eugster, 1967, Eugster, 1969, Jones, Eugster et al., 1977).

Alkaline saline deposits, however are difficult to study because variations in mineralogy are not easy to recognize in the field and the large spatial extent that limits accessibility (Warren, 2006). Alternatively, the access to relatively inexpensive satellite-borne multi-spectral and hyper-spectral data have created new opportunities for the regional mapping of mineralogy, geological structures and rock types including alteration products (Hewson, Cudahy et al., 2005, Vaughan, Hook et al., 2005). These techniques provide identification of different surface expressions and mapping possibilities for minerals in the hydroxyl, silicate, sulphate, carbonate and iron oxide groups covering large extents at times with inaccessible terrains. It has been applied successfully in efflorescent salt crusts in Death Valley, California using Air-borne hyperspectral and space-borne multispectral imagery to map the different surface saline materials (Crowley, 1993, Crowley and Hook, 1996). The motivation of this research is to evaluate the identification and mapping capability of different evaporites and precipitates in Lake Magadi area using space-borne hyperspectral Hyperion data with help of their spectral characteristics. This output will also produce a map of localities of the prospect with favourable conditions for the formation of lacustrine mineral deposits and it can be used to plan the best ground access to the prospect.

Hyperion is the first earth-orbiting imaging spectrometer, which was launched onboard the Earth Observing 1 (EO-1) satellite on November 21, 2000 (Beck, 2003), that operates across the full solar-reflected spectrum with nominal spectral coverage from 0.4 μm -2.5 μm and 10 nm sampling and spectral response functions (Green, Pavri et al., 2003).

Materials and Methods

Spectral properties of evaporites and other associated rock units

Field work was conducted in Lake Magadi area from July 20 to August 14, 2008. The entire study area was surveyed, 92 rock and 26 soil samples were collected from the relatively homogeneous bare land areas, which have a spatial extent larger than 60 X 60 m². Each sample location was characterized using land cover analysis, geomorphologic analysis, GPS data

collection and field photographs. All the soil samples were air-dried, crushed after drying and passed through a 2 mm sieve. Spectral acquisition of the 26 soil samples were done at the World Agroforestry Centre (ICRAF) in Nairobi, Kenya, using a Bruker Fourier-Transform near infrared spectrometer (Multi-Purpose Analyzer). Reflectance spectra of 58 rock samples were taken using a Vertex-70 FTIR instrument at International Institute for Geo-Information Science and Earth Observation (ITC) in the Netherlands. All the rock and soil samples were grouped into several categories after analyzing spectral signatures of reflectance spectra and physical properties/appearance of the sample. The mineralogy of each category was confirmed using X-ray diffraction spectroscopy at the Institute for Nanotechnology (MESA), University of Twente in the Netherlands.

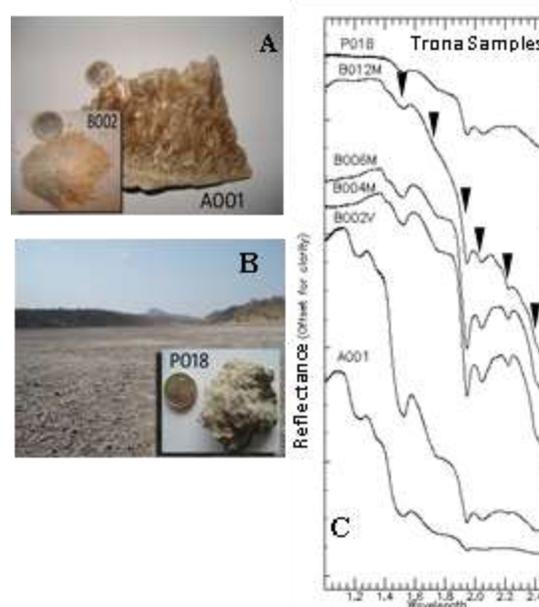


Figure 1. A: Crystallized trona (A001) and its powder form (B002), B: Surface evaporates in southern part of Lake Magadi area, C: Reflectance spectra of Trona samples

The spectrum (Fig. 1C) exhibits six common absorption features at 1.50 μm , 1.74 μm , 1.94 μm , 2.03 μm , 2.22 μm , and 2.39 μm for all samples.

Spectral properties of siliceous rocks

Siliceous rocks were classified using reflectance spectra, XRD patterns, and description of hand

specimens and contain; (a) Laminated chert (sample no: P017, Fig: 2a),(b) Laminated green chert (Sample no: P024, Fig: 2b), (c) Pillow chert (Sample no: S047 & P035, Fig: 2c), (d) Dyke chert (Sample no: P019_01 & P019_02, Fig: 2d), (e) Green beds (Sample no: B015 and P030, Fig: 2e), (f) Quartz chert (Sample no: S008 and P019_02) and (g) High Magadi beds (Sample no: S037, P009, Fig: 2f).1978). Nitrate (mg/l-) contents were measured by using Hatch

Portable Data logging Spectrophotometer (Model DR/2010).

Above all categories showed same type of spectra (Fig: 3) containing four main absorption features at 1.42 μm , 1.91 μm , 2.21 μm and 2.46 μm in each spectrum

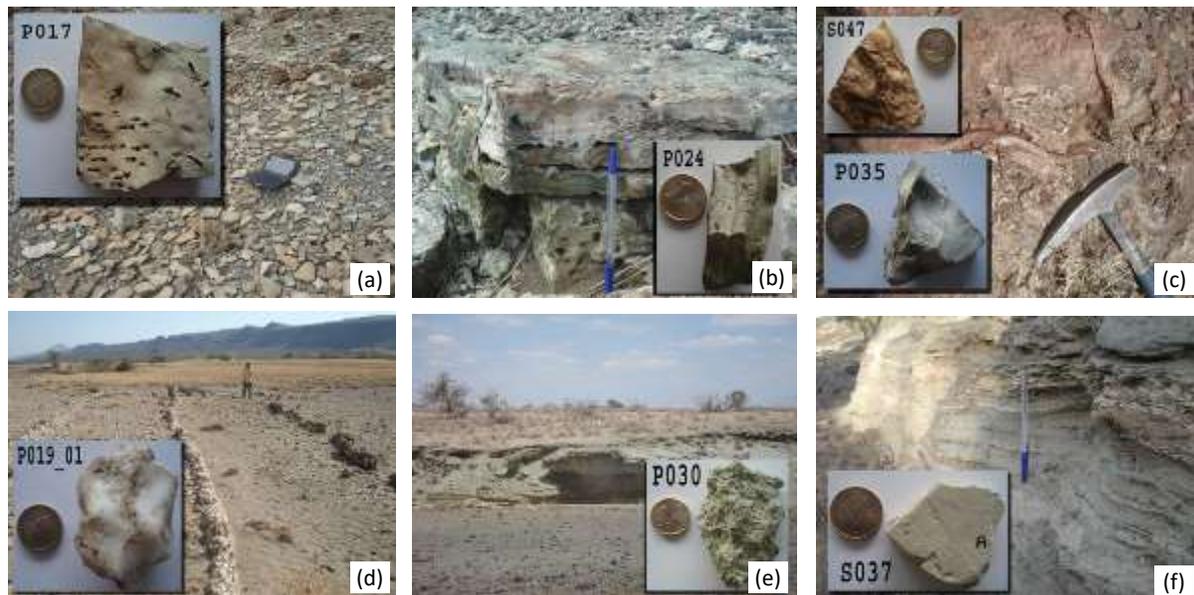


Figure: 2. (a). Crystal casts in Chert plates from Southern end of Lake Magadi. (b). Laminate Green Chert from northern part of the Lake Magadi. (c). Pillow Chert: Near to the Magadi town. (d). Chert dykes from North-eastern part of the Lake Magadi. (e). Green beds from southern part of Lake Magadi.

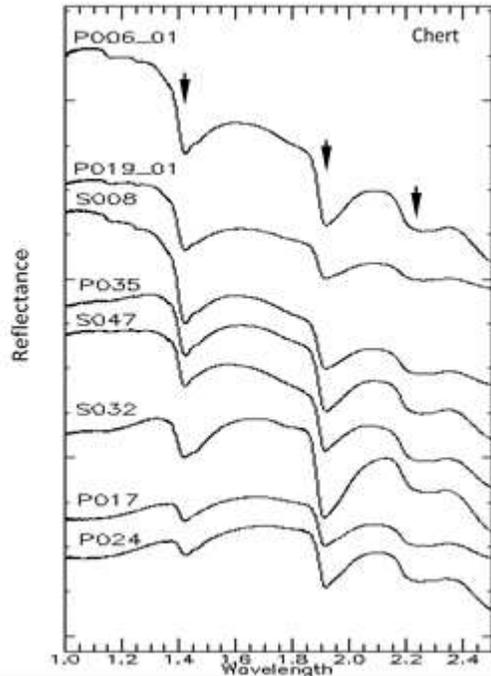


Figure: 3 Reflectance spectra of Magadi- Chert Series

All the samples contain molecular water as well as hydroxyl bonds due to 1.9 μm molecular water absorption feature and 1.4 μm hydroxyl ion absorption

feature. Other than above mentioned four (main) common absorption features, Sample No: P019_01, S008 and P006_01 showed another two absorption features at 1.16 μm and 1.25 μm . Causes of these two absorption features were not studied in detail.

Data processing and mineral mapping methods

The radiometrically corrected Hyperion image, which was acquired on 1st July, 2008, was processed as follows; (a) fix bad pixels/band using Pushbroom Plugger (b) gain and offset correction for columns using Pushbroom Destriper (c) atmospheric radiative transfer using FLAASH (d) effort polishing (e) identification of scene spectral end members using n-dimensional visualizer and Spectral Feature Fitting (SFF) method and (f) generation of surface compositional map using Mixture Tuned Matched Filtering (MTMF) method (Mason, 2002).

Results and Discussion

Figure 4 is a surface mineral map of the Lake Magadi area that was derived from the Hyperion image showing the surface minerals related to the local geology and geochemical precipitation process.

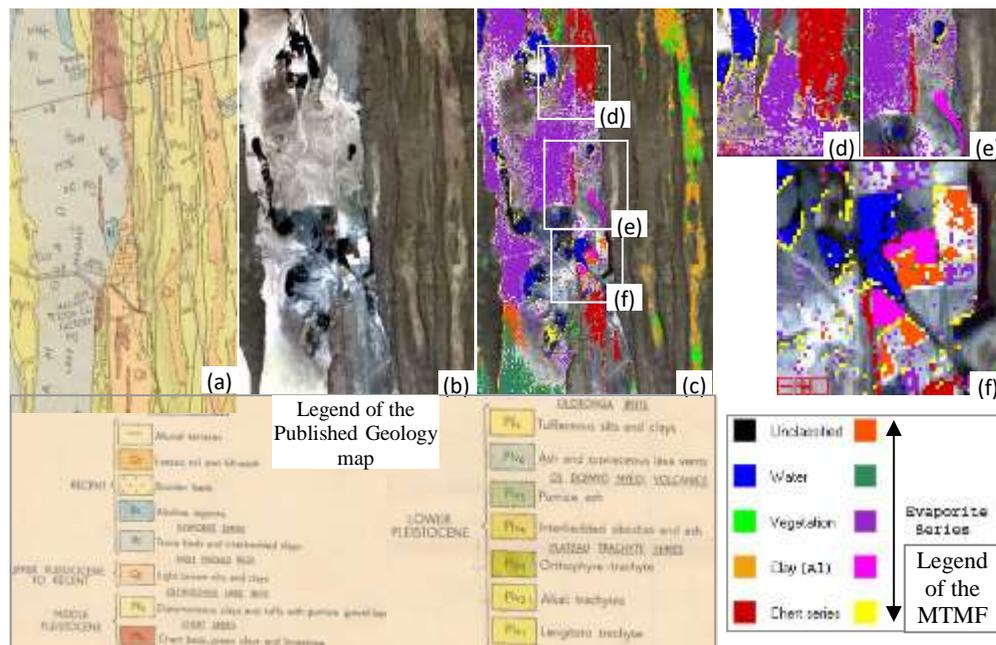


Figure 4. (a) Published Geology map of the study area, (b) Hyperion image of the area, (c) MTMF classification overlain on the Hyperion image, (d), (e) and (f) subsets of the image showing different sites of the area

Spatial distribution of chert series and evaporites in the mineral map is superimposed with the published geology map of the area (Fig. 4a and 4b). Although different types of evaporites and solutions have been categorized as one (trona) in the published geology map, the mineral mapping process using remote sensing clearly identified and mapped the different types/stages of evaporites and solutions. Spatial distribution of mineral precipitates and related solutions improve the understanding of mineral formations of the area with the help of hydro-geochemical literature. Subsets of the surface mineral map in Fig. 4d and Fig. 4e demonstrate the existence of different stages of evaporites that are formed by interacting with water, bed rock and chert series. This is the first step to locate the places where more detailed field and laboratory work is needed to understand the mineral formation reactions. Fig. 4f of the derived mineral map clearly shows the different stages of evaporites/trona in manmade fields. Using this output together with fieldwork investigations during the same period could be used to map the suitable stage of trona for mining purposes after studying image spectra of the selected fields.

The results of this study illustrate the successful application of the MTMF method to map evaporite minerals. Although different types of evaporites are shown in the mineral output map, the chemistry of some of them could not be established due to the limited chemical analysis and/or the absence of important end members in the spectral reflectance database. On the other hand, occurrences of mixtures between two geo-chemical phases are not modelled correctly by reflectance spectra. This may cause pixels to be misclassified or remain as unclassified because of infeasibility scores in the MTMF method. Originally, the Hyperion image shows low signal-to-noise ratio, and when combined with other environmental effects this makes it difficult to match field spectra with image spectra. This negative effect is more enhanced in this area due to wetness.

Conclusion

The result of this study demonstrates the potential value of hyperspectral remote sensing as a tool for mapping alkaline saline deposits having chemical composition derived from Lake Magadi ground waters. Although it was not easy to map all the chemical phases that occurred, due to the lack of spectral literatures for all of the different types of evaporites in the study area, the results are promising for reconnaissance studies.

Further field sampling and chemical analysis at the same time of image acquisition is required to accurately map the detailed surface chemistry and further test the Hyperion mineral mapping capabilities. These results will assist in locating promising sites for industrial open-pit mine in a qualitative and quantitative manner.

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