Alteration mineral mapping in inaccessible regions using target detection algorithms to ASTER data

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Abstract. In this study, the applications of target detection algorithms such as Constrained Energy Minimization (CEM), Orthogonal Subspace Projection (OSP) and Adaptive Coherence Estimator (ACE) to shortwave infrared bands of the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data was investigated to extract geological information for alteration mineral mapping in poorly exposed lithologies in inaccessible domains. The Oscar II coast area north-eastern Graham Land, Antarctic Peninsula (AP) was selected in this study to conduct a satellite-based remote sensing mapping technique. It is an inaccessible region due to the remoteness of many rock exposures and the necessity to travel over severe mountainous and glacier-covered terrains for geological field mapping and sample collection. Fractional abundance of alteration minerals such as muscovite, kaolinite, illite, montmorillonite, epidote, chlorite and biotite were identified in alteration zones using CEM, OSP and ACE algorithms in poorly mapped and unmapped zones at district scale for the Oscar II coast area. The results of this investigation demonstrated the applicability of ASTER shortwave infrared spectral data for lithological and alteration mineral mapping in poorly exposed lithologies and inaccessible regions, particularly using the image processing algorithms that are capable to detect sub-pixel targets in the remotely sensed images, where no prior information is available.

1. Introduction
Remote sensing satellite data are commonly used for reconnaissance mapping of inaccessible regions, lithological mapping, structural analysis and mineral exploration in arid and semi-arid and tropical regions around the world [1,2,3].

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) is a high spatial, spectral and radiometric resolution multispectral remote sensing sensor. It has three bands (0.52 and 0.86 µm) with a spatial resolution of up to 15 m in visible and near infrared (VNIR), six bands (1.6 to 2.43 µm) at a spatial resolution of 30 m in shortwave infrared (SWIR) and five bands (8.125 to 11.65 µm) with spatial resolution of 90 m. Each ASTER scene cover 60°x60 km² area, which is suitable for geological regional mapping [4]. The possibility of applying several image processing algorithms to unique integral bands of ASTER is one the most important application of the data for hydrothermal alteration mapping [4]. SWIR bands of ASTER contain great ability for detecting and mapping hydrothermal alteration zones [2,3].

In this investigation, the applicability of target detection algorithms, including Constrained Energy Minimization (CEM), Orthogonal Subspace Projection (OSP) and Adaptive Coherence Estimator
(ACE) algorithms were tested to ASTER SWIR bands for mapping hydrothermal alteration zones in the Oscar II coast area in eastern Graham Land, Antarctic Peninsula.

2. Materials and Methods

2.1 Geology of the study area

The Oscar II coast area is located in north eastern Graham Land, Antarctic Peninsula (AP). It is an inaccessible region due to the remoteness of many rock exposures and travel over severe mountainous and glacier-cover terrains for geological field mapping and sample collection. The lithological units in Oscar II coast area consisting of (i) volcanic and volcaniclastic rocks (Mapple Formation), (ii) intrusive rocks, (iii) sedimentary rocks (Botany Bay and Trinity Peninsula Groups). Figure 1 shows geological map of the Oscar II coast area [5].

![Geological map of the Oscar II Coast area](image)

**Figure 1.** Geological map of the Oscar II Coast area [5]

2.2 ASTER remote sensing data

The ASTER data used in this investigation were obtained from U.S. Geological EROS (http://glovis.usgs.gov/). An ASTER level 1 T (Precision Terrain Corrected Registered At-Sensor Radiance) scenes covering the Oscar II coast region and surrounding areas
(AST_L1T_00311222001131924) (Path/Row 218/106), north eastern part of Graham Land, Antarctic Peninsula (AP) was acquired on November 22, 2001 for the remote sensing analysis.

2.3 Data processing
Atmospheric and crosstalk corrections were applied to shortwave infrared bands of ASTER data before application of target detection algorithms. CEM is a target signature-constrained approach, which constrains the desired target signature with a specific gain while minimizing effects caused by other unknown signatures [6]. OSP algorithm is an unconstrained linear unmixing method that developed by [7]. ACE algorithm is a uniformly most powerful invariant detection statistic that derived from the Generalized Likelihood Ratio (GLR) approach [7]. In this investigation, the reference spectra of selected end-member minerals for implementing target detection algorithms were extracted from the ASTER spectral library version 2.0 and were convolved to the spectral response function of ASTER’s SWIR bands. Selected end-member spectra (target alteration minerals) in this study were muscovite, illite, montmorillonite, epidote, chlorite and biotite. The results of CEM, OSP and ACE appear as a series of gray scale (rule) images, one for each selected endmember. The value in resultant image represents the sub-pixel abundance of the target alteration mineral in each pixel. Rule image classifier tool was used for post classification of the resultant images. They were classified by maximum value option, and 0.050 was selected as appropriate threshold value for all resultant rule images [8,9].

3. Results and discussion
Figure 2 displays the reference spectra of selected end-member minerals for implementing CEM, OSP and ACE algorithms, which was convolved to the spectral response function of SWIR bands of ASTER. Muscovite, kaolinite, illite, montmorillonite, epidote, chlorite and biotite were target alteration minerals in the study area (Fig. 2). CEM, OSP and ACE algorithms were applied to a selected spatial subset scene the zone between Crane Glacier and Pequod Glacier of the Oscar II coast area (see Fig. 1).

![Figure 2. Reference spectra of selected end-member minerals from ASTER spectral library that convolved to ASTER’s SWIR bands](image-url)
Figure 3 shows the resultant image map derived from CEM algorithm for the zone between Crane Glacier and Pequod Glacier (Oscar II coast region). The distribution of sub-pixel abundance of alteration minerals was mapped. The CEM algorithm was capable to detect detailed surface distribution of fractional abundance of alteration target minerals in the selected zone. In fact, previous alteration classes that simply assigned to chlorite-muscovite, muscovite-chlorite and muscovite contain variety of mineral assemblages (see zoom parts in Figure 3). Montmorillonite is one the high abundance alteration mineral in muscovite-chlorite class especially associated with exposed rocks near Crane Glacier. Biotite was detected in this study; previously it has been classified in many zones as low albedo area in the geology map. In addition, detailed distribution of kaolinite and epidote in the study zone was mapped (see zoom parts in Figure 3).

OSP was applied to the selected spatial subset sector between Crane Glacier and Pequod Glacier (Oscar II coast region) for distinguishing subpixel distribution of end-member minerals. The resultant rule images were classified by 0.050 thresholding the images. But, the resultant image map was not informative and classified. However, the gray scale (rule) images show high DN (digital number) values of the sub-pixel abundance of the target end-member mineral in the image. Despite, testing different threshold values, classified image was not produced using rule image classifier tool. Therefore, RGB color composite was used to visualize the subtle differences in the rule images. This was done because the resultant image map contains information about diagnostic features of selected end-member minerals.

Figure 3. Resultant image map derived from CEM algorithm

Figure 4 displays RGB image map of kaolinite rule image (red), montmorillonite rule image (green) and chlorite (blue). Variety of colors is manifested in the pixel background of exposed lithology, including magenta, purple, pink, red, green, blue, yellow, cyan and white. The detected
pixel classes are consistent with CEM resultant map (Fig. 3). High sub-pixel abundance value for kaolinite is coded in red (Fig. 4); therefore, zones contain high surface distribution of kaolinite appear in shades of red. Montmorillonite high abundance zones depict in shades of green in the rock exposure background. Blue color shade zones contain high sub-pixel abundance value of chlorite (Fig. 4). It is evident that in RGB image map the mixture pixel colors such as magenta, purple, pink, yellow, cyan and white represent combination of alteration mineral assemblages. For instance, yellow color represents a mixture of kaolinite and montmorillonite; purple color exhibits a mixture of kaolinite and chlorite; magenta, cyan, pink and white colors characterize different combinations of sub-pixel abundance of kaolinite, montmorillonite and chlorite mineral assemblages (Fig. 4).

ACE algorithm was also implemented to the selected spatial subset zone (between Crane Glacier and Pequod Glacier; Oscar II coast region) of the study area. Resultant gray scale (rule) images depict high DN values of the sub-pixel abundance of the target mineral in the study zone. Rule image classifier tool was used to produce a classified image map. But, the image map contains very noisy background, and classified mineral zones were not discernable from the background. Accordingly, RGB color composite was applied to produce an image map for the selected zone using the rule images comprise high DN values and low noisy background. Muscovite rule image was selected and assigned to red (R), chlorite rule image was assigned to green (G), and biotite rule image was assigned to blue (B), respectively. Figure 5 shows the resultant image map for the study zone. Magenta and red pixels show high fractional abundance of muscovite, and green pixels are chlorite high abundance area. Biotite papers as purple pixels in rock exposure region. Comparison with CEM and OSP resultant image maps indicates that the detected minerals by ACE algorithm are well agreed with high abundance zones of muscovite, chlorite and biotite.

Figure 4. RGB image map of kaolinite (red), montmorillonite (green) and chlorite (blue) derived from OSP algorithm
4. Conclusion
The remote sensing satellite-based approach used in this investigation to map poorly exposed lithologies has been shown to perform extremely well in the Antarctic environments. It could be comprehensively used for alteration mapping and hydrothermal ore mineral exploration in other inaccessible regions. The capability to distinguish fractional abundance of alteration minerals using CEM, OSP and ACE algorithms provided invaluable information for discrimination lithological units and alteration mineral assemblages in remote and inaccessible terrains at district scale. Sub-pixel abundance value of mafic minerals such as epidote, chlorite and biotite (Fe, Mg-OH absorption), K-feldspar alteration products (kaolinite, illite, montmorillonite) and muscovite (Al-OH absorption) was detected using ASTER SWIR bands in poorly mapped and unmapped regions in the northern and southern sectors of Oscar II coast area, Graham Land.

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