Planetary and Space Science 101 (2014) 108–117

Contents lists available at ScienceDirect

Planetary and Space Science

journal homepage: www.elsevier.com/locate/pss

Mapping the wavelength position of deepest absorption features to explore mineral diversity in hyperspectral images

Frank J.A. van Ruitenbeek [a,*], Wim H. Bakker [a], Harald M.A. van der Werff [a], Tanja E. Zegers [b], Jelmer H.P. Oosthoek [c,d], Zulfa A. Omer [a], Stuart H. Marsh [e,f], Freek D. van der Meer [a]

[a] University of Twente, Faculty of Geo-Information Science and Earth Observation (ITC), Hengelosestraat 99, PO Box 37, Enschede 7500 AA, The Netherlands
[b] Utrecht University, Faculty of Earth Sciences, Budapestlaan 17, 3584CD Utrecht, The Netherlands
[c] TNO/Deltares—Geological Survey of the Netherlands, Princetonlaan 6, 3584CB Utrecht, The Netherlands
[d] Jacobs University Bremen, Campus Ring 1, 28759 Bremen, Germany
[e] British Geological Survey, Kingsley Dunham Centre, Keyworth, Nottingham NG12 5GG, England
[f] University of Nottingham, Nottingham Geospatial Institute, Triumph Road, Nottingham NG7 2TU, England

ARTICLE INFO

Article history:
Received 18 October 2013
Received in revised form
19 June 2014
Accepted 23 June 2014
Available online 1 July 2014

Keywords:
Mars
Mineral
Hyperspectral
OMEGA
CRISM
Wavelength

ABSTRACT

A new method is presented for the exploratory analysis of hyperspectral OMEGA imagery of Mars. It involves mapping the wavelength position and depth of the deepest absorption feature in the range between 2.1 and 2.4 μm, where reflectance spectra of minerals such as phyllosilicates, carbonates and sulphates contain diagnostic absorption features. For each pixel of the image, the wavelength position maps display the wavelength position of the deepest absorption feature in color and its depth in intensity. This can be correlated with (groups of) minerals and their occurrences.

To test the validity of the method, comparisons were made between wavelength position maps calculated from OMEGA images of the Nili Fossae area at two different spatial resolutions, of 0.95 and 2.2 km, and five CRISM images in targeted mode, at 18 m spatial resolution. The wavelength positions and their spatial patterns in the two OMEGA images were generally similar, except that the higher spatial resolution OMEGA image showed a larger diversity of wavelength positions and more spatial detail than the lower resolution OMEGA image. Patterns formed by groups of pixels with relatively deep absorption features between 2.250 and 2.350 μm in the OMEGA imagery were in agreement with the patterns calculated from the CRISM imagery. The wavelength positions of clusters of similar pixels in the wavelength position maps are consistent with groups of minerals that have been described elsewhere in the literature.

We conclude that mapping the wavelength position of the deepest absorption features between 2.1 and 2.4 μm provides a useful method for exploratory analysis of the surface mineralogy of Mars with hyperspectral OMEGA imagery. The method provides a synoptic spatial view of the spectral diversity in one single image. It is complementary to the use of summary products, which many researchers have been using for assessment of the information content of OMEGA imagery. The results of the exploratory analysis can be used as input for the construction of surface mineralogical maps. The wavelength position mapping method itself is equally applicable to other terrestrial and planetary data sets and will be particular useful in areas where field validation is sparse and with imagery containing shallow spectral features.

1. Introduction

Hyperspectral remote sensing has been used for the identification of surface minerals of Mars. By measuring and analysis of reflected electro-magnetic radiation in the visible and reflective infrared wavelength ranges, the mineralogical composition of the Martian surface can be inferred. The analysis and interpretation of hyperspectral imagery acquired by OMEGA (Observatoire pour la Mineralogie, l'Eau, la Glace et l'Activite) (Bibring et al., 2004a), the hyperspectral imager of the Mars Express orbiter, led to the discovery of hydrated minerals such as phyllosilicates and sulphates (Bibring et al., 2005; Gendrin et al., 2005; Poulet et al., 2005). The hyperspectral imager CRISM (Compact Reconnaissance Imaging Spectrometer for Mars) (Murchie et al., 2007), of the Mars

* Corresponding author. Tel.: +31 53 4874280.
E-mail address: f.j.a.vanruitenbeek@utwente.nl (F.J.A. van Ruitenbeek).

http://dx.doi.org/10.1016/j.pss.2014.06.009
0032-0633/

Reconnaissance Orbiter, provided more information on the diversity and composition of hydrous minerals and their occurrences on the Martian surface (e.g. Bishop et al., 2008; Ehlmann et al., 2008, 2009; Mustard et al., 2008).

Exploratory image analysis is commonly applied to make a first assessment of the information content of a hyperspectral image and the minerals or groups of minerals present in the image. The exploratory analysis of hyperspectral imagery of Mars is not straightforward because of (1) the relatively shallow absorption features of surface minerals in the spectra; (2) the instrument artifacts present in the data, including bad detector elements, striping and spectral spiking (Carter et al., 2013a, 2013b); and (3) the lack of ground samples of surface materials for most areas on Mars. The shallow absorption features of surface minerals in the spectra make it difficult to separate mineralogical surface information from instrument artifacts in the images.

Common methods for exploratory analysis of hyperspectral imagery from Mars are based on calculation of spectral indices or summary products (Pelkey et al., 2007). This involves the arithmetic combination of various spectral bands that highlight the presence of spectra of one or more minerals or other materials, such as water ice, in the image. Each of these indices can then be visualized as an image and further analysis may then provide information on the presence and distribution of that particular surface material. Other methods that have been used include analysis of spectral variance using Principle Component (PC) analysis (Murchie et al., 2000), spectral-spatial analysis using image segmentation (Gilmore et al., 2011) and minerals detection with adapted linear unmixing (Schmidt et al., 2014). The critical limitation of all these methods is that in the derivative products, i.e. indices images, PC's etc., information on the wavelength position of absorption features is not explicitly represented. This is inconvenient, since the wavelength positions of absorption features in reflectance spectra of minerals are key identifiers of the types of molecular bonds and their strengths in their crystal lattices (Clark, 1993).

In this paper, we present an alternative method for exploratory analysis of hyperspectral images for mineral identification. This method is based on the calculation of the wavelength position and depth of the deepest absorption feature in image spectra between 2.1 and 2.4 μm. This wavelength region is used because it contains diagnostic absorption features for a wide range of minerals such as phyllosilicates, sulphates and carbonates (e.g. Clark et al., 1990). From the resulting image maps, an assessment of the dominant groups of minerals and their spatial distribution can be readily made and subtle spectral features can be analyzed. These mineral occurrences can then be further mapped and interpreted by comparison with terrestrial analogues of Martian environments (van der Meer et al., 2012), such as hydrothermally altered volcanic rocks and sedimentary rocks in the Archean Pilbara in Australia (Brown et al., 2010; van Ruitenbeek et al., 2012; Westall et al., 2011) and lake sediments and evaporates in the East African Rift Valley (Kodikara et al., 2012). The use of this new wavelength position mapping method is demonstrated in the Nili Fossae area of Mars (Fig. 1), which is known for its large diversity of hydrated minerals (Ehlmann et al., 2009; Mangold et al., 2007; Mustard et al., 2007). It is applied to two overlapping OMEGA images and five CRISM images of the same area.

2. Methods

Two overlapping OMEGA images of different spatial resolution were used in the analysis, as well as 5 high-resolution CRISM images covering different parts of the same area. Maps of the wavelength position of the deepest absorption features within different wavelength ranges were created from all of these images. Wavelength position maps were calculated over the following wavelength ranges: 1.35–1.50 μm, 1.70–2.10 μm and 2.10–2.40 μm. To assess the validity of the maps, the spatial patterns, statistics of wavelength position and depth of absorption features and image spectra of selected Regions of Interest (ROIs) were compared. The ROIs were created from areas of uniform wavelength positions and deep absorption features that could be traced on the OMEGA and CRISM images. Each ROI in the OMEGA image covered between 3 and 11 km^2. ROIs in the CRISM images were created by visually matching them with areas in the OMEGA images, each covering between 900 and 2000 CRISM pixels, which corresponds to 0.29 to 0.65 km^2. The comparison was conducted both between the two OMEGA images of different spatial resolutions and between the high-resolution OMEGA image and the CRISM images.

2.1. Processing of OMEGA imagery

OMEGA images ORB0422_4 and ORB0232_2 were downloaded from the Planetary Science Archive (PSA). The raw data were converted to reflectance images following the procedure of Bakker et al. (2014). First, the downloaded data were converted to radiance values using the public domain software tools Soft07 (ESA, 2010). Noisy spectral bands in the radiance data cubes were identified and masked using an automated process based on their signal-to-noise statistics. Then the images were geocoded using the location information in the geocube file. Each data set acquired by the three different detectors (VNIR, SWIR1 and SWIR2) was geocoded separately to overcome misalignments between the detectors. Spectral subsets of the SWIR1 bands were made and used for further processing. The spatial resolutions of the SWIR 1 data sets after geocoding were 2.2 km and 0.95 km/pixel for images ORB0422_4 and ORB0232_2, respectively. The geocoding of the two images was improved manually by visually matching them with daytime imagery from THEMIS (THermal EMission Imaging System) (Christensen et al., 2004). Solar and atmospheric corrections were applied to the geometrically corrected images. The atmospheric correction was performed in two steps. First, a transmittance model was derived from the image, and second an atmospheric correction was done using this transmittance model. The atmospheric transmittance models were calculated from in-scene statistics and differ between the two OMEGA scenes. Random noise was reduced in the image by spectral spatial filtering over 5 neighboring pixels and 2 neighboring bands.

The processing was conducted using a software package written by one of the team called Hyperspectral Python (HypPy) (Bakker, 2012). The functionality used in this paper for processing and analysis of OMEGA data was developed during the European Space Agency's Mars planetary mapping pilot project (Tragheim et al., 2010).

2.2. Processing of CRISM imagery

CRISM TRR3 images frt0000d6d6, frt0000b012, frt0000a053, frt00009971 and frt000064d9, all acquired in targeted mode, were downloaded from the CRISM map archive (crism-map.jhuapl.edu). The images were processed to reflectance using the CRISM Analysis Tools (CAT, version 7.2) following the procedures described by Morgan et al. (2009). First, a photometric correction was applied using a cosine function. The resulting data were atmospherically corrected with an atmospheric transmittance model obtained by the volcano-scan method. Wavelengths were chosen according to the New McGuire 2-wavelength method (McGuire et al., 2009). Bad bands were removed and the image