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Modeling and assessment of wavelength displacements of characteristic absorption features of common rock forming minerals encrusted by lichens

Sara Salehi [a,b,*], Derek Rogge [c], Benoit Rivard [d], Bjørn Henning Heincke [a], Rasmus Fensholt [b]

[a] Department of Petrology and Economic Geology, Geological Survey of Denmark and Greenland, Copenhagen, Denmark
[b] Department of Geosciences and Natural Resource Management, University Of Copenhagen, Copenhagen, Denmark
[c] German Remote Sensing Data Centre, DLR, Munchnerstr. 20, D-82234, Germany
[d] Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton T6G 2E3, Canada

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ABSTRACT

Arctic environments provide a challenging ground for geological mapping and mineral exploration. Inaccessibility complicates ground surveys and the presence of ice, vegetation, and lichens hinders supportive remote sensing surveys. Spectral mixing of lichens and bare rock can shift the wavelength position of characteristic absorption features, thereby complicating the spectral mapping of minerals and lithologies. The extent to which diagnostic rock features are preserved despite the presence of lichens is of major concern in remotely sensed geological studies and estimates of the critical level of lichen coverage, below which spectral features of the mineral substrate can still be identified, are needed. We investigated how surficial lichen cover affects the characteristics of shortwave infrared (SWIR) mineral absorption features and the efficacy of automated absorption feature extraction. For this purpose, mixed spectra were synthetically generated from laboratory spectra of common rock forming SWIR absorbing minerals and lichens. Wavelength displacements of characteristic absorption features for each mixed spectrum were then analyzed as a function of percentage lichen cover. Distinctive trends were identified that can be used in future analysis: The strong spectral features of mica group minerals around 2200 and 2340–2350 nm maintain their integrity for up to 30% lichen cover, despite the related shift toward shorter wavelengths for higher percentage lichen cover. In contrast, very weak absorption bands around 2440 nm in (white) micas spectra are completely obscured for a lichen cover of ≥50%. Our observations suggest that the chlorite feature around 2250 nm is shifted toward longer wavelengths and the depth of this feature as well as the contrast between lichen and substrate spectra define the amount of lichen needed to mask it. Furthermore, lichens induce a spectral shift towards shorter wavelengths for the features around 2320 nm for the rocks containing amphibole, chlorite, carbonate and serpentine group minerals. In addition, no wavelength displacement is observed for chlorite, biotite and phlogopite features around 2380 nm in mixtures with lichens. By quantifying lichen cover effects on mineral absorption features, our study highlights the importance of being precautious in any interpretation in areas characterized by abundant lichen-covered outcrops. This can be of significant importance for mineral and deposit vectoring as the presence of abundant lichen coverage causing slightly shifted features for a given spectra can be erroneously identified as a path to a deposit.

1. Introduction

Hyperspectral systems are being increasingly used for geological mapping at a subpixel scale through spectral mixture analyses (SMA) (Smith et al., 1990). Large aerial coverage and relatively quick map production are factors, which make this type of analysis particularly attractive in areas of difficult access, such as large parts of the subarctic and arctic (Budkewitsch et al., 2000; Gou et al., 2015; Harris et al., 2001; Harris et al., 2005; Rogge et al., 2009; Rogge et al., 2014; Schetselaar and deKemp, 2000; Schetselaar and Ryan, 2009; Staenz et al., 2000). Expansion of mapping is however needed in remote places (e.g. in Greenland), where a large proportion of the area is still unexplored and the lack of infrastructure reduce the capabilities to economically explore and locate mineral resources using traditional techniques. The discrimination and classification of lithological units using hyperspectral imagery primarily makes use of SMA based on a linear

* Corresponding author at: Department of Petrology and Economic Geology, Geological Survey of Denmark and Greenland, Copenhagen, Denmark.
E-mail addresses: ssal@geus.dk (S. Salehi), derek.rogge@dlr.de (D. Rogge), benoit.rivard@ualberta.ca (B. Rivard), bhm@geus.dk (B.H. Heincke), rf@ign.ku.dk (R. Fensholt).

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combination of pure reflectance spectra referred to as spectral end-members (Singer and McCord, 1979). However, the mixture of signatures from various components within individual pixels can often mask the diagnostic spectral features thereby potentially complicating spectral unmixing and the following classification. A pervasive example of such mixing of signatures in high latitude and subarctic environments is the presence of abundant lichen growing on rock outcrops. Lichens are symbiotic organisms particularly well adapted to extreme environmental conditions, which impede the identification of rocks/minerals in two ways: (1) Lichens prevent transmission of light to the rock substrate and thereby mask the mineral features, such that no useful information can be drawn from the spectra (Ager and Milton, 1987; Bechtel et al., 2002). (2) Lichens grow on rocks in a non-random way and cause mixing of features spectrally. These mixtures can cause shifts in diagnostic absorption features of minerals and may hinder the ability to detect the spectral properties of rocks (Bechtel et al., 2002; Rivard and Arvidson, 1992). A number of studies have investigated the spectra mixing of lichens and their rock substrate and the associated challenges in identification of mineralogy based on interpretation of the spectra (Ager and Milton, 1987; Bechtel et al., 2002; Laakso et al., 2015; Laakso et al., 2016). The underlying principle is that a given spectrum is a linear mixture of the representative signatures from the constituents of each pixel (Kruse et al., 1993). This assumption is reliable for mixtures of lichens and rocks as <3% of light is transmitted through lichens to the substrate throughout the 350–2500 nm region (Ager and Milton, 1987; Bechtel et al., 2002). Bechtel et al. (2002) examined variations in lichen spectra in relation to color, type and lichen species and proposed a set of lichen spectral indices to guide the selection of a single lichen end-member for decomposition of the rock and lichen spectral mixtures by SMA.

While efficacy of hyperspectral methods for mineral exploration purposes has been the topic of various studies, less research has been devoted to studies of arctic and subarctic lichens (Harris et al., 2005; Staenz et al., 2000). A study was performed by Satterwhite et al. (1985) to determine the spectral characteristics of granitic rock encrusting lichens. However, the measurements were confined to the 400–1100 nm spectral region, which excludes the SWIR part of the electromagnetic spectrum that is relevant for the analysis of geological targets and is exploited by many hyperspectral imaging systems (Budkewitsch et al., 2000; Harris et al., 2005; Kruse et al., 2012). Rivard and Arvidson (1992) studied the variability in spectral features as based on a limited number of in situ spectral measurements (450 to 2400 nm) for a group of lichen bearing rocks, yet without identification of the species of lichens. Rollin et al. (1994) focused on the influence of weathering and lichen cover on the reflectance spectra of granitic rocks over visible and infrared wavelengths and suggested that absorption features in the SWIR region are potentially useful to generate indices applicable to detect lichens in airborne/spaceborne hyperspectral imagery. A recent study by Li et al. (2015) revealed multiple lichen related absorption and reflection features and a set of spectral indices were developed (covering the wavelengths of 680–1320 nm, 1660–1725 nm, and 2230–2300 nm) to estimate lichen coverage in remotely sensed imagery and field spectroscopy measurements.

Several gaps in current knowledge about the effect of lichens with respect to geological applications however remain. Mineral compositional variations in an alteration system appear to be strongly correlated with wavelength shifts of diagnostic absorption features (e.g. chlorites, carbonates and sericite). However, organic growth such as lichens can also induce spectral shifts in the wavelength position of the same diagnostic absorption features within the SWIR range and can cause misclassification and false positives if spectral feature fitting methodologies are used for mapping. This can be of significant importance for mineral and deposit vectoring as the presence of abundant lichen coverage causing slightly shifted features for a given spectrum can be erroneously identified as a path to a deposit. Laakso et al. (2016) demonstrated that the apparent spectral shift of the iron feature toward shorter wavelengths, caused by rock-encrusting lichens, might impede classification of gossans based on the iron oxide mineralogy. However, the study did not investigate the impact of lichen cover on spectral recognition of common rock forming mineral features in the SWIR being vital for accurate interpretation of spectra. In addition, previous studies suggest that the abundance of lichens in a mixture can be estimated reasonably well and with an acceptable error level (Théau et al., 2005; Zhang et al., 2004; Zhang et al., 2005), but a rigorous examination of the effect and scale of wavelength displacements of mineral features as a result of mixing with different lichen abundances is yet to be conducted.

We focus here on the SWIR region (2100–2500 nm) and investigate (a) the scale of wavelength displacement induced by different percentage of lichen cover and (b) the extent to which characteristic rock features are preserved despite rock encrusting lichens. This allows us to quantify the problem of displacement and to establish strategies of how to adapt data analysis to minimize this effect. The ASD spectral measurements of a real set of common rock types have been used as a representation of the lichen-free weathered surfaces and lichen signatures have been measured from the rocks themselves. This sample set, including mineral mixtures as well as lichen mixtures, is expected to represent a more realistic case to analyze the trends in shifts for specific minerals for real rocks as compared to using mineral spectra from the USGS library.

2. Study area and geology

Arctic regions such as Greenland are ideal for remote sensing studies due to extensive areas of well-exposed rocks and low vegetation coverage. Greenland is characterized by about 20% of ice-free surface area, dominated by crystalline rocks of the Precambrian shield. This ice-free zone generally consists of very well exposed rocks that, to a variable extent, are covered by the crusts of lichens. For the purpose of this study, samples that comprise common and economically important rock types were investigated, originating from three tracts at different parts of Greenland, namely Liverpool Land (Central East), Karrat (Central West) and Sisimiut-Kangerlussuaq (South West) (Fig. 1).

The Karrat region in West Greenland comprises three main formations: the Mârmorilik (dominated by carbonates), Qeqertarssuaq (mainly siliciclastic and comprises hornblende schist, amphibolite and commonly minor carbonate), and Nukavsak (dominated by dark colored alternating pelitic and semipelitic schists) (Escher and Watt, 1976). The Sisimiut- Kangerlussuaq region is located approximately 500 km to the south of Karrat. This region is characterized by metamorphic terrains of both Archaean and Palaeoproterozoic ages with metamorphic grade varying from low amphibolite facies to granulite facies towards the north. The area hosts an alkaline province and a variety of ultramafic alkaline rocks, including swarms of kimberlite and lamproite dykes (Jensen et al., 2002; Larsen and Rex, 1992). The crystalline complex of North Liverpool Land in Central East Greenland is characterized by Precambrian, marble bearing metamorphic rocks and granites-quartz-monzonites of Caledonian or Neoproterozoic age (Coe and Cheeney, 1972).

There is a rich lichen flora in all three areas, and the lichens show fairly high cover percentage (up to 95% of the ground cover) in many places (Graham, 1999). Heaths and dry cyperaceous communities, snow-patch vegetation, grassy meadows and swamps are the typical features of Liverpool Land. The Karrat region is particularly characterized by willow scrub, meadows, various heaths and steppe-like communities rich in xerophilous lichens. The Sisimiut region is characterized by alder scrub, tall luxuriant willow scrub and freshwater vegetation. The local temperature varies from 2° to 10 °C in July for Liverpool Land, Karrat and Sisimiut, respectively.