Remote Sensing of Environment 131 (2013) 173–181

Contents lists available at SciVerse ScienceDirect

Remote Sensing of Environment

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

The longwave infrared (3–14 μm) spectral properties of rock encrusting lichens based on laboratory spectra and airborne SEBASS imagery

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ARTICLE INFO

Article history:
Received 1 November 2012
Received in revised form 21 December 2012
Accepted 23 December 2012
Available online 20 January 2013

Keywords:
Reflectance
Transmittance
Longwave
Infrared
Spectra
Lichens
SEBASS
Minerals

ABSTRACT

There has been a progressive emergence of airborne longwave spectral sensing capabilities (e.g. spatially enhanced broadband array spectrograph system, SEBASS) of potential value for remote geological mapping in arctic and subarctic regions. However the presence of rock encrusting lichens can obscure spectral features diagnostic of minerals. This paper documents the longwave (3–14 μm) spectral transmittance and reflectance properties of rock encrusting lichens as determined from lichen samples, from rock samples encrusted with lichens and observations from airborne SEBASS imagery. The samples and SEBASS airborne hyperspectral imagery were acquired over the 1.9 Ga Cape Smith greenstone belt of northern Quebec.
Within the Restrahlen region (8–12 μm), where silicate minerals display peaks in reflectance, the maximum reflectance observed for rock encrusting lichens is 1.6%. These lichens display low reflectance and spectral contrast and approach a blackbody behavior. For lichens detached from the rock substrate, spectra obtained on two backgrounds of contrasting reflectance are similar (<0.75% difference in reflectance) indicating that lichens transmit little or no light.
Detailed observations reveal three features that can be attributed to organic compounds in lichens (3.41, 6.58, 8.13 μm). The feature located near 8.13 μm is a reflectance peak within the Restrahlen region of enhanced mineral reflectance. A measure of the strength of this feature and the mean reflectance in the Restrahlen region for laboratory data and SEBASS imagery reveals linear mixing trajectories between a lichen endmember and a suite of geological endmembers. This data representation enables the visualization of mixing lines, the delineation of geologically informative endmembers, and provides a means to mask pixels in imagery that encompass the greatest abundance of rock encrusting lichens therefore facilitating geological mapping. The implications for the detection of geological endmembers and mapping are discussed.

1. Introduction

The ability to map lithologic units or mineral assemblages is one of the most useful contributions of hyperspectral imaging to the field of geology. In arctic and subarctic regions the application of remote sensing data is particularly attractive owing to the extensive bedrock exposure. However, in these regions lichens are typically the first colonizers on rock substrate (Kiang et al., 2007) and their presence can hamper mapping efforts by reducing the effective area of bedrock available for observation and obscuring spectral features diagnostic of minerals (Rivard & Arvidson, 1992; Bechtel et al., 2002).

Since the 90's there have been a number of investigations of the optical properties of lichens to support the analysis of multispectral/hyperspectral airborne and spaceborne imagery as this data had become readily available. In 2002 we determined that the transmission of light through lichen was less than 3% throughout the 350–2500 nm spectral range (Bechtel et al., 2002). Thus, in the optical spectrum lichens largely prevent the transmission of light through the lichen mat to the underlying rock substrate. Their effect on the spectral reflectance of a rock surface is variable, depending on the spectral contrast between the lichen and the bare rock (Satterwhite et al., 1985; Mulder et al., 2011) and the extent of cover of lichen. Using the band ratios 2132/2198 and 2232/2198 nm for five crustose lichen species, Bechtel et al. (2002) showed the similarity in shape of 10 lichen species in the short wave infrared (SWIR) which supported similar observations by Rivard and Arvidson (1992) and Rees et al. (2004). These results implied that the mixing of lichen and rock spectra within a scene should be linear for this spectral range. A laboratory investigation by Zhang et al. (2005) demonstrated the linear mixing systematic of lichen rock spectral mixtures using a lichen covered rock sample from Alberta, Canada with unmixing results correlated well ($R^2 > 0.9$) with abundances estimated from photography. The NIR properties of lichens were also investigated (Bechtel et al., 2002) revealing that groups of lichen species could be discerned on spectral grounds primarily owing to differences in pigments.

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0034-4257/$ – see front matter
http://dx.doi.org/10.1016/j.rse.2012.12.018

Laboratory investigations were followed by regional demonstrations where lichen distribution could be mapped using airborne hyperspectral imagery. Rogge et al. (2007, 2009) found that a single image endmember provided a good match with published lichen spectra (Bechtel et al., 2002) and field spectra of the dominant rock encrusting lichens. Applying spectral mixture analysis (SMA, Mustard & Sunshine, 1999; Smith et al., 1990) to HyMap airborne imagery for Baffin Island, Canada, Rogge et al. (2007, 2009) showed that the abundance map of the lichen endmember defined a spatial distribution that was correlative with known rock units, even in instances of almost complete lichen cover. The map thus had considerable value for geologic mapping. For the same area Harris et al. (2005) found that lichen predominate mostly on gabbros. In a recent study Leverington and Moon (2012) also indicated that the complicating effects of lichen for multispectral lithologic mapping are best mitigated through the definition and use of separate lichen endmembers during SMA.

The studies listed above point to a history of emerging knowledge related to the basics of lichen spectroscopy and its use to develop sophisticated methods of image analysis, particularly hyperspectral imagery. However, this knowledge is presently limited to the optical spectrum. More recently there has been a progressive emergence of airborne longwave spectral sensing capabilities including the SEBASS (spatially enhanced broadband array spectrograph system, Aerospace Corp.), TASI (Itres), and Hypercam (Telops) systems. These systems are appealing for geological investigations given that silicates, minerals and rocks have diagnostic Restrahlen features in the 8–12 μm region (Lyon, 1965, 1972; Walter & Salisbury, 1989; Nash & Salisbury, 1991). In particular, SEBASS has been flown for large regional surveys to support geological investigations. We know of no published data on the longwave (3–14 μm) spectral reflectance properties of encrusting lichens in the literature. Ager and Milton (1987) quote unpublished laboratory measurements stating that at least for the mid-infrared region (3–5 μm) lichen transmits little or no radiation. Transmittance from 2.2 to 14.5 μm is said to be less than 0.15% for one green foliose and two brown foliose species, and less than 1.3% for another green foliose species. No crustose lichens were measured due to the difficulty of removal from their host rock. Thus, the above results need to be confirmed.

This paper starts where optical studies began, that is with a documentation of the transmittance and reflectance properties of rock encrusting lichens as determined from lichen samples, from rock samples encrusted with lichens and with preliminary observations from airborne imagery. The samples and SEBASS airborne hyperspectral imagery were acquired over the 1.9 Ga Cape Smith greenstone belt of northern Quebec (Nunavik), Canada (62 Lat, −75 Long) (Fig. 1) where lichen encrusted bedrock exposure is extensive (Rivard et al., 2010a, 2010b; Feng et al., 2012). Within the Restrahlen region (8–12 μm), we will show that lichens display very low reflectance and transmit little or no light. Detailed observations reveal that lichens display features that can be attributed to organic compounds in lichens. The use of these features is shown to define mixing trajectories in laboratory data and SEBASS imagery between a lichen endmember and a suite of geological endmembers. The implications for the detection of geological endmembers and mapping are discussed.

2. Data and experimental approach

2.1. Study area

The Cape Smith greenstone belt is host to Nickel–Cu-(PGE) mineralization occurring within a series of thick (50–200 m) mafic–ultramafic complexes that belong to the Povungnituk and Chukotat groups (Fig. 1). Vegetation is minimal, but rock encrusting lichens are predominant on bedrock surfaces, adding to the challenge of remotely mapping packages of rocks (mafic to ultramafic) with similar mineralogy. The mineral ores, host rocks, and country rocks have been regionally metamorphosed to lower greenschist facies, but igneous and volcanic fabrics and textures are well preserved.

2.2. Description of sample suite

Fifty two rock samples (labeled DR# in Tables 1 and 2) were collected from bedrock outcrops across the Goldbrook property (Fig. 1) as part of Ni–Cu(PGE) exploration efforts. The rock sample suite is dominated by basalt, gabbro, pyroxenite, and peridotite (Table 1), but also includes a limited number of sedimentary rocks (Table 2). X-ray diffraction (XRD) was conducted on the mafic and ultramafic samples (Table 1) to determine the dominant mineralogy. The mineralogy of the main rock units is indicative of greenschist metamorphism and includes: (antigorite, ±diopside, ±clinochlore, magnetite) for peridotite, (antigorite, ±talc, clinochlore, Fe-amphibole, magnetite) for pyroxenite, and (Ca-amphibole, clinochlore, ±phlogopite, ±epidote, albite/orthoclase) for gabbro/basalt.

Each rock sample was collected to preserve the exposed surface, which for all samples, displays a range of lichen cover and lichen types (Fig. 2). For a subset of four rock samples it was possible to detach foliose (leaf like) lichen samples (labeled LDR# in Tables 1, 2 and Fig. 3) from the rock substrate without damaging or altering the lichen. Seven foliose (leaf-like) samples were obtained from three samples (LDR16, 18, 44; Fig. 3). One filamentous (hair-like) sample was collected from sample LDR45 (Fig. 3). These eight detached lichen samples were used to assess the light transmittance of lichen by acquiring spectra of lichen on a background of known reflectance.

2.3. Laboratory reflectance spectra collected from samples

Reflectance spectra were obtained from samples in the laboratory using an MB102 Fourier transform InfraRed (FTIR) spectrometer equipped with a Mercury/Cadmium/Telluride (MCT) detector and a

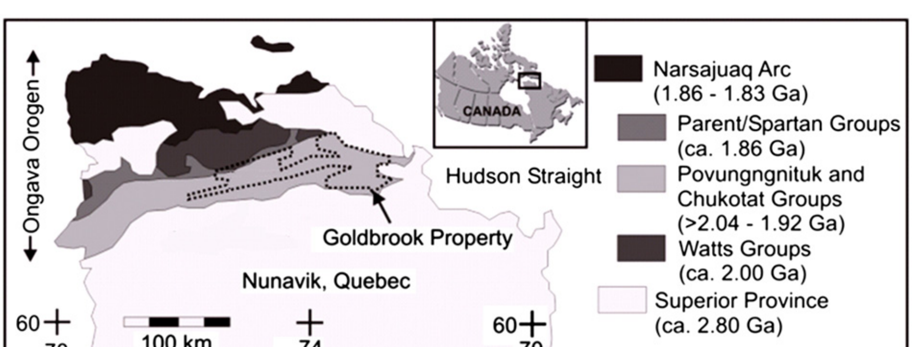

Fig. 1. Regional geology of Nunavik, Quebec. The Cape Smith greenstone belt is outlined by the distribution of the Povungnituk and Chukotat groups and includes the project area within the Goldbrook property.