ISPRS Journal of Photogrammetry and Remote Sensing 114 (2016) 137–150

Contents lists available at ScienceDirect

ISPRS Journal of Photogrammetry and Remote Sensing

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

Enhanced detection of gossans using hyperspectral data: Example from the Cape Smith Belt of northern Quebec, Canada

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ARTICLE INFO

Article history:
Received 4 October 2015
Received in revised form 25 January 2016
Accepted 5 February 2016
Available online 23 February 2016

Keywords:
Gossan
Iron oxide minerals
Mineral exploration
Geological mapping
Hyperspectral airborne remote sensing

ABSTRACT

Owing to the links between gossans and mineral deposits, detecting gossans by remote sensing means is essential for mineral exploration. In northern regions, gossans can develop as thin oxidized surfaces, named thin gossans, that can be covered with lichens. This study investigates the effects of spectral mixing between such gossans with lichens and their rock substrates using laboratory spectroscopic data obtained from samples collected in the Cape Smith Belt of Canada. These observations are then scaled up to the airborne hyperspectral data obtained from the same area. Our laboratory results indicate that the presence of lichens on gossans induces a general spectral shift towards shorter wavelengths of the iron absorption typical of gossan spectra. The opposite shift is observed due to the influence of the rock substrates. These effects can thus impede classification of gossans based on the interpretation of iron oxide mineralogy from spectra. Our airborne spectral results suggest that thin gossans can be detected and discriminated from thick gossans, and further broken down into several classes according to their host rock substrates. The ability to define distinct classes of thin gossans is significant since the association of these gossans with specific rock substrates can be exploited for exploration. The ability to distinguish thin and thick gossans alone can contribute to mineral exploration since it can be either the former or the latter group of gossans that acts as an ore deposit vector.

1. Introduction

Gossans are rocks with oxidized surfaces that result from the weathering of sulfide-bearing rocks and are comprised of predominantly iron oxide and iron hydroxide minerals (here collectively called the iron oxide minerals) such as goethite (α-FeOOH) and hematite (Fe_2O_3). Gossans have distinct earthy colors that result from their spectral characteristics in the visible and near infrared (VNIR; 400–1300 nm) wavelength region. These characteristics and the economic significance of gossans have drawn the attention of the geologic remote sensing community aspiring to detect gossan outcrops by remote sensing in support mineral exploration (see Rowan et al., 1977; and references therein). The majority of remote sensing studies that pertain to gossans have focused on arid and semi arid regions where ground cover is minimal or absent. Regions located above the treeline at high latitudes are ideal for remote sensing studies due to the dearth of standing vegetation. However, field access is difficult at high latitudes and lichens, the dominant autotrophs of polar and subpolar ecosystems (Longton, 1988), typically form extensive mats on rock outcrops and obscure the spectral properties of the underlying bedrock (Rivard and Arvidson, 1992) due to their optical thickness that prevents the transmission of light to the rock substrate (Ager and Milton, 1987; Bechtel et al., 2002). Similarly, the spectral properties of some gossans (e.g. thin oxidized surfaces) can be influenced by the underlying rock substrates through spectral mixing.

Gossans form at or near the surface where ferrous iron and sulfide minerals are unstable in the presence of weathering agents such as water-dissolved oxygen. These minerals are then converted to iron oxide and sulfate minerals that are less soluble and more stable under surface conditions (Krauskopf, 1967). Weathering of the iron sulfides leads to a drop in pH which in turn increases acidity and the weathering rates of sulfides. The profiles that develop through these processes are highly variable but can be tens of meters thick (Bellott et al., 1991; Maria Dreher et al., 2005) and leave a loose and poor substrate for vegetation. The iron oxide minerals of gossans have characteristic absorption features in the visible-near infrared wavelength region (VNIR; 400–1300 nm)

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http://dx.doi.org/10.1016/j.isprsjprs.2016.02.004
0924-2716/

due to electronic transitions and charge transfers of iron (Hunt et al., 1971). They display a pronounced ferric absorption feature near 900 nm (the ferric iron $^6A_1 \rightarrow {}^4T_1$ transition; the F_{900} from herein after Murphy et al., 2014) with an average band position varying from 884 nm for hematite, 917 nm for goethite, to 961 nm for lepidocrocite (Cornell and Schwertmann, 2003). The iron oxide minerals also show pronounced absorptions near 500 nm and 650 nm caused by the electronic transitions (Cornell and Schwertmann, 2003). The wavelength position and band depth of the iron oxide mineral absorptions can change due to several factors, e.g. replacement of iron by aluminium, variation in iron oxide abundance and particle size (Buckingham and Sommer, 1983; Cudahy and Ramanaidou, 1997). Nevertheless, several studies have used the band position of the F_{900} to determine the proportions of different iron oxide minerals in a mixture (Townsend, 1987; Cudahy and Ramanaidou, 1997; Murphy et al., 2014).

Previous studies have shown that orbital multispectral scanners, such as Landsat and ASTER, can be used to detect gossan outcrops in the absence of significant vegetation even at a spatial resolution of 30 m (e.g. Landsat Thematic Mapper) (see e.g. Abdelsalam et al., 2000; Volesky et al., 2003). Studies by Bierwirth et al. (2002) and Rogge et al. (2014) have demonstrated that meter-sized gossan outcrops can be delineated, and their iron oxide compositions estimated, by means of airborne hyperspectral datasets of high spatial and spectral resolutions. In these studies, the detection of gossans typically relies on sensing of VNIR spectral features in rocks rich in iron oxides. Generally, gossan bearing areas have sparse vegetation making the detection and characterization of the associated mineralogy possible (e.g. West et al., 2009), but several species of e.g. *Acarosporion sinopicae* lichen communities can grow on these low-pH, iron-rich environments (Purvis and Halls, 1996). With increased lichen growth, spectral mixing of gossans and lichens will take place, potentially significantly impacting the spectral characterization and detection of gossans from VNIR spectra.

The Cape Smith Belt is a high latitude (60 degrees north) Proterozoic fold and thrust belt that is the fourth largest magmatic Ni–Cu district in Canada (measured by its total metal content; Lydon, 2007). The belt comprises numerous gossan outcrops that span a range of characteristics. Thick gossans, which are commonly associated with sedimentary rocks and exhalites, occur as large showings and are not associated with economically viable ore deposits as they developed through weathering of the iron-rich gangue minerals, such as pyrite, or by means of transportation. These gossan surfaces are referred to as barren gossans to distinguish them from fertile gossans that potentially host significant concentrations of sulfide minerals (Taylor, 1987). Thick gossans typically form a loose substrate and thus have little or no encrusting lichens in the study area. In contrast, lichens generally occur on gossans that only have a thin oxidized layer. These are thin gossans which, in this location, are commonly associated with ultramafic rocks and in the context of exploration act as spatial indicators for prospective deposits. Thus the detection of thin gossans by means of remote sensing is of merit to support exploration activities.

This study was motivated by the observation that despite the voluminous literature on remote sensing of thick concentrations of the iron oxide minerals (e.g. Ruiz-Armenta and Prol-Ledesma, 1998; Madani, 2009; Farooq and Govil, 2013; Pour et al., 2013; Sadeghi et al., 2013; Rahimzadegan et al., 2015), little attention has been paid to the detection of thin gossans, which may be indicators of potential ore bodies. In pursuing the detection one has to understand the effect that biogenic coatings (e.g. lichens) and rock substrate mineralogy could impart on the spectral properties of thin gossans. The detection of thick gossans typically relies on sensing of VNIR spectral features diagnostic of iron oxide minerals (e.g. hematite and goethite) and establishing associations with specific bedrocks. Thin gossans on the other hand may reveal short-wave infrared (SWIR, 1300–2500 nm) spectral properties of the rock substrates beneath the oxidized surfaces. In this respect, Bedini (2011) and Cloutis et al. (2010a) noted that thin iron oxide weathering surfaces do not always completely mask the underlying rock substrates in the short-wave infrared (SWIR, 1300–2500 nm) region. There is thus potential remote sensing information that could be used to distinguish fertile gossans from barren gossans in areas of a known association between specific rock types and mineral deposits.

This paper begins by providing geological background on the study area and a description of the various spectroscopic data used, followed by a description of the methodological approach. Then we examine laboratory spectroscopic data (point and imaging spectroscopy) obtained from field samples encompassing thin gossans of the Cape Smith belt with varying degree of lichen cover. From these data we investigate the effects of the rock substrates (sedimentary, mafic and ultramafic) and the effects of lichens on the VNIR spectra of gossans. Next we scale upwards to airborne hyperspectral imagery to highlight and discriminate thick and thin gossans and associate thin gossans to substrate rock type based on the detection of SWIR spectral features. Thus we examine the ability to detect the spectral properties of the rock substrates in the SWIR from airborne imagery. We close by discussing the implications of the airborne image analysis for regional mapping of gossans.

2. Study area

The Cape Smith Belt (60°43′N–62°35′N, 78°11′W–71°59′W) has a rolling topography with relatively good exposure of bedrock. The area is located in a treeless shrub tundra biome that has a mean annual temperature of −7 °C (Payette et al., 1989; St-Onge and Lucas, 1993). Due to the climatic conditions, the flora of the study area comprises lichens, mosses, shrubs and other low-growing plants. Lichen cover on bedrock varies from nil to exceeding 75%, but generally partially covers rock outcrops.

Geologically the Cape Smith Belt is a Proterozoic fold and thrust belt that constitutes the Ungava segment of the Trans-Hudson orogen (Parrish, 1989). The belt consists of several Early Proterozoic tectonic units (from 2.038 to 1.826 Ga; Machado et al., 1993) that separate the Archean gneisses of the Superior Province in the south from the Churchill Province gneisses to the north (Fig. 1) (Modeland et al., 2003). The Povugnituk group, the southernmost unit, consists of sedimentary and volcanic rocks associated with initial Paleoproterozoic rifting of the Superior Province (St-Onge et al., 2000). Farther north, the pillowed and lensoid lava flows of the Chukotat group record a transition from continental rifting to the formation of oceanic crust (Hynes and Francis, 1982). The Ni–Cu–PGE deposits of the Cape Smith Belt are associated with mafic and ultramafic lithologies of the Povungnituk and Chukotat groups (Lesher, 2007) and these map units were the focus of our field sampling of gossans. The disseminated, net-textured and massive sulfides comprise pyrrhotite, pentlandite, chalcopyrite, magnetite, ferrochromite, pyrite and PGE minerals (Dillon-Leitch et al., 1986). These sulfides are interpreted to result from magmatic segregation (Usselman et al., 1979). All lithologies were metamorphosed under lower greenschist to middle amphibolite facies conditions and consequently serpentine, amphibole and chlorite group minerals abound (St-Onge and Lucas, 1993). Details on units occurring further north (Fig. 1; Parent and Spartan groups, Watts Group, Narsajuaq Arc) can be found in Scott et al. (1992), St-Onge et al. (1992) and St-Onge and Lucas (1993).