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Regolith-geology mapping with support vector machine: A case study over weathered Ni-bearing peridotites, New Caledonia

Florian De Boissieu[a,*], Brice Sevin[b], Thomas Cudahy[c], Morgan Mangeas[a], Stéphane Chevrel[d], Cindy Ong[c], Andrew Rodger[c], Pierre Maurizot[b], Carsten Laukamp[c], Ian Lau[c], Touraivane Touraivane[e], Dominique Cluzel[e], Marc Despinoy[a]

[a] UMR ESAPCE-DEV, IRD, BPA5, 98848 Noumea, New Caledonia
[b] Geological Survey of New Caledonia, DIMENC, BP 465, 98845 Noumea, New Caledonia
[c] CSIRO Mineral Resources Flagship, CSIRO, 26 Dick Perry Avenue, Kensington, WA 6151, Australia
[d] BRGM, BP 6009, 45060 Orleans, France
[e] University of New Caledonia, BP R4, 98851 Noumea, New Caledonia

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ABSTRACT

Accurate maps of Earth's geology, especially its regolith, are required for managing the sustainable exploration and development of mineral resources. This paper shows how airborne imaging hyperspectral data collected over weathered peridotite rocks in vegetated, mountainous terrane in New Caledonia were processed using a combination of methods to generate a regolith-geology map that could be used for more efficiently targeting Ni exploration. The image processing combined two usual methods, which are spectral feature extraction and support vector machine (SVM). This rationale being the spectral features extraction can rapidly reduce data complexity by both targeting only the diagnostic mineral absorptions and masking those pixels complicated by vegetation, cloud and deep shade. SVM is a supervised classification method able to generate an optimal non-linear classifier with these features that generalises well even with limited training data. Key minerals targeted are serpentine, which is considered as an indicator for hydrolysed peridotitic rock, and iron oxy-hydroxides (hematite and goethite), which are considered as diagnostic of laterite development. The final classified regolith map was assessed against interpreted regolith field sites, which yielded approximately 70% similarity for all unit types, as well as against a regolith-geology map interpreted using traditional datasets (not hyperspectral imagery). Importantly, the hyperspectral derived mineral map provided much greater detail enabling a more precise understanding of the regolith-geological architecture where there are exposed soils and rocks.

1. Introduction

The last 20 years has seen the emergence of proximal and remote multispectral and hyperspectral sensing technologies, which have opened up new opportunities in natural resource mapping and monitoring. In contrast to multispectral systems like the satellite ASTER system (Abrams et al., 2015) that measure 3–30 spectral bands, hyperspectral sensors measure up to hundreds of spectral bands. Most hyperspectral sensors measure across the visible, near infrared and shortwave infrared (VNIR-SWIR; 400–2500 nm), and to a lesser degree, thermal infrared (TIR 7600–14,000 nm) wavelengths regions. Importantly, many major rock types and their alteration products (metamorphic, metasomatic and weathering) comprise diagnostic absorption features at these wavelengths (Clark and Roush, 1984; Lyon, 1965; Lyon and Burns, 1963). Hyperspectral systems are now operating using drill core (Cudahy et al., 2009; Huntington et al., 2005), in the field (Sonntag et al., 2012) and from airborne (Cocks et al., 1998; Crowley et al., 1989; Green et al., 1998; Kruse et al., 2006; Rowan et al., 2004; van der Meer et al., 2012) and spaceborne (Cudahy et al., 2001; Kruse et al., 2003) platforms.

The transformation of raw hyperspectral data into mineral products of value for a given application usually involves a series of image processing steps, including: (i) calibration of instrument data to radiance at sensor; (ii) radiative transfer correction; and (iii) information extraction. The last step has many possible approaches from unmixing strategies (Boardman et al., 1995) to spectral feature extraction (Sunshine et al., 1990) and various classification methods (Sabins, 1999; Vapnik, 1998). Two of the largest, publicly accessible airborne hyperspectral mineral mapping surveys (~250 flight lines) completed to date, namely Afghanistan (King et al., 2011) and north-Queensland

* Corresponding author.
E-mail address: florian.de-boissieu@teledetection.fr (F. De Boissieu).

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in Australia (Cudahy et al., 2008), generated mineral maps using unmixing and spectral feature extraction methods, respectively. However, these maps are formed of a suite of mineral product layers requiring an end user able to interpret them into valuable geological information appropriate for their needs.

One way to bridge the gap between "mineral information" and "geological knowledge" is to use a classification method applied to the suite of mineral maps instead of raw reflectance or radiance data, as often is the case. For this task, a promising method able to work with complex associations and relatively few training data is support vector machine (SVM) (Camps-Valls and Bruzzone, 2005). SVM is a kernel-based method able to process efficiently non-linearly separated classes, which is common in natural systems, though few studies have applied it to geological applications (Abedi et al., 2012; Kavitha and Arivazhagan, 2010).

New Caledonia is economically reliant on its lateritic Ni production so that new discoveries, sourced in areas that are relatively poorly mapped (Mudd and Jowitt, 2014), will be required in the future to improve resource management. This article evaluates the combined use of mineral spectral feature extraction and SVM classification on the first airborne hyperspectral imagery collected over New Caledonia. The aim is to create a regolith-geology thematic map targeting Ni mineralisation associated with weathered peridotite. Potential complications include variable vegetative and cloud cover, terrain effects (including illumination-shadowing) and surface mineralogy unrelated to the geological target. To reduce complexity, spectral features based on within-pixel normalisation were designed to measure key minerals, such as serpentine (target bedrock) and iron oxides (laterite cover). The results are validated and interpolated into the sub-surface with field sample data, digital elevation model and a conventional regolith map.

2. Location and geology

The study area in New Caledonia (Fig. 1) is mountainous and variably covered by vegetation developed upon weathered peridotite. Peridotite is a coarse-grained mantle rock mostly composed of olivine and pyroxene (e.g, elements Si, Fe and Mg), which may be partially altered into hydrous Mg silicate (serpentine). During near-surface weathering (Nahon, 2003), percolating waters leach mobile elements Mg and Si to leave a lateritic residue of Fe^{3+} and Ni. Ni can be concentrated into hydrous Ni-Mg silicates collectively referred to as "garnierite" and iron oxyhydroxides (goethite and hematite) (Fig. 2).

In the study area the peridotite bedrock is covered by a lateritic weathering profile composed from the base to the top of coarse saprolite (partially weathered rock), yellow laterite (goethite), red laterite (mixed goethite and hematite), ferricrete (hardened hematite) and a discontinuous pisolith layer (hematite) (Fig. 2).

From a Ni exploration perspective, the most prospective areas for surface sampling are saprolite and yellow laterite (Fig. 2). Thus generating maps from the remote sensing data that show development of these units would be valuable for follow-up field exploration programs. Areas of in situ ferricrete and red laterite are also potentially prospective because they may be underlain by thick layers of Ni-bearing laterite and saprolite.

Given the above, the target minerals with diagnostic hyperspectral absorption features at VNIR-SWIR wavelengths include iron oxides (hematite and goethite) and serpentine (van der Meer, 1995). Olivine, clinopyroxene and orthopyroxene, do not have diagnostic features at VNIR-SWIR wavelength, but could be measureable at TIR wavelengths (Launer, 1952; Logan et al., 1973; Lyon, 1965; Lyon and Burns, 1963; Salisbury and Walter, 1989), unfortunately not available for this survey.

3. Material and methods

3.1. Data

A range of data was acquired for this study, namely: (i) airborne hyperspectral HyMap™ imagery; (ii) field hyperspectral data; (iii) ground geological information; and (iv) a regolith map interpreted from other spatial data.

3.1.1. Airborne HyMap imagery

The HyMap system (Cocks et al., 1998) was used to collect airborne hyperspectral imagery. HyMap is a whiskbroom imaging sensor that measures 126 bands over the wavelength range of 450–2500 nm across a 512 pixel swath. Twenty-five HyMap flight-lines at approximately 3.6 m pixel resolution from seven test sites across New Caledonia covering a total area of about 500 km^2 (Fig. 1) were acquired in 2010. This study focuses on a single, cloud-free flight-line (3 × 15 km area) from the Fantoche plateau near Tiebaghi (Fig. 1) where soils and geology are exposed through variable vegetation cover. Data were supplied as both radiance at sensor and surface reflectance, together with geolocation and other survey information.

3.1.2. Field sample spectra

Field samples were measured using an Analytical Spectral Device (ASD) FieldSpec 3 spectrometer, which senses 2150 wavelengths between 350 and 2500 nm, i.e. with 1 nm resolution. Each field measurement was taken under sun illumination at a distance of 1 m from

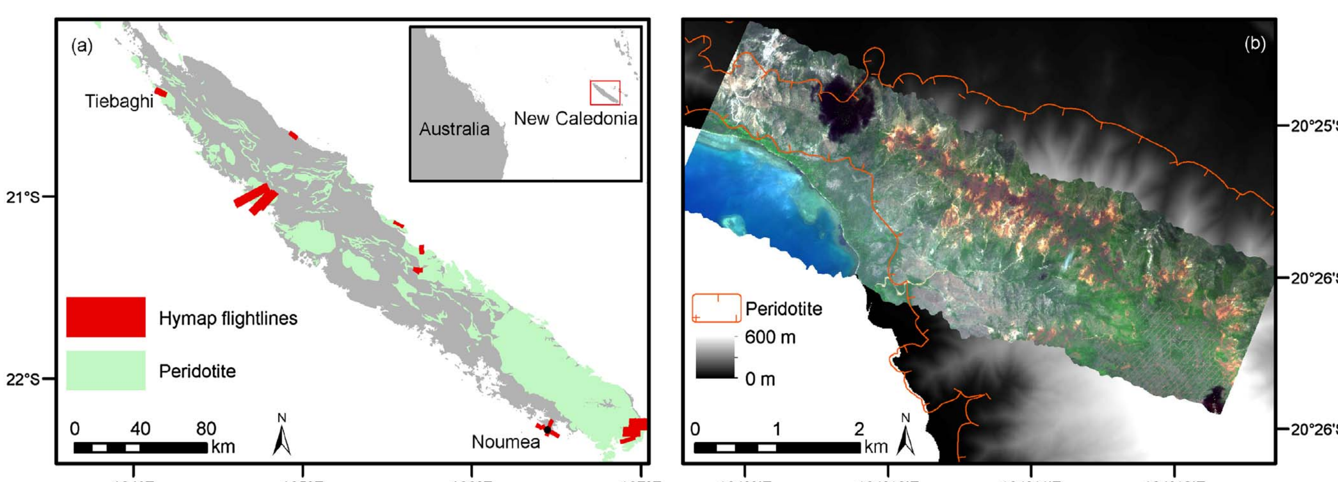

Fig. 1. (a) New Caledonia main island, with the 2010 HyMap survey coverage. (b) HyMap natural color image of the Tiebaghi study area. Exposed regolith of the Fantoche plateau (at the summit of Teibaghi massif) is apparent as dark white-red-brown tones.