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Mapping mineral chemistry of a lateritic outcrop in new Caledonia through generalized regression using Sentinel-2 and field reflectance spectra

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ABSTRACT

Mining is fundamental for human development, yet it currently requires innovative spatial techniques as it faces diverse environmental and social pressures. With the free Sentinel-2 data of the Copernicus programme, new opportunities arise for studies related to nickel laterite, especially with its reported potential in mapping iron-oxide. This work utilizes samples from drill-holes extracted from Tiebaghi, New Caledonia. The chemical composition and the hyperspectral reflectance of each sample are obtained. The reflectance spectra are resampled to Sentinel-2's characteristics, and generalized linear regression was used to accurately predict Fe_2O_3, MgO, SiO_2, Al_2O_3, and nickel content where three regression approaches were compared: Ridge, Elastic Net, and the Least Absolute Shrinkage and Selection Operator (LASSO). With the resulting regression models, mineral chemistry of an outcrop in the vicinity of the drill-holes is mapped by a scene of Sentinel-2. The work shows the great potential of free satellite imagery in mapping chemical characteristics of minerals and rocks. It opens up great opportunities for monitoring outcrops and for achieving more efficient mineral exploration.

1. Introduction

Grande Terre (Fig. 1), the main island of New Caledonia in the South Pacific, possesses more than a quarter of the world's nickel (Ni) reserves with its world's largest nickel laterite deposits (Dalvi et al., 2004; Horowitz, 2010; Myagkiy et al., 2017). Nickel mining started in 1874 and accounts for most of New Caledonia's exports, where this extracted nickel is essential for the production of protective plating, stainless steel, and other alloys (Ali and Grewal, 2006). In the context of Ni exploration, the most prospective areas are saprolite and yellow laterite, making it essential to survey these areas and their overlaying red laterite (Despinoy et al., 2012; Wells et al., 2013; Jébrak and Marcoux, 2015). In a tropical setting, erosion is a threat making rocks vulnerable, especially in steep areas (Beauvais et al., 2007), and it can modify the lateritic landscape. Thus, surveying the regolith is of high interest for future management of the reserves since lateritic weathering and degradation of the superficial zone due to natural processes can have an economic significance.

Hyperspectral remote sensing (remote and proximal) has been used for mapping lateritic transects (Cudahy et al., 2008; King et al., 2011; Despinoy et al., 2012; Wells et al., 2013; De Boissieu et al., 2017). This approach is very useful since an iron-oxide reflectance spectrum shows strong reflection in the visible and near-infrared region due to various electronic transitions (Viscarra Rossel et al., 2010). Specifically, goethite absorption is reported due to charge transfer absorption features at 500 nm (Ong et al., 2001; Ducart et al., 2016) and due to iron-oxide at 950 nm (Ramanaidou et al., 2008; Viscarra Rossel et al., 2010; van der Werff and van der Meer, 2015). Furthermore, the wavelength position of the absorption feature around 900 nm is considered essential to determine the goethite/hematite ratio (Ramanaidou et al., 2008). On the other hand, OH-bearing minerals, such as serpentine, have absorption features at 1400 and 2100 to 2450 nm (Ramanaidou et al., 2015; Schodlok et al., 2016) whose depth is a great proxy to estimate the abundance of these minerals. Furthermore, particle size affects the overall reflectance spectra where reflectance increases as particle size decreases (Cudahy and Ramanaidou, 1997).

Spaceborne remote sensing also shows great potential in mining applications (Tote et al., 2010). Various spaceborne data such as those acquired by ASTER, ALI, and Hyperion allow the mapping of broad mineral groups like the abundance of iron-oxides (Cudahy et al., 2008; Madani, 2009; King et al., 2011; Feizi and Mansouri, 2013; Pour and Hashim, 2014; Ducart et al., 2016). The advantages of using spaceborne acquisitions are large data coverage and the possible temporal repetition of the acquisition. This allows integrated monitoring at a relatively low cost. When considering the use of freely available data, spatial and spectral resolutions have been limiting, yet, Sentinel-2 shows great

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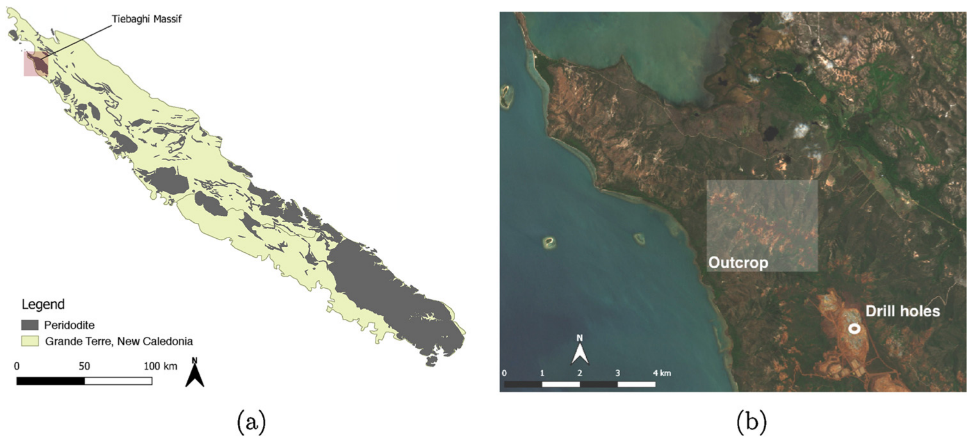

Fig. 1. An overview of the study area. (a) New Caledonia's ultramafics and the location of the Tiebaghi massif based on *Massifs de péridotites de Nouvelle-Calédonie SMC/DIMENC*, last update Sept. 2011. (b) RGB of Sentinel-2 MSI image of 11 February, 2018 showing the site location and the drill-hole location.

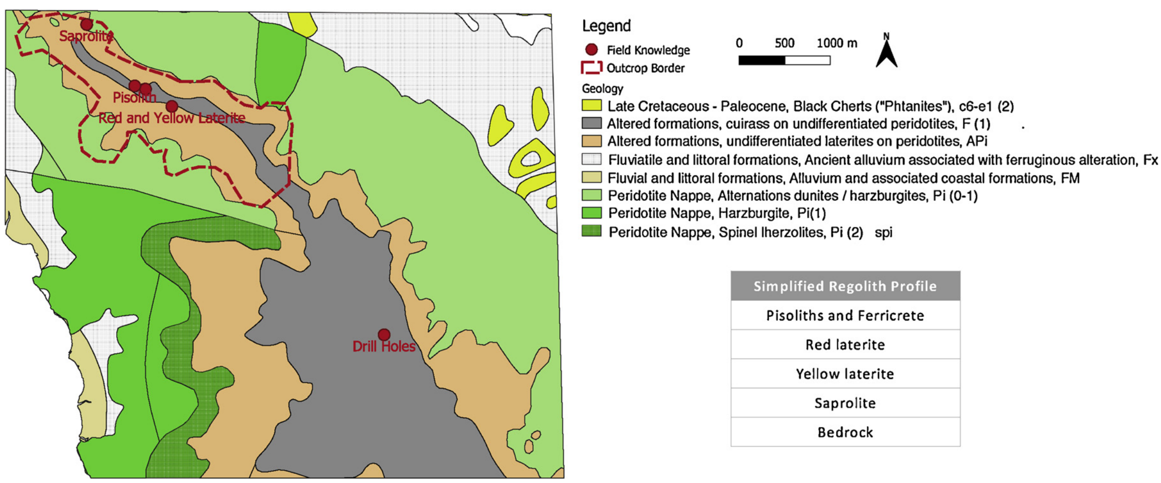

Fig. 2. A geological map of the outcrop area and its surroundings based on *Carte géologique de la Nouvelle-Calédonie au 1/50.000ème péridotites de Nouvelle-Calédonie – SMC/DIMENC*, Last update 26/03/2013 with highlighted field knowledge based on De Boissieu et al. (2017) and (Wells et al., 2013), and a simplified regolith profile based on Sevin et al. (2014).

Table 1
The ASD spectral characteristics. FWHM: full width at half maximum

Module	Spectral range [nm]	Band width [nm]	FWHM [nm]	Number of bands [–]
VIS	380–748	4	6	93
NIR	752–1400	4	6	163
SWIR	1404–2500	4	4.5	275

Table 2
Characteristics of Sentinel-2 MSI (ESA, 2018).

Band	Central wavelength [nm]	FWHM [nm]	Spatial resolution [m]	Comment
b1	443	20	60	Excluded from the analysis
b2	490	65	10	
b3	560	35	10	
b4	665	30	10	
b5	705	15	20	
b6	740	15	20	
b7	783	20	20	
b8	842	115	10	
b8A	865	20	20	
b9	945	20	60	Excluded from the analysis
b10	1375	30	60	Excluded from the analysis
b11	1610	90	20	
b12	2190	180	20	

potential (van der Werff and van der Meer, 2016; Ge et al., 2018). Sentinel-2 is a sun-synchronous spaceborne platform provided by the Copernicus European Earth Observation programme established by the European Space Agency (ESA). It hosts on-board the multispectral instrument (MSI) of 13 bands in the visible (VIS), near-infrared (NIR), and short-wave infrared (SWIR). The spatial resolution of acquired data depends on the spectral band and can be either 10 m, 20 m, or 60 m (Drusch et al., 2012).

The emphasis is great on Sentinel-2's capabilities in mapping iron-oxides (Mielke et al., 2014; van der Werff and van der Meer, 2015, 2016) where the major feature successfully used has been the absorption dip around 900 nm (Mielke et al., 2015; Kopačková and Koucká, 2017). Yet, rarely has it been addressed to map other oxides that typically result in absorption features not depicted through Sentinel-2's spectral characteristics (e.g. in OH-bearing minerals). With regression, an understanding of the contribution of the whole spectrum in describing a chemical property could be achieved, without relying on absorption features alone. When non-parametric generalized regression approaches are used, the chemical properties can be well described without risking an overfitted solution, and they could allow the identification of the important features in the dataset (Verrelst et al., 2012;