Applications of hyperspectral mineralogy for geoenvironmental characterisation

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ABSTRACT

Technological innovations and emerging analytical capabilities are transforming the mineralogical and textural analysis of rock samples and drill core. Accurate mineralogical identification and systematic documentation can enhance deposit knowledge across the mining chain. From the earliest stages of mine-life, accurate mineralogical identification can also enhance environmental characterisation which traditionally utilises a range of wet chemical tests to predict acid generation and acid neutralisation potential. An enhanced understanding of both the ore and gangue mineralogy allows accurate prediction of the geoenvironmental characteristics of future waste materials. This study presents examples using thermal infrared (TIR) hyperspectral data for domaining acid neutralisation capacity in an exploration drill hole in a volcanic hosted massive sulfide (VHMS) district and a porphyry Cu-Au deposit by rapidly identifying the distribution and relative abundance of carbonate-group minerals. The results are validated using mineralogical and chemical analytical techniques (XRD and EMPA) and are compared to industry standard chemical tests (paste pH, NAG pH) used for acid base accounting (ABA) of mine materials. Utilising hyperspectral core scanning platforms for identifying acid neutralising domains can facilitate deposit-scale geoenvironmental modelling from the earliest of mine stages and improve long-term waste management practices.

1. Introduction

There is continuing demand for discoveries of large (>500 Mt) to giant (>1000 Mt) deposits of copper, gold, molybdenum and other metals to account for compound annual growth in metal demand of 2–3% per annum (Jennings and Schodde, 2016). Future mines must contain adequate resources (both grade and tonnage), provide long mine lives (>30 years) and be able to operate with low production and energy costs. Significantly, environmental and social responsibility is becoming increasingly important for the development of new mining operations. Environmental protection legislation and increased social awareness of the potential environmental risks associated with mining can impact the development of new mines.

Environmental prediction test work is typically carried out at the pre-feasibility and feasibility stages of mine development (GARD Guide, 2014). Field- and laboratory-based chemical tests

and kinetic trials are used to determine acid rock drainage (ARD) formation potential of low or no grade material which has been designated as waste in block models and mine plans (White et al., 1999; Parbhakar-Fox and Lottermoser, 2015). However, these chemical tests are typically non-reproducible, costly and time consuming and therefore, may only be carried out on a restricted number of samples considered to be representative of larger intervals of a particular rock unit or alteration type. Furthermore, traditionally the tests focus on wet chemical techniques with only minor consideration of mineralogical variability.

However, improved geoenvironmental assessments have been achieved by integrating process mineralogy tools such as automated mineral analysers including the MLA and QEMSCAN with traditional predictive chemical tests (Parbhakar-Fox et al., 2011; Brough et al., 2013; Parbhakar-Fox et al., 2013). However, the long analysis time and high cost of MLA (>$500 USD per sample) makes this a non-routine approach for characterising waste materials. Instead, we document the use of hyperspectral mineral analysis and core scanning technologies to map the distribution of acid neutralising domains in drill core and document how this can be

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used to reduce the subjectivity associated with sampling for chemical predictive environmental testing. Geoenvironmental risk assessments based on mineralogical mapping of drill core enables enhanced deposit-scale characterisation of waste rock domains and allows for more targeted static and kinetic testing for developing more accurate geoenvironmental risk models.

## 2. Hyperspectral mineralogical techniques

Hyperspectral reflectance spectrometers are widely used for mineralogical applications in airborne and satellite remote sensing applications including for mapping regional-to district-scale geological and alteration features (Laukamp et al., 2011; Yang et al., 2011; van Ruitenbeek et al., 2012) and more recently for mapping acid mine drainage (Ong and Cudahy, 2014). Field portable, non-automated hyperspectral reflectance spectrometers (e.g., PIMA, TerraSpec™) analysing the near infrared (NIR) to shortwave infrared (SWIR) wavelengths are capable of identifying phyllosilicates (mica, clay and chlorite), sulfates (alunite, gypsum and jarosite), carbonates (calcite, dolomite, ankerite and magnesite) and hydroxylated silicates (e.g., epidote and amphibole) based on diagnostic spectral absorption features (Yang et al., 2011; Laakso et al., 2016). Absorption features recorded in VNIR and SWIR reflectance spectra are mainly caused by sub-molecular vibrations (bending and stretching) of molecular bonds in response to the absorption of specific wavelengths of light. Mineral species produce characteristic absorption features which correspond to specific molecular bonds such as OH, H_2O, CO_3 and other components of hydrous silicate minerals including Al—OH, Mg—OH and Fe—OH bonds (Fig. 1; Hunt and Salisbury, 1971, 1973; Gaffey, 1986).

Anhydrous silicate minerals including quartz, feldspar-group and pyroxene-group minerals do not produce characteristic VNIR-SWIR reflectance spectra because they lack cations bonded to OH molecules. These mineral groups can be identified using dedicated spectrometers measuring in the thermal infrared (TIR) part of the electromagnetic spectrum (e.g., Huang and Kerr, 1960; Cudahy et al., 2009). Significantly, certain mineral groups, including carbonate-group minerals, which do produce spectral absorption features in the VNIR-SWIR region, also produce mineral specific reflectance spectra in the TIR region (Green and Schodlok, in press; Schodlok et al., in press). Combined VNIR-SWIR and TIR spectral analysis allows identification of a wide range of rock forming and alteration minerals for robust mineralogical mapping.

The first automated hyperspectral core scanner named the HyLogger was developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and acquired continuous downhole spectral mineralogy in drill cores (Huntington et al., 2011). The HyLogger-3 is equipped with VNIR, SWIR and TIR reflectance spectrometers which continuously analyse the drill core surface providing spectral data equivalent to spot measurements at 8 mm intervals (Mason and Huntington, 2012). Automated sample movement, spectral scanning and semi-automated data interpretation through dedicated software allows for rapid, continuous scanning of up to 1000 m of drill core per day (Mason and Huntington, 2012; Schodlok et al., in press).

Spectral imaging platforms, modified largely from airborne remote sensing applications, are now capable of producing 2D spectral images along the drill core surface. Systems include Corescan's HCI-3 platform(www.corescan.com.au) and SPECIM's SisuRock/SisuCHEMA system (www.specim.fi) which currently analyse in the VNIR-SWIR regions to generate spectral mineral maps spatial pixel resolution of approximately 0.5 mm. SPECIM's AISA OWL is a commercially available TIR hyperspectral imaging camera capable of mapping anhydrous minerals and carbonate-group
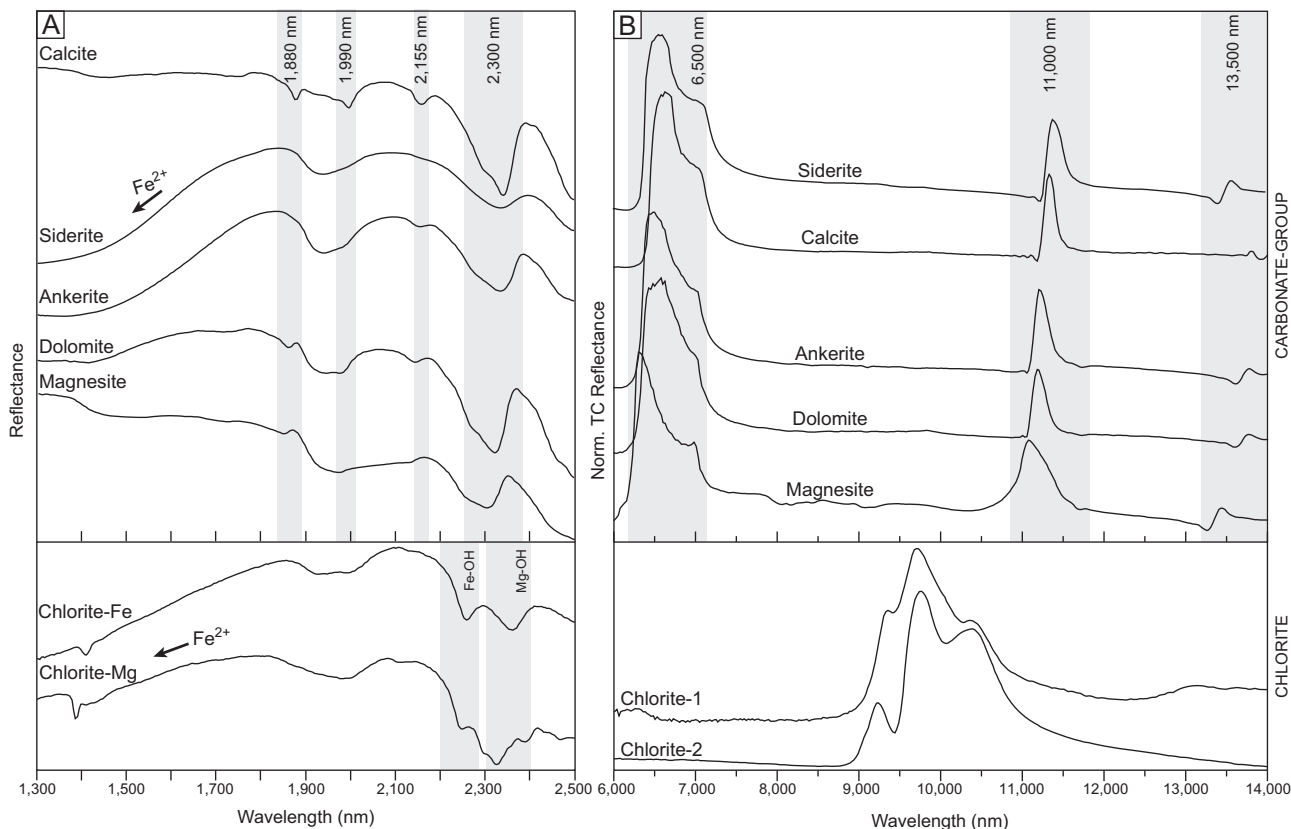
Fig. 1. (A) Short wave infrared (SWIR) reflectance spectra for reference library samples of carbonate and chlorite minerals showing the position of key diagnostic features and potential interferences with chlorite minerals. (B) Long wave infrared (LWIR or TIR) reflectance spectra for carbonate-group minerals and the positions of key spectral features used for diagnosis. Reflectance spectra of pure minerals from the TSG reference library.