Application of near infrared sensors to preconcentration of hydrothermally-formed copper ore

Shekwonyadu Iyakwari [a,*], Hylke J. Glass [a], Gavyn K. Rollinson [a], Przemyslaw B. Kowalczuk [b]

[a] Camborne School of Mines, University of Exeter, Tremough Campus, Penryn, Cornwall TR10 9FE, UK
[b] Wroclaw University of Technology, Division of Mineral Processing, WybrzezeWyspianskiego 27, 50-370 Wroclaw, Poland

ABSTRACT

Near infrared sensors can be a very useful technique for the qualitative analysis of complex ores, and thus could be useful for the preconcentration of ores. In this paper, individual particles of hydrothermally-formed copper ore sampled from a mine in the Los Pozos mining district, northern Chile, were classified as product, middling and waste based on their near infrared response. The classification of copper bearing minerals (product) from gangue (waste) was considered for vibration combination bands at longer wavelengths from 2000 to 2400 nm. This region exhibits characteristic features for carbonates and hydroxyl gangue bearing minerals. The near infrared features at 1400 and 1900 nm were not considered favourable for classification and subsequent discrimination because they can be influenced by moisture and other environmental factors and are easily suppressed by iron-rich minerals.

Two near infrared preconcentration strategies were applied for particle discrimination. Results indicate that targeting only the calcite (carbonate) dominated particles for discrimination as waste provided the best option for preconcentration. The near infrared discrimination analysis correlates well with mineralogical (QEMSCAN® and XRD) and elemental (XRF) data classification. The results indicate that near infrared spectroscopy is a suitable preconcentration method for supergene copper ore.

1. Introduction

Staying ahead of the competition and maintaining profitability is a key challenge in the extractive industry, especially during fluctuating economic conditions. Therefore, it is important to develop novel techniques and strategies for mineral processing which can provide enhanced recovery of the useful components from a low-grade ore, reduce energy consumption and mitigate environmental impacts. A technique which shows promise in such application is Near InfraRed (NIR) spectroscopy (Gaydon et al., 2009; Curtis, 2012; Iyakwari et al., 2013; Dalm et al., 2014; Iyakwari and Glass, 2015).

NIR spectroscopy measures the reflective properties of mineral samples without rigorous sample pre-treatment. It is a fast, non-invasive and non-destructive technique that provides multi-constituent analysis of virtually any matrix (Pasquini, 2003). It covers the wavelength range from the visible range (780 nm) to the mid infrared region (2526 nm) (Clark, 1995; Reich, 2005). The vibrational spectrum of a molecule is a unique physical property (Coates, 2000), thus the NIR could be used as a fingerprint for each pixel of a sample. Furthermore, minerals can be subsequently identified by comparison of the fingerprint spectrum with previously recorded reference spectra of pure minerals. These measurements can hence be used to inform more generic mineral identification and classification methods (Iyakwari et al., 2013).

A major consideration of NIR spectroscopy is the measurement of the reflectance of a pixel which size or position may not correspond to the characteristics of the mineral assembly (Iyakwari and Glass, 2015). In order to obtain a 1:1 correlation between minerals and the NIR spectra, analysis of polished sections of sample particles was carried out using QEMSCAN®. The QEMSCAN® is an automated technique for the rapid characterization of mineral species via combined Scanning Electron Microscopy and Energy Dispersive X-ray Spectrometry (SEM–EDS) (Gottlieb et al., 2000; Pirrie and Rollinson, 2011). The QEMSCAN® allows spatial determination of minerals by the interpretation of chemical spot analyses (Anderson et al., 2014).

The study presented in this paper aims to use NIR sensor-based classification as a tool for the preconcentration of hydrothermally-formed copper samples from associated carbonate and or clay waste. The research was performed with reference to acid leaching as the next and final stage of copper extraction. The preconcentration strategy takes into account the advantage of NIR as a tool for

* Corresponding author.
   E-mail address: si233@exeter.ac.uk (S. Iyakwari).

discriminating minerals based on their constituent functional groups (–OH and CO_3^{2-}). Also no two minerals display identical absorption features at the same wavelength positions within the NIR region, even if they contain the same functional groups (Povarennykh, 1978; Iyakwari and Glass, 2014).

Iyakwari and Glass (2015) classified minerals into three major groups, based on their near infrared sensitivity: (a) NIR-active minerals that show absorption features, (b) NIR-active minerals that do not show absorption features, but absorb strongly throughout the longer wavelength region of NIR, and (c) non-active minerals. The non-active minerals do not absorb NIR or display features, even when present in combination with other minerals. Identification of individual minerals in complex particles is influenced by mineral accessibility to radiation, concentration and/or composition (Iyakwari and Glass, 2015). Iyakwari and Glass (2015) showed that the preconcentration of copper-bearing minerals chrysocolla and/or malachite can be achieved by the removal/reduction of calcite and/or muscovite-bearing particles from the feed. The removal of these non-copper bearing NIR-active minerals prior to downstream acid leaching is desirable (Robb, 2005; Iyakwari et al., 2013).

2. Sample characterization and methods

60 particles ranging in size between 5 and 10 cm were selected from a copper ore sampled from a mine in the Los Pozos mining district in the Coastal Range of the Atacama Region, northern Chile. Each of the 60 particles was subjected to the characterization process outlined in Fig. 1.

Splits A1 and A2 were crushed with a Retsch steel jaw crusher (to −3 mm), then milled to −45 μm using a tungsten-carbide mill prior to X-ray Fluorescence (XRF) and X-ray Diffraction (XRD) analysis respectively. Splits B1 were mounted into epoxy resin and cut and polished to an even 1 micron finish. The 30 mm diameter polished blocks were marked for orientation and scanned with NIR and Portable X-ray Fluorescence (PXRF). The polished sample blocks were then carbon coated before scanning with the QEMSCAN®. In order to properly map each sample for a 1:1 correlation of NIR and QEMSCAN®, individual mounts were demarcated into three sectors measuring 9 mm each, corresponding to the NIR pixel height with a width of 2.9 mm (Fig. 2). By tracking the position of the individual pixels (spectrum), precise correlation between the NIR spectra and spatial mineralogical data (field scan) from the QEMSCAN® was possible. Splits B2 with sizes ranging from 2 to 10 cm were scanned with the NIR and PXRF without any sample preparation, as the samples were dry and dust free.

Mineralogical analysis was performed using the QEMSCAN® 4300 system at Camborne School Mines, University of Exeter, UK.
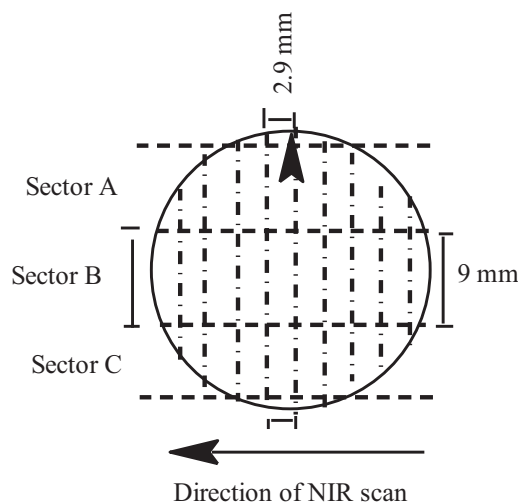

Fig. 2. Split B1 samples (in 30 mm diameter polished blocks) marked for directional scanning and spectral/mineral mapping.

Each sample was mapped using the field scan measurement mode, with a beam stepping interval of 10 μm (i.e. an X-ray was acquired every 10 μm across the sample in a grid). This resulted in the acquisition of typically more than 3,500,000 individual X-ray analysis points per sample (i.e. the total number of analysis points, approximately collected per sample, was dependent upon the size/area of the sample as the epoxy resin is ignored). The mineral mass data and an approximate abundance of copper and other elements were based on the assumed average density of each mineral and back-calculated from the QEMSCAN® primary list, where chemical data is supplied manually. Note that the average density and chemistry values were taken from webmineral.com and can only be used as indicative values. A Siemens Bruker D500 XRD analyser (www.bruker.com) was used to semi-qualitatively measure the mineralogical composition of the samples. XRD measurements were matched with known mineral markers using Bruker EVA software. Mineral data obtained from the XRD analysis were compared with the QEMSCAN® data.

The NIR spectra of samples were measured individually with the NIR line scanner, which acquires spectral data on a succession of adjacent area or pixels across the particle surface. Each pixel had dimensions of 2.9 by 9 mm (Fig. 2). Details on NIR background, procedure of NIR data acquisition, instrumentation and data pretreatment are described in Iyakwari et al. (2013) and Iyakwari and Glass (2015).
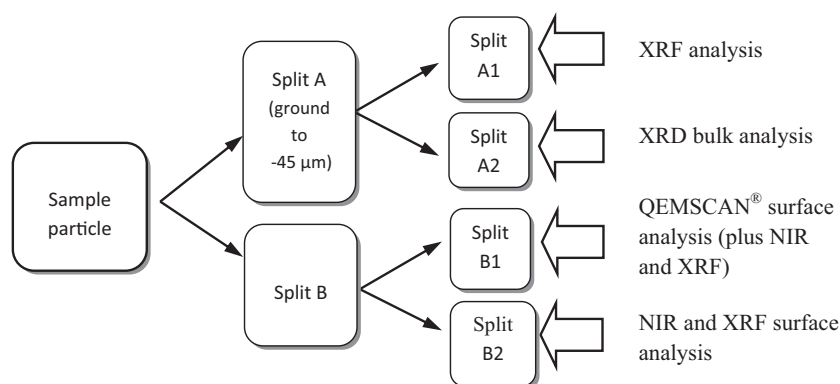

Fig. 1. Subdivision of sample particles for characterization.