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Application of near-infrared spectroscopy to sensor based sorting of a porphyry copper ore

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ABSTRACT

Test work was conducted to define the possibilities and limitations of a near-infrared (NIR) sensor to distinguish between Cu grades of 150 porphyry Cu ore samples. NIR spectroscopy allowed determination of NIR active minerals. At porphyry systems, NIR active minerals are usually alteration minerals that are produced by a specific type of hydrothermal alteration.

None of the Cu-bearing minerals that were determined from the sample set by petrography produced diagnostic absorptions in the NIR. Because of this, no spectral features were present in the measured NIR spectra of the ore samples that relate directly to the Cu grade.

An indirect relation was present between the Cu grade and the NIR active mineralogy that was determined from the NIR response of the samples. This indirect relation was based on sample groups with different NIR active mineral assemblages that represented different zones of hydrothermal alteration and constituted different ranges of Cu grades.

From a logistic regression resulted that based on the NIR response, it was possible to reliably estimate a probability that the Cu grade of a sample is below the cut-off grade for economic processing of the ore. The predictors used in this regression were several characteristic spectral features of the NIR active mineralogy.

1. Introduction

Automated sensor based sorting is an established technology with applications in various processing operations. It is for example widely used within the food, pharmaceutical and recycling industry. Within the mining industry however, sensor based sorting is still an emerging technology with only a limited number of proven applications (e.g., Salter and Wyatt, 1991; Sivamohan and Forssberg, 1991; Wotruba and Riedel, 2005; Death et al., 2005; Chadwick, 2008; Harbeck and Kroog, 2008; Wotruba et al., 2009; CommodasUltrasort, 2009; Bergmann, 2011). Technological developments on available sensors and increasing throughputs of automated sorting equipment have created interest to explore sensor based sorting solutions for the mining industry.

Sensor based sorting represents all applications where singular particles are individually analysed and mechanically separated on certain physical properties after determining these properties by a sensor. The main potential advantage of this technology for the mining industry is that it can be applied on relatively coarse particles. This allows sensor based sorting to be incorporated as a pre-concentration step in ore processing operations in order to eliminate waste or sub-economic material prior to the conventional concentrating methods. The goal is to reduce the amount of mineral liberation processes that are required for the production of ore concentrates. Because mineral liberation processes by milling are generally expensive, pre-concentrating the ore with sensor based sorting has great potential to decrease ore processing costs (Salter and Wyatt, 1991; Sivamohan and Forssberg, 1991; Wotruba and Riedel, 2005; CommodasUltrasort, 2009). Sensor types that are currently used with sensor based sorting include optical, near-infrared, X-ray transmission and electromagnetic sensors (Harbeck and Kroog, 2008; Bergmann, 2011).

Pre-concentrating porphyry Cu ores with sensor based sorting will be aimed at eliminating ore particles with Cu grades that are below the cut-off grade for profitable ore processing. However, no sensor is currently known that allows direct detection of the Cu content of this ore type. Ore mineralisation at porphyry systems is usually related to certain hydrothermal alteration zones (Lowell and Guilbert, 1970; Sillitoe, 2010). The near-infrared (NIR) sensor has been proven to be a valuable tool in mapping the distribution of mineral alterations in hydrothermal ore deposits (e.g., Sabins, 1999; Thompson et al., 1999; van Ruitenbeek et al., 2005). NIR spectroscopy might therefore allow characterisation of Cu grades by using the alteration mineralogy as indirect indicators. The aim of this paper is to define the

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possibilities and limitations of a NIR sensor to distinguish between Cu grades of a porphyry Cu ore.

2. Hydrothermal alteration at porphyry Cu systems

Porphyry ore systems can be defined as large volumes of hydrothermally altered rock centred on a porphyry stock intrusion (Sillitoe, 2010). These can also contain skarn, carbonate-replacement, sediment-hosted, and high and intermediate sulphidation epithermal deposits and precious metal mineralisation (Sillitoe, 2010). A porphyry stock is formed by the intrusion of oxidised magma, saturated with sulphide and metal rich aqueous fluids. During formation, these aqueous fluids are released from the magma and penetrate the surrounding rock. Due to the high pressures and temperatures involved in this process, these aqueous fluids can lead to addition, removal and/or redistribution of the pre-existing rock components (Lowell and Guilbert, 1970; Pirajno, 1992; Sillitoe, 2010). This process is referred to as hydrothermal alteration. The intensity of hydrothermal alteration decreases with increasing distance from the stock intrusion. This allows classification of different concentric hydrothermal alteration zones with characteristic alteration mineral assemblages. Figs. 1 and 2 present schematic models of the different hydrothermal alteration zones and ore mineralisation zones for a generalised porphyry Cu system.

From Figs. 1 and 2, it can be observed that the main ore zone in a generalised porphyry Cu system is related to the boundary between potassic and phyllic hydrothermal alteration. In practice, the relations between hydrothermal alteration and Cu mineralisation are often more complicated than displayed in this figure. This is mainly due to the fact that the vertical distribution of the different hydrothermal alteration zones depends on the degree of telescoping within the porphyry system (Sillitoe, 2010). Telescoping refers to overprinting of the older hydrothermal alteration types by the younger ones. If the degree of telescoping at a porphyry system is limited, all hydrothermal alteration zones are spatially distributed as displayed in Fig. 1. But in highly telescoped systems, the propylitic alteration can impinge downward upon the potassic alteration zone and (partially) overprint the previously formed hydrothermal alteration types.

The distribution of hydrothermal alteration zones at porphyry systems can also be affected by superimposed breccia and/or diatreme intrusions (Lowell and Guilbert, 1970; Pirajno, 1992; Sillitoe, 2010). These types of intrusions are commonly associated with porphyry systems and can locally overprint the previously formed hydrothermal alteration types (Sillitoe, 2010). Overprinting of the alterations by telescoping, breccia intrusions and/or diatreme intrusions distorts the general relations between hydrothermal alteration and Cu mineralisation. The extent and characteristics of these relations therefore depend on the local geology of the porphyry Cu system.

3. Methods

3.1. General approach

To assess the capabilities of a NIR sensor to distinguish between Cu grades of porphyry ore material, test work was conducted on 150 porphyry Cu ore samples. These samples are around 5–7 cm in diameter and originate from the oversize output of a semi-autogenous grinding (SAG) mill at a South American mining operation.

The test work included several NIR reflectance measurements on each ore sample, taken with an ASD Fieldspec3 portable spectroradiometer. The acquired NIR reflectance spectra were analysed for characteristic mineral absorptions by comparison to reference spectra from the USGS spectral library by Clark et al. (2007) and the spectral interpretation field manual (G-MEX) by Pontual et al. (1997). This allowed determination of one or several NIR active minerals that are responsible for the absorption features in each NIR reflectance spectrum. For certain NIR active minerals, also mineral characteristics such as crystallinity and compositional variations could be determined from the NIR spectra.

Prior to the test work, all the samples were cut in halves. This provided a smooth, uncontaminated surface on which the NIR reflectance measurements were performed. Cutting the samples also allowed one half of each sample to be used for X-ray fluorescence (XRF), X-ray diffraction (XRD) and/or petrographic analysis. This provided data on the mineralogy and chemical composition of the samples that was used to validate the determined NIR active mineralogy and assess the relations between NIR response and Cu grade. Table 1 presents an overview of the different combinations of XRF, XRD and petrographic analysis that were performed on five subsets of the sample set. Sample selection for these subsets was based on an optical classification to ensure that the variability of the subsets resembled the variability of the entire sample set.

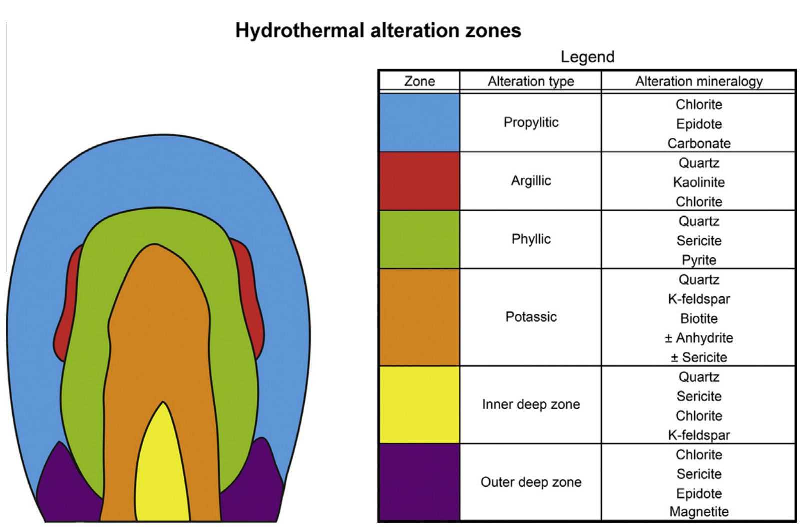

Fig. 1. Hydrothermal alteration zones of a generalised porphyry Cu system (Modified from Lowell and Guilbert, 1970). Typical dimensions are 1.2 × 2 km horizontally and 3 km vertically.