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Techniques and applications for predictive metallurgy and ore characterization using optical image analysis

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Abstract

Optical image analysis (OIA) as a predictive metallurgical tool has been advanced by work completed at SGS Mineral Services by integrating a standard image analysis system with innovative preparation methods and measurement techniques. The preparation of sized material into non-touching particle polished sections as well as the selective coating of epoxy facilitates the recognition of non-opaque minerals, thus correctly identifying locked and complex particles. Advanced data analysis enables the preparation of predictive metallurgical data. Test cases were compared to metallurgical test results including size distribution, mineral release and grade/recovery data for various ore deposits. The limiting factor in direct optical image analysis is the discrimination between minerals with similar reflective properties. Advances made at the University of Liege have made it possible to optically distinguish these minerals using multispectral imaging. Integrating these technologies will enable OIA to be an affordable and viable alternative for gathering process mineralogical data.

Keywords: Ore mineralogy; Liberation; Liberation analysis

1. Background

The basics of microscopy have been applied to mineral identification for over a 100 years beginning with the study of metals and meteorites by Sorby in 1861. The first microscopes were poorly illuminated and often relied on chemical etching to assist in distinction between minerals. In the early 20th century Murdoch (1916) detailed the colour and reflectance of ore minerals and used micro-chemical techniques to identify minerals. His work was later expanded by other mineralogists to include photometric measurements, and polarizing techniques. As microscopes and optical lenses improved over time other properties of minerals were observed. In 1962 the Commission on Ore Microscopy produced a Table of Quantitative Data which contained the incorporation of reflectance standards to assist in mineral identification. The table included, for the first time, the reflectance data of minerals for four wavelengths (470, 546, 589, and 650 nm) and was eventually published as the quantitative data file (QDF) (Criddle, 1998). The work of mineralogists such as Ramdohr (1969), Uytenbogaardt and Burke (1971), Craig and Vaughan (1981), Picot and Johan (1982) have presented this data along with detailed descriptions for use by mineralogists to identify the ore minerals. Currently OIA systems purchased "off the shelf" are often developed for metallography or the biomedical industries and include no mineralogical recognition database software. Recognition is dependant upon the ability of the user. In the future advanced OIA systems for mineralogical applications would employ the use of this QDF database and specific wavelength filters for automated mineral identification. It must be remembered that

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these "off the shelf" systems are still of value to the mineralogist and have been utilized effectively to carry out quantitative mineral analysis on simple ore types.

2. Imaging

In the past digital imaging has had limited quantitative use and has been restricted to the presentation of photomicrographs detailing relative textures that influence recovery and/or grade. In order to more effectively apply current technology to quantitative mineral analysis it is important to understand how the digital imaging equipment gathers this information, since the image acquisition has the greatest effect on the performance of any imaging system. In plane incident light the accurate representation of the reflectance spectrum of the mineral components is essential to reduce misidentification and accurately quantify mineral proportions and other attributes.

Digital cameras used in optical microscopy usually incorporate a charged-coupled device (CCD) to capture images. The CCD transfers the optical photon data received through a filter into electronic pulses or photogenerated electrons. Voltage created is then converted to pixels using an analog to digital converter (ADC) and stored until the entire number of pixels representing the image are captured and then presented in their entirety on the monitor for visual inspection (Spring et al., 2007). Three methods for compiling a colour image using a CCD digital camera exist as follows:

1. Three chip CCD
2. Bayer mosaic filter
3. Three shot colour sampling

The three chip CCD is primarily used on analog cameras, where each chip is located under the lens and collects images representing the red, green and blue regions of the spectrum (Fig. 2). These are then merged to form a single image using compiling hardware and software. A Bayer mosaic filter is a single filter having alternating pixel areas of red, green and blue in front of an imaging sensor. Software and hardware are employed to interpolate between the varying pixels to form a single colour image. This adequately represents colour as viewed by the human eye and is primarily centered around the 450, 550, and 650 nm ranges for blue, green and red, respectively (Fig. 1, Pirard, 2004). Finally a three shot colour sampling system employs the collection of three separate images of the entire CCD using filters representing red, green, and blue regions of the spectrum (Kuyatt et al., 2007). These three images are then merged to make a single colour representation of the item. This is based upon a mobile RGB filter or LCD (liquid crystal display) filter that changes colour in response to an applied voltage.

OIA systems designed for metallography, can be applied to mineralogy after some modifications to allow for specific data requirements. The basic criteria for an optical image

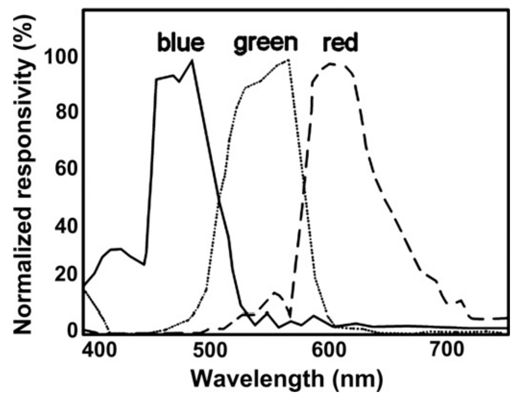

Fig. 1. Typical RGB filter transmittance curves used in digital colour imaging (Pirard, 2004).

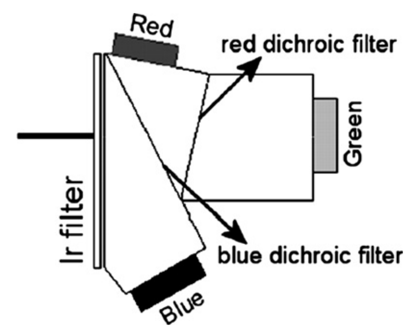

Fig. 2. 3 CCD sensor fitted to a prism to discharge specific colour electrons (Pirard, 2004).

analysis system include an incident light microscope (reflected light), automated stage controlled by an integrated imaging software package and a digital camera. The equipment used at SGS minerals included a 3 CCD Sony analog camera attached to a Nikon ME600 microscope, Clemex Vision PE software and automated stage. In order to correctly analyze the mineral specimens some hurdles must be crossed that have made the quantitative analysis of minerals from polished sections a difficult task for optical systems. These include:

- Density settling of heavy minerals and coarse particles.
- Touching particles.
- Discrimination of non-opaque gangue minerals from the epoxy.
- Reflectance overlap of minerals.

3. Sample preparation

SEM-based technologies were developed to overcome some of these difficulties and include methods such as graphite inclusion. The addition of graphite to the epoxy helps reduce some of the density settling of the minerals as well as remove/reduce particle touching, but this is not practical for optical systems because the reflectance and