MULTIRADIAL IMAGE ANALYSIS IN REFLECTED LIGHT MICROSCOPY

Eric PIRARD & Sophie LEBICHOT

Université de Liège

I. INTRODUCTION.

Experienced operators in Reflected Light Microscopy are used to identify phases based on qualitative optical properties (colour, apparent brightness,…) eventually complemented by characteristic features revealed by polishing (cleavages,…) or selective etching.
Despite extensive experimental work on visible specular reflectance spectroscopy (Criddle & Stanley, 1993), very few investigations have been undertaken to take advantage of reflectance properties for identifying minerals in video image analysis (Berrezueta, 2004; Pirard, 2004). Emerging “chemical imaging” microscopy offers a wide potential in that respect.
In addition, non-symmetric crystal lattices give rise to bireflectance / pleochroïsm under simply polarized light that can further be exploited to enhance discrimination between minerals. In this work we demonstrate the usefulness of combining narrow bandwidth interference filters and rotating polars to improve phase identification in visible light microscopy.

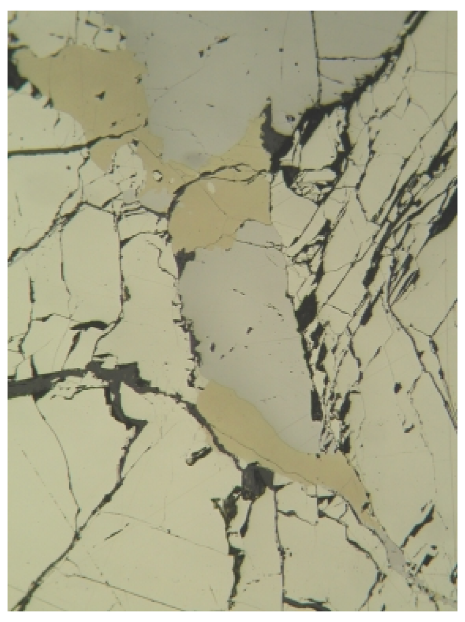

Fig.1

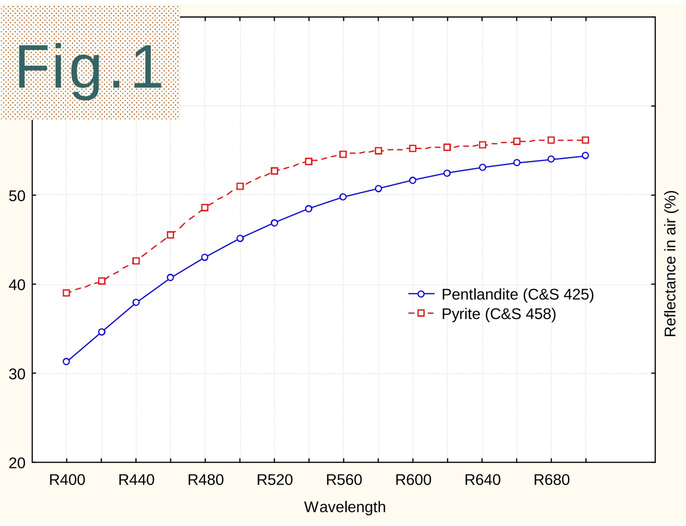

Fig.2

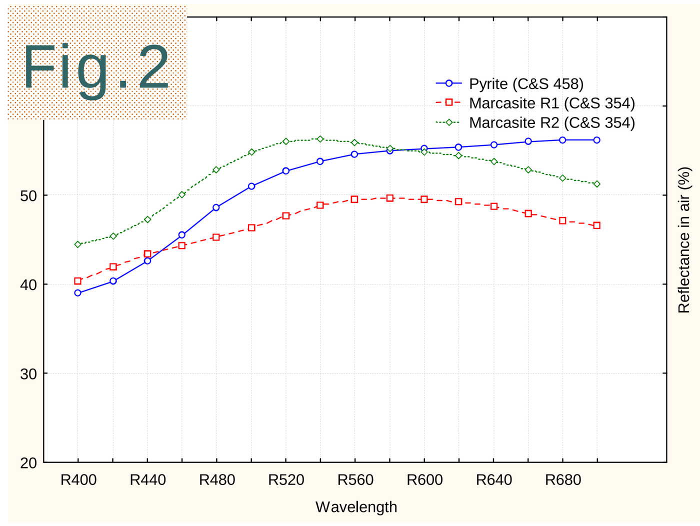

FIGURE 1
Common ore minerals such as Pyrite (FeS_2 cubic), Marcassite (FeS_2 orthorhombic) or Pentlandite ($(Fe,Ni)_9S_8$) display too subtle differences to be discriminated using colour video imaging (100 nm bandwidth). Multispectral imaging (10 nm bandwidth) has demonstrated its potential for discriminating isotropic minerals (Pirard, 2004).
Fig. 1 is a plot of Pentlandite vs. Pyrite visible reflectance spectra after Criddle & Stanley, 1993.
FIGURE 2
Further discrimination between bireflectant minerals requires grabbing the anisotropic light behaviour. Fig. 2 shows how the Marcassite spectra are a function of crystal lattice orientation and overlap with the isotropic Pyrite spectrum .

II. CALIBRATED MULTIPLE IMAGING.

A series of images from the same scene are taken using a set of selected 10nm bandwidth interference filters. In addition, the orientation of the incident light beam polarisation is turned by steps of 30° *(!instead of turning the specimen holder)*.
For each combination, images are taken using time-averaging to reduce pixel noise and background correction to remove non-even illumination and optical artefacts.
Images are stacked together into a line sequential multivalued image file (*.LAN). Image translation and warping is eventually applied to achieve perfect co-registration of the different images.
For each selected wavelength an indicative bireflectance image is computed from :

$$B_i^{\lambda} = \left| Max\left\{P_i^{\lambda,\theta}\right\} - Min\left\{P_i^{\lambda,\theta}\right\}\right|$$

where $P_i^{\lambda,\theta}$ is the intensity of i^{th} pixel at wavelength λ under polarisation orientation θ.

Fig.3

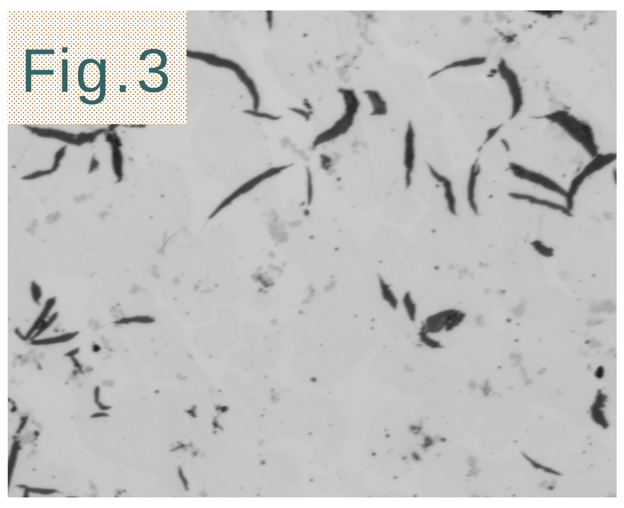

Fig.4

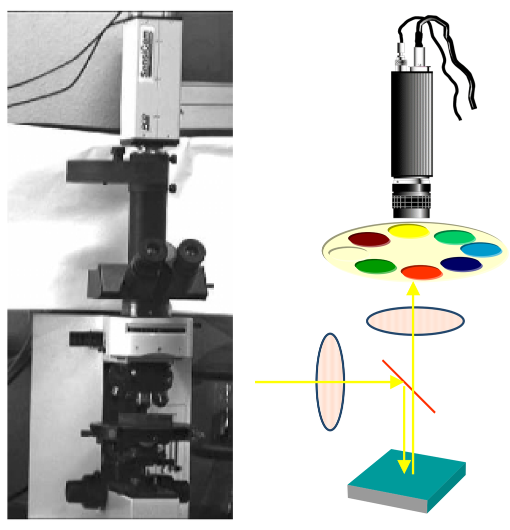

Fig.5

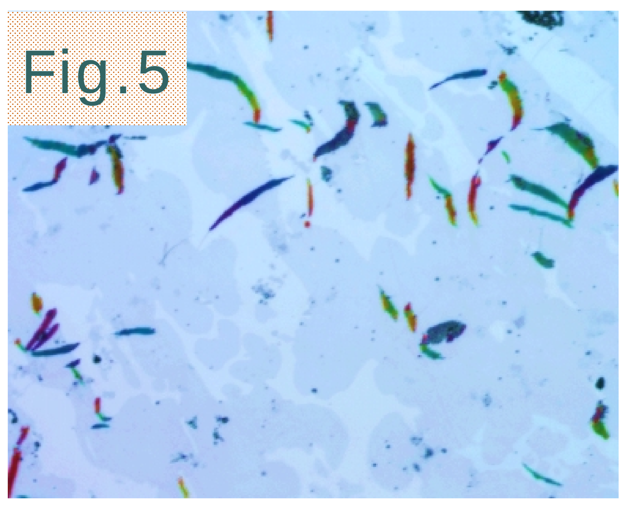

FIGURE 3
Monochrome image of cast iron in white light. Cast iron is classically observed in such conditions after eventual specific etching to reveal carbides, cementite, martensite, etc.
FIGURE 4
Instrumental setup : reflected light microscope fitted with a filter wheel and rotating polars. The use of interference filters and polarizing filters offers enhanced discrimination without having to rely on poorly reproducible etching conditions.
FIGURE 5
False colour image combining three polarised orientations (30°, 90°, 120°) into a single colour (R,G,B) image. Colour reveals the strength of optical bireflectance (e.g. extremely strong in graphite).

III. MULTIVARIATE IMAGE CLASSIFICATION.

Multivalued image classification is achieved using supervised algorithms initially developed for remote sensing purposes. Instead of clustering algorithms, these consider that the user has an “a priori” knowledge of the image content and is capable of training the system by selecting representative regions within the material specimen. The standard Fisher Linear Likelihood method (Biehl and Landgrebe Multispec ®) proves to be efficient enough in most cases. An optimal phase image is obtained by combining multispectral information with the bireflectance image.
On the other hand, using a multiple thresholding operation on the single bireflectance image leads to segmentation of individual grains. Such an image can be further exploited for textural studies that are increasingly required for ore processing purposes. Limited crystal lattice orientation could be extracted from the mapping of polar orientation at minimum/maximum intensities offering a simple and flexible alternative to more sophisticated EBSD analysis.

Fig.6

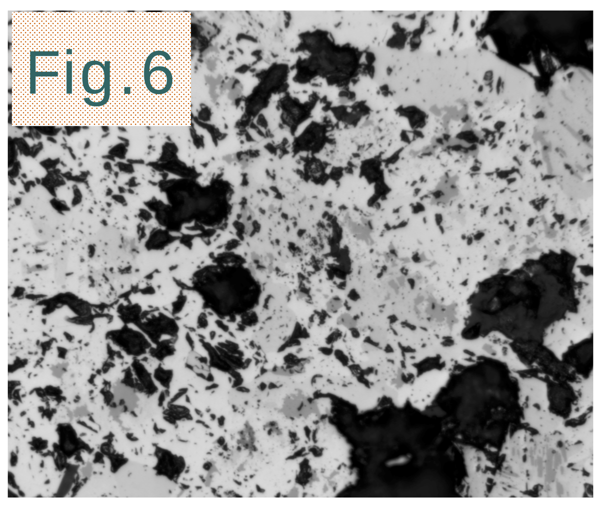

Fig.9

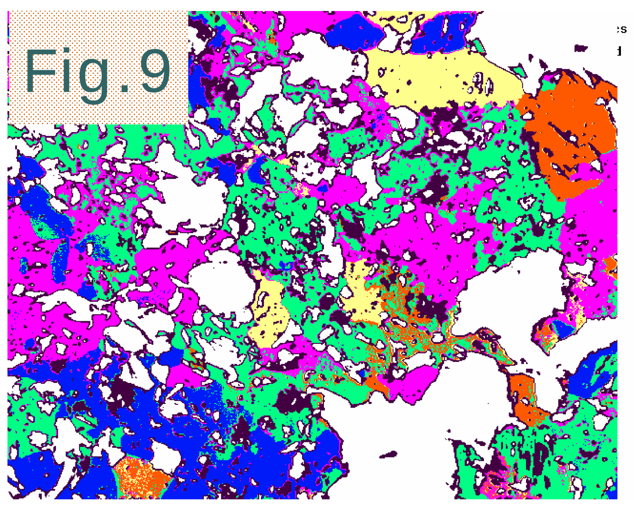

Fig.8

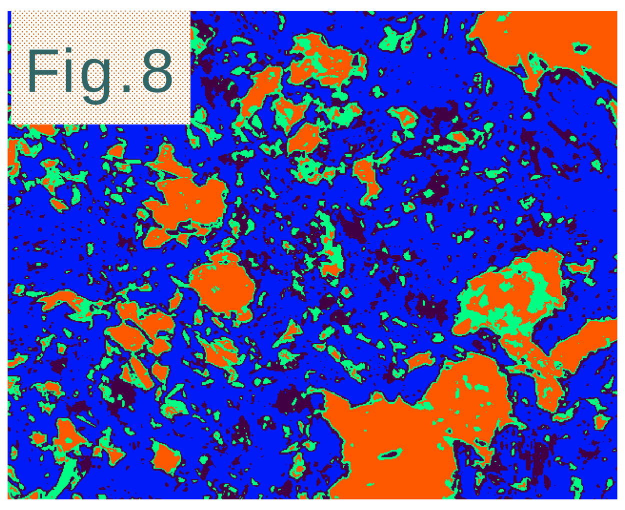

Fig.7

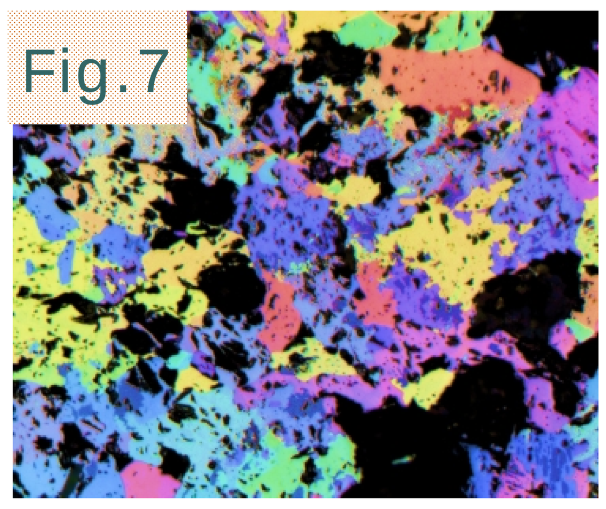

FIGURE 6
Monochrome image of iron ore (magnetite, hematite)
FIGURE 7
False colour bireflectance imaging of the same scene as fig.6
FIGURE 8
Fisher Linear Likelihood classification of magnetite and hematite based on bireflectance images
FIGURE 9
Segmentation of hematite grains based on bireflectance intensities

IV. CONCLUSIONS & PERSPECTIVES.

Proper reflected light microscopy imaging taking advantage of all optical properties of minerals open competitive perspectives for addressing modal and textural analysis requirements.
In many cases, this technology is able to rival with BSE and EBSD imaging techniques under the SEM.
Polarisation imaging has been pioneered by Oldenbourg (1995). However to reach quantitative bireflectance (change in reflectance with orientation) and optical anisotropy (change in the polarisation angle) measurements involves a partial redesign of the optical microscope

V. REFERENCES.

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Université de Liège
Dpt GeomaC
Géoressources Minérales
&
Imagerie Géologique

Sart Tilman, B52 4000 LIEGE
eric.pirard@ulg.ac.be
http://www.geomac.ulg.ac.be/mica