Multiradial Imaging in Optical Ore Microscopy

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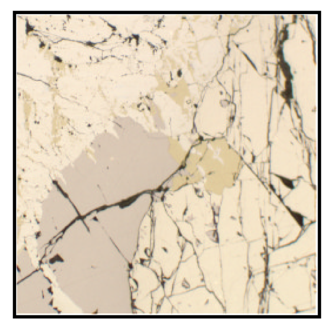
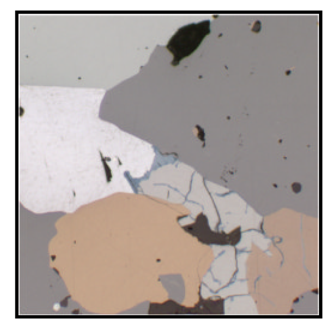
1. INTRODUCTION—QUANTITATIVE ORE MICROSCOPY

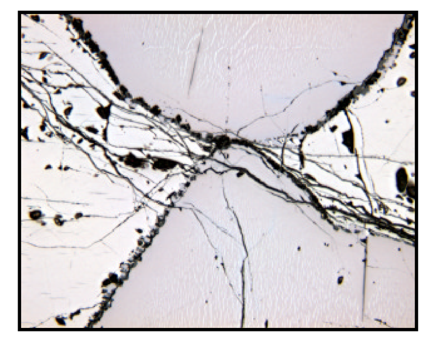
Ores are best characterised through a complete modal analysis (volume phase ratio) of their constituting minerals. In order to achieve this with image analysis, contrasted images of the various minerals have to be obtained. Several authors rely on Back-Scattered Electron images eventually complemented by EDX microanalysis (QEMScan) (Sutherland & Gottlieb, 1991).
Reflected light optical microscopy imaging is often disregarded, although trained human operators very easily identify the different ore minerals in this way.
Previous works using black and white imaging true colour imaging or multispectral imaging have shown significant improvement in phase recognition. The last step added in this work is to deal with the dispersion of reflected polarised light.



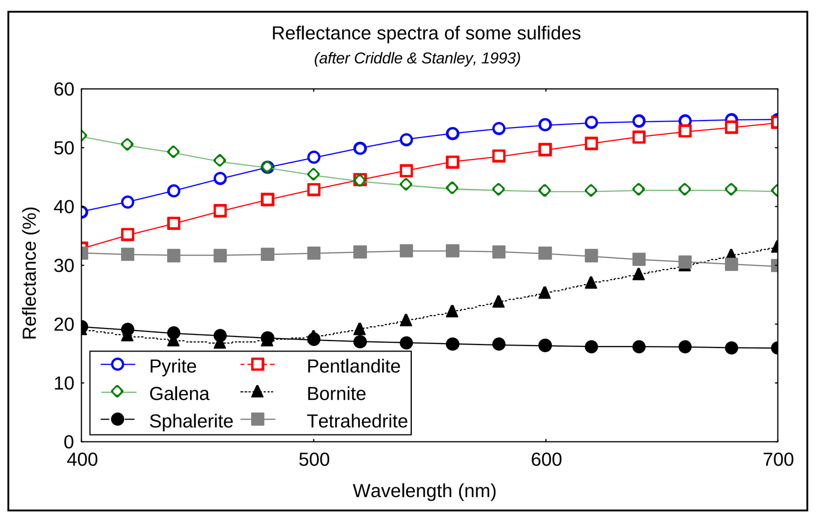
True colour image (3 CCD) of a nickel sulphide ore from Sudbury (Canada)



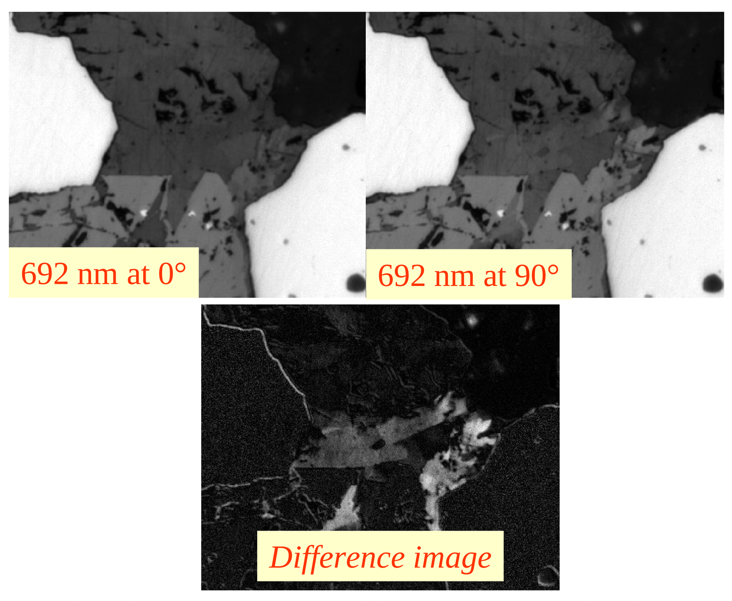
True colour image (3 CCD) of a copper sulphide ore from Kipushi (Congo)



True colour image (3 CCD) of a titanium oxyde ore from Tellnes (Norway)



Some reflectance spectra (in air) for common isotropic ore minerals.



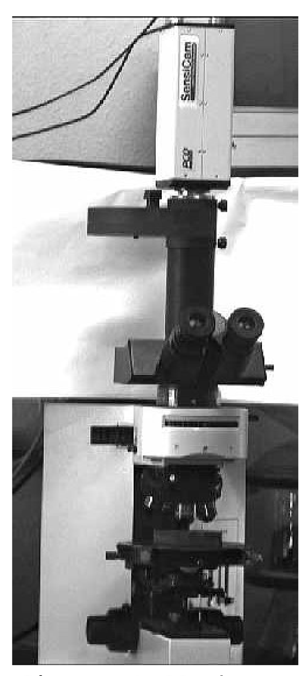
Coveline (CuS) shows strong bireflectance and pleochroism. Two images taken under polarised reflected light at different angles show distinct differences in intensity at 692 nm.

2. PRINCIPLES - POLARIZED LIGHT MICROSCOPY

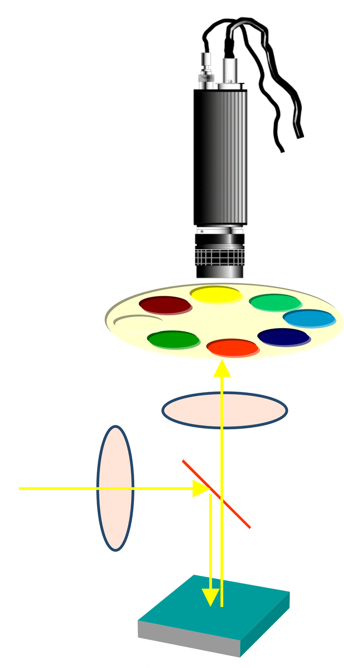
The amount of light reflected by opaque minerals is governed by two intrinsic properties : the absorption coefficient (K) and the refraction index (n). Both properties are wavelength dependent and so a characteristic reflectance spectrum can be measured for any mineral. The Commission on Ore Microscopy has published a large database of such reflectance spectra. (Criddle & Stanley, 1993). The orientation of the crystal lattice affects the overall intensity (bireflectance) of the reflectance spectra and its geometry (pleochroism). It also affects the dispersion pattern of a plane polarised light hitting the surface. Through the use of a second polariser (analyser) on the reflected beam, microscopists traditionally identify anisotropic minerals by rotating the sample stage.

3. METHODS - MULTIRADIAL IMAGING

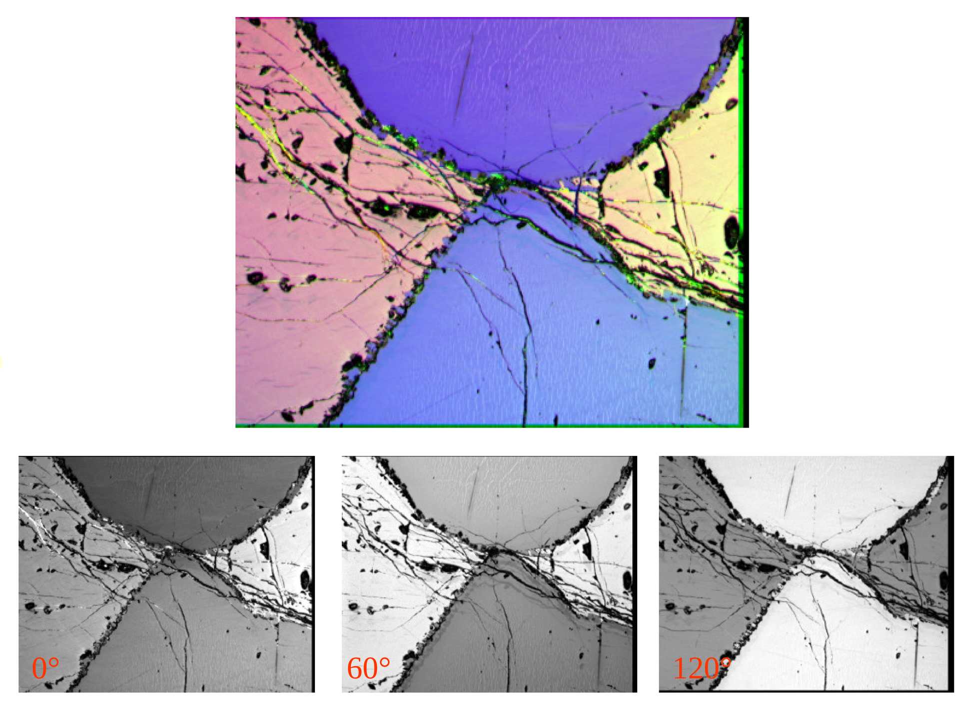
An Olympus BX 60 microscope fitted with a rotating polariser (incident light beam) and a rotating analyser (reflected light beam) has been used for this study. Instead of rotating the sample stage, a synchronised rotation of the polarisers (nichols) has been developed. The same principle has already been adopted by Fueten in transmitted light microscopy (Fueten, 1997). The advantage of such a system is to allow for taking pictures at multiple polarising angles without having to rotate the digital images in memory.
A PCO Sensicam with Peltier cooling and variable exposure timings (1ms to 1000s) has been used for taking high-resolution pictures. For each scene a series of images with sub-crossed nichols (85°) are taken for various angles. Variable intensities reveal anisotropy of the crystal structure.



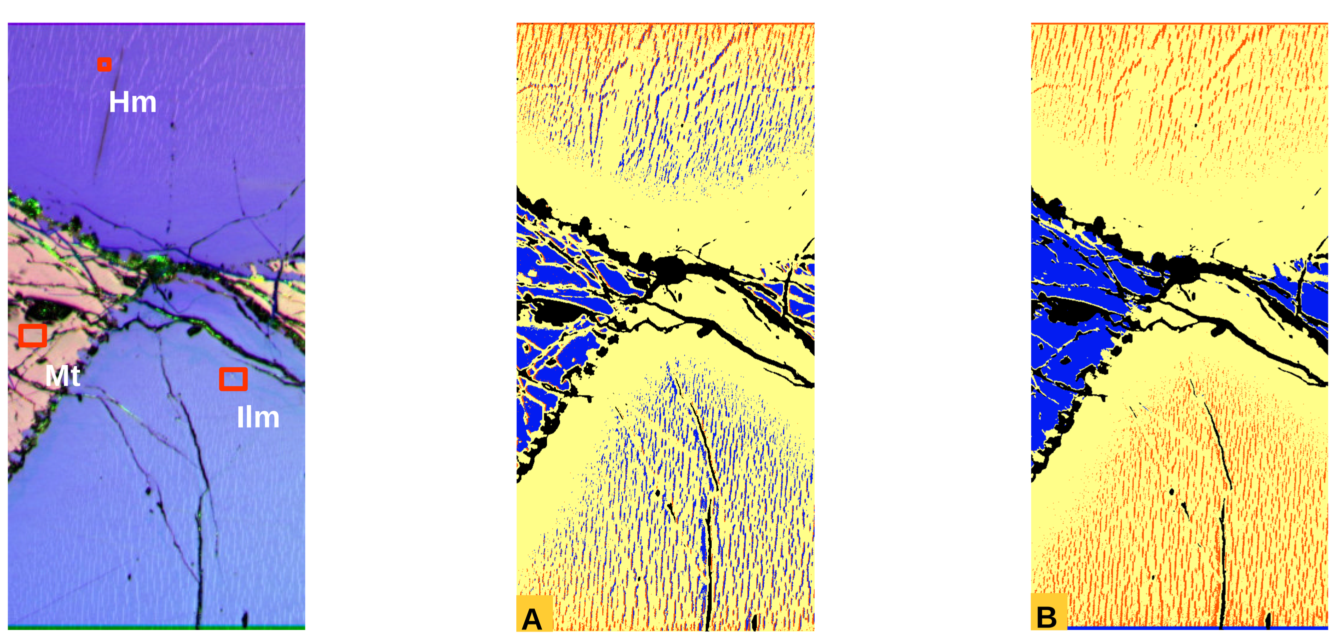
An Olympus BX60 microscope fitted with a multispectral filter wheel and a PCO Sensicam.



Scheme of a multispectral / multiradial imaging system with synchronised nichols



Imaging under crossed nichols at different angles and the equivalent colour composite visualisation



A scene with magnetite (Mt), ilmenite (Ilm) and hematite (Hm) has been taken in both multispectral imaging (438nm – 489nm – 591nm – 692nm) and multiradial imaging modes.
Fisher Linear Likelihood classification with identical training sets performs perfectly when multiradial imaging is added (B), whereas multispectral information alone leads to confusion between Mt and minute Hm exsolutions (A).

4. RESULTS - MAGMATIC Ti MINERALISATION

Multiradial images gathered from the polarising microscope can be processed in exactly the same way as colour or multispectral images.
The most suitable way for ore microscopy is to rely on supervised classification after having trained the system on regions of the image considered to be representative of the existing minerals. Discriminant analysis will then classify the remaining pixels into the indicated mineral categories (Pirard & Bertholet, 2000).
The titanium mineralisation of Tellnes (Norway) contains, among others, ilmenite ($FeTiO_3$), magnetite (Fe_3O_4) and hematite (Fe_2O_3).Both hematite and ilmenite are anisotropic but have clearly different reflectance values, whereas magnetite is isotropic but shows possible confusion with either ilmenit of minute hematite exsolutions.

5. CONCLUSIONS - PERSPECTIVES

This multimodal imaging approach appears to be the most promising for automatic phase recognition under the reflected light microscope.
Nevertheless, further work has to be done to reach a fully automatic image acquisition of multispectral and multiradial information. In particular, optimal image exposure and exact pixel co-registration from image to image could be improved as well as some reflectance ghosts generated by the semi-reflecting mirror.
Classification of large sets of images with strongly variable crystal lattice orientations should be tested for its robustness.

6. REFERENCES

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