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IMAGING BIREFRINGENT MINERALS WITHOUT EXTINCTION USING CIRCULARLY POLARIZED LIGHT

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Abstract

Linear cross-polarized optical images reveal the birefringence of mineral grains and are very useful in petrography. However, if the vibration directions of the crystal are not at 45° to the polarizers, then the intensity of the interference colors is reduced, and in some orientations, to zero (extinction). This reduction in intensity, and extinction, can be eliminated if circular polarizers are used in place of linear polarizers. The interference colors of colorless minerals then correspond exactly with those on the Michel-Lévy chart. Similarly, isogyres are eliminated from conoscopic images. This simple, inexpensive technique can be used with ordinary petrographic microscopes and scanners. It can be very useful for quantification of textures (microstructures) from single images.

Keywords: optical mineralogy, polarized light, circular polarization, textural quantification, birefringence.

Sommaire

Les images optiques produites avec polarisation linéairement orthogonale révèlent la biréfringence de grains de minéraux, et s'avèrent très utiles en pétrographie. Toutefois, si les directions de vibration du cristal ne sont pas orientées à 45° des nicols polariseurs, l'intensité des couleurs d'interférence s'en trouve réduite et, dans certaines orientations, jusqu'à zéro (c'est-à-dire, jusqu'à l'extinction). On peut éliminer cette réduction en intensité, et l'extinction, en utilisant des polariseurs circulaires au lieu des polariseurs linéaires. Les couleurs d'interférence de minéraux incolores correspondent alors exactement à celles de l'abaque de Michel-Lévy. De même, les isogyres sont éliminées des images conoscopiques. On peut se servir de cette technique simple et peu couteuse avec des microscopes pétrographiques ordinaires et avec numériseurs. Elle peut être très utile pour quantifier les textures (microstructures) à partir d'une seule image.

(Traduit par la Rédaction)

Mots-clés: mineralogie optique, lumière polarisée, polarisation circulaire, quantification de textures, biréfringence.

Introduction

Microscope observation of transparent minerals in cross-polarized light is a familiar technique discussed in all optical mineralogy textbooks (*e.g.*, Dyar *et al.* 2008). The sample (generally a thin section) is illuminated with linearly polarized light and observed through a second linear polarizer oriented orthogonally to the illuminating polarizer. Isotropic materials are extinct (no light passes through). Anisotropic minerals are also extinct if viewed along an optic axis. All other orientations of anisotropic materials will show retardation (birefringent) interference-colors, whose intensity varies with orientation. If the vibration directions of the crystal are parallel to either polarizer, then the intensity of the retardation colors will be zero, and the crystal appears extinct. These extinction positions are used to determine aspects of the orientation of the indicatrix of the crystal. They can also help the observer to distinguish adjacent crystals of the mineral. In some circumstances, they can be a hindrance, however. This is particularly the case if a petrographer wants to image a thin section and examine quantitatively the texture (microstructure) of the grains. In this case, several sections with different orientations of the polarizers must be examined. Interference colors also give information on crystal orientation but,

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again, intensity variations with rotation will complicate image analysis. This is particularly a problem for low-birefringence minerals, such as quartz and the feldspars.

Most petrographers and mineralogists consider that variable intensity of retardation colors and extinction are unavoidable, but there exists a simple, inexpensive optical technique that can reveal all anisotropic crystals in a section, except for those with a vertical optic axis. The circularly polarized light technique is not new, but deserves to be more widely applied.

Circularly Polarized Light

Conventional petrographic microscopes use two linear polarizers to produce images of anisotropic minerals. This is generally termed cross-polarized light (XP). Unpolarized light passes through a linear polarizer, which only allows a single direction of polarization. This polarized light then passes through the sample, generally a thin section, where it is split into two orthogonal components. Where these components emerge from the crystal, there is a difference in phase called the retardation. The components are combined in a second, orthogonal polarizer, where interference colors are produced. The colors are controlled by the birefringence of the mineral in the direction of propagation of the light. However, the intensity of the interference color will depend on the orientation of the light components with respect to the polarizers: if they are parallel, then no light will pass through, and the mineral is said to be at extinction. Hence, the intensity of the retardation color will change as the stage is rotated.

It is commonly taught that retardation colors all fall on the Michel-Lévy chart. In fact, the Michel-Lévy chart shows the brightest interference-colors, visible where the vibration directions are at 45° to the polarizers. If the stage is not rotated, then most of the interference colors will be less intense than those on the Michel-Lévy chart. This is the situation in a simple photomicrograph.

The proportion of mineral grains that are at extinction in a sample without preferred orientation can be calculated readily. There are two origins for extinction: 1) alignment of the optic axis close to the vertical, and 2) alignment of the vibration directions parallel to the polarizers. Although both effects apply to unique directions, in reality extinction extends over a band of orientations. The width of this band will depend on many factors, but principally the birefringence. For the purposes of calculation, the band is considered to be ±5°, a value typical for low-birefringence minerals like quartz and the feldspars. For the first situation, consider a sphere of radius $180/\pi$ mm; each degree on the surface has a length of 1 mm. The area at extinction around an optic axis is πr^2, here 78.5 mm^2. The area of the sphere is $4 \pi r^2$, here 41250 mm^2. The percent of extinct positions for a biaxial mineral is then 0.76%, and half that value for a uniaxial mineral. For the second situation, the calculation is even simpler. If a mineral is extinct for ±5° of each 90° segment, then 10/90, or 11%, of crystals will be extinct.

The technique presented here uses circularly polarized (CP) light. This simple treatment is for a single wavelength of light. As before, unpolarized light passes through the lower polarizer (Fig. 1). It then passes through a quarter-wave plate oriented with a fast direction at 45° to the polarization direction, which splits the light into two components with a phase difference of 90°. The electric vector of this light traces out a helical path, hence the term circularly polarized light. The CP light then passes through the sample. Here the differences in index of refraction for different orientations orthogonal to the propagation direction will modify the shape of the helix and make the light elliptically polarized. The light then passes through a second quarter-wave plate with its fast direction orthogonal to that of the first quarter-wave plate. The elliptical polarization is then resolved back into linearly polarized light with a different orientation from the initial polarizer. This then passes through the analyzing polarizer, producing a similar result to the first case with linearly polarized light. There is no extinction for any orientation of the crystal because all polarization orientations are present. Indeed, there is no change in the intensity of the final interference-colors with rotation of the sample.

Circular polarization is only produced for a single wavelength of light in this setup, four times the retardation of the quarter-wave plates. For typical quarter-wave plates, this is in the range 560 – 620 nm, *i.e.*, orange light. However, despite this limitation, the CP technique works remarkably well for polychromatic light, as departures from circularity of polarization are minor. The interference colors of colorless minerals match exactly those of the Michel-Lévy chart, without the loss in intensity observed in XP images.

The CP technique can also be applied to conoscopic observations. Indeed one of the earliest references was in this context: Craig (1961) described the "Benford Plate" for the study of interference figures. Such figures in CP are simpler than the conventional images in that they lack the familiar isogyres. However, they still have melatopes and isochromes. Hence they can be used for distinguishing uniaxial and biaxial minerals, as well as for the determination of optic signs. The CP method has also been used to make bomb sights (Gunter 2003).

One should note that CP does not completely replace linear polarizers. Extinction can help distinguish adjoining mineral grains, and it gives the orientation of vibration directions. Also a linear polarizer is necessary for the identification of pleochroic colors. Combinations of a linear polarizer and circular analyzer, and the inverse, have been explored principally by researchers in materials science and biology (Glazer *et al.* 1996, Oldenbourg & Mei 1995). These methods have considerable advantages for the analysis of low-birefringence materials.

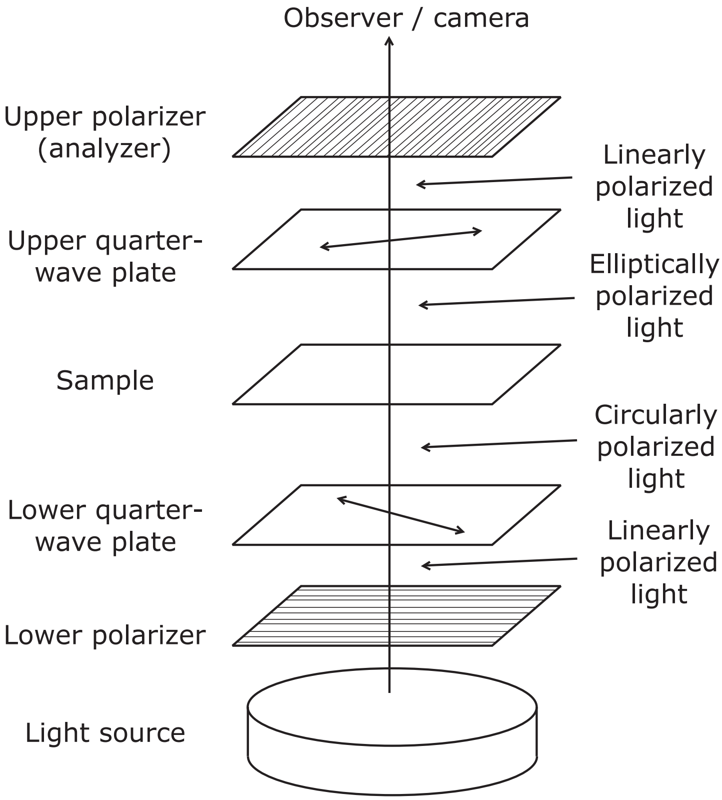

FIG. 1. Circularly polarized light observations of anisotropic materials. The directions of the linear polarizers are indicated by hatching. The fast direction of the quarter-wave plates is indicated by an arrow. Petrographic microscopes typically have all of these components except the lower quarter-wave plate. A similar setup can be used on a flat bed scanner with an upper illuminator.

APPLICATION OF THE CP TECHNIQUE

Some microscope manufacturers can supply circular polarizers and analyzers, but generally these must be improvised. Quarter-wave plates (also known as retarder plates) are manufactured from quartz, mica and plastic. The two quarter-wave plates should have the same retardation: 140 to 155 nm are typical values. Those for petrographic microscopes are readily available and are generally made of quartz. Most petrographic microscopes have a position for a quarter-wave accessory plate between the sample and the upper polarizer. However, very few microscopes have a position for the other quarter-wave plate between the lower polarizer and the sample. In some microscopes, an unmounted 20-mm-diameter wave plate can be placed on the condenser. Otherwise, a lower quarter-wave plate can be placed under the sample on the stage. Of course the stage cannot be rotated, but this is not necessary using the CP set-up. A holder can also be made that holds the filter under the stage.

Scanners are very useful for imaging both regular and large whole thin sections. Inexpensive flat-bed scanners with an upper light source can easily achieve 10 μm resolution, and slide scanners can surpass this (Tarquini & Armienti 2001). For this type of imaging, the polarizing and quarter-wave plates need to be the same size as the thin section. Polarizing material is available as rigid, mounted sheets, but unmounted material reduces the scanner–slide distance. Quarter-wave plastic retarder film is also available with good optical quality. Both materials are inexpensive and available in large sheets. Suitable sources of these materials are available at http:// geologie.uqac.ca/~mhiggins/cp_images.htm

Examples

The first example shows the application of the CP method to low-birefringence minerals. A sample of vesicular dacite lava from Taapaca volcano, in Chile, contains abundant plagioclase and minor sanidine. An image of the feldspar crystals was needed so that the crystal-size distribution could be calculated (Higgins 2006). The simplest way to produce such images is by thresholding the image. It is difficult to distinguish consistently the feldspars from vesicles in unpolarized light, as both are bright. In linear cross-polarized light (XP), the feldspars are clearly distinguished from vesicles, but some crystals are at extinction (Fig. 2A). In CP, almost all crystals are revealed, except for a small proportion with vertical optic axes (Fig. 2B). The differences between the images have been brought out in Figure 2C. Images of the feldspars in Figures 2A and 2B were produced by thresholding. These images were then colored and combined to produce Figure 2C. In this image, crystals in black are present in both images; blue crystals are only present in the CP images. The few red

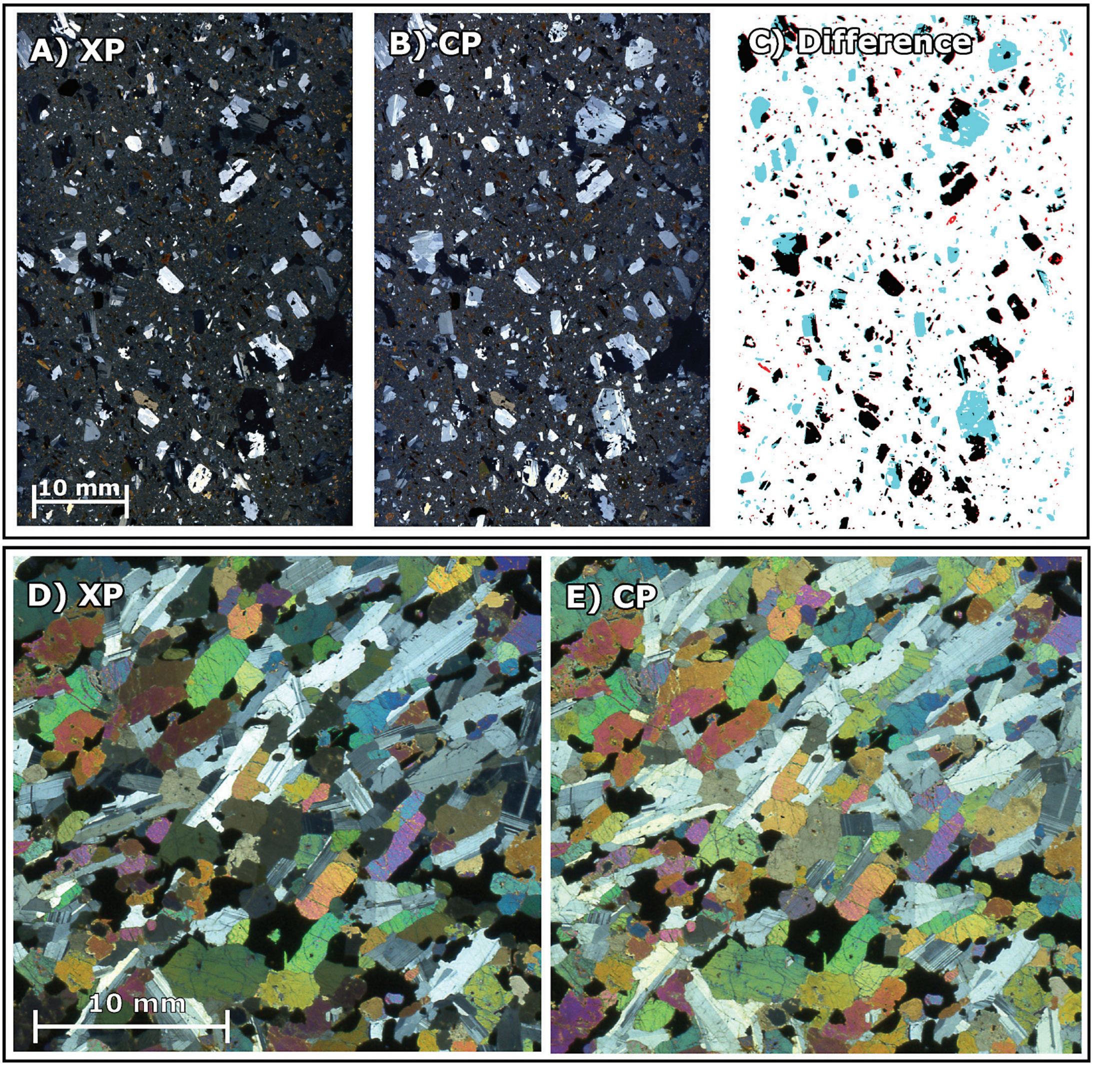

FIG. 2. Thin section images obtained using a flat-bed scanner. A) Linear cross-polarized image (XP) and B) circular cross-polarized image (CP) of a dacite lava. More crystals are visible in the CP image. C) Difference image for plagioclase in A) and B). Crystals visible in the CP image only are shown in blue. D) Linear cross-polarized image (XP) and E) circular cross-polarized image (CP) of a gabbro.

crystals, which are only present in the XP image, are probably due to slight differences in the threshold used to make each image.

A second example involves minerals with higher birefringence. Figures 2D (XP) and 2E (CP) are of a gabbro from the Skaergaard intrusion, in eastern Greenland. The rock contains plagioclase, olivine, clinopyroxene and an Fe oxide. In the conventional image (XP), some crystals of all transparent phases are at extinction, and many others have intensities of retardation colors significantly less than their maximum values. In the CP image, very few transparent crystals are at extinction, and the rest show retardation colors that resemble those in the Michel–Lévy chart. It is considerably easier to identify minerals in this image.

Conclusions

The circular polarization (CP) technique is a useful addition to the petrographer's toolkit. It is especially useful for producing images for illustration and quantification of textures. It is easily applied to petrographic microscopes for detailed work and to scanners for images of whole thin sections.

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