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The Application of Polarized Light Microscopy to Identify Minerals– A Preliminary Study of Forensic Geology

China E. Shieh[1]; Yung-fou Chen[2*], Ph.D.

[1]Department of Earth Sciences, University of Toronto, Toronto, Canada M5S 3B1

[2] Department of Forensic Science, Central Police University,
56 Shu-Jen Road, Kwei-San, Taoyuan 33304, Taiwan ROC.

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Abstract

In criminal cases it is crucial to collect and preserve any traces of evidence no matter how small they are. Even traces of evidence which can only be observed clearly at a microscopic level can provide critical details pertaining to the investigation. The ability to identify traces of minerals in forensics is important because they may provide important details. In order to effectively gather evidence, investigators must be able to pay attention to fine detail in order to notice even the smallest possible pieces of evidence. Polarized light microscopy (PLM) is by far the dominant technique used in forensic microscopy and key in the trace evidence analysis. PLM is a contrast-enhancing technique that uses birefringent materials to improve the quality of the images obtained by the microscope.

This study involved the analysis of 25 common minerals by polarized light microscopy. All minerals were inspected thoroughly and notes about distinguishing features were taken down. Observations such as maximum interference color, noting the Becke line movement direction, extinction and other physical properties which aid in mineral identification are noted. The data is gathered into a table and then used to establish a theoretical flow chart which can potentially help in future forensic mineral identification.

Keywords: forensic science, polarized light microscopy, trace evidence, criminalistics, mineral, soil, forensic geology

Introduction

Evidence from crime scenes can help investigators piece together the stories behind incidents. Forensic geology is the study of evidence relating to minerals, oil, petroleum, and other materials found in the Earth, used to answer questions related to legal issues [1-2]. The ability to identify minerals is beneficial as they are able to provide a lot of information. Although there are several thousand minerals, only about 20 or so are very common. Of these minerals, 9 of them make up about 95% of the crust [3]. As a result, if there any non-common minerals found it can be very indicative. The minerals found on a suspect's clothing can also help investigators figure out where they have been, as minerals have distinct chemical compositions and therefore the area in which they are formed must be abundant in such resources [4]. Investigators must be careful and making sure the traces of minerals they are analyzing are from the incident or related to it in some way and not from an irrelevant time.

One of the most powerful tools forensic scientists have is the polarizing light microscopy (PLM); a tool which can be used for all kinds of forensic applications. Sadly, in this computerized instrumentation era, few scientists routinely use a polarized light microscope (We missed Dr. Walter C. McCrone's good old days). With the help of PLM, we can analyze all sorts of samples, from asbestos to diamond. The PLM exploits optical properties of materials to discover details about the

*Corresponding author : nanoforensics@mail.cpu.edu.tw

structure and composition of materials, and these lead to its identification and characterization. Materials fall into one of two categories, isotropic and anisotropic. The isotropic materials demonstrate the same optical properties in all directions, such as gases, liquids, and certain crystals. The anisotropic materials possess optical properties which vary with the orientation of the incoming light and the optical structure of the material. About 90% of all solid materials are anisotropic. The refractive indexes (RI) vary in anisotropic materials depending both on the direction of the incident light and on the optical structure. Based on these optical properties we can differentiate unknown minerals found at crime scenes by PLM.

In Taiwan, it is not common to conduct the identification of minerals for criminal cases. Though the more traditional techniques such as the use of a polarized microscope are now being replaced by more advanced forms of technologies in the realm of mineral identification, it is still considered a reliable, simple and inexpensive method. The same information can be gathered with more sophisticated methods such as scanning electron microscopy (SEM), energy dispersion X-ray (EDX) or X-ray diffraction [4-5]. Though PLM is becoming a rather obsolete method, a large majority of minerals can still be distinguished from one another with enough experience and practice in identification. The use of polarized light microscopy for mineral identification requires the observation of interference color, extinction, comparison of relative refractive index using the Becke line test as well as the use of other physical properties. In this study a full wavelength plate (530 nm) is used to determine sign of elongation and interference figures as well as optic sign are also obtained.

Experimental

Materials

The minerals analyzed in this study are from Cargille Reference Set M-2b. All 25 specimens are powdered forms of the mineral mounted in Cargille Melt Mount which is the medium. This Melt Mount has a refractive index of 1.662. The minerals on these slides measure between 80 to 180 microns in diameter (personal communication with Cargille Labs, 2013).

Method

For each mineral, the name, and distinguishing features under both plane-polarized and cross-polarized light are included. Particularly important characteristics which are recorded include interference color at maximum birefringence, color, optical sign as well as any key notes about morphology.

Equipment

Olympus BX-50 Polarized Light Microscope, 1 λ (UTP-530) and 1/4 λ (UTP-137) retardation plates.

Mineral Samples

Cargille Reference Standards Set M-25.

Procedures

Set-up polarized light microscope. Turn on light source. Place slides under objective lens and bring field to focus. Observe mineral sample under both plane-polarized (PPL) and cross-polarized (XPL) light while making notes on distinguishing properties in the data table. Make use of 1 λ and 1/4 λ retardation plates in order to determine sign of elongation, while also making a note of it in the data table. Flowchart is constructed in a logical manner such that each step down is less generic than the previous in order to narrow possibilities down. Under cross-polarized light, rotate stage to determine whether mineral is isotropic or anisotropic (careful with apatite) while being sure to look at a collective because it's possible to be viewing an anisotropic mineral down an optic axis and therefore having it appear isotropic.

After the initial step of determining whether a mineral is isotropic or not, there is not any particular order which must be followed, as the process to fully justify the identity of a mineral is not unique. Some may require multiple observations using both plane-polarized and cross-polarized light, while others may have a significantly diagnostic property which can found under either PPL or XPL. Therefore there is no need in following a laid-out step; there are just certain steps and techniques used when looking for specific features under a polarized light microscope.

The most obvious feature which can be seen right away is the color of the mineral. This property is only observed under PPL conditions. A property which is very characteristic of a few minerals is pleochroism. This is

the ability to absorb different wavelengths of transmitted light depending on the crystallographic orientation [6-7]. As a result, by rotating the stage under PPL some minerals will change colors. The way to identify the "true colors" of a mineral if it is pleochroic is to make it go extinct under XPL and then remove the analyzer and view it in PPL. Then, by rotating the stage another 90° to find the next extinction position and once again viewing it in PPL you can see the true colors.

Another test under PPL which can be conducted is known as the Becke Line test. This test helps determine the relative refractive index of the desired specimen to the surrounding medium. By dimming down the light and focusing on the edge of a grain, we can monitor the movement of a white, ghost-like line which appears. By lowering the stage, turning the fine adjustment knob toward oneself, we can find which object has a higher refractive index as the line will move towards the object with a higher refractive index.

Secondly, there are also many properties that can be observed under XPL; however they are only useful for anisotropic minerals because isotropic ones will always appear the same. A property which can be examined is extinction. When rotating the stage around, an isotropic mineral will go extinct four times, once at every 90° of rotation. Extinction occurs when the mineral is oriented such that a vibration direction is parallel with the lower polarizer, as when this occurs the light which does pass through the mineral is absorbed at the upper polarizer causing the viewer to see a black mineral [8]. There are several types of extinction known as parallel, inclined, birds-eye and undulose. With parallel extinction the mineral is extinct when the cleavage is aligned parallel to one of the crosshairs. With inclined extinction the mineral is extinct when the cleavage is at an inclined angle to the crosshairs. Undulose extinction is a form of extinction which is quite characteristic of quartz, but is a result of strain the mineral has experienced. Under the microscope undulose extinction within a mineral grain has different parts going extinct at different times, sometimes it appears similar to a wave moving throughout the mineral.

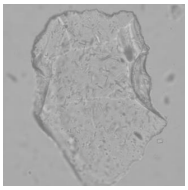
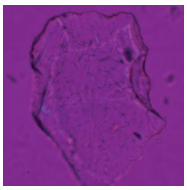
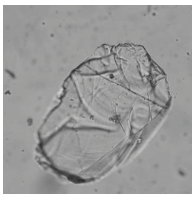
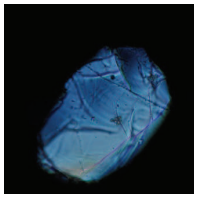
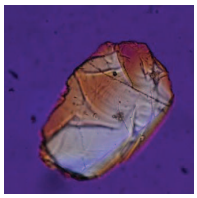
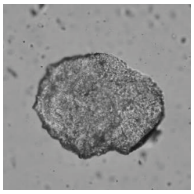
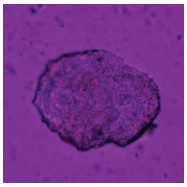
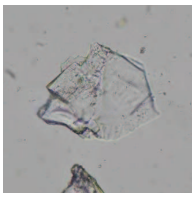
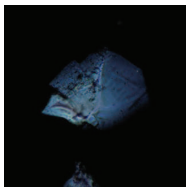
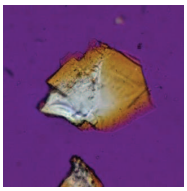
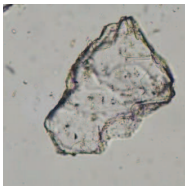
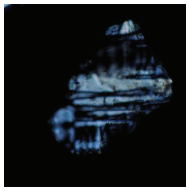
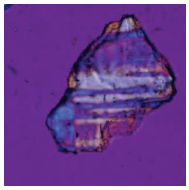
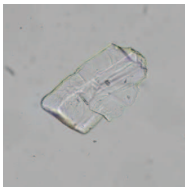
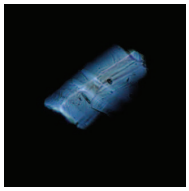
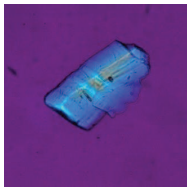
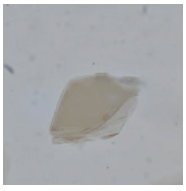
A more diagnostic property which is found under XPL is the interference color, especially when the mineral is aligned so that the greatest birefringence is observed. This color is found 45° from the extinction angle. This observed color represents the maximum difference between the refractive indices of the fast and slow waves, also known as the mineral's birefringence [6]. Due to the fact that interference only occurs when polarized light rays have an identical vibration direction, the maximum birefringence is observed when the angle between the specimen principal plane and the illumination vibrational direction overlap [9]. When viewing the color, one is able to compare it to a Michel-Levy Chart to determine the order of birefringence. This only works after one measures the diameter of the mineral in question or happens to know the thickness of the slide (assuming one is using a thin section).

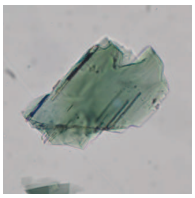
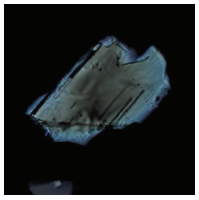
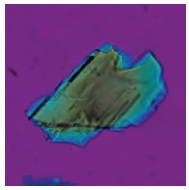
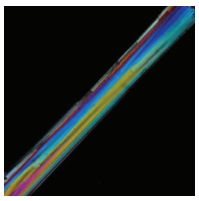
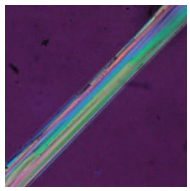
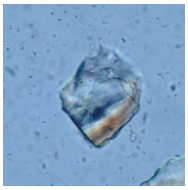
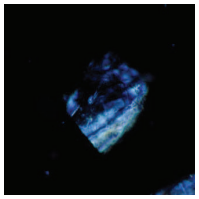
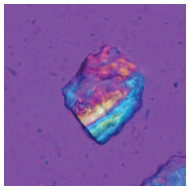
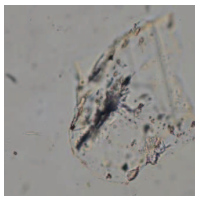
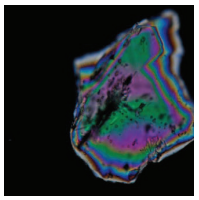
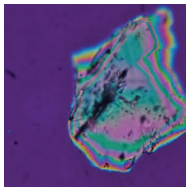
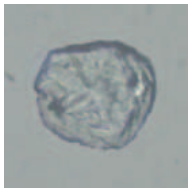
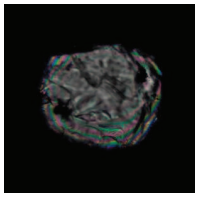
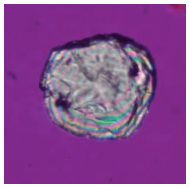
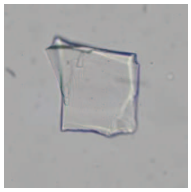
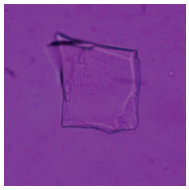
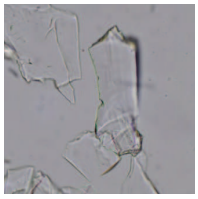
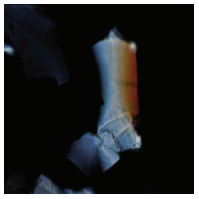
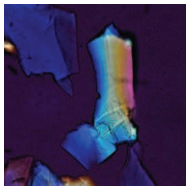
Results and Discussion

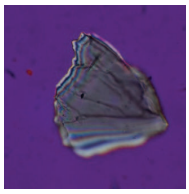
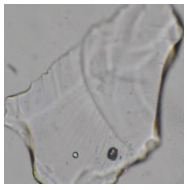
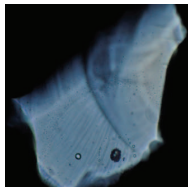
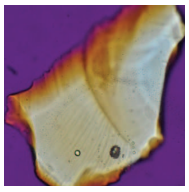
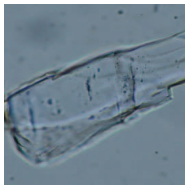
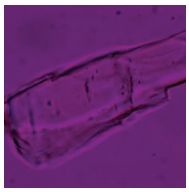
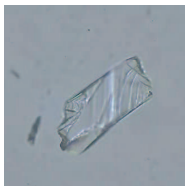
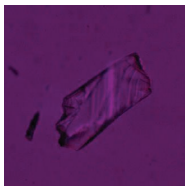
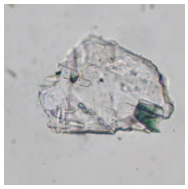
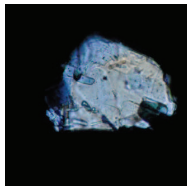
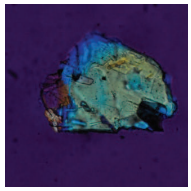
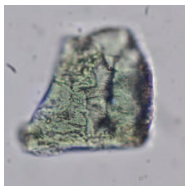
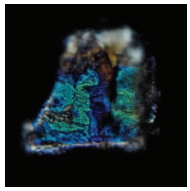
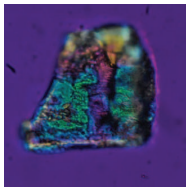
Starting with an unknown sample from the 25 studied, there needed to be a logical way to deduce what any given sample was using methodological steps.

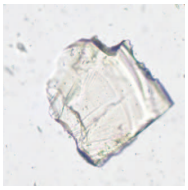
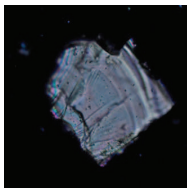
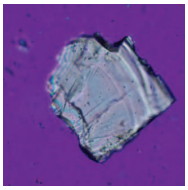
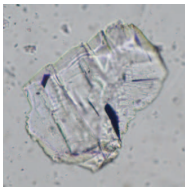
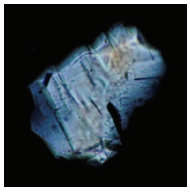
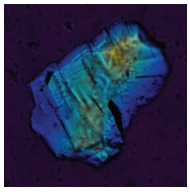
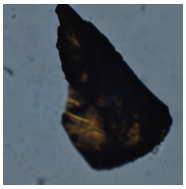
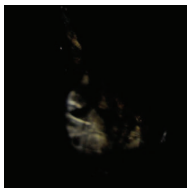
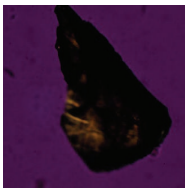
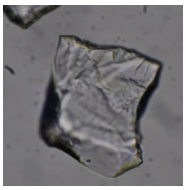
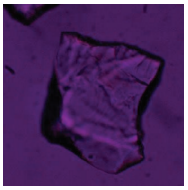
The first step which has been suggested is to figure out whether the mineral is isotropic or anisotropic. However, after the initial step there are no logical steps which must be followed. The proposed flowchart is not unique nor is it the only method to deduce what mineral is being viewed. Table 1 includes images of the mineral viewed under PPL and XPL (20x magnification) at an orientation such that the greatest birefringence can be observed while Table 2 contains interference figures.

Table 1. Optical Properties of Mineral Samples Under 20x Magnification

Mineral	Under PPL	Under XPL (at maximum birefringence)	Full-Wavelength Plate (to determine elongation)
Obsidian		Isotropic	
Quartz			
Opal		Isotropic	
Nepheline			
Microcline			
Albite			
Biotite		Unable to obtain*	Unable to obtain*

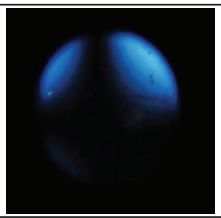
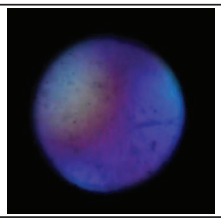
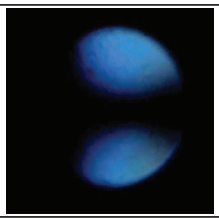
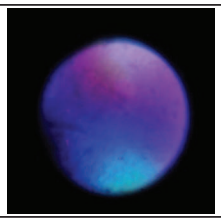
Hornblende			
Tremolite			
Serpentine			
Olivine			
Zircon			
Garnet (Almandite)		Isotropic	
Topaz			

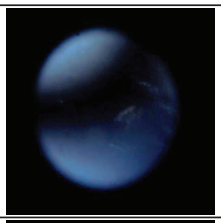
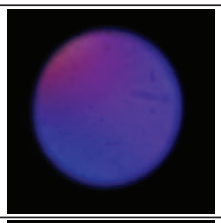
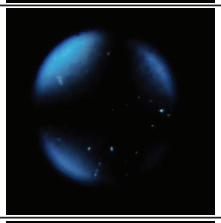
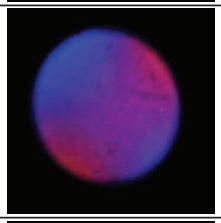
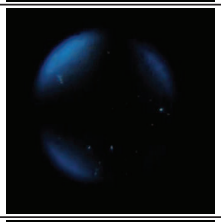
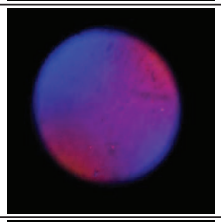
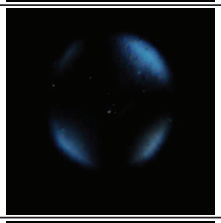
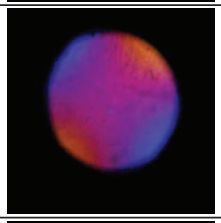
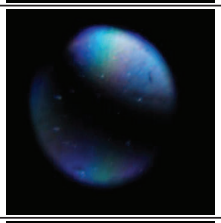
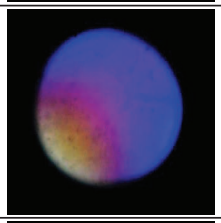
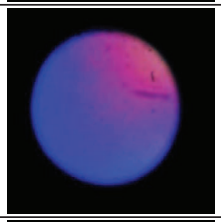
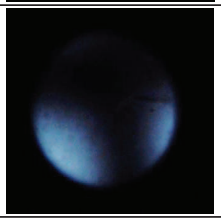
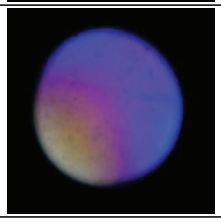
Tourmaline			
Beryl			
Apatite		Birefringence so low that it appears isotropic	
Calcite			
Fluorite		Isotropic	
Corundum			
Augite			

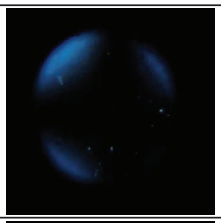
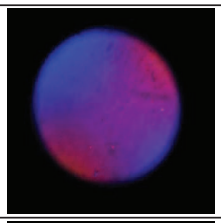
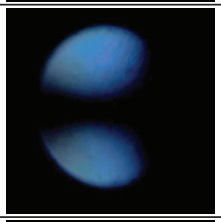
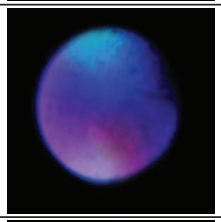
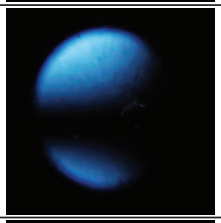
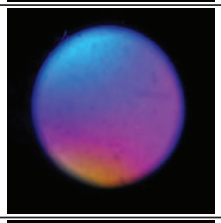
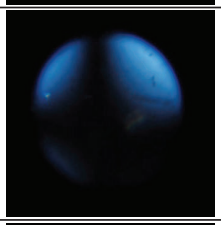
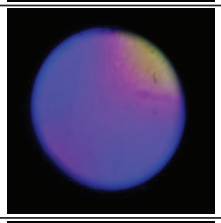
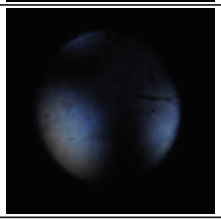
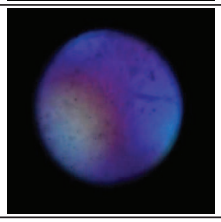
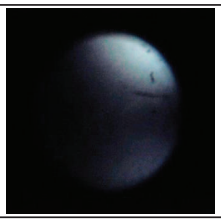
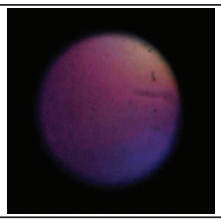
Titanite			
Labradorite			
Rutile			
Sodalite		Isotropic	

* There was a slight issue with the biotite slide as the way the slide had been prepared was so that somehow all the grains appeared isotropic. The most likely cause is that it was always being viewed down the optic axis. Therefore, not much information could be obtained besides its interference figure.

Table 2. Interference Figures of Mineral Samples

Mineral	Interference Figure	Optic Sign Determination
Obsidian	No Image	No Image
Quartz		
Opal	No Image	No Image
Nepheline		

Microcline		
Albite		
Biotite		
Hornblende		
Tremolite		
Serpentine		
Olivine		
Zircon	Unable to obtain	Unable to obtain
Garnet (Almandite)	No Image	No Image

Topaz		
Tourmaline		
Beryl		
Apatite		
Calcite		
Fluorite	No Image	No Image
Corundum		
Augite	Unable to Obtain	Unable to Obtain
Titanite	Very Difficult to Obtain	Very Difficult to Obtain
Labradorite	Unable to Obtain	Unable to Obtain
Rutile	Unable to Obtain	Unable to Obtain
Sodalite	No Image	No Image

Data collected from observations under PPL and XPL conditions are listed in Table 3 and Table 4 separately. Flowcharts are then derived from the distinguishing features of these data.

Table 3. Observations Under Plane-Polarized Light

Name	Color	Pleochroism	Becke Line Movement	Relief	Other Notes
Obsidian	Colorless	None	Out	High	Tubular and cylindrical-like inclusions
Quartz	Colorless	None	Out	High	Appearance of inside of seashells
Opal	Colorless	None	Out	High	Appears with sandy texture
Nepheline	Colorless	None	Out	High	
Microcline	Colorless	None	Out	Mod.	
Albite	Colorless	None	Out	Mod.	
Biotite	Brown		Out	Low	
Hornblende	Green, Brown		In	Low-Mod.	
Tremolite	Colorless	None	Out	Mod.	
Serpentine	Colorless, Pale Green-Brown	None	Out	Very High	
Olivine	Colorless	None	In	Low	
Zircon	Colorless, Pale-Brown	None	In	Very High	
Garnet (Almandite)	Colorless	None	In	High	
Topaz	Colorless	None	Out	Mod.	
Tourmaline			Out	High	Often triangular shaped
Beryl	Colorless	None	Out	Low-Mod.	
Apatite	Colorless	None	Out	Mod.	May be small hexagonal shapes
Calcite	Colorless	None	Out	High	
Fluorite	Colorless	None	Out	High	Often slender, elongated crystals
Corundum	Colorless	None	In	Mod.	
Augite	Brown, Green	None	In	High	
Titanite	Colorless	None	In	Very High	
Labradorite	Colorless, Gray	None	Out	High	
Rutile	Red-Brown	None	In	Very High	Dark, easily recognizable color
Sodalite	Colorless	None	Out	High	Massive, blocky shapes

Table 4. Observations Under Crossed-Polarized Light

Name	Interference Color	Extinction	U/B/I	Optic Sign	Sign of Elongation	Other Notes
Obsidian		N/A	I	N/A	N/A	
Quartz	1st order grey	Undulose	U	+	Positive	May exhibit undulose extinction
Opal		N/A	I	N/A	N/A	
Nepheline	1st order grey	Parallel	U	-	Negative	
Microcline	1st order grey	Inclined	B	-		Tartan twinning
Albite	1st order grey	Parallel	B	+		Albite twinning
Biotite			B	-		
Hornblende	2nd order green	Parallel to Inclined	B	-		
Tremolite	2nd to 3rd order	Parallel	B	-		Fibrous, prismatic habit
Serpentine	Anomalous		B	-		
Olivine	3rd order+		B	-		
Zircon	Very very high	Parallel			Positive	May see interference color at edges
Garnet (Almandite)		N/A	I	N/A	N/A	
Topaz	Up to 1st order orange	Inclined	B	+		
Tourmaline	2nd order blue	Parallel	U	-	Negative	Interference color masked
Beryl	1st order grey		U	-		
Apatite	Very low 1st order	Parallel	U	-	Negative	Birefringence so low, it may appear to be isotropic
Calcite	Very very high		U	-		Changing relief upon rotation
Fluorite		N/A	I	N/A	N/A	
Corundum	1st order grey		U	-		
Augite	2nd order blue & purple	Inclined	B	+		
Titanite	Very very high				Not easy to determine	
Labradorite	1st order grey		Difficult to Obtain			
Rutile	Very very high	Parallel				Interference color often masked
Sodalite		N/A	I	N/A	N/A	

**U: uniaxial material; B:biaxial material; I: isotropic material; N/A: not available

The primary flowchart (Figure 1) provided summarized but not detailed information. As the way the flowchart has been designed is so that there are smaller flowcharts within the larger one. The sub flowcharts which have been created can be found in Figures 2 to 5. Figure 2 is for sub group A (isotropic minerals). Figure 3 shows the sub group B minerals, the anisotropic with various types of interference color. Figure 4 shows the sub group C minerals, the colorless uniaxial minerals. Finally, Figure 5 illustrated the sub group D minerals, the colorless biaxial minerals.

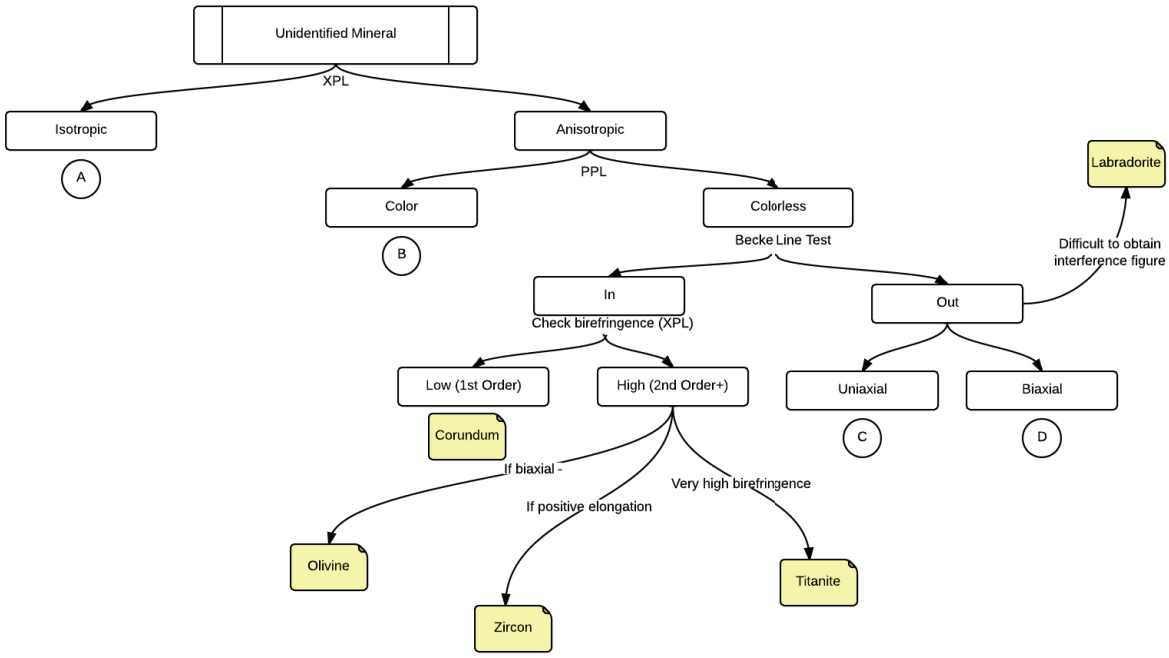


Fig. 1 Primary Flowchart

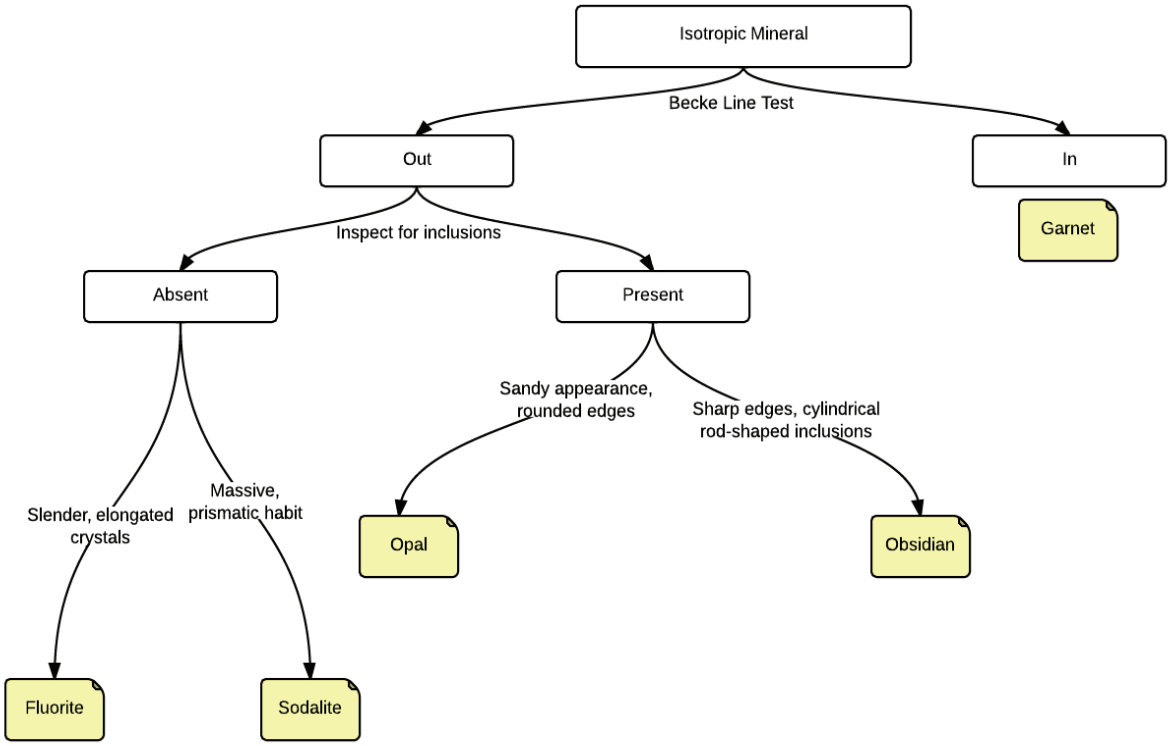


Fig. 2 Sub Flowchart A

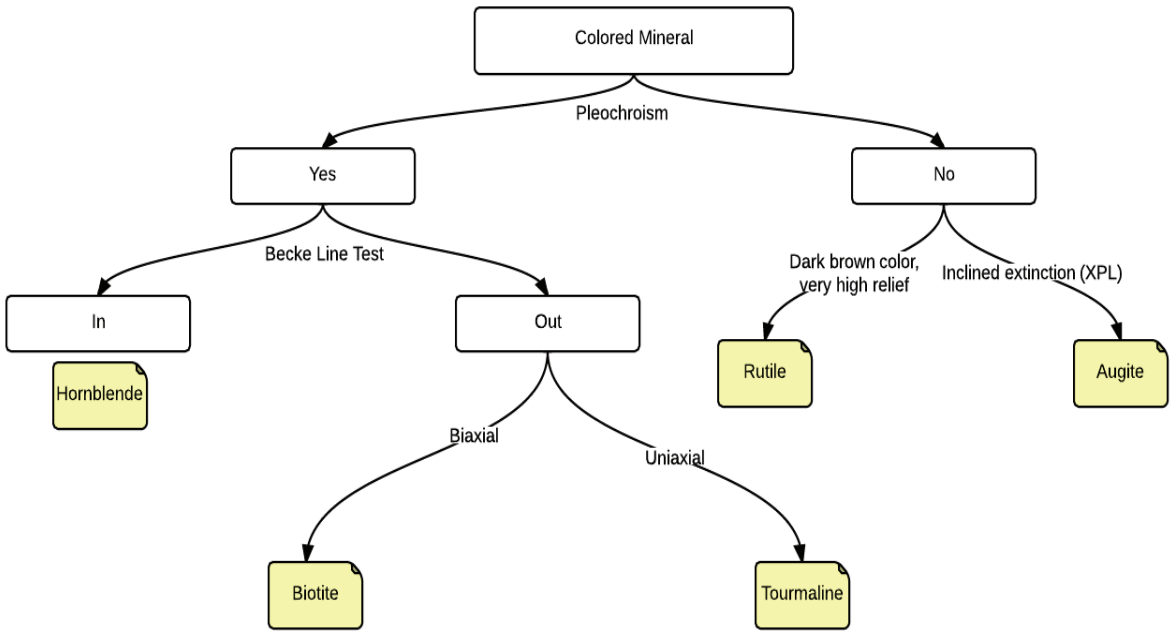


Fig. 3 Sub Flowchart B

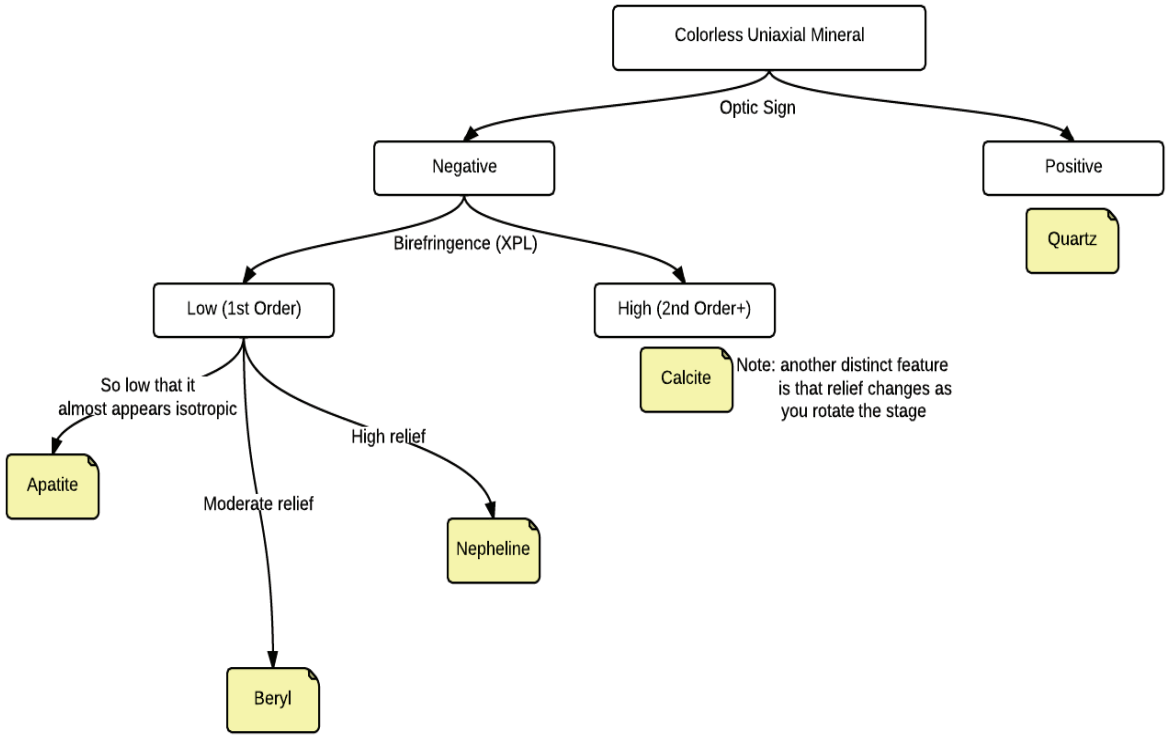


Fig. 4 Sub Flowchart C

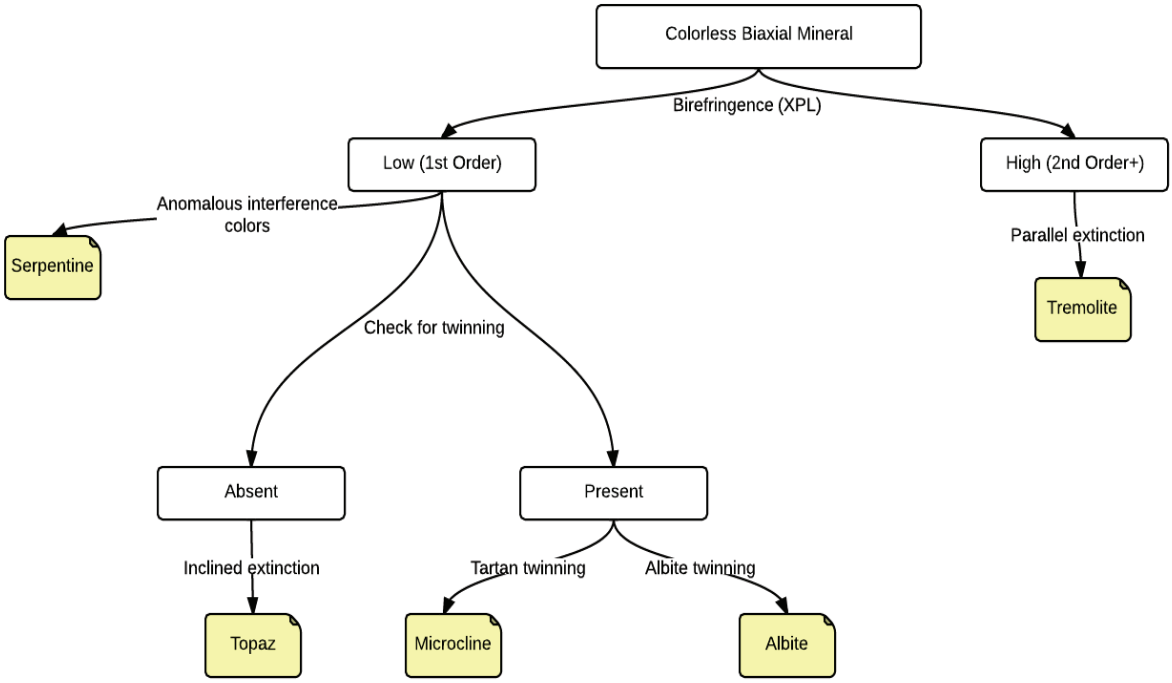


Fig. 5 Sub Flowchart D

The PLM identification process would be very straight-forward and simple with experienced examiners. However, as minerals come from nature the steps needed in order to identify them are generally more complex than one would like them to be. Minerals may have been altered chemically or undergone stress from the environment causing them to appear different. During our investigation, some results may also be affected depending on the mounting medium for future researcher one would have to keep that in mind. One must incorporate tests in both plane-polarized as well as cross-polarized light to be as precise as possible and there are alternative ways to come to the same conclusions.

Although it is currently uncommon for scientists to use PLM in forensic cases to identify minerals, hopefully there will be future implementations. Though many forensic scientists in Taiwan are unfamiliar with the PLM techniques due to the lack of optical crystallography background, this theorized flowchart should be useful in reviving such methods of analysis and bring more of PLM use to identify minerals.

Conclusions

This study included 25 mineral samples which are used to develop a strategy to aid in forensic identification using a polarized light microscope. Though the method proposed resembles nothing of a typical flowchart, it can be said that it is simply one large flowchart with smaller ones within. The theorized flowchart has been created such that each step of the way the features become more concise. Therefore the broadest distinction which can be made is whether or not a mineral is isotropic or anisotropic; making it the proposed first step down.

Forensic mineral identification with a polarized light microscope is a quick and inexpensive way to identify unknown samples, even in small amounts. In the future, it is also possible for someone to come along and expand upon this foundation and incorporating other observations to make a more robust flowchart. One possible idea is to add in true numeric values of birefringence and retardation using a Berek compensator (The Berek compensator is capable of quantitatively determining the wavelength retardation of birefringent materials by measuring the rotation angle of a calcite or magnesium fluoride optical plate cut perpendicular to the optical microscope axis.) or a similar device. If the flowchart is altered, it may be interesting to study how many different ways there are in confirming the identity of a mineral and whether the order of the steps matter in terms of efficiency.

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中央警察大學
誠
CENTRAL POLICE UNIVERSITY