INTRODUCTION TO PETROLOGY



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Book: Introduction to Petrology (John and Liu)

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1: OVERVIEW

1.1: What is Petrology?
1.2: How is This Book Organized?
1.3: Why is Petrology Useful?

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1.1: What is Petrology?

Learning Objectives

Students will be able to:

- Describe the three main branches of petrology.
- List key aspects of petrology.

Prior Knowledge and Skills

None

Definition

Petrology (from the Ancient Greek: πέτρος, romanized: *pétros*, lit. 'rock' and λόγος, *lógos*) is the branch of geology that studies rocks and the conditions under which they form.

The field of petrology is traditionally split into three subcategories: igneous, metamorphic, and sedimentary petrology. Click on the pull-down menu below to explore the definitions of these sub-fields:

Guided Inquiry Figure 1.1.1 Petrology Sub-fields

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At the university level, igneous and metamorphic petrology are traditionally (but not always) taught together because they both contain heavy use of chemistry, chemical methods, and phase diagrams (Teaching Mineralogy and Petrology). Sedimentary petrology is more commonly taught as a stand-alone class or together with stratigraphy because stratigraphy deals with the processes that form sedimentary rocks. ***Introduction to Petrology*** covers igneous and metamorphic petrology for this reason.

However, it is increasingly common for mineralogy and petrology (sometimes igneous, metamorphic, and sedimentary) to be combined into a semester- or year-long Earth Materials course. The modular structure of this online book is designed so that students and instructors can use the modules relevant to the course at their college or university.

Guided Inquiry Question 1.1.1

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Key Aspects of Petrology

Click on the pull-down menu below to explore some of the ways scientists study igneous and metamorphic rocks:

Guided Inquiry Question Figure 1.1.2

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This chapter contains material from “Petrology” by Wikipedia which is licensed under CC BY-SA 4.0.

References
Teaching Igneous and Metamorphic Petrology (ret. 7/1/2019) https://serc.carleton.edu/NAGTWorkshops/petrology/index.html

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1.2: How is This Book Organized?

This book is in initial stages of development. The authors received a VIVA Course Redesign Grant to create Module 2 (Microscopes). Further modules will be created as we secure additional resources.

Learning Objectives

Students will be able to:

- Compare the organization of learning modules to the organization of a petrology course that scaffolds learning.
- Match examples of questions or exercises to the appropriate level in Bloom's taxonomy.

Prior Knowledge and Skills

None

Organization of This Book

This book is arranged in **modules** to make it easy for students to access what they need to learn for their course. Instructors are encouraged to use modules that are relevant to their course, and to rearrange the order in which modules or chapters are used to fit the needs of their curricula and syllabi. Each module comes with a list of learning objectives and outcomes to guide this process.

In other words, the modules of this book (especially in the first half of the book) are arranged by topic as you would find them in a **reference book**. This may be different from the order that your instructor may choose to present these materials **during the course**.

Organization of A Petrology Course: An Example

Author Elizabeth Johnson's ***Introduction to Petrology*** course at James Madison University is an example course which uses the content from modules in this book but does not present materials in the order in which they are compiled.

The learning outcomes for this course are:

Course Learning Goals

Students will be able to:

- Observe and describe the mineralogy and textures of igneous and metamorphic rocks in hand sample and thin section;
- Classify igneous and metamorphic rocks using standard hand sample, thin section, and geochemical schemes;
- Interpret the geologic history of igneous or metamorphic rock and connect it to plate tectonic processes using textural, geochemical, and thermodynamic observations and models;
- Create and modify hypotheses to explain geochemical and petrologic data.

The diagram below maps the modules from the book (Book Chapters) to their use in the course through a typical semester using color-coded arrows. The course is subdivided into units, with Unit 1 covered at the start of the semester, and Unit 8 concluding the semester.

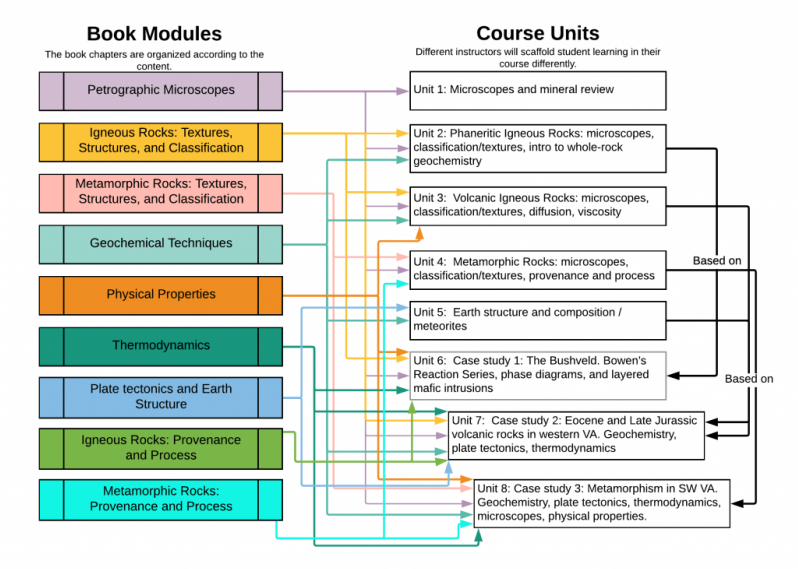


Figure 1.2.1 Comparison of book structure to a course structure.

This is a complicated diagram, but there are two main observations:

1. Chapters from within each textbook module are used or re-introduced in multiple course units; and
2. Course units in the last half of the semester build upon and expand knowledge from units in the first half of the semester.

The course uses a “spiral” approach to student learning (Knowles and Cole, 1994), in the sense that content and concepts are revisited and built upon as the course progresses. Units 1-5 cover microscope skills, classification, basic geochemistry, and texture and mineral identification for igneous and metamorphic rocks. Units 6-8 require students to apply these skills to case studies and add additional skills in geochemistry, thermodynamics, and plate tectonics / structural geology. Students are able to apply core skills at least twice during the semester.

Bloom’s Taxonomy

Petrology is often in the middle of the sequence of required courses for a traditional geology major. Generally, introductory and/or historical geology and mineralogy are meant to be taken before this course, and various courses such as structural geology, stratigraphy, upper-level electives, and a field course might be taken after petrology. The exact courses may vary for your curriculum, of course.

Because petrology is often a transition from lower-level to upper-level courses, the course might include assignments that start at the “remember” “understand” and “apply ” levels, and then transition into “analyze,” “evaluate,” and “create” levels by the end of the course.

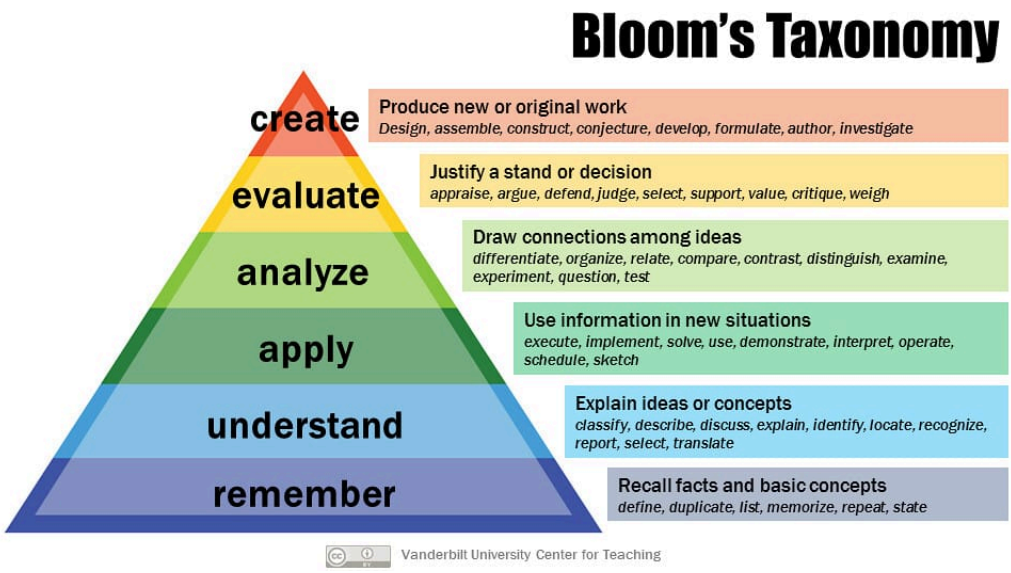


Fig 1.2.3 Revised Bloom's Taxonomy of Learning.

Guided Inquiry

Question 1.2.1

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Question 1.2.2

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References

Armstrong, P. Bloom's Taxonomy. Retrieved 7/1/2019 at https://cft.vanderbilt.edu/guides-sub-pages/blooms-taxonomy/
Knowles, J. G. and Cole, A. L. (1994) Through Preservice Teachers' Eyes: Exploring Field Experiences through Narrative and Inquiry New York: Macmillan. p. 61.

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1.3: Why is Petrology Useful?

Applications to Geology

Petrology aids our understanding of the larger Earth system in many ways. The interactive diagram below shows four examples of how petrology can help us understand questions in other sub-disciplines:

Guided Inquiry: Figure 1.3.1

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Career Paths in Petrology

In academia, petrology can lead to a number of different graduate school options. These can include projects in volcanology, plate tectonics, experimental petrology of the deep Earth, even the study of meteorites and planetary science.

Students who excel in a petrology course or might do an undergraduate research project in petrology can go on to careers which apply some of the chemistry or materials science skills learned. These could include: environmental consulting jobs applying hydrology and groundwater geochemistry, working for energy resource companies to site pipelines or model natural gas and petroleum flow through rock units, materials development and testing of solids (glass and concrete/building materials).

Skills that Transfer to Other Careers

Don't plan on becoming a professional petrologist or someone who teaches about rocks? No problem – petrology is still important for your career. Geochemistry and thermodynamics are applied to many Earth systems including hydrology, water geochemistry, and climate systems. The higher-order thinking skills you learn from a petrology course should be applicable to many situations in your career, no matter what you might end up doing. Creating hypotheses is important for any scientific field! Any technical skill you might learn while using instrumentation is valuable, including microscopes, thin section making equipment, an SEM or XRF , or other equipment that might be available at your university. Finally: the ability to correctly identify rocks is always a valuable skill!

Key Takeaways

Based on the information above, list at least one way petrology can help you in your educational path or future career. If you are completely unsure of your future path, then describe one aspect of petrology that you think is interesting or would be useful to you in a geosciences career.

References

Structural Geology:Mikenorton. Asymmetric folds developed within a dextral sense shear zone near Cala Portixol, Cap de Creus area, Catalunya. Wavelength varies with quartz mylonite layer thickness. Pen for scale – 14 cm long. (ret. 7/2/2019) commons.wikimedia.org/wiki/File:Dextral_shear_folds.JPG CC BY-SA 3.0

Unported.Ore Deposits:Alexgiovi. Ascending hydrothermal solutions rich in gold, sulfur and metals were channelled upward along major fracture and fault zones. Fluid that made it to the surface would have vented as hot springs and geysers. Localized erosion through the thrust sheet has created windows into the underlying ore-bearing rocks. Adapted from Edwards and Atkinson (1985).

(ret. 7/2/2019) commons.wikimedia.org/wiki/File:Origin_of_Carlin-type_gold_deposits.png CC BY-SA 4.0.

Plate Tectonics:USGS. Map of East Africa showing some of the historically active volcanoes(red triangles) and the Afar Triangle (shaded, center) — a so-called triple junction (or triple point), where three plates are pulling away from one another: the Arabian Plate, and the two parts of the African Plate (the Nubian and the Somali) splitting along the East African Rift Zone. The red triangles show historically active volcanoes. (ret. 7/2/2019) commons.wikimedia.org/wiki/File:EAfrica.png Public Domain.

Geophysics: Oilfieldvegetarian. commons.wikimedia.org/wiki/File:FarallonTomoSlice.png. Simplified and interpreted P- and S-wave velocity variations in the mantle across southern North America showing the subducted Farallon Plate. Adapted from Grand et al. (1997) GSA Today 7(4):1–7. CC BY-SA 4.0.

Wikipedia. Structural Geology. (ret. 7/2/2019) en.Wikipedia.org/wiki/Structural_geology

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2: USING THE PETROGRAPHIC MICROSCOPE

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2.2: Thin Sections

2.3: Light and Optics

2.4: Parts of the Petrographic Microscope

2.5: Common Issues Using a Petrographic Microscope

2.6: Properties Under Plane Polarized Light

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2.9: Atlas of Minerals in Thin Section

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2.1: Introduction

Why Learn About Microscopes?

A petrographic microscope is a type of optical microscope used to identify rocks and minerals in thin section and to investigate microscopic textures and features that are present in minerals and rocks. Modern petrographic microscopes use polarized light to help identify minerals using a number of optical techniques.

Microscopes are technology that developed in the mid-1800's (Sorby, 1882). Yet we still use them today!

Guided Inquiry Question 2.1.1

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Learning Outcomes

Learning Outcomes for the Module

Students will be able to:

- Describe the parts of a thin section and how thin sections are made.
- Operate and describe the parts of a petrographic microscope.
- Troubleshoot issues with using a petrographic microscope.
- Make observations in plane polarized light and crossed polarized light.
- Obtain and identify optical interference figures.
- Use the correct terminology to describe parts of the microscope, measurement techniques, and textures.
- Compile and use distinguishing features of similar minerals to correctly identify them in thin section.

What is NOT Covered in This Module

This module is intended as an introduction to applied optical microscopy for a petrology course, so it does not include ALL possible ways of using a petrographic microscope to analyze minerals and rocks.

If you are interested in learning more in-depth techniques, that is great! The references below provide more detailed discussions of optical techniques and cover additional techniques and microscope accessories, such as the universal stage.

REFERENCES

McNamee, B.D. and Gunter, M.E. (2014) Mineralogy and Optical Mineralogy. Lab Manual. 51 pp. Free to download: http://www.minsocam.org/msa/openaccess_publications/

Nesse, W. (2012) Introduction to Optical Mineralogy, 4th edition. Oxford University Press, 384 pp. ISBN-13: 978-0199846276

Raith, M.M., Raase, P. and Reinhardt, J. (2012) Guide to Thin Section Microscopy, 2nd edition 127 pp. ISBN 978-3-00-037671-9 (English) Free to download: http://www.minsocam.org/msa/openaccess_publications/

Sorby, H. C. (1982). Preparation of transparent sections of rocks and minerals: Northern Microscopist, London, 2, 18, 133-140. [Read this eBook Free on Google Play Books site at: https://play.google.com/books/reader?id=SSEuAQAAIAAJ&hl=en&pg=GBS.PA133.]

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2.2: Thin Sections

Learning Objectives

- Describe the parts of a standard thin section.
- Describe the differences between a standard petrographic thin section, a thin section prepared for electron or ion microbeam analyses, and a thick section.
- Describe the steps necessary to produce a standard thin section, in the correct order.

Prior Knowledge and Skills

None

What is a Thin Section?

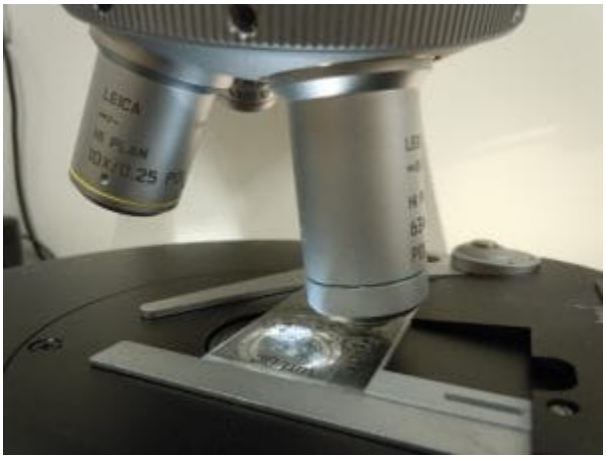


Figure 2.2.1. A thin section on a petrographic microscope stage.

The general procedure for creating thin sections has remained nearly the same since the modern version was created nearly 200 years ago. In this section, we review examples of modern thin section making procedures.

Guided Inquiry

Figure 2.2.2 Interactive diagram showing different types of thin sections.

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Question 2.2.1

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Question 2.2.2

An electron microprobe determines the composition of a mineral in thin section by comparing X-rays generated from a beam of electrons hitting the atoms within the mineral to a set of compositional standards. What is the difference between a "microprobe" thin section and a standard thin section, and why do you think this difference is necessary?

Question 2.2.3

Thick sections are prepared for special analyses, such as fluid inclusion work (https://en.Wikipedia.org/wiki/Fluid_inclusion) or FTIR spectroscopic analyses which is sensitive to epoxy and glass, so the rock section must be removable from the glass and glue. How is a thick section different from a standard thin section?

How are Thin Sections Made?

Guided Inquiry

Preparation in a University Lab:

Use Hirsch, Dave (2012; Ret. 11/21/2018) How to make a thin section. https://davehirsch.com/other/thinsections/ to answer these questions:

Question 2.2.4

What do you do to a glass slide to "frost" it?

Question 2.2.5

What is a rock chip?

Question 2.2.6

Why do the instructions say to grind one corner off the glass slide?

Question 2.2.7

What should you do to the rock before you cut a slab out of it?

Question 2.2.8

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Guided Inquiry

Professional Preparation: Watch these videos from Spectrum Petrographics, a professional thin section and petrography company, about how they create thin sections:

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Question 2.2.9 Why does Spectrum Petrographics put quartz grains in the rim of each thin section billet?

Question 2.2.10 How does Spectrum Petrographics label the glass slides?

Question 2.2.11 Approximately how thick is the section after it is initially cut in the cutoff saw?

Additional Resources for Learning to Make Thin Sections



Figure 2.2.3 Screenshot of rock saw video.

If you are interested in more detailed descriptions of the thin section equipment and steps to make thin sections, please see the following resources:

- Analytical Methods in Geosciences chapter on thin section preparation: https://courses.lumenlearning.com/labmethods/

chapter/equipment_thin_section_preparation/

- Video playlist on YouTube showing detailed thin section procedures in laboratories at James Madison University and Northern Virginia Community College: https://www.youtube.com/playlist?list=PLc1yUU5DczrXJU5YL4mael1uDeST0vwtS

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2.3: Light and Optics

Introduction

You may be well aware of the importance of visible light for making observations in the geosciences. For example, the color of minerals and rocks can help us identify them (although it is not always the best identifier!). Color is determined by the relative absorbance or reflection of different wavelengths of visible light.

For example, a gem-quality emerald is a deep green color. This is because it is reflecting the green wavelengths of light to our eyes, and is absorbing the other visible wavelengths of light. Emerald is the mineral beryl, but it is trace Cr^{3+} in the mineral structure that causes the green color.



Figure 2.3.1 Emerald from Muzo Mine, Columbia

Visible light represents a small range of the electromagnetic spectrum. Even though no human can see beyond the visible range, we can still use technology to “see” the electromagnetic spectrum beyond anyone’s reach.

The electromagnetic energy we cannot see (but can detect with instrumentation) can be used to study the chemical composition of materials, can detect the vibrations of molecules and minerals, and can see the structure of solid materials, among other things.

This chapter provides a practical basis for applying knowledge of electromagnetic energy to optical microscopy.

Learning Objectives

Students should be able to:

- Describe the categories of electromagnetic energy within the electromagnetic spectrum, and be able to place these categories relative to each other in wavelength and energy.
- Describe the wavelengths of visible light and name a color for a given wavelength range.
- Describe the ways in which electromagnetic energy can behave when it interacts with an object.
- Define characteristics of light, including the speed of light, wave front, and light ray.
- Define refractive index.
- Differentiate between the electric and magnetic components of light.

- Use the electric (E) vector of light to describe the behavior of plane polarized light.

Prior Knowledge and Skills

None

The Electromagnetic Spectrum

The video below gives an overview of the electromagnetic spectrum:

YouTube Video

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The number of crests that pass a given point within one second is described as the **frequency** of the wave. One wave—or cycle—per second is called a Hertz (Hz), after Heinrich Hertz who established the existence of radio waves. A wave with two cycles that pass a point in one second (as shown for the top wave in **Figure 2.3.2**) has a frequency of 2 Hz.

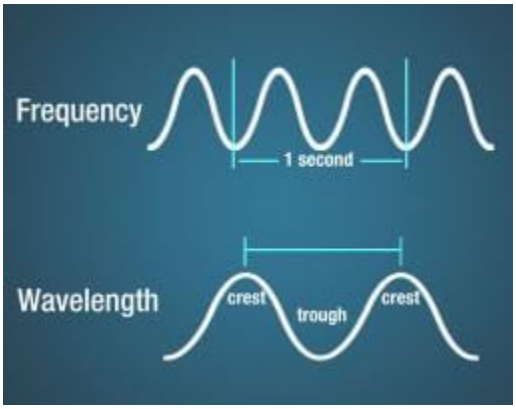


Figure 2.3.2. Wavelength and Frequency

Electromagnetic waves have crests and troughs similar to (but not identical in behavior to) those of ocean waves. The distance between crests is the **wavelength**.

The figure below shows the wavelength (meters) and energy (Hz) ranges for different types of electromagnetic energy:

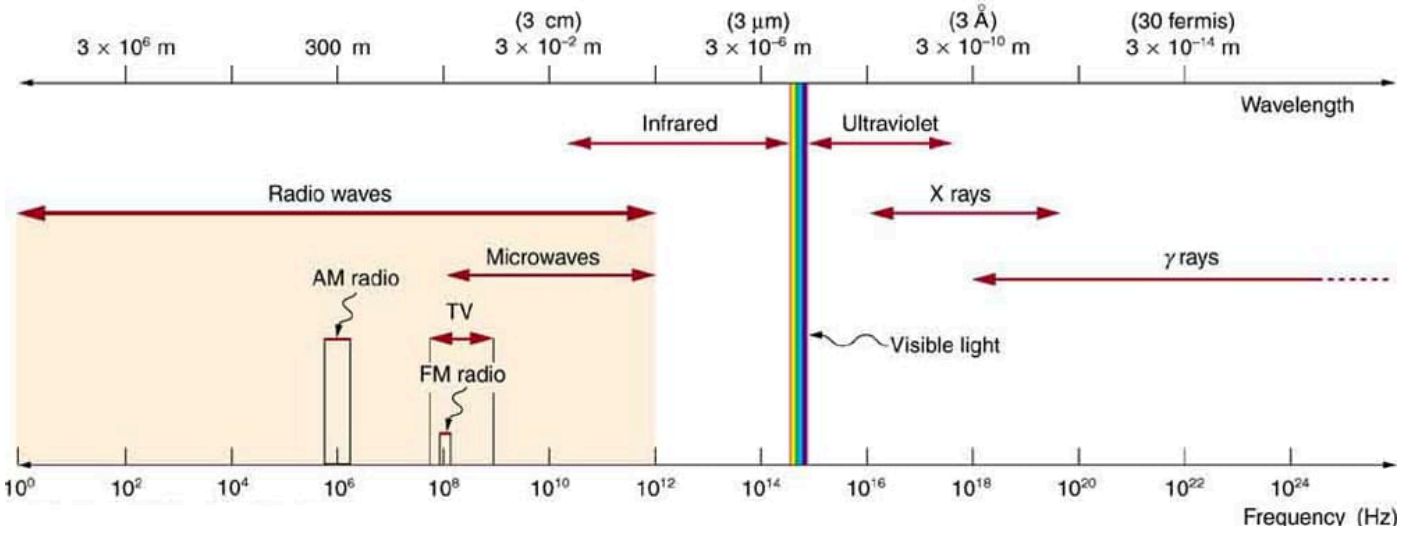


Figure 2.3.3. The Electromagnetic Spectrum.

After watching the video and examining the figure above, answer these questions:

Guided Inquiry

Question 2.3.1

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Question 2.3.2

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Question 2.3.3

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Visible Light

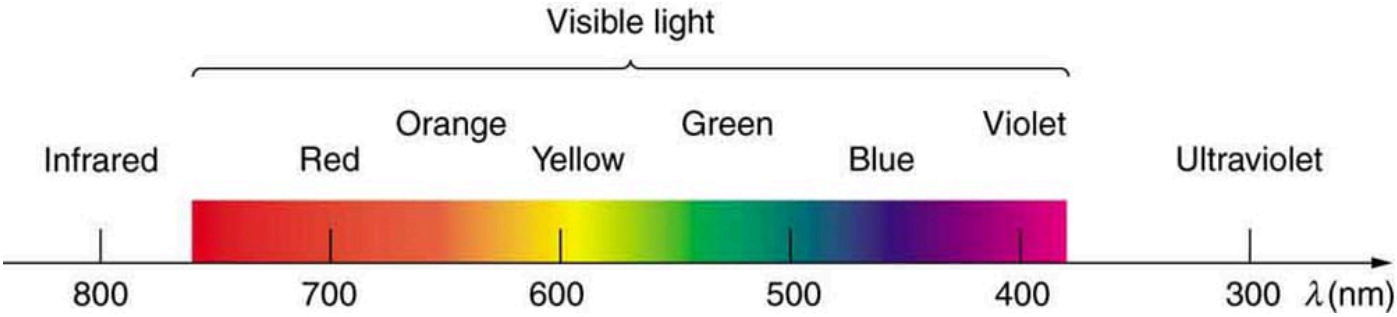


Figure 2.3.4. The visible light spectrum, showing wavelength ranges for colors in nanometers.

The visible light region is divided into color regions (**Figure 2.3.4**). We will use colors (and color changes due to different microscopy techniques) to help identify minerals under thin section.

Guided Inquiry

Question 2.3.4

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Question 2.3.5

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Behavior of Light

Light waves across the electromagnetic spectrum behave in similar ways. When a light wave encounters an object, it is either transmitted, reflected, absorbed, refracted, polarized, diffracted, or scattered depending on the composition of the object and the wavelength of the light.

Absorption, Transmission, and Reflection

This video reviews the concepts of absorption, transmission, and reflection of light:

YouTube Video

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Diffraction, Scattering, and Refraction

Diffraction is the bending and spreading of waves around an obstacle. It is most pronounced when a light wave strikes an object with a size comparable to its own wavelength. In the case of visible light, the separation of wavelengths through diffraction results in a rainbow. The figure below shows the grooves on a CD diffracting visible light and producing iridescent colors.



Figure 2.3.5. A CD demonstrating diffraction from grooves in the surface, producing iridescent colors.

Scattering occurs when light bounces off an object in a variety of directions. The amount of scattering that takes place depends on the wavelength of the light and the size and structure of the object.

The sky appears blue because of this scattering behavior. Light at shorter wavelengths—blue and violet—is scattered by nitrogen and oxygen as it passes through the atmosphere. Longer wavelengths of light—red and yellow—transmit through the atmosphere. This scattering of light at shorter wavelengths illuminates the skies with light from the blue and violet end of the visible spectrum. Even though violet is scattered more than blue, the sky looks blue to us because our eyes are more sensitive to blue light.

Refraction is when light waves change direction as they pass from one medium to another. Light travels slower in air than in a vacuum, and even slower in water. As light travels into a different medium, the change in speed bends the light. Different wavelengths of light are slowed at different rates, which causes them to bend at different angles. For example, when the full spectrum of visible light travels through the glass of a prism, or through a raindrop, the wavelengths are separated into the colors of the rainbow.

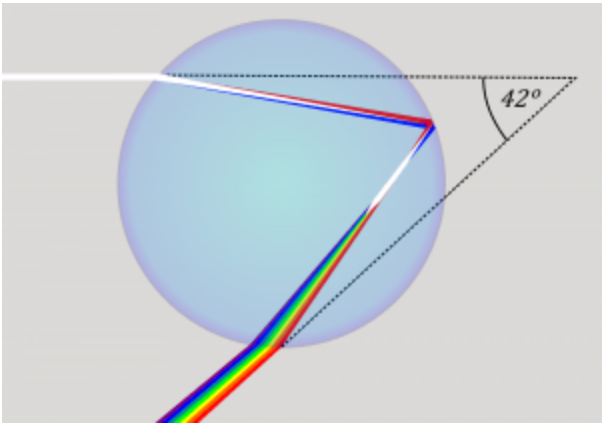


Figure 2.3.6. Scattering and refraction in a raindrop to produce a rainbow. White light separates into different colors (wavelengths) on entering the raindrop, as red light is refracted by a lesser angle than blue light. On leaving the raindrop, the red rays have turned through a smaller angle than the blue rays, producing a rainbow.

We will discuss **refraction** in more detail and introduce **polarization** of light in the sections below. These concepts are especially important for understanding techniques in optical mineralogy and petrology.

Guided Inquiry Question 2.3.6

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Properties of Light

The **speed of light** (electromagnetic energy) in a **vacuum** is a constant value: ***c*** = 3.00 x 10^8 m/s. However, we will see below that electromagnetic energy slows down when it travels through matter, including minerals.

Knowing the propagation direction or direction of travel is important if we wish to understand how light moves through the microscope and our samples. The diagram below shows three views of an electromagnetic wave. In each view , a light **ray** pointing parallel to the direction of propagation and the **wavefront** perpendicular to the propagation direction are shown.

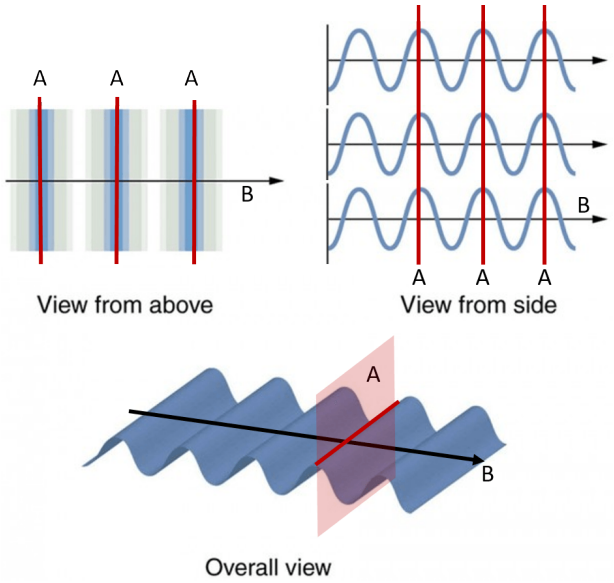


Figure 2.3.7. A transverse wave, such as an electromagnetic wave like light, can be viewed from above, from the side, or in three dimensions.

Guided Inquiry Question 2.3.7

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Electromagnetic waves contain both electric and magnetic fields that change or oscillate. The electric field vector **E** is always perpendicular to the magnetic field vector **B**. Both **E** and **B** are perpendicular to the propagation direction of the wave. We will learn more about the electric field vector **E** in the section on polarization of light.

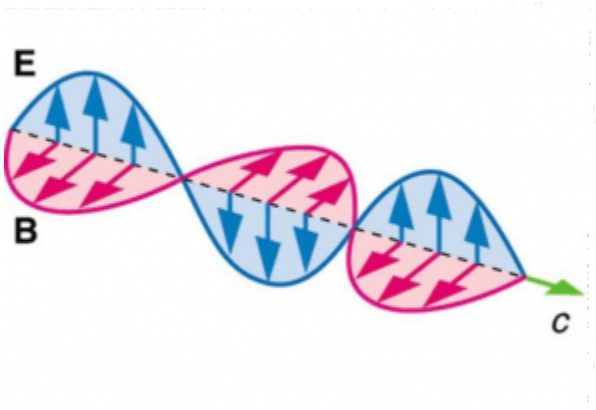


Figure 2.3.8. The electric (E) and magnetic (B) field vectors of electromagnetic energy.

Refractive Index

Electromagnetic energy travels at the speed of light, ***c***, in a vacuum. However, when electromagnetic waves travel through matter, they slow down. The speed at which they travel through a material is specific to the density and composition of the material.

The **refractive index** of a material characterizes the relationship between the speed of light in a vacuum and the speed of light in that material.

The **refractive index** of a material is defined as:

$$n = \frac{c}{v}$$

where **n** is the refractive index, ***c*** is the speed of light in a vacuum, and ***v*** is the observed speed of light in the material. Since the speed of light in matter is always less than ***c***, the index of refraction is always greater than or equal to one.

This table lists some examples of refractive indices of different materials:

Refractive Indices of Materials	
Material	n
Air (0 Celsius, 1 atm)	1.000293
Water, fresh	1.333
Glass, crown	1.52
Quartz	1.544
Zircon	1.923
Diamond	2.419

Guided Inquiry Question 2.3.8

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The amount that a light ray changes its direction depends both on the incident angle and the amount that the speed changes. For a ray at a given incident angle, a large change in speed causes a large change in direction and thus a large change in angle. The exact mathematical relationship is the law of refraction, or **Snell's law**, after the Dutch mathematician Willebrord Snell (1591–1626), who discovered it in 1621. The law of refraction is stated in equation form as:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

Here $\mathbf{n_1}$ and $\mathbf{n_2}$ are the indices of refraction for media 1 and 2, and $\boldsymbol{\theta_1}$ and $\boldsymbol{\theta_2}$ are the angles between the rays and the perpendicular in media 1 and 2. The incoming ray is called the incident ray, the outgoing ray is called the refracted ray, and the associated angles are the incident angle and the refracted angle, respectively.

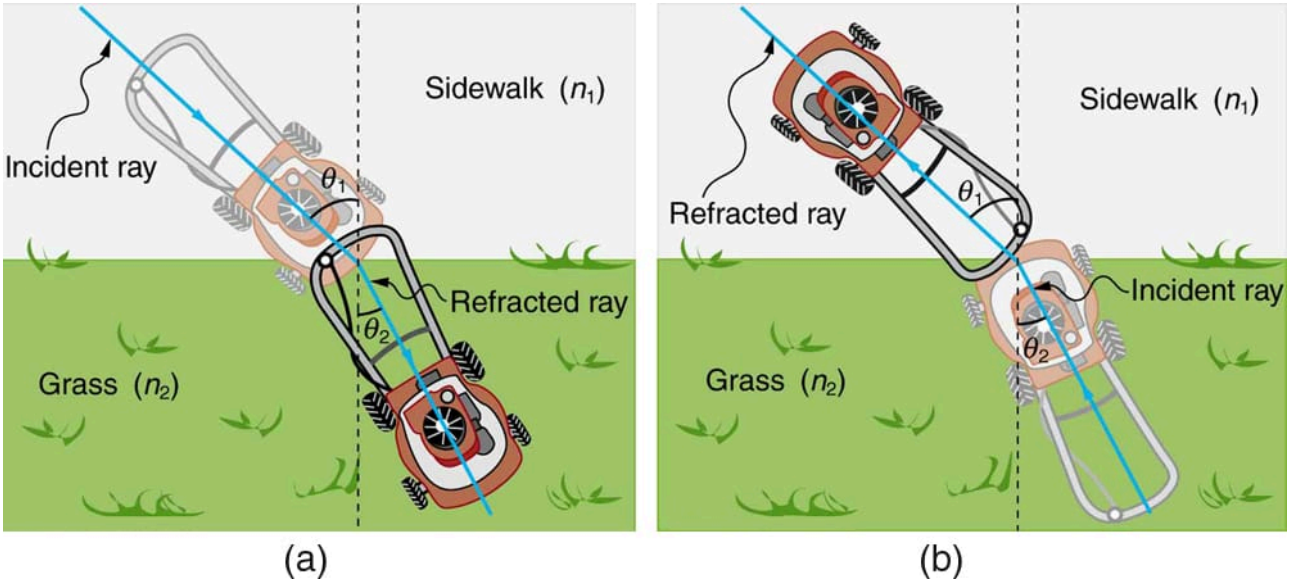
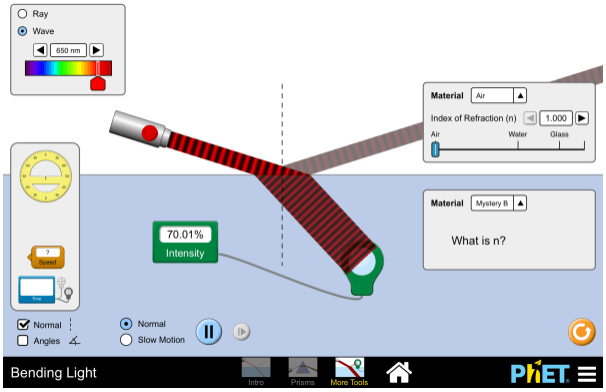


Figure 2.3.9. The change in direction of a light ray depends on how the speed of light changes when it crosses from one medium to another. The speed of light is greater in medium 1 than in medium 2 in the situations shown here. (a) A ray of light moves closer to the perpendicular when it slows down. This is analogous to what happens when a lawn mower goes from a footpath to grass. (b) A ray of light moves away from the perpendicular when it speeds up. This is analogous to what happens when a lawn mower goes from grass to footpath. The paths are exactly reversible.

Figure 2.3.9 shows how a ray of light changes direction when it passes from one medium to another. The angles are measured relative to a perpendicular to the surface at the point where the light ray crosses it. (Some of the incident light will be reflected from the surface, but for now we will concentrate on the light that is transmitted.) The change in direction of the light ray depends on how the speed of light changes. The change in the speed of light is related to the indices of refraction of the media involved. In the situations shown in **Figure 2.3.9** medium 2 has a greater index of refraction than medium 1. This means that the speed of light is less in medium 2 than in medium 1.

Note that as shown in **Figure 2.3.9(a)**, the direction of the ray moves closer to the perpendicular when it slows down. Conversely, as shown in **Figure 2.3.9(b)**, the direction of the ray moves away from the perpendicular when it speeds up. The path is exactly reversible.

In both cases, you can imagine what happens by thinking about pushing a lawn mower from a footpath onto grass, and vice versa. Going from the footpath to grass, the front wheels are slowed and pulled to the side as shown. This is the same change in direction as for light when it goes from a fast medium to a slow one. When going from the grass to the footpath, the front wheels can move faster and the mower changes direction as shown. This, too, is the same change in direction as for light going from slow to fast.



Light," an interactive simulation of light refraction.

Guided Inquiry

Question 2.3.9

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Question 2.3.10

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Polarized Light

Polaroid sunglasses are familiar to most of us. They have a special ability to cut the glare of light reflected from water or glass. Polaroids have this ability because of a wave characteristic of light called polarization. What is polarization? How is it produced? What are some of its uses? The answers to these questions are related to the wave character of light.

Watch the first **6 minutes** of the video below to see a practical overview of plane polarized light, using crossed polarizers, and how a third polarizer (which is how many minerals act) can be used to increase light output from crossed polarizers.

YouTube Video

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Electromagnetic waves are **transverse waves** consisting of varying electric and magnetic fields that oscillate perpendicular to the direction of propagation and perpendicular to each other.

The Sun and many other light sources produce waves in which **E** (and **B**, though it is not shown) are not preferentially oriented – they exist in every direction perpendicular to the direction of propagation (see **Figure 2.3.11**). Such light is said to be **unpolarized** because it is composed of many waves with all possible directions of polarization.

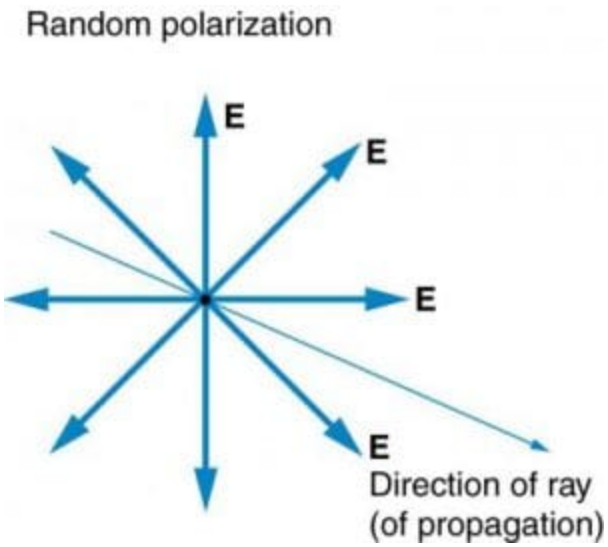


Figure 2.3.11. The slender arrow represents a ray of unpolarized light. The bold arrows represent the direction of polarization of the individual waves composing the ray. Since the light is unpolarized, the arrows point in all directions.

In contrast, light that is **plane polarized** (also called **linearly polarized**) has **E** oriented in one specific direction in space (**Figure 2.3.12**). The polarization direction is defined by the orientation of **E** (as opposed to **B**).

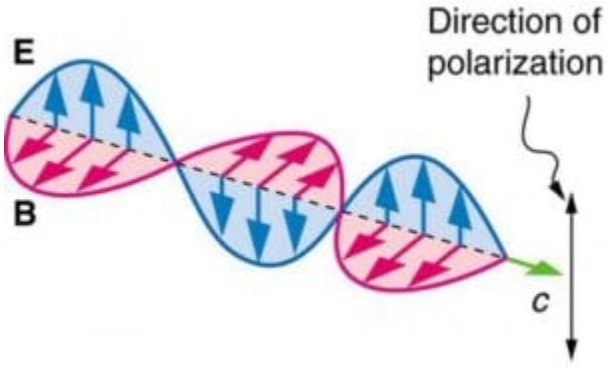


Figure 2.3.12. The polarization direction of plane polarized light is defined as the vibration direction of the electric vector E.

Polarizers are composed of long molecules aligned in one direction. Thinking of the molecules as many slits, analogous to those for the oscillating ropes, we can understand why only light with a specific polarization can get through. The *axis of a polarizing filter* is the direction along which the filter passes the electric field of an EM wave (see **Figure 2.3.13**).

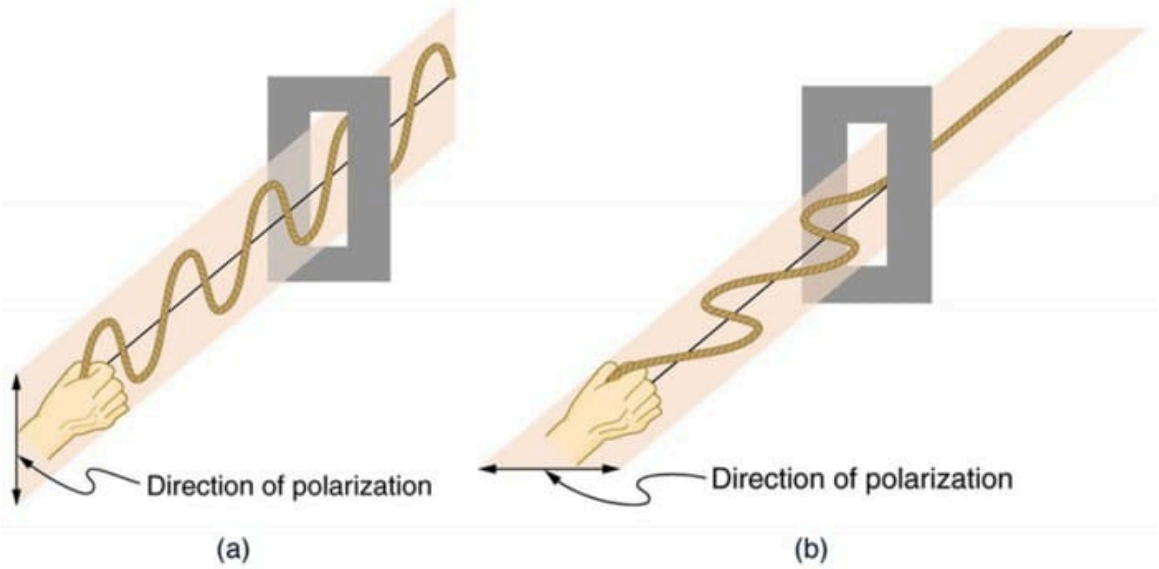


Figure 2.3.13. The transverse oscillations in one rope are in a vertical plane, and those in the other rope are in a horizontal plane. The first is said to be vertically polarized, and the other is said to be horizontally polarized. Vertical slits pass vertically polarized waves and block horizontally polarized waves.

To examine this further, consider the transverse waves in the ropes shown in **Figure2.3.13**. The oscillations in one rope are in a vertical plane and are said to be *vertically polarized*. Those in the other rope are in a horizontal plane and are *horizontally polarized*. If a vertical slit is placed on the first rope, the waves pass through. However, a vertical slit blocks the horizontally polarized waves. For EM waves, the direction of the electric field vector **E** is analogous to the disturbances on the ropes (**Figure 2.3.14**).

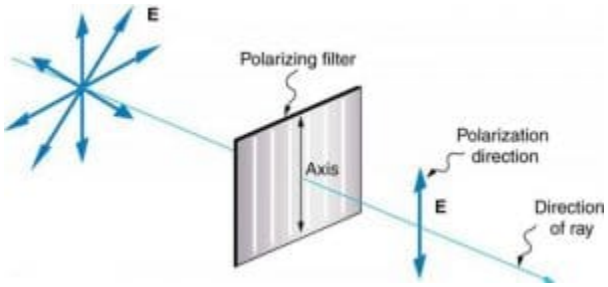


Figure 2.3.14. A polarizing filter has a polarization axis that acts as a slit passing through electric fields parallel to its direction. The direction of polarization of an EM wave is defined to be the direction of its electric field.

ATOMIC EXPLANATION OF POLARIZING FILTERS

Polarizing filters have a polarization axis that acts as a slit. This slit passes electromagnetic waves (often visible light) that have an electric field parallel to the axis. This is accomplished with long molecules aligned perpendicular to the axis as shown in **Figure 2.3.15**.

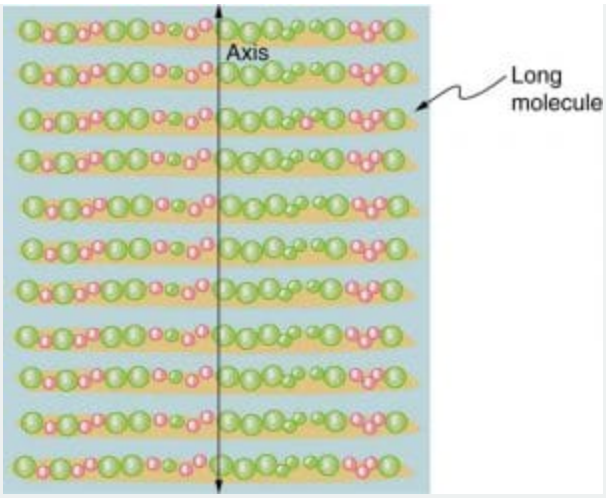


Figure 2.3.15. Long molecules are aligned perpendicular to the axis of a polarizing filter. The component of the electric field in an EM wave perpendicular to these molecules passes through the filter, while the component parallel to the molecules is absorbed.

Figure 2.3.16 illustrates how the component of the electric field parallel to the long molecules is absorbed. An electromagnetic wave is composed of oscillating electric and magnetic fields. The electric field is strong compared with the magnetic field and is more effective in exerting force on charges in the molecules. The most affected charged particles are the electrons in the molecules, since electron masses are small. If the electron is forced to oscillate, it can absorb energy from the EM wave. This reduces the fields in the wave and, hence, reduces its intensity. In long molecules, electrons can more easily oscillate parallel to the molecule than in the perpendicular direction. The electrons are bound to the molecule and are more restricted in their movement perpendicular to the molecule. Thus, the electrons can absorb EM waves that have a component of their electric field parallel to the molecule. The electrons are much less responsive to electric fields perpendicular to the molecule and will allow those fields to pass. Thus the axis of the polarizing filter is perpendicular to the length of the molecule.

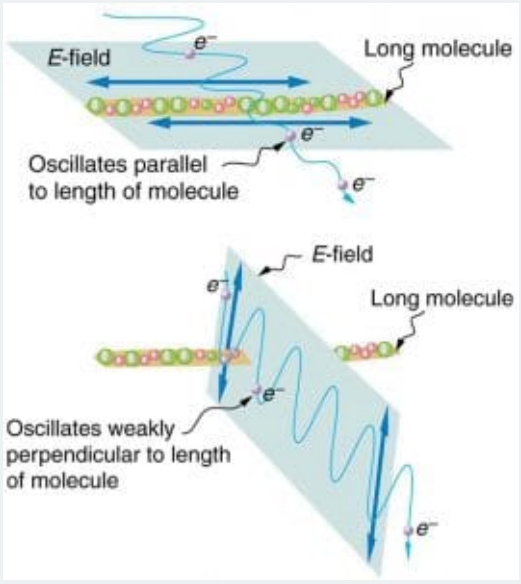


Figure 2.3.16. Artist's conception of an electron in a long molecule oscillating parallel to the molecule. The oscillation of the electron absorbs energy and reduces the intensity of the component of the EM wave that is parallel to the molecule.

Figure 2.3.17 shows the effect of two polarizing filters on originally unpolarized light. The first filter polarizes the light along its axis. When the axes of the first and second filters are aligned (parallel), then all of the polarized light passed by the first filter is also passed by the second. If the second polarizing filter is rotated, only the component of the light parallel to the second filter's axis is passed. When the axes are perpendicular, no light is passed by the second.

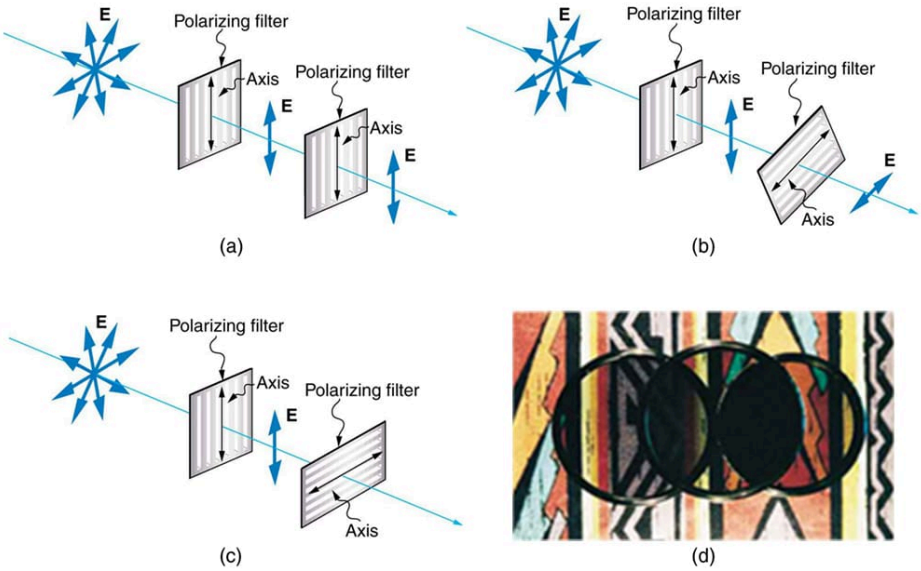


Figure 2.3.17. The effect of rotating two polarizing filters, where the first polarizes the light. (a) All of the polarized light is passed by the second polarizing filter, because its axis is parallel to the first. (b) As the second is rotated, only part of the light is passed. (c) When the second is perpendicular to the first, no light is passed. (d) In this photograph, a polarizing filter is placed above two others. Its axis is perpendicular to the filter on the right (dark area) and parallel to the filter on the left (lighter area). (credit: P.P. Urone)

Only the component of the EM wave parallel to the axis of a filter is passed. Let us call the angle between the direction of polarization and the axis of a filter θ. If the electric field has an amplitude E, then the transmitted part of the wave has an amplitude $E \cos \theta$ (see **Figure 2.3.18**). Since the intensity of a wave is proportional to its amplitude squared, the intensity I of the transmitted wave is related to the incident wave by $I = I_0 \cos 2\theta$, where I_0 is the intensity of the polarized wave before passing through the filter.

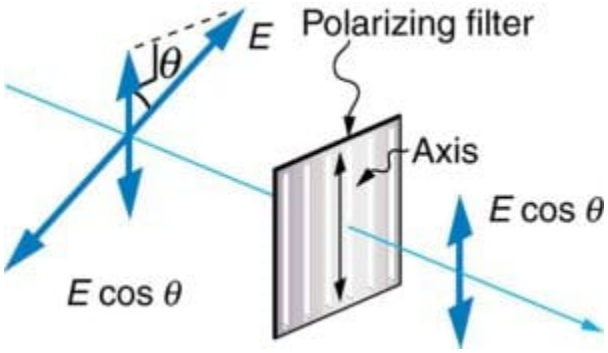


Figure 2.3.18. A polarizing filter transmits only the component of the wave parallel to its axis, Ecosθ , reducing the intensity of any light not polarized parallel to its axis.

Liquid Crystal DISPLAYS and Optically Active Materials

While you are undoubtedly aware of liquid crystal displays (LCDs) found in watches, calculators, computer screens, cellphones, flat screen televisions, and other myriad places, you may not be aware that they are based on polarization. Liquid crystals are so named because their molecules can be aligned even though they are in a liquid. Liquid crystals have the property that they can rotate the polarization of light passing through them by 90 degrees. Furthermore, this property can be turned off by the application of a voltage, as illustrated in **Figure 2.3.19**. It is possible to manipulate this characteristic quickly and in small well-defined regions to create the contrast patterns we see in so many LCD devices.

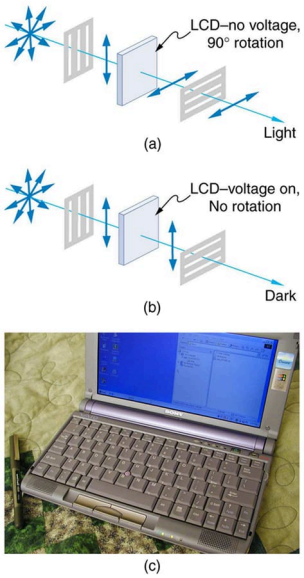


Figure 2.3.19. (a) Polarized light is rotated 90° by a liquid crystal and then passed by a polarizing filter that has its axis perpendicular to the original polarization direction. (b) When a voltage is applied to the liquid crystal, the polarized light is not rotated and is blocked by the filter, making the region dark in comparison with its surroundings. (c) LCDs can be made color specific, small, and fast enough to use in laptop computers and TVs. (credit: Jon Sullivan)

In flat screen LCD televisions, there is a large light at the back of the TV. The light travels to the front screen through millions of tiny units called pixels (picture elements). One of these is shown in Figure **2.3.19** (a) and (b). Each unit has three cells, with red, blue, or green filters, each controlled independently. When the voltage across a liquid crystal is switched off, the liquid crystal passes the light through the particular filter. One can vary the picture contrast by varying the strength of the voltage applied to the liquid crystal.

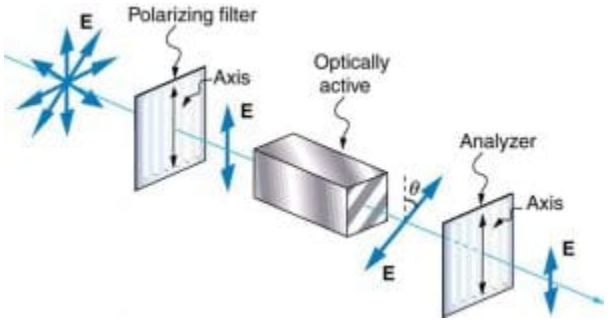


Figure 2.3.20. Optical activity is the ability of some substances to rotate the plane of polarization of light passing through them. The rotation is detected with a polarizing filter or analyzer.

Many crystals and solutions rotate the plane of polarization of light passing through them. Such substances are said to be optically active. Examples include sugar water, insulin, and collagen (see **Figure 2.3.20**). In addition to depending on the type of substance, the amount and direction of rotation depends on a number of factors. Among these is the concentration of the substance, the distance the light travels through it, and the wavelength of light. Optical activity is due to the asymmetric shape of molecules in the substance, such as being helical. Measurements of the rotation of polarized light passing through substances can thus be used to measure concentrations, a standard technique for sugars. It can also give information on the shapes of molecules, such as proteins, and factors that affect their shapes, such as temperature and pH.

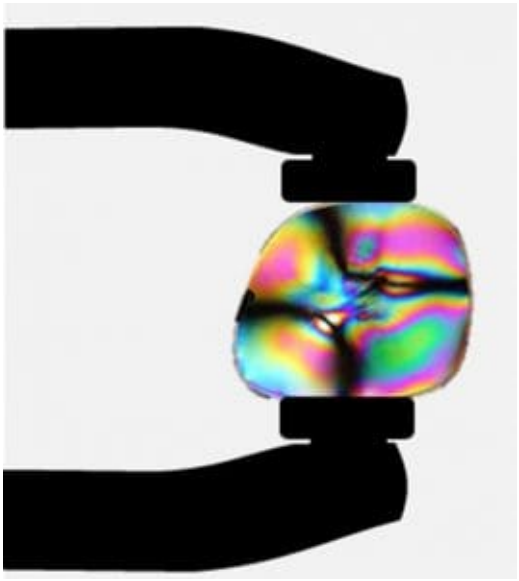


Figure 2.3.21. Optical stress analysis of a plastic lens placed between crossed polarizers. (credit: Infopro, Wikimedia Commons)

Glass and plastic become optically active when stressed; the greater the stress, the greater the effect. Optical stress analysis on complicated shapes can be performed by making plastic models of them and observing them through crossed filters, as seen in **Figure 2.3.21**. It is apparent that the effect depends on wavelength as well as stress. The wavelength dependence is sometimes also used for artistic purposes.

Birefrigence

Another interesting phenomenon associated with polarized light is the ability of some minerals and other crystals to split an unpolarized beam of light into two polarized beams (**Figure 2.3.22**). Such crystals are said to be **birefringent**.

Each of the separated rays has a specific polarization. One behaves normally and is called the **ordinary ray (o or ω)**, whereas the other does not obey Snell's law and is called the **extraordinary ray (e or ε)**. Birefringent crystals can be used to produce polarized beams from unpolarized light. Some birefringent materials preferentially absorb one of the polarizations. These materials are called dichroic and can produce polarization by this preferential absorption. This is fundamentally how polarizing filters and other polarizers work. We will use the property of birefringence to help us identify and distinguish minerals in thin section!

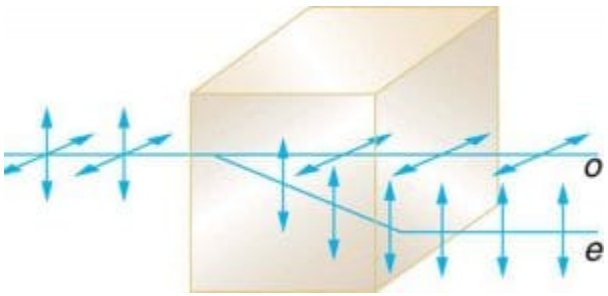


Figure 2.3.22. Birefringent materials, such as the common mineral calcite, split unpolarized beams of light into two. The ordinary ray behaves as expected, but the extraordinary ray does not obey Snell's law.

Key Terms

- Wavelength
- Frequency
- Visible, Infrared, Ultraviolet light

- Transmission
- Reflection
- Absorption
- Diffraction
- Scattering
- Refraction
- Polarization
- Speed of Light
- Wave front
- Ray
- Electric field vector
- Magnetic field vector
- Refractive Index
- Snell's Law
- Transverse wave
- Unpolarized
- Plane (linear) polarization
- Birefringence
- Ordinary Ray
- Extraordinary Ray

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File:Béryl var. émeraude sur gangue (Muzo Mine Boyaca – Colombie) 2.jpg. (2018, August 10). *Wikimedia Commons, the free media repository*. Retrieved 17:51, February 11, 2019 from commons.wikimedia.org/w/index.php?title=File:B%C3%A9ryl_var._%C3%A9meraude_sur_gangue_(Muzo_Mine_Boyaca_-_Colombie)_2.jpg&oldid=314327347.

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2.4: Parts of the Petrographic Microscope

In this section, we explore the parts of the petrographic or polarizing light microscope. This section is appropriate for students who have no prior experience with using microscopes. This is also a good review for those who could use a refresher on the anatomy of a microscope.

Learning Objectives

Students will be able to:

- Identify and describe the purpose of each part of a petrographic microscope.
- Describe the typical pathway of light through a petrographic microscope.

Prior Knowledge and Skills

- 2.3 Light and Optics (Recommended)

Overview of the Microscope

What does a microscope look like? Although all petrographic microscopes have common parts and functions, there are many brands of microscope, each of which may look different. If petrographic microscopes are maintained and handled carefully, they can last for literally generations of students. The microscopes in your classroom or the laboratory could be new, a few years old, or decades old, and have different design aspects from younger or older microscopes.

There are research-grade microscopes that have better-quality optics and more accessories, in contrast to student-grade microscopes that may have fewer features but are built for typical analyses and heavier use. Let's look at three examples of petrographic microscopes:

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Question 2.4.2

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If all microscopes look somewhat different from each other, are the examples shown here relevant to your microscope? They should be! It turns out that even though various microscopes might look different at first glance, because all petrographic microscopes will have common functions, the overall design and structure of microscopes is similar. Even if the analyzer on your microscope looks different from mine, they should be in a similar location on both microscopes and should function in a similar way.

Let's explore the general structure of a petrographic microscope. Click on the + signs to show the part names. In the sections below, we will investigate each part in detail.

Figure 2.4.2

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Fig. 2.4.2. general structure of a petrographic microscope

The Illuminator

The **illuminator** is a steady light source that is located in the base of the microscope. It is used for transmitted light microscopy.

The switch to turn on the illuminator is typically located at the rear or on the side of the base of the microscope. When the illuminator is ON, light will be visible through the base in the microscope. The following video clips show examples of turning on the illuminator for different microscopes:

Figure 2.4.3

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Fig. 2.4.3. Turning on the illuminator.

If you are lucky enough to have a microscope that has both transmitted and reflected light capabilities, then the microscope will also have a light source near the top rear which can illuminate the sample from above.

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The Condenser and Substage Assembly

The parts of the microscope that are located above the base but below the stage are called the **substage assembly**. The substage assembly includes the condenser, the lower polarizer, light filters, and diaphragms.

Figure 2.4.5

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Figure 2.4.5. Interactive video showing typical adjustments that can be made on the substage assembly.

Condenser

The condenser consists of two or more lenses that focus the illuminator light onto the sample placed on the stage, and one or more apertures to control illumination (see below). The condenser should be adjusted each time the objective lens is changed to maximize the quality of the image.

Lower Polarizer

The first polarizer is located below the condenser and is shown in the interactive video above (**Figure 2.4.5**). Please see the separate section below on polarizers for more information.

Light filter

Halogen lights used in microscopes typically give off a yellowish light, so a blue filter is often added to compensate for the yellow color of the light, providing a truer white light to pass through the sample.

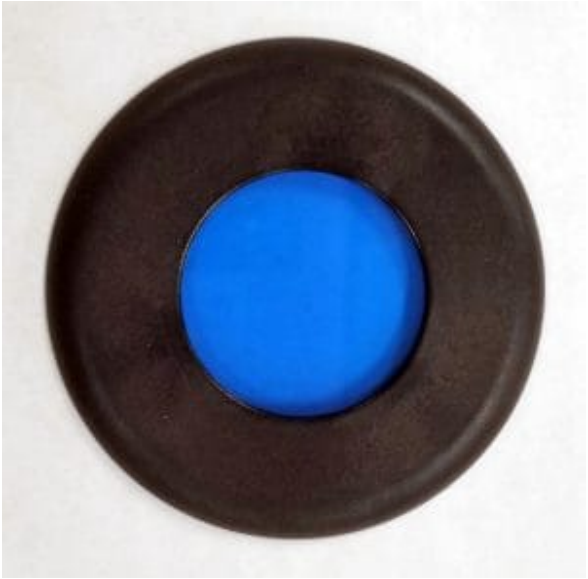


Figure 2.4.6. A blue filter from a polarizing light microscope. This filter sits on top of the illuminator.

Diaphragm or Aperture

A diaphragm or aperture cuts down the amount of light that reaches the sample by restricting the area that light can pass through. There are often multiple apertures on a microscope (**Figure 2.4.5**), including an aperture as part of the condenser assembly, as well as a field diaphragm that controls the size of the area which is illuminated on a sample.

Figure 2.4.7 shows the view through the microscope as the substage field diaphragm is opened and closed.

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The Stage

Rotating Stage, Goniometer, and Vernier Scale

The **stage** is the platform upon which the thin section is placed. The thin section spans a hole in the stage which lets light from the illuminator pass through the sample. One special feature of polarizing light microscopes used for petrography, in contrast to many other types of microscopes, is the **rotating stage**.

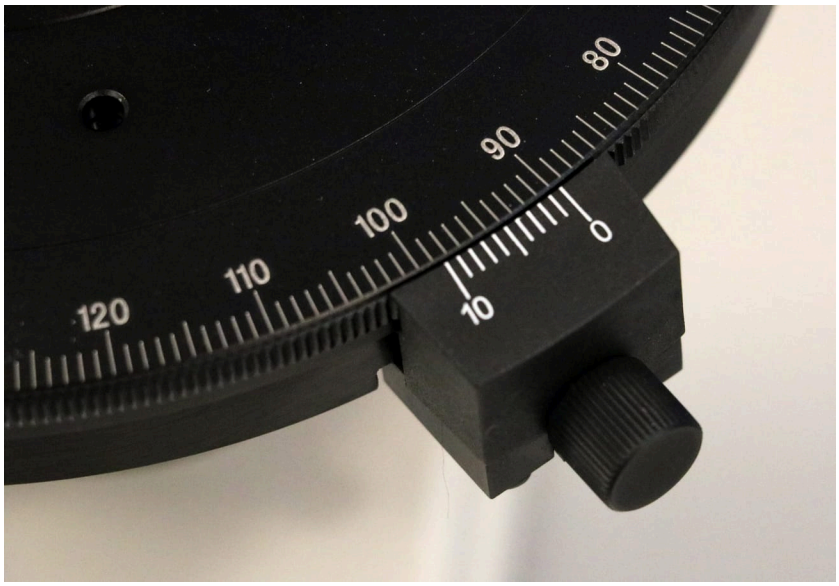


Figure 2.4.8.A. The vernier and goniometer on the rotating stage.

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Figure 2.4.8.B.The rotating stage in action, showing how the angle of orientation can be measured using the goniometer and venier. The rotating stage can be locked with the knob on the vernier.

The rotating stage has degrees marked on it: 360 degrees around the circular stage, in units of 1 degree. The angle of rotation can be measured to the nearest tenth of a degree by using the markings on the **vernier scale**. The rotating stage can therefore be used as a **goniometer**, or an instrument that measures rotational angle.

The vernier scale is a clever way of taking an accurate measurement reading between two markings on a linear scale by using mechanical interpolation. **Figure 2.4.9** shows the distance reading recorded as the yellow vernier scale slides alongside the ruler scale. The distance starts at exactly 5.0 mm, when "0" on the vernier exactly aligns with "5" on the ruler. To determine a distance greater than 5.0 mm (but less than 6.0 mm), one identifies the line on the vernier which aligns with one of the lines on the main ruler. For example, when line "1" on the vernier aligns perfectly with one of the lines on the ruler, then the distance is 5.1 mm.

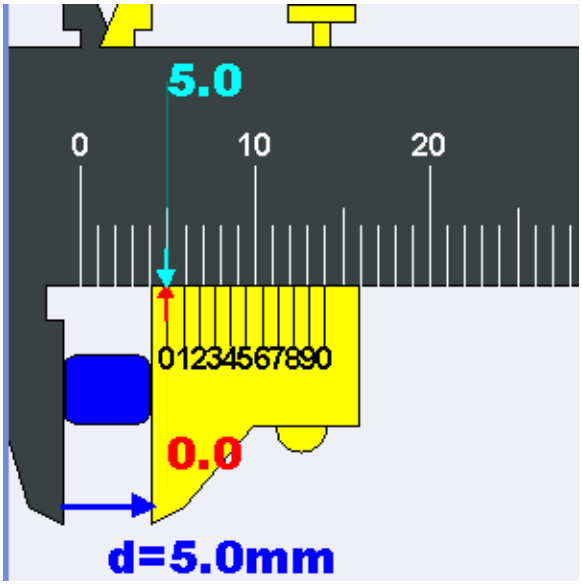


Figure 2.4.9. A vernier scale is constructed so that it is spaced at a constant fraction of the fixed main scale.

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Mechanical Stage

The **mechanical stage** is an accessory which can be attached to the top of the rotating stage. Rather than a rotating motion, it allows motion along the *x*-axis (left-right) and *y*-axis (top-bottom). In **Figure 2.4.10**, the gold knob at the top controls motion in the *x* direction, and the gold knob on the right controls the *y* direction motion. The pincer-like arms (bottom left) wrap around the thin section and hold it in place.

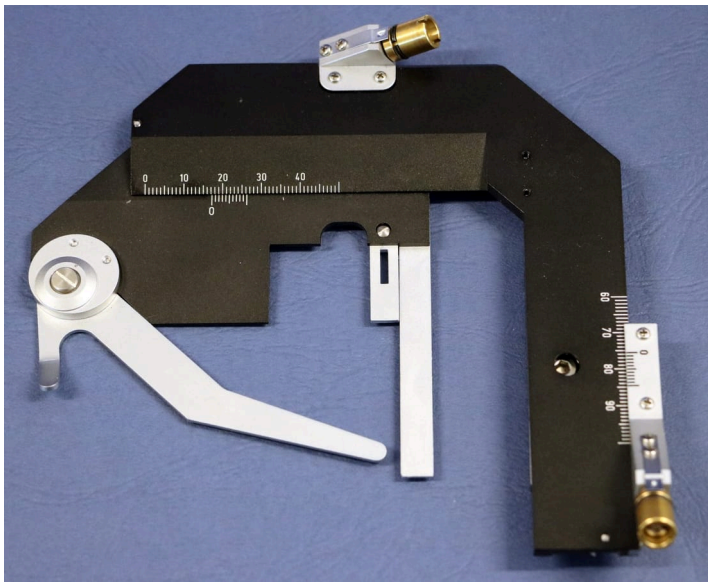


Figure 2.4.10. The mechanical stage that can be attached to the rotating stage.

The mechanical stage is not necessary for the optical mineralogy procedures discussed in this chapter. However, it is useful for point counting, in which the petrographer stops at several hundred points along an x-y grid on a thin section and identifies the mineral at each point. This technique is used to determine the modal abundance of minerals in the thin section, and is used to determine the name and composition of rocks.

The Focus

Most polarizing light microscopes have two focusing knobs on each side of the microscope. The **coarse focus** is used to rapidly change the level of the stage and sample, and the **fine focus** knob is used to gently bring a sample into complete focus.



Figure 2.4.11. The coarse (larger) and fine (smaller and marked with a depth scale) focus knobs.

Care is required when using the coarse focus knob! Because it changes the level of the stage rapidly, it may be easier to run the sample into an objective and damage the thin section and possibly the objective also.

The Objectives and Revolving Nosepiece

Objectives are the main (but usually not the only) magnification mechanism in the microscope. Magnifications typically range from about 4x-64x, although objectives as low as 2.5x and as high as 200x are available. Because most polarizing light microscopes are compound microscopes containing more than one lens, the total magnification can be much higher (see the **oculars** section below).



Figure 2.4.12 Objective lenses from two brands of polarizing light microscope. The magnification (10x) and numeric aperture (0.25 and 0.30) are written on each objective.

Objectives are attached to the **revolving nosepiece** (see **Figure 2.4.2**). They can be centered using centering screws on either side of the objective. To change objectives, one should grasp the nosepiece, and not the objective itself.

The Polarizers

The polarizers in petrographic microscopes are plane (linearly) polarized. See section 2.3 for more information about how polarizers work. There is a polarizer in the substage assembly, and a second polarizer called the **analyzer** between the objectives and the Bertrand lens.

Typically the lower polarizer and analyzer are oriented at 90 degrees to each other, and oriented N-S and E-W relative to the base of the microscope. Polarization directions are marked either on the base of the microscope, or on the polarizers themselves. In some microscopes, the analyzer and the lower polarizer can be rotated (**Figure 2.4.13**) for custom measurements. This is not necessary for standard petrographic analyses.

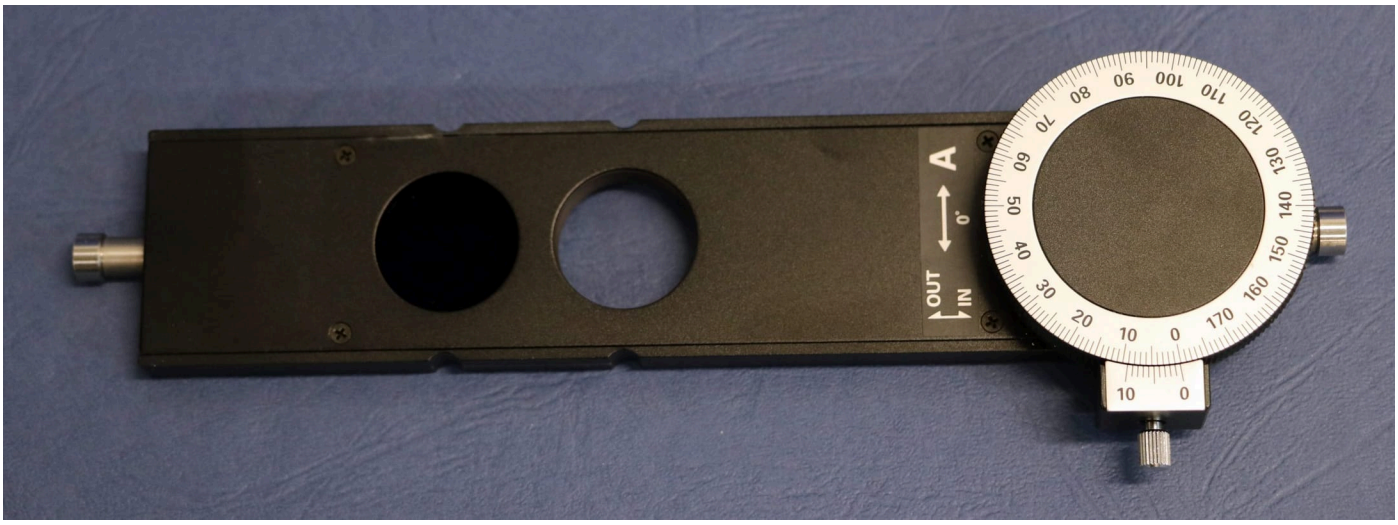


Figure 2.4.13. The analyzer (top polarizer) removed from a polarizing light microscope. In many microscopes, the analyzer is fixed with an orientation perpendicular to the lower polarizer. In this microscope, the analyzer orientation is adjustable with the goniometer and vernier on the right.

The (Amici-) Bertrand Lens

The Amici-Bertrand lens (or simply the Bertrand lens) changes the plane of focus so that the viewer can observe interference figures (a technique discussed in section 2.8).

YouTube Video

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Figure 2.4.14. The Bertrand lens being inserted and removed, as viewed with the ocular removed.

The Eyepieces or Oculars

Polarizing light microscopes have **eyepieces** or **oculars** through which the user can observe the sample. Most modern microscopes are **binocular** and have two eyepieces which can be adjusted relative to each other to comfortably fit the user's eyes. Older models may have only one eyepiece (as in **Figure 2.4.1**), but are just as effective in making petrographic observations.



Figure 2.4.15. Eyepieces or oculars removed from two different brands of polarizing light microscope. The magnification (10x) is marked on each ocular.

Most oculars contain magnifying lenses that are typically 10x magnification but can vary from model to model. The magnification should be marked on the eyepiece, and should be included in the total magnification of the microscope.

One ocular (typically the right one in a binocular microscope) will include crosshairs with a distance scale. This distance scale can be calibrated for each magnification, to determine the field of view (the diameter of the viewing circle) and the distance represented by each mark on the ocular scale (see **Question 2.4.7** below).

Oculars have a focusing mechanism to adjust the focus to each individual eye. The top portion of the ocular (the part with writing as seen in **Figure 2.4.15**) can be rotated to adjust the focus. If the crosshairs look fuzzy, or one eye seems in focus but the other is not, try adjusting the ocular focus to help you see better,

Guided Inquiry

The total magnification of a compound microscope such as a polarizing light microscope is given by this formula:

Total magnification = magnification of the objective x magnification of the ocular.

For example, if the ocular has 10x magnification and I am using the 10x objective, the total magnification is 100x.

Question 2.4.5

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The Camera

Some polarizing light microscopes have digital camera attachments, making it possible to directly photograph the field of view in the microscope. Some microscopes (**Figure 2.4.16.A**) have a camera embedded within the microscope, while for others the camera is attached to the microscope with its own viewing tube (**Figure 2.4.16B**). In microscopes with separate camera viewing

tubes, the light must be adjusted to travel partially or completely to the camera. This is accomplished with a pull-out knob (seen to the right of the eyepieces in **Figure 2.4.16B**).

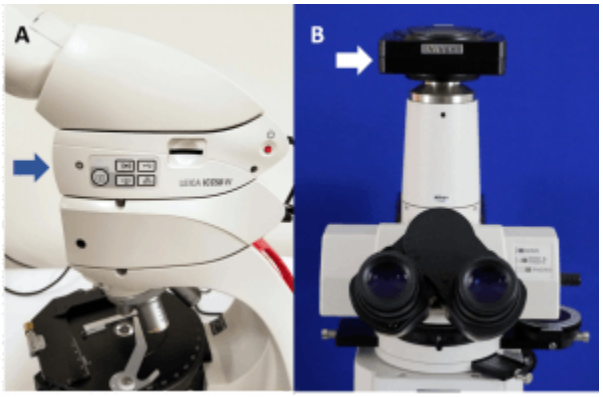


Figure 2.4.16. Digital cameras attached to two different polarizing light microscopes. In a), the camera is attached between the stage and oculars. In b), the camera is attached to the top of the microscope.

It is possible to obtain images from a microscope by aiming a smart phone camera down the ocular. However, these images will be circular in shape and may be distorted or partially out of focus. If available, the camera attached to the microscope will likely produce better-quality images.

The Accessory Plates

Figure 2.4.17 shows examples of accessory plates including a **quartz wedge**, a **530 nm plate**, and a **1/4 λ plate**. These can be inserted into the microscope (**Figure 2.4.2**) above the objectives. The accessory plates are used to conduct advanced optical tests such as optical sign determination.

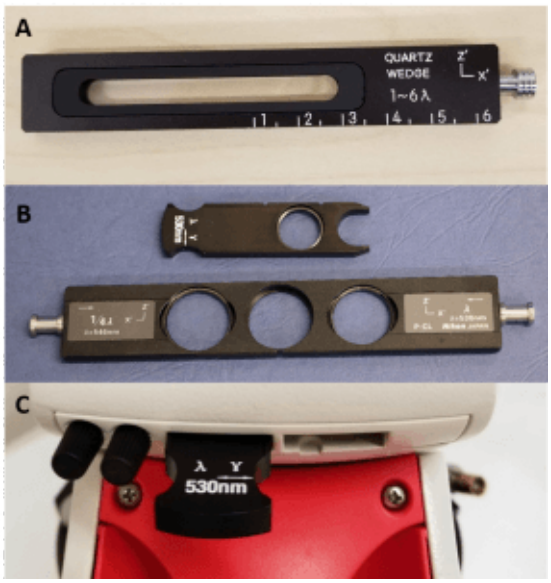


Figure 2.4.17. Examples of accessory plates. a) A quartz wedge plate. b) A 530 nm plate (top) and a combination 530 nm and 1/4 wavelength plate (bottom). c) Some microscopes include storage of accessory plates in the microscope itself, while others are stored in separate boxes.

The **quartz wedge** is just that – a slab of quartz polished into a wedge that has a thicker side which grades into a thinner side. The **530 nm plate** can also be called a gypsum plate or a 1λ plate, or be a slightly different wavelength (550 or 537 nm). The **1/4λ plate** can also be called a mica plate, glimmer plate, or 147 nm.

Summary Questions

Question 2.4.6

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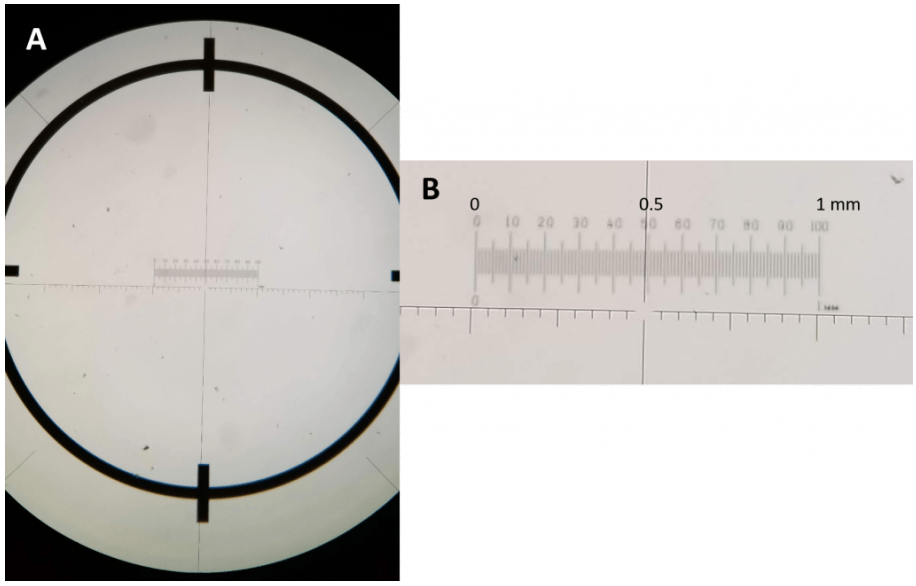


Figure 2.4.18. a) A view through the ocular showing the ocular crosshairs and micrometer (not labeled with numbers) superimposed on a 1 mm scale on a micrometer slide. b) A close-up view of the micrometer slide scale (top) with a total distance of 1 mm marked in hundredths of a mm, and the ocular micrometer scale (bottom).

Question 2.4.7. Using **Figure 2.4.18**, determine the field of view (the diameter of the circular illuminated area). Note that the thick dark circle and hatch marks are part of the micrometer slide. The field of view includes the entire white area and is cut off on the right and left sides, but its edges can be viewed on the top and bottom of the photo.

Question 2.4.8. Using **Figure 2.4.18** and the micrometer slide scale, determine the distance between each small tick mark on the unmarked ocular micrometer scale.

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Figure 2.4.19. *Two commonly used ways to change objective lenses. One of these methods is incorrect and should not be used!*

Question 2.4.8

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Key Takeaways

- Although petrographic microscopes can look different from each other, since they all function in a similar manner, the parts should be located in similar positions from microscope to microscope.
- Understanding the function of each part of the microscope will help when making petrographic observations and measurements.

Key Terms

- Accessory plate
- (Amici-) Bertrand lens
- Analyzer
- Aperture
- Base
- Condenser
- Condenser aperture diaphragm
- Eyepiece or Ocular
- Field diaphragm
- Focus (coarse and fine)
- Goniometer
- Illumination intensity controller
- Illuminator
- Light Filter
- Mechanical stage
- Objective lens
- Petrographic microscope
- Polarizer
- (Revolving) nosepiece
- Rotating stage
- Substage assembly
- Substage centering screw
- Vernier scale
- Viewing tube

References

Wikipedia. Vernier scale. (Ret. 12/12/19) en.Wikipedia.org/wiki/Vernier_scale

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2.5: Common Issues Using a Petrographic Microscope

Even after you learn about the parts and operation of a petrographic microscope, problems will arise as you work with a microscope on a day-to-day basis. This is especially true if there are multiple users of the same microscope. Someone in a different class, or who is doing a different type of research project, might adjust the settings to be different from the way you are using the microscope. Or, it might be necessary for you to look at different types of samples and adjust the microscope accordingly.

It is said that the way to most thoroughly understand a piece of equipment is to fix it when it does not work. This does **not** mean you should intentionally break a microscope! However, you will gain expert knowledge of how the microscope works if you carefully and logically attempt to solve an issue yourself, without further "messing up" the equipment.

In this module, we explore ways to troubleshoot common issues that may arise while using a petrographic microscope.

Learning Objectives

Students will be able to:

- Create testable explanations for problems encountered while using a petrographic microscope.
- Create a flowchart or list of steps to take in order to diagnose common issues with using a petrographic microscope.

Prior Knowledge and Skills

- 2.4 Parts of the Petrographic Microscope
- 2.2 Thin Sections (Recommended)

Top 10 (-ish) reasons why your microscope isn't working correctly

- **The bottom polarizer is rotated out of its proper position** (For example, on Leica student microscopes, 0 degrees should be aligned with the dot), or **there is an accessory plate inserted into the microscope**. These will create abnormal colors in crossed-polarized light- which is fine if you meant to do so with the accessory plate, and you realize it is there!

- **One of the objectives or the condenser are misaligned.** This rarely happens on good-quality microscopes that are regularly maintained. Misalignment often means that someone has been forceful in using the microscope resulting in the optics being thrown out of alignment.

- **The nosepiece is not fully rotated** so that an objective aligns with the substage condenser. This will produce an incomplete image.

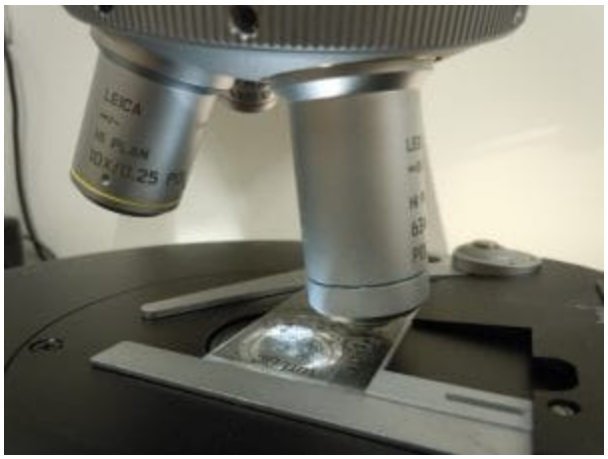


Figure 2.5.1. Nosepiece out of alignment.

- **The condenser settings are not appropriate** for the objective lens you are using, or the purpose for which you are using the microscope. Check the magnification on the condenser aperture diaphragm.
- **The crosshairs are not vertical and horizontal in the field of view.** The orientation of the crosshairs can be adjusted in the right eyepiece. Simply lift and rotate to the proper orientation.



Figure 2.5.2A. Eyepiece oriented with crosshairs horizontal/vertical.

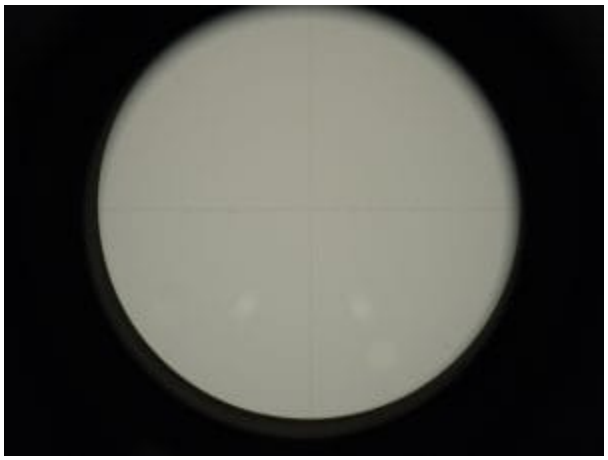


Figure 2.5.2B. Horizontal/vertical crosshairs.

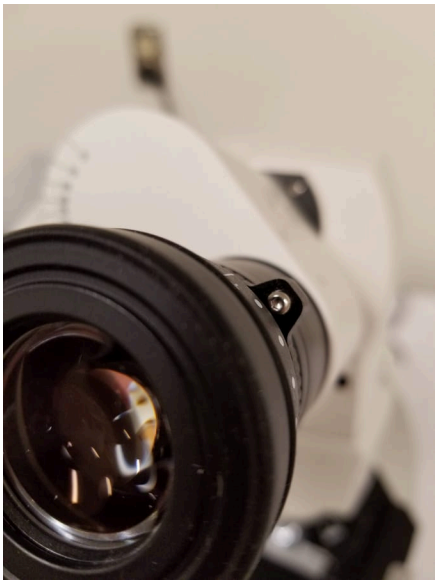


Figure 2.5.2C. Eyepiece oriented with crosshairs diagonal.

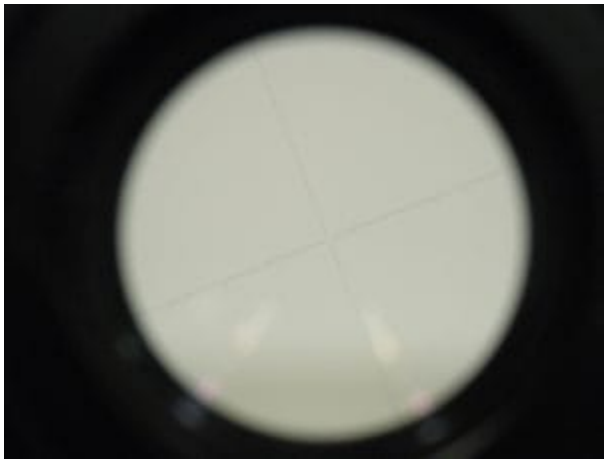


Figure 2.5.2D. Diagonal crosshairs.

- **One or both of the eyepieces are not focused for your eyes, or you are using a binocular microscope and you cannot see the entire field of view.** Rotate the focus adjustments on the eyepieces themselves until you can see clearly. Most binocular microscopes have a way to adjust the distance between the eyepieces to fit your eyes. For many microscopes, gently pull the eyepiece tubes apart or push together gently until you can see the field of view out of both eyes.

- **Something is in the way (or partially in the way) of the view.**
  - If the analyzer or an accessory plate is only partially inserted, part of the view will be obstructed or darkened.
  - If the field diaphragm is closed too far for the chosen objective, a dark ring will block light on the outside of your field of view.
  - If the Bertrand lens is in, but you are at low magnification, you will get a fuzzy view or a very constricted view of an optical interference figure.

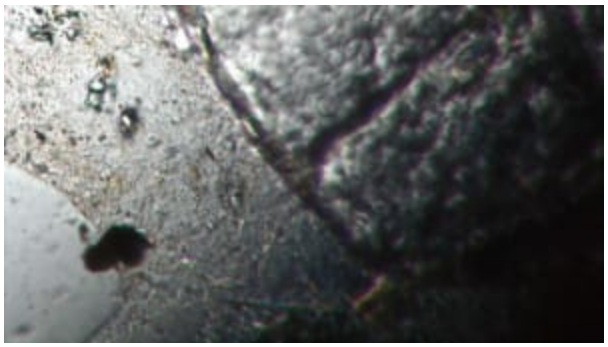


Figure 2.5.3A. Accessory plate partially obscuring the view of a thin section.

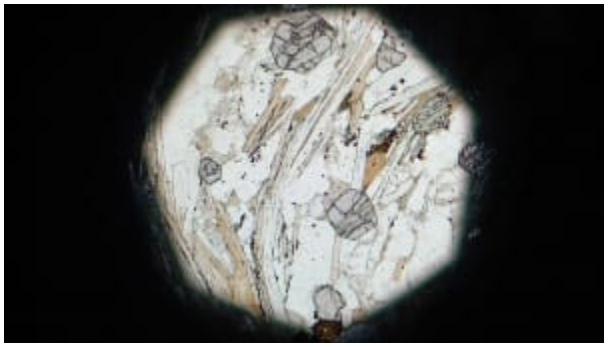


Figure 2.5.3B. Field diaphragm partially blocking the field of view.

- **The illuminator is on its minimum setting**, producing a dark or almost dark field of view. Rarely, a **light bulb will burn out**, but if the microscopes are regularly maintained, this rarely occurs.

- **The electrical outlet has reset or the plug is not firmly attached to the microscope**, resulting in a lack of power to the illuminator (or camera, if your microscope has one).
  - This is a very common occurrence at my university because all the power outlets are the type that are typically used for hair dryers in a bathroom (they have ground fault circuit interrupters (GFCI)). Turn off the microscope power button, make sure the cord is firmly attached to the microscope and the plug is completely in the outlet, then push the “test” and “reset” buttons on the outlet. Try turning the microscope on again.

And the number one issue I see in my petrology course is...

- **The thin section is upside down.** The thin slice of rock on the thin section should be on TOP of the glass slide. Remember that not all thin section labels will be on the top side of the thin section – this is especially true for thin sections used in research. At low magnification, for example when the 4x objective is used, the focal range of the objective can accommodate the height difference between having the rock slice above the glass, or the glass above the rock section. However, at higher magnifications the narrow focal region makes it necessary for the rock slice to sit on top of the glass slide to be focused.

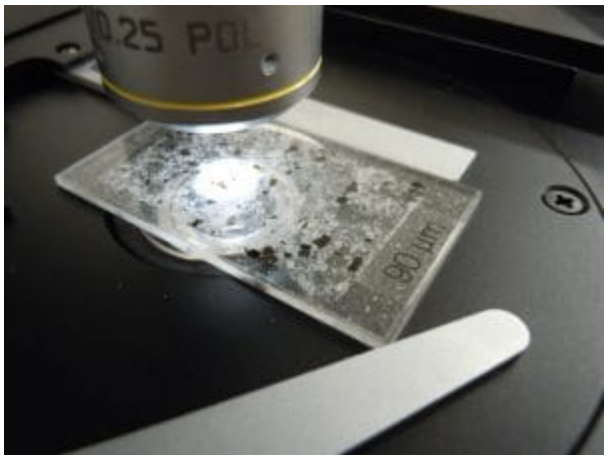


Figure 2.5.4A. A thin section right side up on the stage. Note you can see the edge of the cover slip and top layer of epoxy all the way around the top edge of the thin section.

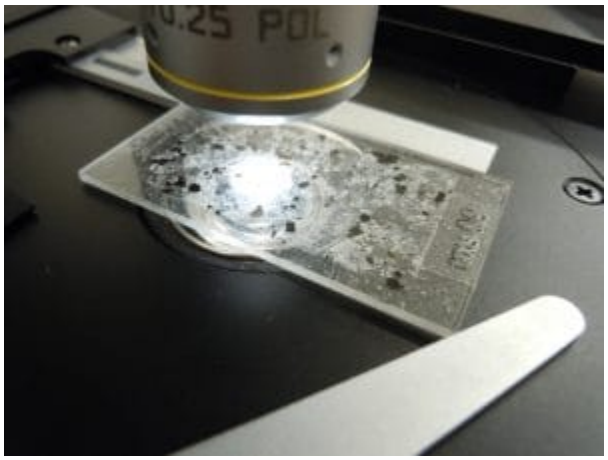


Figure 2.5.4B. A thin section upside down on the stage. Only the clean edge of the glass slide can be seen around the top edge. Note that sample labels are not always placed on the top side of thin sections.

Bonus issue

- **Do you observe smudges or specks interfering with your view?**

The microscope eyepieces, and perhaps the objective lenses, could be coated with dust or oils from human contact. Our microscopes are heavily used by multiple classes, so cleaning the eyepieces with an approved lens wipe on a regular basis is a good way to keep the field of view clear (and is also hygienic).

If the objective lens is indeed dirty, it is advisable to ask an instructor for help with cleaning. Make sure to use the correct type of lens wipe and cleaner and take care not to scratch the lens!

Color Blindness

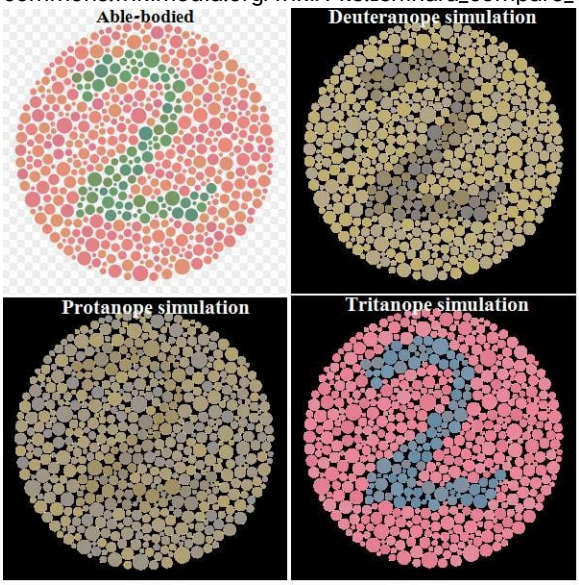
Q: It doesn't matter which microscope I use, I don't see the colors of the minerals the same way that other people in the class are describing them.

A: It is possible you could have a type of color blindness. Color blindness is common, and can be tested online: https://www.aao.org/eye-health/diseases/how-color-blindness-is-tested. One of the test options is here: https://colormax.org/color-blind-test/

Do not be discouraged if you cannot see or can only partially distinguish some colors – many successful petrologists have partial or total color blindness, including the person who taught the Petrology course for 36 years at my university before I did. There are many observations which can be used to identify minerals using the petrographic microscope, and color tends to be among the

least reliable. If you need help reading birefringence colors or interpreting accessory plate tests, please ask your instructor for help.

commons.wikimedia.org/wiki/File:Ishihara_compare_1.jpg



Guided Inquiry Exercises

Guided Inquiry

Question 2.5.1. Using your knowledge of the parts of a petrographic microscope and ways the microscope can be used incorrectly, create a flowchart diagram that would help you diagnose a problem with your microscope.

For each scenario described below, provide at least one testable explanation for the observation.

Question 2.5.2.

There is no light passing through the microscope.

Question 2.5.3.

It looks like something circular is partially blocking the field of view of the microscope.

Question 2.5.4.

The cross-polarized view of your thin section looks “funny”- the colors seem wrong for the minerals in the thin section.

Question 2.5.5.

The thin section is in focus at low magnification, but it is not possible to focus it at higher magnification.

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2.6: Properties Under Plane Polarized Light

In this section, we explore properties that can be observed for minerals under plane polarized light, when only the lower polarizer is inserted into the polarizing light microscope.

Learning Objectives

In this section, students will learn to:

- Distinguish opaque minerals from transparent minerals.
- Identify the color(s) of minerals in plane polarized light.
- Identify and describe pleochroism.
- Determine if a mineral has low, medium, or high relief.
- Describe the relationship between refractive index and relief.
- Describe mineral form as euhedral, subhedral, or anhedral.
- Identify cleavage and fracture in minerals.

Overview of Properties in Plane Polarized Light

This video gives an overview of some of the important properties of minerals in plane polarized light. These properties are explored in more detail in the sections below.

YouTube Video

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Figure 2.6.1. *Some techniques that use plane polarized light. Earth Optics Videos, Creative Commons Attribution License.*

Opaque vs. Transparent Minerals

Transparent minerals transmit light, whereas **opaque** minerals block light from passing through them. Because most student microscopes only have an option to look at minerals under transmitted light, this means that ***all opaque minerals will appear dark in plane polarized light***. Some very small opaque minerals, or minerals within a group that contains both opaque and transparent minerals (such as the spinel group) may let some light through and could appear to have some color.

Microscopes with the ability to view thin sections under both reflected and transmitted light do exist, and different opaque minerals will reflect light differently. This type of microscope is most commonly used for studying ore deposits or other rocks containing many opaque mineral species.

Figure 2.6.2

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Figure 2.6.3

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Question 2.6.1. The two figures above show magnetite (**Figure 2.6.2**) and garnet (**Figure 2.6.3**) in both plane polarized light (PPL) and cross polarized light (XPL). Based upon the definition of opaque minerals, which of these are opaque? Why?

Color

Some minerals that are darkly colored in hand sample will also appear to have color in thin section, even though the rock slices in thin sections are typically only 30 micrometers thick. Sometimes the color of a mineral in plane polarized light can aid in identification (see examples in the figures below) because it is characteristic for a specific mineral.

But, be cautious about relying too heavily on color as an identification tool! Minerals within a solid solution group can have very different color characteristics in hand sample (as shown in **Figure 2.6.6**) and under the microscope.

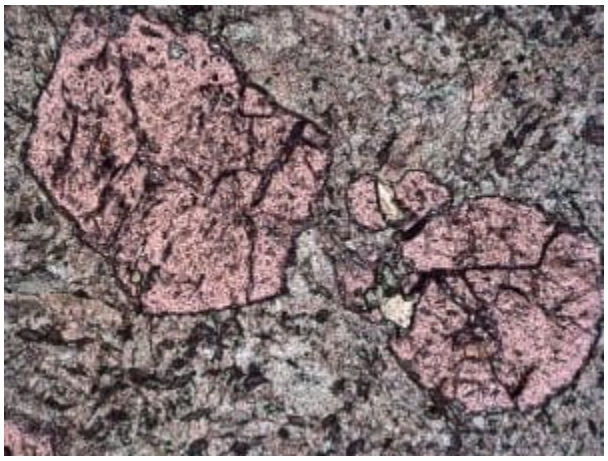


Figure 2.6.4. Garnet (pink) and clinopyroxene (green) under plane polarized light. Eclogite, California, Ward's collection sample, 40x total magnification.

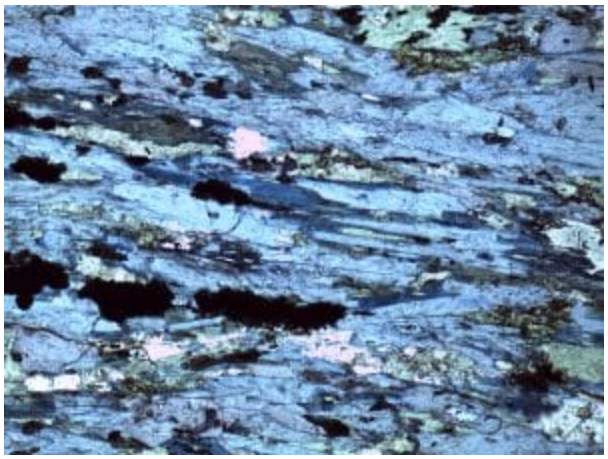


Figure 2.6.5. Glaucophane in plane polarized light. Total magnification: 25x.

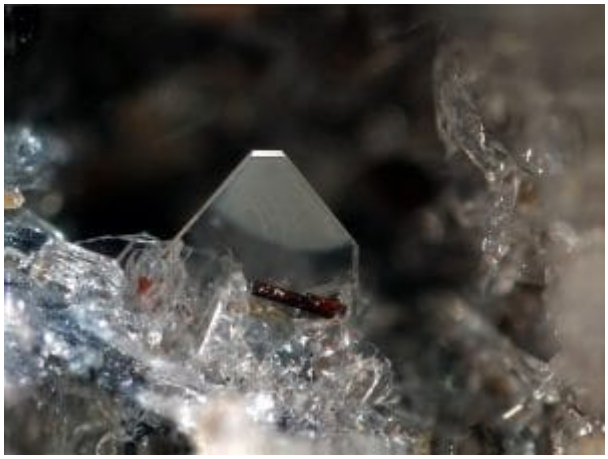


Figure 2.6.6 A. A colorless forsterite crystal (olivine group) from Wannenköpfe, Ochtendung, Eifel region, Germany.



Figure 2.6.6 B. Light green forsterite crystal (Mg-Fe olivine) from Naran-Kagan Valley, Kohistan District, North-West Frontier Province, Pakistan.



Figure 2.6.6 C. Fayalite (F
G

Pleochroism

Pleochroism is when a mineral changes color as it is rotated relative to the polarizer in plane polarized light. This effectively shows how the color properties of the mineral vary with direction within the crystal structure.

Testing for pleochroism using a polarizing light microscope is straightforward.

- First, make sure you are using plane polarized light by removing the analyzer.
- Locate the mineral you wish to test. If possible, it is advisable to look at more than one grain of the same mineral, since these will likely be oriented in a variety of directions and will give a better sense of the pleochroic behavior.
- Rotate the stage and observe the color changes in the mineral grains.

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Figure 2.6.7.A. Glaucophane showing strong pleochroism in plane polarized light. Total magnification: 25x.

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Figure 2.6.7.B Epidote in plane polarized light. Total magnification: 40x.

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Question 2.6.2

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Relief and Refractive Index

The **refractive index** of a mineral characterizes the relationship between the speed of light in a vacuum and the speed of light in that material. Refractive index is discussed in Section 2.3 Light and Optics. The refractive index of a mineral can vary according to crystal orientation. For example, the refractive index of kyanite ranges from 1.712-1.734 (Wikipedia).

Mineral **relief** is related to the refractive index of the mineral. If a mineral has a refractive index that is much higher or lower than the surrounding materials, it will stand out relative to the surrounding material and will have thick or distinct . In a grain mount, the surrounding material is likely to be epoxy or mineral oil. In a thin section, the surrounding material will be adjacent minerals. For the purposes of identifying minerals in thin section, it is sufficient to describe relief as **high, intermediate**, or **low**.

Mineral Relief Categories:

High relief	Refractive index > 0.12 different from surrounding media
Intermediate relief	Refractive index 0.04 – 0.12 different from surrounding media
Low relief	Refractive index <0.04 different from surrounding media

In practice, it is not necessary to measure the refractive index of the mineral or the surrounding media directly. Instead, we look at the thickness of the grain boundaries around the mineral and how the mineral appears to either stand out or blend in with surrounding media or minerals. Examples of high, intermediate, and low relief are shown in **Figure 2.6.8**.

Figure 2.6.8

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Figure 2.6.8. *High, intermediate, and low relief minerals (click on hotspots to identify). Image taken at 25x total magnification.*

The relative refractive indices of two materials (minerals, glass, or epoxy) adjacent to each other in a thin section can be determined using **Becke lines** (pronounced beck-ee). The procedure for checking Becke lines is summarized in the video (**Figure 2.6.1**) at the start of this chapter. When the stage is lowered in plane polarized light, the bright Becke line will either move into or out of a mineral. If the Becke line moves into the mineral grain, that mineral has a higher index of refraction and higher relief. If the Becke line moves out of the grain, the mineral has a lower index of refraction and lower relief. These properties are summarized in **Figure 2.6.9** below.

Figure 2.6.9

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Figure 2.6.9. *Becke lines move into the material with the higher refractive index when the stage is lowered. In these figures, "B" indicates the location of the Becke lines as the stage is lowered. The Becke lines appear above the sample, because after the stage is lowered, the microscope is focused on a plane above the sample.*

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Mineral Form

Mineral form refers to the ideal crystal form, or the shape a mineral takes when left to grow without barriers or interference with other nearby mineral grains. Minerals take characteristic shapes according to their crystal symmetries and structures.

Most of the time, however, crystals in igneous and metamorphic rocks do not grow freely. They run up against other crystals that have already formed, or ones that are growing simultaneously. This prevents them from being their true shape.

The terms **euhedral, subhedral,** and **anhedral** are used to describe how well a mineral displays its ideal form. **Euhedral** minerals

show perfect or nearly perfect crystal faces. **Subhedral** minerals are rounded but still show the general characteristic shape of that mineral. **Anhedral** crystals are completely irregular in shape and do not resemble the characteristic form for that mineral.

Figure 2.6.10

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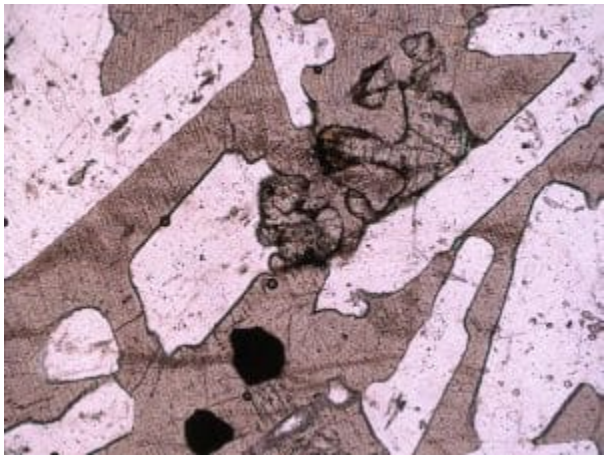


Figure 2.6.11. Subhedral plagioclase (white) and anhedral clinopyroxene (brown-green) and olivine (brown-green, high relief) in a gabbro, 100x total magnification.

In igneous rocks, mineral shape helps us determine the crystallization order from the magma and allows us to connect observations in thin section to thermodynamic models.

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Cleavage and Fracture

Cleavage and **fracture** can be used to help distinguish minerals in thin section.

Cleavage is the tendency of minerals to break along atomic planes of weakness within the crystal structure. Minerals may have one or more directions of cleavage dictated by the atomic arrangement and bonding within that mineral.

Fractures are irregular cracks within a mineral. These can form within any mineral, but when only fractures appear in a mineral, it may indicate that it has poor or no cleavage.

Figure 2.6.12

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Figure 2.6.12. Hornblende in plane polarized light, 40x total magnification.

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Question 2.6.6

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Figure 2.6.1. Earth Optics Video 1: Plane Polarized Light. Earth Optics Videos, Creative Commons Attribution License. https://youtu.be/ahS5KlXqQXc

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2.7: Properties Under Cross Polarized Light

In this section, we explore properties that can be observed for minerals under cross polarized light, when both the lower polarizer and the analyzer (top polarizer) are inserted into the polarizing light microscope.

Learning Objectives

In this section, students will learn to:

- Distinguish between anisotropic and isotropic minerals.
- Determine the interference colors, birefringence, and retardation for a mineral grain.
- Evaluate if a mineral has parallel or inclined extinction to help identify the mineral.
- Observe and record other mineral properties in cross polarized light such as twinning, zoning, and textural features.

OVERVIEW OF PROPERTIES IN Cross POLARIZED LIGHT

This video gives an overview of some of the important properties of minerals in cross polarized light. These properties, plus a few others, are explored in more detail in the sections below.

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***Figure 2.7.1**. Explanations of isotropic versus anisotropic minerals, interference colors, birefringence, and retardation. Earth Optics Videos, CC-BY.*

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Isotropic vs. Anisotropic Minerals

Isotropic minerals have crystal structures which have the same structure in every direction. They belong to the **isometric** crystal system. All other minerals are **anisotropic**, meaning their crystal structures vary with direction. These are minerals belong to the hexagonal, tetragonal, orthorhombic, monoclinic, and triclinic crystal systems. (See Section 2.8 Interference Figures and Crystal Symmetry for a chart of the crystal systems). The table below summarizes characteristics of opaque, isotropic, and anisotropic minerals.

Mineral type	Characteristics in Plane Polarized Light	Characteristics in Cross Polarized Light
Opaque	Mineral appears dark	Mineral appears dark even when rotated
Isotropic	Light passes through mineral	Mineral appears dark even when rotated
Anisotropic	Light passes through mineral	Mineral exhibits interference colors and goes dark (extinct) every 90 degrees

Figure 2.7.2

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Question 2.7.2

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Inclined and Parallel Extinction

If a mineral has cleavage, determining if it has parallel or inclined extinction can be useful to distinguish it from similar minerals. Under cross polarized light, a mineral with **parallel extinction** will go extinct (dark) when the cleavage direction is parallel to the north-south and east-west directions as the stage is rotated. A mineral with **inclined extinction** will go extinct with the cleavage at an angle to these directions as the stage is rotated. The cross hairs on the ocular should be used as a guide for this measurement.

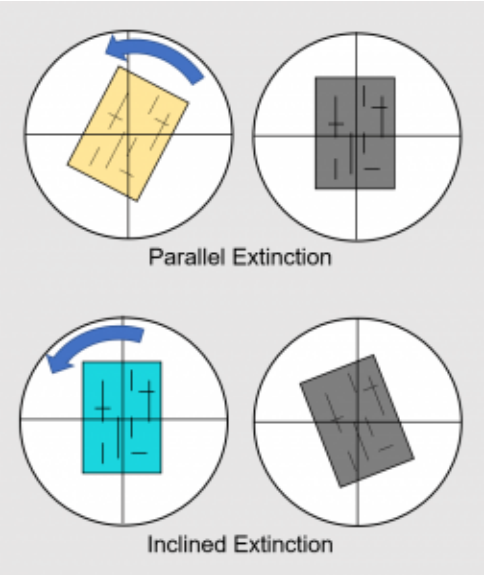


Figure 2.7.5. A comparison of parallel and inclined extinction.

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Figure 2.7.4. *An example of determining inclined or parallel extinction. 40x total magnification.*

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Interference Colors, Birefringence and Retardation

The color of a mineral under cross-polarized light is called its **interference color**. Interference colors categorized by first, second, third, and fourth-order colors are shown in **Figure 2.7.3**.

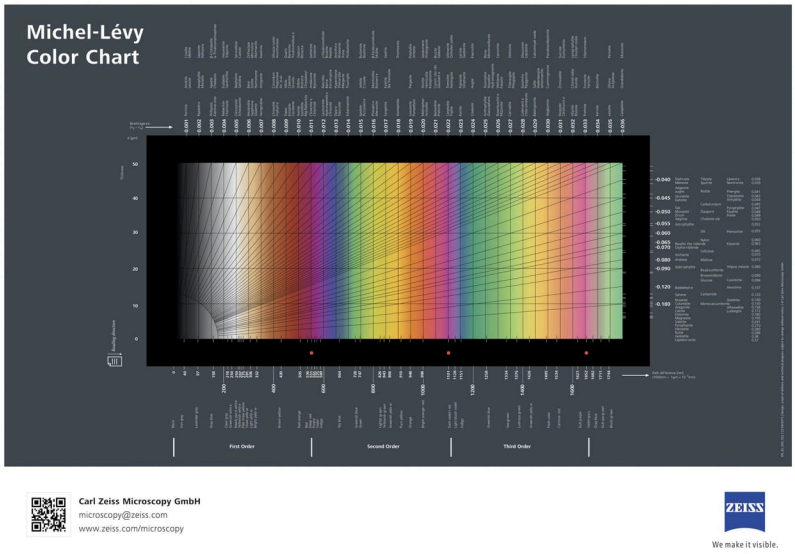


Figure 2.7.3. The Michel-Levy Interference Color Chart. ZEISS Microscopy from Germany, CC-BY-SA. commons.wikimedia.org/wik

Figure 2.7.3 is the Michel-Levy Interference Color Chart. To better view the text and labels on the full-sized image, click on **this link to the original file on Wikipedia**. This diagram displays the interference colors in the chart, with **verbal descriptions** of first-, second-, and third-order colors below the x-axis. The y-axis on the left side of the diagram is thickness of the mineral (or thin section) in micrometers.

The physical property called **birefringence(δ_n, or $n_\gamma - n_\alpha$)** is plotted along diagonal lines across the diagram. The value of birefringence for each diagonal line is listed at the top and right sides of the diagram. Minerals are listed across the top and right side of the diagram next to their birefringence value.

The slice of rock on a standard thick section is about 30 micrometers thick. To determine birefringence, use these steps:

1. Determine the (maximum) interference color of the mineral. It may be necessary to look at several grains of the same mineral, since many times they will be oriented differently within the thin section. If you are unsure of the interference color, it can be helpful to look at the edges of the mineral grain, which may show interference color banding that can help narrow down the color.
2. Locate the interference color on the Michel-Levy chart, and find where it intersects the horizontal line for 30 micrometers.
3. From this point, follow the diagonal line to the top of the chart to determine the birefringence value, and to see minerals with this birefringence.

Figure 2.7.6

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Other Textures Under Crossed Polarized Light

There are many other textures and features that may be revealed under cross polarized light which are not visible or not obvious under plane polarized light. These can include **twinning** (**Figure 2.7.7**), **zoning** due to compositional changes during crystal growth (**Figure 2.7.8**), **undulatory extinction** (**Figure 2.7.9**) or other deformation textures, and **exsolution lamellae** (**Figure 2.7.10**) in which one mineral separates into two minerals, producing a striped effect.

Figure 2.7.7

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Figure 2.7.8. *Oscillatory zoning in plagioclase crystals, 100x total magnification. Mt. Jefferson dacite, Oregon.*

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Figure 2.7.9. *Quartz exhibiting undulatory extinction under cross polarized light 100x total magnification. Cranberry Gneiss, near Galax, VA.*

Figure 2.7.10

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Earth Optics Videos (Nov 27, 2015). Earth Optics Video 2: Cross Polarized Light. CC-BY license. https://www.youtube.com/watch?v=OB7UbgiDGW0

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2.8: Interference Figures

Interference figures are a technique which can be used to help identify minerals using a polarizing light microscope. In this chapter, we explore the practical aspects of obtaining and interpreting interference figures and other related observations.

Learning Objectives

Students should be able to:

- Describe the steps used to obtain interference figures.
- Correctly name the parts of an interference figure.
- Describe the features of an indicatrix.
- Identify the type of interference figure produced.
- Connect crystal symmetry to the type of interference figure(s) that are produced.
- Use interference figures to narrow down the possible symmetry choices and help identify a mineral.
- Make optical sign determinations and 2V angle estimates to further help identify minerals (optional).

How to Obtain an Interference Figure

These videos show the steps to obtaining an interference figure. They are shot at two different angles so it is possible to see the operation of the microscope better.

Do you remember?

What is a Bertrand Lens? See section 2.4 to review!

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Figure 2.8.1 A and 2.8.1 B. *Basic steps to obtain an interference figure on a mineral.*

In each of these videos, there is a single mineral crystal on the slide. If you are looking at multiple grains of the same mineral, you may find it helpful to***locate mineral grains with the lowest interference colors (lowest retardation)*** to obtain interference

figures that are the easiest to identify (e.g., uniaxial optic axes figures, or biaxial acute bisectrix figures, which will be described below).

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Figure 2.8.2

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Question 2.8.1. *Drag and drop the steps of obtaining an interference figure in the correct order.*

Anatomy of an Interference Figure

Below is an example of one type of interference figure. This figure contains three types of features: isogyres, a melatope, and isochromes.

Figure 2.8.3

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Figure 2.8.3. *Anatomy of an interference figure.*

The Indicatrix

The index of refraction is different in different crystallographic directions within a mineral, according to its crystal symmetry. We can characterize this using an ellipsoid (roughly the shape of an American football or rugby ball-shaped object) which shows the refractive index in every direction, including the three principle optical axes. This ellipsoid is called an **indicatrix**.

The **indicatrix** is a 3-dimensional visualization of the indices of refraction of a mineral. As discussed previously in light and optics, the index of refraction is different for different minerals. It can also vary as a function of direction within the crystal structure. Minerals with lower symmetries have greater variation in the index of refraction with direction.

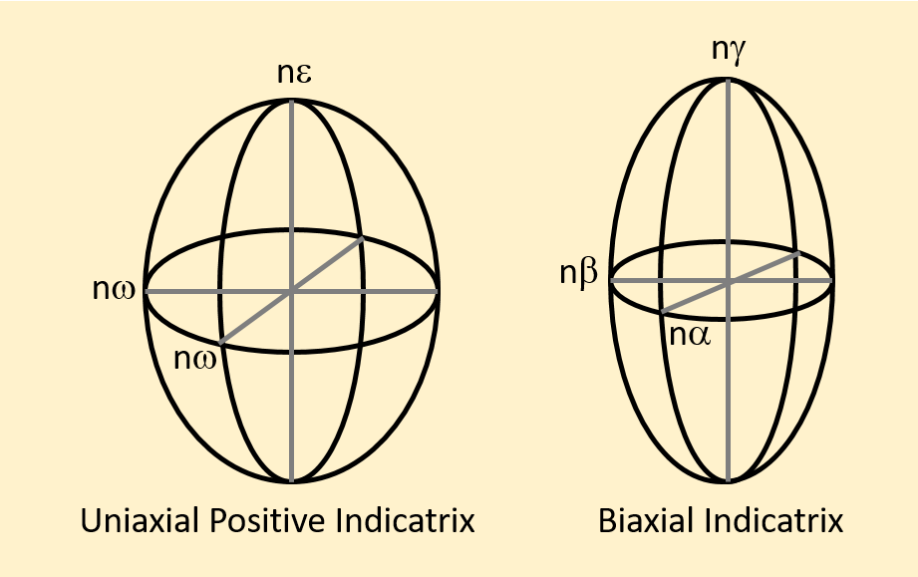


Figure 2.8.4. Examples of a uniaxial indicatrix and a biaxial indicatrix. The indices of refraction are plotted parallel to the vibration direction of light.

As discussed in Section 2.3 Light and Optics, Birefringence, a solid material such as a mineral can split light waves into two polarized beams, the ordinary ray (represented by "o" or "ω" and the extraordinary ray (represented by "e" or "ε"). Uniaxial minerals exhibit the same refractive index along two principal axes (**nω**), and a different refractive index along the third principal axis (**nε**). Biaxial minerals have different refractive index values along each principal axis, with **nα** as the lowest refractive index, **nβ** as an intermediate refractive index, and **nγ** as the largest refractive index.

Why create this type of diagram? It is useful for thinking about how the interference figure will vary as the crystal is oriented in different directions in the thin section. Indicatrices are shown in the figures showing uniaxial and biaxial interference figures in the sections below. The figures show the orientation of the indices of refraction with respect to the thin section surface using the indicatrix, and the resulting interference figure.

Uniaxial Interference Figures

The following two videos explain how to obtain uniaxial interference figures and how to determine optic sign for a uniaxial mineral. **Figure 2.8.7** summarizes the types of interference figures that can be observed for uniaxial minerals.

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Figure 2.8.5. *Earth Optics Videos. Video 4: Uniaxial Minerals, CC-BY license. https://youtu.be/JShFwEIqUzY*

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Figure 2.8.6. *Earth Optics Videos. Video 5: Uniaxial Flash Figure, CC-BY license. https://youtu.be/KBwFSC4vPRc*

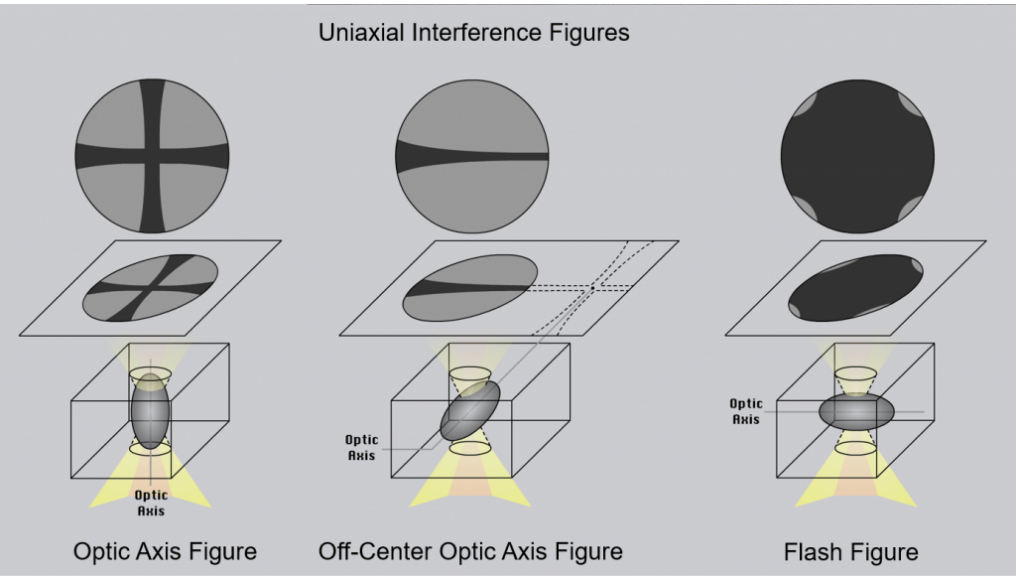


Figure 2.8.7. Different types of interference figures produced by uniaxial minerals. For simplicity, isochromes are not shown. The lower part of each image shows the orientation of the indicatrix for the mineral. The middle part of the diagram shows the interference figure relative to the thin section and the upper image shows the view through the microscope ocular.

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Figure 2.8.8. *Uniaxial optic axis figure obtained on quartz.*

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Figure 2.8.9. *Uniaxial flash figure obtained on quartz.*

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Biaxial Interference Figures

The following two videos explain how to obtain biaxial interference figures, how to determine optic sign for a biaxial mineral, and how to estimate a 2V angle.

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Figure 2.8.10. *Earth Optics Videos. Video 6: Biaxial Minerals. CC-BY license. https://youtu.be/pA_fJnbPRtg*

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Figure 2.8.11. *Earth Optics Videos. Video 7: Biaxial Flash Figure. CC-BY license. https://youtu.be/qCkljJ1Isjw*

Biaxial interference figure diagrams.

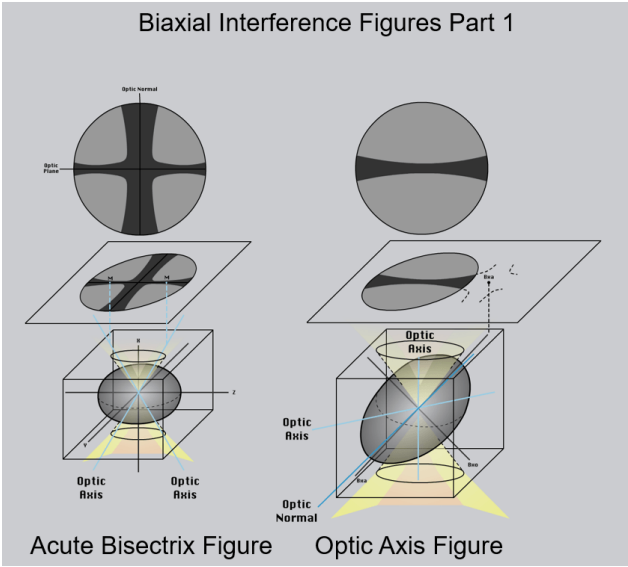


Figure 2.8.12.A. Different types of interference figures produced by biaxial minerals. For simplicity, isochromes are not shown. The lower part of each image shows the orientation of the indicatrix for the mineral. The middle part of the diagram shows the interference figure relative to the thin section and the upper image shows the view through the microscope ocular.
M= melatope; Bxa = acute bisectrix; Bxo = obtuse bisectrix.

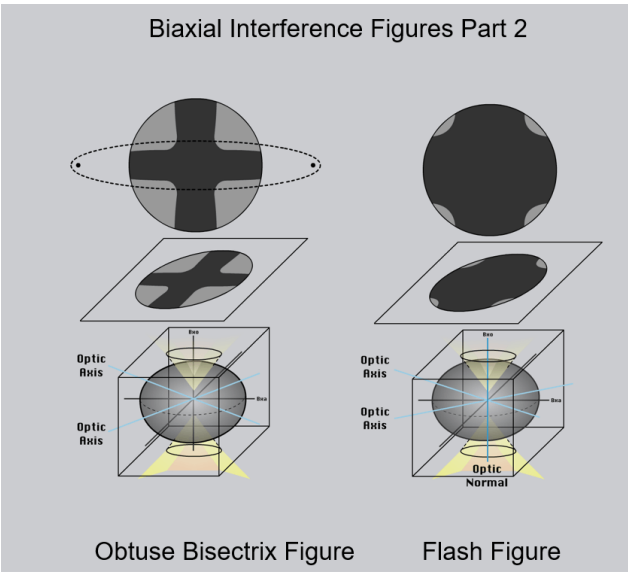


Figure 2.8.12.B. Different types of interference figures produced by biaxial minerals. For simplicity, isochromes are not shown. The lower part of each image shows the orientation of the indicatrix for the mineral. The middle part of the diagram shows the interference figure relative to the thin section and the upper image shows the view through the microscope ocular.
Bxa = acute bisectrix; Bxo = obtuse bisectrix.

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Figure 2.8.13. *An acute bisectrix optical interference figure obtained on albite.*

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Figure 2.8.14. *An optical interference figure obtained on an augite crystal oriented parallel to the 001 crystallographic direction.*

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Figure 2.8.15. *An optical flash figure obtained on an augite crystal.*

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Interference Figures and Crystal Symmetry

The types of interference figures that a mineral produces are related to the crystal symmetry of that mineral. The figure below summarizes the division of crystal symmetries into isotropic, uniaxial, and biaxial optical properties.

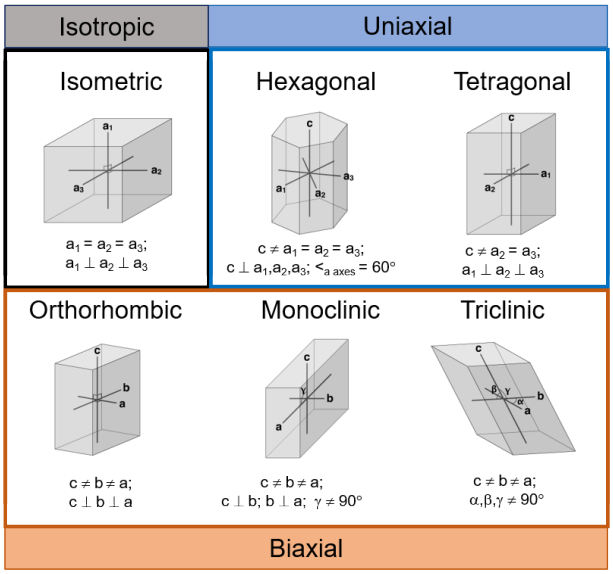


Figure 2.8.16. The crystal systems labelled with optical properties (isotropic, uniaxial, or biaxial). If the symmetry of a crystal is known, it can be used to predict which type of interference figures the mineral will produce in thin section.

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Synthesis: Is it Uniaxial or Biaxial?

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Figure 2.8.17. *An interference figure obtained on a calcite crystal.*

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Figure 2.8.18. *An interference figure obtained on a nepheline crystal.*

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2.9: Atlas of Minerals in Thin Section

Now that you are familiar with how to use a petrographic microscope and some of the optical characteristics that can be observed for minerals, it is possible to identify minerals under the polarizing light microscope (or at least to eliminate some possibilities).

This section is intended for use as a **reference** for students who have completed the earlier sections of this chapter. Sources to locate optical data as well as images of igneous and metamorphic minerals are compiled below in alphabetical order by reference name.

Please note that this is intentionally NOT a comprehensive table of data for each mineral. In the next section of this chapter (2.10) there is a student synthesis assignment in which students compile their own tables and criteria to distinguish commonly-occurring rock-forming minerals.

Resources: Optical Properties

John Fathfull (ret. 1/12/2020) Identification Tables for Common Minerals in Thin Section. http://funnel.sfsu.edu/courses/geol426/Handouts/mintable.pdf

Smith College Geoscience Students (ret. 1/12/2020) Petrographic Data Files. http://www.science.smith.edu/geosciences/petrology/petrography/mineral_list.html

Webmineral.com (ret. 1/12/2020) A to Z listing of minerals . http://webmineral.com/Alphabetical_Listing.shtml#.XhtMwchKhGM

Resources: Minerals in Thin Section

Atlas of Metamorphic Minerals (ret. 1/12/2020) http://www.earth.ox.ac.uk/~oesis/atlas/metmins/index.html

Hollocher, Kurt (ret. 1/12/2020) Igneous Minerals in Thin Section: https://minerva.union.edu/hollochk/c_petrology/ig_minerals.html

Hollocher, Kurt (ret. 1/12/2020) Metamorphic Minerals in Thin Section: https://minerva.union.edu/hollochk/c_petrology/met_minerals.html

Mazdab, Frank K. (ret. 1/12/2020) thin section scans. https://www.rockptx.com/thin-section-scans/

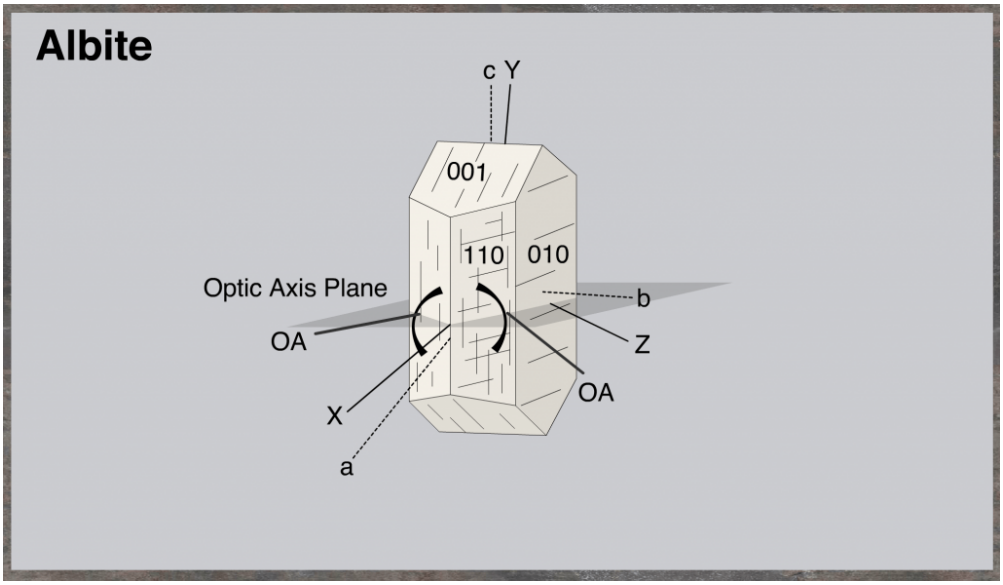
rockPTX (ret. 1/12/2020) Playlist of mineral videos in thin section (ppl, xpl): https://www.youtube.com/channel/UClRPHZ4xYNB6BCQ3zaIv9Pw/playlists

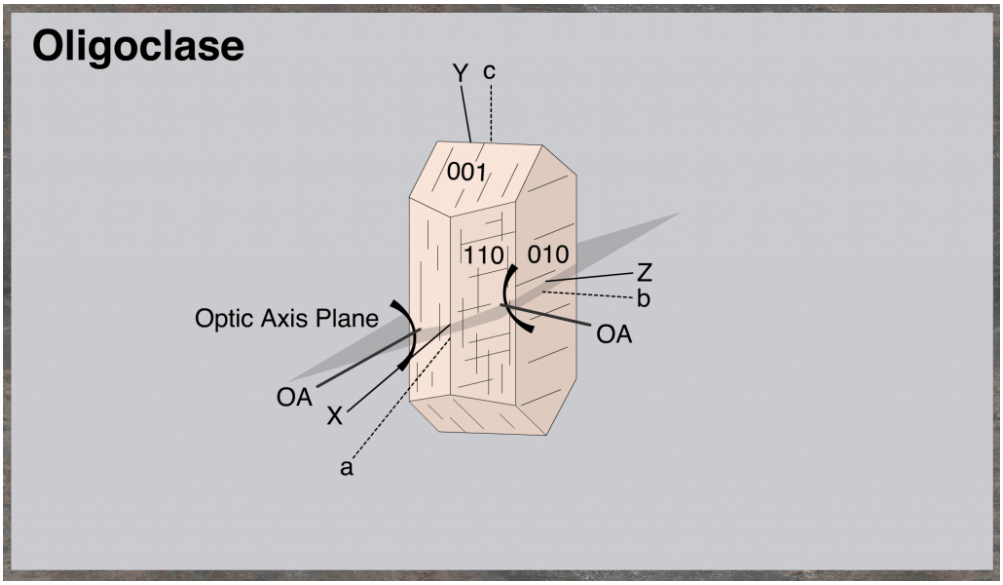
Siddall, R., 2014, Minerals Menu: a catalogue of minerals & textures in thin section. http://www.ucl.ac.uk/~ucfbrxs/PLM/PLMhome.html

Optical and Crystallographic Axes Diagrams

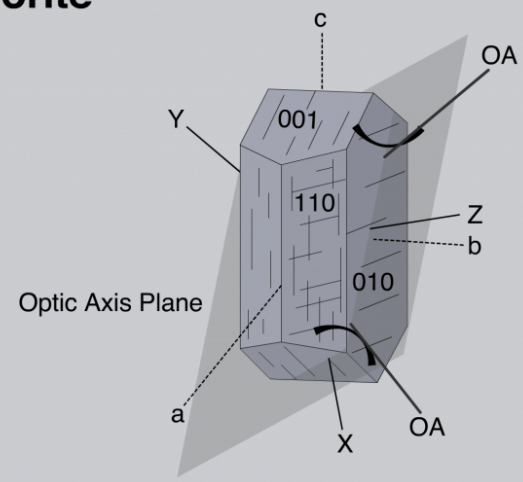
The diagrams below show the geometric relationships between principle optical axes and crystallographic axes for some common ***biaxial*** rock-forming minerals. In these diagrams, **OA** = optic axis; **X**, **Y**, and **Z** are principal optic axes; **a**, **b**, and **c** are crystallographic axes. Crystal faces are labelled with Miller Indices (e.g. 001, 110, etc.).

Feldspar Group

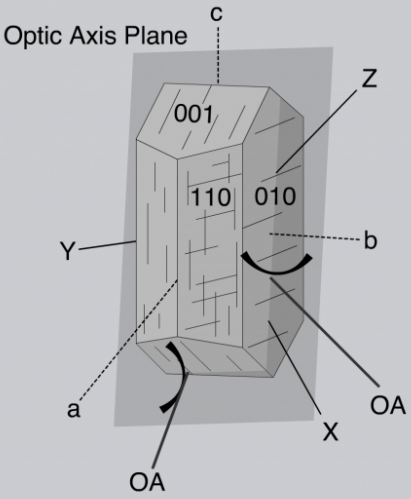




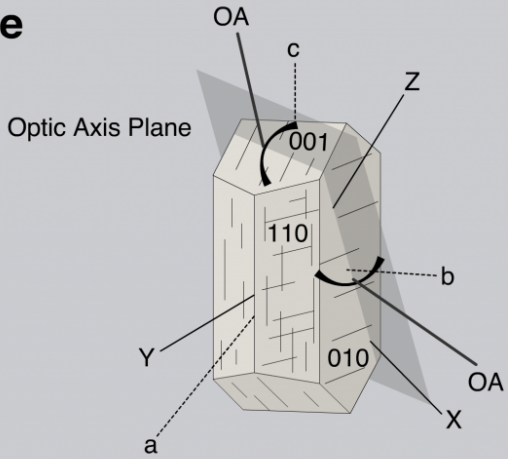
Labradorite

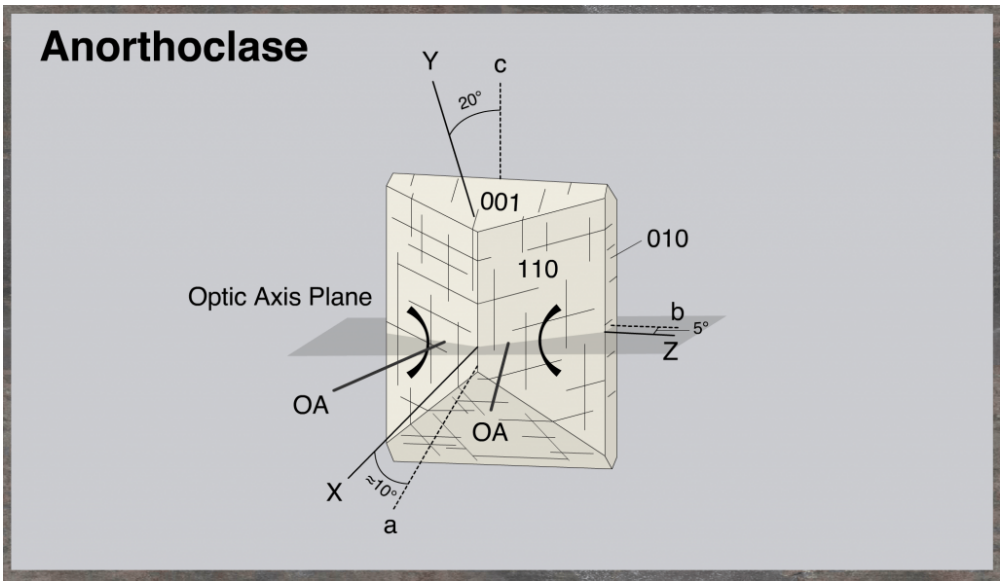


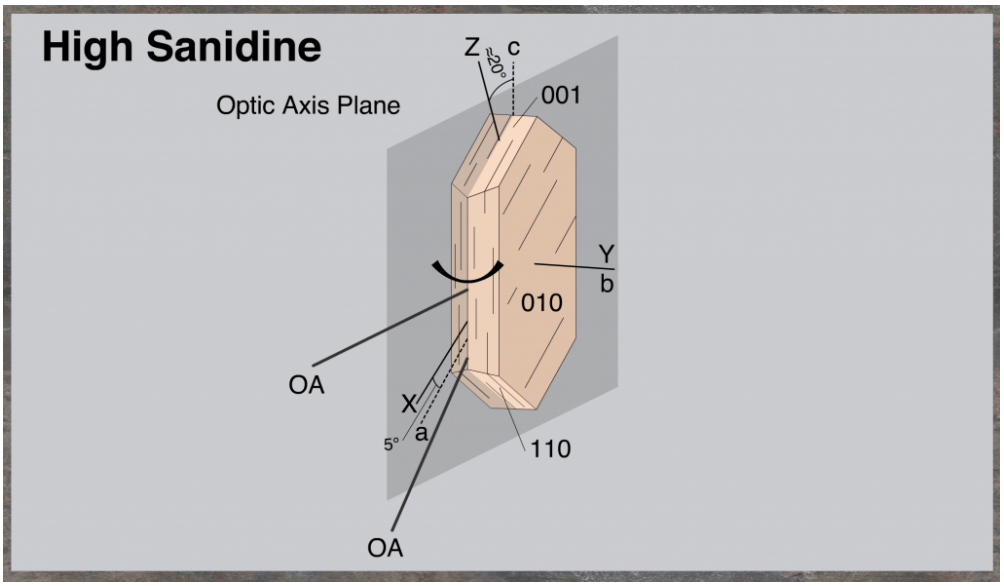
Bytownite

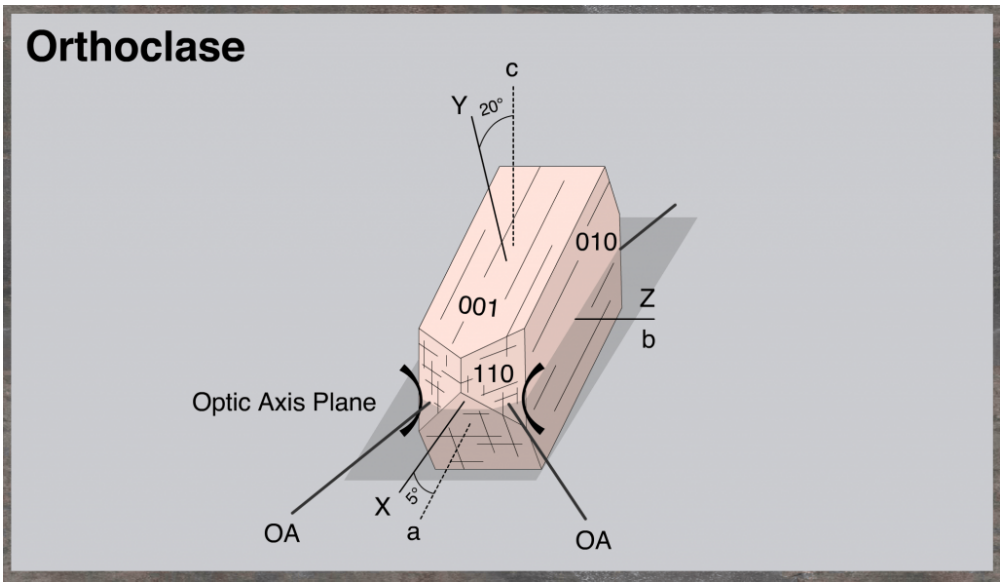


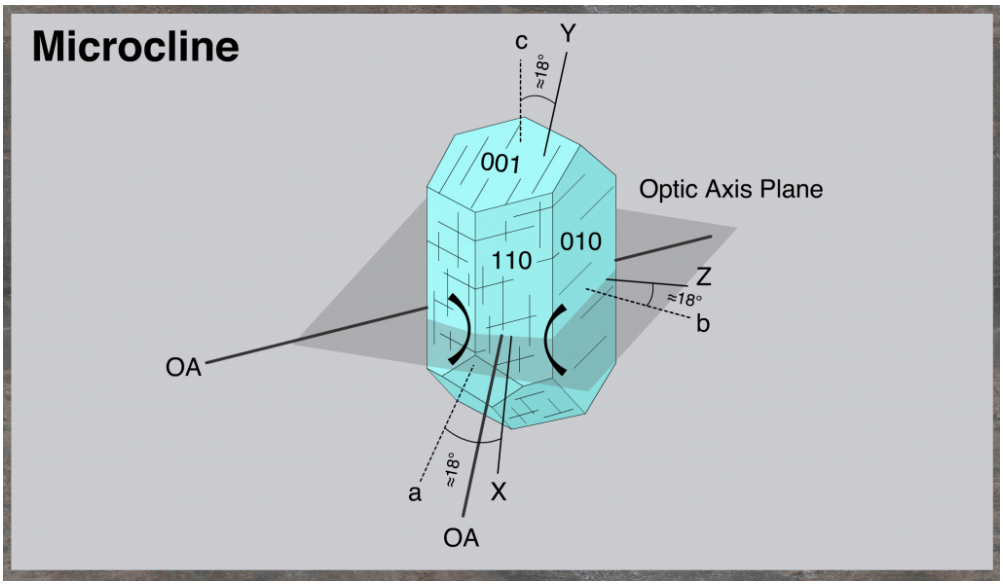
Anorthite



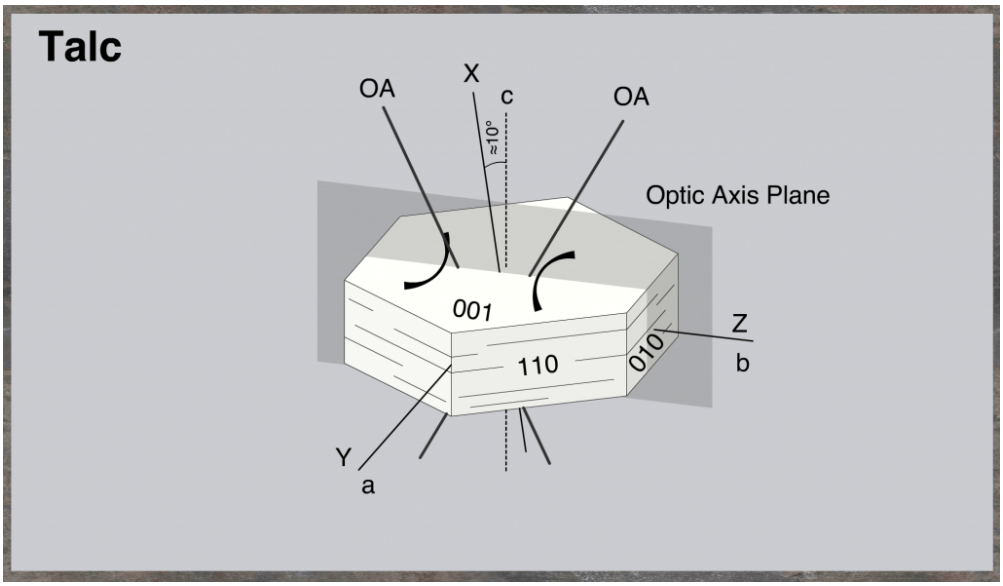

Anorthoclase
Y
c
20°
001
010
110
Optic Axis Plane
b
5°
Z
OA
OA
X
≈10°
a


High Sanidine
Z
c
≈20°
Optic Axis Plane
001
Y
b
010
OA
X
5°
a
110
OA

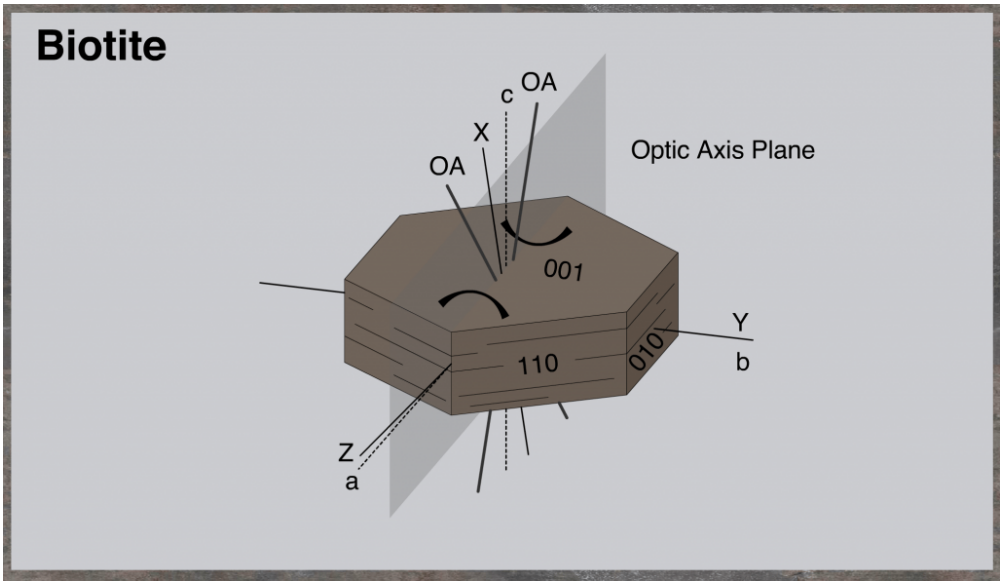

Orthoclase
c
Y
20°
010
001
Z
b
110
Optic Axis Plane
X
5°
a
OA
OA

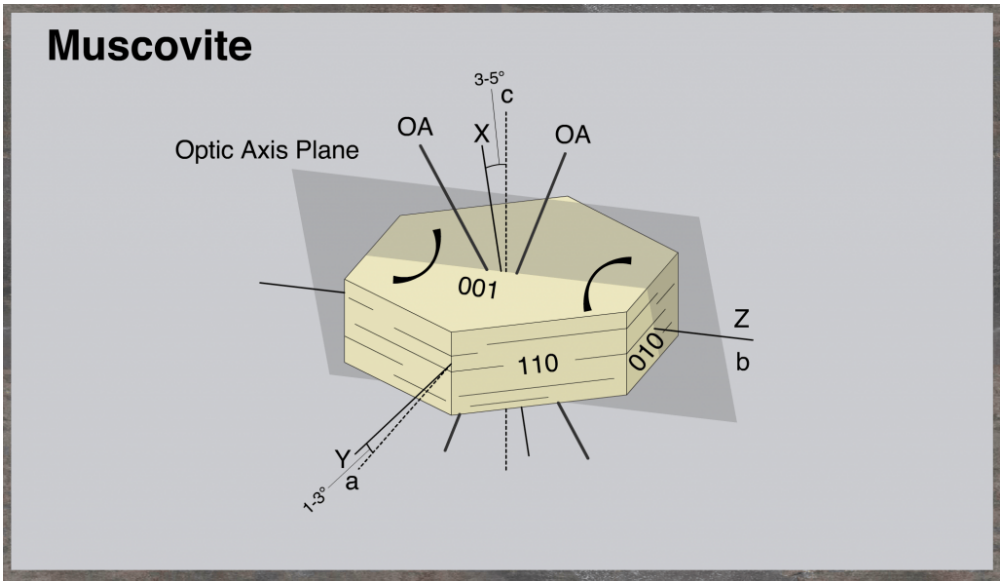

Microcline
c
Y
≈18°
001
Optic Axis Plane
110
010
Z
≈18°
b
OA
a
≈18°
X
OA

Talc

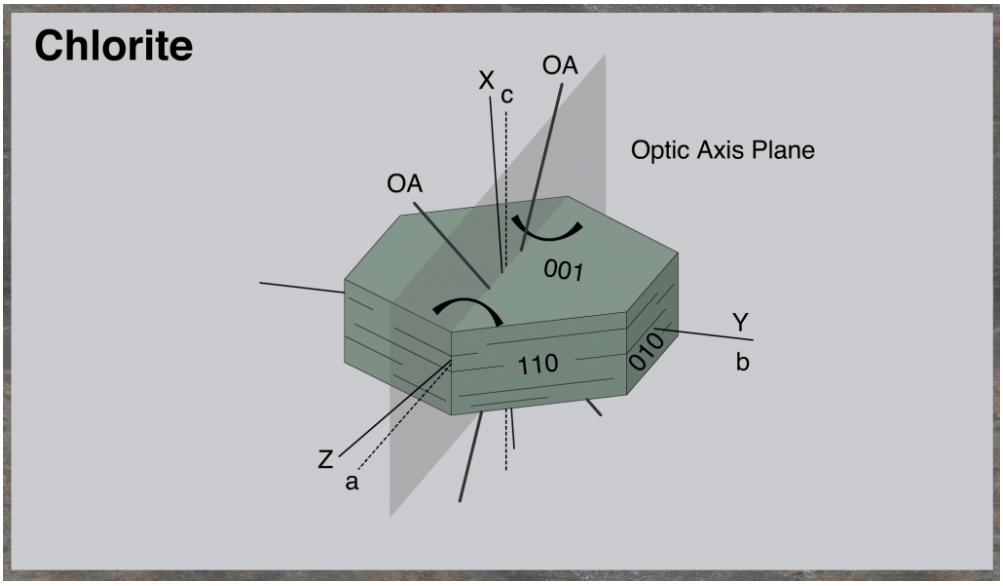

Talc
OA
X
c
OA
≈10°
Optic Axis Plane
001
110
010
Z
b
Y
a

Mica Group

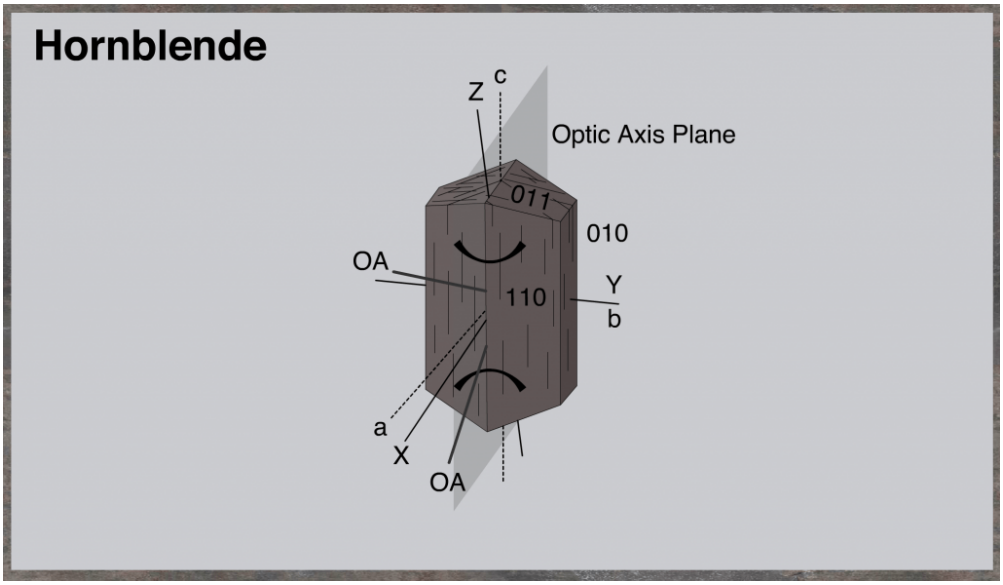

Biotite
c
OA
X
OA
Optic Axis Plane
001
Y
b
110
010
Z
a


Muscovite
3-5°
c
OA
X
OA
Optic Axis Plane
001
Z
b
110
010
Y
1-3°
a

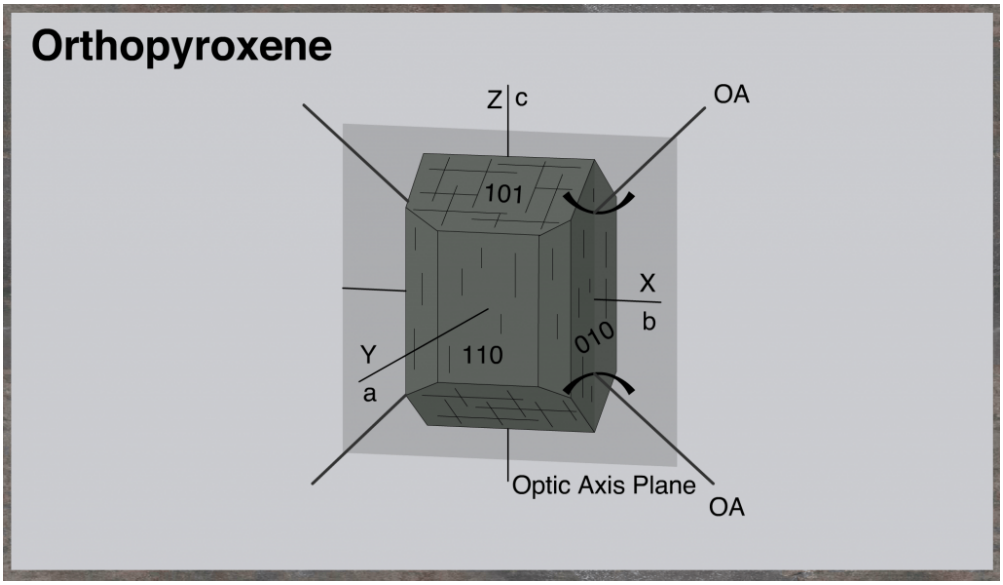
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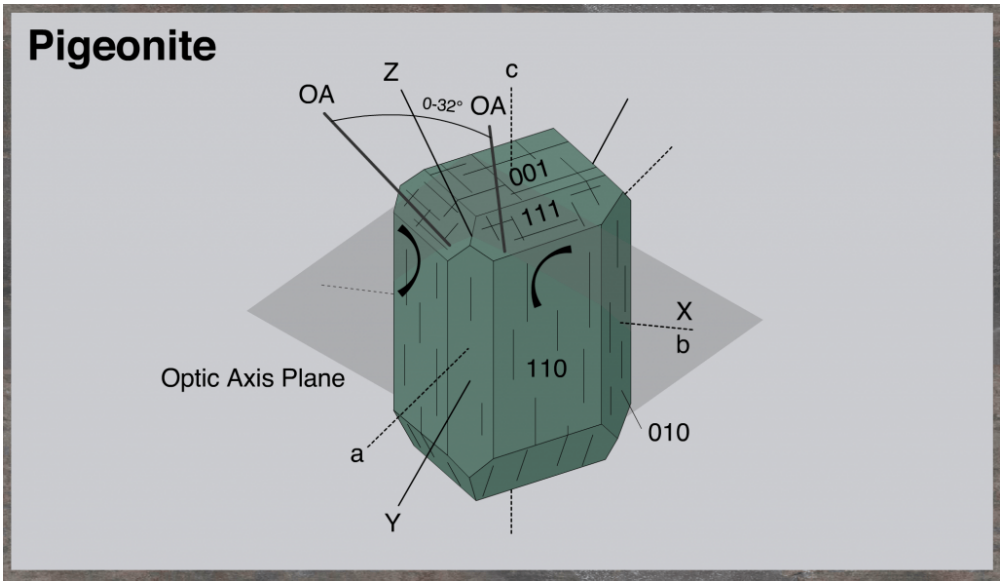


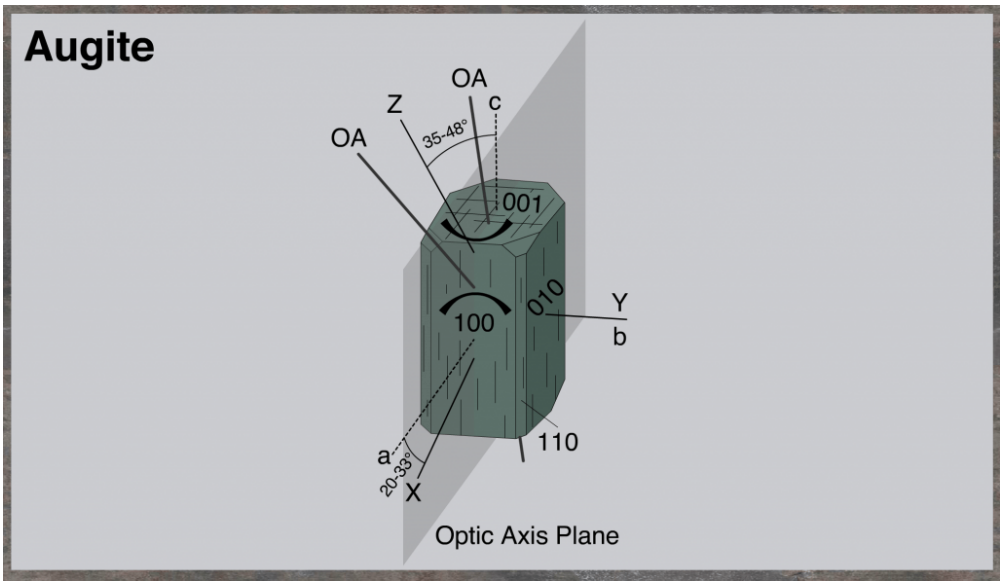
Amphibole Group

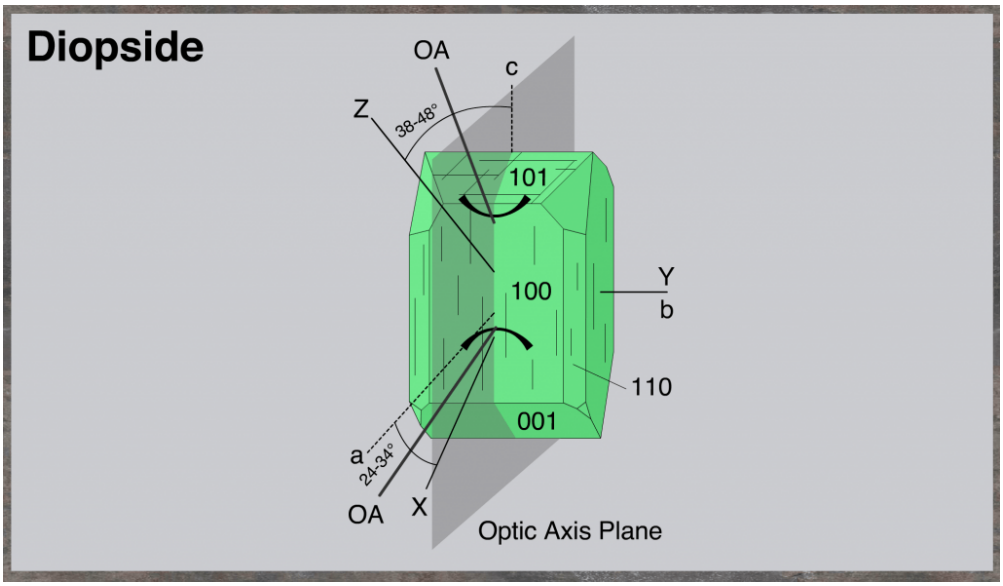


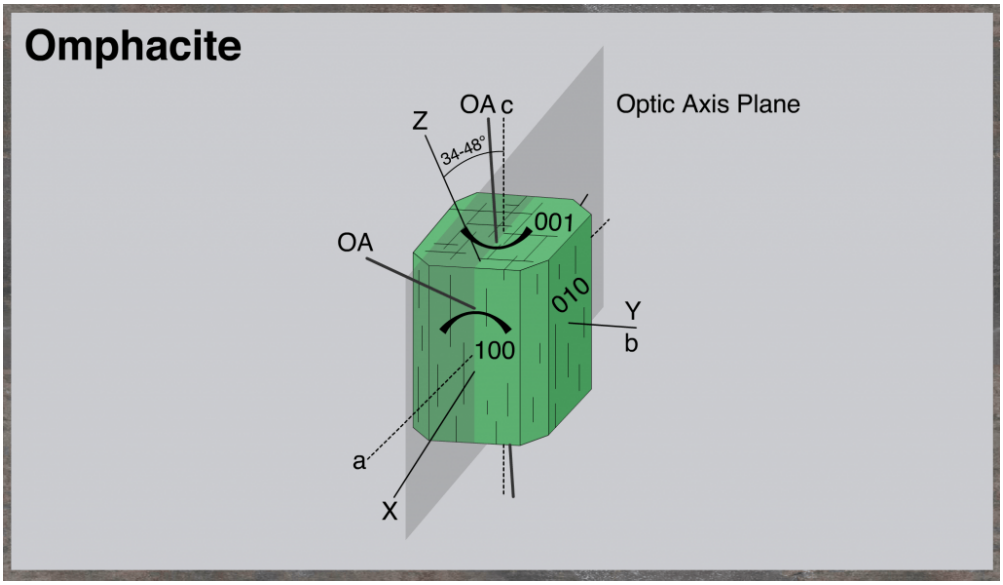
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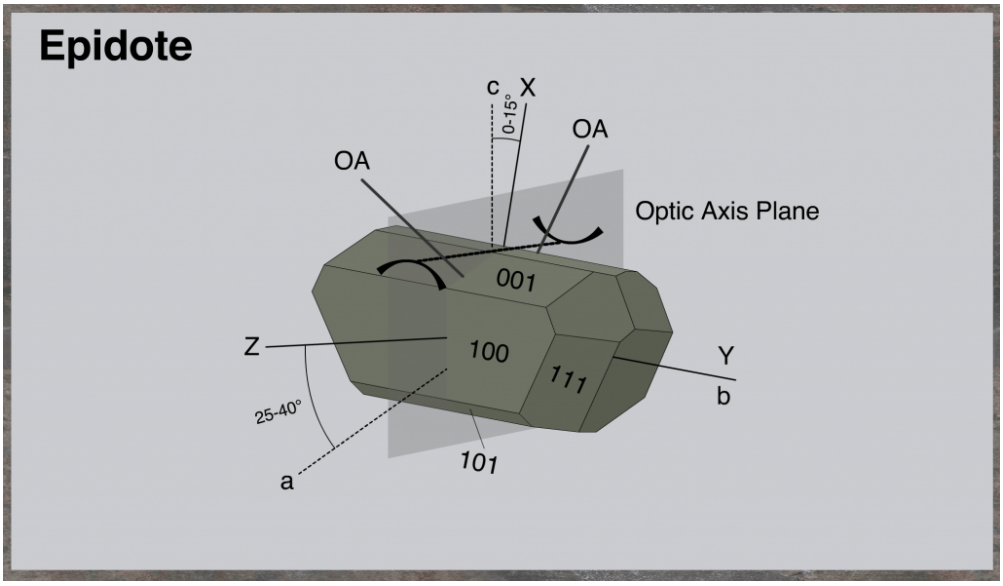



Augite
OA
Z
c
OA
35-48°
001
100
010
Y
b
110
a
20-33°
X
Optic Axis Plane

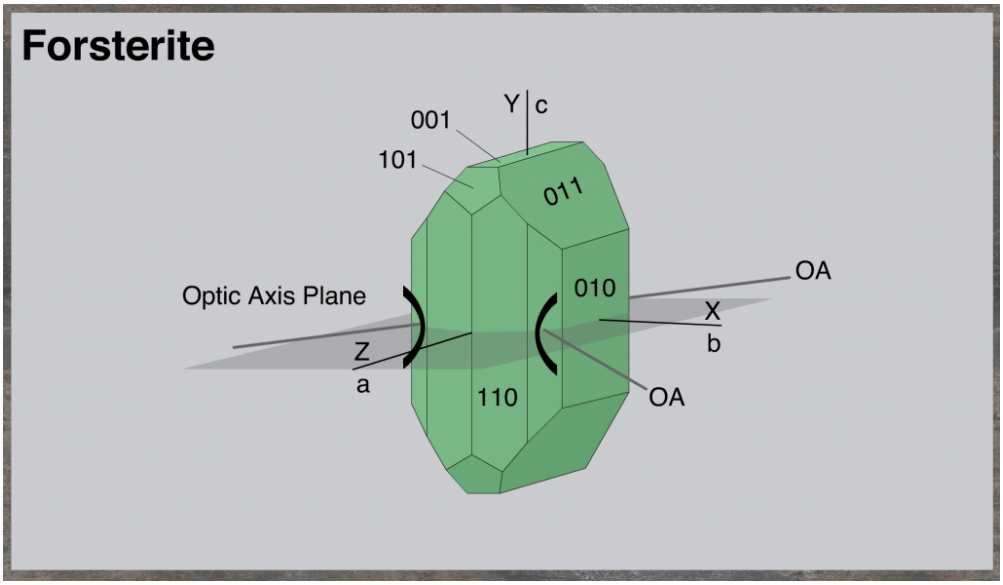

Diopside
OA
c
Z
38-48°
101
100
Y
b
110
001
a
24-34°
OA
X
Optic Axis Plane

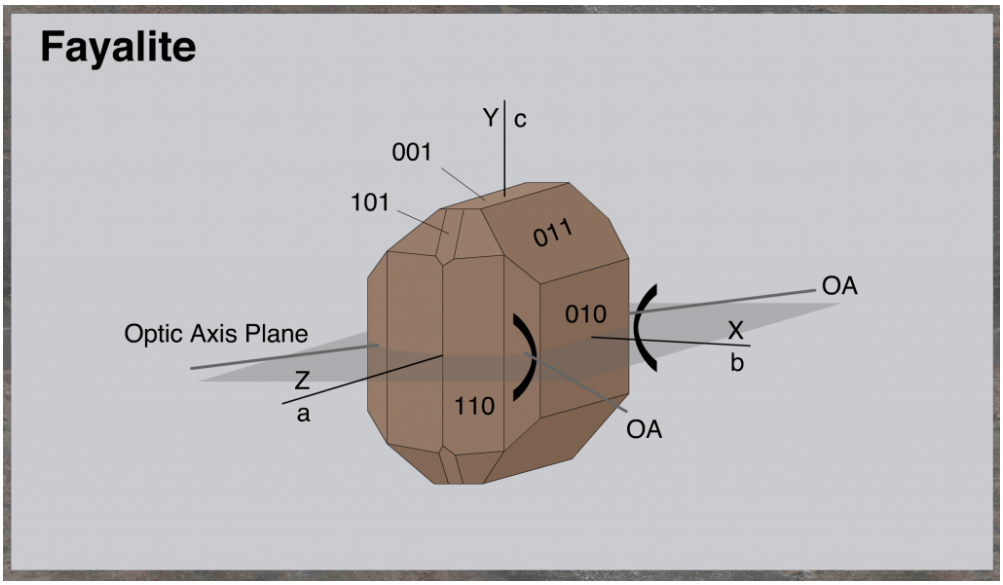

Omphacite
Optic Axis Plane
OA c
Z
34-48°
001
OA
010
Y
b
100
a
X

Epidote Group

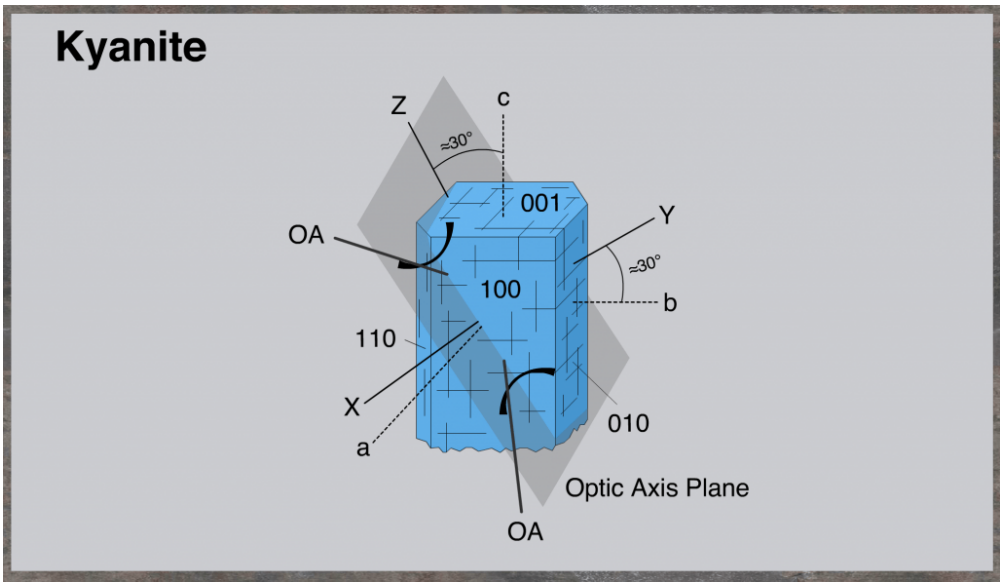


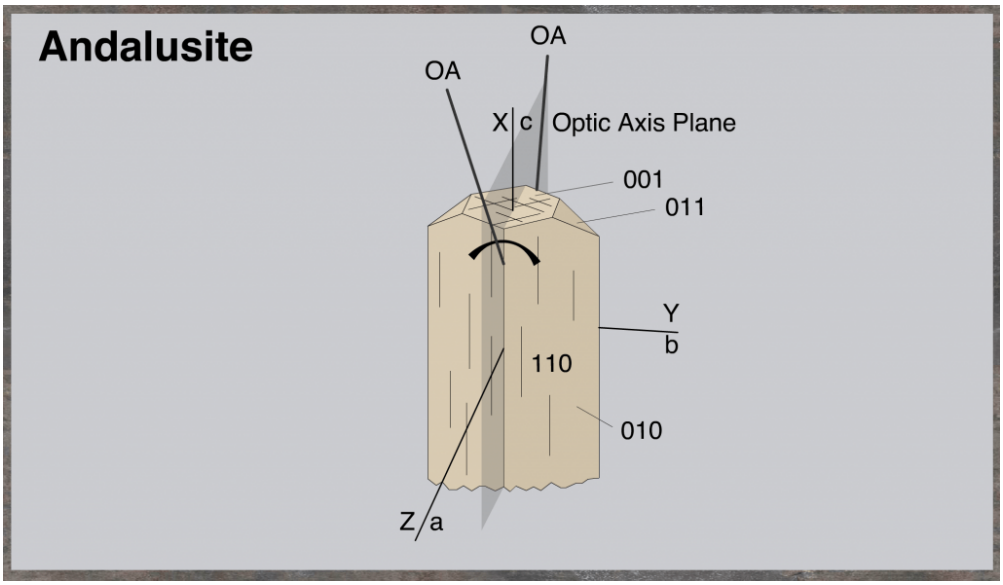
Olivine Group

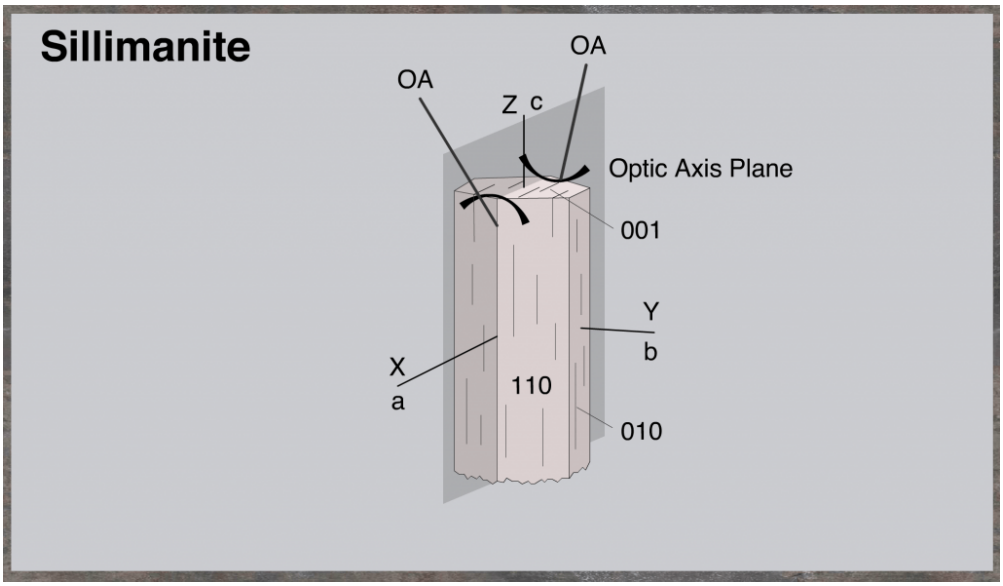




Aluminosilicates







References

Optical and crystallographic axes data for figures are taken from:

Deer, W.A., Howie, R.A., and Zussman, J. (1992) An Introduction to the Rock-Forming Minerals (2nd Edition). Prentice Hall. 712 p.

Nesse, W.D. (1991) Introduction to Optical Mineralogy. Oxford University Press, 335 p.

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3: INSTRUCTOR GUIDE

3.1: Chapter 1

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3.1: Chapter 1

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4: BUSHVELD IGNEOUS COMPLEX

4.1: BC/Bu 3 (Critical Zone)

4.2: BC/Bu 5 (Critical Zone)

4.3: BC/Bu 19 (Critical Zone)

4.4: BC/Bu 20 (Critical Zone)

4.5: BC/Bu 18 (Basal Zone)

4.6: Geologic Map and Stratigraphy

4.7: BC/Bu 28 (Rashoop Granophyre)

4.8: BC/Bu 7 (Upper Zone)

4.9: BC/Bu 25 (Upper Zone)

4.10: BC/Bu 31 (Upper Zone)

4.11: BC/Bu 32 (Upper Zone)

4.12: UG2 (Platinum Ore Layer)

4.13: BC/Bu 10 (Merensky Reef)

4.14: BC/Bu 1 (Critical Zone)

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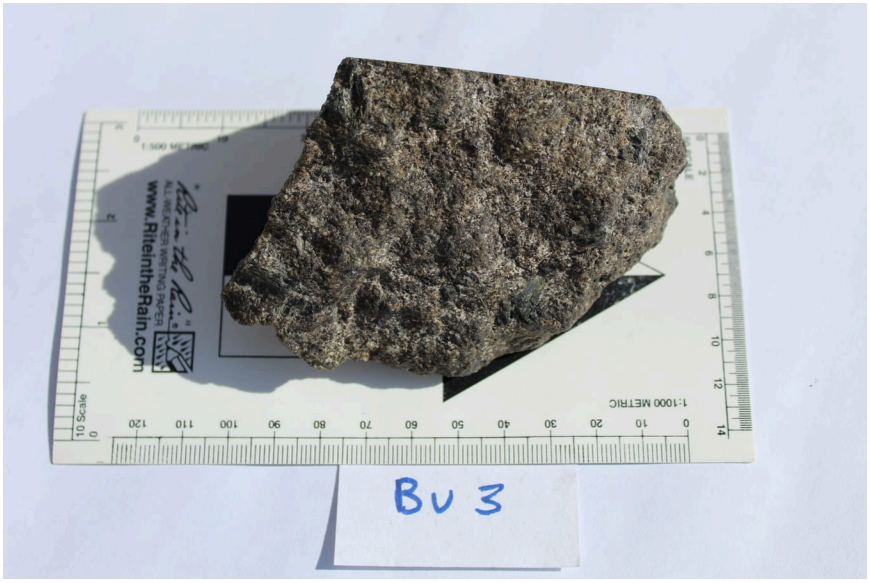
4.1: BC/Bu 3 (Critical Zone)

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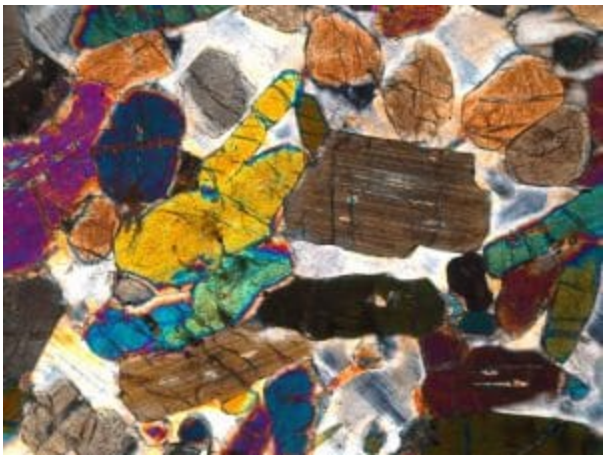
THIN SECTION IMAGES AND VIDEOS

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Please note: this thin section is a bit thick. Plagioclase has first-order yellow colors in some images.

Spot 1



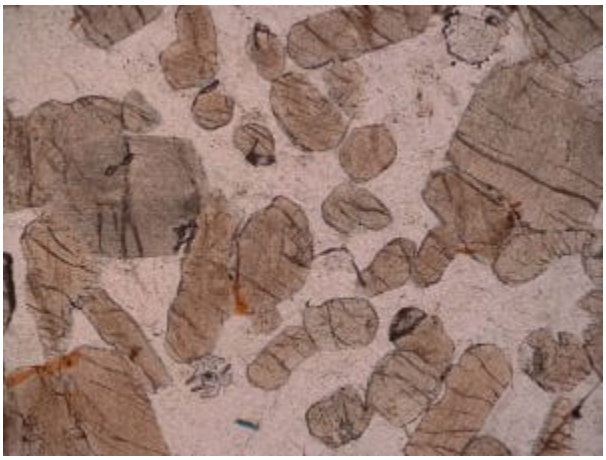


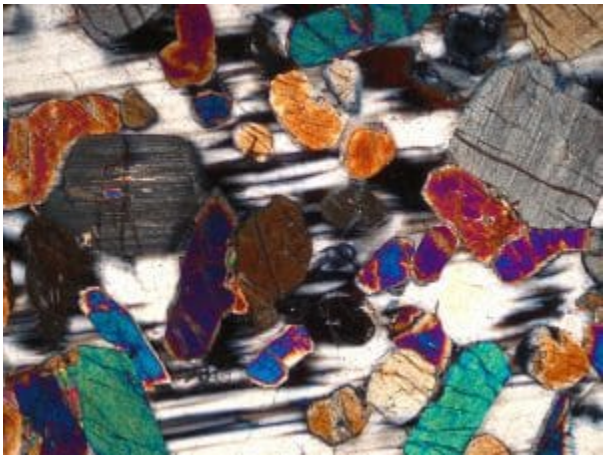
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Spot 2





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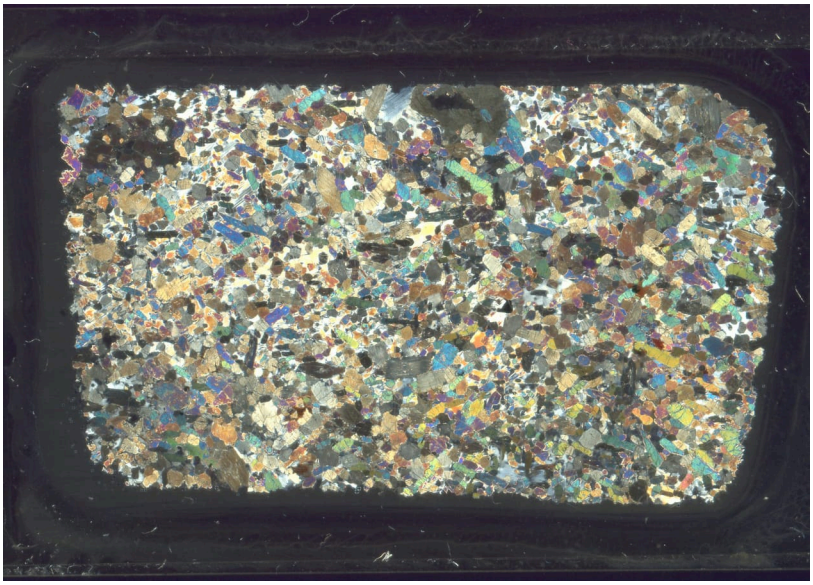
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THIN SECTION SCANS

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Query 4.1.1

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4.2: BC/Bu 5 (Critical Zone)

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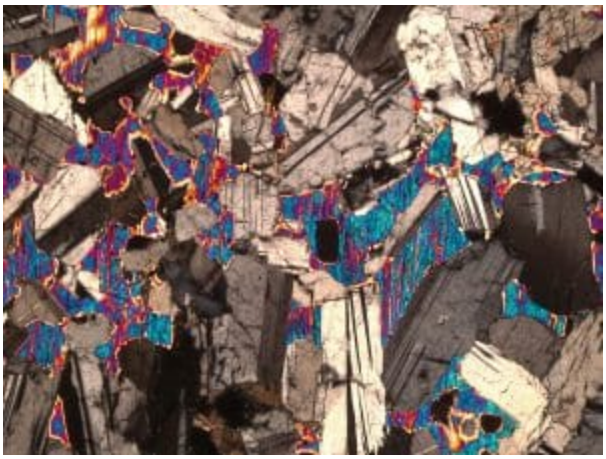
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Spot 1



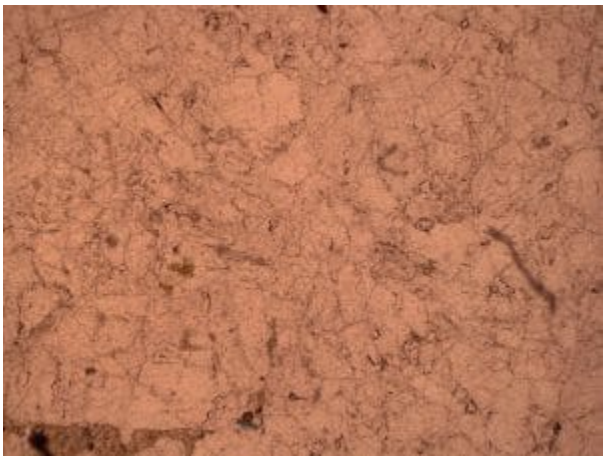


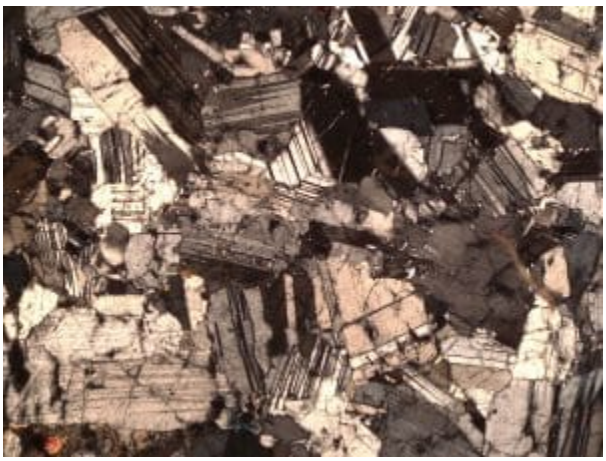
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Spot 2





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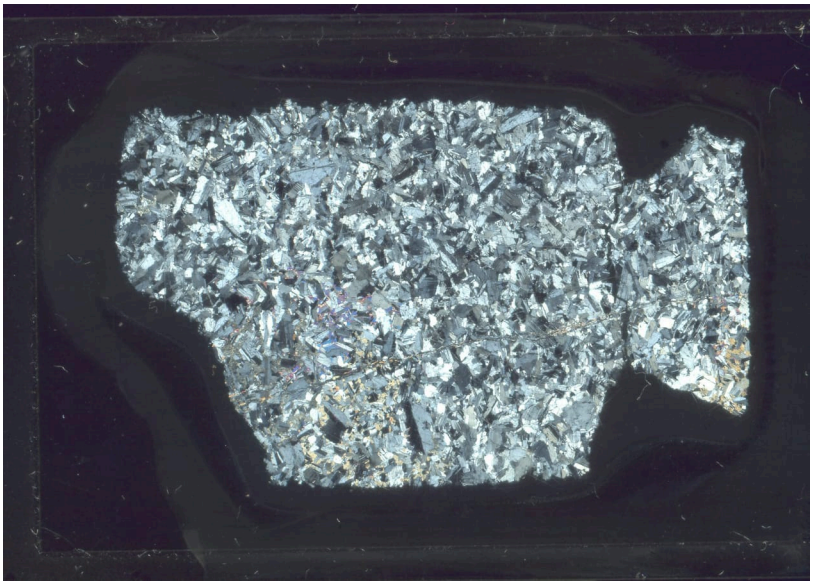
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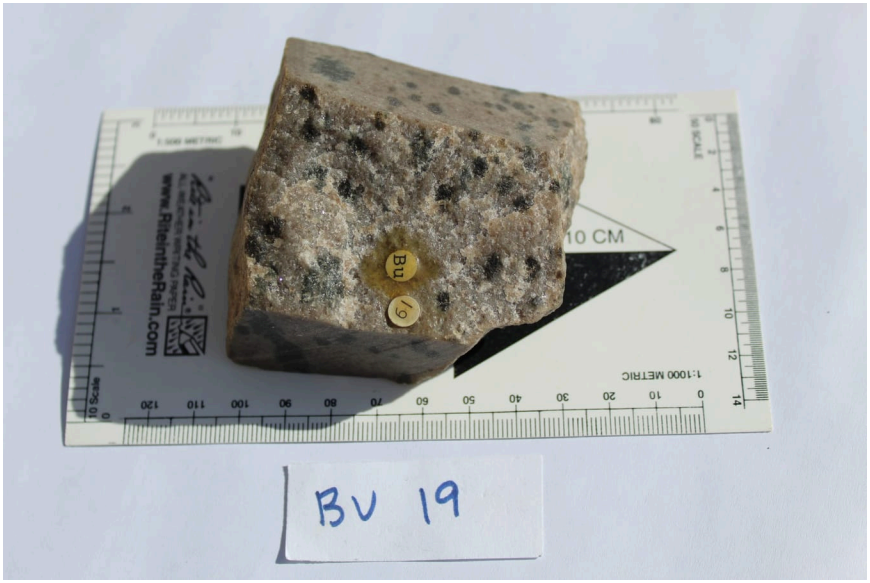
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4.3: BC/Bu 19 (Critical Zone)

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Spot 1



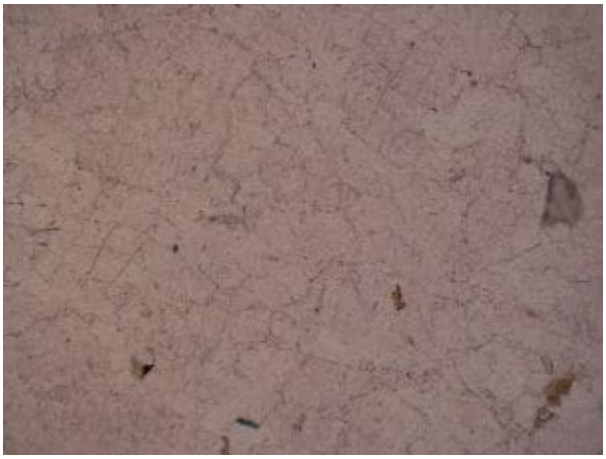


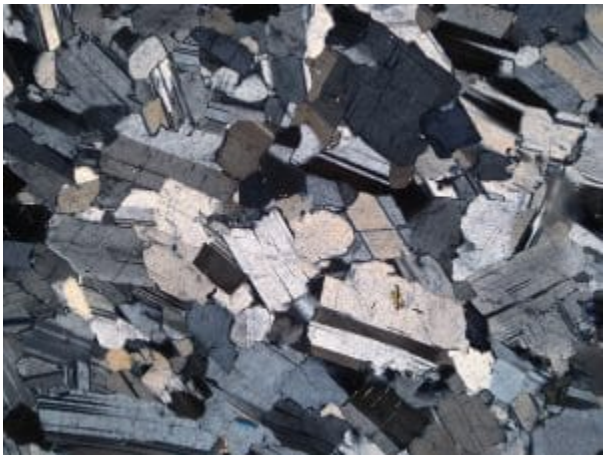
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Spot 2





YouTube Video

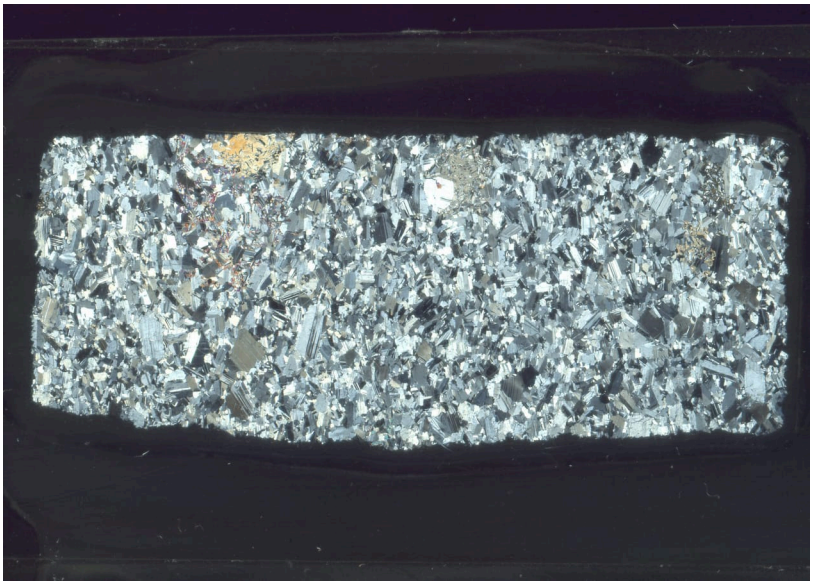
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Top image = plane polarized light. Second image = cross polarized light. Third image = juxtaposition of ppl and xpl. Thin section is 2.54 cm wide (distance from top to bottom of image).





Query 4.3.1

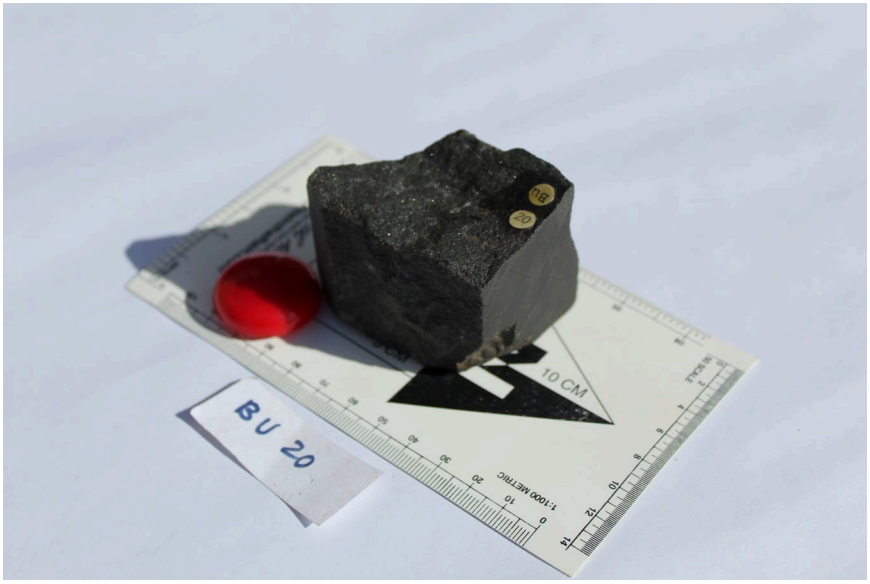
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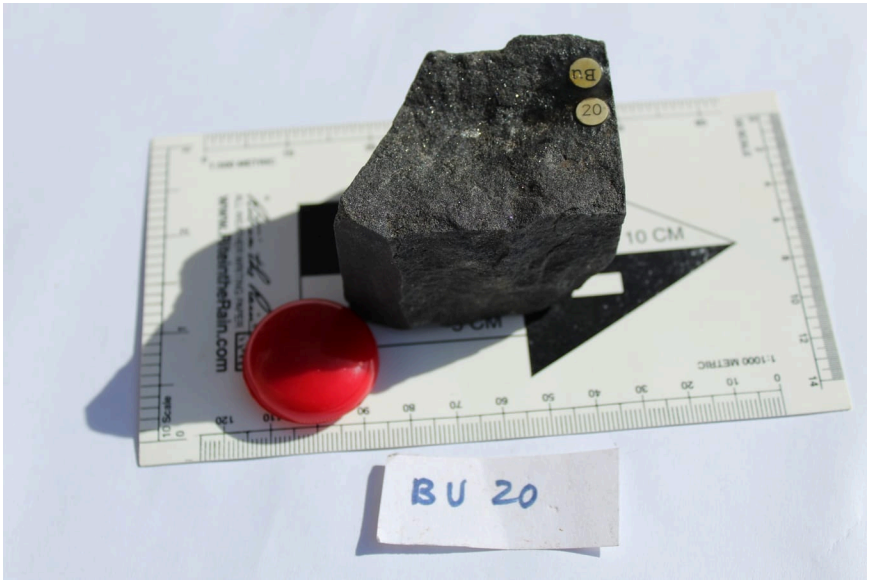
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4.4: BC/Bu 20 (Critical Zone)

HAND SAMPLE IMAGES AND VIDEOS





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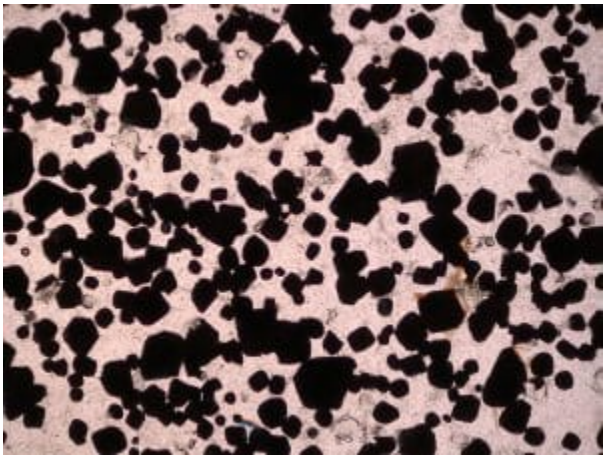
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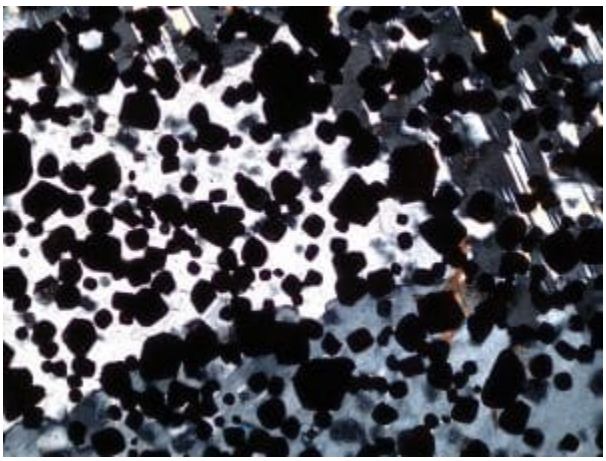
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THIN SECTION IMAGES AND VIDEOS

Images were obtained using a 4x objective (40x total magnification). 1st image = PPL. 2nd image = XPL.

Spot 1



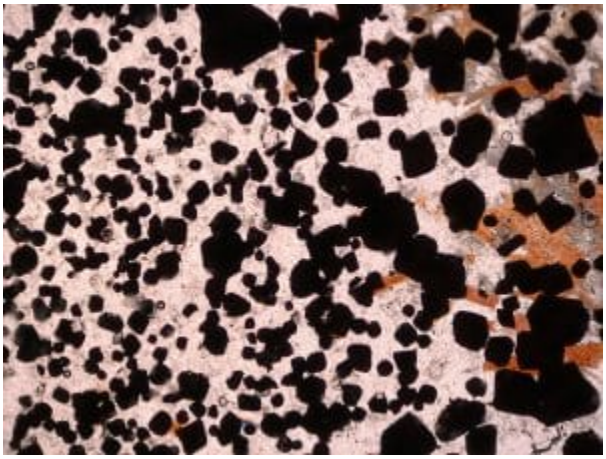


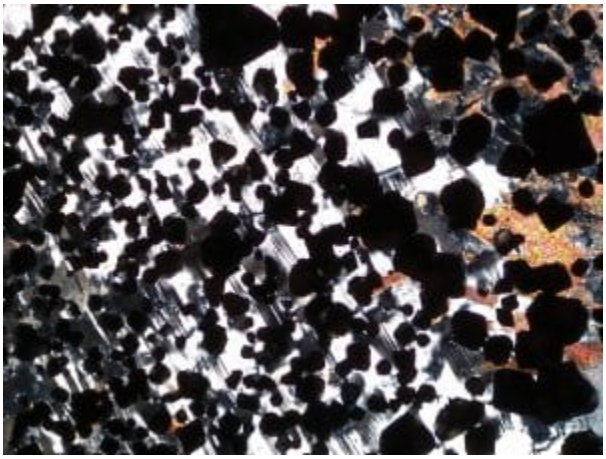
YouTube Video

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Spot 2





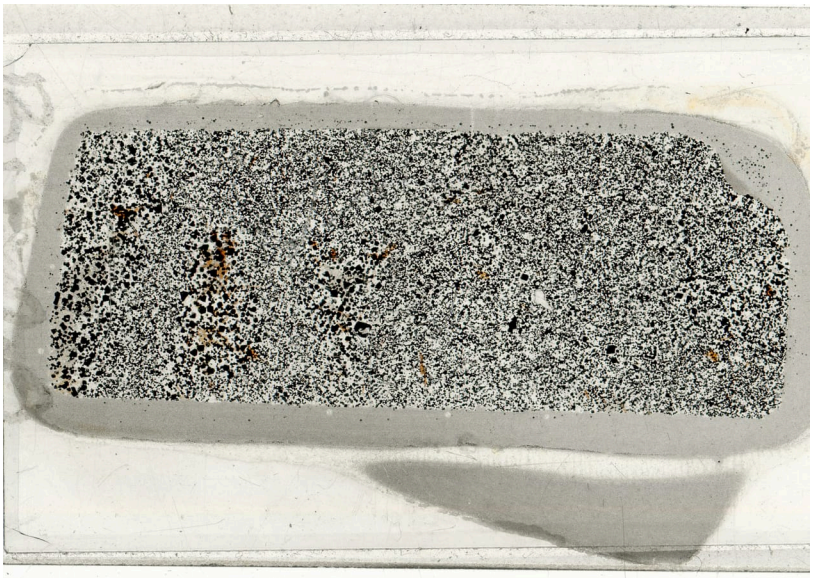
YouTube Video

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THIN SECTION SCANS

Top image = plane polarized light. Second image = cross polarized light. Third image = juxtaposition of ppl and xpl. Thin section is 2.54 cm wide (distance from top to bottom of image).





Query 4.4.1

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4.5: BC/Bu 18 (Basal Zone)

HAND SAMPLE IMAGES AND VIDEOS

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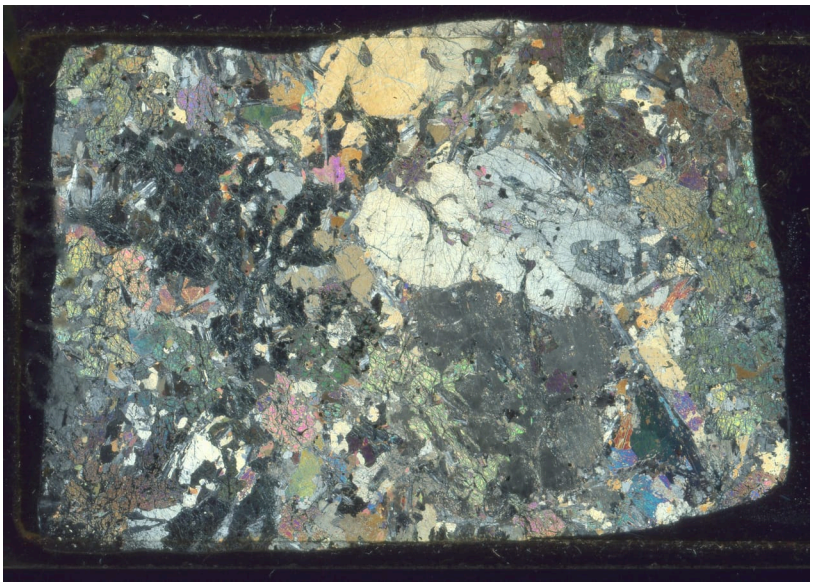
THIN SECTION IMAGES AND VIDEOS

None available. I forgot to bring it home to scan!

THIN SECTION SCANS

Click on the image to bring up a larger version. Top image = plane polarized light. Second image = cross polarized light. Third image = juxtaposition of ppl and xpl. Thin section is 2.54 cm wide (distance from top to bottom of image).





Query 4.5.1

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4.6: Geologic Map and Stratigraphy

Geologic Map

Figure 1 shows the sample locations for this lab. Figure 1 is an excerpt from the Bushveld Igneous Complex Map (Figure 2).

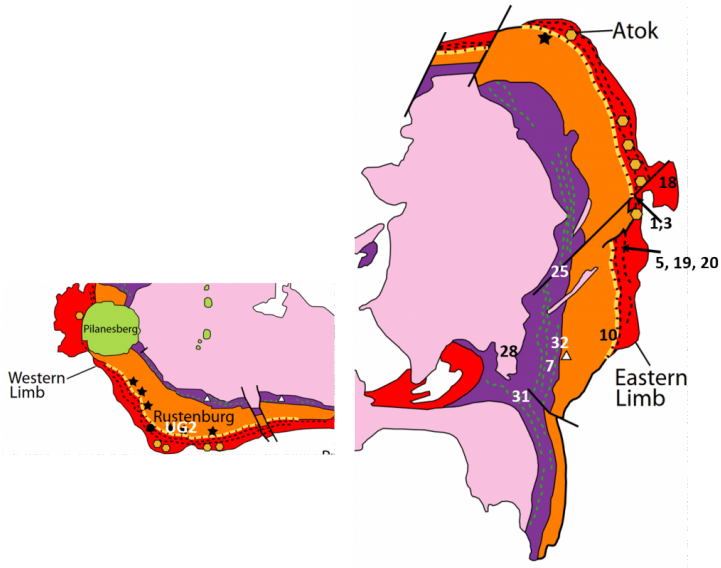


Figure 1. Sample locations for this study. See Figure 2 for the complete Bushveld Igneous Complex map with legend.

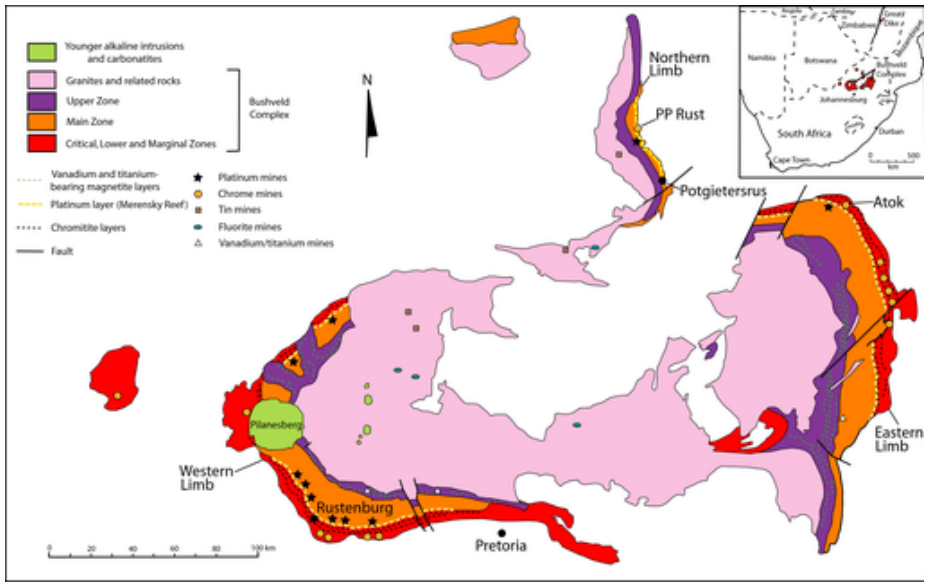


Figure 2. Bushveld Igenous Complex. Click on the image to link to the full size map.

By Taylor, C.D., Schulz, K.J., Doebrich, J.L., Orris, G.J., Denning, P.D., and Kirschbaum, M.J. – Geology and nonfuel mineral deposits of Africa and the Middle East, USGS Open-File Report 2005-1294-E, Public Domain, Link

Stratigraphy

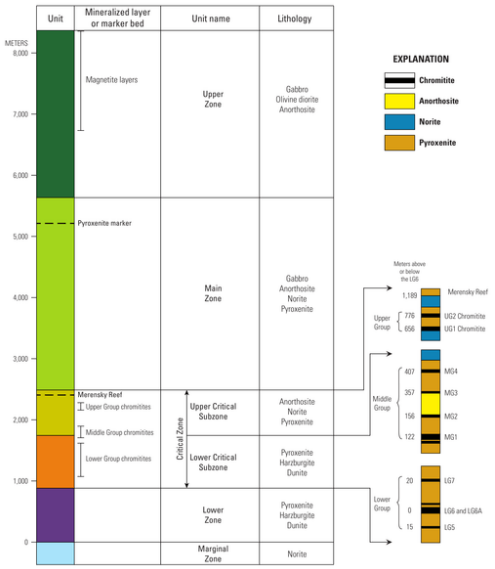


Figure 3. Stratigraphy of the Bushveld Igneous Complex.

Michael L. Zientek, J. Douglas Causey, Heather L. Parks, and Robert J. Miller / Public domain, Link

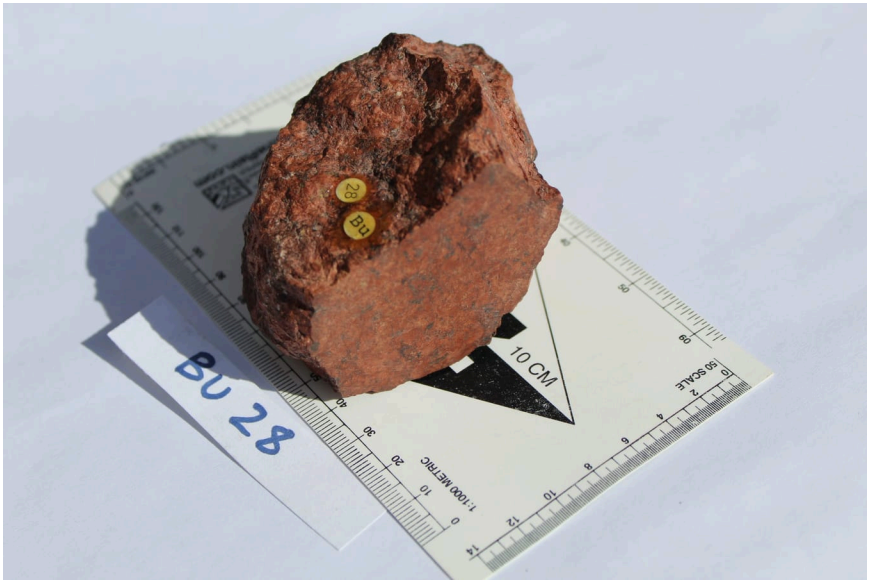
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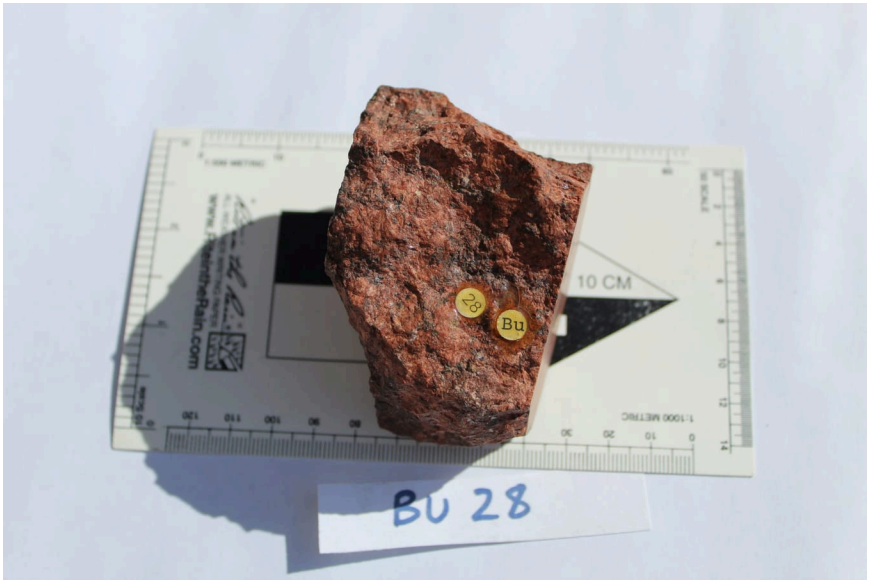
https://en.Wikipedia.org/wiki/Bushveld_Igneous_Complex

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4.7: BC/Bu 28 (Rashoop Granophyre)

Hand Sample Images and Videos





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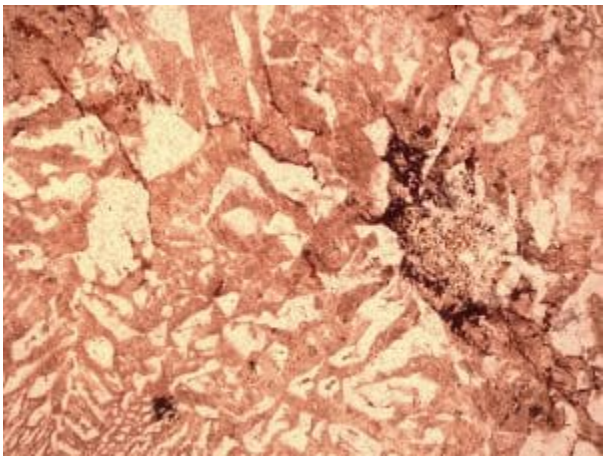
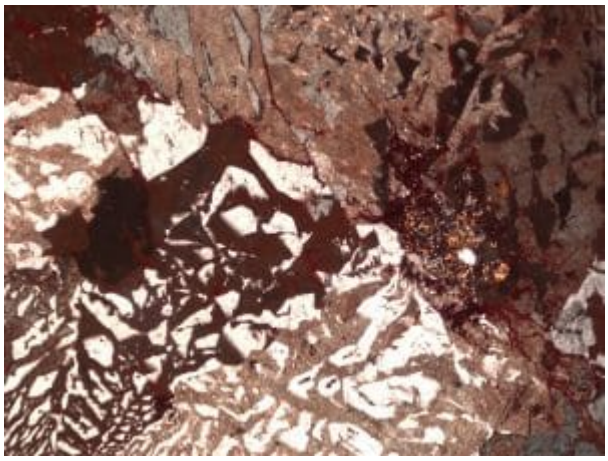
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Thin Section images and Videos

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Spot 1

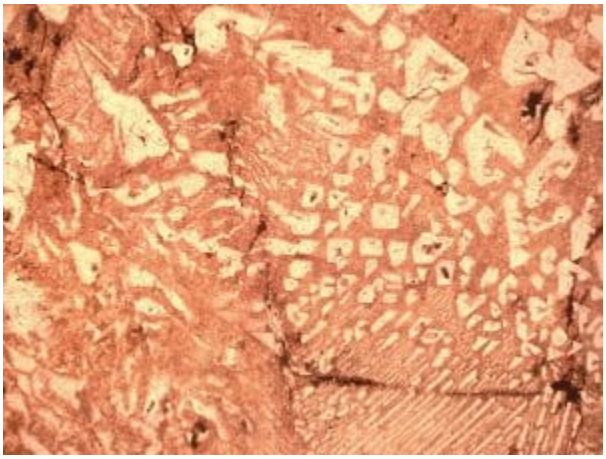



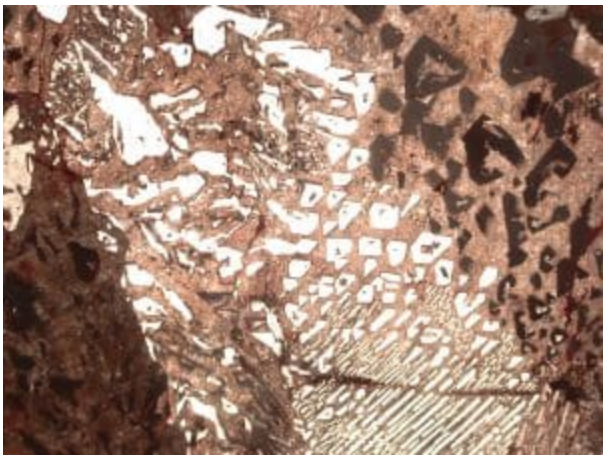
YouTube Video

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Spot 2





YouTube Video

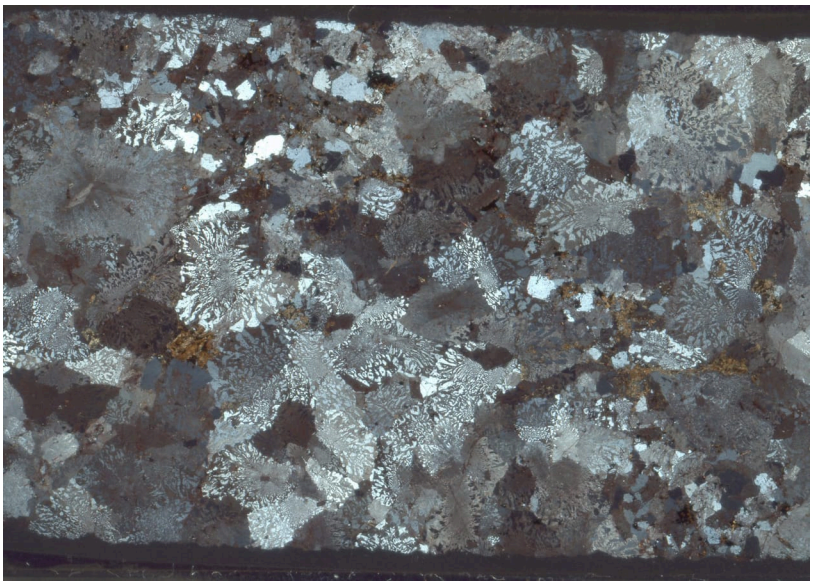
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Thin Section Scans

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Query 4.7.1

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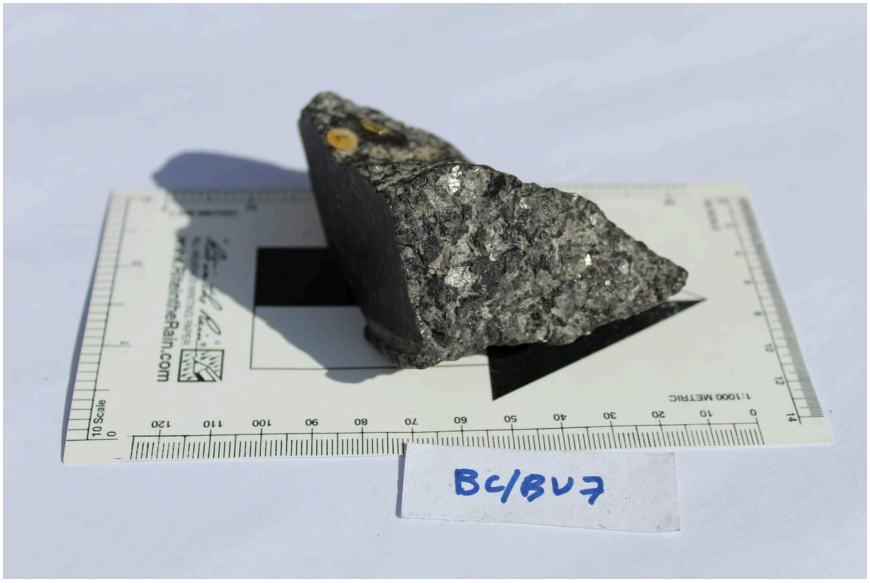
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4.8: BC/Bu 7 (Upper Zone)

HAND SAMPLE IMAGES AND VIDEOS







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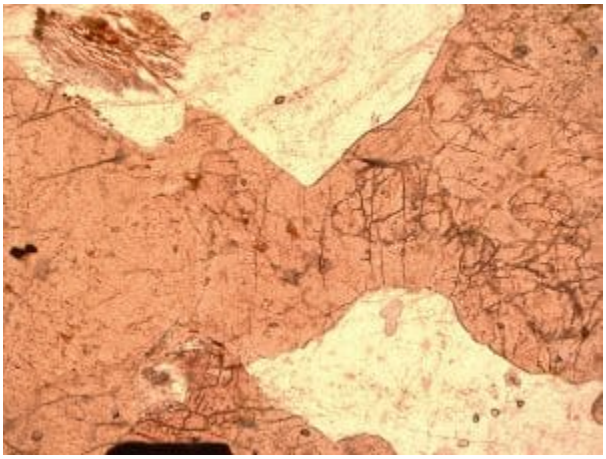
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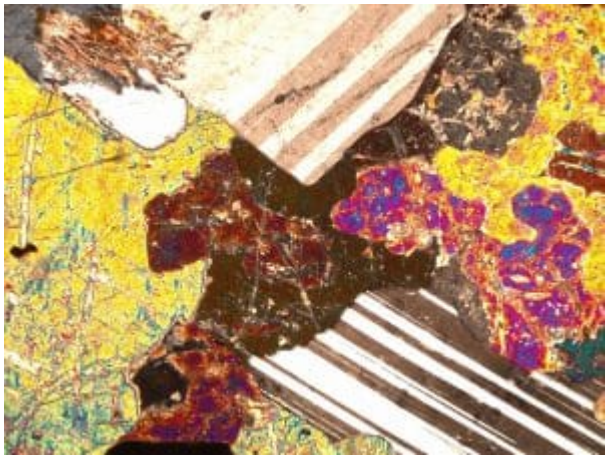
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THIN SECTION IMAGES AND VIDEOS

Images were obtained using a 4x objective (40x total magnification). 1st image = PPL. 2nd image = XPL.

Spot 1



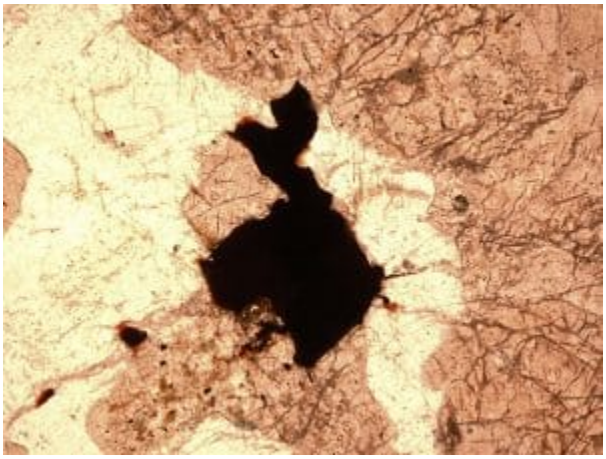


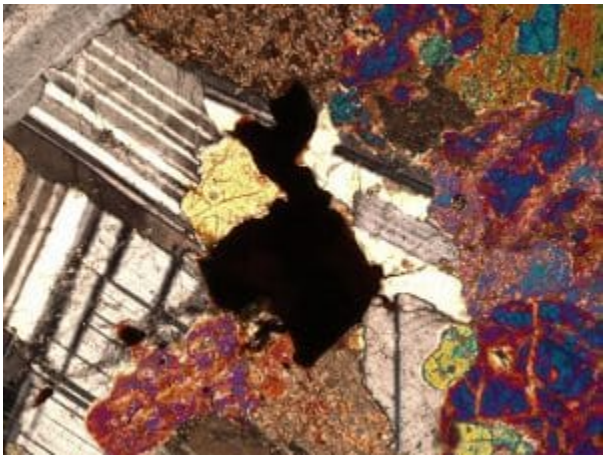
YouTube Video

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Spot 2





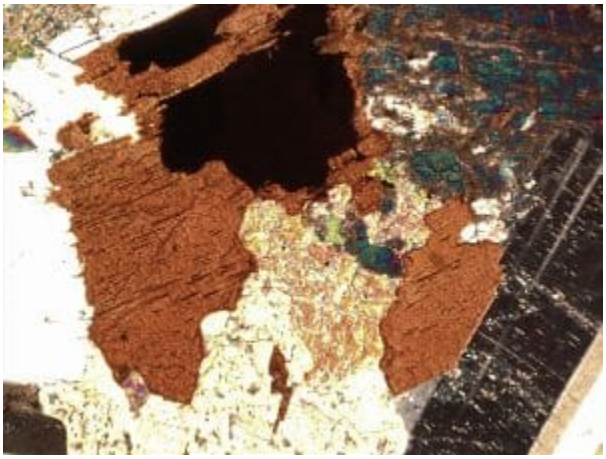
YouTube Video

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Spot 3





YouTube Video

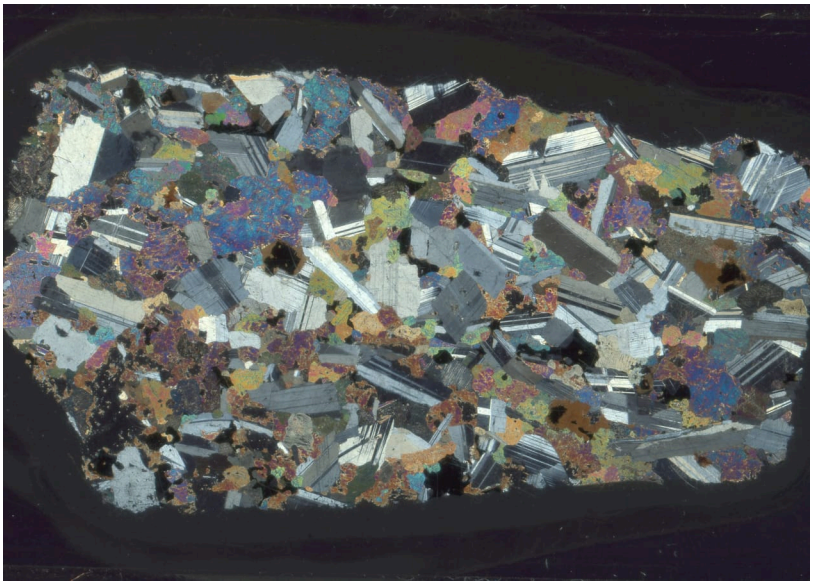
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THIN SECTION SCANS

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Query 4.8.1

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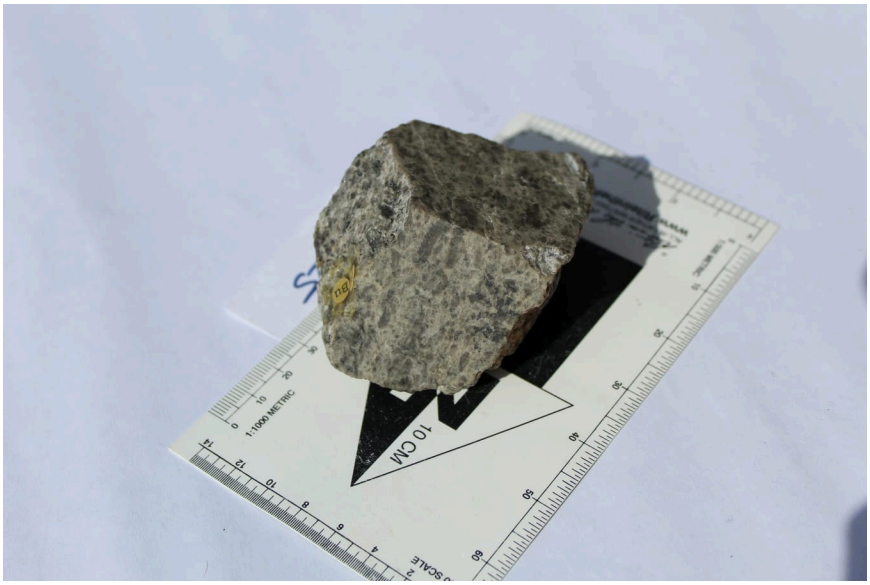
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4.9: BC/Bu 25 (Upper Zone)

HAND SAMPLE IMAGES AND VIDEOS





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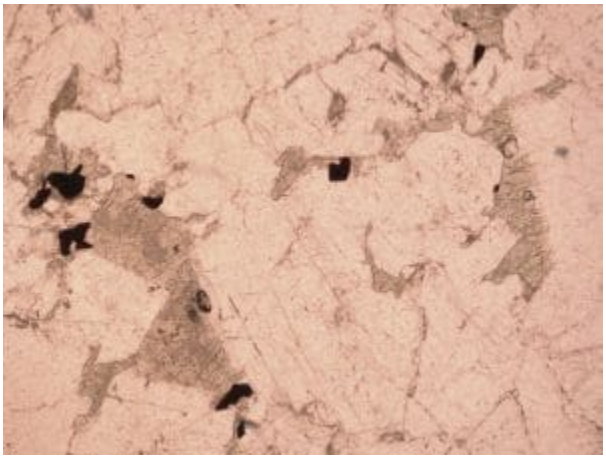
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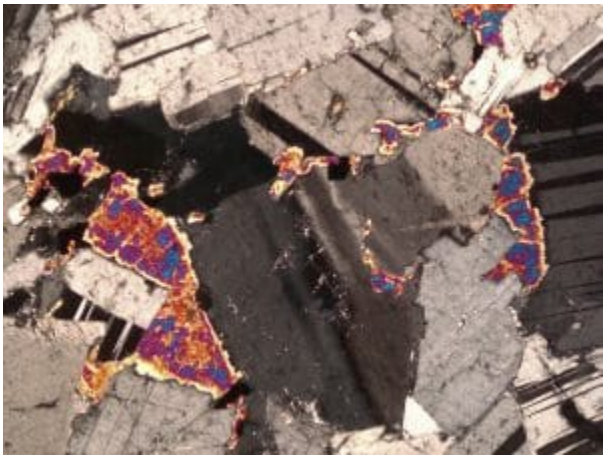
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THIN SECTION IMAGES AND VIDEOS

Images were obtained using a 4x objective (40x total magnification). 1st image = PPL. 2nd image = XPL.

Spot 1



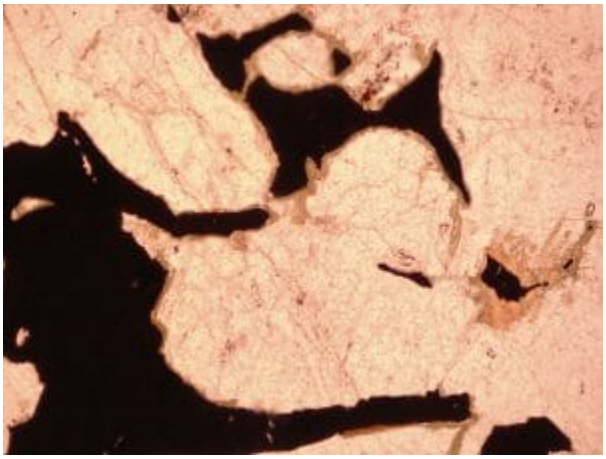


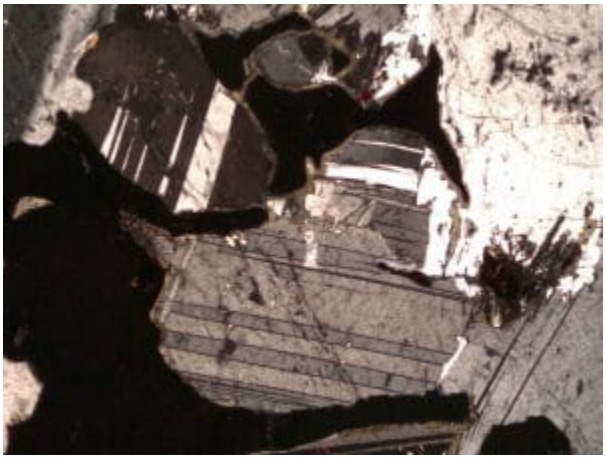
YouTube Video

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Spot 2



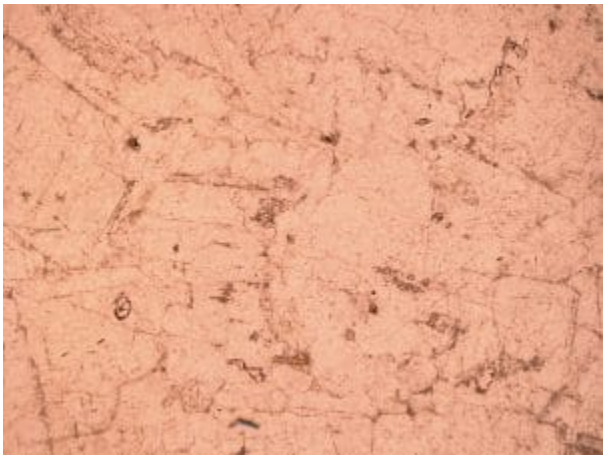


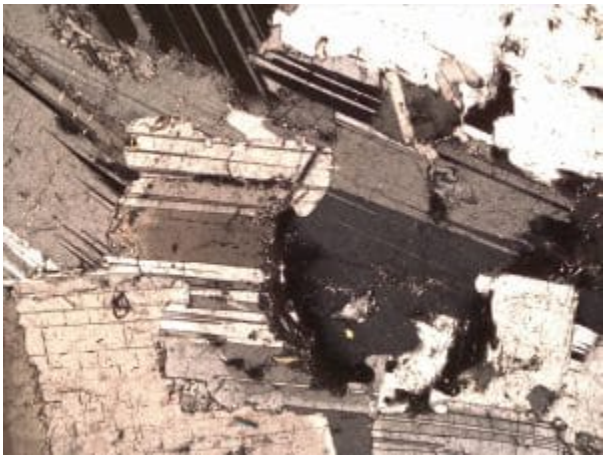
YouTube Video

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Spot 3





YouTube Video

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THIN SECTION SCANS

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Query 4.9.1

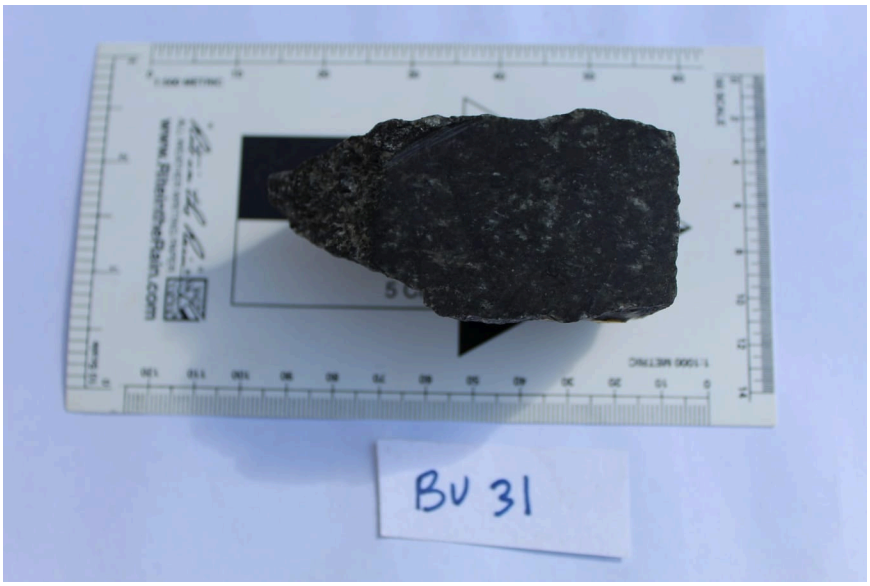
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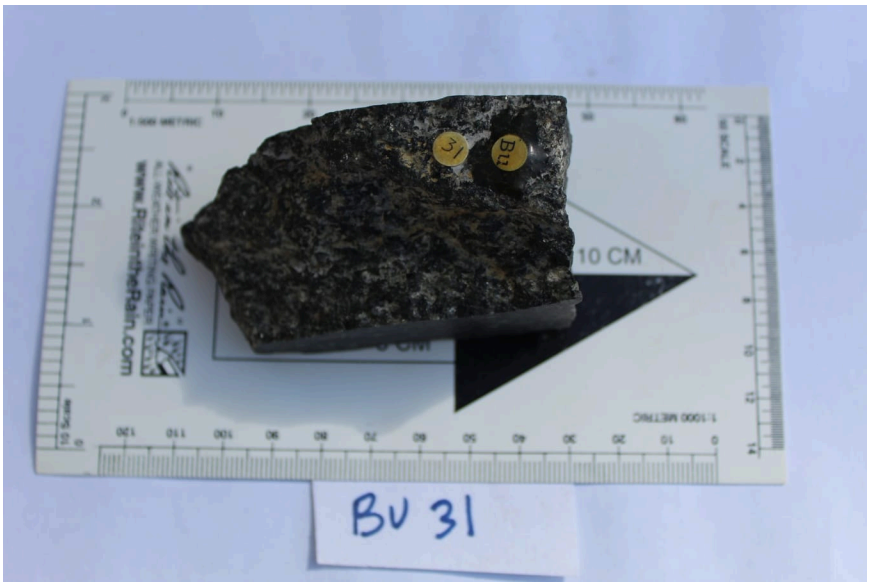
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4.10: BC/Bu 31 (Upper Zone)

HAND SAMPLE IMAGES AND VIDEOS





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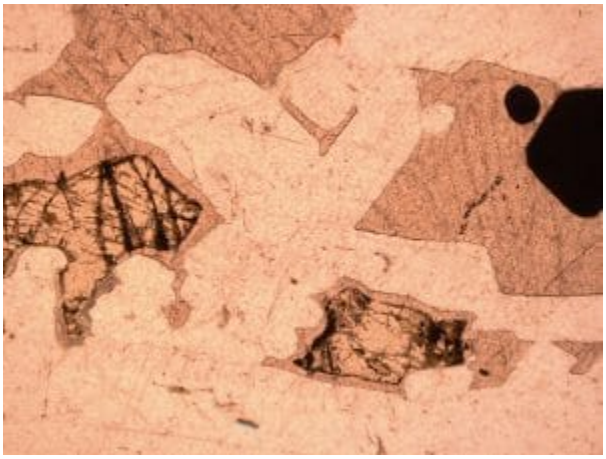
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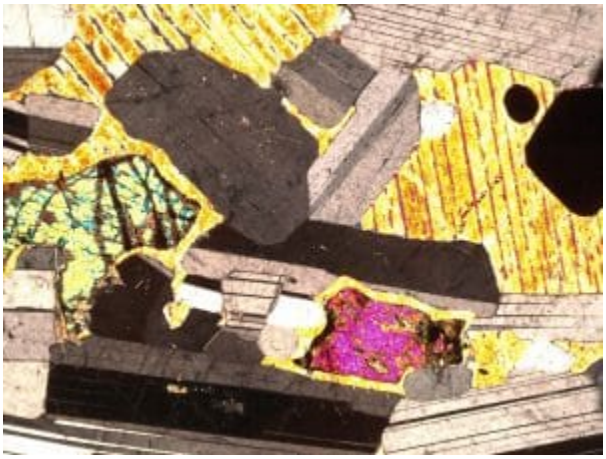
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THIN SECTION IMAGES AND VIDEOS

Images were obtained using a 4x objective (40x total magnification). 1st image = PPL. 2nd image = XPL.

Spot 1



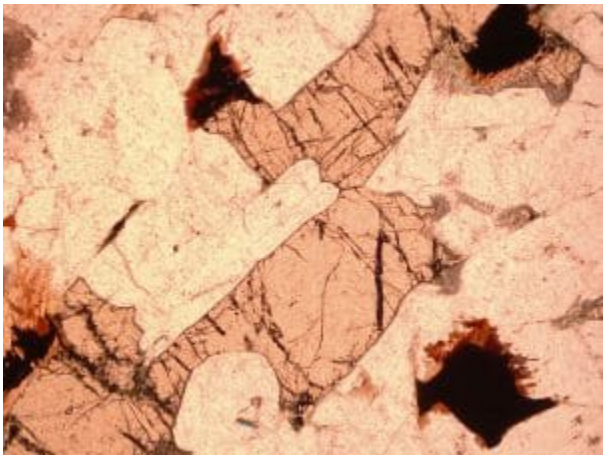


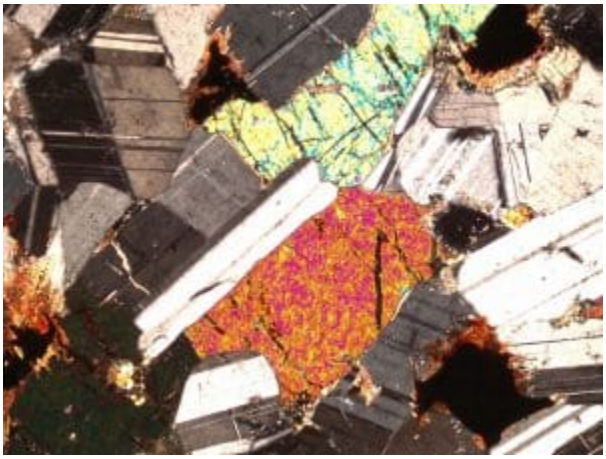
YouTube Video

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Spot 2



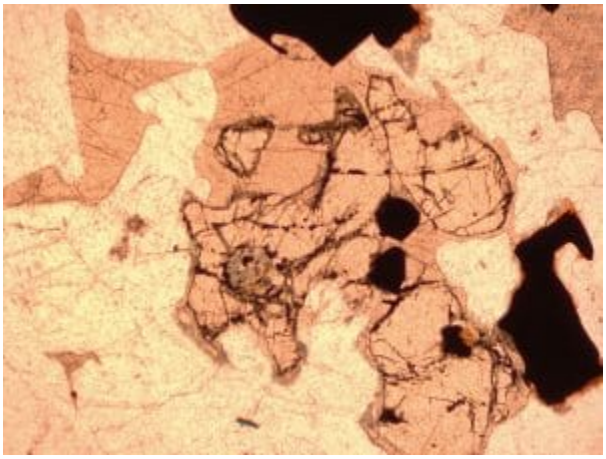


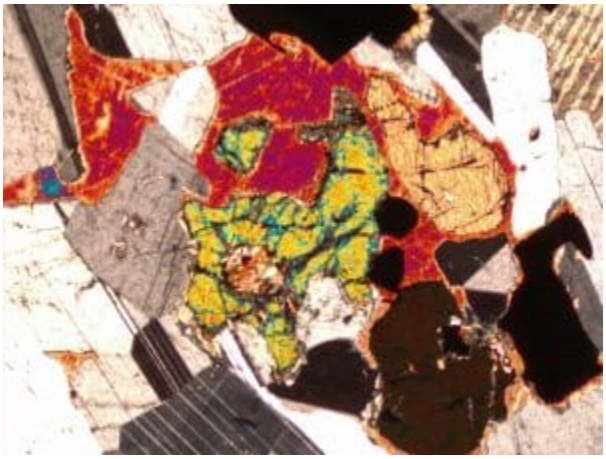
YouTube Video

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Spot 3





YouTube Video

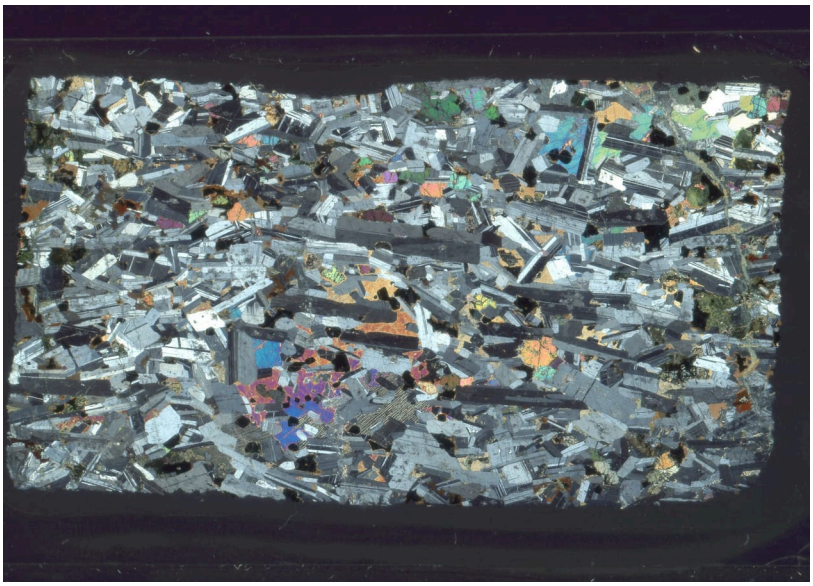
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THIN SECTION SCANS

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Query 4.10.1

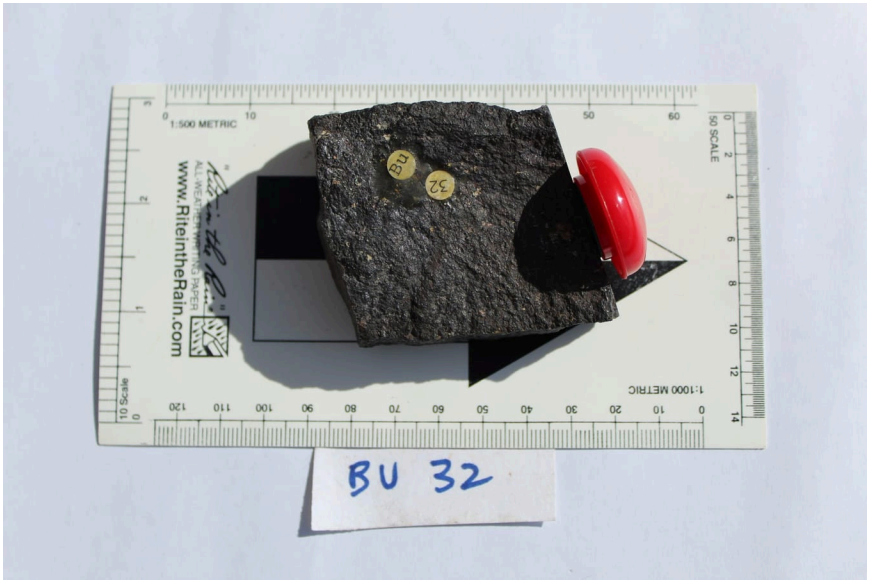
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4.11: BC/Bu 32 (Upper Zone)

HAND SAMPLE IMAGES AND VIDEOS



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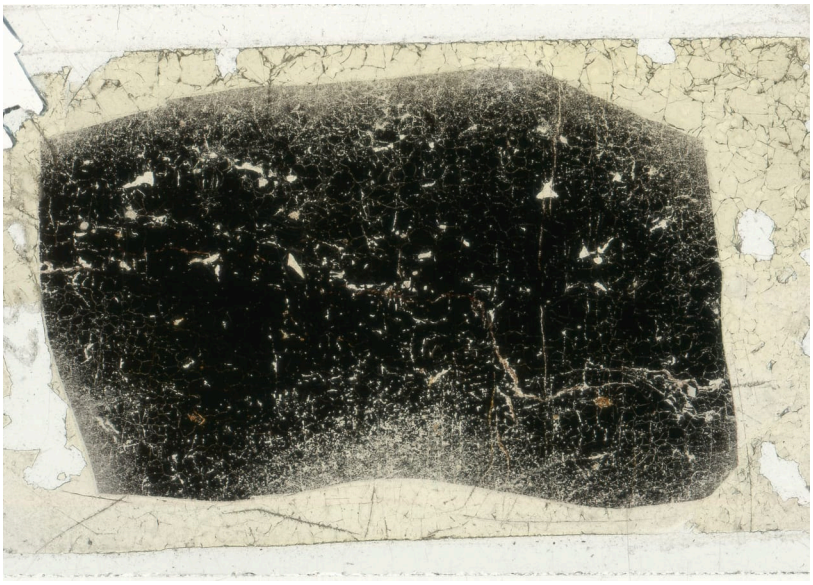
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THIN SECTION IMAGES AND VIDEOS

No thin section images for this one. See the scan below.

THIN SECTION SCANS

Top image = plane polarized light. Thin section is 2.54 cm wide (distance from top to bottom of image).



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4.12: UG2 (Platinum Ore Layer)

HAND SAMPLE IMAGES AND VIDEOS

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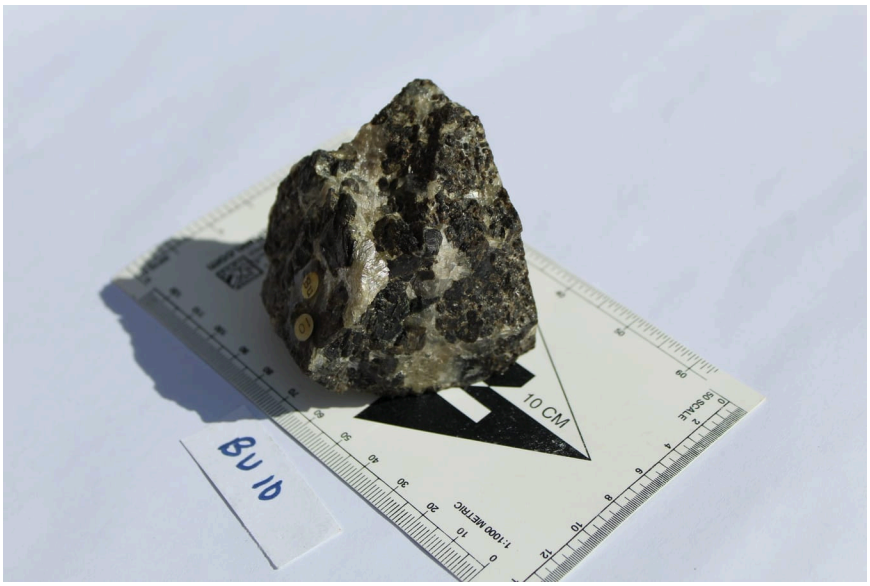
This page titled 4.12: UG2 (Platinum Ore Layer) is shared under a CC BY-NC-SA 4.0 license and was authored, remixed, and/or curated by Elizabeth Johnson and Juhong Christie Liu (Virtual Library of Virginia) via source content that was edited to the style and standards of the LibreTexts platform.

4.13: BC/Bu 10 (Merensky Reef)

HAND SAMPLE IMAGES AND VIDEOS

Click on the image for a larger, downloadable version.







YouTube Video

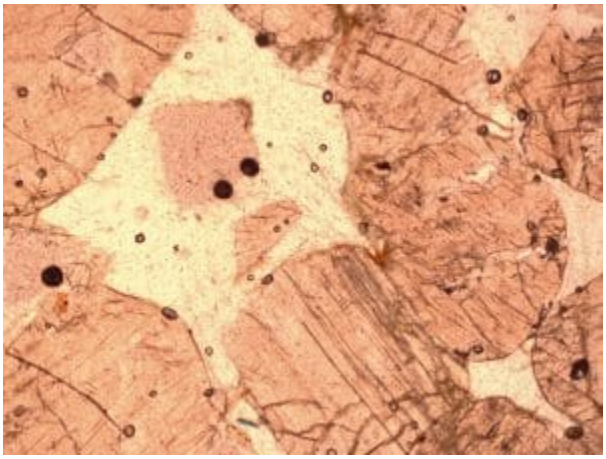
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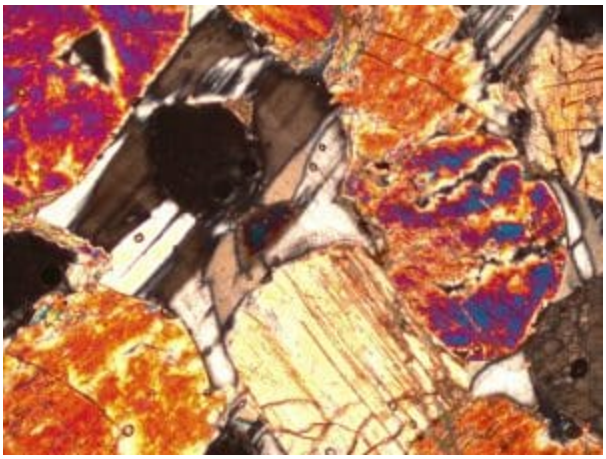
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THIN SECTION IMAGES AND VIDEOS

Images were obtained using a 4x objective (40x total magnification). 1st image = PPL. 2nd image = XPL.

Spot 1



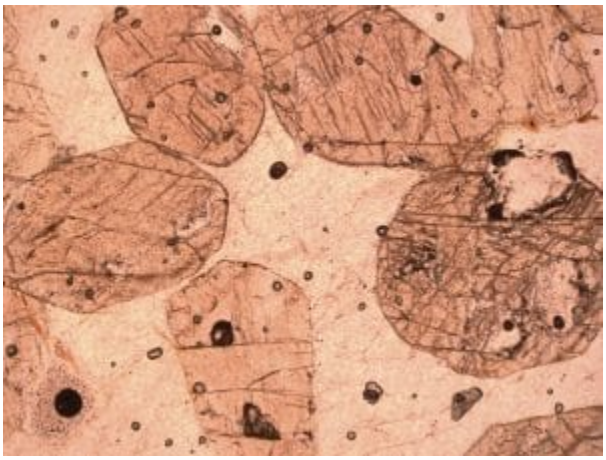


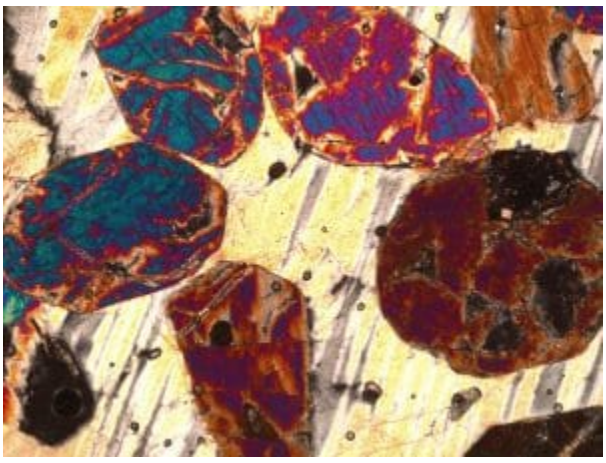
YouTube Video

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Spot 2



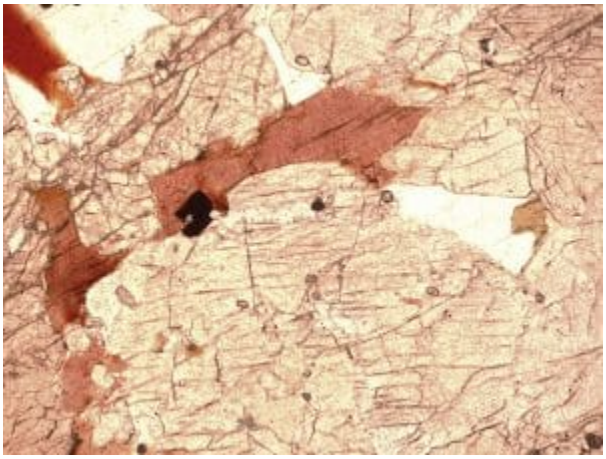


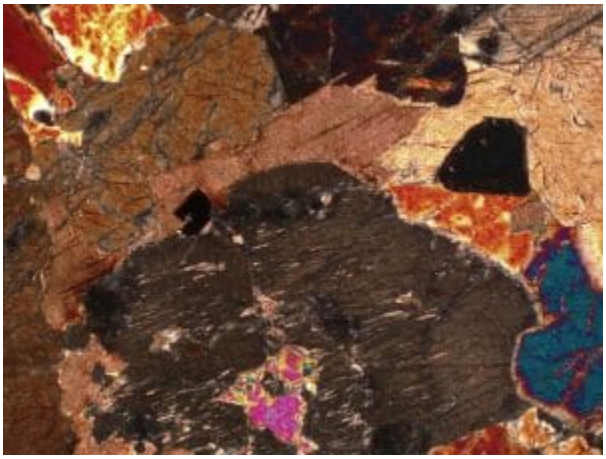
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Spot 3





YouTube Video

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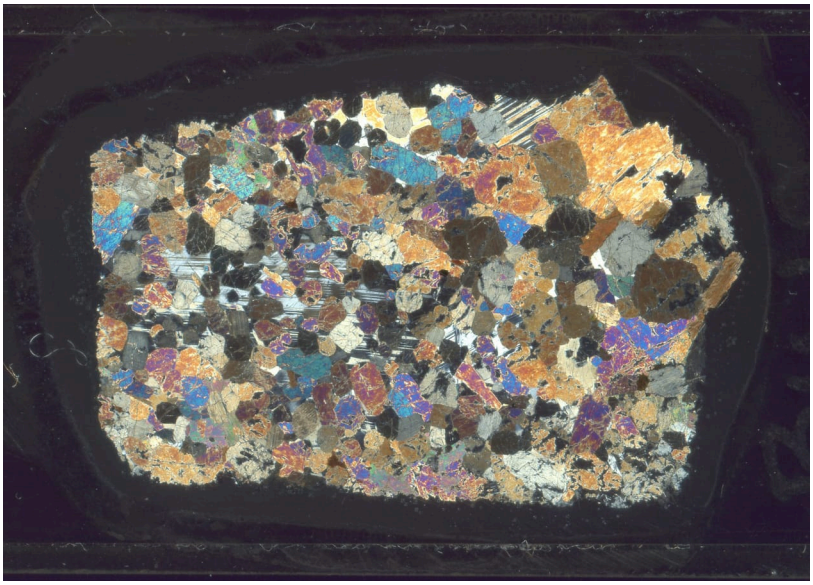
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THIN SECTION SCANS

Click on the image for a larger, downloadable version. Top image = plane polarized light. Second image = cross polarized light.

Third image = juxtaposition of ppl and xpl. Thin section is 2.54 cm wide (distance from top to bottom of image).





Query 4.13.1

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4.14: BC/Bu 1 (Critical Zone)

HAND SAMPLE IMAGES AND VIDEOS





YouTube Video

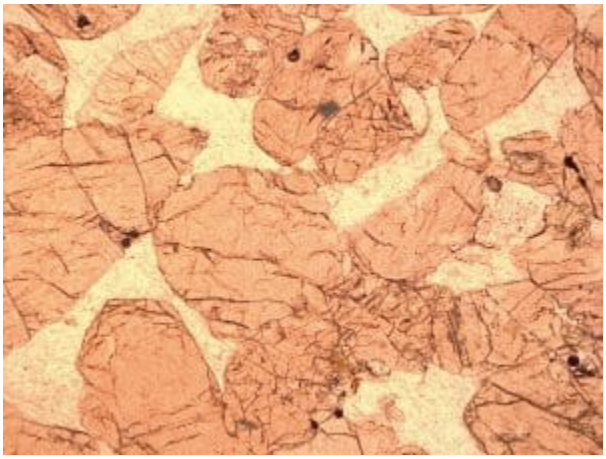
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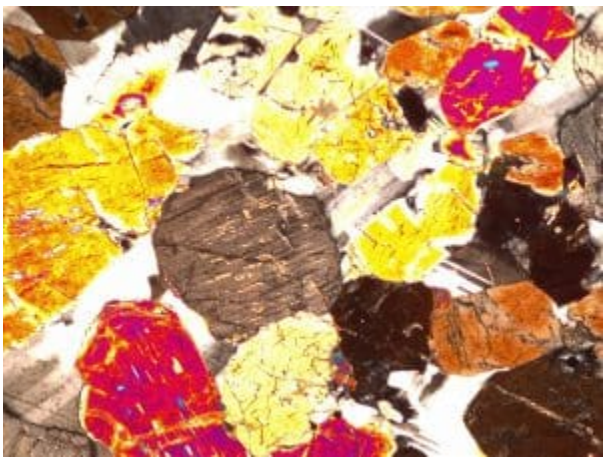
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THIN SECTION IMAGES AND VIDEOS

Images were obtained using a 4x objective (40x total magnification). 1st image = PPL. 2nd image = XPL.

Spot 1



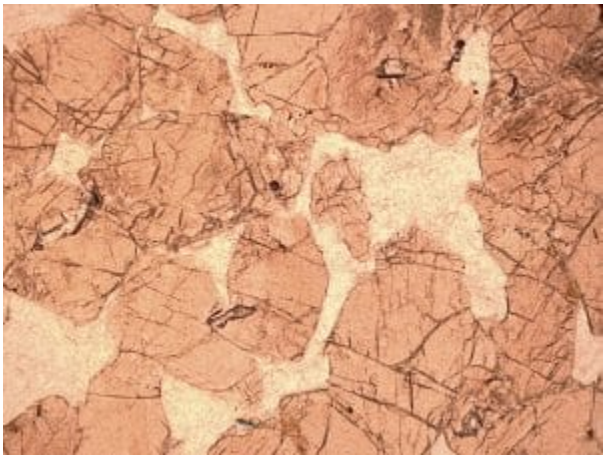


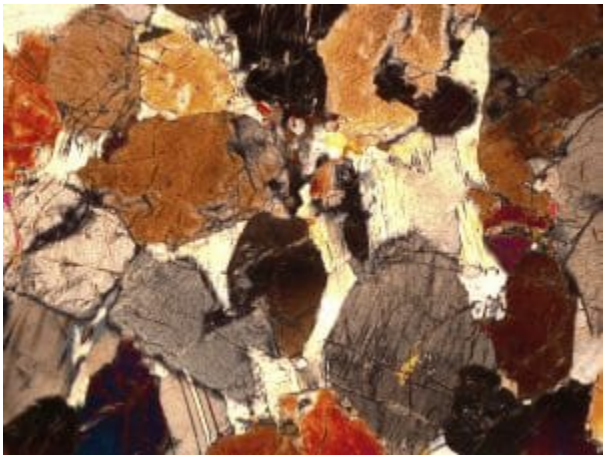
YouTube Video

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Spot 2



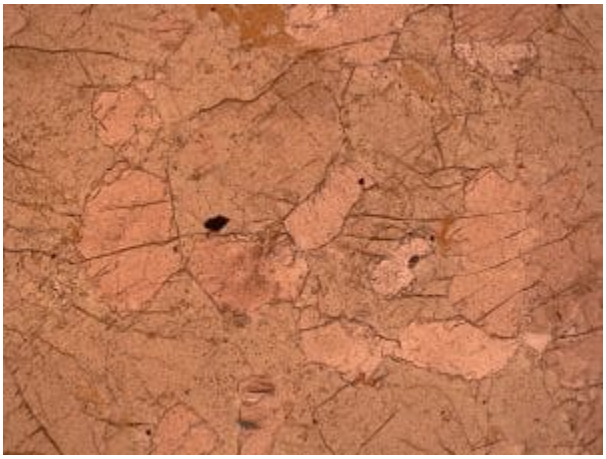


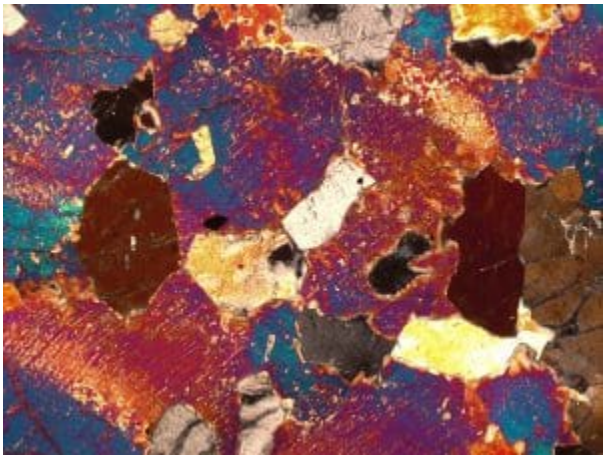
YouTube Video

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Spot 3





YouTube Video

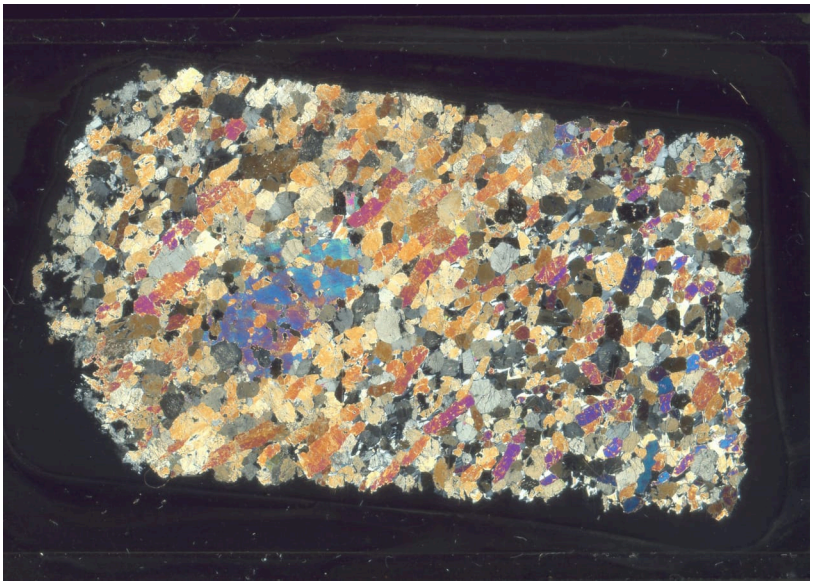
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THIN SECTION SCANS

Top image = plane polarized light. Second image = cross polarized light. Third image = juxtaposition of ppl and xpl. Thin section is 2.54 cm wide (distance from top to bottom of image).





Query 4.14.1

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5: SOUTHWESTERN VIRGINIA CASE STUDY

5.1: S6 Striped Rock Granite

5.2: UM1 Soapstone and Serpentinite

5.3: Unicoi 1 Mudstone

5.4: Unicoi 2 Greenstone

5.5: Geologic Map

5.6: A1 Amphibolite

5.7: A1 B2 Schist

5.8: A3 Amphibolite

5.9: A3 Schist

5.10: A4 Mylonite 1

5.11: A4 Mylonite 2

5.12: Cranberry Gneiss (Orthogneiss)

5.13: S5 Cranberry Gneiss (Paragneiss)

5.14: Unicoi 3 Conglomerate

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5.1: S6 Striped Rock Granite

Outcrop and Hand Sample Photos and Videos

The “Striped Rock” name comes from Anna Jonas Stose. The “stripes” are not part of the rock itself; rather, they are formed from oxidation and staining of the surface of the granite as can be seen in the 1st picture of a quarry wall:



The Striped Rock granite does contain enclaves, or xenoliths, of a more mafic igneous rock. There is a long, skinny enclave in the boulder to the right of the person with the red hat (below). You can also see an example in the YouTube hand sample video.



YouTube Video

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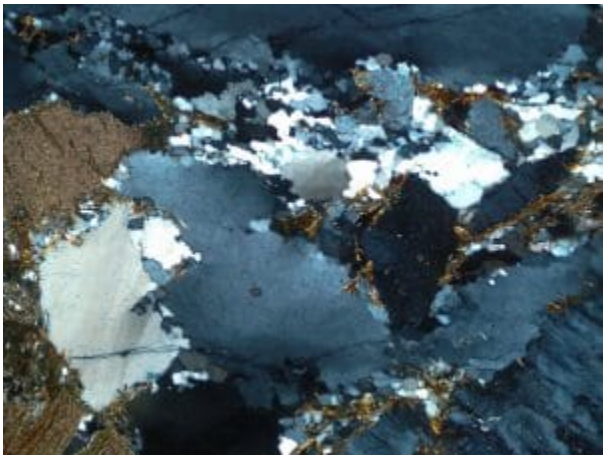
View this YouTube Video online

Thin Section Photos and Videos

1st = plane polarized light; 2nd = cross-polarized light.

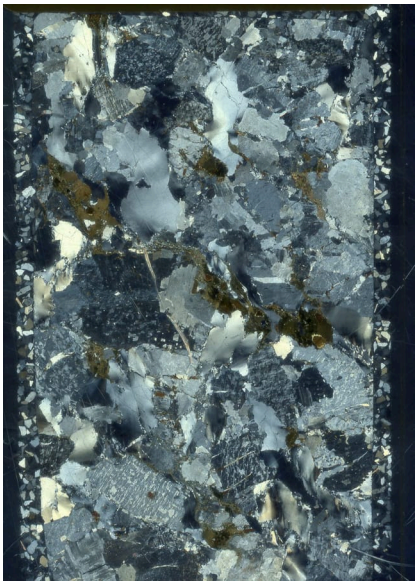
Biotite, quartz, k-feldspar. Can you see the recrystallization texture in the quartz?





Entire thin section scan. 1st = ppl; 2nd = xpl.





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5.2: UM1 Soapstone and Serpentinite

Outcrop and Hand Sample Photos and Videos

This outcrop is on the appropriately named Soapstone Rd. It is next to a creek and a small house that (at least used to) contain many, many dogs.

Can you see the very weak foliation of the rock in the 1st picture (best observed in the left side of the photo)?



The “bumpy” texture seems to be due in part to the weathering of the inhomogeneous rock. If you watch the YouTube video of the hand sample, clasts of ultramafic rock (peridotite?) are surrounded by reaction rims of serpentine. The main rock contains talc (feels slippery), magnetite, serpentine, and chlorite.





YouTube Video

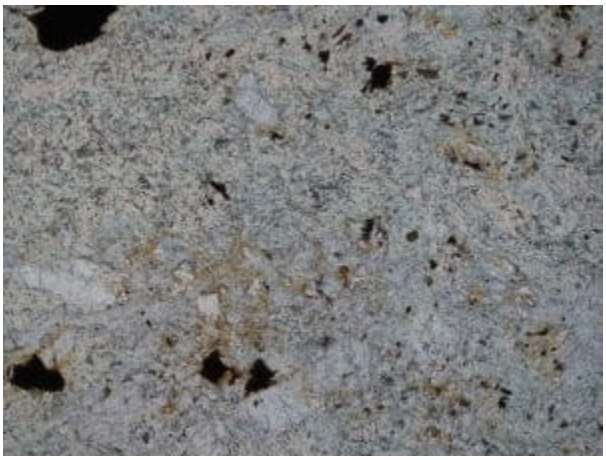
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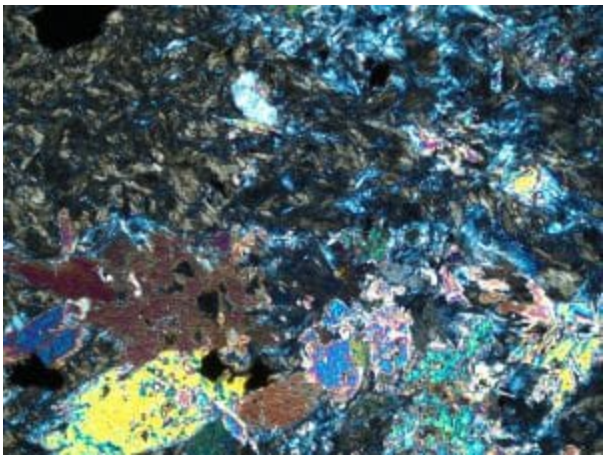
View this YouTube Video online

Thin Section Photos and Videos

1st = plane polarized light; 2nd = cross-polarized light.

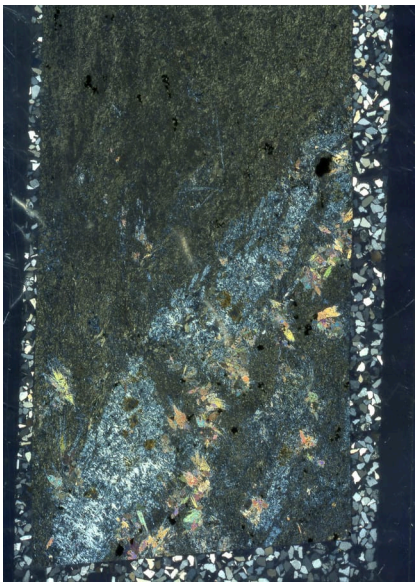
Unfortunately, we don't have a thin section of one of the ultramafic clasts. However, you can see some of the minerals in the main section of the rock here. At the top = lower interference colors and fibrous = serpentine minerals and chlorite. At the bottom, higher-order interference colors = talc. Magnetite is opaque.





Entire thin section scan. 1st = ppl; 2nd = xpl.





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5.3: Unicoi 1 Mudstone

Outcrop and Hand Sample Photos and Videos

Click on the image to enlarge.

This is a shale / mudstone which is part of the Unicoi Formation. This rock, plus the Unicoi 2 and Unicoi 3 samples (see next pages), plus some sandstones, are all present in one glorious section of roadcut along Rt. 21 north of Independence, VA. The Unicoi Formation is roughly equivalent to the Chilhowee Group of Skyline Drive and the Shenandoah Valley.



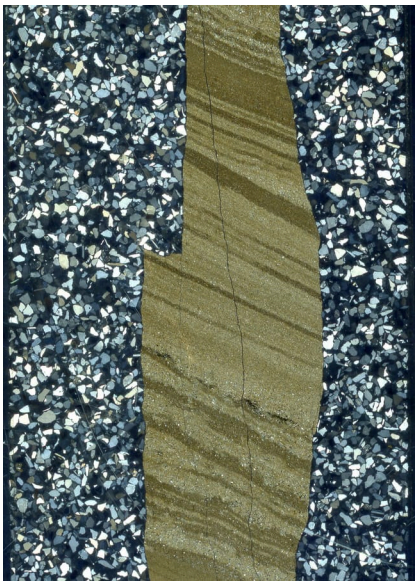
Thin Section Photos and Videos

Click on the image to make it larger. 1st = plane polarized light; 2nd = cross-polarized light.

I didn't make thin section close-ups for this one. It is very fine-grained. The laminate bedding of the mudstone is clearly

Entire thin section scan. 1st = ppl; 2nd = xpl. **Click on the image to make it larger.**





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5.4: Unicoi 2 Greenstone

Outcrop and Hand Sample Photos and Videos

The greenstone (metamorphosed basalt; greenish) is on the right. The sandstone unit is on the left. There is near vertical primary bedding here. Can you see how the metamorphic foliation of the greenstone is at an angle to the bedding plane of the sandstone?



Can you see the amygdules and vesicles in the greenstone? These are filled with chlorite and zeolites.

YouTube Video

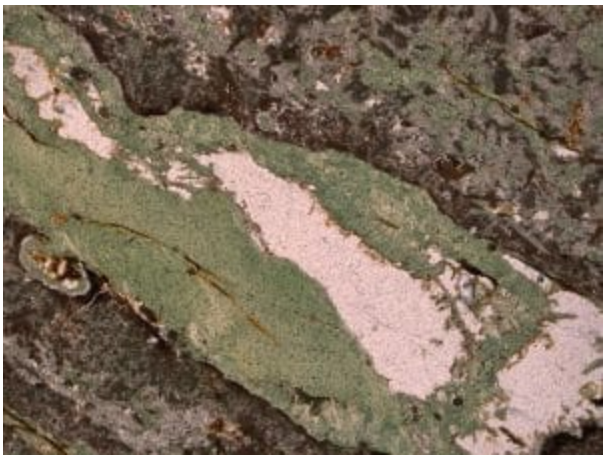
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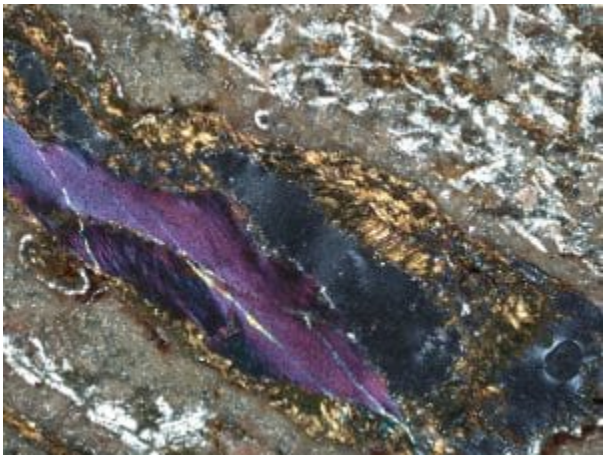
View this YouTube Video online

Thin Section Photos and Videos

1st = plane polarized light; 2nd = cross-polarized light.

The center of this thin section image is a partially filled vesicle (amigdule). The white in ppl is a hole in the amygdule The chlorite (green) shows anomalous interference colors – this is “Berlin blue.” In xpl, you can see the remnants of plagioclase microphenocrysts in the surrounding metabasalt.





Entire thin section scan. 1st = ppl; 2nd = xpl.

The amygdules are clearly visible in this image. Some are clearly stretched by metamorphism.





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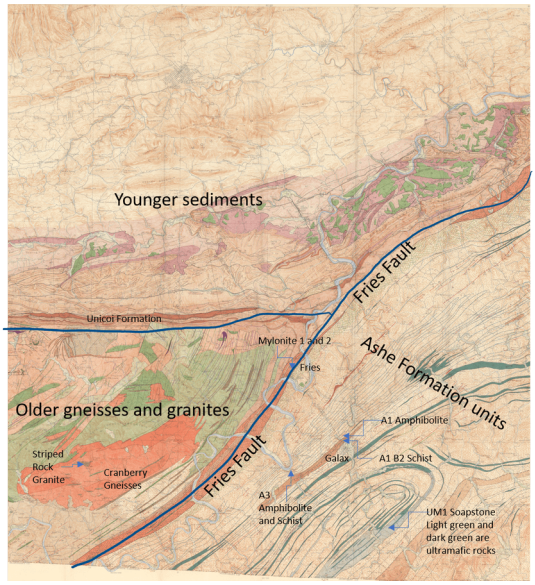
5.5: Geologic Map

Map

This is the map of the area (without annotations):



Here is an annotated map of the area, showing approximate sample locations and towns, as well as the Fries Fault and major structural units:



Rock Units

Formation	Age	Sample #	Rock Type	Protolith

Ashe Formation	Protolith Age: 600 Ma (Late Proterozoic). Age of metamorphism: 450-430 Ma.	A1 B2, A3 schist	Staurolite Schist (Pelite)	Fine-grained mudstone
		A1 amph, A3 Amph	Amphibolite	Basalt or Gabbro
		UM1	Soapstone / serpentinite	Ultramafic (peridotite)
Fries Fault Zone	Fault Age To Be Determined	A4 Mylonite 1	Mylonite	Cranberry Gneiss
		A4 Mylonite 2	Mylonite	Ultramafic or mafic protolith
Cranberry Gneiss	Protolith Age: ~1.1 Ga (billion years) Age of metamorphism: gneissic fabric – 900 Ma? faulting age is unknown.	Cranberry	Orthogneiss	Granite
		S5 Cranberry	Paragneiss	Sedimentary
Striped Rock Granite	Crystallization age ~690 Ma. Perhaps associated with Mt Rogers volcanics (~750 Ma)?	S6 Striped Rock	Granite	Not applicable
Unicoi Formation	Early Cambrian (like the Chilhowee Group near JMU)	Unicoi 1	Shale / mudstone	Not applicable
		Unicoi 2	Greenstone	Basalt
		Unicoi 3	Conglomerate	Not applicable

Field Bulletin

The map and field descriptions of this area (by Stose and Stose) are available here: https://www.dmme.virginia.gov/commercedocs/BUL_72.pdf

And from this page (it is free to download, even though it is the DMME “store”): https://www.dmme.virginia.gov/commerce/ProductDetails.aspx?productID=2272

Like most map bulletins, the text is first, and the maps are at the very end of the .pdf document.

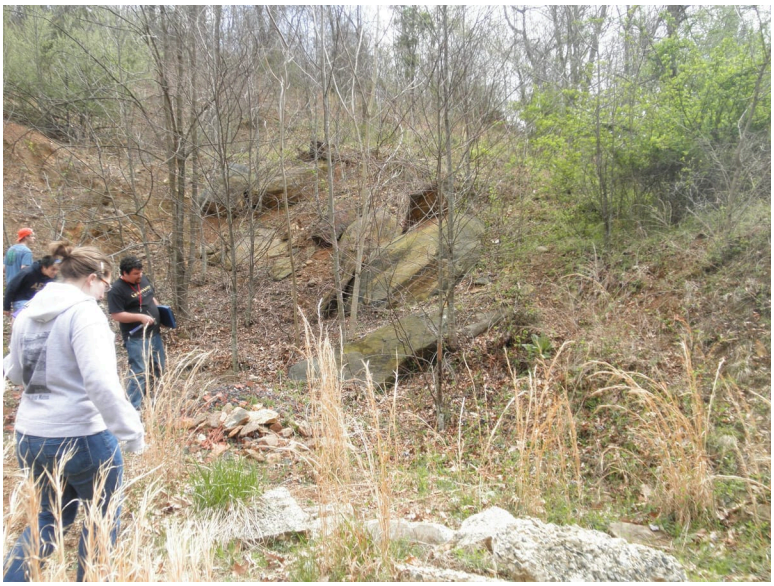
This page titled 5.5: Geologic Map is shared under a CC BY-NC-SA 4.0 license and was authored, remixed, and/or curated by Elizabeth Johnson and Juhong Christie Liu (Virtual Library of Virginia) via source content that was edited to the style and standards of the LibreTexts platform.

5.6: A1 Amphibolite

Outcrop and Hand Sample Photos and Videos

Click on the image to enlarge.

This is in Galax. Houses were constructed on this site shortly after this field trip. You can see some of the cabins/houses in the background. This is an amphibolite (massive boulders) with some schist on the left side of the first photo. This is on the other side of a hill from A1 B2 Schist (next stop).







YouTube Video

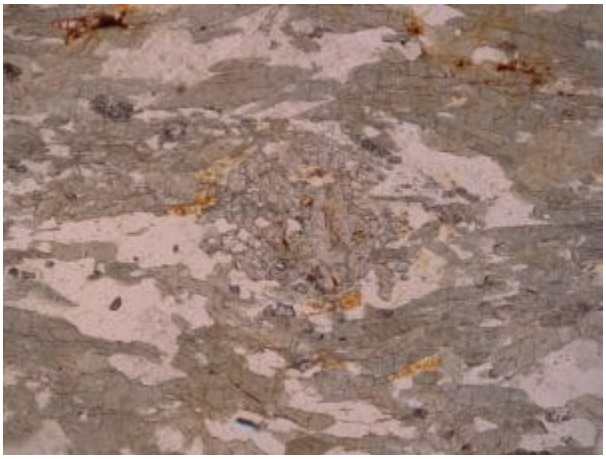
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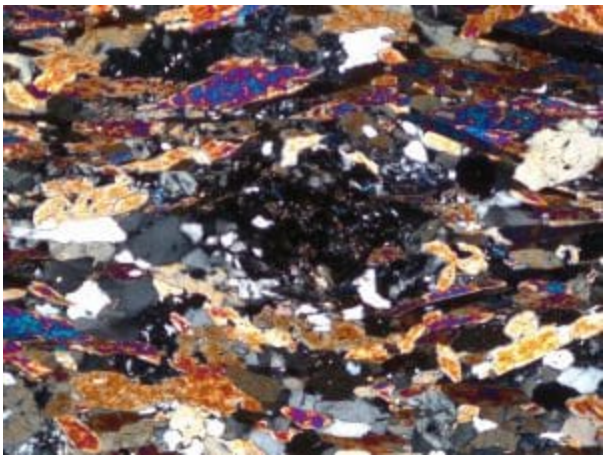
View this YouTube Video online

Thin Section Photos and Videos

1st = plane polarized light; 2nd = cross-polarized light.

Garnet surrounded by hornblende and quartz. Look at the inclusions in the garnet porphyroblast.





Entire thin section scan. 1st = ppl; 2nd = xpl.





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5.7: A1 B2 Schist

Outcrop and Hand Sample Photos and Videos

This outcrop is on a busy road. The schist is coated in a dark later of pollution from car exhaust, making it look black on the outcrop. A fresh surface reveals a shiny silver schist.





The staurolite is the large orange porphyroblasts in the hand sample. Dark minerals are biotite. Much of the rock is muscovite, some quartz, a little plagioclase. Kyanite is rumored to be present. Tiny garnets are hardly visible in hand sample.

YouTube Video

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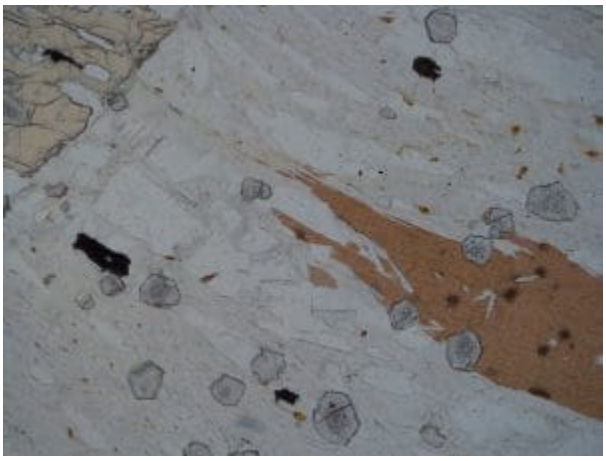
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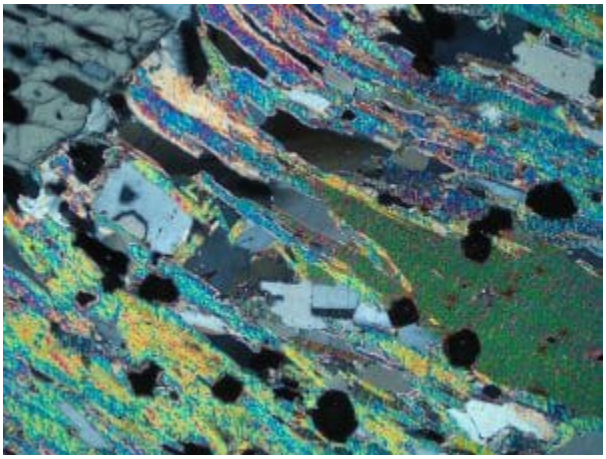
Thin Section Photos and Videos

1st = plane polarized light; 2nd = cross-polarized light.

Area 1

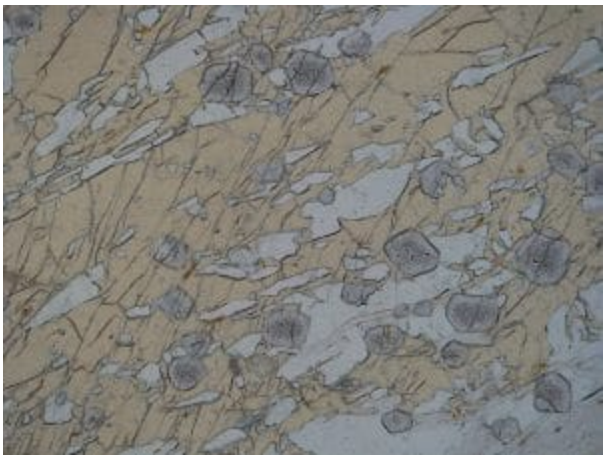
Biotite (brown in ppl) and staurolite (yellow in ppl, top left) porphyroblasts. High-relief euhedral mineral is garnet. Qtz and muscovite are also present.

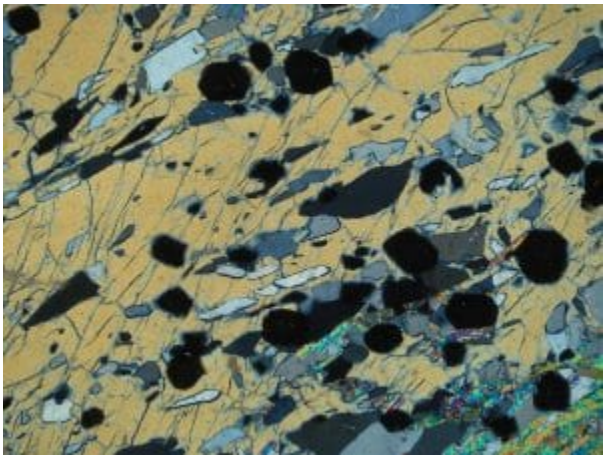




Area 2

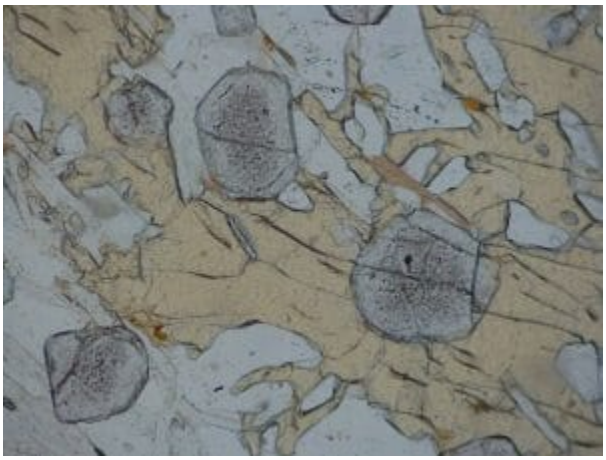
Staurolite (yellow), qtz, garnet (isotropic, high relief), a little muscovite.

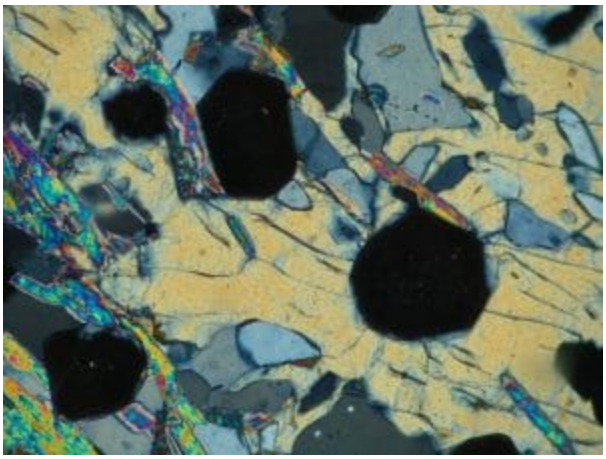




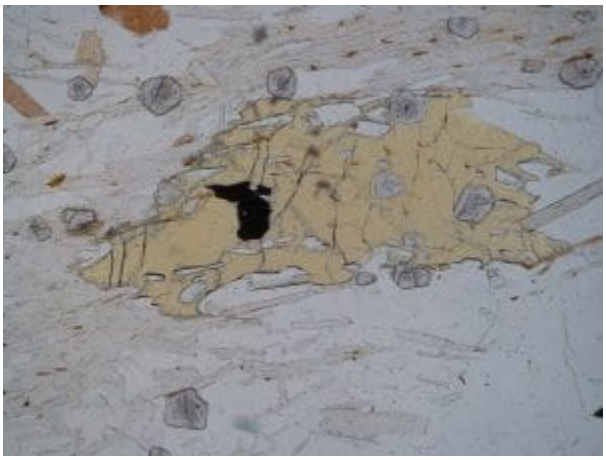
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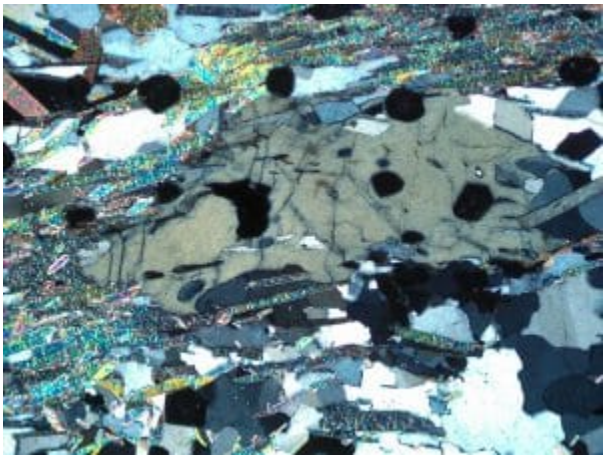
Close up of garnets (+ stl, qtz, musc). Note the pattern of inclusions in the garnet in ppl.





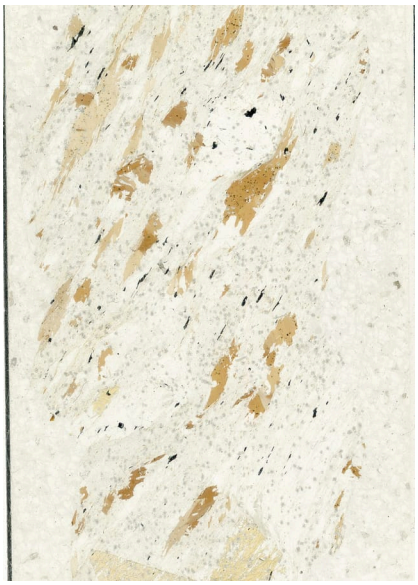
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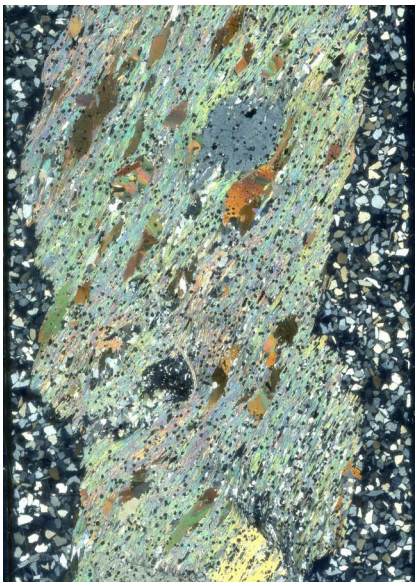




Entire thin section scan. 1st = ppl; 2nd = xpl.

This thin section is super interesting for thinking about deformation and metamorphic events.





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5.8: A3 Amphibolite

Outcrop and Hand Sample Photos and Videos

Click on the image to enlarge.

This is a massive amphibolite. The field stop seems to have been used as a rock quarry and dump for road construction. Note the jointing in the rocks (especially in 2nd photo).





YouTube Video

This interactive element is not available in this format. Visit the link or scan the QR code to access it online.

View this YouTube Video online

Thin Section Photos and Videos

1st = plane polarized light; 2nd = cross-polarized light.

Interlocking clusters of hornblende (amphibole, green in ppl) and quartz.





Entire thin section scan. 1st = ppl; 2nd = xpl.





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5.9: A3 Schist

Outcrop and Hand Sample Photos and Videos

Click on the image to enlarge.

These outcrops are only a couple hundred meters down the road from the A3 amphibolite. The schist shows distinctive foliation in outcrop.





The hand sample shows the complex foliation in more detail. Pause the video when I show the side of the rock cut by a rock saw.

YouTube Video

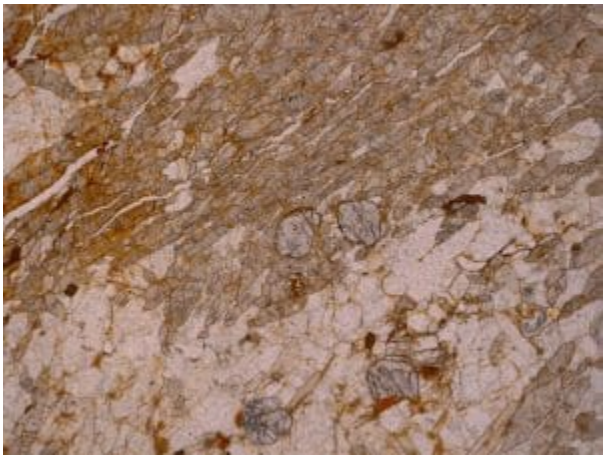
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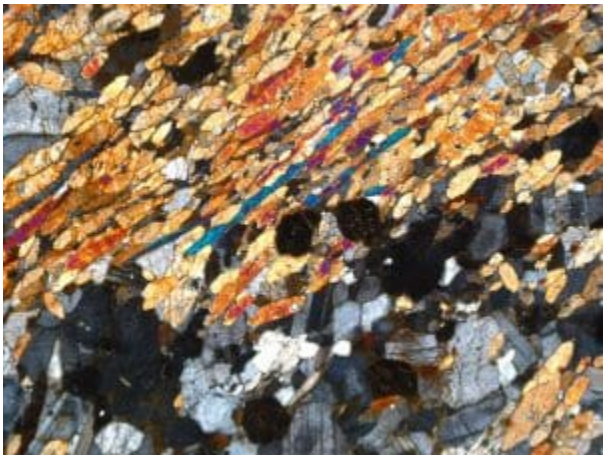
View this YouTube Video online

Thin Section Photos and Videos

1st = plane polarized light; 2nd = cross-polarized light.

Hornblende (green-brown in ppl, yellow-orange-blue in xpl), garnet, qtz, plagioclase.





Entire thin section scan. 1st = ppl; 2nd = xpl.

This thin section is super interesting! Especially for thinking about deformation events. It was made from the cut side of the hand sample shown in the YouTube video above.





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5.10: A4 Mylonite 1

Outcrop and Hand Sample Photos and Videos

Click on the image to enlarge.

This is one continuous outcrop containing mylonite 1 (this page) and mylonite 2 (next page). Can you see the mylonite fabric (looks like a foliation) in the rock? The protolith of Mylonite 1 was probably one of the Cranberry Gneiss units.





This cut hand sample shows the mylonite texture in more detail.

YouTube Video

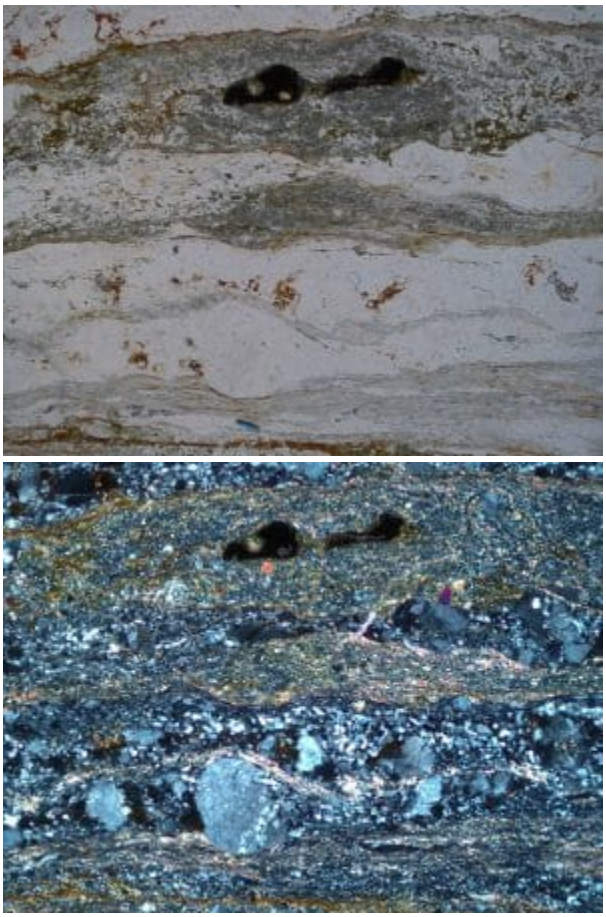
This interactive element is not available in this format. Visit the link or scan the QR code to access it online.

View this YouTube Video online

Thin Section Photos and Videos

1st = plane polarized light; 2nd = cross-polarized light.

Hopefully you can see porphyroclasts (augens) and mylonite texture in the thin section images below. Porphyroclasts are mostly qtz, rusty brown layers are clays produced by shearing.



Entire thin section scan. 1st = ppl; 2nd = xpl.





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5.11: A4 Mylonite 2

Outcrop and Hand Sample Photos and Videos

Click on the image to enlarge.

This mylonite is located in the same outcrop as mylonite 1 (mylonite 2 is farther south than mylonite 1). It is hard to know what the protolith was, but based upon the porphyroclasts it was likely an ultramafic or mafic rock.

Can you see the mylonite fabric in this photo?



The students are pointing to one metamorphic feature with their pencils. There is another structure above and to the left of the blue pencil. Can you identify it also?



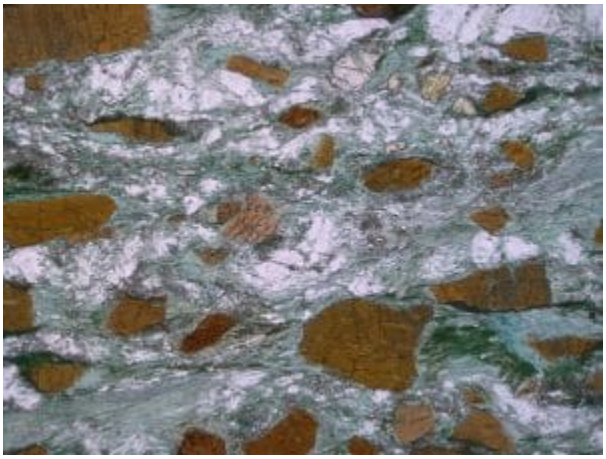
It's huge! What am I standing next to?

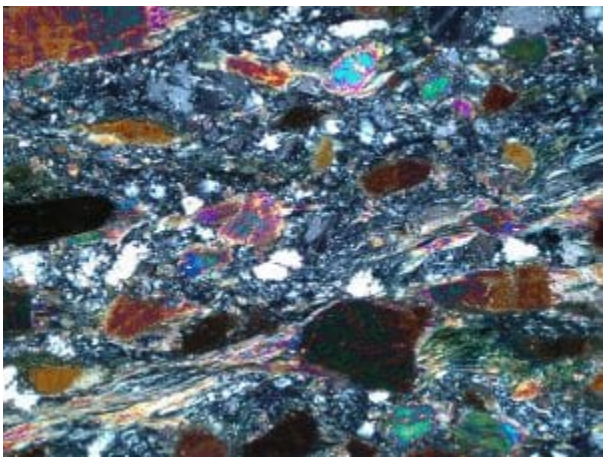


Thin Section Photos and Videos

Click on the image to make it larger. 1st = plane polarized light; 2nd = cross-polarized light.

The brown minerals (in ppl) are likely some type of amphibole. Green in ppl is chlorite. Qtz is also present. Are the amphiboles prophyroclasts or porphyroblasts?





Entire thin section scan. 1st = ppl; 2nd = xpl. **Click on the image to make it larger.**

S-C fabric is visible in the thin section.





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5.12: Cranberry Gneiss (Orthogneiss)

Outcrop and Hand Sample Photos and Videos

No outcrop images available. This was collected near Independence, not too far away from the other Cranberry Gneiss sample (next page).

The classic interpretation of the Cranberry Gneiss is that it is a paragneiss (sedimentary protolith). This is true in many places, including sample S5 (next page). However, the Cranberry Gneiss on this page is pretty clearly an orthogneiss (igneous protolith). Field mappers in the area are now starting to distinguish between these two types of gneisses.

YouTube Video

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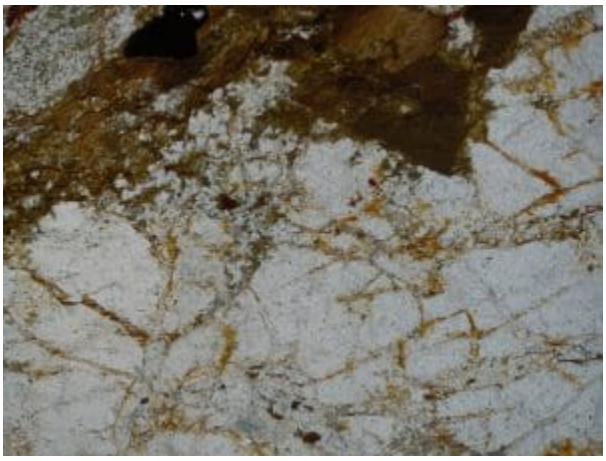
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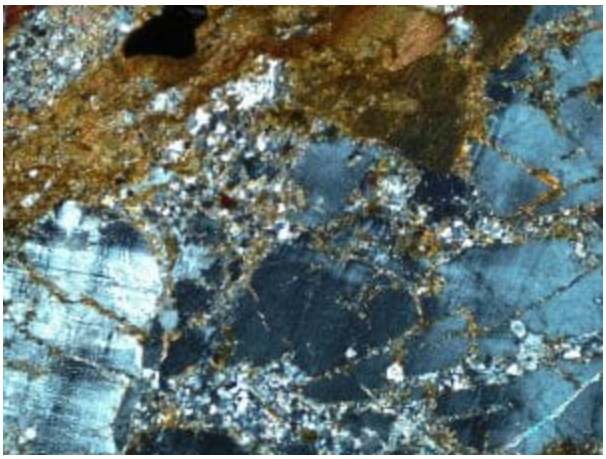
Thin Section Photos and Videos

1st = plane polarized light; 2nd = cross-polarized light.

Spot 1

Biotite (brown), orthoclase, recrystallized quartz.

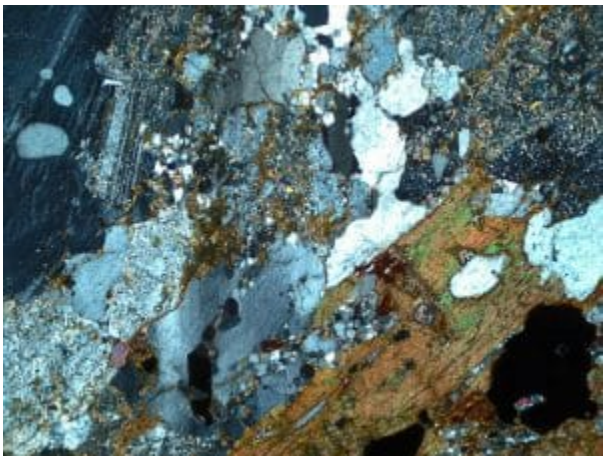




Spot 2

Biotite,quarts, magnetite, plagioclase, dusty orthoclase, a zircon (inside the magnetite at bottom right).





Entire thin section scan. 1st = ppl; 2nd = xpl.





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5.13: S5 Cranberry Gneiss (Paragneiss)

Outcrop and Hand Sample Photos and Videos

This is a quartz-rich paragneiss. Can you see the foliation in the outcrop?





YouTube Video

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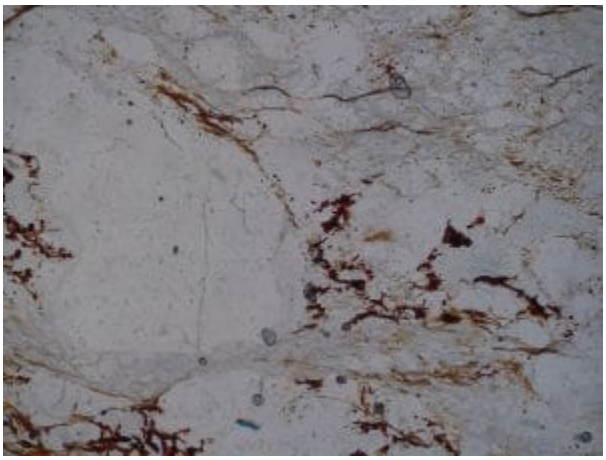
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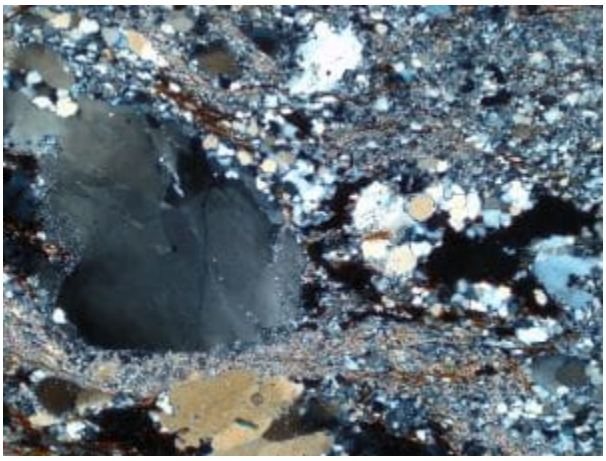
Thin Section Photos and Videos

1st = plane polarized light; 2nd = cross-polarized light.

Spot 1

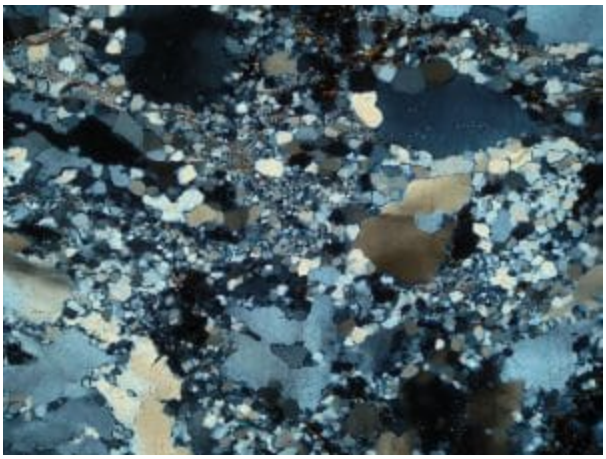
Quartz porphyroclast in fine-grained quartz matrix. What type of quartz textures do you see in the following images?





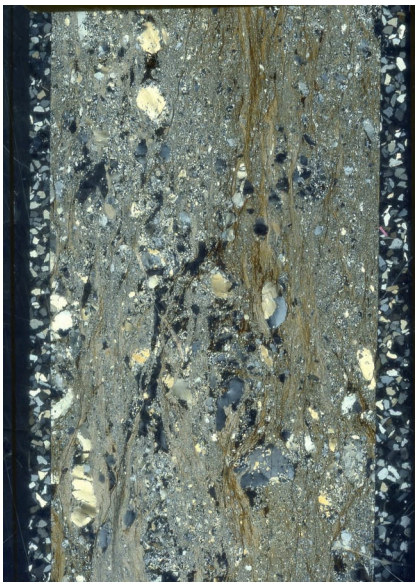
Spot 2





Entire thin section scan. 1st = ppl; 2nd = xpl.





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5.14: Unicoi 3 Conglomerate

ELIZABETH A. JOHNSON

OUTCROP AND HAND SAMPLE PHOTOS AND VIDEOS

There are at least two conglomerate beds in this outcrop. These images show the conglomerate with the larger (cm-sized) clast size.

The videos below show both the larger and smaller clast sizes.

YouTube Video

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View this YouTube Video online

YouTube Video

This interactive element is not available in this format. Visit the link or scan the QR code to access it online.

View this YouTube Video online

Thin Section Photos and Videos

1st = plane polarized light; 2nd = cross-polarized light.

The thin section images are from the smaller clast size conglomerate. This close-up shows clasts of quartzite (top), k-feldspar/granite (bottom right), and shale (bottom left). There are also volcanic clasts in these rocks. The volcanics are from the Mount Rogers complex – remember this from the history of magmatism in VA?

Entire thin section scan. 1st = ppl; 2nd = xpl.

The shale clast is on the left – it's the darker clast. Other rounded clasts can be seen in ppl and xpl.

Media Attributions

- Unicoi 3 Conglomerate
- Unicoi 3 Conglomerate 2
- Unicoi3 ppl 4x
- Unicoi3 xpl 4x
- Unicoi 3 ppl
- Unicoi 3 xpl

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INDEX

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GLOSSARY

S

Sample Word 1 | Sample Definition 1

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