Introduction to Petrology

ELIZABETH JOHNSON AND JUHONG CHRISTIE LIU

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Introduction: Design with A Process-Oriented Guided Inquiry Learning Approach

ELIZABETH JOHNSON, JUHONG CHRISTIE LIU, AND MARK PEALE

INTRODUCTION

POGIL stands for Process-Oriented Guided Inquiry Learning.

There are two crucial aspects to the design of a POGIL activity. First, a model or guiding worksheet with well-selected sufficient information, clearly-stated objectives, and meaningful prompts must be provided for students to "experience" or "explore" so that they can develop the understanding of desired concepts. Second, the guiding questions must be sequenced in a carefully constructed manner so that not only do students reach the appropriate conclusion, but at the same time students will be able to develop and implement various process and learning skills. The third aspect, usually optional and voluntary but essential to laboratory-based science learning, is group work and/or potentially application scenarios. The small groups can be formulated with self selection or facilitated by the instructor.

Typically the guided inquiry activity starts with a brief description of the unit and learning objectives. The expectation of prior knowledge is also stated along with the objectives so that student initial engagement with learning content can be established. The core of this type of inquiry-based learning consists of guiding questions. These questions direct student attention to the information presented with the model, scaffold student recognition of the relationships and patterns in the data, and lead toward their concept development. Based on these, students will be able to reflect possible application of the learned knowledge, and when necessary collaborate with group members to dig deeper into the learning process. An inquiry-based learning activity usually concludes with questions that may involve applying the concepts to new situations and generalizing students' new knowledge and understanding. Thus, POGIL activities follow the structure of the learning cycle, concept invention and application, and improve long-term retention of scientific knowledge (Vanags, Pammer, & Brinker, 2013).

FOR STUDENTS

FOR INSTRUCTORS

Process-oriented Guided Inquiry Learning (POGIL) is an active learning strategy that initially appeared in teaching chemistry courses (Farrell, Moog, & Spencer, 1999) and was later adopted widely in teaching and learning of science. It has the roots in a Piagetian model of learning, and has integrated the principles and concepts of inquiry-based learning and experiential learning cycles in science and laboratory education (Abdulwahed & Nagy, 2009; Kolb, 2014; Piaget, 1964). POGIL has been proved effective in science learning (Freeman, Eddy, McDonough, Smith, Okoroafor, Jordt, & Wenderoth, 2014; Vanags, Pammer, & Brinker, 2013).

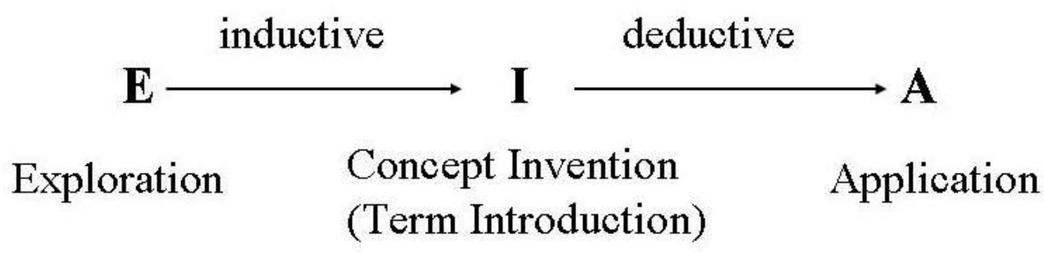
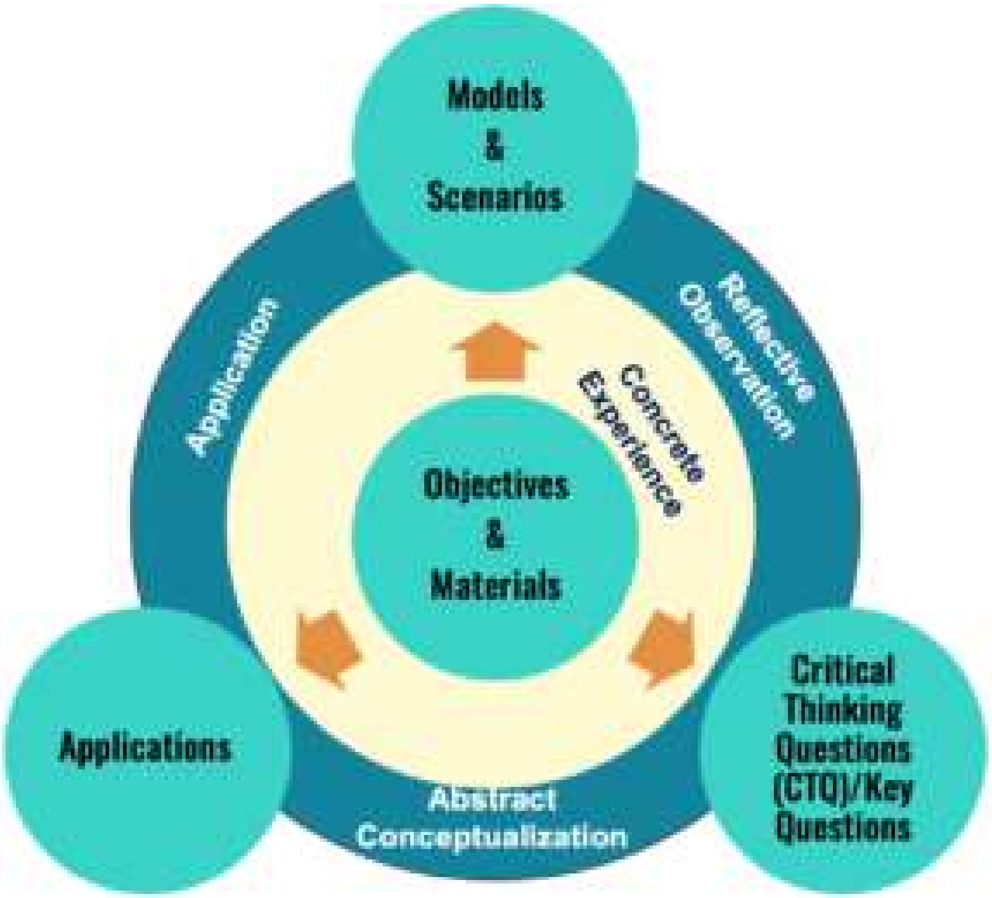


Image source: https://serc.carleton.edu/sp/pkal/pogil/what.html

The core components of a POGIL lesson includes **Scenarios** and **Models**, **Critical Thinking Questions (CTQ)** or **Key Questions**, and **Applications**. **Scenarios** provide the description of the learning unit, objectives, and prerequisite knowledge. **Models** are presentation of the subject content of the unit in multiple formats to ensure learners with all abilities to have access. **Key Questions** are designed to engage students with effective engagement of the learning. **Applications** are intended for students to be able to associate the learned knowledge with future learning and/or real-world practices. In a laboratory-based learning environment, these components provide scaffolding for students to perform reflective observation, be able to reach abstract conceptualization, and apply the conceptual knowledge to actual operation, analysis, and synthesis. These happen with the concrete experiences, align with learning objectives, and are supported with learning materials.



A POGIL Scenario sets the context and main theme for a learning activity. The setting objectives and starting a unit with core questions are very similar to the *Gaining Attention* step in Gagne's Conditions of Learning.
This Guide provides suggestions to learning activities and assessment, for instructors.

Resources

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- https://serc.carleton.edu/sp/pkal/pogil/what.html
- https://serc.carleton.edu/sp/pkal/pogil/why.html
- https://serc.carleton.edu/sp/pkal/pogil/references.html

Contributors and Support

ELIZABETH JOHNSON, JUHONG CHRISTIE LIU, AND MARK PEALE

"Nothing in the world is worth having or worth doing unless it means effort, pain, difficulty…"- Theodore Roosevelt, 23rd President of the United States

"Nothing is easy. If it is, someone has already done it." – George R. Rossman, Mineralogist

We would like to acknowledge those who have helped to create these resources:

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OTHER CONTRIBUTORS AND REVIEWERS

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recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

MODULE 1: OVERVIEW

1.1 What is Petrology?

ELIZABETH JOHNSON, JUHONG CHRISTIE LIU, AND MARK PEALE

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

Figure 1.1.2.

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Attributions

Introduction to Petrology by Elizabeth Johnson, Juhong Christie Liu, and Mark Peale is licensed under a Creative Commons Attribution 4.0 International License, except where otherwise noted.

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

1.2 How is This Book Organized?

ELIZABETH JOHNSON, JUHONG CHRISTIE LIU, AND MARK PEALE

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 contrast with the order 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 an 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.

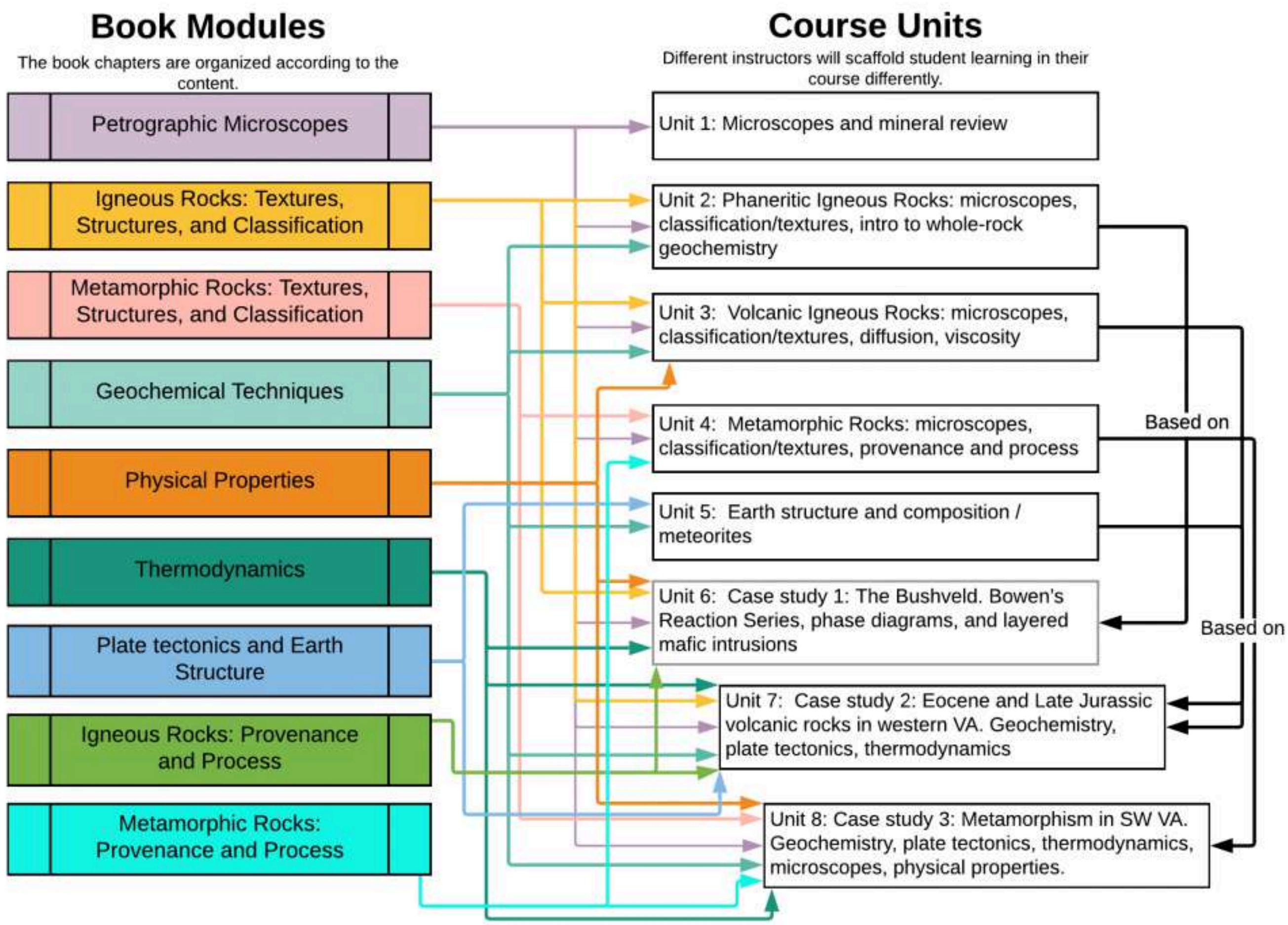

Figure 1.2.1 Comparison of book structure to course structure.

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.

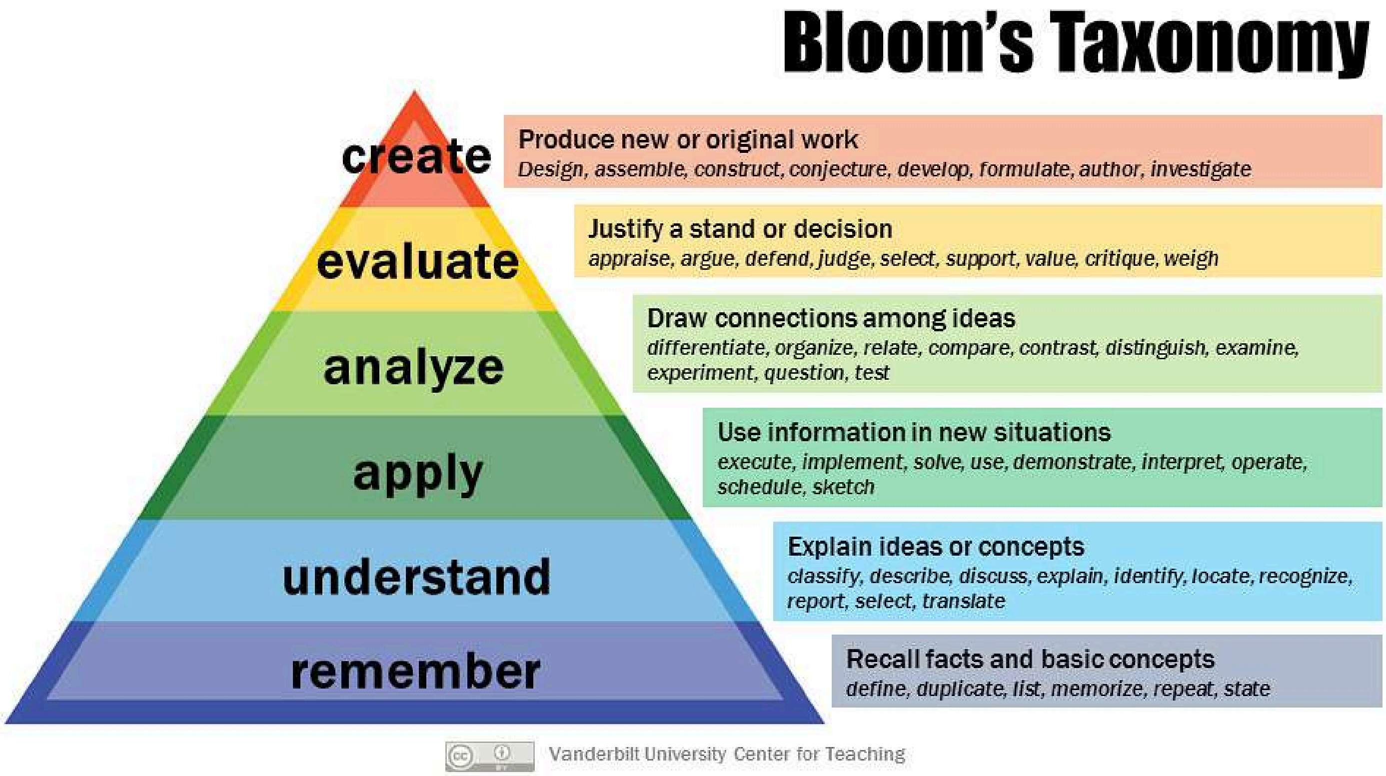

Fig 1.2.3 Revised Bloom’s Taxonomy of Learning.

Guided Inquiry

Question 1.2.1.

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Question 1.2.2.

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Armstrong, P. Bloom's Taxonomy. (ret. 7/1/2019) 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.

Media Attributions

- Figure 1.2.1 Comparison of book structure to course structure. by Juhong Christie Liu and Elizabeth Johnson
- Fig 1.2.3 Revised Bloom's Taxonomy of Learning. by Center for Teaching Vanderbilt © CC BY-NC (Attribution NonCommercial)

1.3 Why is Petrology Useful?

ELIZABETH JOHNSON, JUHONG CHRISTIE LIU, AND MARK PEALE

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

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https://viva.pressbooks.pub/petrology/?p=37

Figure 1.3.1. Geologic applications of petrology. Click on the information buttons in each diagram to learn more.

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.

Figure Attributions

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) https://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) https://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) https://commons.wikimedia.org/wiki/File:EAfrica.png Public Domain.

Geophysics:

Oilfieldvegetarian. https://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.

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MODULE 2: USING THE PETROGRAPHIC MICROSCOPE

2.1 Introduction

ELIZABETH JOHNSON, JUHONG CHRISTIE LIU, AND MARK PEALE

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/

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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. (1882), Preparation of transparent sections of rocks and minerals: Northern Microscopist, London, 2, 18, 133-140. Google books:

https://books.google.com/books?id=SSEuAQAAIAAJ&lpg=PA137&dq=Preparation%20of%20transparent%20sections%20of%20rocks%20and%20minerals%3A%20Northern%20Microscopist&pg=PA133#v=onepage&q&f=true

2.2 Thin Sections

ELIZABETH JOHNSON, JUHONG CHRISTIE LIU, AND MARK PEALE

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?

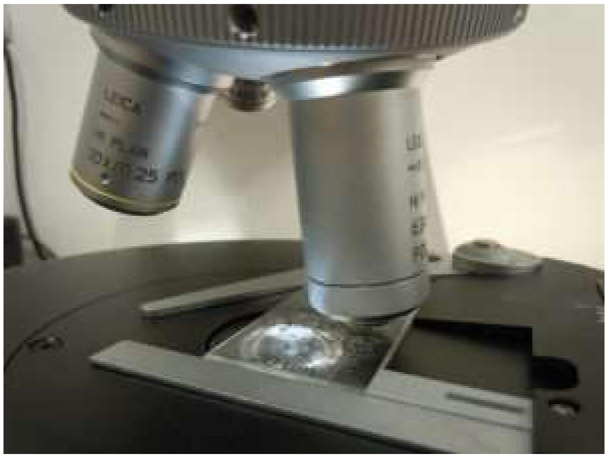

Figure 2.2.1. A thin section on a petrographic microscope stage.

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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A YouTube element has been excluded from this version of the text. You can view it online here: https://viva.pressbooks.pub/petrology/?p=52

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

Media Attributions

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- Figure 2_2_3 Screenshot of Rock Saw Video by Elizabeth Johnson © CC BY-SA (Attribution ShareAlike)

2.3 Light and Optics

ELIZABETH JOHNSON, JUHONG CHRISTIE LIU, AND MARK PEALE

UNDER CONSTRUCTION

REFRACTIVE INDEX

https://phet.colorado.edu/en/simulation/bending-light

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.

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

Learning Objectives

Students should be able to:

- Describe the categories of electromagnetic energy, 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.
- Convert wavelengths of electromagnetic energy between commonly used units.
- Describe the ways in which electromagnetic energy can behave when it interacts with an object.
- 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

Watch these videos on the electromagnetic spectrum:

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The relevant portion of the second video is from 0-4 minutes.

After reviewing the videos, look closely at the following diagrams of the electromagnetic spectrum:

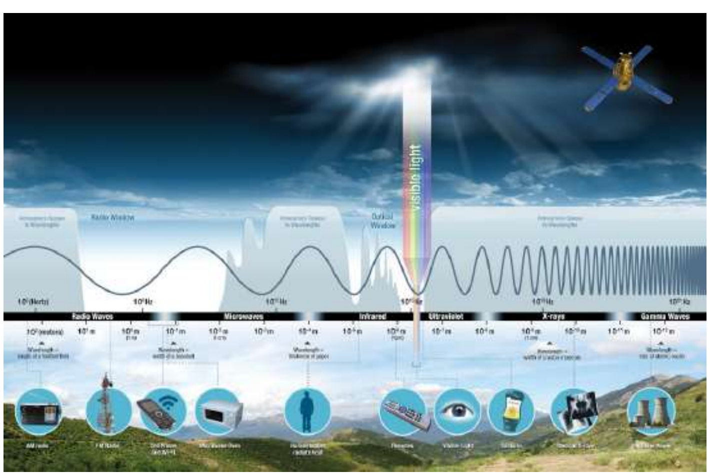

Figure 2.3.1. The Electromagnetic Spectrum. National Aeronautics and Space Administration, Science Mission Directorate. (2010). Introduction to the Electromagnetic Spectrum.

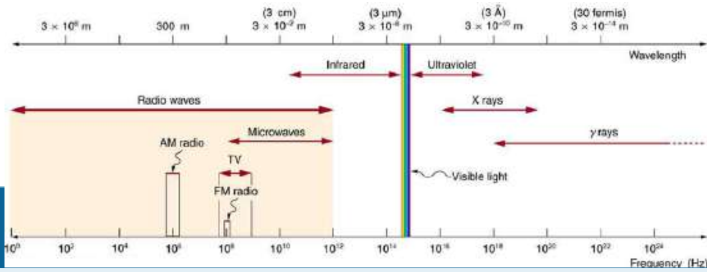

Figure 2.3.2. The Electromagnetic Spectrum.

Guided Inquiry

Question 2.3.1. Does ultraviolet light have longer or shorter wavelengths than infrared light?

Question 2.3.2. Do X-rays have larger or smaller energy than visible light?

Question 2.3.3. A Raman spectrum includes a peak at 10 micrometers wavelength. In which region is this peak located?

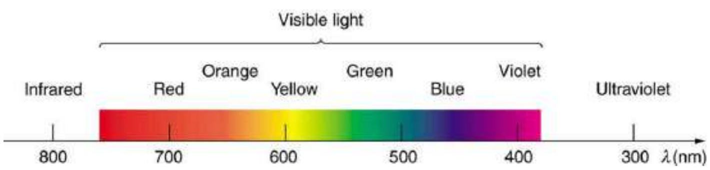

Figure 2.3.3. The visible light spectrum, showing wavelength ranges for colors in nanometers.

BEHAVIOR OF LIGHT

Text

POLARIZED LIGHT

Text

KEY TERMS

- Wavelength
- Frequency
- Visible, Infrared, Ultraviolet light

References

CrashCourse (July 9, 2015) Light: Crash Course Astronomy #24. https://youtu.be/jjy-eqWM38gLumen Learning Physics Textbook: https://courses.lumenlearning.com/physics/National Aeronautics and Space Administration, Science Mission Directorate. (2010). Introduction to the Electromagnetic Spectrum. Retrieved March 9, 2019, from NASA Science website: http://science.nasa.gov/ems/01_intro

National Aeronautics and Space Administration, Science Mission Directorate. (2010). Anatomy of an Electromagnetic Wave. Retrieved March 9, 2019, from NASA Science website: http://science.nasa.gov/ems/02_anatomy

OpenStax, College Physics. OpenStax CNX. Mar 4, 2019 http://cnx.org/contents/031da8d3-b525-429c-80cf-6c8ed997733a@14.48

Russell, Randy. Wavelengths of the visible spectrum. Windows to the Universe® (http://windows2universe.org) © 2010, National Earth Science Teachers Association.This work is licensed under a Creative Commons Attribution-NonCommercial-ShareAlike 3.0 Unported License.

Attributions

Photo Attribution: Emerald, Muzo Mine, Vasquez-Yacopí Mining District, Boyacá Department

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 https://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

ELIZABETH JOHNSON, JUHONG CHRISTIE LIU, AND MARK PEALE

UNDER CONSTRUCTION

In this section, we explore the parts of the petrographic microscope. This section is appropriate for students who have no prior experience with using microscopes.

This is also a good review for students who have previously used a petrographic microscope but 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:

Guided Inquiry

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An interactive or media element has been excluded from this version of the text. You can view it online here: https://viva.pressbooks.pub/petrology/?p=73

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.

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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:

Fig. 2.4.3. Turning on the illuminator.

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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.

Guided Inquiry

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2.4.3 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.

CONDENSER

Video: MVI_9395.mp4 shows the condenser and adjustments.

LOWER POLARIZER

The first polarizer is located below the condenser. Please see the separate section below on polarizers for more information.

LIGHT FILTER

Halogen lights used in microscopes typically give of 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.

DIAPHRAGMS

A diaphragm cuts down the amount of light that reaches the sample.

2.4.4 THE STAGE

ROTATING STAGE AND VERNIER

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 petrographic microscopes, in contrast to other types of microscopes, is the rotating stage.

Stationary figure: rotating stage (illustration from Katherine?)

Video: MVI_9371.mp4 shows rotating the stage and locking it down with 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. The rotating stage can therefore be used as a **goniometer**, or an instrument that measures rotational angle.

IMG_9367.jpg Figure Caption/Alt text: The goniometer on the vernier.

Question:

MECHANICAL STAGE

The mechanical stage is an accessory which can be attached to the top of the rotating stage.

Static image of the mechanical stage (on the table)

Someone using the mechanical stage. Have students observe.

Question: What are the two advantages to using a mechanical stage?

Answer: Can move thin section in an x-y grid motion. Holds thin section securely to the stage.

2.4.5 THE FOCUS

Text

2.4.6 THE OBJECTIVES

Text

2.4.7 THE POLARIZERS

Text

2.4.8 THE (AMICI-) BERTRAND LENS

Text

2.4.9 THE EYEPIECES OR OCULARS

Text

2.4.10 THE CAMERA

Text
Images of different cameras.
Can I just use my cell phone camera?
If you must, try removing the eyepiece and shooting through the tube to the sample directly.

2.4.11 THE ACCESSORY PLATES

Text

2.4.11.1 GYPSUM PLATE

SUMMARY QUESTIONS

1. Put the parts of the microscope in the correct order in which light passes through them after exiting the illuminator:
2. Magnification: what is the total magnification for using an objective lens of 4x? How could you test this by measuring a sample?
3.

Key Takeaways

- Although petrographic microscopes of different ages and brands can look different, they should all have many common functions and parts should be located in a similar position from microscope to microscope.

Glossary Terms

Liz: this part is perfect for H5P flashcards: https://h5p.org/flashcards

Accessory plate
(Amici-) Bertrand lens
Analyzer
Aperture
Base
Condenser
Condenser aperture diaphragm
Eyepiece or Ocular
Field diaphragm
Focus (coarse and fine)
Goniometer: https://en.wikipedia.org/wiki/Goniometer
Illumination intensity controller
Illuminator
Mechanical stage
Objective lens
Petrographic microscope
Polarizer
(Revolving) nosepiece
Rotating stage
Substage assembly
Substage centering screw
Vernier
Viewing tube

2.5 Common Issues Using a Petrographic Microscope

ELIZABETH JOHNSON, JUHONG CHRISTIE LIU, AND MARK PEALE

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.

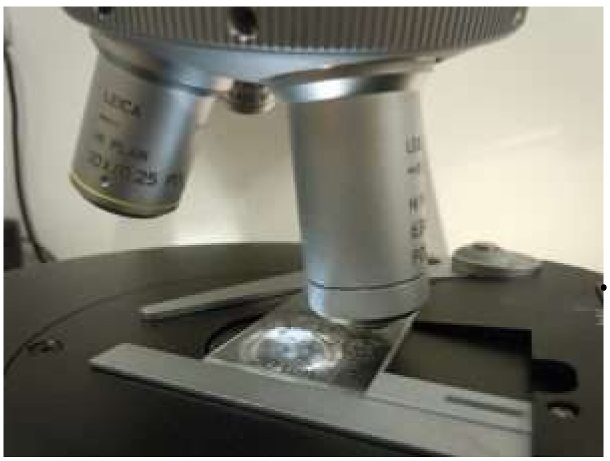


Figure 2.5.1. Nosepiece out of alignment.

- **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.

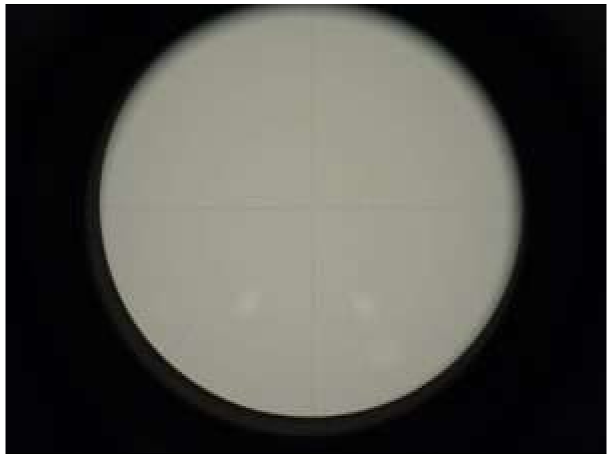


Figure 2.5.2B. Horizontal/vertical crosshairs.

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.

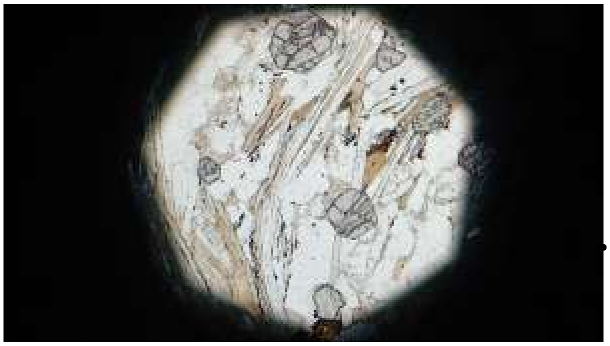


Figure 2.5.3B. Field diaphragm partially blocking the field of view.

- **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.

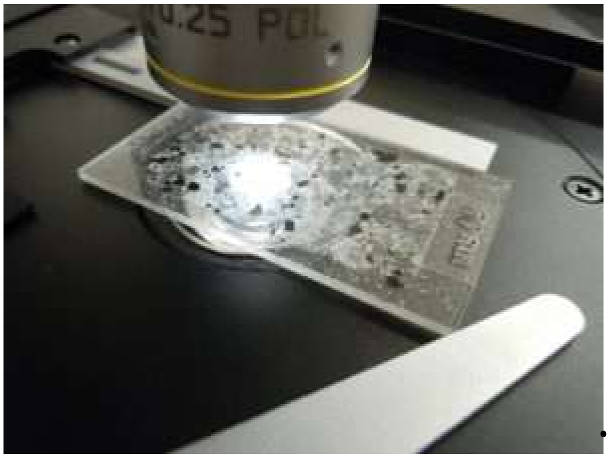


Figure 2.5.4B. A thin section upside down on the stage. Only the clean edge of the glass slide can be seen around the top edge. Note that sample labels are not always placed on the top side of thin sections.

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

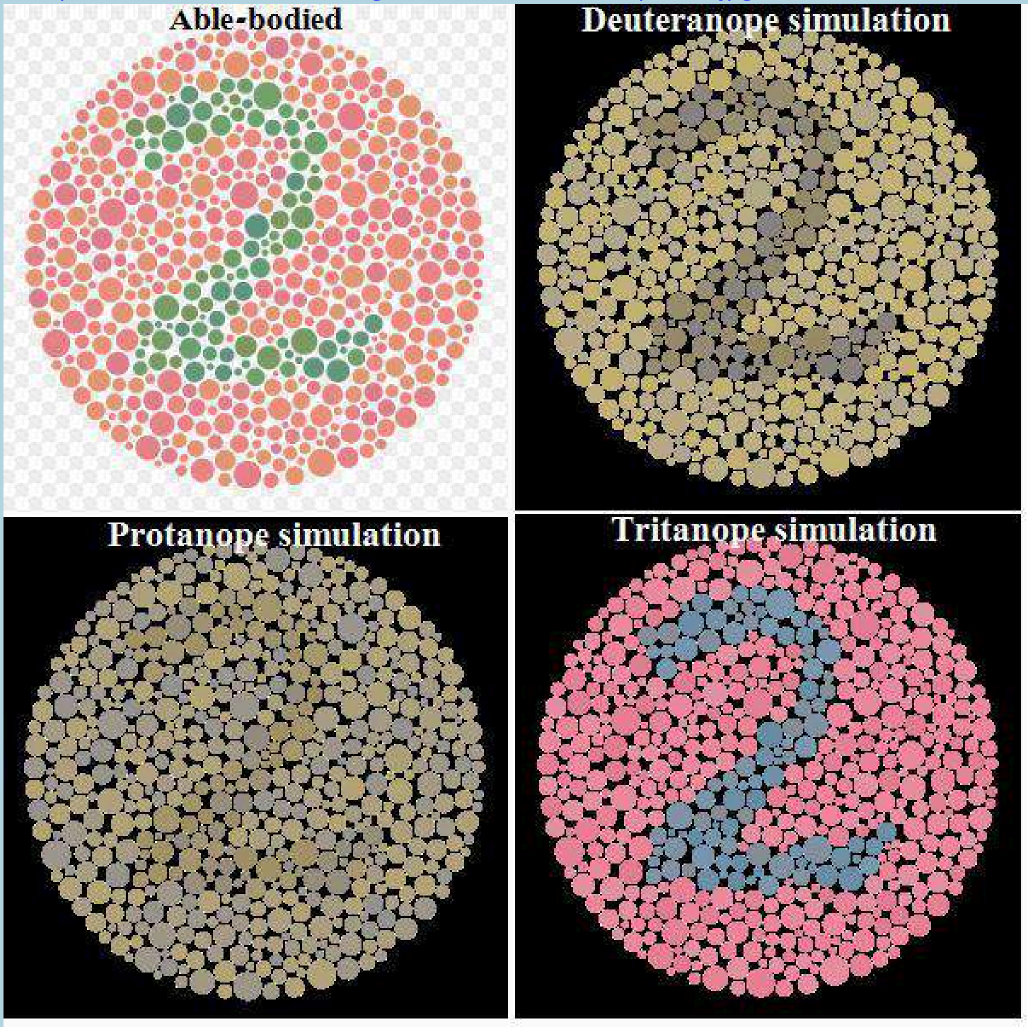
Q: It doesn't matter which microscope I use, I don't see the colors of the minerals the same way that other people in the class are describing them.

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.

https://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

ELIZABETH JOHNSON, JUHONG CHRISTIE LIU, AND MARK PEALE

UNDER CONSTRUCTION

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http://www.minsocam.org/msa/DGT_Figures/Chapter5/Chapter5_16.html

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2.6.1 OPAQUE MINERALS

Text

2.6.2 COLOR

Text

2.6.3 PLEOCHROISM

Text

2.6.4 RELIEF AND REFRACTIVE INDEX

Text

2.6.5 MINERAL FORM

Text

2.6.6 CLEAVAGE AND FRACTURE

Text

2.6.7 INCLINED AND PARALLEL EXTINCTION

Text

2.6.8 TEXTURES UNDER PLANE POLARIZED LIGHT

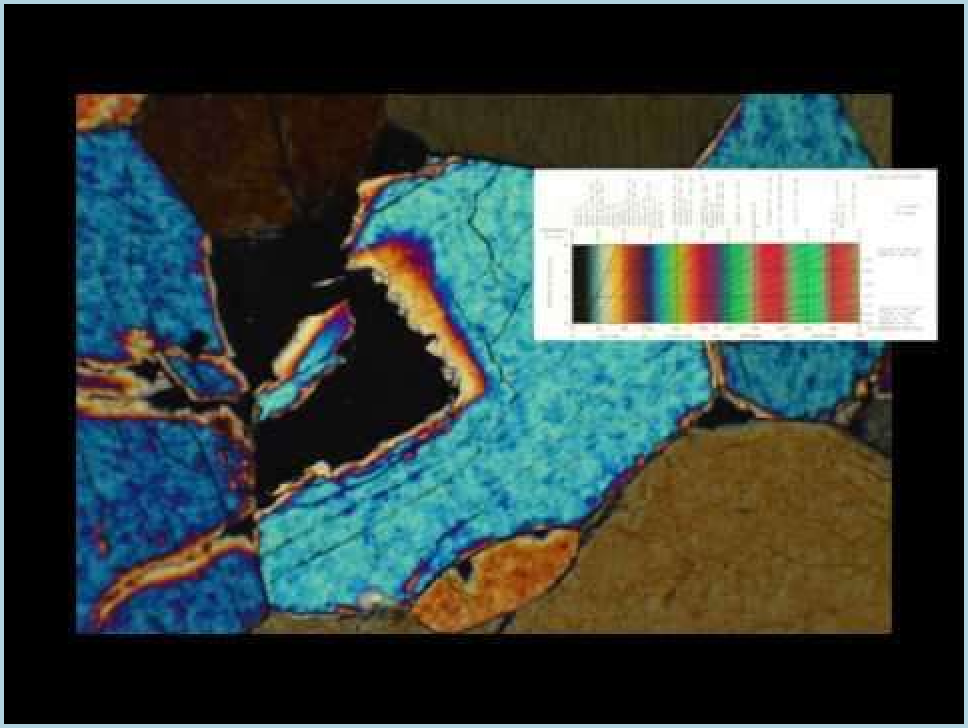
Text

Text

2.7 Properties Under Crossed Polarized Light

ELIZABETH JOHNSON, JUHONG CHRISTIE LIU, AND MARK PEALE

UNDER CONSTRUCTION



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2.7.1 ISOTROPIC VS. ANISOTROPIC MINERALS

Text

2.7.2 BIREFRINGENCE

Text

2.7.3 TEXTURES UNDER CROSSED POLARIZED LIGHT

Text

2.8 Interference Figures

ELIZABETH JOHNSON, JUHONG CHRISTIE LIU, AND MARK PEALE

UNDER CONSTRUCTION

2.8.1 HOW TO OBTAIN AN INTERFERENCE FIGURE

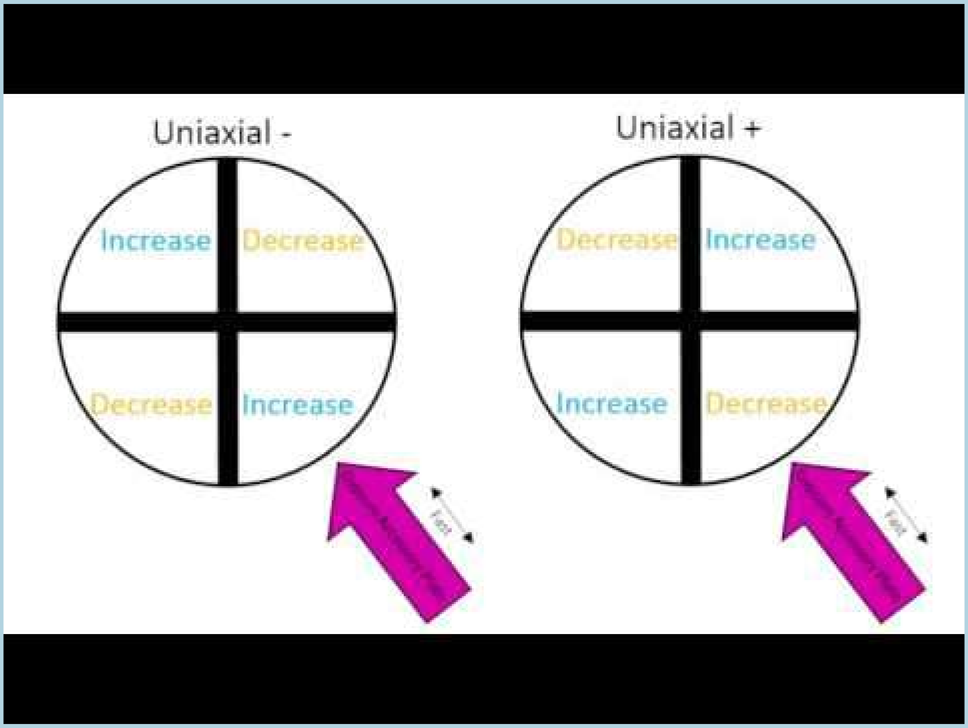
Text

2.8.2 INTERFERENCE FIGURES AND CRYSTAL SYMMETRY

Text

2.8.3 UNIAXIAL INTERFERENCE FIGURES

Text



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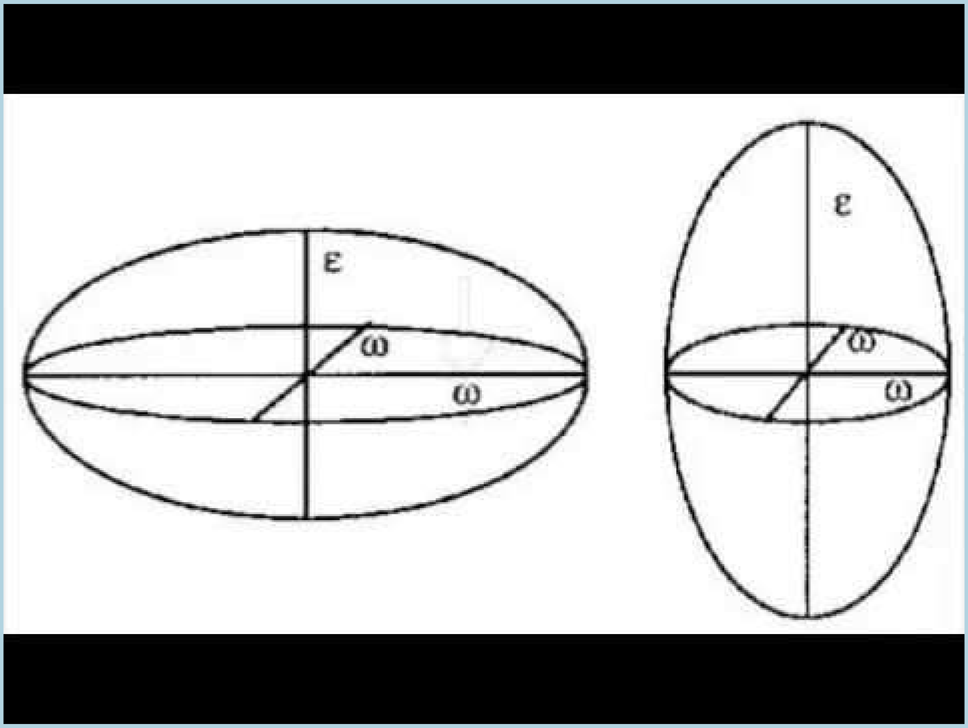

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2.8.4 BIAXIAL INTERFERENCE FIGURES

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2.8.5 SYNTHESIS: IS IT ISOTROPIC, UNIAXIAL, OR BIAXIAL?

Text

2.8.6 COMMON ISSUES WITH OBTAINING INTERFERENCE FIGURES

Text

http://www.minsocam.org/msa/Figures/Chapter5/Chapter5_21.html

2.9 Atlas of Minerals in Thin Section

ELIZABETH JOHNSON, JUHONG CHRISTIE LIU, AND MARK PEALE

Mineral Group	Mineral Name	Optical Properties from WebMineral	Optical Properties from Mindat	Optical Properties from Other Sources	Examples in Thin Section
Pyroxene	Orthopyroxene				
Pyroxene	Clinopyroxene				
Olivine	Forsterite				
Feldspar	Orthoclase	http://webmineral.com/data/Orthoclase.shtml#.XSYP--hKhGM	https://www.mindat.org/min-3026.html		
Feldspar	Sanidine				
Feldspar	Plagioclase				
Feldspar	Anorthoclase				
	Quartz				

2.10 Synthesis Exercises

ELIZABETH JOHNSON, JUHONG CHRISTIE LIU, AND MARK PEALE

2.10.1 DISTINGUISHING AMONG SIMILAR MINERALS IN THIN SECTION

Text

2.10.2 WHAT IS THIS MINERAL?

Text

INSTRUCTOR GUIDE

Welcome to the Instructor's Guide for "Introduction to Petrology."

For each module, we include:

1. Ideas and strategies for how to use the module material in your course, and
2. An answer key / guide to questions that are not answered within the text.

The answer keys are password-protected. If you are an instructor who wishes to access the keys, please contact us using the e-mail addresses below. We are happy to share!

Elizabeth (Liz) Johnson: johns2ea@jmu.edu

Juhong (Christie) Liu: liujc@jmu.edu

Module 1 [Overview]	Instructor's Guide	Answer Key
Module 2 [Petrographic Microscopes]	Instructor's Guide	Answer Key
Upcoming modules added here	Instructor's Guide	Answer Key
	Instructor's Guide	Answer Key
	Instructor's Guide	Answer Key

Module 1 Instructor Guide [Overview]

ELIZABETH JOHNSON, JUHONG CHRISTIE LIU, AND MARK PEALE

Module 1 provides an overview of the course. All guided inquiry questions in this section include interactive feedback, so answers are provided within the text.

Why not reveal our pedagogy to students? The content of this module is not necessary for understanding the other modules of the book. But, motivation to complete online readings and exercises could increase if students understand why they are being asked to do online guided inquiry learning exercises in addition to or as a replacement for other exercises or readings. It seems fair to let our students in on our educational strategies- they might help us learn something as well!

OPTIONS FOR USING THIS MODULE IN A COURSE

- Assign as a pre-class reading and ask students to turn in their guided inquiry answers as homework (online or in-person).
- In small groups or pairs, have students read Chapter 1.2 and compare their course outline to the outline of the book. This could lead to small group discussions followed by a class discussion. What strategies are you using as an instructor to help them effectively learn? How does the organization (or re-organization) of materials as presented in the book help you guide their learning?
- Similarly, students could read Chapter 1.3 on the uses of Petrology and then have a small group or class discussion on their interests and how they relate to topics covered in Petrology.

Module 1 Answer Key [Overview]

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Guided Inquiry

All of the guided inquiry questions in this section are interactive only, or are answered within the text.

Module 2 Instructor Guide [Petrographic Microscopes]

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Unit 4.2

The body of description of Unit 4.1 goes here.

Unit 4.1	Unit 4.2
Unit 4.3	Unit 4.4
Unit 4.5	Unit 4.6

Unit 4.1 || Unit 4.3

The main body of description goes here.

Unit 4.1	Unit 4.2
Unit 4.3	Unit 4.4
Unit 4.5	Unit 4.6

Unit 4.1 | | Unit 4.2 | | Unit 4.4

The main body of description goes here.

Unit 4.1	Unit 4.2
Unit 4.3	Unit 4.4
Unit 4.5	Unit 4.6

The main body of description goes here.

Unit 4.1	Unit 4.2
Unit 4.3	Unit 4.4
Unit 4.5	Unit 4.6

Unit 4.5 main body of text goes here.

Unit 4.1	Unit 4.2
Unit 4.3	Unit 4.4
Unit 4.5	Unit 4.6

Glossary

petrographic microscope

A **petrographic microscope** is a specific type of microscope used to look at geological materials, including thin sections, smear slides, and mineral mounts. A petrographic microscope includes two linear polarizers and an Amici-Bertrand lens, and often has multiple objective lenses and a rotating stage.

Index of Visual Digital Objects

H5P Interactive Objects	Title	Reference
h5p id="23"	Dispersion Effects	Nesse, W. (1987). Introduction to optical mineralogy. Applied Optics, 26, 3739. p. 28
h5p id="24"	Sphere Shapes	Nesse (1987), p.78
h5p id="21"	Becke Lines	Phillips, W. R. (1971). Mineral optics: principles and techniques (p. 249). San Francisco: WH Freeman. p. 53