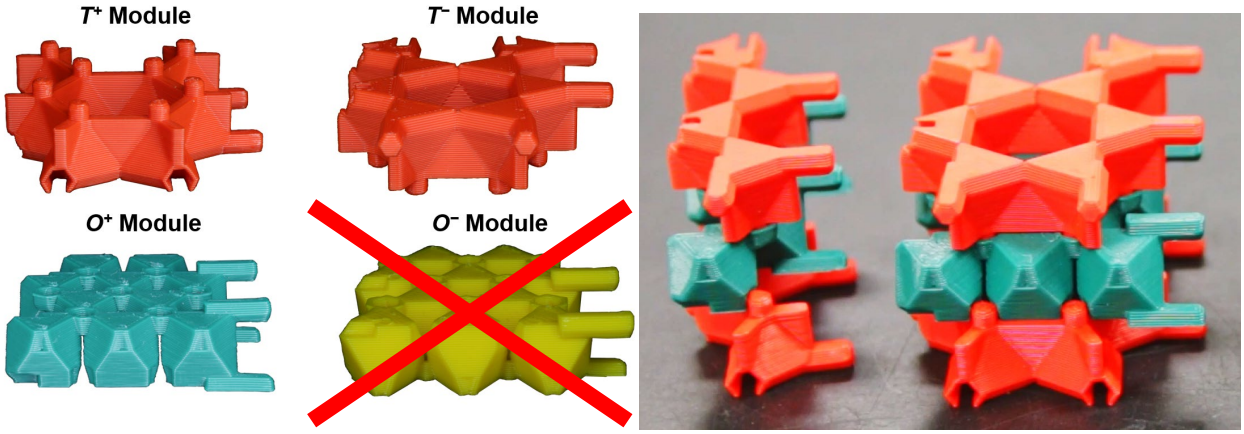
Optical Mineralogy Lab: Getting started with TotBlocks

The biopyriboles: LEGO-like minerals

Last revised May 2, 2023

The building blocks of modular rock-forming minerals consist of tetrahedral (*T*) and octahedral (*O*) modules. There are two different variations of each module, reflecting the direction that these modules point. We denote these two variations with '+' and '–', with + meaning that the apices of the polyhedra are pointing upward when the widthwise pegs are pointing rightward, whereas − means that the apices of the polyhedral are pointing downward. Note that the *T* modules are reversible, so the + and − notation is relative and not restricted to the modules themselves. For the *T* modules, we'll use both the T^+ and T^- variations. For the *O* modules, we will only use the O^+ modules (no O^- modules).



These modules are connected to make *T*-*O*-*T* modules. **In this lab, we'll keep the *T*-*O*-*T* modules together (we won't break them apart)**, but instead we'll look at how *T*-*O*-*T* modules can be linked together widthwise.

To unlink the *T*-*O*-*T* modules, always pull apart parallel to the pegs. Do not twist the pegs or they will break! However, if by chance a module breaks, don't worry. 3D printing is cheap; broken modules can easily be replaced. Please tell a TA if a module is broken.

The most important takeaway of this lab is to go through the experience of building crystal structures. The questions in this lab manual are there solely to guide you to think about the structural relationships between different minerals, as well as the fractal relationship between crystal structures and physical/optical properties.

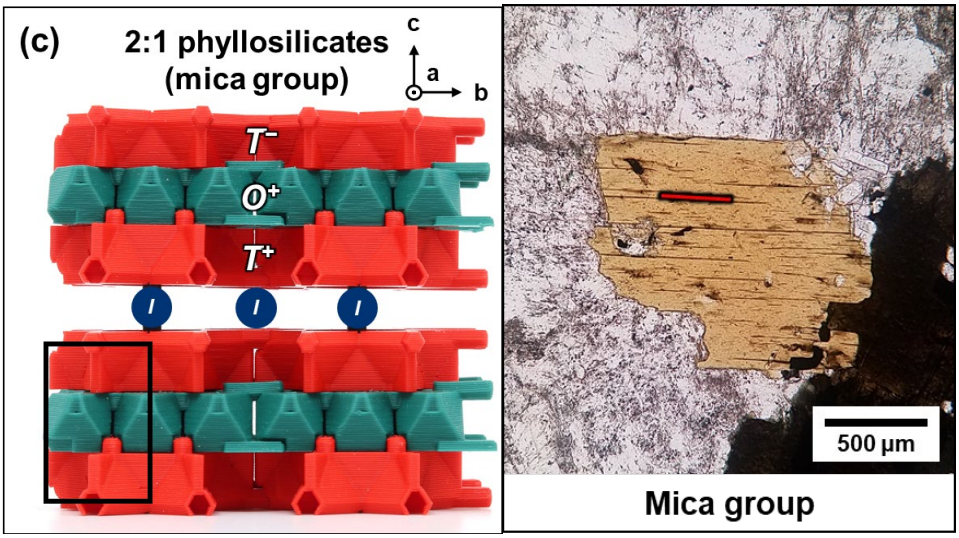
Lab activity

Mica group

1. The mica group, structural formula $\boldsymbol{IM_3T_4O_{10}A_2}$, is a 2:1 phyllosilicate with interlayer cations. The main mica-group minerals are annite-phlogopite (biotite series), $K(Fe^{2+},Mg)_3(AlSi_3O_{10})(OH)_2$, and muscovite, $KAl_2(AlSi_3O_{10})(OH)_2$.

   The red layers represent infinite sheets of vertex-sharing tetrahedra (*T*), commonly occupied by Si and Al; whereas the cyan layers represent infinite sheets of edge-sharing octahedra (*O*), commonly occupied by Mg, Fe, and Al. Black vertical pegs are used to hold the sheets together. In the space between the *T*-*O*-*T* modules is the interlayer (*I*), where large cations such as K, Na, and Ca reside (these are not shown by TotBlocks). To build the crystal structure of the mica group, follow the instructions below:

- Connect two sets of two double-chain-width *T*-*O*-*T* modules such that there is no vertical offset between the modules. The adjoined *T*-*O*-*T* modules represent the sheeted structure of the 2:1 phyllosilicates.
- To vertically stack individual sheets, vertical pegs are inserted into the slots of the O layer to form the connection. Note: The vertical pegs can be substituted for marbles or 3D-printed spheres with a 2 cm diameter, which represent the interlayer cation site.



b. Describe the cleavage of a mica (number of cleavages, angle). How does the crystal structure of the mica group dictate its cleavage? Mark the cleavage plane on the picture above.

c. Annite (the Fe-bearing member of the biotite series) commonly displays strong pleochroism. Given the sheeted crystal structure of annite and where Fe is located within it, explain why annite is strongly pleochroic.

d. Assuming that the substage polarizer is oriented N-S, when looking down (parallel to) the cleavage (see example photo above), is the absorption (*i.e.*, colour) stronger when the cleavage is oriented N-S or E-W?

    i. Check this on the microscope. Is this consistent with what you expected?

We will now **disassemble the mica structure** to demonstrate that the building blocks of the micas are the same as those found in the pyroxenes and amphiboles.

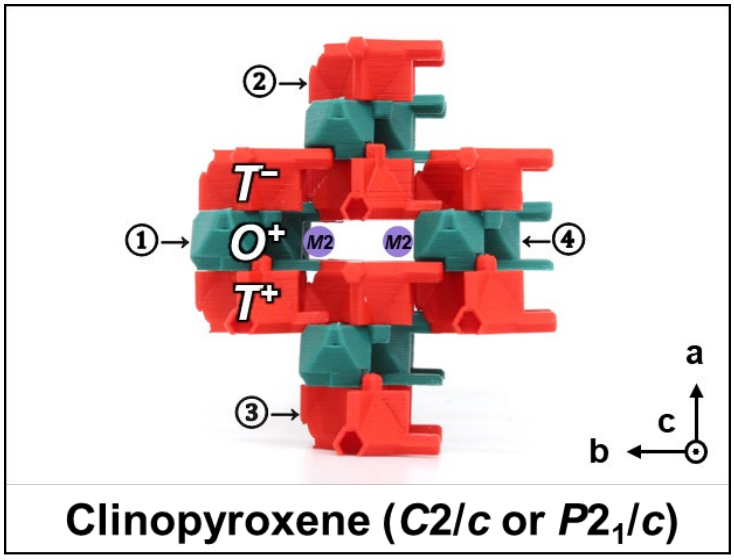
- Holding the mica structure sideways (one hand holding the top two *T*-*O*-*T* modules, the other holding the bottom two *T*-*O*-*T* modules), pull the two sets of modules apart to pull out the vertical pegs. **Do not twist the modules!**
- The grey vertical pegs will be stuck in one of the modules. Pull these pegs straight out of the modules.
- For each of the two sets of mica structures, hold one *T*-*O*-*T* module in each hand and **carefully** pull apart horizontally. **Do not twist the modules!** Repeat for the other set.
- You should now have four separate double-chain *T*-*O*-*T* modules and two vertical pegs. You won't need the vertical pegs anymore, so give these back to the TAs.

Pyroxene group

2. The pyroxenes are single-chain inosilicates with the structural formula ***M2M1*** $\boldsymbol{T_2O_6}$. Common pyroxenes include the enstatite-ferrosilite series, $(Mg,Fe^{2+})_2Si_2O_6$, and diopside, $CaMgSi_2O_6$.

   Aside from the *T*-*O*-*T* modules (hosting the *T* and *M*1 sites, respectively) in the structure, there is another site that borders the *O* modules (the *M*2 site), which is slightly larger than the *M*1 site in the *O* module (not shown). We'll focus on the building the crystal structure of the clinopyroxenes (see figure below):

- Connect one single-chain-width *T*-*O*-*T* module (labelled as ①) to a second single-chain-width module ② such that the T^- module of the first ① is joined to the bottom of the *O* module of the second ② [and top of *O* of ① joined to T^+ of ②].
- A third single-chain-module ③ can then be joined so that the T^+ of the first module ① is joined to the top of the *O* module of the third [and bottom of *O* of ① joined to the T^- of ②].
- A fourth *T*-*O*-*T* module ④ is joined to the second ② and third ③ *T*-*O*-*T* modules.

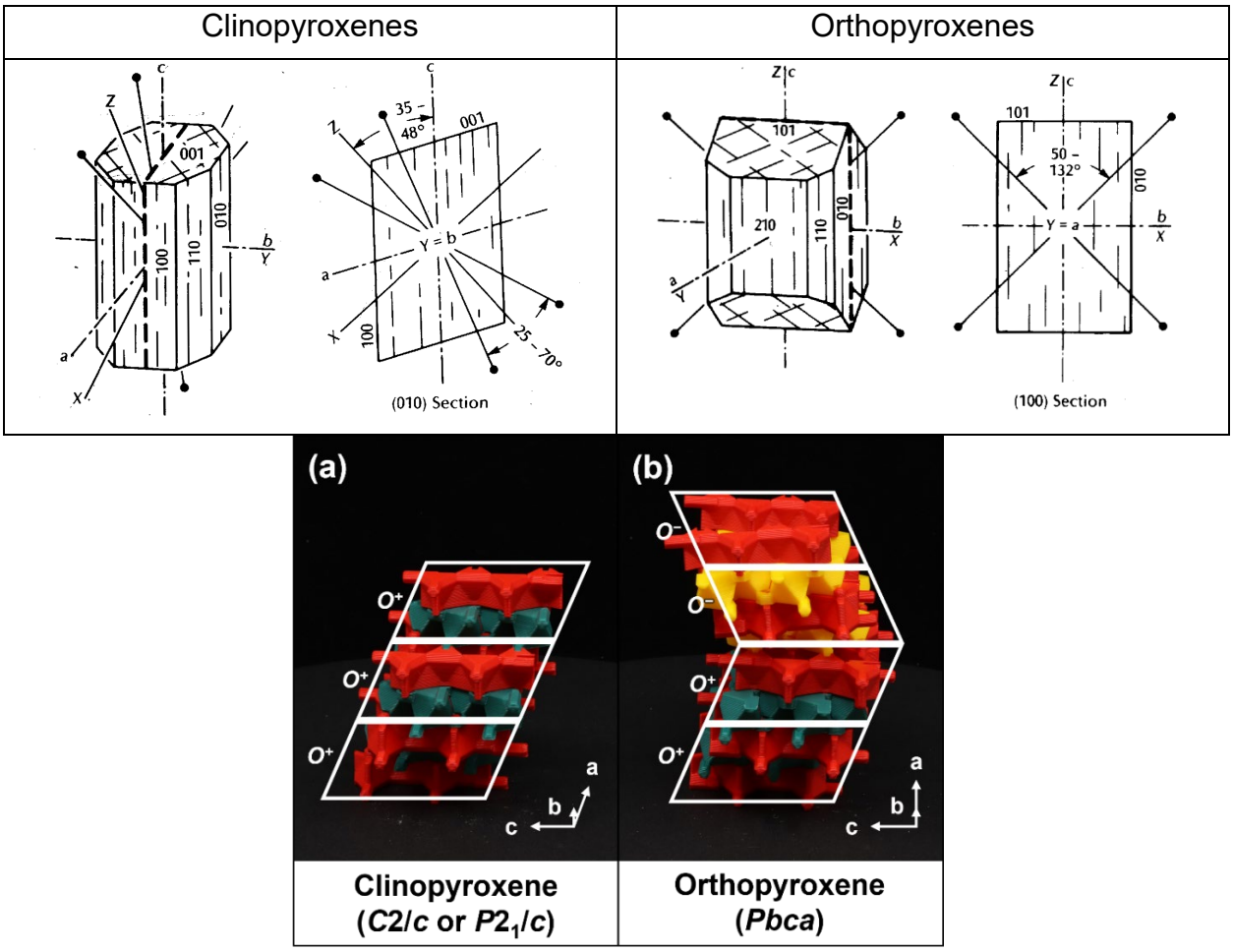


Clinopyroxene (*C*2/*c* or $P2_1/c$)

   a. Based on the assembled structure, what type of cleavage (number, angle) would a clinopyroxene display when viewed along the *c* axis ([001]), as shown on the figure above? Draw this on the figure.

   b. Clinopyroxenes can be distinguished from orthopyroxenes by their extinction angles. The figures on the next page (top set) show the orientations of the principal vibration directions (X, Y, and Z) with respect to the crystallographic axes (*a*, *b*, and *c*) for clinopyroxenes (top) and orthopyroxenes (bottom), along with the orientations of the two cleavage planes. The bottom set of figures show the clinopyroxene and

orthopyroxene structures in side view, showing the differences in stacking and symmetry between the two pyroxene structures.



Images from pp. 205 and 209 in Introduction to Optical Mineralogy by Nesse (1991; top set) and Leung and dePolo (2022; bottom set).

ii. Based on the assembled clinopyroxene structure and the figures above, which orientation (*i.e.*, looking down *a*, *b*, or *c*) would show inclined extinction? What kinds of extinction do the other two orientations show?

iii. Why is this relevant when it comes to differentiating clinopyroxenes from orthopyroxenes? In other words, can you use any orientation to distinguish between clinopyroxenes and orthopyroxenes?

We will now disassemble the clinopyroxene structure back into the four *T*-*O*-*T* modules with which we started. Be sure to pull the modules straight along the direction of the widthwise pegs. **Do not twist the modules!** Also, do not attempt to disassemble the modules themselves.

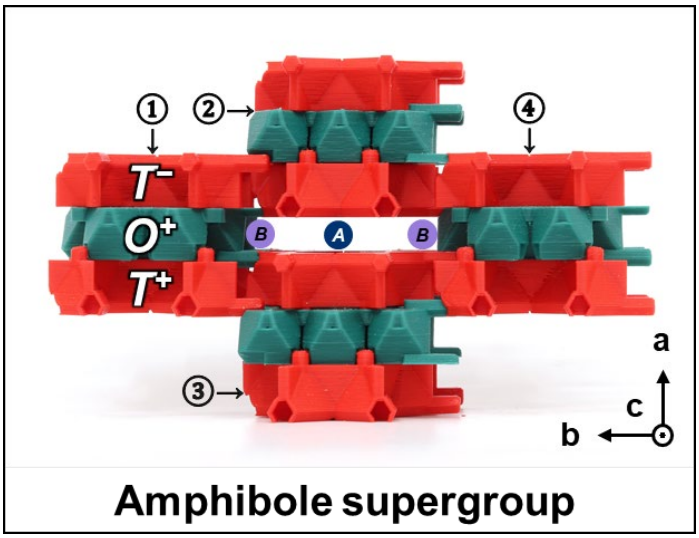
1. Connect two single-chain modules side-by-side so that there is no vertical offset.
    a. How are pyroxenes structurally related to amphiboles?

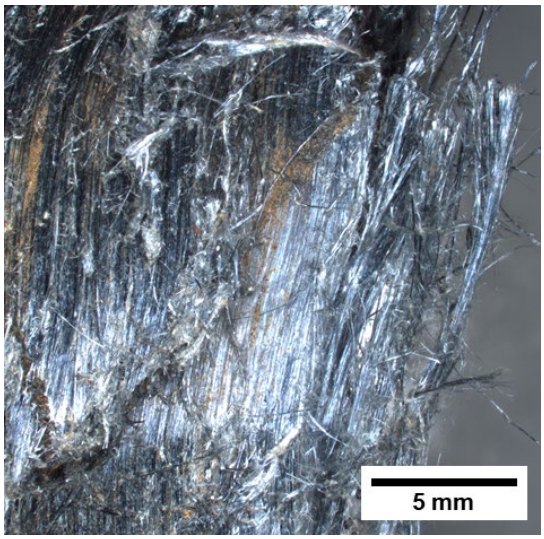
Amphibole supergroup

3. The amphiboles are double-chain (ino-)silicates with the general structural formula $\boldsymbol{AB_2C_5T_8O_{22}W_2}$ and include the following minerals: cummingtonite-gruenerite series, $(Mg,Fe^{2+})_2(Mg,Fe^{2+})_5Si_8O_{22}(OH)_2$; hornblende series, $Ca_2(Mg,Fe^{2+},Al)_5(Si,Al)_8O_{22}(OH)_2$; and tremolite-actinolite series, $Ca_2(Mg,Fe^{2+})_5Si_8O_{22}(OH)_2$.

   Like the pyroxenes, the crystal structure of the amphiboles contains an extra site that borders the *O* modules called the *B* (or *M*4) site. Like the micas, there is also a site that lies in between the *T*-*O*-*T* modules (*A* site). We'll focus on constructing the clinoamphibole structure (see figure below):

- Connect one double-chain-width *T*-O^+-*T* module ① to a second double-chain-width module ②, such that the T^- module of ① is joined to the bottom of the *O* module of ② (the top of *O* for ① will also connect to the T^+ of ②).
- A third double-chain module ③ can then be joined so that the T^+ of the first module ① is joined to the top of the *O* module of the third ③ (the bottom of *O* for ① should also join to the T^- of ③).
- A fourth module ④ is joined to the second ② and third ③ modules.





   b. Now, let's consider the cleavages of the pyroxenes, amphiboles, and micas all together. You should have the assembled structures of the pyroxenes and amphiboles in front of you. For reference, there is an extra mica structure on display at the front of the classroom. The pyroxenes have the shortest module width (single chains), followed by the amphiboles (double chains), and the micas consist of sheets.

      i. As the module width increases from single to double chain, how do the cleavage angles change?

      ii. What would you expect to be the cleavage for a mineral with a wider width of modules (*e.g.*, triple chains)?

iii. What would you expect in terms of cleavages for a mineral with an infinitely wide module, and what is this mineral?

We will now disassemble the amphibole structure back into the four *T*-*O*-*T* modules with which we started. Be sure to pull the modules straight along the direction of the widthwise pegs. **Do not twist the modules!** Also, do not attempt to disassemble the modules themselves.

1. Now let's extend the four double-chain modules lengthwise (along the c axis).
    a. What crystal habit(s) would this structure produce (hint: see photo above)?
    c. What health effects have been associated with these habits?

Questionnaire (5 min)

Circle the word that best describes your experience:

I understand the modular relationships between 2:1 phyllosilicates, pyroxenes, and amphiboles **better/worse/the same** as before completing this lab.

I understand pleochroism **better/worse/the same** as before completing this lab.

I understand cleavage **better/worse/the same** as before completing this lab.

I understand extinction angles **better/worse/the same** as before completing this lab.

Free response questions:

What was your experience of building crystal structures with TotBlocks like (*e.g.,* were the instructions clear?)

Things in this lab that went well:

Things in this lab that were confusing:

Additional comments: