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A simple method to create mineral mounts in thin section for teaching optical mineralogy

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Abstract

Mineral separates mounted in thin section help introduce mineralogy students to concepts of relief, color, pleochroism, and birefringence and serve as reference materials both for research and teaching. Here, a simple method is described to produce materials that can be sent to thin section manufacturers to construct sets of mineral mounts. The method is relatively inexpensive, requires only simple equipment and few skills, and allows mounting of multiple minerals (easily 10–20) in a single thin section. The key to the method is to create first a slurry of 500–1000 mg of each crushed mineral plus ~300 mg (500 μL) of epoxy and use a microspoon spatula to spoon each slurry into a 4 cm long tube made from 6 mm (or ¼″) diameter, standard wall, glass tubing. After epoxy sets, the 4 cm long tubes can be bundled together and shipped to thin section makers, who can set the bundles in epoxy (ends down) and make 10 or more duplicate sections. Photomicrographs are presented for selected mineral reference slides produced by this method, along with detailed instructions on how to create them. These methods allow both randomly oriented mineral separates and oriented crystals to illustrate isotropic appearance in quartz and reverse pleochroism in tourmaline.

Keywords: Optical mineralogy, thin section, pleochroism, birefringence, relief, color, education

Introduction

Of geoscience programs in the United States, 85–90% require a course in mineralogy or Earth materials, while 70–80% require igneous and metamorphic petrology (e.g., Viskupic et al. 2020; Klyce and Ryker 2023). These courses commonly include some level of optical mineralogy, which forms a foundation for the identification of minerals and diagnosis of a rock's petrogenesis. Thus, undergraduate students gain key practical and theoretical skills when they learn how to use the optical properties of minerals to investigate mineralogy and petrology (e.g., Gunter 2004; Reinhardt 2004). Historically, commercial thin sections were available that illustrated differences in the optical properties of minerals. For example, multiple mineral separates might be mounted in a single thin section with sequentially increasing refractive index, Δ (maximum difference in refractive index or birefringence), variations in color, etc. However, such materials are unavailable today, leaving a gap in educational resources for mineralogy and petrology instructors.

Here, a simple method is described by which reference slides of minerals may be created to illustrate systematic differences among minerals in relief, color, pleochroism, and birefringence. The method requires relatively few resources or technical skills. In fact, undergraduate students may participate in the key steps in constructing the needed materials. The process is described starting with separation of minerals, mounting in a way that provides for multiple reference thin sections, and, if desired, further processing to create custom thin sections. Because many universities no longer maintain thin section making facilities, the goal is not to make thin sections per se but instead to create materials that can be sent to a commercial thin section lab for processing.

Methods

Overview

The basic process consists of the following steps:

(1) Make or obtain pure mineral separates of a convenient mass and size fraction (Fig. 1).

(2) Mix minerals with epoxy to create a bubble-free slurry (Fig. 2).

(3) Spoon slurry into cut glass tubes and cure to make "sticks" (Fig. 3). These sticks can be shipped to thin section makers directly.

The following steps are optional:

(4) Special orientations of minerals—quartz and tourmaline (Fig. 4)

(5) Cut sticks into ca. 1 mm thick disks (Fig. 5).

(6) Mount disks into epoxy blocks (Fig. 6). These blocks can be shipped to thin section makers, similarly to standard rock billets.

The following sections detail each of these operations. Note that any reference to commercial products does not constitute or imply endorsement of those products.

Make or obtain pure mineral separates

Making or obtaining pure mineral separates is possibly the most challenging step in this process. Some companies sell mineral separates (e.g., Ward's Science), but the quality cannot be guaranteed, and many separates contain grains that are altered or contain inclusions. Fortunately, a few minutes of hand-picking can remove contaminants. One of the simplest ways to obtain pure minerals is simply to buy single crystals or "gems" (sensu lato) through online retailers (Fig. 1a). Otherwise, separating minerals from polymineralic rocks can be challenging. For example, apatite, sillimanite, orthopyroxene, and andalusite are useful for teaching relief, birefringence, and pleochroism but can be difficult to separate to >98% purity in typical rocks because they rarely dominate a rock's mineralogy. However, commercial sources can readily supply large apatite crystals (from localities such as Durango, Mexico or Bancroft, Ontario) or apatite separates, necklaces of sillimanite or andalusite beads, and large polished cabochons of "bronzite" orthopyroxene (Fig. 1a). Synthetic sources are also possible for some minerals (e.g., sulfur, garnets, rutile), but their crystal habit can differ from natural minerals. The Online Materials[1] provide commentary on useful sources for diverse minerals, with the goal of keeping costs to a minimum while maintaining high purity. The most problematic mineral separates might be for

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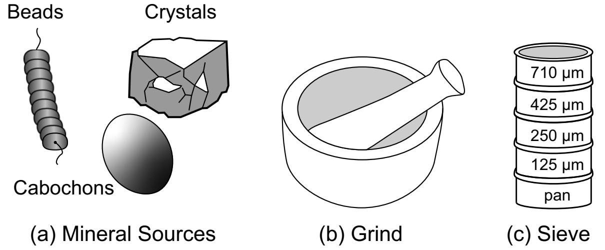

Figure 1. Simple sources of pure minerals and initial processing to make mineral separates. (**a**) Single crystals and jewelry. (**b**) Grinding in mortar and pestle. (**c**) Sieving.

micas, not because it is difficult to obtain pure materials but because grinding them is tedious. In this case, if mineral separation facilities are available, it can be more expedient to grind and sieve a fine- to medium-grained rock to a useful grain size, then separate micas using standard magnetic separation and shaking on an inclined piece of paper (sheet silicates will tend to remain while other minerals roll off). Another problematic mineral is K-feldspar, which is commonly turbid. This issue is discussed in more detail below.

Once a pure mineral is obtained, it can be ground in a mortar and pestle (Fig. 1b) and sieved to a grain size of between 150 and 750 μm (Fig. 1c). Most separates for this project were sized to between 250 and 425 μm. For the method described here, this range provides 2–3 dozen grains at different orientations for each mineral in a thin section. Larger sizes tend to produce too few grains to be representative, while finer grain sizes produce numbers that are overwhelming.

Mix minerals with epoxy to create a bubble-free slurry

Two options are possible. First, mixing epoxy very slowly can avoid bubbles. This epoxy can then be pipetted into a microcentrifuge tube using either a standard pipettor (if pipetting by volume) or a disposable transfer pipette (if pipetting by weight; Fig. 2a). The mineral separate can then be weighed and poured on top of the epoxy (Fig. 2b) and (normally) gravity will settle grains with minimal bubbles. Alternatively, if a centrifuge is available, epoxy can be mixed vigorously, introducing bubbles, and then centrifuged to remove them. The epoxy is then pipetted into a microcentrifuge tube, mixed vigorously with a mineral separate, which reintroduces bubbles, then centrifuged again to remove them. The proportions of mineral to epoxy in this work were 0.5–1 g of mineral (depending on density) and 0.3 g (500 μL) of epoxy. Less dense minerals (quartz, feldspar) require less material than denser materials (rutile, cassiterite). Any excess epoxy can be pipetted off the top of the slurry using a disposable transfer pipette.

Spoon slurry into cut glass tubes and cure to make sticks

Virtually any glass tubing can serve as a mold for the mineral slurry. This study employed Vycor (96% quartz) tubing simply because we had excess in stock from other projects, but Pyrex or other sodium borosilicate glass tubing would likely also work. Plastic mold material should be avoided because it can smear when attempting to make a thin section (Matt Selden, Spectrum Petrographics, personal communication 2023). Either ¼″ or 6 mm diameter, standard wall tubing served well. Smaller diameter tubing reduces the number of grains (unless they are ground finely), while larger diameter tubing requires much more mineral separate per tube. Tubing can be cut to length simply by scoring with a metal file, or diamond wafering saw (if available), moistening the score mark with either water or saliva (e.g., with a wet finger), then applying bending pressure to snap the tubing along the scoring mark (Fig. 3a). In this study, standard tube lengths were 4 cm. Sharp edges are not normally a problem, but for safety can be ground down either with sandpaper or (more quickly) on the edge of a diamond saw.

Holding each tube vertically, a mineral slurry can be spooned into the top of the open tube using a microspoon spatula (Figs. 3b–3c). The slurry will mound on the top of the tube and slowly slide downward with a minimum of bubbles (Figs. 3d–3e). As the mound diminishes in size, more slurry can be spooned on top. If the slurry progresses too far down the tube, such that a gap appears at the top of the tube, the addition of slurry risks creating a bubble. In this case, the tube can be inverted for a few seconds until the mound reforms before reverting to its original orientation and adding more slurry. Ultimately, a length of several centimeters of filled tube is created. Tubes are then laid on their sides and cured at room temperature to form "sticks" (Fig. 3f). Surface tension prevents the slurry from leaking out the open ends. The total amount of time needed to prepare each stick, from crushing and sieving minerals to setting them to cure (but not including curing), is about 45 min.

Mineral sticks can be arranged (bundled) into blocks and shipped to a commercial thin section maker. Note that typical thin sectioning equipment removes 1–2 mm per cut. Including loss to polishing, no more than ~10 thin sections should be anticipated with this method.

Optional: Special orientations of minerals—quartz and tourmaline

Although the purpose of this project was not to provide special orientations for minerals (e.g., to show centered BxA figures or centered optic axes), some special orientations for quartz and tourmaline are especially valuable for teaching about birefringence and pleochroism. For quartz, sections perpendicular to the c-axis are simple to create. Hundreds of small crystals ("matchstick points"; Fig. 4a) can be purchased inexpensively, and invariably these points are elongate parallel to the c-axis. Some will have maximum diameters (~4 mm) that allow them to barely slip inside the glass tube. Such a point is inserted into a tube (Fig. 4a), pipetting or spooning epoxy into the open end. Gravity and surface tension pull the epoxy down and around the quartz point with a minimum of bubbles. Any cuts perpendicular to the tubing will also be perpendicular to the c-axis of the quartz grain.

Tourmaline exhibits reverse pleochroism (darker when elongation is perpendicular to the principal polarization direction of the lower polarizer) and forms an instructional contrast to most other silicates, especially biotite, chlorite, hornblende, etc. Although, like quartz, tourmaline is commonly elongate parallel to its c-axis, separation of small elongate crystals is tedious. A more straightforward method uses a diamond wafering saw to cut strips out of large tourmaline crystals. First, a slab of tourmaline, thinner than the internal diameter of the tubing (e.g., 3½ mm), is cut perpendicular to the c-axis of the crystal (Fig. 4b) and glued to a glass slide. Then, strips are cut with widths that are less than the thickness of the slab (e.g., 1 mm; Fig. 4b). In cross-section, the elongation of the strip is thus parallel to the c-axis

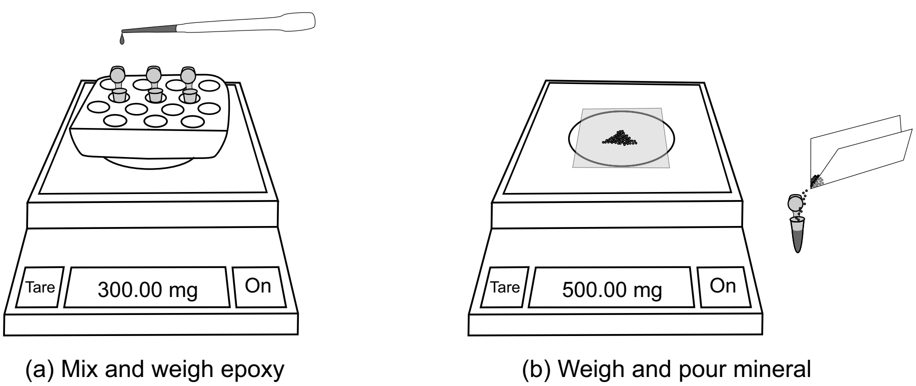

Figure 2. Preparing mineral slurries. (**a**) Pipetting mixed epoxy into microcentrifuge tube on the scale. (**b**) Weighing mineral on scale and pouring into microcentrifuge tube (with weighed epoxy).

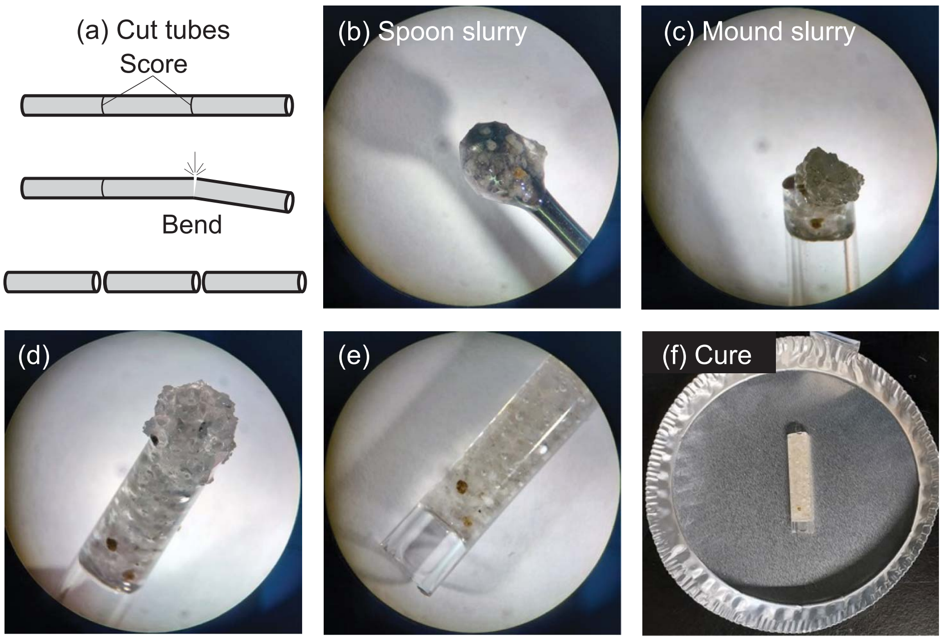

Figure 3. Preparing mineral "sticks." (**a**) Cutting glass tubing. (**b**) Spooning slurry; spoon is ~6 mm across. (**c**) Initial application of slurry to end of tube. (**d**) Intermediate stage of tube filling. (**e**) Slurry has nearly reached the opposite end of the tube. (**f**) Curing the "stick" in an aluminum pan.

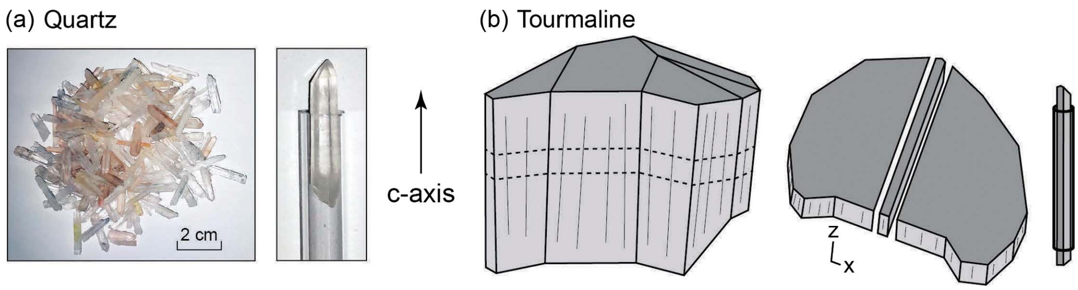

Figure 4. Preparing special orientations of quartz and tourmaline. (**a**) "Matchstick points" of quartz can be purchased in bulk, and some will have diameters that just fit inside glass tubing. Any section cut perpendicular to the tube will also be perpendicular to the quartz c-axis. (**b**) Tourmaline is first cut perpendicular to the c-axis (or nearly so) into a slab of thickness z. A strip is then cut of width x, such that the x < z. A cross section of this strip will be elongate parallel to the c-axis and exhibit reverse pleochroism.

of the crystal and shows reverse pleochroism. The strip is inserted into a tube, and epoxy is pipetted around it, similar to the technique used to mount quartz points.

Optional: Cut sticks (filled tubes) into 1 mm thick disks and mount into epoxy blocks

A more frugal use of material employs a wafering saw (Fig. 5). In this study, a Buehler IsoMet low-speed precision cutter was equipped with a 4″ diameter, ultra-thin (0.004″ or 0.1 mm thick) saw blade. This blade removes as little as 250 μm of material per cut (the cutting portion of the blade is thicker than the core), so up to 25 disks, 1 mm in thickness, can be cut from each stick. Mineral disks can be arranged systematically and cast into a block of epoxy. First, double-stick tape is affixed to a glass plate. Our glass plates are ¼″ × 2″ × 2″ (6 mm × 5 cm × 5 cm), and we use Bertech polyimide tape, 1½″ (3.8 cm) in diameter. Disks are flattened on coarse sandpaper, then flat surfaces are pressed onto the tape (Fig. 6a). A 1″ × 2″ × ¼″ (2.5 cm × 5.1 cm × 6 mm) aluminum sleeve is coated with a release agent on the inside, then pressed onto the tape around the disks (Fig. 6b). Epoxy is then poured over the disks and cured overnight. The aluminum sleeve is removed by prying off the tape with a wrench (Fig. 6b), and the epoxy block with mineral disks is pressed out of the sleeve (Fig. 6c). This block broadly resembles rock billets (Fig. 6c) and can be sent to manufacturers for a single thin section (Fig. 6d).

Results

For this project, single slides were designed to illustrate color and pleochroism (combined), relief, and birefringence for 3 reference slides for these optical properties. The number of minerals per slide was 19 for color and pleochroism, 15 for birefringence, and 14 for relief. Ultimately, 3 minerals were dropped from color and pleochroism (a biotite type, pale actinolite, and dumortierite) for a standard set of 16. For the relief and birefringence reference slides, colorless minerals were preferred.

With a few exceptions of minerals from the author's research collection (chlorite, gedrite, glaucophane) and some more expensive minerals (e.g., piemontite, relatively colorless zircon, synthetic rutile), most of these minerals are available commercially at little expense. See the Online Materials[1] for commentary on sources and options. Some effort was made to choose reference minerals that are either instructional in the context of petrology or extremely

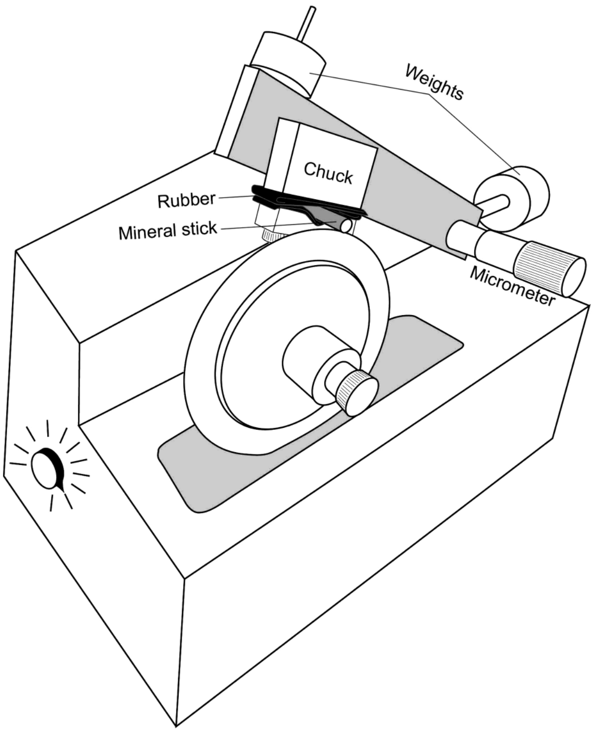

Figure 5. Cutting a mineral stick on a wafering saw. The stick is protected with layers of rubber (from a bicycle inner tube).

common (e.g., all three aluminosilicates; as well as olivine, clinopyroxene, orthopyroxene, hornblende, quartz, K-feldspar). However, not all common minerals (e.g., plagioclase) are represented because other minerals bracket or have comparable optical properties.

Color and pleochroism

The original design for the relief slide contained 19 minerals arranged from brown minerals (as seen in plane-polarized light) to green to pink to yellow to blue. Specific minerals in the initial test section were biotite (3 types), tourmaline, hornblende (2 types), gedrite, acmite, actinolite, calcic clinopyroxene, chlorite, "bronzite" (orthopyroxene), andalusite, "rosalite" (commercial name for pale piemontite; not roselite), piemontite, staurolite, epidote, dumortierite, and glaucophane. Ultimately, only two biotite varieties were used, actinolite was dropped because it was insufficiently pleochroic, and dumortierite was dropped as it tends to pluck, leading to slides with 16 minerals. Examples of minerals are shown in Figure 7.

Relief

The design for the relief slide contains 14 minerals (numbers in parentheses represent typical indices of refraction): cryolite (1.34), fluorite (1.43), K-feldspar (1.52), quartz (1.54), K-feldspar plus quartz (1.52, 1.54), muscovite (1.58), apatite (1.64), enstatite (1.66), olivine (1.70), garnet (1.80), scheelite (1.90), cassiterite (2.10), synthetic rutile (2.75), and calcite (variable). Examples of minerals are shown in Figure 8.

Birefringence

The design for the birefringence slide contains 15 minerals (numbers in parentheses refer to the maximum difference in refractive index, Δ): fluorite (0.000); apatite (0.004); quartz (0.009); quartz perpendicular to c-axis (0.000); kyanite (0.015); sillimanite (0.022); lepidolite (0.029); olivine (0.033); muscovite (0.040); talc (0.050); zircon (0.059); datolite (0.069); cassiterite (0.107); calcite (0.172); and sulfur (0.287). Examples of minerals are shown in Figure 9.

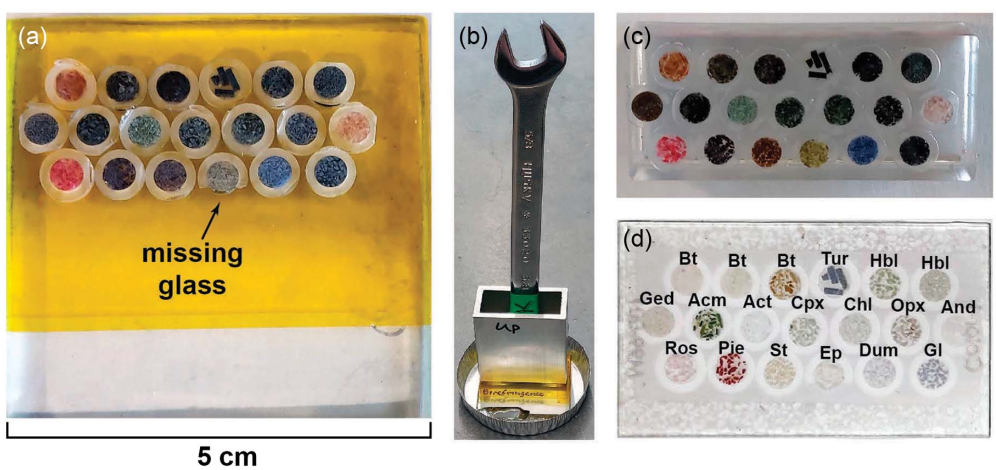

Figure 6. Preparing an epoxy block. (**a**) 1 mm thick disks are pressed into double-stick tape. Note that glass has separated in some disks, and some disks are ground slightly to take up less space. (**b**) Aluminum sleeve is used as a mold, and epoxy is backfilled to form a block. Wrench provides leverage to remove mold from plate after epoxy has cured. (**c**) Finished block. Abbreviations: Bt = biotite; Tur = tourmaline; Hbl = hornblende; Ged = gedrite; Acm = acmite; Act = actinolite; Cpx = clinopyroxene; Chl = chlorite; Opx = orthopyroxene; And = andalusite; Ros = rosalite (commercial name); Pie = piemontite; St = staurolite; Ep = epidote; Dum = dumortierite; Gl = glaucophane.

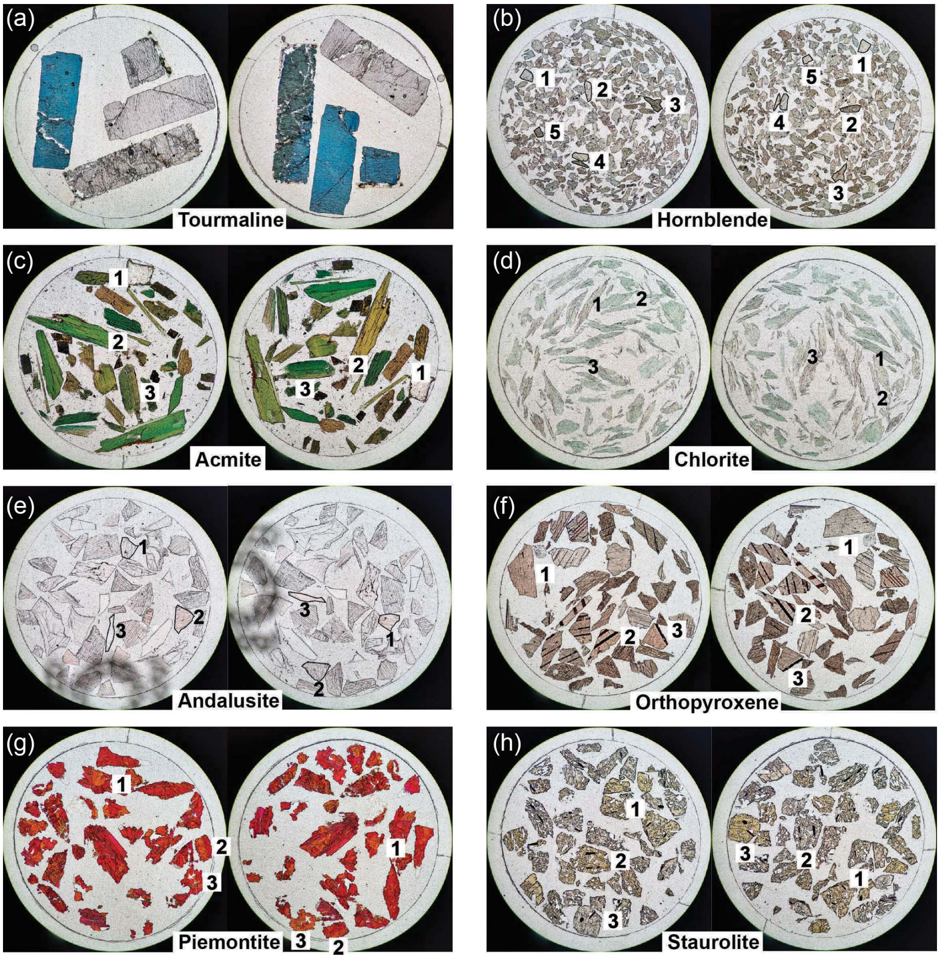

Figure 7. Images from a color and pleochroism reference slide. All images are in plane-polarized light, and the right image for each pair is rotated ~90° clockwise. Field of view is ~5 mm. Numbers in some images are positioned next to relatively pleochroic grains. Unless otherwise stated, grains were sieved to between 250 and 425 μm. (**a**) Specially prepared tourmaline, showing dark blue, reverse pleochroism (darker when grains run vertically in this image). (**b**) Fine-grained hornblende (125–250 μm) with green to brown pleochroism. Several grains are outlined in black for clarity. (**c**) Acmite with bright green to brownish-green pleochroism. Not all grains are pleochroic. (**d**) Chlorite with faint green pleochroism. (**e**) Andalusite with faint pink pleochroism. Grains are outlined in black for clarity. (**f**) Orthopyroxene with faint pink pleochroism. Green pleochroism is extremely subtle. Dark bands are oxide alteration along cleavage planes. (**g**) Piemontite, showing strong dark pink to orange pleochroism within domains. (**h**) Staurolite with faint yellow pleochroism.

Discussion

Advantages and disadvantages of mineral separates

Mineral separates confer two main advantages over thin sections of rocks. First, a large number of minerals can be mounted in a single slide and arranged systematically with respect to optical property to facilitate comparison (Figs. 6d and 7–9). Second, the use of glass tubing constrains each mineral separate, so that they are easy for students to find. In addition, the extensive range of refractive indices clearly illustrates the similarity between positive and negative relief. For example, the epoxy used for mounting disks (EMS Epofix) has an index of refraction of n~1.55, so K-feldspar (n~1.52; Fig. 8c) shows slightly higher (negative) relief than quartz (n~1.54; Fig. 8d). At the low-n extreme, cryolite (n~1.34; Fig. 8a) appears to have relief comparable to garnet (n~1.8; Fig. 8i).

Three main disadvantages are also apparent. First, mineral separates and glass tubing are more difficult to polish than rocks, and plucking can be problematic. This is more apparent for some minerals (e.g., kyanite; Fig. 9c) than others (e.g., quartz; Fig. 9b). Second, most of each slide contains no minerals, so the amount of background transmitted light far exceeds that in typical thin sections. Excess light renders color and pleochroism more subtle than in typical thin sections (e.g., Figs. 7d–7f). Third, stress accumulates around the edges of grains and at fractures in the glass, so the epoxy is not always completely isotropic (e.g., Fig. 9a). This may cause some confusion for students.

Minor issues include slightly impure separates (cryolite; Fig. 8a) and inclusions (staurolite; Fig. 7h). Sheet silicates also tend to orient such that they are parallel to tube walls on the sides and perpendicular in the center. Preferential orientation affects pleochroism (generally more obvious on the sides than in the center) and interference colors (generally higher on the sides than in the center). Epoxy tends to separate from glass walls, so some disks lack pieces of the glass ring (e.g., epidote, Fig. 6a). This does not affect the minerals but does mean that some minerals are not completely encircled by glass. This problem is specific to construction of disks and should not be an issue if whole sticks are sent to thin section makers for multiple sections.

Implications

Future improvements

Epoxy. This project used a single type of epoxy with a particular refractive index. Other epoxies might mitigate plucking, be less susceptible to stress-induced birefringence, or adhere

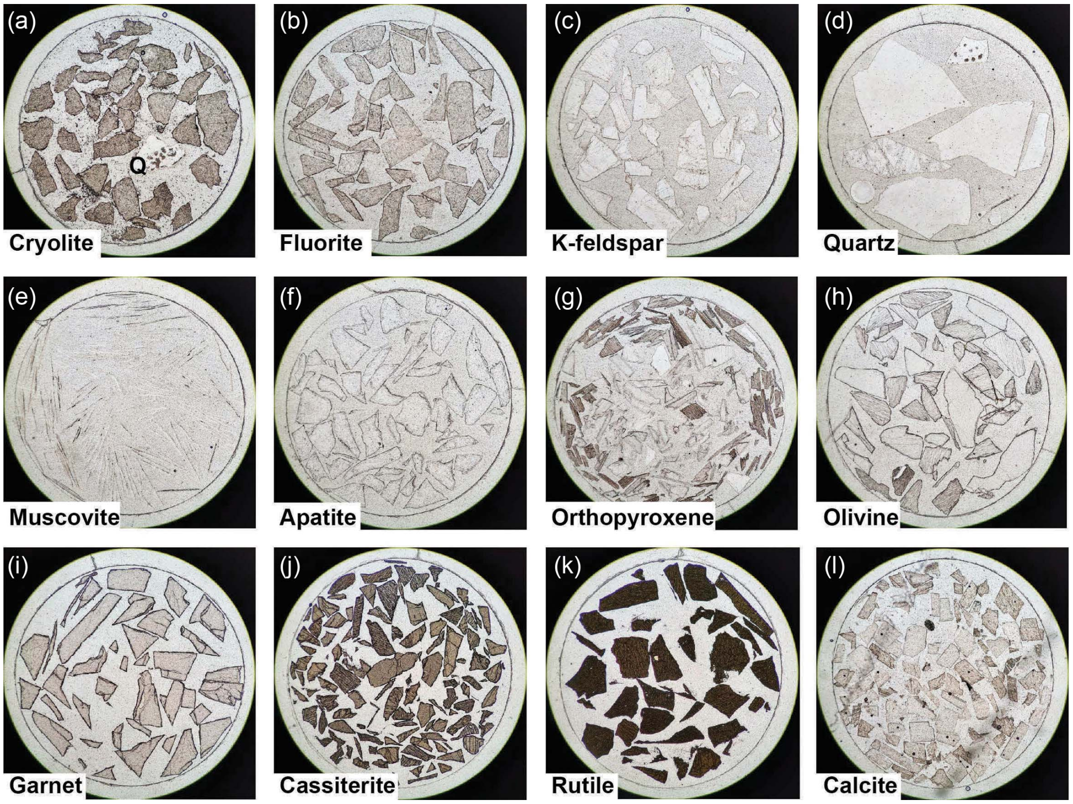

FIGURE 8. Images from a relief reference slide. (**a**) Cryolite (extreme negative relief). Q = quartz grain. (**b**) Fluorite (negative relief). (**c**) K-feldspar. (**d**) Quartz; grains sieved to between 500 and 1000 μm. (**e**) Muscovite (indistinct in this epoxy). (**f**) Apatite. (**g**) Orthopyroxene. Apparent high relief represents finely space cleavages. (**h**) Olivine. (**i**) Garnet. (**j**) Cassiterite. (**k**) Rutile. (**l**) Calcite, showing characteristic variable relief.

better to glass tubing. Other epoxies were not systematically surveyed, but optical adhesive did not harden in the centers of tubes, even after 2 h curing time, probably because glass is relatively opaque to UV radiation, and the sticks may be too thick to permit effective UV light penetration. With the correct choice of epoxy and mineral separates, additional teaching goals could be met, for example, observing differences in Becke lines for the same mineral in different epoxies. Jensen and Kackstaetter (2021) reviewed numerous sources of epoxies, although not the EMS Epofix used in this study. Refractive indices for epoxies that satisfied basic mounting requirements (minimal bubbles, no delamination) ranged down to ~1.4, with most between 1.49 and 1.53. This range provides opportunities for observing subtle optical property differences (e.g., Becke lines) among minerals with lower indices of refraction, especially feldspars, quartz, etc.

Relief. Relief might be better illustrated using minerals that either lack cleavage or are in the cubic crystal system. Otherwise, cleavages can make relief appear variable (e.g., compare orthopyroxene or olivine vs. garnet, Figs. 8g–8i). However, there are far fewer non-cleavable or cubic crystal system minerals, so a systematic distribution of relief is harder to develop. In addition, illustrating the variability of the appearance of common minerals may confer instructional advantages.

Rare minerals. Obtaining up to 1 g of pure mineral can be expensive or time-prohibitive for some minerals. Minerals can be diluted by mixing with 0.5 or 1 mm diameter glass microbeads designed for lysing cells (bead beating). However, the epoxy should have an index of refraction similar to the beads, or they can be optically distracting.

K-feldspar. Most commercial K-feldspar is turbid, so finding a cheap, non-turbid variety would benefit the community. In this project, rough thin sections were made for different K-feldspar crystals until a clean crystal was identified from our teaching collections. The source of this crystal is, however, unknown. Adularia, commonly marketed as "sanidine" (or "sanadine" [sic]), is a good option but can be expensive.

Mineral choices. Although this project focused on systematic optical properties, other reference sections could be produced, for example creating a "quartzo-feldspathic" reference slide with systematically different feldspar compositions, quartz, and feldspathoids. Reference sections with systematically different compositions, amphiboles, pyroxenes, etc., could also be created, although finding sources of these different minerals might prove difficult.

Student training

The main steps in this project (crushing and sieving minerals, cutting glass tubing, making epoxy, mixing with minerals, and mounting in tubes) are readily accessible to students, as well as using a wafering saw to cut disks. Although only some institutions

Figure 9. Images from the birefringence reference slide. (**a**) Fluorite; note stress-induced birefringence on the edges of crystals. (**b**) Quartz. (**c**) Kyanite; note some plucking. (**d**) Olivine. (**e**) Muscovite. (**f**) Talc. (**g**) Zircon. (**h**) Calcite.

now retain equipment for final thin section production, students can gain experience in basic mineral processing and mounting procedures, allowing them to receive practical training and contribute to educational institutions' mission.

Research applications—fragile materials

Although the primary purpose of this project was to mount mineral separates for teaching, at least one application to research involves the production of durable thin section billets from fragile (but still consolidated) materials where spatial associations are important. In preparing sections of fragile zeolites for an online optical mineralogy textbook (Perkins et al. 2024; http://optical.minpet.org), it was realized that pieces of rock could be mounted equivalently to glass disks in the Al sleeves. The epoxied rectangular blocks were ground to an appropriate level of rock exposure and then sent to a thin section maker for commercial production. This approach preserves delicate structures, even of fibrous natrolite-group zeolites (Fig. 10). This approach is similar to standard methods of creating round epoxy mounts, except the blocks are rectangular and permit a larger area for observation. If larger areas are desired, metal or plastic blocks could be milled to the ideal dimensions of standard glass slides.

Acknowledgments and Funding

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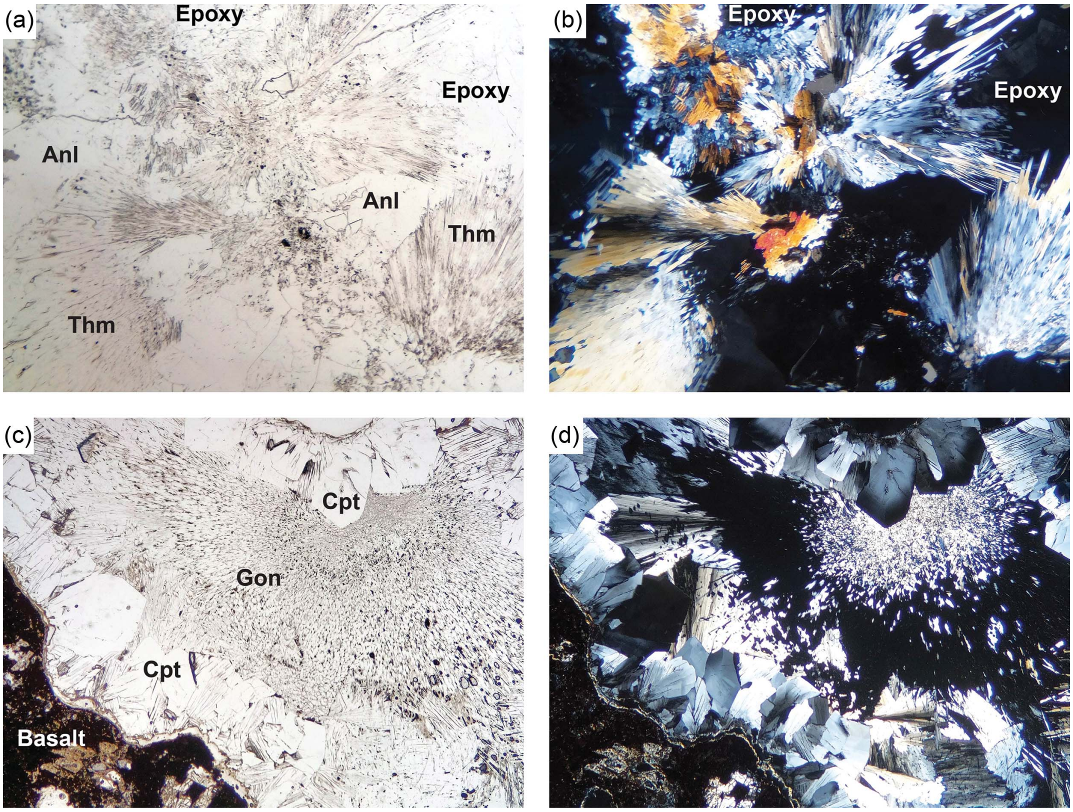

Figure 10. Images of fragile zeolite crusts in plane-polarized and cross-polarized light in thin sections prepared using the technique described here for mounting materials in epoxy blocks. (**a**, **b**) Analcime (Anl) and thomsonite (Thm). Epoxy represents open space in the original material, not plucking. (**c**, **d**) Clinoptilolite (Cpt) and gonnardite (Gon) developed on basalt. Horizontal field of view is 8 mm in all images.

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Endnotes:

[1]Deposit item AM-25-29285. Online Materials are free to all readers. Go online, via the table of contents or article view, and find the tab or link for supplemental materials.