Petrology Lab
Thin Sections
Distinguishing Features of Minerals

Lab 1 (ultramafics)

Olivine: Usually colorless to pale yellow in thin section, darker colors correspond to higher iron content. Pleochroism of fayalite-rich samples is X = Z = pale yellow, and Y = orangish, yellowish, or reddish brown. Elongate crystals display parallel extinction and may be either length fast or length slow depending on how they are cut. Grains in thin section usually display a distinctive irregular fracture pattern. It is recognized by its high birefringence, distinctive fracturing, lack of cleavage, and alteration products. Clinopyroxenes show somewhat lower birefringence, have recognizable cleavage, often show lamellar twinning, and have inclined extinction, is optically negative, and may display a patchy, pistachio-green color.

Magnetite: Opaque in thin section; gray in reflected light as viewed through microscope. No cleavage, but distinct octahedral parting {111} is common although it generally will not be seen because of opacity. Easily confused with ilmenite and chromite, although chromite is transparent along very thin edges, and ilmenites crystal shape is different. Pyrite is usually cube shaped and is yellowish in reflected light. Hematite is often reddish. Identification with hand-sample properties is more reliable than with the conventional petrographic microscope.

Calcic Clinopyroxene: (Augite) Usually pale colored in thin section, with subtle pinkish to greenish pleochroism. Are distinguished from orthopyroxene by inclined extinction and higher birefringence and from pigeonite by larger 2V. The more sodium-rich clinopyroxenes (aegirine-augite, acmite, and omphacite) are usually more distinctly green and have larger 2V. Acmite is optically negative. Some amphiboles may be similar but they have cleavage at 56 and 124º. Wollastonite is colorless, has lower indices and birefringence, and is optically negative. Olivine lacks cleavage and has higher birefringence.

Biotite: Typically brown, brownish green or reddish brown, and distinctly pleochroic. With rare exceptions, adsorption is $Z \approx Y > X$, and grains are darker when the cleavage trace is parallel to the vibration directions of the lower polar. Common colors are X = colorless, light tan, pale greenish-brown, pale green; $Y \approx Z$ = brown, olive-brown, dark green, or dark red-brown. Intensity of color increases with increasing Fe content. Cleavage flakes and sections parallel to (001) yield darker colors with little pleochroism. Perfect cleavage on {001} easily seen in thin section, and controls fragment orientation and shape. Extinction is parallel or close to parallel with a maximum angle of a few degrees, rarely up to nine. Birefringence is strong and yields maximum interference colors in the third, or occasionally fourth, order, but the strong mineral color typically masks the

interference colors. Cleavage flakes and sections cut parallel to (001) show low birefringence. Exhibits pebbly or finely mottled “birds eye” extinction that is characteristic of the micas. Chlorite has lower birefringence and often displays anomalous interference colors. Green or brown tourmaline resembles biotite but is darker when its long dimension is oriented at right angles to the vibration direction of the lower polar. Amphiboles have two cleavages with the distinct amphibole cross section and show inclined extinction without the “birds-eye” characteristic.

Phlogopite: (Mg-rich biotite) Nearly colorless to pale brown in thin sections. Less intense colors than biotite because of lack of iron content. Perfect cleavage on {001} easily seen in thin section, and controls fragment orientation and shape. Extinction is parallel or close to parallel with a maximum angle of a few degrees, rarely up to nine. Birefringence is strong and yields maximum interference colors in the third, or occasionally fourth, order, but the strong mineral color typically masks the interference colors. Cleavage flakes and sections cut parallel to (001) show low birefringence. Exhibits pebbly or finely mottled “birds eye” extinction that is characteristic of the micas. Muscovite is distinguished from most biotite by its lack of color but Mg-rich biotite (phlogopite) may be nearly colorless but has a smaller 2V than muscovite. Chlorite has lower birefringence and often displays anomalous interference colors. Green or brown tourmaline resembles biotite but is darker when its long dimension is oriented at right angles to the vibration direction of the lower polar. Amphiboles have two cleavages with the distinct amphibole cross section and show inclined extinction without the “birds-eye” characteristic.

Plagioclase: Colorless in thin section. The {001} cleavage is perfect and the {010} cleavage is good; the poor cleavage on {110} is not seen on thin section. Cleavage may not be obvious unless the aperture diaphragm is stopped down to emphasize what little relief there is. In carefully made thin sections, cleavage cracks may not develop in large enough numbers to be noticeable. Cleavage is usually most noticeable in grains along the slide’s edge. The optic orientation varies in a very regular manner with composition and provides much of the basis for determining composition. Except by chance, extinction is inclined in almost all orientation. Indices of refraction show a very systematic increase with increasing anorthite content. Birefringence varies between about 0.007 and 0.013, too small of a change to be useful in determining composition. Maximum interference colors in thin section are usually first-order gray or white. Only for very calcic plag will first-order yellow colors be seen. The low relief, lack of color, biaxial character, and polysynthetic twinning distinguish plagioclase from most other minerals. Untwinned plagioclase greatly resembles quartz and may be easily overlooked. However, quartz is uniaxial, has no cleavage, and usually does not show the incipient alteration or clouding common in plagioclase. Monoclinic K-feldspars lack polysynthetic twinning.

Apatite: Usually colorless in thin section. Strongly colored samples may display pale colors corresponding to the hand-sample color, with weak to moderate pleochroism and absorption. Cleavage is poor and does not have a strong influence on fragment orientation. Elongate sections through crystals show parallel extinction and are length fast. The interference color of common apatite is first-order gray, often with a slightly anomalous blue cast to it. Carbonate-apatite has higher birefringence and may produce interference colors up to upper first or lower second order in thin section. Distinguished by its moderate to high relief, low birefringence, and uniaxial character. In thin section it usually displays a slightly pebbly surface texture. It is distinguished from garnet by its weak birefringence. Topaz, sillimanite, and mullite have higher birefringence and are biaxial. Colored varieties of apatite may resemble tourmaline, but apatite is darker when the long axis of grains is aligned parallel to the vibration direction of the lower polar, and tourmaline is lighter. Apatite also resembles beryl, but beryl has lower indices and lower relief. Andalusite is biaxial, has somewhat higher birefringence, and shows more distinct cleavage.

Serpentine: Colorless to pale green in thin section. Except for cross-fibers of chrysotile in veins, the varieties of serpentine can not reliable be distinguished without X-ray diffraction or related techniques. The fibrous amphiboles (riebeckite, anthophyllite, tremolite, etc.) are distinguished because they have higher indices of refraction and birefringence. Chlorite is more strongly pleochroic than serpentine and brucite is uniaxial and has abnormal interference colors.

Orthopyroxene: (Enstatite/Orthoferrosilite/Hypersthene) Usually pale colored in thin section, with subtle pinkish to greenish pleochroism. Orthopyroxene is distinguished from clinopyroxene by lower birefringence, parallel extinction, and the common pale pink to green pleochroism. Andalusite is similar to enstatite but does not have the pyroxene cleavage and is optically negative. Monoclinic polymorphs of orthopyroxene (clinoenstatite and clinohypersthene) are rare in terrestrial rocks. These polymorphs may form lamellae in calcic clinopyroxene or discrete crystals in clinker associated with burned coal beds. They may be distinguished by inclined extinction and smaller 2V (20-50º).

Chromite: Opaque in thin section. Easily confused with magnetite and ilmenite. Chromite is much less magnetic than magnetite, and ilmenite has a different crystal shape. Some chromite is transparent along thin edges. Positive identification with the conventional petrographic microscope may be difficult and use of reflected light microscope or other techniques is recommended.

Diopside: (A clinopyroxene) usually colorless, gray, pale green, pale brown or brownish green in thin section. Darker colors are associated with iron rich samples. Chrome-diopside is relatively common in ultramafic rocks such as kimberlite and peridotite.

Richterite: Colorless to yellow or violet in thin section. Pleochroism variable in shades of pale yellow or green with red of orange tints. Colorless varieties resemble tremolite and may be difficult to distinguish from it. The color in pleochroic varieties of richterite is distinctive.

Perovskite: Colorless to shades of brown in thin section, rarely green or gray. Distinguished by extreme relief, habit, and possible weak birefringence and lamallar twinning. Brown spinel and garnet have lower relief and a different habit and rutile has extreme birefringence and a different habit.

Cr-Spinel: Color in thin section corresponds with hand sample color, some can be opaque. Generally distinguished by high relief in thin section, strong color, and isotropic character. Different crystal shape and lighter color distinguishes garnet from spinel. In grain mounts it may be difficult to differentiate between the spinel and garnet groups, and X-ray or other techniques may be required.

Dolomite: Usually colorless in thin section. Dolomite and calcite are commonly found together in limestone, dolomite, marble and related rocks and they may be difficult to distinguish optically. Dolomite is more commonly euhedral. Calcite is more commonly twinned. Dolomite has higher refractive indices. Dolomite may be colorless, cloudy, or stained by iron oxides, whereas calcite is usually colorless.

Magnesite: Colorless in thin section, may be cloudy. Magnesite is distinguished from the other rhombohedral carbonates by lack of twin lamellae, indices of refraction, and physical properties.

Chlorite: Usually light to medium green in thin section and pleochroic, expressed in shades of colorless, pale green, yellowish green, green, or brownish green. Grains are darker when the trace of cleavage is parallel with the vibration direction of the lower polar. Perfect cleavage on {001} controls fragment orientation. The maximum extinction angle to the trace of cleavage is usually no more than a few degrees and rarely more than 9º. Birefringence is usually low, so maximum interference colors are rarely above first-order white or yellow. Anomalous brown, bluish, or purplish interference colors are possible. Chlorite is distinguished from muscovite and biotite by its green color, pleochroism, and weak birefringence. Serpentine usually has lower refractive indices and is less pleochroic.

Brucite: Colorless in thin section. Brucite is most commonly mistaken for talk, micas or gypsum. Both talc and the micas are biaxial negative and have higher birefringence, and gypsum is biaxial positive. Chlorite and serpentine are also similar but are usually a pale green color, are usually length slow, and are biaxial. Brucite may be stained to aid in rapid identification.

Amphibole: (Hornblende) Distinctly colored and pleochroic, usually in shades of green, yellow-green, blue-green, and brown. Green varieties usually have X = light yellow, light yellow-green, light blue-green; Y = green, yellow-green, gray-green; Z = dark green, dark blue-green, dark gray-green. Brownish varieties usually have X = yellow, greenish yellow, light greenish brown; Y = yellow-brown, brown, reddish brown; Z = gray-brown, dark brown, reddish brown. Typical amphibole cleavages on {110} intersect at 56º and 124º, and fragment shape is controlled by cleavage and is usually elongate parallel to the *c* axis. Extinction angle of 12º to 34º are seen in sections parallel to (010), which show one cleavage direction and maximum birefringence. In most cases, the extinction angle is between 14º and 25º. The highest interference colors in thin sections are usually upper first or lower second order but are often masked by mineral color. Tremolite is light colored and has lower indices, actinolite has lower indices and a lower extinction angle.

Lab 2 (Basalts) – additional minerals

Hematite: Deep red-brown in very small crystals or along thin edges and usually opaque. Thin crystals are pleochroic (brownish-red to yellowish-red or brown). Metallic black with red internal reflection in reflected light under petrographic microscope. In grains that are sufficiently thin to be transparent, extinction should parallel to the basal parting and to the top and bottom of tabular crystals. However, the extreme dispersion commonly prevents the grains from becoming extinct with stage rotation, and the mineral color and extreme birefringence make determining the sign of elongation impossible. It is distinguished from other opaque minerals by red color on thin edges.

Epidote: High positive relief. Iron content produces light yellow-green colors in thin section that are pleochroic with Y>Z>X: X = colorless, pale yellow, or pale green; Y = yellow-green; Z = colorless or pale yellow-green. The maximum extinction angle to the basal {001} cleavage is seen in sections cut parallel to (010), which also show maximum birefringence and yield flash figures. The extinction angle is between about 25º and 40º, but should not be used as a reliable guide to composition due to variability. Both indices of refraction and birefringence increase with increasing iron content. Highest interference colors for epidote range from upper first order to third order, and grains oriented to give first-order colors may be anomalously blue or greenish yellow. Distinguished from allanite (usually brown), piemontite (usually pink), zoisite (parallel extinction), vesuvianite (uniaxial negative and lacks good cleavage). Small grains in thin section may be difficult to ID and may require other techniques for positive ID.

Quartz: Colorless in thin section. Twinning cannot be observed in thin section because the twin segments have the same *c* axis orientation. Because quartz is uniaxial, the optic axis is the *c* axis. Elongate euhedral crystals cut from end to end are length slow. Quartz that has been deformed shows undulatory

extinction. Birefringence is 0.009 and interference colors range up to first-order white with a tinge of yellow. Quartz is recognized by its low relief, low birefringence, and lack of cleavage or twinning. Plagioclase is biaxial, has cleavage, and is usually twinned. Orthoclase and sanidine are biaxial, have cleavage, and may show a single twin plane.

Calcite: Colorless in thin section. Calcite has perfect rhombohedral cleavage and fragments commonly lie flat on cleavage surfaces. Lamellar twins commonly exist on the negative rhomb, and the lamellae are usually parallel to one edge of the cleavage rhomb or along the long diagonal of the rhomb. Extinction is inclined or symmetrical to cleavage traces. Because birefringence is extreme (.172), interference colors in thin section are typically creamy high-order colors even if the optic axis is close to vertical. Twin lamellae may show as bands of pastel pink or green, and zones of overlap of inclined twin lamellae may not go entirely extinct with stage rotation. Calcite is recognized by its cleavage, extreme birefringence, change of relief with rotation, and reaction with weak acid.

Sericite = very fine, ragged grains and aggregates of white mica, usually muscovite or phengite, produced by the alteration of feldspars or other minerals (see muscovite)

Muscovite: Typically colorless in thin section, rarely very pale pink or green. Perfect cleavage on {001} is well displayed in thin section and controls fragment orientation; twinning rarely seen. Extinction is essentially parallel to cleavage in all orientations, because the maximum extinction angle is less than 3º. Grains are commonly bent and may show wavy or undulose extinction. Birefringence is high (.036-.049) and interference colors may be as high as third order, and vivid colors of the second order are typical. Muscovite is distinguished from biotite by its lack of color. A distinctive character of muscovite and the other micas is a pebbly surface texture seen near extinction called “bird’s-eye” extinction.

Pigeonite: (low-Ca clinopyroxene) Colorless, pale brownish green, or pale yellowish green, and generally not pleochroic (although weak pleochroism is sometimes found). Good cleavages at 87º, parallel to the {110} prism faces. Single and lamellar twins with composition planes parallel to {100} and {001} common. In basal sections showing both cleavages, extinction is symmetrical. In longitudinal sections showing only one cleavage direction, extinction ranges from parallel to inclined, depending on orientation. Interference colors in thin section range up to lower second order, with first-order yellow and red being common. Distinguished from the other pyroxenes by its smaller optic angle. Orthopyroxene has lower birefringence and larger 2V.

Orthoclase: Colorless in thin section, and clouding (especially in orthoclase) is common. Birefringence is typically around .007, so interference colors are no higher than first-order white. Cleavage difficult to see in thin section because of low relief, but is perfect on {001} and good on {010} and intersect at 90º;

cleavage controls fragment orientation. To see cleavage, look at fractured grains on the slide's edge and adjust the aperture diaphragm to accentuate the relief. Twinning is common. Extinction angle may be as large as 13º. Birefringence is low (.007) so maximum interference colors are first-order white. Usually use 2V of 40º to distinguish between sanidine and orthoclase, but orthoclase's 2V may be as large as 85º. Orthoclase is distinguished from microcline based on lack of grid twinning. Orthoclase greatly resembles quartz, but it shows negative relief, is often slightly clouded with incipient alteration, and is biaxial.

Lab 3 (Gabbros) – additional minerals

Pyrite: Cubic (remember?). Sections through cubic crystals often are triangular, rectangular or square. It is pale brassy yellow in reflected light as seen through a petrographic microscope (this distinguishes it from magnetite, ilmenite and hematite). Commonly alters to Fe oxides, they often form pseudomorphs after pyrite. Can be confused with marcasite, pyrrhotite and chalcopyrite. *** examining a hand sample with a hand lens is often more productive than examining it in thin section***

Labradorite: (See Plagioclase) $Ab_{50}An_{50}$ – $Ab_{30}An_{70}$

Lab 4 (Monzonites and Diorites) – additional minerals

Zircon: Very high positive relief. Usually colorless to pale brown in thin section, although high relief and small grain size tend to make it look darker. In grain mount, the color may be more apparent with weak pleochroism, so that grains are darker when the long axis is aligned parallel to the vibration direction of the lower polar. Some samples may be cloudy due to numerous inclusions or may show concentric color zoning or patchy color. Commonly occurs as euhedral to subhedral tetragonal crystals with pyramidal terminations. It is not uncommon for euhedral overgrowths to be developed on rounded or subhedral cores. Cleavages are poor and not usually seen in thin section. Not usually twinned, but twinning has been reported on {111}. Interference colors of relatively fresh zircon in thin section range up to third and fourth order. Usually recognized as small, high-relief grains with bright interference colors. Can be mistaken for xenotime (higher birefringence), monazite (colored and is biaxial), or rutile (darker colored, higher indices, higher birefringence). Often included in ferromag minerals (e.g. biotite, hornblende), and may produce dark halos in surrounding mineral due to bombardment of radioactive elements in zircon.

Uralite = predominantly fine-grained, light-colored amphibole
Uralitized = altered to fine-grained pale green amphibole (sometimes occurs in clinopyroxenes)

Sanidine: Low negative relief. Colorless in thin section, and clouding is common. *High sanidine* is optically monoclinic K-feldspar with the optic plane

parallel to (010) and 2V between 0 and ~47. *Low sanidine* is optically monoclinic K-feldspar with the optic plane *perpendicular* to (010) and 2V between 0 and ~40. Birefringence is typically around .007, so interference colors are no higher than first-order white. Sanidine is common as phenocrysts that are tabular parallel to (010) and somewhat elongate parallel to the *a* axis. Perfect cleavage on {001} and good cleavage on {010} intersect at 90º. Cleavage may not be visible in thin section due to low relief. Look at fractured grain on slide's edge and adjust aperture diaphragm to accentuate relief. Carlsbad twins with composition plane parallel to (010) divide crystals into 2 segments. Low sanidine is distinguished from orthoclase by smaller 2V angle. High sanidine is distinguished from orthoclase and low sanidine by orientation of the optic plane. Quartz has similar appearance but is uniaxial and has indices higher than cement.

Allanite: High positive relief, but strongly metamict varieties may be low. Member of epidote group with significant amounts of ferrous iron. Usually some shade of brown in thin section, less commonly greenish. Pleochroism in all varieties of metamict allanite is distinct in various shades of brown, red-brown, yellow-brown, or less commonly, greenish-brown or green. Color zoning common with darker core and lighter rim. May form pleochroic halos enclosing biotite, chlorite, or hornblende because of its radioactivity. Cleavage generally not well-developed, twinning not common. Elongate sections show parallel extinction, although mineral color makes determination of elongation difficult. Indices of refraction and birefringence increase with increasing Fe, Ce, and other rare earth elements. Highest interference color in thin section usually upper first- or second-order colors, although the mineral color often masks the interference color. Usually biaxial negative with 2V between 40º and 90º, but some varieties are biaxial positive with 2V values between 57º and 90º. High relief, color, and pleochroism are distinctive. Brown hornblende has good cleavage and a different habit.

Sphene: Very high positive relief. Typically shades of brown in thin section, less commonly colorless or yellow. Non- to weakly pleochroic in thin section; color and pleochroism more distinct in grain mount. Euhedral to subhedral grains with a wedge or diamond-shaped cross section are common, as are rounded or irregular anhedral grains. Radioactive varieties may form halos around biotite, chlorite, or hornblende. Cleavage not obvious in thin section. Simple twins on {100} are not uncommon and are expressed as composition plane parallel to long diagonal of diamond-shaped cross sections. Extreme birefringence produces upper-order white interference colors in thin section but is often masked by color of the mineral.

Lab 5 (Syenite – Trachyte Family) – additional minerals

Nepheline: The most common feldspathoid. White or gray in hand sample; vitreous to greasy luster. Colorless in thin section. Birefringence is low, maximum interference colors are first-order gray. Fractures tend to be irregular.

Resembles the feldspars but lacks good cleavage and twinning and has lower birefringence.

Sodalite: Blue or gray in hand sample. Colorless, gray or pale blue in thin section. Sodalite is isotropic, so it is NOT pleochroic. Poor cleavage.

Hastingsite (a member of the Hornblend group): see hornblende.

Acmite-Aegirine series: They are compositional variations, there is a complete range to augite compositions. Form elongate crystals. Cleavage approx. 87 degrees. Acmite extinction angle = 0 – 10 degrees. Aegiring extinction angle = 0 – 20 degrees. Acmite refers to the brownish samples, Aegirine refers to the green to black samples. Brown varieties are often sharply pointed, black to green varieties are usually bluntly terminated. They are distinctly pleochroic. Zoning is common, rim is usually darker than core, sometimes hourglass zoning.

Sanidine: (Alkali feldspar) Zoning is common, expressed as variations in birefringence and extinction angle. Low birefringence, interference colors of first-order white or lower. Carlsbad twins common. Perfect cleavage on {001} and good cleavage on {010} intersect at 90 degrees. Similar appearance to quartz but is biaxial and has indices lower than cement.

Forsterite: (Mg rich member of olivine), see olivine (solid solution fayalite to forsterite).

Siderite: Moderate to high positive relief, changes upon rotation. (solid solution from magnesite to rhodochrosite). Colorless, ash gray, pale yellow or yellowish brown in thin section. May be pleochroic. Perfect rhombohedral cleavage. May show lamellar twinning similar to calcite. Interference colors are upper-order white and gray.

Barite: White, yellow, gray, or brown in hand sample. Colorless in thin section, sometime pale colors with weak pleochroism. Tabular crystals. Crystals are often intergrown, rosettes. Four cleavage directions. Interference colors range up to first-order yellow.

Fluorite: Cubic. Colorless, blue, purple, or green in hand sample. Colorless in thin section, but pale colors corresponding to hand sample is possible. Samples may be zoned parallel to crystal faces. Isotropic, so NOT pleochroic. Perfect octahedral cleavage. High relief and octahedral cleavage.

Anorthoclase: Crystals can be prismatic, microlites or anhedral. Complex pattern of twinning. Perfect and good cleavages intersect at about 92 degrees. Birefringence is low, max interference colors are first-order gray or white. Resembles microcline but twin lamellae are usually finer.

Analcime: White, pink or gray in hand sample. Colorless in thin section. Commonly weakly birefringent and may display lower first-order interference colors. Crystals are typically well formed trapezohedrons, which yield eight-sided to nearly round sections; or anhedral granules. Lamellar twinning on the {001} and {110} faces. Similar to leucite and sodalite.

Lab 11 Metamorphic Rocks– additional minerals

Rutile: Reddish brown, pale brown or almost opaque in thin section. Pleochroism is weak, may be color zoned. Good cleavage and twinning is common. Elongate sections show parallel extinction. Birefringence is extreme, yielding upper-order white interference colors that are generally masked by the color of the mineral. Shows extreme relief.

Andradite/ Almandine (Garnet Group): Isometric. Isotropic (no pleochroism!), high positive relief. Commonly colorless in thin section or pale version of the hand sample color. No cleavage, often show irregular fractures, no twinning**.**

Wollastonite: Colorless in thin section. There is perfect cleavage on {100}, good cleavage on {001} and {102}. {100} and {001} intersect at 84.5º and {102} and {001} intersect at 70º. Twinning is common. Maximum interference color in thin section is first-order yellow.

Graphite: Opaque.