ECONOMIC GEOLOGY

Tables for the Determination of Common Opaque Minerals

Paul G. Spry and Brian L. Gedlinske

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Preface

Measurements of the optical properties of opaque minerals using a reflected-light polarizing microscope are difficult for the unskilled investigator because they require demanding and exacting techniques. Unlike transparent minerals, which can be easily identified by tests using a transmitted-light petrographic microscope, opaque minerals have few optical properties that can lead to unambiguous identification. The principal properties used to identify opaque minerals are color and color intensity, but these involve subjective decisions on the part of the investigator. Color is determined in part by the colors of the surrounding minerals; color intensity is influenced by reflectance. This, in turn, is influenced by sample preparation. Many teaching institutions, private consultants, and professional companies do not possess microscopes which have the additional equipment to test microhardness, or photometers to test the reflectance of minerals; however, microhardness and reflectance data have been included for those people who have access to such equipment.

The following two tables, one for colored minerals, one for noncolored minerals, include 95 common opaque minerals, 13 transparent minerals, and 8 minerals that range from transparent-translucent to opaque. The tables are by no means complete because they are designed to serve as a rapid and efficient way of identifying the common opaque minerals. We have found by experience that unless told the identity of a mineral, the unskilled user often finds alphabetical tables of opaque mineral properties imposing and time consuming. In an attempt to overcome this problem, we use an identification scheme which enables the user to identify a mineral by a process of elimination. The scheme is straightforward and utilizes a tree diagram (Fig. 1) in conjunction with a list of the mineral properties that can be easily observed under the microscope. The mineral is identified by moving from the top of the tree diagram to the bottom through a series of decisions based on optical properties. These properties are, in order: color intensity, pleochroism, anisotropism and its intensity, internal reflection, and relative hardness. A final choice of the mineral's identity can be made when the end of the branch is reached. In only a small number of cases are all five decisions required to make this choice. Since this procedure may not always give a unique answer, additional features are included that will help elucidate the mineral's identity. These are: the presence or absence of cleavage and twinning, the composition of commonly associated minerals, and a summary of key identifying criteria. Although the procedure used here is very successful, it is not infallible, because some minerals fall between two categories. For example, depending upon the nature of associated minerals, it may be difficult to decide whether a mineral such as pyrrhotite is colored or weakly colored. In such cases, we have listed the mineral in more than one group. One further problem will obviously arise if there is only one mineral present in the sample and a decision has to be based on its relative hardness. For such situations, we suggest looking at the soft, medium, and hard categories. Weak to very weak pleochroism is often difficult to discern, especially for large mineral grains. We have listed minerals showing weak pleochroism with nonpleochroic minerals.

Explanation and Discussion of Terms Used in the Tables

Group number: the number located at the end of the branch of the tree diagram (Fig. 1).

Mineral: the mineral name.

Composition: the chemical formula using the terminology of Fleischer (1987).

System: the crystal system.

Polishing cleavage: the observable cleavage pattern on a polished surface, and if known, its relation to crystallographic axes.

Reflectance and color: the colors observed when air and immersion oil are between

the objective and the sample. Oil is used when high magnification and resolution are required. Note that the color intensity of a mineral generally increases under oil: it is often slightly darker. Also, the color may appear different depending on the minerals with which it is in contact. Even though quantitative reflectance values, R% (see below), are included, qualitative terms (e.g., strong, medium, low) are also given for the reflectance of each mineral. A decision on the color of a mineral should be made with a low-power objective when observed under plane-polarized light. The rheostat setting should be at full voltage for the lamp used. Also, the intensity of illumination should be kept constant for color comparisons.

R%: quantitative reflectance values in air at a 546-nm wavelength. Some reflectance values are given at other wavelengths.

VHN: quantitative identification microhardness (Vickers hardness number) at a load of 100 g. Some microhardness values are given for different loads.

Polishing hardness: behind this feature is the principle that for two minerals in contact, the hardest mineral stands up in relief. The identification procedure involves an optical feature known as the Kalb line. Use a high-power objective and a partly closed diaphragm (to reduce the light) and then observe the contact between the two minerals under plane-polarized light (medium illumination). If the stage of the microscope is lowered or the microscope tube is raised, the Kalb line (analogous to the Becke line in transmitted-light microscopy) moves toward the softer grain.

During sample polishing some minerals may remain scratched. The use of polishing scratches is an excellent way to determine relative hardness, because the scratches will often affect a soft mineral and stop at its contact with a hard mineral.

The terms soft, medium, and hard have been used. They refer to numerical values on the Mohs' hardness scale (given in parentheses) and correspond to values of up to and including 3, greater than 3 and up to and including 5, and greater than 5, respectively. A mineral which shows a range of hardness that overlaps these boundaries has been assigned to the harder category. For example, carrollite has a range of hardness of 4.5 to 5.5 and is in the hard category. The numbers are followed by the hardness of the mineral in question relative to commonly associated minerals.

Pleochroism (bireflectance): the property of a mineral of showing a variation in color, under plane-polarized light and when the analyzer is not inserted, as the stage of the microscope is rotated. Where this variation is weak, other minerals showing pleochroism should not be in the same field of view. Keep the illumination constant for comparisons. The presence of immersion oil permits the observation of weak pleochroism. The terms strong, moderate, weak, and nonpleochroic have been used to describe the degree of pleochroism. The category used in Figure 1 is that which is observed in air.

Anisotropism: the property of a mineral of showing a variation in color, under plane-polarized light and when the analyzer is inserted, as the stage of the microscope is rotated. Optimum conditions for observation are a low-power objective for large grains (high-power for small grains), a partly closed diaphragm, and an intense light source. Observe a number of grains and record the maximum color variation. Weak anisotropism is best detected by rotating the analyzer a few degrees off the crossed position with the polarizer and by observing the sample under immersion oil. The terms strong, moderate, weak, and isotropic have been used to describe the degree of anisotropism.

Internal reflections: the diffuse patches of color (most often near fractures or grain boundaries) which are produced in minerals that are not completely opaque. In minerals displaying this property, a little light penetrates below the surface and is reflected back to the observer from cracks, cleavages, twin surfaces, and other discontinuities in the mineral.

Twinning: a characteristic exhibited in many minerals, best observed under high-intensity illumination and a low-power objective with almost completely crossed nicols.

Associated minerals: minerals commonly associated with others. A knowledge of

these associations is of invaluable assistance for identification purposes. Commonly associated minerals are included and listed in alphabetical order. However, because of space limitations, not all commonly associated minerals could be included. In nearly all cases, where mineral A is listed as associated with mineral B, the latter has also been cross listed so that it appears as an association of mineral A. The exceptions to this are the minerals that are associated with the common opaque phases: arsenopyrite, pyrite, pyrite, pyrrhotite, galena, sphalerite, chalcopyrite, and magnetite. Space limitations also preclude the incorporation of many associated minerals. Where a number of minerals which contain common elements or a common element are associated with a given mineral, they may be grouped under a general term, for example, Bi minerals or Co-Ni arsenides.

Identification criteria: a summary of the key criteria for identifying a given mineral.

Although the tables list minerals that contain common elements often associated with each other, they also list a number of groups of associated minerals that look alike. A knowledge of these groups is of considerable assistance for identification purposes. Some of these are:

Manganese minerals: bixbyite, braunite, hausmannite, jacobsite, psilomelane, and pyrolusite.
Platinum minerals: braggite, cooperite, platinum, and sperrylite.
Nickel-cobalt-iron arsenides: cobaltite, gersdorffite, skutterudite, and ullmanite.
Nickel-cobalt arsenides: arsenopyrite, breithauptite, glaucodot, loellingite, niccolite, pararammelsbergite, rammelsbergite, and safflorite.
Silver-bearing sulfosalts: acanthite, dyscrasite, pearceite, polybasite, proustite, pyrargyrite, tetrahedrite, and tennantite.

Tellurides, sellenides, bismuth sulfosalts, lead-arsenic sulfosalts, and iron-group minerals also contain a number of commonly associated minerals which look similar to each other. Many of these minerals are rare and are not included here; however, they are listed in Schouten (1962).

Based on classroom experience, a common problem is the difficulty in discriminating between nonopaque gangue minerals and opaque minerals that show low reflectance (i.e., gray). As a consequence of this problem, some common gangue minerals (amphibole, biotite, calcite, feldspar, garnet, pyroxene, and quartz) have also been included for comparison. Attempts at identification using reflected-light techniques often yield ambiguous results because many opaque and nonopaque minerals have similar optical properties. Hence only a limited number of nonopaque minerals have been included. These and other common gangue minerals (e.g., ankerite, clays, dolomite, sericite, siderite, and topaz) are best identified using a transmitted-light microscope.

Other sources of reference are required to identify less common and rare opaque minerals. For these minerals, we recommend Schouten (1962), Uytenbogaart and Burke (1971), Ramdohr (1980), and Picot and Zahan (1982). In preparing these tables, the following references have been used extensively:

Craig, J. R., and Vaughan, D. J., 1981, Ore microscopy and ore petrography: New York, Wiley, 406 p.
Fleischer, M., 1987, Glossary of mineral species, 5th ed.: Tucson, Mineralogical Record, 227 p.
Henry, N. F. M., ed., 1977, Commission on ore microscopy IMA/COM quantitative data file (first issue): London, Mineralogical Society Applied Mineralogy Group.
Picot, P., and Johan, Z., 1982, Atlas of ore minerals: Amsterdam, Elsevier, 458 p.
Ramdohr, P., 1980, The ore minerals and their intergrowths. Vols. 1 and 2: Oxford, Pergamon, 1207 p.
Schouten, C., 1962, Determinative tables for ore microscopy: Amsterdam, Elsevier, 242 p.

Short, M. N., 1940, Microscopic determination of the ore minerals: U.S. Geological Survey Bulletin 914, 314 p.

Uytenbogaart, W., and Burke, E. A. J., 1971, Tables for microscopic identification of ore minerals: Amsterdam, Elsevier, 430 p.

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March 9, 1987

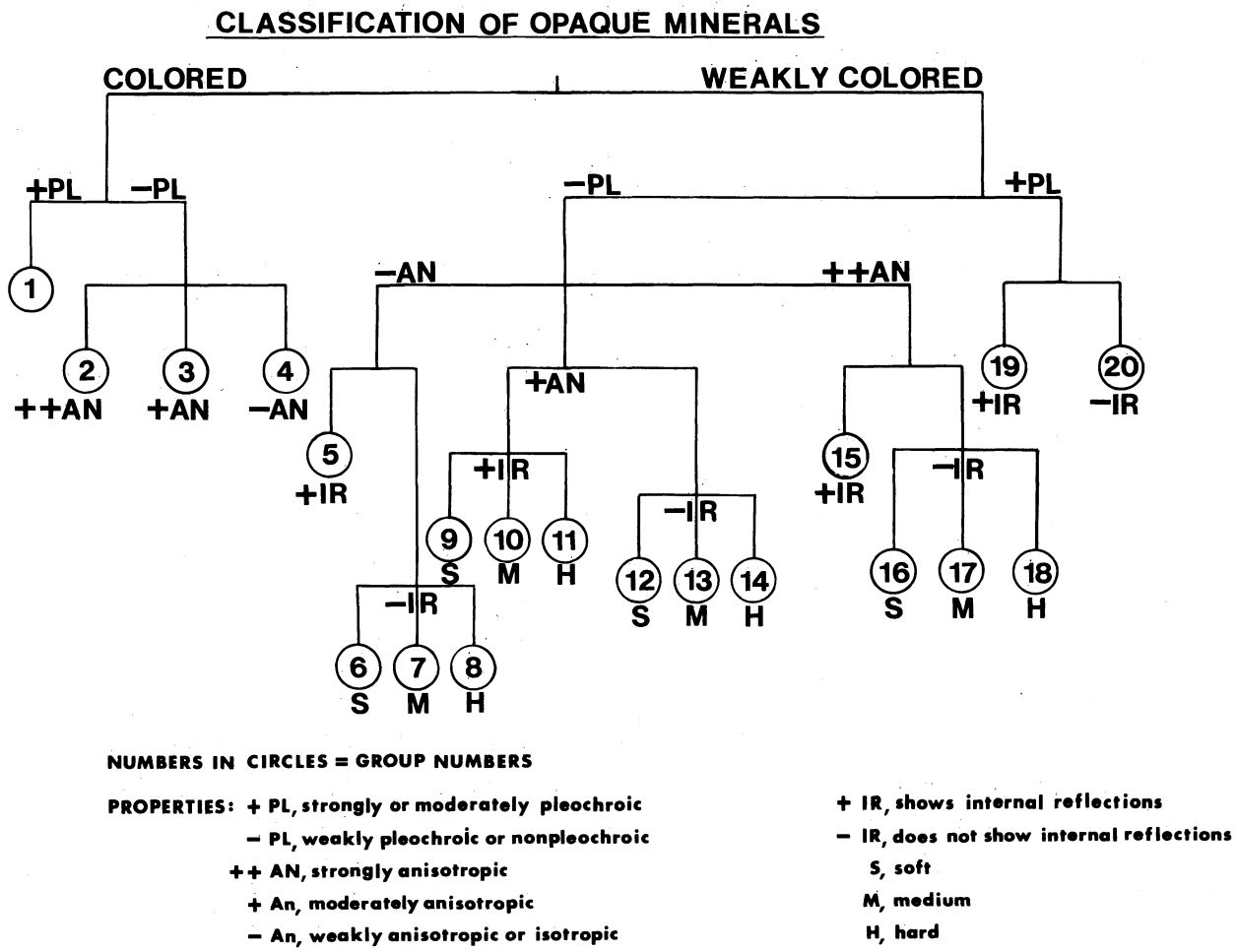

FIG. 1. Tree diagram for the identification of opaque minerals using optical properties.

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Colored Minerals

GROUP NUMBER	1	1	1
MINERAL	Breithauptite	Covellite	Delafossite
COMPOSITION	NiSb	CuS	$CuFeO_2$
SYSTEM	Hexagonal	Hexagonal	Hexagonal
POLISHING CLEAVAGE	Not visible	(0001) often visible	May be visible
REFLECTANCE AND COLOR — AIR	Strong: pink with violet tint	Medium: indigo-blue with violet tint to bluish white	Medium: rose-brown to cream-brown
REFLECTANCE AND COLOR — OIL	Strong: pink with violet tint	Medium: purple to violet to blue-gray slightly pinkish	Medium: pink-gray to brown-gray
R%	36.9 - 48.2	7.2 - 23.7	~ 20 - 25
VHN	412 - 584	128 - 138	No data
POLISHING HARDNESS	Hard (5.5): ~niccolite, <safflorite, <skutterudite	Soft (1.5-2): <chalcocite, <chalcopyrite	Medium (4.5): >chalcocite, <pyrite
PLEOCHROISM — AIR	Strong: light pinkish to pinkish violet	Strong: indigo-blue with violet tint to bluish white	Moderate: rose-brown to cream-brown
PLEOCHROISM — OIL	Strong: light pinkish red to bright pinkish violet	Strong: purple to violet-red to blue-gray	Moderate: pink-gray to brown-gray
ANISOTROPISM	Strong: bluish green, bluish gray, violet-red	Strong: 45 degrees - orange to reddish brown	Moderate to strong: bluish gray, straight extinction,characteristic green tints
INTERNAL REFLECTIONS	Not present	Not present	Not present
TWINNING	Not present	Not present	Not present
ASSOCIATED MINERALS	Ag sulfosalts, allargentum, arsenic, dyscrasite, gersdorffite, linnaeite, maucherite, niccolite, pyrrhotite, safflorite, silver, skutterudite	Bornite, chalcocite, chalcopyrite, copper, cuprite, delafossite, digenite, enargite, famatinite, idaite, linnaeite, luzonite, tetrahedrite-tennantite	Bornite, chalcocite, copper, covellite, cuprite, goethite, limonite, tenorite, tetrahedrite-tennantite
KEY IDENTIFICATION CRITERIA	Pink with violet tint color under ordinary light and anisotropism are most characteristic. Occurs as subhedral to euhedral grains, often showing zoned associations with niccolite, giving alternating bands of breithauptite and niccolite. Niccolite is similar. Violerite appears similar but lacks zoning.	Indigo-blue color, strong pleochroism, and exteme anisotropism are characteristic. Occurs as subhedral to anhedral masses, as laths, and as platelike crystals. Often as aggregates of twisted lamellae, generally with deformation and traces of recrystallization.	Rose-brown color, strong anisotropy in green tints, possible colloform texture, and associated minerals are characteristic. Occurs as masses of subparallel crystals and sheaflike bundles or as fine inclusions in goethite. Concentric and botryoidal textures common.

GROUP NUMBER	1	1	1
MINERAL	Famatinite	Idaite	Luzonite
COMPOSITION	Cu_3SbS_4	Cu_3FeS_4	Cu_3AsS_4
SYSTEM	Tetragonal	Hexagonal	Tetragonal
POLISHING CLEAVAGE	Not visible	Not visible	Not visible
REFLECTANCE AND COLOR — AIR	Medium: pale purplish pink	Medium: orange-red or red-brown to yellowish gray	Medium: pinkish orange
REFLECTANCE AND COLOR — OIL	Medium: pale purplish pink	Medium: orange-red or red-brown to yellowish gray	Medium: pinkish orange color becomes more striking
R%	24 - 27.4	27 - 33.6	24.8 - 25.6 (at 540 nm)
VHN	205 - 397	176 - 260	205 - 397
POLISHING HARDNESS	Medium (3.5): ~enargite, >bornite, >chalcopyrite, <sphalerite	Soft (2.5): ~ or >covellite, <bornite, <chalcopyrite	Medium (3.5): >bornite, ~ or >tetrahedrite-tennantite, ~enargite, <sphalerite
PLEOCHROISM — AIR	Moderate to strong: light pink-yellow to dark purplish pink	Strong: orange-red or red-brown to yellowish gray	Moderate: pale orange-yellow to pink-brown. Accentuated by the lamellar twinning
PLEOCHROISM — OIL	Strong: orange-brown to grayish violet	Strong: orange-red or red-brown to yellowish gray	Strong: pale pink-yellow, orange-brown
ANISOTROPISM	Strong: yellowish brown to gray-green	Strong: brightly colored with yellow-green, green, or gray-green tints	Strong: shades of green
INTERNAL REFLECTIONS	Not present	Not present	Not present
TWINNING	Polysynthetic twins very common	Not present	Lamellar twins in one direction
ASSOCIATED MINERALS	Bornite, chalcocite, chalcopyrite, covellite, enargite, galena, prousite-pyrargyrite, pyrite, sphalerite, tetrahedrite-tennantite	Bornite, chalcopyrite, covellite, digenite, pyrite	Bornite, covellite, digenite, enargite, pyrite, sphalerite, tetrahedrite-tennantite
KEY IDENTIFICATION CRITERIA	Color, anisotropy, and polysynthetic twins are characteristic. Polysynthetic twins distinguish it from enargite. Forms solid solution with luzonite. Tint of famatinite is more purplish pink than luzonite.	Strong anisotropy, color, and association with chalcopyrite and bornite are characteristic. Commonly occurs as a replacement of bornite.	Pinkish orange color, anisotropism in green tints, and lamellar twins are characteristic. Twinning distinguishes it from enargite. Famatinite is more purplish pink and polarizes in more yellow-brown-colored tints.

GROUP NUMBER	1	1	1
MINERAL	Mackinawite	Marcasite	Mawsonite
COMPOSITION	$(Fe,Ni)_9S_8$	FeS_2	$Cu_6Fe_2SnS_8$
SYSTEM	Tetragonal	Orthorhombic	Tetragonal
POLISHING CLEAVAGE	(001) may be visible	(101) often visible	Not visible
REFLECTANCE AND COLOR — AIR	Strong: pinkish or reddish gray	Strong: yellowish white with greenish or pinkish tint	Strong: brownish orange
REFLECTANCE AND COLOR — OIL	Strong: pinkish or reddish gray	Strong: yellowish white with greenish or pinkish tint	Strong: brownish orange
R%	22 - 46	48.2 - 55.8	26.9 - 29.7
VHN	52 - 58	1288 - 1681	166 - 210
POLISHING HARDNESS	Medium (4): ~pyrrhotite	Hard (6-6.5): ~pyrite, >pyrrhotite	Medium (3.5-4): >bornite
PLEOCHROISM — AIR	Strong: pinkish gray to gray	Strong: white with brown tint, yellow with green tint	Strong: orange to brown
PLEOCHROISM — OIL	Strong: pinkish gray to gray	Strong: white with brown tint, yellow with green tint	Strong: orange to brown
ANISOTROPISM	Strong: grayish white, bluish, brownish	Strong: blue, green-yellow	Strong: straw yellow to royal blue, green-yellow tints
INTERNAL REFLECTIONS	Not present	Not present	Not present
TWINNING	Lamellar twins may be visible	Lamellar twins nearly always present	Not present
ASSOCIATED MINERALS	Arsenopyrite, chalcopyrite, cobaltite, cubanite, magnetite, pentlandite, pyrrhotite	Cinnabar, galena, magnetite, orpiment, pyrite, pyrrhotite, sphalerite	Arsenopyrite, bornite, cassiterite, chalcocite, chalcopyrite, enargite, galena, pyrite, stannite, tetrahedrite-tennantite, wolframite
KEY IDENTIFICATION CRITERIA	Strong pleochroism and anisotropism, and association as small exsolution blebs with chalcopyrite or pentlandite are characteristic. Association with cubanite is also characteristic. Occurs as small wormlike grains and lamellae.	Strong anisotropism in blue to green-yellow, strong reflectance, lamellar twins, and association with pyrite are characteristic. Occurs as subhedral to lamellar intergrowths with pyrite as euhedral crystals. Also occurs as radiating colloform bands.	Brownish orange color and strong anisotropy in straw yellow to royal blue with green-yellow tints are characteristic. Occurs as irregular blebs in or is associated with bornite.

GROUP NUMBER	1	1	2
MINERAL	Niccolite	Valleriite	Cubanite
COMPOSITION	NiAs	$4(Fe,Cu)S.3(Mg,Al)(OH)_2$	$CuFe_2S_3$
SYSTEM	Hexagonal	Hexagonal	Orthorhombic
POLISHING CLEAVAGE	May be visible	Not visible	(001) may be visible (110) rarely visible
REFLECTANCE AND COLOR — AIR	Strong: yellowish pink to brownish orange-pink	Low: brown, bronze to gray	Strong: creamy gray, pale brown or peach
REFLECTANCE AND COLOR — OIL	Strong: yellowish pink to brownish orange-pink	Low: brown, bronze to gray	Strong: gray-brown to cream-white
R%	47.2 - 51.6	14.2 - 22.0	35.4 - 39.4
VHN	363 - 372	30 (at 50 g)	247 - 287
POLISHING HARDNESS	Hard (5-5.5): >>gold, <rammelsbergite, <skutterudite	Medium (3.5-4): ~pentlandite, >chalcopyrite, <chromite	Medium (3.5-4): >chalcopyrite, <sphalerite, <<pyrrhotite
PLEOCHROISM — AIR	Weak to moderate: yellowish, pinkish white to pale pinkish brown, orange	Strong: bronze to gray	Weak: cream-gray, pale brown to peach
PLEOCHROISM — OIL	Moderate: pinkish white to deep pinkish brown	Strong: bronze to gray	Moderate: cream-gray to brownish gray
ANISOTROPISM	Strong: yellowish, grayish green, violet-blue, blue-gray	Strong: white to gray-bronze with a satinlike texture	Strong: highly characteristic blue tints, brownish to blue
INTERNAL REFLECTION	Not present	Not present	Not present
TWINNING	Rare: often parallel to (10T1)	Not present	Thin twin lamellae
ASSOCIATED MINERALS	Ag and Bi minerals, allargentum, breithauptite, gersdorffite, gold, maucherite, molybdenite, pitchblende, rammelsbergite, skutterudite, ullmanite, uraninite	Chalcopyrite, chromite, ilmenite, magnetite, millerite, pentlandite, sperrylite	Alabandite, arsenopyrite, chalcopyrite, cobaltite, galena, ilmenite, linnaeite, mackinawite, magnetite, pentlandite, pyrrhotite, sperrylite, sphalerite, violarite
KEY IDENTIFICATION CRITERIA	High reflectance, brown-orange color, and anisotropy in green-blue tints are characteristic. Occurs as isolated subhedral and euhedral crystals, as anhedral aggregates, as concentric bands, and as complex intergrowths with associated minerals.	Low reflectance, strong pleochroism, and anisotropy are characteristic. Occurs as veinlets, interstitial fillings, and tiny blebs in and around associated minerals. Graphite and mackinawite are similar.	Pleochroism in brown tints, strong anisotropy in blue tints, and exsolution lamellae in chalcopyrite are characteristic.

GROUP NUMBER	2	2	2
MINERAL	Enargite	Millerite	Niccolite
COMPOSITION	Cu_3AsS_4	NiS	NiAs
SYSTEM	Orthorhombic	Hexagonal	Hexagonal
POLISHING CLEAVAGE	(110) often visible	(10T1) often visible	May be visible
REFLECTANCE AND COLOR — AIR	Medium: light pinkish brown or pinkish gray	Strong: light yellow to yellow	Strong: yellowish pink to brownish orange-pink
REFLECTANCE AND COLOR — OIL	Medium: violet-gray or brownish gray	Strong: light yellow to yellow	Strong: yellowish pink to brownish orange-pink
R%	24.2 - 25.2	50.2 - 56.6	47.2 - 51.6
VHN	285 - 327	192 - 376	363 - 372
POLISHING HARDNESS	Medium (3-3.5): >bornite, >galena, ~ or >luzonite, ~ or >tennantite, <sphalerite	Medium (3-3.5): >chalcopyrite, <pentlandite	Hard (5-5.5): >>gold, <rammelsbergite, <skutterudite
PLEOCHROISM — AIR	Weak: pinkish gray to grayish violet	Weak: light yellow to pale yellow-brown	Weak to moderate: yellowish, pinkish white to pale pinkish brown, orange
PLEOCHROISM — OIL	Strong: pinkish gray to grayish violet	Moderate: bright yellow to pale yellow-brown	Moderate: pinkish white to deep pinkish brown
ANISOTROPISM	Strong: bluish, greenish, reddish, orange tints	Strong: bright yellow to slate blue-gray	Strong: yellowish, grayish green, violet-blue, blue-gray
INTERNAL REFLECTIONS	Rare: deep red	Not present	Not present
TWINNING	Rare: parallel (320)	Double twin lamellae often present	Rare: often parallel to (10T1)
ASSOCIATED MINERALS	Arsenopyrite, bornite, chalcocite, chalcopyrite, copper, covellite, digenite, famatinite, luzonite, mawsonite, molybdenite, pyrite, sphalerite, stannite, tennantite	Chromite, linnaeite, Ni minerals (especially bravoite), pentlandite, pyrrhotite, valleriite, violarite	Ag and Bi minerals, allargentum, breithauptite, gersdorffite, gold, maucherite, molybdenite, pitchblende, rammelsbergite, skutterudite, ullmanite, uraninite
KEY IDENTIFICATION CRITERIA	Light pink-brown color, medium reflectance, and highly colored anisotropy are characteristic. Occurs as anhedral to subhedral grains. Luzonite is more orange-yellow and always shows lamellar twins.	Strong anisotropy in yellow to blue-gray is characteristic. Occurs as radiating aggregates and as anhedral granular masses.	High reflectance, brown-orange color, and anisotropy in green-blue tints are characteristic. Occurs as isolated subhedral and euhedral crystals, as anhedral aggregates, as concentric bands, and as complex intergrowths with associated minerals.

GROUP NUMBER	2	3	3
MINERAL	Pyrrhotite	Bornite	Chalcocite
COMPOSITION	$Fe_{1-x}S$ *	Cu_5FeS_4	Cu_2S
SYSTEM	Monoclinic, hexagonal	Tetragonal< 228 deg. C >cubic	Orthorhombic< 103 deg. C >hexagonal
POLISHING CLEAVAGE	(0001) may be visible, (10T0) rarely seen	(100) or (111) often visible	(111) may be visible
REFLECTANCE AND COLOR AIR	Strong: creamy pinkish brown	Medium: pinkish brown to orange, tarnishes to purple	Medium: gray-white to bluish white
REFLECTANCE AND COLOR OIL	Strong: creamy pinkish brown	Medium: pinkish brown to orange, tarnishes to purple	Medium: gray-white to bluish white
R%	34.8 - 39.9(mono); 34.0 - 39.2(hex)	21.3	33.1 - 33.4
VHN	373 - 409(mono); 230 - 318(hex)	95 - 105	84 - 87
POLISHING HARDNESS	Medium (4) ; >>chalcopyrite, ~pentlandite, <<arsenopyrite, <<pyrite	Soft (3): >covellite, ~ or <chalcopyrite, <sphalerite	Soft (2.5-3): >>acanthite, >>argentite, ~digenite, ~galena, <bornite
PLEOCHROISM AIR	Weak to strong: creamy brown to reddish brown along grain boundaries	Weak: may be visible along grain boundaries	Weak to nonpleochroic
PLEOCHROISM OIL	Moderate to strong: creamy brown to reddish brown along grain boundaries	Weak: may be visible along grain boundaries	Weak to nonpleochroic: occasionally observable along grain boundaries
ANISOTROPISM	Strong: yellow-gray, greenish gray, or grayish blue	Weak: may appear isotropic	Weak to moderate: emerald green to light pinkish
INTERNAL REFLECTIONS	Not present	Not present	Not present
TWINNING	Not present	Polysynthetic and orthogonal twins may be observed	(111) observed in hexagonal form
ASSOCIATED MINERALS	Arsenopyrite, brannerite, carrollite, chalcopyrite, cobaltite, cubanite, galena, ilmenite, magnetite, marcasite, millerite, pentlandite, pyrite, stannite	Carrollite, cassiterite, chalcopyrite, covellite, digenite, enargite, famatinite, freibergite, idaite, luzonite, mawsonite, sphalerite, tetrahedrite-tennantite	Cu minerals, galena, sphalerite, stannite, tetrahedrite-tennantite
KEY IDENTIFICATION CRITERIA	Creamy pinkish brown color and the strong anisotropy are characteristic. Cubanite is softer. Occurs commonly as anhedral granular aggregates. * FeS is troilite.	Pinkish brown to orange color, weak anisotropy, twins, and the purple tarnish are characteristic. Occurs as irregular polycrystalline aggregates.	Bluish white to gray-white color, anisotropy, and association with Cu sulfides are characteristic. Occurs as anhedral polycrystalline aggregates and vein fillings.

GROUP NUMBER	3	4	4
MINERAL	Chalcopyrite	Bornite	Bravoite
COMPOSITION	$CuFeS_2$	Cu_5FeS_4	$(Ni,Fe)S_2$
SYSTEM	Tetragonal	Tetragonal< 228 deg. C >cubic	Cubic
POLISHING CLEAVAGE	(111) rarely visible	(100) or (111) often visible	(110) rarely visible
REFLECTANCE AND COLOR AIR	Strong: yellow to brassy yellow	Medium: pinkish brown to orange, tarnishes to purple	Medium to strong: varies with composition; Fe - creamy to pinkish, Ni - pinkish, brownish to violet
REFLECTANCE AND COLOR OIL	Strong: yellow to brassy yellow	Medium: pinkish brown to orange, tarnishes to purple	Medium to strong: varies with composition; Fe - creamy to pinkish, Ni - pinkish, brownish to violet
R%	44.6 - 45.0	21.3	31.0 - 53.9
VHN	181 - 203	95 - 105	668 - 1535
POLISHING HARDNESS	Medium (3.5-4): >galena, <pyrite, <sphalerite	Soft (3): >covellite, ~ or <chalcopyrite, <sphalerite	Medium to hard (3.5-6): depends on composition
PLEOCHROISM AIR	Weak: occasionally observable	Weak: may be visible along grain boundaries	Nonpleochroic
PLEOCHROISM OIL	Weak: occasionally observable	Weak: may be visible along grain boundaries	Nonpleochroic
ANISOTROPISM	Weak but distinct: gray-blue, greenish yellow	Weak: may appear isotropic	Isotropic
INTERNAL REFLECTIONS	Not present	Not present	Not present
TWINNING	Common parallel (100), (110), and (111); fine or broad lamellae	Polysynthetic and orthogonal twins may be observed	Not present
ASSOCIATED MINERALS	Arsenopyrite, covellite, cubanite, enargite, famatinite, galena, mackinawite, pyrite, pyrrhotite, sphalerite, stannite, valleriite	Carrollite, cassiterite, chalcopyrite, covellite, digenite, enargite, famatinite, freibergite, idaite, luzonite, mawsonite, sphalerite, tetrahedrite-tennantite	Bismuth, breithauptite, chalcopyrite, galena, ilmenite, linnaeite, magnetite, millerite, pentlandite, pyrrhotite, saffloríte, siegenite, sphalerite, violerite
KEY IDENTIFICATION CRITERIA	Yellow to brassy yellow color, lamellar twins, and weak but characteristic anisotropic colors are best criteria. Occurs as medium- to coarse-grained anhedral aggregates.	Pinkish brown to orange color, weak anisotropy, twins, and the purple tarnish are characteristic. Occurs as irregular polycrystalline aggregates.	Generally shows a very characteristic zonal texture with alternating light and dark bands (light zones = pyrite and darker = more Ni-Co rich). Occurs as euhedral isolated cubes or octahedral crystals.

GROUP NUMBER	4	4	4
MINERAL	Chalcopyrite	Copper	Digenite
COMPOSITION	$CuFeS_2$	Cu	Cu_9S_5
SYSTEM	Tetragonal	Cubic	Cubic
POLISHING CLEAVAGE	(111) rarely visible	Not visible	(111) often visible
REFLECTANCE AND COLOR — AIR	Strong: yellow to brassy yellow	Strong: pink but tarnishes red-brown (copper red)	Medium: grayish blue
REFLECTANCE AND COLOR — OIL	Strong: yellow to brassy yellow	Strong: pink but tarnishes red-brown (copper red)	Medium: grayish blue, blue color more intensified
R%	44.6 - 45.0	60.6	23.1
VHN	181 - 203	96 - 104	67 - 76
POLISHING HARDNESS	Medium (3.5-4): >galena, <pyrite, <sphalerite	Soft (2.5-3): >chalcocite, <cuprite	Soft (2.5-3): ~chalcocite, <chalcopyrite
PLEOCHROISM — AIR	Weak: occasionally observable	Nonpleochroic	Nonpleochroic
PLEOCHROISM — OIL	Weak: occasionally observable	Nonpleochroic	Nonpleochroic
ANISOTROPISM	Weak but distinct: gray-blue, greenish yellow	Isotropic: fine scratches will appear anisotropic	Isotropic
INTERNAL REFLECTIONS	Not present	Not present	Not present
TWINNING	Common parallel (100), (110), and (111); fine or broad lamellae	(111)	Not present
ASSOCIATED MINERALS	Arsenopyrite, covellite, cubanite, enargite, famatinite, galena, mackinawite, pyrite, pyrrhotite, sphalerite, stannite, valleriite	Bornite, chalcocite, covellite, cuprite, delafossite, enargite, goethite, magnetite, pyrrhotite, tenorite	Bornite, carrollite, chalcocite, chalcopyrite, covellite, enargite, idaite, luzonite, tetrahedrite-tennantite
KEY IDENTIFICATION CRITERIA	Yellow to brassy yellow color, lamellar twins, and weak but characteristic anisotropic colors are best criteria. Occurs as medium- to coarse-grained anhedral aggregates.	Strong reflectance, the red-brown tarnish, the pink color, and the association with cuprite are characteristic. Occurs as coarse- to fine-grained aggregates. Occasionally as dendritic or spear-like crystals.	Bluish color, medium reflectance, isotropism, and octahedral cleavage are characteristic. Occurs as irregular aggregates of anhedral grains that contain lamellar intergrowths with other Cu sulfides (especially chalcocite or covellite). Alters to covellite.

GROUP NUMBER	4	4	4
MINERAL	Gold / Electrum	Pyrite	Tetrahedrite - Tennantite
COMPOSITION	Au / Au-Ag alloy	FeS_2	$(Cu,Fe)_{12}Sb_4S_{13}$ - $(Cu,Fe)_{12}As_4S_{13}$
SYSTEM	Cubic	Cubic	Cubic
POLISHING CLEAVAGE	Not visible	(100) often visible	May be visible
REFLECTANCE AND COLOR — AIR	Strong: bright or golden yellow; electrum is slightly lighter and less yellow	Strong: yellowish white	Medium: grayish white to greenish gray-white, greenish shade especially in tennantite
REFLECTANCE AND COLOR — OIL	Strong: bright or golden yellow; electrum is slightly lighter and less yellow	Strong: yellowish white	Medium: grayish white to greenish gray-white, tetrahedrite may have slight bluish tint.
R%	71.5	51.7	30 - 30.5
VHN	53 - 58	1505 - 1620	285 - 354
POLISHING HARDNESS	Soft (2.5-3): >stibnite, <pyrite, <chalcopyrite	Hard (6-6.5): >arsenopyrite, >hematite, ~marcasite	Medium (3-4.5): ~chalcopyrite, >digenite, <sphalerite
PLEOCHROISM — AIR	Nonpleochroic	Nonpleochroic	Nonpleochroic
PLEOCHROISM — OIL	Nonpleochroic	Nonpleochroic	Nonpleochroic
ANISOTROPISM	Isotropic but incomplete extinction; a greenish shade is often observed	Usually isotropic: however, it may be weakly anisotropic (blue-green to orange-red)	Isotropic
INTERNAL REFLECTIONS	Not present	Not present	Brownish red, common in tennantite; reddish, rare in tetrahedrite
TWINNING	(111) common	Not visible	Not present
ASSOCIATED MINERALS	Arsenopyrite, berthierite, calaverite, chalcopyrite, cinnabar, cobaltite, niccolite, pitchblende, pyrite, sperrylite, stibnite, tellurides, ullmanite, uraninite	Practically all minerals but especially arsenopyrite, chalcopyrite, galena, magnetite, marcasite, pyrrhotite, sphalerite	Ag minerals, bornite, bournonite, brannerite, calaverite, chalcopyrite, Co-Ni minerals, covellite, delafossite, digenite, enargite, famatinite, luzonite, mawsonite
KEY IDENTIFICATION CRITERIA	Golden yellow color, strong reflectance, and softness are characteristic. Occurs as isolated grains and veinlets in many sulfides (especially in pyrite and arsenopyrite). Electrum contains 20% or more silver causing the color to be more whitish and the reflectance to increase.	Yellowish white color, strong reflectance, hardness, and uneven polishing are characteristic. Occurs as euhedral cubes and pyritohedra, as anhedral crystalline masses, and as botryoidal masses with rhythmic zoning and radiating texture. Most common sulfide.	Medium reflectance, good polish, and its association with galena, chalcopyrite, or bournonite are characteristic. Often occurs as small blebs in galena and sphalerite. Tetrahedrite and tennantite form a complete solid solution.

GROUP NUMBER	4
MINERAL	Ulvospinel or ulvite
COMPOSITION	$TiFe_2O_4$
SYSTEM	Cubic
POLISHING CLEAVAGE	(100) may be visible
REFLECTANCE AND COLOR — AIR	Low: brown to reddish brown
REFLECTANCE AND COLOR — OIL	Low: brown to reddish brown
R%	15.5
VHN	No data
POLISHING HARDNESS	Hard (6): >magnetite
PLEOCHROISM — AIR	Nonpleochroic
PLEOCHROISM — OIL	Nonpleochroic
ANISOTROPISM	Isotropic
INTERNAL REFLECTIONS	Not present
TWINNING	Not present
ASSOCIATED MINERALS	Chromite, ilmenite, magnetite
KEY IDENTIFICATION CRITERIA	Occurs as extremely fine, dark isotropic exsolution lamellae in magnetite giving a clothweave texture.

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Noncolored Minerals

GROUP NUMBER	5	5	5
MINERAL	Alabandite	Amphibole	Biotite
COMPOSITION	MnS	$A_{0-1}B_2Y_5Z_8O_{22}(OH,F,Cl)_2$ *	$K(Mg,Fe^{+2})_3(Al,Fe^{+3})Si_3O_{10}(OH,F)_2$
SYSTEM	Cubic	Monoclinic, orthorhombic	Monoclinic
POLISHING CLEAVAGE	(100) often visible	Cleavage angles of 124 degrees always visible	One cleavage always visible
REFLECTANCE AND COLOR — AIR	Medium: gray (tarnishes rapidly)	Low: dull gray	Low: dull gray
REFLECTANCE AND COLOR — OIL	Medium: gray	Low: dull gray, surface almost disappears	Low: dull gray, surface completely disappears
R%	22.8	No data	No data
VHN	240 - 251	No data	No data
POLISHING HARDNESS	Medium (3.5): ~sphalerite	Hard (5-6): >biotite, ~pyroxene, <garnet, <quartz, <pyrite	Soft (2.5-3): ~chalcopyrite, ~galena, <<amphibole, <<garnet, <<quartz, <<pyrite
PLEOCHROISM — AIR	Nonpleochroic	Nonpleochroic	Weak
PLEOCHROISM — OIL	Nonpleochroic	Nonpleochroic	Weak
ANISOTROPISM	Isotropic	Not present	Strong: masked by internal reflections
INTERNAL REFLECTIONS	Common: dark green to brown; less common: yellow-green	Common: in various colors	Common: pearly iridescence
TWINNING	Lamellar twins observable	Multiple twinning common	Not present
ASSOCIATED MINERALS	Chalcopyrite, cubanite, galena, pyrite, pyrolusite, pyrrhotite, sphalerite	Many minerals including biotite, chalcopyrite, galena, garnet, quartz, pyrite, pyroxene, pyrrhotite, sphalerite	Many minerals including amphibole, chalcopyrite, galena, garnet, quartz, pyrite, pyroxene, pyrrhotite, sphalerite
KEY IDENTIFICATION CRITERIA	Green internal reflections and rapid tarnishing are characteristic. Occurs as euhedral crystals and as anhedral aggregates. Cleavage, lamellar twinning, and zonal textures may be visible. Reflectance is higher than sphalerite.	Cleavage, bladed to needlelike development, and hardness are characteristic. Occurs as gangue in magmatic ores, pneumatolytic replacements, and metamorphosed ore deposits. * A = Na,K; B = Ca,Fe, Li,Mg,Mn; Y = Al,Fe,Mg,Mn; Z = Al, Si,Ti.	Exceptional cleavage, tabular form, hardness, and low reflectance are characteristic. Characteristics also apply to the white micas. Common gangue mineral.

GROUP NUMBER	5	5	5
MINERAL	Brannerite	Chromite	Columbite - Tantalite
COMPOSITION	$(U,Ca,Ce)(Ti,Fe)_2O_6$	$Fe^{+2}Cr_2O_4$	$(Fe^{+2},Mn)(Ta,Nb)_2O_6$
SYSTEM	Monoclinic (metamict)	Cubic	Orthorhombic
POLISHING CLEAVAGE	Not visible	May be visible	(100) often visible (010) may be visible
REFLECTANCE AND COLOR — AIR	Low: gray	Low: dark gray to brownish gray	Low: gray-white with brownish tint
REFLECTANCE AND COLOR — OIL	Low: gray	Low: dark gray to brownish gray	Low: gray-white with brownish tint
R%	15.0 - 15.1	12.3	15.3 - 17.3
VHN	690	1332	240 - 1021
POLISHING HARDNESS	Soft (2.5): >molybdenite, <pyrrhotite, <<magnetite, <<rutile	Hard (5.5): >magnetite, ~ilmenite	Hard (6): >galena, ~ or <cassiterite
PLEOCHROISM — AIR	Nonpleochroic	Nonpleochroic	Weak
PLEOCHROISM — OIL	Nonpleochroic	Nonpleochroic	Weak to moderate along grain boundaries
ANISOTROPISM	Not present	Isotropic	Weak, moderate in oil
INTERNAL REFLECTIONS	Common: brownish gray in coarse crystals; dark brown to yellowish, blue-gray to white in fine crystals	Common: brown to red-brown in Mg-Al-rich samples; absent in Fe-rich samples	Common: red to red-brown
TWINNING	Not present	Not present	Rare
ASSOCIATED MINERALS	Chalcopyrite, coffinite, galena, hematite, magnetite, molybdenite, pitchblende, pyrite, pyrrhotite, rutile, sphalerite, tetrahedrite-tennantite, uraninite	Hematite, ilmenite, magnetite, millerite, pentlandite, pyrrhotite, sperrylite, ulvospinel, valleriite	Cassiterite, galena, hematite, ilmenite, pitchblende, rutile, uraninite, wolframite
KEY IDENTIFICATION CRITERIA	Association with uraninite and rutile, elongated prisms, and metamict aspect are characteristic. Occurs as euhedral prismatic to needlelike crystals and as subhedral aggregates.	Low reflectance, hardness, isotropism, and internal reflections are characteristic. Usually occurs as subhedral (rounded) to euhedral crystals or as coarsely crystalline aggregates. Cataclastic effects common. Zonal textures with lighter (Fe-rich) rims are common. May form myrmekitic intergrowths.	Low reflectance, weak anisotropy, and abundant internal reflections are characteristic. Occurs as euhedral crystals and anhedral aggregates. May be zoned. Occurs frequently as tiny exsolution blebs in cassiterite. May occur as tufts of radiating crystals. Resembles wolframite.

GROUP NUMBER	5	5	5
MINERAL	Cuprite	Feldspar	Franklinite
COMPOSITION	Cu_2O	XZ_4O_8 *	$(Zn,Mn^{+2},Fe^{+2})(Fe^{+3},Mn^{+3})_2O_4$
SYSTEM	Cubic	Monoclinic, triclinic	Cubic
POLISHING CLEAVAGE	(111) rarely visible	Often visible	(111) often visible
REFLECTANCE AND COLOR AIR	Medium: white-gray with bluish tint	Low: dull gray	Low: gray with faint greenish tint
REFLECTANCE AND COLOR OIL	Low: white-gray with greenish tint	Low: almost black	Low: gray with faint greenish tint
R%	26.6	No data	18.4 (at 550 nm)
VHN	193 - 207	No data	667 - 847
POLISHING HARDNESS	Medium (3-4): >copper, >tenorite, >chalcopyrite, <goethite	Hard (6)	Hard (5.5-6.5): >zincite
PLEOCHROISM AIR	Weak to nonpleochroic	Nonpleochroic	Nonpleochroic
PLEOCHROISM OIL	Masked by deep red internal reflections	Nonpleochroic	Nonpleochroic
ANISOTROPISM	Moderate to strong when coarse-grained and along grain boundaries: gray-blue to olive-green; tints are largely masked by internal reflections	Masked by internal reflections	Isotropic; a very weak pinkish gray to gray-black anisotropy may be visible in strained samples
INTERNAL REFLECTIONS	Abundant: deep red	Abundant: light internal reflections	Abundant: deep red
TWINNING	Not present	Simple or multiple twins common	(111) rare
ASSOCIATED MINERALS	Chalcocite, chalcopyrite, copper, covellite, delafossite, goethite, tenorite	Many opaque minerals including chalcopyrite, galena, pyrite, pyrrhotite, sphalerite	Chalcophanite, hausmannite, jacobsite, magnetite, zincite
KEY IDENTIFICATION CRITERIA	White-gray color with bluish tints, colored anisotropy with extensive internal reflections, and association with native copper are characteristic. Occurs as euhedral octahedra and in a fine-grained "earthy" form.	Low reflectance, hardness, and twins are characteristic. Common gangue mineral. * X = Ba,Ca,K,Na, NH_4,Sr; Z = Al,B,Si.	Internal reflections and association with zincite are characteristic. Magnetite is similar but lacks internal reflections. Often occurs as subhedral to euhedral crystals.

GROUP NUMBER	5	5	5
MINERAL	Freibergite	Garnet	Jacobsite
COMPOSITION	$(Ag,Cu,Fe)_{12}(Sb,As)_4S_{13}$	$A_3B_2(SiO_4)_3$ *	$(Mn^{+2},Fe^{+2},Mg)(Fe^{+3},Mn^{+3})_2O_4$
SYSTEM	Cubic	Cubic	Cubic
POLISHING CLEAVAGE	(100) rarely visible	Not visible	Not visible
REFLECTANCE AND COLOR AIR	Medium: gray	Low: pale pinkish brown-gray	Low: rose-brown to brownish gray
REFLECTANCE AND COLOR OIL	Medium: gray with faint yellow-brown tint	Low: pale pinkish brown-gray	Low: gray with olive tint
R%	29.4	No data	19.4
VHN	252 - 375	No data	665 - 707
POLISHING HARDNESS	Soft (2): <galena, <sphalerite	Hard (6.5-7.5)	Hard (6): ~magnetite
PLEOCHROISM AIR	Nonpleochroic	Nonpleochroic	Nonpleochroic
PLEOCHROISM OIL	Nonpleochroic	Nonpleochroic	Nonpleochroic
ANISOTROPISM	Isotropic	Isotropic	Isotropic
INTERNAL REFLECTIONS	Common: brownish red	Common: red and orange	Rare: deep red especially when Mn rich
TWINNING	Not present	Not present	Not present
ASSOCIATED MINERALS	Calaverite, chalcopyrite, Co-Fe-Ni arsenides, galena, krennerite, pearceite-polybasite, proustite-pyrargyrite, silver, sphalerite	Many opaque minerals including chalcopyrite, galena, pyrite, pyrrhotite, sphalerite	Bixbyite, braunite, hausmannite, franklinite, psilomelane, pyrolusite
KEY IDENTIFICATION CRITERIA	Brownish red internal reflections, lack of pleochroism, hardness, isotropism, and faint yellow-brown tint in oil are characteristic. Occurs as irregular masses and inclusions of anhedral crystals with and in associated minerals.	Forms 4-, 6-, 8-sided polygonal sections. Also as rounded grains, aggregates, or inclusions. Common gangue mineral in metamorphosed massive sulfide deposits and skarns. * A = Ca,Fe,Mg,Mn; B = Al, Cr,Fe,Mn,Ti,V,Zr; Si partly replaced by Ti and Al.	Association with manganese oxides, olive-brown tint, and isotropism are characteristic. Occurs as anhedral grains and rounded subhedral crystals. Alters to other minerals including goethite, hematite, psilomelane, and pyrolusite.

GROUP NUMBER	5	5	5
MINERAL	Pyroxene	Quartz	Sphalerite
COMPOSITION	ABZ_2O_6 *	SiO_2	(Zn,Fe)S
SYSTEM	Monoclinic, orthorhombic	Hexagonal	Cubic
POLISHING CLEAVAGE	Often visible	Not visible	(110) may be visible
REFLECTANCE AND COLOR — AIR	Low: dull gray	Low: dull gray	Low: dark gray sometimes with brown or blue tint
REFLECTANCE AND COLOR — OIL	Low: surface almost completely disappears	Low: almost black	Low: dark gray
R%	No data	No data	16.7
VHN	No data	No data	218 - 227
POLISHING HARDNESS	Hard (5-6): >amphibole, >galena, ~pyroxene, <garnet, <quartz, <pyrite	Hard (7): >>biotite, >>calcite, >amphibole, >galena, >pyrite, >pyroxene, ~garnet	Medium (3.5-4): >chalcopyrite, <magnetite, <pyrrhotite
PLEOCHROISM — AIR	Nonpleochroic	Nonpleochroic	Nonpleochroic
PLEOCHROISM — OIL	Nonpleochroic	Nonpleochroic	Nonpleochroic
ANISOTROPISM	Not present	Masked by internal reflections	Isotropic
INTERNAL REFLECTIONS	Abundant: in various colors	Abundant: light internal reflections	Common: white, yellow, reddish, reddish brown; color varies with composition and Fe content
TWINNING	Not present	Not present	(111) and (211) often visible
ASSOCIATED MINERALS	Many minerals including amphibole, biotite, chalcopyrite, galena, garnet, quartz, pyrite, pyrrhotite, sphalerite	Many minerals including amphibole, biotite, calcite, chalcopyrite, galena, garnet, pyrite, pyrrhotite, sphalerite	Many opaque minerals but especially arsenopyrite, chalcopyrite, cubanite, galena, hematite, luzonite, magnetite, marcasite, pyrite, pyrrhotite, stannite
KEY IDENTIFICATION CRITERIA	Hardness and cleavage are characteristic. Occurs as gangue type minerals in magmatic ores, pneumatolytic replacements, and metamorphosed ore deposits. * A = Ca, Fe,Li,Mg,Na; B = Al,Cr,Fe,Mg,Mn; Z = Al,Si.	Low reflectance, complete absence of cleavage, hardness, and common euhedral habit are characteristic. Very common gangue mineral.	Low reflectance, common internal reflections, isotropism, and dark gray color are characteristic. Occurs as irregular anhedral masses. Commonly contains blebs of chalcopyrite, galena, or pyrrhotite. Magnetite is similar but lacks internal reflections.

GROUP NUMBER	5	5	5
MINERAL	Tetrahedrite - Tennantite	Uraninite or pitchblende	Wurtzite
COMPOSITION	$(Cu,Fe)_{12}Sb_4S_{13}$ - $(Cu,Fe)_{12}As_4S_{13}$	UO_2	(Zn,Fe)S
SYSTEM	Cubic	Cubic	Hexagonal
POLISHING CLEAVAGE	May be visible	(111), (100) may be visible	(0001) rarely visible
REFLECTANCE AND COLOR AIR	Medium: grayish white to greenish gray-white, greenish shade especially in tennantite	Low: gray with brown tint	Low: gray with slight bluish tint
REFLECTANCE AND COLOR OIL	Medium: grayish white to greenish gray-white, tetrahedrite may have slight bluish tint	Low: gray with brown tint	Low: very dark gray
R%	30 - 30.5	10.0 - 17.1	17.2 - 19.5
VHN	285 - 354	314 - 929	146 - 264
POLISHING HARDNESS	Medium (3-4.5): ~chalcopyrite, >digenite, <sphalerite	Hard (5-6): >galena	Medium (3.5-4): ~sphalerite
PLEOCHROISM AIR	Nonpleochroic	Nonpleochroic	Nonpleochroic
PLEOCHROISM OIL	Nonpleochroic	Nonpleochroic	Nonpleochroic
ANISOTROPISM	Isotropic	Isotropic	Isotropic
INTERNAL REFLECTIONS	Brownish red, common in tennantite; reddish, rare in tetrahedrite	Common: dark brown to reddish brown	Abundant: red-brown, yellow-brown or yellowish very common
TWINNING	Not present	(111) common	Not present
ASSOCIATED MINERALS	Ag minerals, bornite, bournonite, brannerite, calaverite, chalcopyrite, Co-Ni minerals, covellite, delafossite, digenite, enargite, famatinite, luzonite, mawsonite	Bismuthinite, brannerite, chalcopyrite, coffinite, columbite-tantalite, Co-Ni-Fe arsenides, galena, gold, molybdenite, niccolite, siegenite	Ag sulfosalts, galena, sphalerite, stannite
KEY IDENTIFICATION CRITERIA	Medium reflectance, good polish, and its association with galena, chalcopyrite, or bournonite are characteristic. Often occurs as small blebs in galena and sphalerite. Tetrahedrite and tennantite form a complete solid solution.	Forms, internal reflections, and the radioactive halo which commonly surrounds the mineral are characteristic. Occurs as growth-zoned crystals and colloform, oolitic, and dendritic masses. Pitchblende is the massive fine-grained (colloform) form of uraninite.	Sphalerite is the only similar mineral and distinction is based on wurtzite's fibrous texture, absence of polysynthetic twins, and slightly stronger anisotropy. Wurtzite is commonly zoned and usually occurs as concentric and radiating aggregates of acicular crystals. Far less common than sphalerite.

GROUP NUMBER	5	6	6
MINERAL	Zincite	Calaverite	Chalcocite
COMPOSITION	(Zn,Mn)O	$AuTe_2$	Cu_2S
SYSTEM	Hexagonal	Monoclinic	Orthorhombic< 103 deg. C >hexagonal
POLISHING CLEAVAGE	(0001) often visible	Not visible	(111) may be visible
REFLECTANCE AND COLOR — AIR	Low: pinkish brown to gray	Strong: white with slight brownish yellow tint	Medium: gray-white to bluish white
REFLECTANCE AND COLOR — OIL	Low: dark pinkish brown to dark gray	Strong: white with slight brownish yellow tint	Medium: gray-white to bluish white
R%	11.8	61.3 - 65.9 (at 540 nm)	33.1 - 33.4
VHN	190 - 219	198 - 209	84 - 87
POLISHING HARDNESS	Medium (4.5-5): <<franklinite, <<hausmannite	Soft (2.5-3): ~ or <galena, <<chalcopyrite	Soft (2.5-3): >>acanthite, >>argentite, ~digenite, ~galena, <bornite
PLEOCHROISM — AIR	Weak	Weak but distinct along grain boundaries: yellowish brown, yellowish white	Weak to nonpleochroic
PLEOCHROISM — OIL	Masked by internal reflections	Weak but distinct along grain boundaries: yellowish brown, yellowish white	Weak to nonpleochroic: occasionally observable along grain boundaries
ANISOTROPISM	Masked by internal reflections	Weak: brown to dark gray tints, grayish red, green, greenish brown	Weak to moderate: emerald green to light pinkish
INTERNAL REFLECTIONS	Abundant: red, orange, to yellowish	Not present	Not present
TWINNING	Not present	Generally not visible, sometimes lamellar twins at grain borders	(111) observed in hexagonal form
ASSOCIATED MINERALS	Chalcophanite, franklinite, hausmannite, magnetite	Chalcopyrite, freibergite, galena, gold-electrum, krennerite, silver, tetradymite	Cu minerals, galena, sphalerite, stannite, tetrahedrite-tennantite
KEY IDENTIFICATION CRITERIA	Low reflectance, abundant red to yellow internal reflections, and well-developed cleavage are characteristic. Occurs as rounded grains. Forms oriented intergrowths with hausmannite.	This mineral does not have good diagnostic characteristics, but the very high reflectance, weak and slightly colored anisotropism, and association with other tellurides are the best identification criteria.	Bluish white to gray-white color, anisotropy, and association with Cu sulfides are characteristic. Occurs as anhedral polycrystalline aggregates and vein fillings.

GROUP NUMBER	6	6	6
MINERAL	Djurleite	Freibergite	Galena
COMPOSITION	$Cu_{31}S_{16}$	$(Ag,Cu,Fe)_{12}(Sb,As)_4S_{13}$	PbS
SYSTEM	Orthorhombic	Cubic	Cubic
POLISHING CLEAVAGE	Not present	(100) rarely visible	(100) often visible as triangular pits
REFLECTANCE AND COLOR AIR	Medium: grayish white with bluish tint	Medium: gray	Strong: white to light gray
REFLECTANCE AND COLOR OIL	Medium: distinctly bluish white	Medium: gray with faint yellow-brown tint	Strong: white to light gray; sometimes reddish tint
R%	~30.0	29.4	43.1
VHN	74 - 83 (at 50 g)	252 - 375	59 - 65
POLISHING HARDNESS	Soft (2.5-3): ~chalcocite, ~galena, <sphalerite	Soft (2): <galena, <sphalerite	Soft (2.5): >>acanthite-argentite, >proustite-pyrargyrite, <bournonite, <tetrahedrite-tennantite
PLEOCHROISM AIR	Weak	Nonpleochroic	Nonpleochroic
PLEOCHROISM OIL	Weak	Nonpleochroic	Nonpleochroic
ANISOTROPISM	Weak	Isotropic	Isotropic
INTERNAL REFLECTIONS	Not present	Common: brownish red	Not present
TWINNING	Not present	Not present	Not present
ASSOCIATED MINERALS	Cu minerals, galena, sphalerite	Calaverite, chalcopyrite, Co-Fe-Ni arsenides, galena, krennerite, pearceite-polybasite, proustite-pyrargyrite, silver, sphalerite	Acanthite-argentite, arsenopyrite, bournonite, chalcopyrite, cubanite, magnetite, marcasite, proustite-pyrargyrite, pyrite, pyrrhotite, sphalerite, tetrahedrite-tennantite
KEY IDENTIFICATION CRITERIA	Bluish tint, association with Cu minerals, hardness, weak pleochroism, and weak anisotropy are characteristic.	Brownish red internal reflections, lack of pleochroism, hardness, isotropism, and faint yellow-brown tint in oil are characteristic. Occurs as irregular masses and inclusions of anhedral crystals with and in associated minerals.	Strong reflectance, triangular pits, and association with sphalerite and pyrite are characteristic. Occurs as anhedral masses to euhedral cubes. The perfect (100) cleavage is usually visible as triangular pits.

GROUP NUMBER	6	6	7
MINERAL	Silver	Tetradymite	Allargentum
COMPOSITION	Ag	Bi_2Te_2S	$Ag_{1-x}Sb_x$
SYSTEM	Cubic	Hexagonal	Hexagonal
POLISHING CLEAVAGE	Not visible	Basal cleavage always visible	Not visible
REFLECTANCE AND COLOR — AIR	Strong: bright white with creamy tint, tarnishes rapidly to reddish	Strong: white with creamy or light yellow tint	Strong: white with slight gray tint
REFLECTANCE AND COLOR — OIL	Strong: may apprear slightly yellow when it contains a small amount of gold	Strong: white with creamy or light yellow tint	Strong: white with slight gray tint
R%	94.2	50.9 - 57.1	~70
VHN	55 - 63	51.1 - 56.9	143 - 157
POLISHING HARDNESS	Soft (2.5-3): >galena, <tetrahedrite-tennantite, <<sphalerite	Soft (2.5): <galena	Medium (3.5-4): >silver
PLEOCHROISM — AIR	Nonpleochroic	Weak: greenish gray tints	Nonpleochroic
PLEOCHROISM — OIL	Nonpleochroic	Weak: greenish gray tints	Nonpleochroic
ANISOTROPISM	Isotropic	Moderate: bluish gray to yellow-gray	Weak
INTERNAL REFLECTIONS	Not present	Not present	Not present
TWINNING	Common	Rare: lamellar twins	Rare: lamellar twins
ASSOCIATED MINERALS	Allargentum, arsenic, bismuth, breithauptite, calaverite, dyscrasite, freibergite, galena, Ni-Co arsenides, sphalerite, stromeyerite, tetrahedrite-tennantite	Arsenopyrite, calaverite, chalcopyrite, galena, krennerite, magnetite, pyrite, pyrrhotite	Ag and Bi minerals, breithauptite, niccolite, pararammelsbergite, rammelsbergite, silver
KEY IDENTIFICATION CRITERIA	Strong reflectance and isotropism are characteristic. Occurs as irregular masses, veinlets, blebs, and as dendrites within arsenides. Tarnishes reddish rapidly. Lamellar intergrowths with allargentum.	Creamy white color, anhedral granular texture and perfect basal cleavage are characteristic. Forms intergrowths with other tellurides.	Can be confused with dyscrasite which is practically never lamellar. Occurs as lamellar intergrowths in silver.

GROUP NUMBER	7	7	7
MINERAL	Carrollite	Coffinite	Cooperite
COMPOSITION	$Cu(Co,Ni)_2S_4$	$U(SiO_4)_{1-x}(OH)_{4x}$	(Pt,Pd,Ni)S
SYSTEM	Cubic	Tetragonal	Tetragonal
POLISHING CLEAVAGE	(100) often visible, (111) may be visible	Not visible	(111) may be visible
REFLECTANCE AND COLOR AIR	Strong: creamy white, sometimes with slight pinkish tint	Low: gray	Medium: brownish white
REFLECTANCE AND COLOR OIL	Strong: creamy white, sometimes with slight pinkish tint	Low: gray	Medium: brownish white
R%	45.0	7.9 - 8.0	39.0 (at 550 nm)
VHN	525 - 542	230 - 302	505 - 588
POLISHING HARDNESS	Hard (4.5-5.5): >chalcopyrite, <pyrite	Hard (5-6): ~pitchblende	Medium (4): <platinum, <<sperrylite
PLEOCHROISM AIR	Nonpleochroic	Weak to nonpleochroic	Weak
PLEOCHROISM OIL	Nonpleochroic	Weak to nonpleochroic	Weak but distinct along grain boundaries
ANISOTROPISM	Isotropic	Weak to absent	Weak to isotropic: gray-pink to gray-green; relatively strong in oil
INTERNAL REFLECTIONS	Not present	Rare: brown or deep bluish gray	Not present
TWINNING	Not present	Not present	Not present
ASSOCIATED MINERALS	Bornite, chalcocite, chalcopyrite, digenite, pyrite, pyrrhotite, siegenite	Brannerite, goethite, pitchblende, pyrite, uraninite	Braggite, platinum, sperrylite, and other platinum minerals
KEY IDENTIFICATION CRITERIA	Creamy white color is characteristic. Carrollite is whiter than linnaeite, siegenite, and violarite. Occurs as anhedral granular masses to subhedral and euhedral octahedra.	Association with pitchblende and low reflectance are characteristic. Occurs as euhedral tetragonal crystals, as fine aggregates, and as colloform bands.	Hardness, lower reflectivity, and the weak anisotropy distinguish it from other platinum minerals and also pyrrhotite. Occurs usually as very small, thick tabular inclusions in platinum or surrounding it. Alters to platinum starting at its borders.

GROUP NUMBER	7	7	7
MINERAL	Maghemite	Maucherite	Pentlandite
COMPOSITION	γ - Fe_2O_3	$Ni_{11}As_8$	$(Fe,Ni)_9S_8$
SYSTEM	Cubic	Tetragonal	Cubic
POLISHING CLEAVAGE	Not visible	Not visible	(111).
REFLECTANCE AND COLOR — AIR	Medium: white to grayish blue	Strong: white with weak pinkish tint	Strong: light creamy or yellowish
REFLECTANCE AND COLOR — OIL	Medium: bluish gray	Strong: white with weak pinkish tint	Strong: light creamy or yellowish
R%	24.4	47.8 - 48.5	46.5
VHN	412 (at 50 g)	715 - 743	268 - 285
POLISHING HARDNESS	Medium (5): >magnetite, <hematite	Medium (5): >chalcopyrite, >sphalerite, <loellingite, <safflorite	Medium (3.5-4): >chalcopyrite, <pyrrhotite
PLEOCHROISM — AIR	Nonpleochroic	Nonpleochroic	Nonpleochroic
PLEOCHROISM — OIL	Nonpleochroic	Nonpleochroic	Nonpleochroic
ANISOTROPISM	Isotropic	Weak to isotropic: more distinct in oil	Isotropic
INTERNAL REFLECTIONS	Rare: brownish red	Not present	Not present
TWINNING	Not present	Frequent twin lamellae	Not present
ASSOCIATED MINERALS	Goethite, hematite, ilmenite, magnetite	Breithauptite, chromite, cobaltite, dyscrasite, linnaeite, niccolite, Ni-Co arsenides, pentlandite, pyrrhotite, sphalerite	Bravoite, chalcopyrite, chromite, cubanite, ilmenite, magnetite, millerite, pyrrhotite, sperrylite, valleriite
KEY IDENTIFICATION CRITERIA	Color, reflectance higher than magnetite but lower than hematite, and isotropism are characteristic. Forms as a rare oxidation product of magnetite and is irregularly present in oxidized magnetite as lamellae and porous patches.	Slight pinkish color, strong reflectance, weak anisotropy, fibrous texture, twin lamellae, and association with niccolite are characteristic. Commonly occurs as euhedral crystals and as anhedral aggregates with frequent twin lamellae.	Flamelike exsolutions in pyrrhotite, octahedral cleavage, and alteration to bravoite are characteristic. Generally occurs as granular veinlets or as "flames" or lamellae in pyrrhotite. Alters to violarite, millerite, and bravoite.

GROUP NUMBER	7	7	8
MINERAL	Platinum	Tetrahedrite - Tennantite	Bixbyite
COMPOSITION	Pt	$(Cu,Fe)_{12}Sb_4S_{13}$ - $(Cu,Fe)_{12}As_4S_{13}$	$(Mn^{+3},Fe^{+3})_2O_3$
SYSTEM	Cubic	Cubic	Cubic
POLISHING CLEAVAGE	Not visible	May be visible	(111) may be visible
REFLECTANCE AND COLOR — AIR	Strong: white with bluish to yellowish tint	Medium: grayish white to greenish gray-white, greenish shade especially in tennantite	Medium: gray with cream to yellow-brown tint
REFLECTANCE AND COLOR — OIL	Strong: white with bluish to yellowish tint	Medium: grayish white to greenish gray-white, tetrahedrite may have slight bluish tint	Medium: gray with cream to yellow-brown tint
R%	70.3	30 - 30.5	22.2
VHN	122 - 129	285 - 354	946 - 1402
POLISHING HARDNESS	Medium (4-4.5): >sphalerite, <pyrrhotite	Medium (3-4.5): ~chalcopyrite, >digenite, <sphalerite	Hard (6): >hausmannite, ~braunite
PLEOCHROISM — AIR	Nonpleochroic	Nonpleochroic	Nonpleochroic
PLEOCHROISM — OIL	Nonpleochroic	Nonpleochroic	Nonpleochroic
ANISOTROPISM	Isotropic	Isotropic	Isotropic: some anomalous anisotropism
INTERNAL REFLECTIONS	Not present	Brownish red, common in tennantite; reddish, rare in tetrahedrite	Not present
TWINNING	Not present	Not present	Cruciform twins common with parquet texture
ASSOCIATED MINERALS	Braggite, chalcopyrite, chromite, cooperite, magnetite, pentlandite, pyrrhotite, sperrylite	Ag minerals, bornite, bournonite, brannerite, calaverite, chalcopyrite, Co-Ni minerals, covellite, delafossite, digenite, enargite, famatinite, luzonite, mawsonite	Braunite, hausmannite, jacobsite, pyrolusite
KEY IDENTIFICATION CRITERIA	Strong reflectance and association with other platinoids are characteristic. Occurs as isolated euhedral to subhedral crystals.	Medium reflectance, good polish, and its association with galena, chalcopyrite, or bournonite are characteristic. Often occurs as small blebs in galena and sphalerite. Tetrahedrite and tennantite form a complete solid solution.	Cruciform twins and yellow tint are characteristic. Occurs as euhedral crystals and as granular aggregates. Cleavage (111) and zonal growth may be visible.

GROUP NUMBER	8	8	8
MINERAL	Braunite	Carrollite	Chromite
COMPOSITION	$3Mn_2O_3.MnSiO_3$	$Cu(Co,Ni)_2S_4$	$Fe^{+2}Cr_2O_4$
SYSTEM	Tetragonal	Cubic	Cubic
POLISHING CLEAVAGE	Not visible	(100) often visible, (111) may be visible	May be visible
REFLECTANCE AND COLOR — AIR	Low: gray with brownish tint	Strong: creamy white, sometimes with slight pinkish tint	Low: dark gray to brownish gray
REFLECTANCE AND COLOR — OIL	Low: gray with brownish tint	Strong: creamy white, sometimes with slight pinkish tint	Low: dark gray to brownish gray
R%	18.6 - 19.5	45.0	12.3
VHN	689 - 776	525 - 542	1332
POLISHING HARDNESS	Hard (6-6.5): >magnetite, <bixbyite	Hard (4.5-5.5): >chalcopyrite, <pyrite	Hard (5.5): >magnetite, ~ilmenite
PLEOCHROISM — AIR	Weak: gray	Nonpleochroic	Nonpleochroic
PLEOCHROISM — OIL	Moderate: shades of dark gray	Nonpleochroic	Nonpleochroic
ANISOTROPISM	Weak but distinct in oil: brownish gray to slate blue, often undulose	Isotropic	Isotropic
INTERNAL REFLECTIONS	Rare: dark brown to deep red	Not present	Common: brown to red-brown in Mg-Al-rich samples; absent in Fe-rich samples
TWINNING	Rare	Not present	Not present
ASSOCIATED MINERALS	Bixbyite, hausmannite, hematite, jacobsite, magnetite, manganite, pyrolusite	Bornite, chalcocite, chalcopyrite, digenite, pyrite, pyrrhotite, siegenite	Hematite, ilmenite, magnetite, millerite, pentlandite, pyrrhotite, sperrylite, ulvospinel, valleriite
KEY IDENTIFICATION CRITERIA	Low reflectance, weak anisotropy, and association with other manganese minerals are characteristic. Occurs as anhedral granular masses and as subhedral to euhedral crystals. Zonal textures have been reported.	Creamy white color is characteristic. Carrollite is whiter than linnaeite, siegenite, and violarite. Occurs as anhedral granular masses to subhedral and euhedral octahedra.	Low reflectance, hardness, isotropism, and internal reflections are characteristic. Usually occurs as subhedral (rounded) to euhedral crystals or as coarsely crystalline aggregates. Cataclastic effects common. Zonal textures with lighter (Fe-rich) rims are common. May form myrmekitic intergrowths.

GROUP NUMBER	8	8	8
MINERAL	Cobaltite	Coffinite	Gersdorffite
COMPOSITION	CoAsS	$U(SiO_4)_{1-x}(OH)_{4x}$	NiAsS
SYSTEM	Orthorhombic< 800 deg. C >cubic	Tetragonal	Cubic
POLISHING CLEAVAGE	(100) may be visible	Not visible	(100) often visible as triangular pits
REFLECTANCE AND COLOR AIR	Strong: white with pink or violet tint	Low: gray	Strong: white with yellowish or pinkish cream tint
REFLECTANCE AND COLOR OIL	Strong: white with pink or violet tint	Low: gray	Strong: white with yellowish or pinkish cream tint
R%	50.5	7.9 - 8.0	54.2
VHN	935 - 1131	230 - 302	782 - 835
POLISHING HARDNESS	Hard (5.5-6): >skutterudite, ~arsenopyrite, <pyrite	Hard (5-6): ~pitchblende	Hard (5.5): >linnaeite, ~skutterudite, <<pyrite
PLEOCHROISM AIR	Weak: white to pinkish white	Weak to nonpleochroic	Nonpleochroic
PLEOCHROISM OIL	Weak: white to pinkish white	Weak to nonpleochroic	Nonpleochroic
ANISOTROPISM	Weak to moderate in oil: blue-gray to brown	Weak to absent	Isotropic: some anomalous anisotropism
INTERNAL REFLECTIONS	Not present	Rare: brown or deep bluish gray	Not present
TWINNING	Shows complex twins with lamellar intergrowths	Not present	Commonly thin small lamellae
ASSOCIATED MINERALS	Arsenopyrite, bismuth, chalcopyrite, cubanite, dyscrasite, gersdorffite, glaucodot, gold, molybdenite, pyrrhotite, silver	Brannerite, goethite, pitchblende, pyrite, uraninite	Ag and Bi minerals, breithauptite, chalcopyrite, cobaltite, galena, linnaeite, niccolite, pyrite, skutterudite, sphalerite, ullmanite
KEY IDENTIFICATION CRITERIA	Pink-white color, hardness, euhedral crystals, weak anisotropy, and complex twins are characteristic. Commonly occurs as euhedral crystals and as polycrystalline aggregates.	Association with pitchblende and low reflectance are characteristic. Occurs as euhedral tetragonal crystals, as fine aggregates, and as colloform bands.	Yellowish or pinkish tint, cleavage, hardness, and the euhedral crystals are characteristic. May show zonal growth.

GROUP NUMBER	8	8	8
MINERAL	Jacobsite	Linnaeite	Magnetite
COMPOSITION	$(Mn^{+2},Fe^{+2},Mg)(Fe^{+3},Mn^{+3})_2O_4$	$CoCo_2S_4$	$Fe^{+2}Fe_2^{+3}O_4$
SYSTEM	Cubic	Cubic	Cubic
POLISHING CLEAVAGE	Not visible	(100) may be visible	Not visible
REFLECTANCE AND COLOR — AIR	Low: rose-brown to brownish gray	Strong: white with creamy tint	Medium: gray, commonly with brownish tint
REFLECTANCE AND COLOR — OIL	Low: gray with olive tint	Strong: white with creamy tint	Medium: gray, commonly with brownish tint
R%	19.4	49.5	20.0
VHN	665 - 707	450 - 613	592 (average)
POLISHING HARDNESS	Hard (6): ~magnetite	Hard (4.5-5.5): >>chalcopyrite, >pyrrhotite, <<pyrite	Hard (5.5): >pyrrhotite, <ilmenite, <<hematite, <<pyrite
PLEOCHROISM — AIR	Nonpleochroic	Nonpleochroic	Nonpleochroic
PLEOCHROISM — OIL	Nonpleochroic	Nonpleochroic	Nonpleochroic
ANISOTROPISM	Isotropic	Isotropic	Isotropic
INTERNAL REFLECTIONS	Rare: deep red especially when Mn-rich	Not present	Not present except when Mn rich
TWINNING	Not present	Not present	(111) commonly lamellar twinning
ASSOCIATED MINERALS	Bixbyite, braunite, hausmannite, franklinite, psilomelane, pyrolusite	Bravoite, breithauptite, chalcopyrite, covellite, cubanite, gersdorffite millerite, niccolite, pyrite, pyrrhotite, safflorite, siegenite, ullmanite	Bravoite, chalcopyrite, cubanite, galena, hematite, ilmenite, marcasite, pentlandite, pyrite, pyrrhotite, rutile, sphalerite, ulvospinel, valleriite, zincite
KEY IDENTIFICATION CRITERIA	Association with manganese oxides, olive-brown tint, and isotropism are characteristic. Occurs as anhedral grains and rounded subhedral crystals. Alters to other minerals including goethite, hematite, psilomelane, and pyrolusite.	Creamy white color and reflectance, lower than pyrite are characteristic. Occurs as euhedral crystals and subhedral aggregates. May be intergrown in lamellar pattern with associated minerals.	Hardness, brownish tint, and magnetic character are characteristic. Occurs as euhedral, subhedral, and skeletal crystals, and as anhedral aggregates. Often contains exsolution or oxidation lamellae of hematite. Lamellae of ilmenite and ulvospinel are common. Alters to hematite and goethite.

GROUP NUMBER	8	8	8
MINERAL	Pyrite	Siegenite	Skutterudite
COMPOSITION	FeS_2	$(Ni,Co)_3S_4$	$CoAs_{2-3}$
SYSTEM	Cubic	Cubic	Cubic
POLISHING CLEAVAGE	(100) often visible	(100) may be visible	(100) may be visible
REFLECTANCE AND COLOR — AIR	Strong: yellowish white	Strong: creamy white with slight pink tint	Strong: creamy white to grayish white, often in zones
REFLECTANCE AND COLOR — OIL	Strong: yellowish white	Strong: creamy white with slight pink tint	Strong: creamy white to grayish white, often in zones
R%	51.7	45.4	54.4
VHN	1505 - 1620	503 - 525	792 - 907
POLISHING HARDNESS	Hard (6-6.5): >arsenopyrite, >hematite, ~marcasite	Hard (4.5-5.5): ~linnaeite	Hard (5.5-6): >niccolite, ~safflorite, <pyrite
PLEOCHROISM — AIR	Nonpleochroic	Nonpleochroic	Nonpleochroic
PLEOCHROISM — OIL	Nonpleochroic	Nonpleochroic	Nonpleochroic
ANISOTROPISM	Usually isotropic: however, it may be weakly anisotropic (blue-green to orange-red)	Isotropic	Isotropic
INTERNAL REFLECTIONS	Not present	Not present	Not present
TWINNING	Not visible	Not present	Not present
ASSOCIATED MINERALS	Practically all minerals but especially arsenopyrite, chalcopyrite, galena, magnetite, marcasite, pyrrhotite, sphalerite	Bravoite, carrollite, Cu and Cu-Fe sulfides, linnaeite, pitchblende, pyrite, uraninite, violarite	Ag and Bi minerals, arsenic, breithauptite, gersdorffite, niccolite, pyrite, rammelsbergite, safflorite, silver, ullmanite
KEY IDENTIFICATION CRITERIA	Yellowish white color, strong reflectance, hardness, and uneven polishing are characteristic. Occurs as euhedral cubes and pyritohedra, as anhedral crystalline masses, and as botryoidal masses with rhythmic zoning and radiating texture. Most common sulfide.	Creamy white color with pink tint, strong reflectance, and hardness are characteristic. Difficult to distinguish from linnaeite. Occurs as euhedral and subhedral crystals and anhedral polycrystalline aggregates.	Characterized by frequent euhedral habit. Commonly and characteristically occurs as radial bladelike crystals with well-developed growth zoning.

GROUP NUMBER	8	8	8
MINERAL	Sperrylite	Ullmannite	Violarite
COMPOSITION	$PtAs_2$	NiSbS	Ni_2FeS_4
SYSTEM	Cubic	Cubic	Cubic
POLISHING CLEAVAGE	(100) may be visible	(100) often visible as triangular pits	(100) often visible, (111) may be visible
REFLECTANCE AND COLOR — AIR	Strong: pure white	Strong: white with bluish tint	Strong: brownish gray with violet tint
REFLECTANCE AND COLOR — OIL	Strong: white with faint creamy or bluish tint	Strong: white with bluish gray tint	Strong: brownish gray with violet tint
R%	55.5 (at 540 nm)	46.4	46.6
VHN	960 - 1277	536 - 592	241 - 373
POLISHING HARDNESS	Hard (6.5-7): >>platinum, ~pyrite	Hard (5-5.5): >linnaeite, ~gersdorffite, <pyrite	Hard (4.5-5.5): >chalcopyrite, <linnaeite, <pyrrhotite
PLEOCHROISM — AIR	Nonpleochroic	Nonpleochroic	Nonpleochroic
PLEOCHROISM — OIL	Nonpleochroic	Nonpleochroic	Nonpleochroic
ANISOTROPISM	Isotropic	Isotropic, but some varieties show a slight anisotropism	Isotropic
INTERNAL REFLECTIONS	Not present	Not present	Not present
TWINNING	Not present	Not present	Not present
ASSOCIATED MINERALS	Braggite, chromite, cooperite, cubanite, gold, ilmenite, magnetite, pentlandite, platinum, valleriite	Ag and Bi minerals, chalcopyrite, galena, gersdorffite, gold, linnaeite, niccolite, pyrite, skutterudite	Bravoite, chalcopyrite, cubanite, millerite, Ni-Co arsenides, pyrite, pyrrhotite, seigenite
KEY IDENTIFICATION CRITERIA	Associated minerals, white color, hardness, and tendency to develop idiomorphically are characteristic. It is whiter and has a stronger tendency to form euhedra than pyrite. Platinum is softer and more xenomorphic and also has a higher reflectance.	Bluish tint, triangular pits, and subhedral to euhedral crystals are characteristic. Occurs as dispersed subhedral to euhedral crystals. It is sometimes zoned.	Brownish gray color with violet tint is characteristic. Commonly occurs as a porous alteration product along grain boundaries and fractures of pentlandite, pyrrhotite, and millerite. Occurs as equant anhedral grains and sometimes as fine lamellar intergrowths.

GROUP NUMBER	9	9	10
MINERAL	Pearceite - Polybasite	Realgar	Cuprite
COMPOSITION	$Ag_{16}As_2S_{11}$ - $(Ag,Cu)_{16}Sb_2S_{11}$	AsS	Cu_2O
SYSTEM	Monoclinic	Monoclinic	Cubic
POLISHING CLEAVAGE	(001) rarely visible	Not visible	(111) rarely visible
REFLECTANCE AND COLOR AIR	Medium: gray-white to greenish	Medium: grayish white with purplish tint	Medium: white gray with bluish tint
REFLECTANCE AND COLOR OIL	Medium: blue-green-gray	Medium: grayish white with purplish tint; much lighter in air	Low: white-gray with greenish tint
R%	30.7 - 32.5	22.1	26.6
VHN	180 - 192	47 - 60	193 - 207
POLISHING HARDNESS	Soft (1.5-2): ~freibergite, <stephanite, <<pyrite	Soft (1.5-2): <orpiment, <<stibnite	Medium (3-4): >copper, >tenorite, >chalcopyrite, <goethite
PLEOCHROISM AIR	Weak to nonpleochroic	Weak but distinct: gray with reddish to bluish tint	Weak to nonpleochroic
PLEOCHROISM OIL	Moderate: green to gray with violet-blue tint	Weak but distinct: gray with reddish to bluish tint	Masked by deep red internal reflections
ANISOTROPISM	Moderate to strong in air: bright green and green-blue tints; strong in oil: blue, gray, yellow-green, brown	Moderate to strong: often masked by internal reflections	Moderate to strong when coarse grained and along grain boundaries: gray-blue to olive-green; tints are largely masked by internal reflections
INTERNAL REFLECTIONS	Abundant: deep red	Abundant: intense red, orange-red, yellowish red or orange	Abundant deep red
TWINNING	Not present	Not present	Not present
ASSOCIATED MINERALS	Ag and Ni-Co minerals, chalcopyrite, freibergite, galena, pyrite, sphalerite	As sulfosalts, cinnabar, graphite, orpiment, pyrite, sphalerite, stibnite	Chalcocite, chalcopyrite, copper, covellite, delafossite, goethite, tenorite
KEY IDENTIFICATION CRITERIA	Color, green anisotropism, and deep red internal reflections are characteristic. Pearceite and polybasite form complete solid solution. Occurs as platelike to equant grains. Pearceite polarizes in green, polybasite in green-blue.	Softness, medium reflectance, and highly abundant internal reflections are characteristic. Occurs as irregular platelike masses with orpiment.	White-gray color with bluish tints, colored anisotropy with extensive internal reflections, and association with native copper are characteristic. Occurs as euhedral octahedra and in a fine-grained "earthy" form.

GROUP NUMBER	10	10	11
MINERAL	Scheelite	Zincite	Cassiterite
COMPOSITION	$CaWO_4$	(Zn,Mn)O	SnO_2
SYSTEM	Tetragonal	Hexagonal	Tetragonal
POLISHING CLEAVAGE	Not visible	(0001) often visible	(110) rarely visible
REFLECTANCE AND COLOR AIR	Low: gray to white	Low: pinkish brown to gray	Low: brownish gray
REFLECTANCE AND COLOR OIL	Low: gray to white	Low: dark pinkish brown to dark gray	Low: brownish gray to dark gray
R%	9.9 - 10.0	11.8	11.5 - 12.4
VHN	387 - 409	190 - 219	1168 - 1332
POLISHING HARDNESS	Medium (5): <wolframite, <pyrite	Medium (4.5-5): <<franklinite, <<hausmannite	Hard (6-7): >>bismuth, >>bismuthinite, >>molybdenite, >stannite
PLEOCHROISM AIR	Nonpleochroic	Weak	Weak to nonpleochroic
PLEOCHROISM OIL	Nonpleochroic	Masked by internal reflections	Weak to moderate: gray to brownish gray
ANISOTROPISM	Moderate: but masked by internal reflections	Masked by internal reflections	Moderate, masked by internal reflections in oil: gray to dark gray
INTERNAL REFLECTIONS	Abundant: white	Abundant: red, orange, to yellowish	Abundant: whitish yellow to yellow-brown
TWINNING	Not present	Not present	(101) very common
ASSOCIATED MINERALS	Arsenopyrite, bismuth, bismuthinite, molybdenite, pyrite, pyrrhotite, wolframite	Chalcophanite, franklinite, hausmannite, magnetite	Ag sulfosalts, bismuth, bismuthinite, bornite, columbite-tantalite, galena, hematite, magnetite, mawsonite, molybdenite, pyrite, rutile, sphalerite, stannite, wolframite
KEY IDENTIFICATION CRITERIA	Fluoresces pale blue to yellow under ultraviolet light. Low reflectance and white internal reflections are characteristic. Occurs as equant to lathlike polycrystalline aggregates, often as a partial replacement of wolframite.	Low reflectance, abundant red to yellow internal reflections, and well-developed cleavage are characteristic. Occurs as rounded grains. Forms oriented intergrowths with hausmannite.	Low reflectance, frequent twins, abundant internal reflections, and hardness are characteristic. Occurs as compact anhedral masses and as subhedral to euhedral crystals which are often zoned.

GROUP NUMBER	11	11	11
MINERAL	Columbite - Tantalite	Goethite	Hematite
COMPOSITION	$(Fe^{+2},Mn)(Ta,Nb)_2O_6$	α - FeO.OH	α - Fe_2O_3
SYSTEM	Orthorhombic	Orthorhombic	Hexagonal
POLISHING CLEAVAGE	(100) often visible (010) may be visible	(010) rarely visible	(10T1), (0001) may be visible
REFLECTANCE AND COLOR — AIR	Low: gray-white with brownish tint	Low: gray-white, may have bluish tint	Medium: gray-white with bluish tint
REFLECTANCE AND COLOR — OIL	Low: gray-white with brownish tint	Low: gray	Medium: bluish gray
R%	15.3 - 17.3	15.5 - 17.5	26.1 - 30.2
VHN	240 - 1021	667	1038
POLISHING HARDNESS	Hard (6): >galena, ~ or <cassiterite	Hard (5-5.5): ~lepidocrocite, <hematite	Hard (5-6): >goethite, >ilmenite, >magnetite, ~ or <cassiterite, ~ or <rutile
PLEOCHROISM — AIR	Weak	Weak	Weak
PLEOCHROISM — OIL	Weak to moderate along grain boundaries	Moderate: but masked by internal reflections	Weak
ANISOTROPISM	Weak, moderate in oil	Moderate but distinct: gray-blue, gray-yellow, brownish, greenish gray	Moderate: grayish blue, grayish yellow, greenish gray, light brown tints
INTERNAL REFLECTIONS	Common: red to red-brown	Abundant: brownish yellow to reddish brown	Common: deep red
TWINNING	Rare	Not present	(10T1) very common
ASSOCIATED MINERALS	Cassiterite, galena, hematite, ilmenite, pitchblende, rutile, uraninite, wolframite	Chalcopyrite, coffinite, copper, cuprite, delafossite, galena, hematite, lepidocrocite, manganite, psilomelane, pyrite, sphalerite, tenorite	Braggite, brannerite, braunite, cassiterite, chromite, columbite-tantalite, goethite, ilmenite, magnetite, pyrolusite, rutile, sphalerite
KEY IDENTIFICATION CRITERIA	Low reflectance, weak anisotropy, and abundant internal reflections are characteristic. Occurs as euhedral crystals and anhedral aggregates. May be zoned. Occurs frequently as tiny exsolution blebs in cassiterite. May occur as tufts of radiating crystals. Resembles wolframite.	Colloform texture, distinct bluish anisotropy, and abundant internal reflections are characteristic. Common in porous colloform bands with radiating fibrous texture or as porous pseudomorphs after pyrite. Nearly always secondary.	Medium reflectance, difficult polish, distinct anisotropy, and red internal reflections are characteristic. Usually occurs as bladed or needlelike subparallel or radiating aggregates. Lamellar twinning common. Common as exsolution lenses or lamellae in ilmenite or magnetite.

GROUP NUMBER	11	12	12
MINERAL	Wolframite	Acanthite - Argentite	Stephanite
COMPOSITION	$(Fe,Mn)WO_4$	Ag_2S	Ag_5SbS_4
SYSTEM	Monoclinic	Monoclinic< 177 deg. C >cubic	Orthorhombic
POLISHING CLEAVAGE	(010), (100) often visible	Not visible	Not visible
REFLECTANCE AND COLOR — AIR	Low: gray or grayish white	Medium: light gray often with green tint	Medium to strong: gray-white with light brown or pinkish violet tint
REFLECTANCE AND COLOR — OIL	Low: gray with faint brownish or yellow tint	Medium: gray with greenish tint	Medium: gray with distinct pink tint
R%	15.0 - 16.2	30.3 - 31.3	28.1 - 30.4
VHN	312 - 342	23 - 26	26 - 124
POLISHING HARDNESS	Hard (6-6.5): >scheelite, >stannite, ~pyrite, ~ or <cassiterite	Soft (2-2.5): <galena, <silver	Soft (2-2.5): >pearceite-polybasite, >proustite-pyrargyrite, <tetrahedrite-tennantite
PLEOCHROISM — AIR	Weak to nonpleochroic	Weak to nonpleochroic	Weak but distinct: gray to pinkish gray
PLEOCHROISM — OIL	Weak to nonpleochroic	Weak to nonpleochroic	Weak: white to brown-pink
ANISOTROPISM	Weak to moderate in oil: yellow to gray	Moderate: shades of gray	Moderate to strong in oil: green to violet to yellow-brown
INTERNAL REFLECTIONS	Common: deep red especially in oil and if Mn rich	Not present	Not present
TWINNING	(100) very common	(001) broad lamellae abundant	Lamellar twins common, mostly pseudohexagonal twins following (100)
ASSOCIATED MINERALS	Arsenopyrite, bismuth, bismuthinite, cassiterite, chalcopyrite, pyrite, columbite-tantalite, gold, mawsonite, molybdenite, scheelite, stannite	Ag minerals, galena, silver	Ag minerals, Cu-Fe sulfides, Ni-Co-Fe arsenides
KEY IDENTIFICATION CRITERIA	Lamellar form, internal reflections, and low reflectance are characteristic. Occurs as euhedral platelets and as masses of interpenetrating laths.	Green tint and rapid corrosion are characteristic. Lamellar twins result from inversion from cubic to monoclinic indicating a temperature of deposition >177 degrees C. Acanthite is monoclinic and argentite is cubic.	Lamellar twins, greenish to yellow-brown polarization colors, brownish or pinkish tint, and lack of internal reflections are characteristic. Occurs as anhedral aggregates and euhedral columnar crystals.

GROUP NUMBER	12	13	13
MINERAL	Tetradymite	Bournonite	Chalcostibite
COMPOSITION	Bi_2Te_2S	$PbCuSbS_3$	$Cu_6Ti_2SbS_4$
SYSTEM	Hexagonal	Orthorhombic	Orthorhombic
POLISHING CLEAVAGE	Basal cleavage always visible	Not visible	(001) often visible, (100) and (010) rarely visible
REFLECTANCE AND COLOR — AIR	Strong: white with creamy or light yellow tint	Strong: grayish white with distinct bluish green tint	Strong: white with pinkish gray tint
REFLECTANCE AND COLOR — OIL	Strong: white with creamy or light yellow tint	Strong: grayish white with distinct bluish green tint	Strong: white with a brown tint
R%	50.9 - 57.1	34.6 - 39.2	36.9 - 42.2
VHN	51.1 - 56.9	166 - 212 (at 20 - 50 g)	283 - 309
POLISHING HARDNESS	Soft (2.5): <galena	Soft (3): >galena, >boulangerite, <chalcopyrite, <sphalerite	Medium (3-4): >bournonite, <chalcopyrite, <sphalerite
PLEOCHROISM — AIR	Weak: greenish gray tints	Weak: may be visible on grain boundaries and on twin lamellae	Weak
PLEOCHROISM — OIL	Weak: greenish gray tints	Weak: white with bluish green tint to white with olive-brown tint	Moderate: cream to brown
ANISOTROPISM	Moderate: bluish gray to yellow-gray	Weak but distinct along grain boundaries: pale blue, greenish gray, brownish yellow, dark brown, purplish	Moderate to strong: pinkish to greenish or bluish gray, distinct blue tints
INTERNAL REFLECTIONS	Not present	Not present	Rare: pale red
TWINNING	Rare: lamellar twinning	(110) very common, numerous parallel polysynthetic orthogonal twins	May show stibnitelike deformation twins
ASSOCIATED MINERALS	Arsenopyrite, calaverite, chalcopyrite, galena, krennerite, magnetite, pyrite, pyrrhotite	Ag minerals, boulangerite, chalcopyrite, chalcostibite, galena, silver, sphalerite, stannite, tetrahedrite-tennantite	Ag minerals, bismuthinite, bournonite, chalcopyrite, cinnabar, galena, jamesonite, pyrite, sphalerite
KEY IDENTIFICATION CRITERIA	Creamy white color, anhedral granular texture, and perfect basal cleavage are characteristic. Forms intergrowths with other tellurides.	Parallel lamellar twins are characteristic. The bluish green tint and weak anisotropy are also distinct.	Pinkish tint and anisotropism are characteristic. Occurs as anhedral grains. Rarely as euhedral prismatic crystals. Triangular pits may be visible.

GROUP NUMBER	13	13	14
MINERAL	Dyscrasite	Glaucodot	Braunite
COMPOSITION	Ag_3Sb	(Co,Fe)AsS	$3Mn_2O_3.MnSiO_3$
SYSTEM	Orthorhombic	Orthorhombic	Tetragonal
POLISHING CLEAVAGE	Not visible	Not visible	Not visible
REFLECTANCE AND COLOR — AIR	Strong: white often with yellowish tint	Strong: white to light cream	Low: gray with brownish tint
REFLECTANCE AND COLOR — OIL	Strong: grayish white	Strong: white with blue tint	Low: gray with brownish tint
R%	62.1 - 63.2	50.0 - 50.6	18.6 - 19.5
VHN	146 - 160	1097 - 1115	689 - 776
POLISHING HARDNESS	Medium (3.5-4): >galena, >silver, <chalcopyrite	Medium (5): <arsenopyrite, <cobaltite	Hard (6-6.5): >magnetite, <bixbyite
PLEOCHROISM — AIR	Weak: white to creamy white	Weak to nonpleochroic	Weak: gray
PLEOCHROISM — OIL	Weak: white to creamy white	Weak to nonpleochroic	Moderate: shades of dark gray
ANISOTROPISM	Weak to moderate: indistinct tints of brown	Weak to moderate, weaker than arsenopyrite: bluish to orange-brown or red-brown	Weak but distinct in oil: brownish gray to slate-blue, often undulose
INTERNAL REFLECTIONS	Not present	Not present	Rare: dark brown to deep red
TWINNING	Irregular jigsaw forms	Not present	Rare
ASSOCIATED MINERALS	Antimony, arsenic, breithauptite, chalcopyrite, cobaltite, galena, loellingite, miargyrite, pyrite, silver	Arsenopyrite, cobaltite, Ni-Co arsenides, pyrite	Bixbyite, hausmannite, hematite, jacobsite, magnetite, manganite, pyrolusite
KEY IDENTIFICATION CRITERIA	Strong reflectance, yellowish tint, and weak anisotropy are characteristic. Occurs as euhedral platelike to square crystals and as aggregates of anhedral crystals.	Resembles arsenopyrite but anisotropy is weaker. Usually occurs as subhedral to euhedral crystals often with inclusions.	Low reflectance, weak anisotropy, and association with other manganese minerals are characteristic. Occurs as anhedral granular masses and as subhedral to euhedral crystals. Zonal textures have been reported.

GROUP NUMBER	14	15	15
MINERAL	Cobaltite	Cassiterite	Cinnabar
COMPOSITION	CoAsS	SnO_2	HgS
SYSTEM	Orthorhombic< 800 deg. C >cubic	Tetragonal	Hexagonal
POLISHING CLEAVAGE	(100) may be visible	(110) rarely visible	(10T0) rarely visible
REFLECTANCE AND COLOR AIR	Strong: white with pink or violet tint	Low: brownish gray	Medium: white with bluish to greenish gray tint
REFLECTANCE AND COLOR OIL	Strong: white with pink or violet tint	Low: brownish gray to dark gray	Medium: white with bluish to greenish gray tint
R%	50.5	11.5 - 12.4	24.6 - 29.6
VHN	935 - 1131	1168 - 1332	82 - 156
POLISHING HARDNESS	Hard (5.5-6): >skutterudite, ~arsenopyrite, <pyrite	Hard (6-7): >>bismuth, >>bismuthinite, >>molybdenite, >stannite	Soft (2-2.5): >realgar, ~ or >stibnite, <galena, <<pyrite
PLEOCHROISM AIR	Weak: white to pinkish white	Weak to nonpleochroic	Weak to distinct along grain boundaries
PLEOCHROISM OIL	Weak: white to pinkish white	Weak to moderate: gray to brownish gray	Moderate: yellowish gray-white to brownish gray-white
ANISOTROPISM	Weak to moderate in oil: blue-gray to brown	Moderate, masked by internal reflections: gray to dark gray	Strong, but tints may be masked by internal reflections: light green colors may be observed; also various shades of gray with blue and green tints
INTERNAL REFLECTIONS	Not present	Abundant: whitish yellow to yellow-brown	Abundant: bright red
TWINNING	Shows complex twins with lamellar intergrowths	(101) very common	Sinuous and polysynthetic twins may be present
ASSOCIATED MINERALS	Arsenopyrite, bismuth, chalcopyrite, cubanite, dyscrasite, gersdorffite, glaucodot, gold, molybdenite, pyrrhotite, silver	Ag sulfosalts, bismuth, bismuthinite, bornite, columbite-tantalite, galena, hematite, magnetite, mawsonite, molybdenite, pyrite, rutile, sphalerite, stannite, wolframite	Berthierite, chalcopyrite, chalcostibite, galena, gold, marcasite, orpiment, pyrite, realgar, stibnite
KEY IDENTIFICATION CRITERIA	Pink-white color, hardness, euhedral crystals, weak anisotropy, and complex twins are characteristic. Commonly occurs as euhedral crystals and as polycrystalline aggregates.	Low reflectance, frequent twins, abundant internal reflections, and hardness are characteristic. Occurs as compact anhedral masses and as subhedral to euhedral crystals which are often zoned.	Medium reflectance, abundant internal reflections, and frequent association with stibnite are characteristic. Typically anhedral but may be euhedral. Shows redder internal reflections than rutile or realgar.

GROUP NUMBER	15	15	15
MINERAL	Cuprite	Goethite	Hausmannite
COMPOSITION	Cu_2O	α - FeO.OH	$Mn^{+2}Mn^{+3}{}_2O_4$
SYSTEM	Cubic	Orthorhombic	Tetragonal
POLISHING CLEAVAGE	(111) rarely visible	(010) rarely visible	(001) rarely visible
REFLECTANCE AND COLOR AIR	Medium: white-gray with bluish tint	Low: gray-white, may have bluish tint	Low: bluish to brownish gray-white
REFLECTANCE AND COLOR OIL	Low: white-gray with greenish tint	Low: gray	Low: dark gray
R%	26.6	15.5 - 17.5	17.6 - 19.6
VHN	193 - 207	667	536 - 566
POLISHING HARDNESS	Medium (3-4): >copper, >tenorite, >chalcopyrite, <goethite	Hard (5-5.5): ~lepidocrocite, <hematite	Hard (5.5): >manganite, <pyrolusite, <bixbyite, <braunite, <jacobsite
PLEOCHROISM AIR	Weak to nonpleochroic	Weak	Weak
PLEOCHROISM OIL	Masked by deep red internal reflections	Moderate: but masked by internal reflections	Moderate: bluish gray to brownish gray
ANISOTROPISM	Moderate to strong when coarse grained and along grain boundaries: gray-blue to olive-green; tints are largely masked by internal reflections	Moderate but distinct: gray-blue, gray-yellow, brownish, greenish gray	Strong: yellowish or yellow-brown, light gray or bluish gray
INTERNAL REFLECTIONS	Abundant: deep red	Abundant: brownish yellow to reddish brown	Abundant especially in oil: red
TWINNING	Not present	Not present	Common lamellar along (101)
ASSOCIATED MINERALS	Chalcocite, chalcopyrite, copper, covellite, delafossite, goethite, tenorite	Chalcopyrite, coffinite, copper, cuprite, delafossite, galena, hematite, lepidocrocite, manganite, psilomelane, pyrite, sphalerite, tenorite	Bixbyite, braunite, chalcophanite, franklinite, jacobsite, manganite, psilomelane, pyrolusite, zincite
KEY IDENTIFICATION CRITERIA	White-gray color with bluish tints, colored anisotropy with extensive internal reflections, and association with native copper are characteristic. Occurs as euhedral octahedra and in a fine-grained "earthy" form.	Colloform texture, distinct bluish anisotropy, and abundant internal reflections are characteristic. Common in porous colloform bands with radiating fibrous texture or as porous pseudomorphs after pyrite. Nearly always secondary.	Lamellar twins, bright anisotropy, abundant red internal reflections, euhedral tendency, and association with Mn minerals are characteristic. Also occurs as coarse-grained equigranular anhedral crystals, often in veinlets.

GROUP NUMBER	15	15	15
MINERAL	Hematite	Manganite	Pearceite - Polybasite
COMPOSITION	α - Fe_2O_3	MnO(OH)	$Ag_{16}As_2S_{11}$ - $(Ag,Cu)_{16}Sb_2S_{11}$
SYSTEM	Hexagonal	Monoclinic	Monoclinic
POLISHING CLEAVAGE	(10T1), (0001) may be visible	(010) and (110) may be visible	(001) rarely visible
REFLECTANCE AND COLOR — AIR	Medium: gray-white with bluish tint	Low: gray to brownish gray	Medium: gray-white to greenish
REFLECTANCE AND COLOR — OIL	Medium: bluish gray	Low: gray to brownish gray	Medium: blue-green-gray
R%	26.1 - 30.2	14.8 - 20.7	30.7 - 32.5
VHN	1038	698 - 772	180 - 192
POLISHING HARDNESS	Hard (5-6): >goethite, >ilmenite, >magnetite, ~ or <cassiterite, ~ or <rutile	Medium (4), <hausmannite, <magnetite, <<braunite, <<pyrolusite	Soft (1.5-2): ~freibergite, <stephanite, <<pyrite
PLEOCHROISM — AIR	Weak	Weak to moderate along certain sections: brownish gray	Weak to nonpleochroic
PLEOCHROISM — OIL	Weak	Moderate: brownish gray	Moderate: green to gray with violet-blue tint
ANISOTROPISM	Moderate: grayish blue, grayish yellow, greenish gray, light brown tints	Strong: yellow, bluish, gray, violet-gray	Moderate to strong in air: bright green and green-blue tints; strong in oil: blue, gray, yellow-green, brown
INTERNAL REFLECTIONS	Common: deep red	Common: blood red especially in oil and parallel (010)	Abundant: deep red
TWINNING	(10T1) very common	(011) not uncommon	Not present
ASSOCIATED MINERALS	Braggite, brannerite, braunite, cassiterite, chromite, columbite-tantalite, goethite, ilmenite, magnetite, pyrolusite, rutile, sphalerite	Braunite, chalcophanite, goethite, hausmannite, psilomelane, pyrolusite	Ag and Ni-Co minerals, chalcopyrite, freibergite, galena, pyrite, sphalerite
IDENTIFICATION CRITERIA	Medium reflectance, difficult polish, distinct anisotropy, and red internal reflections are characteristic. Usually occurs as bladed or needlelike subparallel or radiating aggregates. Lamellar twinning common. Common as exsolution lenses or lamellae in ilmenite or magnetite.	Brown tint, anisotropy, and blood red internal reflections are characteristic. Occurs as prismatic to lamellar crystal aggregates often intergrown with pyrolusite and psilomelane.	Color, green anisotropism, and deep red internal reflections are characteristic. Pearceite and polybasite form complete solid solution. Occurs as platelike to equant grains. Pearceite polarizes in green, polybasite in green-blue.

GROUP NUMBER	15	15	15
MINERAL	Realgar	Rutile	Zincite
COMPOSITION	AsS	TiO_2	(Zn,Mn)O
SYSTEM	Monoclinic	Tetragonal	Hexagonal
POLISHING CLEAVAGE	Not visible	(110) often visible	(0001) often visible
REFLECTANCE AND COLOR — AIR	Medium: grayish white with purplish tint	Low: light gray with faint blue tint	Low: pinkish brown to gray
REFLECTANCE AND COLOR — OIL	Medium: grayish white with purplish tint; much lighter in air	Low: light gray with faint blue tint	Low: dark pinkish brown to dark gray
R%	22.1	20.3	11.8
VHN	47 - 60	1132 - 1187	190 - 219
POLISHING HARDNESS	Soft (1.5-2): <orpiment, <<stibnite	Hard (6-6.5): >ilmenite, <cassiterite, <hematite	Medium (4.5-5): <<franklinite, <<hausmannite
PLEOCHROISM — AIR	Weak but distinct: gray with reddish to bluish tint	Weak	Weak
PLEOCHROISM — OIL	Weak but distinct: gray with reddish to bluish tint	Moderate	Masked by internal reflections
ANISOTROPISM	Moderate to strong: often masked by internal reflections	Moderate to strong, but colors are masked by internal reflections	Masked by internal reflections
INTERNAL REFLECTIONS	Abundant: intense red, orange-red, yellowish red or orange	Abundant: white, yellowish, reddish brown	Abundant: red, orange, to yellowish
TWINNING	Not present	Commonly lamellar twinning	Not present
ASSOCIATED MINERALS	As sulfosalts, cinnabar, graphite, orpiment, pyrite, sphalerite, stibnite	Brannerite, cassiterite, columbite-tantalite, hematite, ilmenite, maghemite, magnetite	Chalcophanite, franklinite, hausmannite, magnetite
KEY IDENTIFICATION CRITERIA	Softness, medium reflectance, and highly abundant internal reflections are characteristic. Occurs as irregular platelike masses with orpiment.	Abundant internal reflections, twins, and hardness are characteristic. Occurs as euhedral to subhedral needlelike to columnar crystals.	Low reflectance, abundant red to yellow internal reflections, and well-developed cleavage are characteristic. Occurs as rounded grains. Forms oriented intergrowths with hausmannite.

GROUP NUMBER	16	16	16
MINERAL	Bismuth	Bismuthinite	Boulangerite
COMPOSITION	Bi	Bi_2S_3	$Pb_5Sb_4S_{11}$
SYSTEM	Hexagonal	Orthorhombic	Monoclinic
POLISHING CLEAVAGE	Rarely visible	(010) often visible	Not visible
REFLECTANCE AND COLOR — AIR	Strong: white to creamy white, pinkish cream	Strong: white with slight yellow tint	Strong: white with bluish green tint
REFLECTANCE AND COLOR — OIL	Strong: white to creamy white, pinkish cream	Strong: white with bluish gray tint	Strong: gray-green
R%	66.7	38.5 - 45.4	37.4 - 41.8
VHN	15 - 18	110 - 136	92 - 125
POLISHING HARDNESS	Soft (2-2.5): >molybdenite, <bismuthinite, <galena, <<arsenopyrite, <<cassiterite	Soft (2-2.5): >bismuth, <gold, <<cassiterite, <<wolframite	Soft (2.5-3): <bournonite, <galena
PLEOCHROISM — AIR	Weak	Weak	Weak but distinct: gray-green to gray-white
PLEOCHROISM — OIL	Moderate: creamy to pinkish	Moderate: white with cream bluish tint	Moderate: gray-green to gray-white
ANISOTROPISM	Moderate to strong: characteristically greenish	Strong in oil: slate-gray, yellowish brown, gray-violet, yellow-green to light green tints	Moderate to strong: light tan, brown, bluish gray, greenish shades
INTERNAL REFLECTIONS	Not present	Not present	Rare: red
TWINNING	Common lamellar	Stressed induced twins with undulose extinction often seen	Not present
ASSOCIATED MINERALS	Arsenopyrite, bismuthinite, bravoite, cassiterite, chalcopyrite, Co-Ni minerals, galena, molybdenite, pyrite, pyrrhotite, silver, sphalerite, stannite, wolframite	Arsenopyrite, Bi and Co-Ni minerals, bismuth, cassiterite, chalcostibite, gold, magnetite, pitchblende, pyrrhotite, scheelite, tetradymite, uraninite	Bournonite, chalcopyrite, galena, jamesonite, pyrite, sphalerite, tetrahedrite-tennantite
KEY IDENTIFICATION CRITERIA	Strong reflectance, softness, creamy color, reddish tarnishing, anisotropy, and lamellar twins are characteristic. Occurs as irregular masses or inclusions of anhedral crystals.	Moderate pleochroism, strong anisopism in light greenish tints, perfect cleavage, and association with bismuth and Bi minerals are characteristic. Occurs as subhedral lathlike crystals. Less commonly as granular masses.	Bluish green tint, anisotropy, and associated minerals are characteristic. Usually occurs as granular or fibrous aggregates.

GROUP NUMBER	16	16	16
MINERAL	Bournonite	Krennerite	Stromeyerite
COMPOSITION	$PbCuSbS_3$	$AuTe_2$	AgCuS
SYSTEM	Orthorhombic	Orthorhombic	Orthorhombic
POLISHING CLEAVAGE	Not visible	(001) often visible	Not visible
REFLECTANCE AND COLOR — AIR	Strong: grayish white with distinct bluish green tint	Strong: creamy white	Medium: gray-white with violet pinkish tint
REFLECTANCE AND COLOR — OIL	Strong: grayish white with distinct bluish green tint	Strong: creamy white	Medium: gray-white with violet pinkish tint
R%	34.6 - 39.2	71.9 (at 540 nm)	26.3 - 29.7
VHN	166 - 212 (at 20 - 50 g)	117 - 130 (at 25 g)	30 - 32
POLISHING HARDNESS	Soft (3): >galena, >boulangerite, <chalcopyrite, <sphalerite	Soft (2-3): <chalcopyrite, <gold	Soft (2.5-3): >acanthite-argentite, <galena
PLEOCHROISM — AIR	Weak: may be visible on grain boundaries and on twin lamellae	Weak but distinct along grain boundaries: yellowish creamy, may have a violet-gray tint	Weak
PLEOCHROISM — OIL	Weak: white with bluish green tint to white with olive-brown tint	Weak but distinct along grain boundaries: yellowish creamy, may have a violet-gray tint	Moderate: gray-brown to light gray with blue or pink tint
ANISOTROPISM	Weak but distinct along grain boundaries: pale blue, greenish gray, brownish yellow, dark brown, purplish	Strong: light gray, yellow, brown	Strong: light violet, purple, blue, brown, orange-yellow
INTERNAL REFLECTIONS	Not present	Not present	Not present
TWINNING	(110) very common, numerous parallel polysynthetic orthogonal twins	Multiple twinning may occur	Not present
ASSOCIATED MINERALS	Ag minerals, boulangerite, chalcopyrite, chalcostibite, galena, silver, sphalerite, stannite, tetrahedrite-tennantite	Calaverite, chalcopyrite, bornite, freibergite, gold, tetradymite	Acanthite-argentite, chalcopyrite, galena, silver
KEY IDENTIFICATION CRITERIA	Parallel lamellar twins are characteristic. The bluish green tint and weak anisotropy are also distinct.	Strong reflectance, softness, strong anisotropy, and association with other tellurides are characteristic. Cleavage distinguishes it from calaverite.	Anisotropic colors are characteristic. Occurs as granular aggregates and small veinlets. Often intergrown with other Ag minerals.

GROUP NUMBER	16	17	17
MINERAL	Tetradymite	Antimony	Arsenic
COMPOSITION	Bi_2Te_2S	Sb	As
SYSTEM	Hexagonal	Hexagonal	Hexagonal
POLISHING CLEAVAGE	Basal cleavage always visible	Rarely visible	(0001) often visible
REFLECTANCE AND COLOR — AIR	Strong: white with creamy or light yellow tint	Strong: white with slight creamy tint	Strong: white with creamy tint, tarnishes rapidly to brownish gray in a few hours
REFLECTANCE AND COLOR — OIL	Strong: white with creamy or light yellow tint	Strong: white with slight creamy tint	Strong: white with creamy tint
R%	50.9 - 57.1	71.1 - 73.0	51.3 - 56.4
VHN	51.1 - 56.9	84 - 98	83 - 149
POLISHING HARDNESS	Soft (2.5): <galena	Medium (3-3.5): >stibnite, <arsenic, <dyscrasite	Medium (3-4): >antimony, >silver, <loellingite
PLEOCHROISM — AIR	Weak: greenish gray tints	Weak to nonpleochroic	Weak to nonpleochroic
PLEOCHROISM — OIL	Weak: greenish gray tints	Weak but distinct along grain boundaries	Moderate along grain boundaries: grayish white to yellow or bluish gray
ANISOTROPISM	Moderate: bluish gray to yellow-gray	Moderate to strong: yellowish gray, brownish, bluish gray, orange-brown	Moderate to strong: steel gray, yellow-gray to dark gray tints
INTERNAL REFLECTIONS	Not present	Not present	Not present
TWINNING	Rare: lamellar twinning	(01T2) polysynthetic lamellar twins common	Lamellae very common
ASSOCIATED MINERALS	Arsenopyrite, calaverite, chalcopyrite, galena, krennerite, magnetite, pyrite, pyrrhotite	Ag and Ni-Co minerals, arsenic, arsenopyrite, dyscrasite, pyrite, stibnite	Antimony, breithauptite, dyscrasite, loellingite, orpiment, pyrite, rammelsbergite, safflorite, silver, skutterudite
KEY IDENTIFICATION CRITERIA	Creamy white color, anhedral granular texture, and perfect basal cleavage are characteristic. Forms intergrowths with other tellurides.	Strong reflectance, anisotropism in orange-brown tints, and lamellar twins are characteristic. Occurs as fine- to coarse-grained aggregates, rarely euhedral. Often occurs as small grains in stibnite.	Lamellar twins and the rapid tarnishing are characteristic. Occurs as fine- to coarse-grained anhedral aggregates and commonly as colloform bands.

GROUP NUMBER	17	17	17
MINERAL	Braggite	Cubanite	Enargite
COMPOSITION	(Pt,Pd,Ni)S	$CuFe_2S_3$	Cu_3AsS_4
SYSTEM	Tetragonal	Orthorhombic	Orthorhombic
POLISHING CLEAVAGE	Not visible	(001) may be visible (110) rarely visible	(110) often visible
REFLECTANCE AND COLOR — AIR	Moderate: faint bluish or brownish gray	Strong: creamy gray, pale brown, or peach	Medium: light pinkish brown or pinkish gray
REFLECTANCE AND COLOR — OIL	Moderate: faint bluish or brownish gray	Strong: gray-brown to cream-white	Medium: violet-gray or brownish gray
R%	34.5 - 35.5 (at 589 nm)	35.4 - 39.4	24.2 - 25.2
VHN	742 - 1030	247 - 287	285 - 327
POLISHING HARDNESS	Medium (4): ~ or >platinum, <sperrylite	Medium (3.5-4): >chalcopyrite, <sphalerite, <<pyrrhotite	Medium (3-3.5): >bornite, >galena, ~ or >luzonite, ~ or >tennantite, <sphalerite
PLEOCHROISM — AIR	Weak	Weak: cream-gray, pale brown to peach	Weak: pinkish gray to grayish violet
PLEOCHROISM — OIL	Moderate: blue-gray to brown-gray	Moderate: cream-gray to brownish gray	Strong: pinkish gray to grayish violet
ANISOTROPISM	Strong: blue to brown	Strong: highly characteristic blue tints, brownish to blue	Strong: bluish, greenish, reddish, orange tints
INTERNAL REFLECTIONS	Not present	Not present	Rare: deep red
TWINNING	Rare single twin lamellae and chessboard twins	Thin twin lamellae	Rare: parallel (320)
ASSOCIATED MINERALS	Cooperite, platinum, sperrylite, and other Pt minerals	Alabandite, arsenopyrite, chalcopyrite, cobaltite, galena, ilmenite, linnaeite, mackinawite, magnetite, pentlandite, pyrrhotite, sperrylite, sphalerite, violarite	Arsenopyrite, bornite, chalcocite, chalcopyrite, copper, covellite, digenite, famatinite, luzonite, mawsonite, molybdenite, pyrite, sphalerite, stannite, tennantite
KEY IDENTIFICATION CRITERIA	Association with other platinoids and resemblence to pyrrhotite are most characteristic. Rare mineral. Occurs as inclusions in platinum or intergrown with it. Occurs as idiomorphic tabular crystals.	Pleochroism in brown tints, strong anisotropy in blue tints, and exsolution lamellae in chalcopyrite are characteristic.	Light pink-brown color, medium reflectance, and highly colored anisotropy are characteristic. Occurs as anhedral to subhedral grains. Luzonite is more orange-yellow and always shows lamellar twins.

GROUP NUMBER	17	17	17
MINERAL	Pararammelsbergite	Pyrrhotite	Stannite
COMPOSITION	$NiAs_2$	$Fe_{1-x}S$ *	Cu_2FeSnS_4
SYSTEM	Orthorhombic	Monoclinic, hexagonal	Tetragonal
POLISHING CLEAVAGE	(001) rarely visible	(0001) may be visible, (10T0) rarely seen	(110) rarely visible
REFLECTANCE AND COLOR AIR	Strong: white	Strong: creamy pinkish brown	Medium: gray with brownish olive-green tint
REFLECTANCE AND COLOR OIL	Strong: white	Strong: creamy pinkish brown	Medium: olive-gray
R%	56.3 - 57.8	34.8 - 39.9(mono); 34.0 - 39.2(hex)	26.0 - 27.3
VHN	762 - 792	373 - 409(mono); 230 - 318(hex)	140 - 326
POLISHING HARDNESS	Medium (5): >niccolite, <skutterudite	Medium (4) ; >>chalcopyrite, ~pentlandite, <<arsenopyrite, <<pyrite	Medium (4), >chalcopyrite, <sphalerite, <<arsenopyrite
PLEOCHROISM AIR	Weak to nonpleochroic	Weak to strong: creamy brown to reddish brown along grain boundaries	Weak
PLEOCHROISM OIL	Moderate on grain boundaries: yellowish to bluish white	Moderate to strong: creamy brown to reddish brown along grain boundaries	Weak but distinct: light brown to brown-olive-gray
ANISOTROPISM	Strong: pinkish brown to brown, less than rammelsbergite and without the blue	Strong: yellow-gray, greenish gray, or grayish blue	Moderate to strong: yellowish brown, grayish olive-green, bluish or violet-gray
INTERNAL REFLECTIONS	Not present	Not present	Not present
TWINNING	Rare	Not present	Abundant: (111) fine patches or coarse lamellae
ASSOCIATED MINERALS	Ag, Bi, and Ni-Co-Fe minerals, allargentum, bismuth, proustite, pyrite, rammelsbergite	Arsenopyrite, brannerite, carrollite, chalcopyrite, cobaltite, cubanite, galena, ilmenite, magnetite, marcasite, millerite, pentlandite, pyrite, stannite	Arsenopyrite, bismuth, bournonite, cassiterite, chalcopyrite, enargite, jamesonite, mawsonite, pyrite, pyrrhotite, sphalerite, wolframite, wurtzite
KEY IDENTIFICATION CRITERIA	Strong reflectance, white color, euhedral habit, anisotropy in pinkish brown tints, and association with rammelsbergite are characteristic. Occurs as tabular crystals with rectangular outlines and as mosaics of intergrown crystals. May be zoned.	Creamy pinkish brown color and the strong anisotropy are characteristic. Cubanite is softer. Occurs commonly as anhedral granular aggregates. * FeS is troilite.	Brownish olive-green tint, abundant twins (orthogonal and fine), and anisotropy are characteristic. Occurs as anhedral grains, granular aggregates, and as oriented intergrowths in associated minerals.

GROUP NUMBER	18	18	18
MINERAL	Arsenopyrite	Ilmenite	Loellingite
COMPOSITION	FeAsS	$Fe^{+2}TiO_3$	$FeAs_2$
SYSTEM	Monoclinic	Hexagonal	Orthorhombic
POLISHING CLEAVAGE	Rarely visible	Not visible	Not visible
REFLECTANCE AND COLOR — AIR	Strong: white with faint creamy, yellowish, or pinkish tint	Low: gray-white with brownish, pink, or violet tint	Strong: white, often with yellowish tint
REFLECTANCE AND COLOR — OIL	Strong: white with faint creamy, yellowish, or pinkish tint	Low: light brown	Strong: white, often with yellowish tint
R%	51.9 - 52.2	17.0 - 20.1	52.4 - 54.1
VHN	715 - 1354	659 - 703	446 - 560
POLISHING HARDNESS	Hard (5.5-6): >loellingite, >magnetite, <pyrite	Hard (5-6): >magnetite, <hematite	Hard (5-5.5): >>sphalerite, >safflorite, <arsenopyrite
PLEOCHROISM — AIR	Weak	Weak	Weak
PLEOCHROISM — OIL	Weak	Moderate: pinkish brown to dark brown	Weak but distinct: bluish white to yellowish white
ANISOTROPISM	Strong, but not as strong as loellingite: blue, green, reddish brown-yellow	Strong: light greenish gray, brownish gray	Strong, stronger than arsenopyrite: orange-yellow, red-brown, blue, green
INTERNAL REFLECTIONS	Not present	Rare: dark brown	Not present
TWINNING	Lamellar twinning common	Lamellar very common (10T1)	Simple or compound twins very common
ASSOCIATED MINERALS	Chalcopyrite, cobaltite, cubanite, enargite, galena, glaucodot, gold, jamesonite, loellingite, mawsonite, pyrrhotite, sphalerite, stannite, wolframite	Bravoite, chromite, columbite-tantalite, cubanite, hematite, maghemite, magnetite, pentlandite, pyrite, pyrrhotite, rutile, sperrylite, ulvospinel, valleriite	Antimony, arsenic, arsenopyrite, Bi minerals, cassiterite, dyscrasite, galena, Ni-Co arsenides, orpiment, sphalerite, stannite, uraninite, wolframite
KEY IDENTIFICATION CRITERIA	Common lozenge-shaped or rhomb-shaped form, zoning, color, and anisotropy are characteristic. Commonly observed as euhedral to subhedral crystals. More yellow tint, harder, and slightly less anisotropic than loellingite.	Low reflectance, brown-gray color, lamellar twins, and the association with rutile, hematite, and magnetite are characteristic. Occurs as subhedral to anhedral grains and as exsolution lamellae or lenses in hematite or magnetite.	Star-shaped twins, strong anisotropy, and color are characteristic. Occurs as radiating masses of anhedral to subhedral crystals in concentric layers with other arsenide minerals. Also present as euhedral crystals and starlike triplets.

GROUP NUMBER	18	18	18
MINERAL	Pyrolusite	Rammelsbergite	Safflorite
COMPOSITION	MnO_2	$NiAs_2$	$CoAs_2$
SYSTEM	Tetragonal	Orthorhombic	Orthorhombic
POLISHING CLEAVAGE	(010) may be visible	(110) rarely visible	Not visible
REFLECTANCE AND COLOR — AIR	Medium to strong: white with distinct creamy yellow tint	Strong: white	Strong: white often with bluish tint
REFLECTANCE AND COLOR — OIL	Medium to strong: white with distinct creamy yellow tint	Strong: white	Strong: white often with bluish tint
R%	29.0 - 40.0	53.2 - 56.3	55 - 60
VHN	146 - 243	585 - 803	285 - 464
POLISHING HARDNESS	Hard (6-6.5), can vary depending on grain size and orientation	Hard (5.5-6): >niccolite, ~pararammelsbergite, ~skutterudite	Hard (4.5-5.5): >skutterudite, <arsenopyrite, <cobaltite, <loellingite
PLEOCHROISM — AIR	Moderate: yellowish white to light yellowish gray	Weak	Weak: bluish to gray
PLEOCHROISM — OIL	Strong: yellowish white to white-gray	Moderate: yellowish to bluish	Weak: bluish to gray
ANISOTROPISM	Strong: yellowish, brownish, greenish blue, slate gray	Strong: purplish blue, pinkish, brownish, and greenish; stronger than pararammelsbergite which is pinkish brown to brown	Strong, but not as strong as loellingite: blue-gray to dark brown; differing for different zones in zonal textures
INTERNAL REFLECTIONS	Not present	Not present	Not present
TWINNING	Not present	Consistant and characteristic twin lamellae	Star-shaped twins common
ASSOCIATED MINERALS	Alabandite, bixbyite, braunite, chalcophanite, goethite, hausmannite, hematite, jacobsite, magnetite, manganite, psilomelane	Ag and Bi minerals, allargentum, arsenic, bismuth, niccolite, pararammelsbergite, silver, skutterudite	Ag and Bi minerals, antimony, arsenic, bravoite, breithauptite, dyscrasite, linnaeite, Ni-Co arsenides, silver
KEY IDENTIFICATION CRITERIA	Association with Mn minerals, reflectance, yellow tints, anisotropy, and frequent cracks resulting from manganite pseudomorphs are characteristic. Occurs as coarse-grained tabular crystals or as banded aggregates.	Strong reflectance, white color, anisotropy in blue to purple-blue tints, twins, and association with Ni-Co minerals are characteristic. Occurs as fine-grained aggregates of interlocking crystals. Often in zonal, spherulitic, radiating, and fibrous textures.	Star-shaped twins, strong anisotropy, and color are characteristic. Occurs as radiating masses of anheal to subhedral crystals in concentric layers with other arsenide minerals. Also present as euhedral crystals and starlike triplets

GROUP NUMBER	19	19	19
MINERAL	Cinnabar	Jamesonite	Lepidocrocite
COMPOSITION	HgS	$Pb_4FeSb_6S_{14}$	FeO.OH
SYSTEM	Hexagonal	Monoclinic	Orthorhombic
POLISHING CLEAVAGE	(10T0) rarely visible	May be visible	Not visible
REFLECTANCE AND COLOR — AIR	Medium: white with bluish to greenish gray tint	Strong: white	Low: grayish white
REFLECTANCE AND COLOR — OIL	Medium: white with bluish to greenish gray tint	Strong: white	Low: gray with yellow or dirty greenish tint
R%	24.6 - 29.6	37.4 - 42.9	11.6 - 18.4
VHN	82 - 156	113 - 117	402
POLISHING HARDNESS	Soft (2-2.5): >realgar, ~ or >stibnite, <galena, <<pyrite	Soft (2-3): ~boulangerite, <galena, <stannite	Medium (5): <goethite
PLEOCHROISM — AIR	Weak to distinct along grain boundaries	Strong: white to yellow-green	Moderate: gray to brownish gray
PLEOCHROISM — OIL	Moderate: yellowish gray-white to brownish gray-white	Strong: white to yellow-green	Moderate to strong: white with bluish tint, dark gray
ANISOTROPISM	Strong, but tints may be masked by internal reflections: light green colors may be observed; also various shades of gray with blue and green tints	Strong: gray, tan, brown, light blue, dark blue	Strong: shades of gray and white
INTERNAL REFLECTIONS	Abundant: bright red	Common: reddish in Bi jamesonite	Common: red
TWINNING	Sinuous and polysynthetic twins may be present	Twin lamellae very common	Not present
ASSOCIATED MINERALS	Berthierite, chalcopyrite, chalcostibite, galena, gold, marcasite, orpiment, pyrite, realgar, stibnite	Arsenopyrite, boulangerite, chalcopyrite, chalcostibite, galena, Pb sulfantimonides, pyrite, sphalerite, stannite	Goethite, pyrite, and many minerals of the oxidation zone of ore deposits
KEY IDENTIFICATION CRITERIA	Medium reflectance, abundant internal reflections, and frequent association with stibnite are characteristic. Typically anhedral but may be euhedral. Shows redder internal reflections than rutile or realgar.	Twins parallel to the elongation, pleochroism, and anisotropism are characteristic. Occurs as needle-like or lathlike crystals or bundles.	Moderate pleochroism, intense and uncolored anisotropy, low reflectance, and association with goethite are characteristic. Occurs as a weathering product of Fe oxides and sulfides with goethite.

GROUP NUMBER	19	19	19
MINERAL	Miargyrite	Orpiment	Proustite - Pyrargyrite
COMPOSITION	$AgSbS_2$	As_2S_3	Ag_3AsS_3 - Ag_3SbS_3
SYSTEM	Monoclinic	Monoclinic	Hexagonal
POLISHING CLEAVAGE	Not visible	(010) often visible	Not visible
REFLECTANCE AND COLOR AIR	Strong: white	Medium: whitish gray to gray	Medium: bluish gray-white; proustite is bluer and slightly darker than pyrargyrite
REFLECTANCE AND COLOR OIL	Medium: white with bluish tint	Medium: whitish gray to gray	Medium: bluish gray-white; proustite is bluer and slightly darker than pyrargyrite
R%	31.6 - 34.5	23.0 - 27.5	27.4 - 30.3
VHN	88 - 130	22 - 58	103 - 144 (at 50 g)
POLISHING HARDNESS	Soft (2.5): >dyscrasite, >polybasite	Soft (1.5-2): >realgar, <sphalerite, <<arsenopyrite, <<stibnite	Soft (2.5-3): >>argentite, >pearceite-polybasite, <galena
PLEOCHROISM AIR	Moderate: white to bluish gray	Strong: white to dull gray with reddish tint	Moderate to strong: proustite, white with yellowish tint to bluish gray; pyrargyrite, shades of gray
PLEOCHROISM OIL	Moderate: white to bluish gray with reddish cream tint	Strong: grayish white to gray with red tint	Strong: proustite, grayish blue with brownish tint to dark grayish blue; pyrargyrite, shades of gray
ANISOTROPISM	Strong, but may be masked by internal reflections: blue-gray to brownish	Strong, but often masked by internal reflections	Strong, but may be masked by internal reflections: grayish to brownish tints
INTERNAL REFLECTIONS	Common: deep red	Abundant: intense white to yellow	Abundant: intense red to orange
TWINNING	Rare polysynthetic twins	Not present	Simple or lamellar twins may be observed
ASSOCIATED MINERALS	Ag and Co-Ni minerals, dyscrasite, galena, pearceite-polybasite, sphalerite, tetrahedrite-tennantite	Arsenic, arsenopyrite, cinnabar, loellingite, marcasite, pyrite, realgar, sphalerite, stibnite	Ag sulfosalts, arsenopyrite, chalcopyrite, Co-Ni minerals, freibergite, galena, pyrite, sphalerite, tetrahedrite-tennantite
KEY IDENTIFICATION CRITERIA	Deep red internal reflections, strong anisotropy, and strong reflectance are characteristic. Occurs as granular anhedral aggregates.	Softness, intense yellow internal reflections, and association with realgar are characteristic. Occurs as tabular interlocking anhedral masses and as needlelike or lathlike crystals.	Bluish tint and abundant red internal reflections are characteristic. Proustite is darker than pyrargyrite and shows more abundant internal reflections. Occurs as irregular grains and aggregates. Crystals sometimes zoned. Prousite is associated with As minerals and pyrargyrite with Sb minerals.

GROUP NUMBER	19	20	20
MINERAL	Psilomelane	Berthierite	Boulangerite
COMPOSITION	General term for massive manganese oxides	$FeSb_2S_4$	$Pb_5Sb_4S_{11}$
SYSTEM	No definite crystal system	Orthorhombic	Monoclinic
POLISHING CLEAVAGE	Not visible	Rarely visible	Not visible
REFLECTANCE AND COLOR — AIR	Medium: bluish gray to grayish white	Strong: white-gray with pinkish or brownish tint	Strong: white with bluish green tint
REFLECTANCE AND COLOR — OIL	Medium: bluish gray to grayish white	Strong, much lower than in air: white-gray with pinkish or brownish tint	Strong: gray-green
R%	15.0 - 30.0	36.6 - 42.0	37.4 - 41.8
VHN	203 - 813	102 - 213	92 - 125
POLISHING HARDNESS	Hard (5-6): >manganite, <pyrolusite	Soft (2-3): >stibnite, ~cinnabar, <sphalerite, <<arsenopyrite, <<pyrite	Soft (2.5-3): <bournonite, <galena
PLEOCHROISM — AIR	Strong: white to bluish gray	Strong: brownish pink to gray-white to white	Weak but distinct: gray-green to gray-white
PLEOCHROISM — OIL	Strong: white to bluish gray	Strong: yellow-green or olive to grayish yellow-green to white	Moderate: gray-green to gray-white
ANISOTROPISM	Strong: gray-white, sometimes brownish	Strong: blue, gray, white, brown, pink	Moderate to strong: light tan, brown, bluish gray, greenish shades
INTERNAL REFLECTIONS	Rare: brown	Not present	Rare: red
TWINNING	Not present	Not present	Not present
ASSOCIATED MINERALS	Chalcophanite, goethite, graphite, hausmannite, manganite, pyrolusite	Ag sulfosalts, arsenopyrite, chalcopyrite, cinnabar, galena, gold, sphalerite, stibnite, pyrite	Bournonite, chalcopyrite, galena, jamesonite, pyrite, sphalerite, tetrahedrite-tennantite
KEY IDENTIFICATION CRITERIA	Colloform texture, moderate reflectance, anisotropy, and pleochroism are characteristic. Occurs as botryoidal masses of very fine acicular crystals in concentric layers.	Association with stibnite, strong pleochroism, and anisotropism are characteristic. Occurs as euhedral needlelike crystals and as subhedral aggregates.	Bluish green tint, anisotropy, and associated minerals are characteristic. Usually occurs as granular or fibrous aggregates.

GROUP NUMBER	20	20	20
MINERAL	Calcite	Chalcophanite	Graphite
COMPOSITION	$CaCO_3$	$(Zn,Fe^{+2},Mn^{+2})Mn^{+4}{}_3O_7.3H_2O$	C
SYSTEM	Hexagonal	Triclinic	Hexagonal
POLISHING CLEAVAGE	Often visible	(0001) always visible	(0001) may be visible
REFLECTANCE AND COLOR — AIR	Low: gray	Low to medium: white to gray	Low: brownish gray to grayish black
REFLECTANCE AND COLOR — OIL	Low: gray	Low to medium: white to gray	Low: brownish gray to grayish black
R%	No data	9.9 - 24.9	6.8 - 17.4
VHN	No data	188 - 253	12 - 16 (at 50 g)
POLISHING HARDNESS	Soft (3): <<quartz	Soft (2.5): <manganite, <<franklinite	Soft (1-2): less than most associated minerals
PLEOCHROISM — AIR	Strong	Strong: pure white to dark gray	Strong: brown-gray with yellow tint to bluish gray
PLEOCHROISM — OIL	Strong	Strong: pure white to dark gray	Strong: brown-gray with yellow tint to almost completely black
ANISOTROPISM	Strong, but partly masked by very light internal reflections	Strong: white to gray	Strong: straw yellow to dark brown to violet-gray
INTERNAL REFLECTIONS	Light internal reflections	Not present, except when Zn rich (red)	Not present
TWINNING	Polysynthetic twins	Not present	Not present
ASSOCIATED MINERALS	Many minerals including arsenopyrite, chalcopyrite, galena, magnetite, sphalerite, pyrite, pyrrhotite, quartz	Franklinite, hausmannite, manganite, psilomelane, pyrolusite, zincite	Arsenopyrite, galena, magnetite, psilomelane, pyrite, pyrrhotite, realgar, sphalerite
KEY IDENTIFICATION CRITERIA	Low reflectance, strong pleochroism and anisotropism, and polysynthetic twins are characteristic. Often xenomorphic and may occur as euhedral crystals. Frequently replaced by quartz. Common gangue mineral.	Strong anisotropism and pleochroism in white to gray are characteristic. Occurs as aggregates of tabular and radiating crystals and as colloform bands in secondary Mn ores.	Strong pleochroism and anisotropism with yellow tint, low refectance, and perfectly developed cleavage are characteristic. Occurs as small plates, laths, and bundles of blades. Undulose extinction common. More common than molybdenite.

GROUP NUMBER	20	20	20
MINERAL	Mackinawite	Marcasite	Molybdenite
COMPOSITION	$(Fe,Ni)_9S_8$	FeS_2	MoS_2
SYSTEM	Tetragonal	Orthorhombic	Hexagonal
POLISHING CLEAVAGE	(001) may be visible	(101) often visible	(0001) often visible
REFLECTANCE AND COLOR — AIR	Strong: pinkish or reddish gray	Strong: yellowish white with greenish or pinkish tint	Medium to strong: white to gray, may have bluish tint
REFLECTANCE AND COLOR — OIL	Strong: pinkish or reddish gray	Strong: yellowish white with greenish or pinkish tint	Medium to strong: white to gray, may have bluish tint
R%	22 - 46	48.2 - 55.8	19.5 - 38.5
VHN	52 - 58	1288 - 1681	8 - 100
POLISHING HARDNESS	Medium (4): ~pyrrhotite	Hard (6-6.5): ~pyrite, >pyrrhotite	Soft (1-1.5): <bismuth, <<cassiterite, <<cobaltite, <<wolframite
PLEOCHROISM — AIR	Strong: pinkish gray to gray	Strong: white with brown tint, yellow with green tint	Strong: white to gray with bluish tint
PLEOCHROISM — OIL	Strong: pinkish gray to gray	Strong: white with brown tint, yellow with green tint	Strong: white to gray with bluish tint
ANISOTROPISM	Strong: grayish white, bluish, brownish	Strong: blue, green-yellow	Strong: white with pinkish or dark blue tint
INTERNAL REFLECTIONS	Not present	Not present	Not present
TWINNING	Lamellar twins may be visible	Lamellar twins nearly always present	Not present
ASSOCIATED MINERALS	Arsenopyrite, chalcopyrite, cobaltite, cubanite, magnetite, pentlandite, pyrrhotite	Cinnabar, galena, magnetite, orpiment, pyrite, pyrrhotite, sphalerite	Bismuth, brannerite, cassiterite, cobaltite, Co-Ni arsenides, enargite, galena, magnetite, niccolite, pitchblende, sphalerite, uraninite, wolframite
KEY IDENTIFICATION CRITERIA	Strong pleochroism and anisotropism, and association as small exsolution blebs with chalcopyrite or pentlandite are characteristic. Association with cubanite is also characteristic. Occurs as small wormlike grains and lamellae.	Strong anisotropism in blue to green-yellow, strong reflectance, lamellar twins, and association with pyrite are characteristic. Occurs as subhedral to lamellar intergrowths with pyrite as euhedral crystals. Also occurs as radiating colloform bands.	Strong anisotropism and pleochroism, lamellar texture, and cleavage (0001) are characteristic. Occurs as small, often deformed, plates and irregular inclusions. More rarely as rosettes or colloform bands.

GROUP NUMBER	20	20	20
MINERAL	Stibnite	Sylvanite	Tenorite
COMPOSITION	Sb_2S_3	$AgAuTe_4$	CuO
SYSTEM	Orthorhombic	Monoclinic	Monoclinic
POLISHING CLEAVAGE	Rarely visible	(010) and (100) may be visible	Not visible
REFLECTANCE AND COLOR — AIR	Strong: white to grayish white	Strong: creamy white	Medium: gray-white with brown tint
REFLECTANCE AND COLOR — OIL	Strong: white to grayish white	Strong: creamy white	Medium, much lower than in air: gray with brownish tint
R%	31.1 - 48.1	50.3 - 59.0	20.9 - 25.2
VHN	42 - 153	91 - 104	304 - 339
POLISHING HARDNESS	Soft (2): >orpiment, >realgar, ~ or <berthierite	Soft (1.5-2): >acanthite-argentite, <galena, <gold, <sphalerite	Medium (3.5): >copper, <cuprite, <delafossite, <goethite
PLEOCHROISM — AIR	Strong: dull gray-white, brownish gray, white	Moderate: creamy white to creamy brown	Moderate: white to gray
PLEOCHROISM — OIL	Strong: dull gray-white, brownish gray, white	Moderate: creamy white to creamy brown	Strong: white to gray with brown-violet tint
ANISOTROPISM	Strong, but often undulose extinction: blue, gray, brown, pinkish brown	Strong: light bluish gray to dark brown	Strong: blue to light creamy gray
INTERNAL REFLECTIONS	Not present	Not present	Not present
TWINNING	Pressure twins, deformation twins common	Polysynthetic twins always present	Lamellar twins common
ASSOCIATED MINERALS	Ag minerals, antimony, berthierite, chalcopyrite, cinnabar, gold, orpiment, pyrite, pyrrhotite, realgar, sphalerite	Acanthite-argentite, bornite, As, Bi, and Sb sulfides, galena, gold, sphalerite, tellurides	Copper, Cu-Fe oxides, delafossite, goethite
KEY IDENTIFICATION CRITERIA	Deformed twins, strong pleochroism, and anisotropy are characteristic. Occurs as granular aggregates and lathlike crystals.	Remarkable twin lamellae, strong reflectance, pleochroism and anisotropism, and association with tellurides are characteristic. Occurs as skeletal blades.	Brown tint, strong anisotropy, and twin lamellae are characteristic. Occurs as aggregates of acicular crystals and as concentrically grown aggregates.

GROUP NUMBER	20
MINERAL	Valleriite
COMPOSITION	$4(Fe,Cu)S.3(Mg,Al)(OH)_2$
SYSTEM	Hexagonal
POLISHING CLEAVAGE	Not visible
REFLECTANCE AND COLOR — AIR	Low: brown, bronze to gray
REFLECTANCE AND COLOR — OIL	Low: brown, bronze to gray
R%	14.2 - 22.0
VHN	30 (at 50 g)
POLISHING HARDNESS	Medium (3.5-4): ~pentlandite, >chalcopyrite, <chromite
PLEOCHROISM — AIR	Strong: bronze to gray
PLEOCHROISM — OIL	Strong: bronze to gray
ANISOTROPISM	Strong: white to gray-bronze with a satinlike texture
INTERNAL REFLECTIONS	Not present
TWINNING	Not present
ASSOCIATED MINERALS	Chalcopyrite, chromite, ilmenite, magnetite, millerite, pentlandite, sperrylite
KEY IDENTIFICATION CRITERIA	Low reflectance, strong pleochroism, and anisotropy are characteristic. Occurs as veinlets, interstitial fillings, and tiny blebs in and around associated minerals. Graphite and mackinawite are similar.

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