APPENDIX 1

TABLE OF DIAGNOSTIC PROPERTIES OF THE COMMON ORE MINERALS

This Appendix contains data that will help you in your microscopic identification of the most commonly encountered opaque minerals (approximately 100 minerals are included). The data presented are as follows:

1. The mineral name.
2. The chemical formula. This is generally given in its simplest form (e.g., the end member of a solid solution series), although major substitutions are shown.
3. The crystal system.
4. A description of the color of the mineral (the symbol "→ galena, bluish" indicates that the mineral described appears bluish against galena).
5. A description of any observable bireflectance and reflection pleochroism.
6. A description of the presence, intensity, and character of any anisotropism.
7. A description of the character of any observable internal reflections.
8. The quantitative reflectance values ($R\%$) in air at 546 and 589 nm wavelength. These data are consistent with the Quantitative data file (Criddle and Stanley, 1993); however, those data are for a single sample and do not necessarily reflect the ranges of values that have been reported for many minerals.
9. Quantitative color values (in air) quoted using the CIE system and giving chromaticity coordinates (x and y) and the luminance ($Y\%$) following the conventions in Criddle and Stanley (1993). A single value is

given for an isotropic mineral [corresponding to R or two values corresponding to $R_o, R_e (R_{e'})$ or R_1, R_2]. In a few cases, quantitative color data are given for oriented single crystals (corresponding to R_a, R_b, R_c). For isotropic minerals, this is the value of R; for "uniaxial" minerals, R_o is followed by R_e (or $R_{e'}$); and for "biaxial" minerals, R is followed by R_2.

10. Quantitative indentation microhardness (Vickers hardness number) at a load of 100 g (VHN_{100}) unless another load is specified. For some minerals, information is given on indentation characteristics as follows: p, perfect; f, fractured; sf, slightly fractured; cc, concave; cv, convex; sg, sigmoidal.
11. Polishing hardness (PH) given as less than, equal to, or greater than other common ore minerals.
12. Mode of occurrence and other characteristic properties; this is general information on crystal morphology, cleavage, twinning, characteristic alteration effects, and commonly associated minerals.

The data presented in the tables have mainly been derived from the following sources, which should be consulted for further details and information on other minerals:

Uytenbogaart, W., and Burke, E. A. J. (1971). *Tables for Microscopic Identification of Ore Minerals.* Elsevier, Amsterdam.

Ramdohr, P. (1969). *The Ore Minerals and Their Intergrowths.* Pergamon, Oxford.

Schouten, C. (1962). *Determinative Tables for Ore Microscopy.* Elsevier, Amsterdam.

Criddle, A. J. and Stanley, C. J. (1993). *Quantitative Data File for Ore Minerals,* 3rd ed. Chapman and Hall, London.

Following is an "Identification Scheme," which can be used as an aid to determining any unknown minerals. This simplistic scheme should be used as only a preliminary guide to the possible identity of a phase.

TABLE A1.1 Identification Scheme[a]

	Distinctly Colored	
Blue	Isotropic (or weakly anisotropic)	Chalcocite, digenite
	Anisotropic	Covellite
Yellow	Isotropic (or weakly anisotropic)	Gold, chalcopyrite
	Anisotropic	Chalcopyrite, millerite, delafossite, cubanite, mackinawite, valleriite

TABLE A1.1 (*Continued*)

Red-brown to brown	Isotropic (or weakly anisotropic)	Bornite, copper, bravoite
	Anisotropic	Idaite, valleriite, delafossite, mawsonite
Pink, purple, violet	Isotropic (or weakly anisoropic)	Bornite, copper, bravoite, violarite
	Anisotropic	Breithauptite
	Distinctly Colored Internal Reflections (in Minerals Not Distinctly Colored)	
Blue		Anatase, azurite
Yellow		Sphalerite, orpiment, rutile, cassiterite
Red to brown		Cinnabar, proustite, pyrargyrite, tennantite, sphalerite, cuprite, chromite, orpiment, wolframite
	Weakly Colored (If at All) [a]	
Blue	Isotropic	Tetrahedrite
	Anisotropic with internal reflections	Hematite, cuprite, cinnabar, hausmannite, proustite, pyrargyrite
	Anisotropic without internal reflections	Psilomelane
Green	Isotropic (or weakly anisotropic)	Tetrahedrite, acanthite
	Anisotropic	Stannite, polybasite
Yellow	Isotropic	Pyrite, pentlandite
	Anisotropic	Marcasite, niccolite
Red-brown to brown	Isotropic	Magnetite, ulvöspinel
	Anisotropic	Pyrrhotite, ilmenite, enargite
Pink, purple, violet	Isotropic	Cobaltite, linnaeite
	Anisotropic	Niccolite, famatinite
	Not Colored to Any Degree [a]	
$R\% \geqslant 51.7$ (pyrite)		
Isotropic	Hardness	(Pyrite) gersdorffite, skutterudite
	Hardness medium-low	Silver, platinum, allargentum
Anisotropic	Hardness high	(Marcasite) rammelsbergite, pararammelsbergite, safflorite, loellingite, arsenopyrite
	Hardness medium-low	Bismuth, antimony, arsenic, dyscrasite, tetradymite, sylvanite

TABLE A1.1 (*Continued*)

R% 51.7 (pyrite) to 42.9 (galena)		
Isotropic	Hardness high	Siegenite, ullmannite
	Hardness medium-low	Galena, freibergite, alabandite
Anisotropic	Internal reflections	Pyrargyrite
	No internal reflections	Bismuthinite, stibnite, cosalite, kobellite
R% 42.9 (galena) to 19.9 (magnetite)		
Isotropic	No internal reflections	Carrollite, tetrahedrite, maghemite, bixbyite (magnetite)
	Internal reflections	Realgar, tennantite, pearcite
Anisotropic	Internal reflections	Hematite, enargite, miargyrite, pyrargyrite, boulangerite, chalcostibite, orpiment, realgar, chalcophanite
	No internal reflections	Molybdenite, pyrolusite, berthierite, boulangerite, chalcostibite, jamesonite, tenorite, stephanite, stromeyerite, mawsonite, pyrolusite
R% $\geqslant$19.9 (magnetite)		
Isotropic	No internal reflections	Chromite, coffinite
	Internal reflections	Brannerite, sphalerite
Anisotropic	Internal reflections	Columbite-tantalite, manganite, chalcophanite, scheelite, cassiterite, lepidocrocite, zincite, uraninite, manganite, wolframite, goethite, rutile
	No internal reflections	Graphite, braunite

[a] Categories defined are intended only as a rough guide to identification. The following tables should be used to confirm any possible identification.

TABLE A1.2 Alphabetical Listing of Ore Minerals with Diagnostic Properties

Note: Information is reported as follows:

Name Formula Crystal System	C—Color B/P—Bireflectance/ pleochroism A—Anisotropy IR—Internal Reflections	R—Reflectance at 546 and 589 nm in Air QC—Quantitative Color Coordinates	VHN—Vickers Micro-hardness at 100g Load PH—Polishing Hardness	Mode of Occurrence; Other Characteristic Properties
Acanthite Ag_2S Monoclinic (Pseudocubic)	C—Gray, with a greenish tint → Galena, darker, greenish gray → Silver, dark greenish gray B/P—Very weak A—Distinct if well polished IR—Not present	R—31.0–29.5	VHN—23–26 (p) PH—Less than most minerals	Occurs as euhedral cubic crystals Pseudomorphous after argentite (stable >176°C) and as anhedral polycrystalline aggregates. Difficult to polish without scratches because of softness, but twinning often visible when well polished. Occurs as irregular inclusions in galena; often associated with pyrite, galena, sphalerite, tetrahedrite, covellite, proustite, pyrargyrite, polybasite. The high-temperature polymorph, argentite, always inverts to acanthite on cooling, but its former existence may be evidenced by cubic morphology.

(*Continued*)

TABLE A1.2 (*Continued*)

Note: Information is reported as follows:

Name Formula Crystal System	C—Color B/P—Bireflectance/ pleochroism A—Anisotropy IR—Internal Reflections	R—Reflectance at 546 and 589 nm in Air QC—Quantitative Color Coordinates	VHN—Vickers Micro-hardness at 100g Load PH—Polishing Hardness	Mode of Occurrence; Other Characteristic Properties
Alabandite MnS Cubic	C—Gray → Sphalerite, distinctly lighter B/P—Not present A—Isotropic; sometimes with weak anomalous A IR—Common, dark green to brown	R—22.8 22.3 QC—0.301, 0.305, 22.8	VHN—240-251 (p) PH ~ sphalerite	Occurs as euhedral crystals and as anhedral aggregates; resembles sphalerite. Cleavage, lamellar twinning, and zonal textures may be visible. Occurs with pyrite, chalcopyrite, pyrrhotite, pyrolusite, Mn-sphalerite, Mn-carbonate.
Allargentum $Ag_{1-x}Sb_x$ Hexagonal	C—White, slightly grayish → Silver, grayish B/P—Not present A—Weak IR—Not present	R—~ 70	VHN— PH > silver	Occurs as lamellar intergrowths in silver, especially that from Cobalt, Ontario. Originally identified as dyscrasite, which is very similar but is Ag_3Sb.
Allemontite A mixture of As or Sb with AsSb	C—White B/P—Weak A—Distinct IR—Not present	R—50-70	VHN—85-100 PH ~ antimony	Occurs as a myrmekitic intergrowth, which may be on such a fine scale that it is only discernible as two phases under high-power magnification. Two phases

				are often more visible after slight oxidation or etching. Occurs with stibnite in Co-Ni-Ag-Bi-As ores and pegmatites.
Antimony Sb Trigonal	C—White → Arsenic, slightly more white → Galena, brighter white → Silver, less bright → Dyscrasite, similar B/P—Weak A—Distinct; yellowish gray, brownish, bluish gray IR—Not present	R—74.4–77.9 72.9–76.8 QC—0.308, 0.318 73.6 0.310, 0.319 77.3	VHN—50–69 (f-cc) PH > stibnite PH < arsenic	Occurs as fine- to coarse-grained aggregates, rarely euhedral. Cleavage and twinning (often polysynthetic) commonly visible. Occurs with stibnite, pyrite, arsenopyrite, Co-Ni arsenides, and with stibarsen as fine graphic to myrmekitic intergrowths known as "allemontite."
Argentite—*See* Acanthite				
Arsenic As Trigonal	C—White; tarnishes rapidly → Antimony, slightly darker gray → Skutterudite and safflorite, slightly darker gray → Galena, white with a creamy tint BP—Weak in air; distinct in oil; grayish white to yellow or bluish gray	R—51.7–55.7 51.2–55.3 QC—0.306, 0.312 51.6 0.309, 0.315 55.5	VHN—72–173(p-cc) PH > Bismuth, silver	Occurs as fine- to coarse-grained anhedral aggregates and commonly as colloform bands. Twinning and a basal cleavage often visible. Occurs with rammelsbergite, skutterudite, proustite, arsenopyrite, pyrite, and stibarsen as fine graphic to myrmekitic intergrowths of "allemontite." The very rapid (a few hours) tarnish is diagnostic.

(Continued)

TABLE A1.2 (*Continued*)

Note: Information is reported as follows:

Name Formula Crystal System	C—Color B/P—Bireflectance/ pleochroism A—Anisotropy IR—Internal Reflections	R—Reflectance at 546 and 589 nm in Air QC—Quantitative Color Coordinates	VHN—Vickers Micro- hardness at 100g Load PH—Polishing Hardness	Mode of Occurrence; Other Characteristic Properties
	A—Distinct; gray to yellowish gray IR—Not present			
Arsenopyrite FeAsS Monoclinic	C—White → Pyrite, white → Loellingite, safflorite, creamy white → Antimony, grayish white → Galena, sphalerite, white with pale yellow tint B/P—Weak A—Strong; blue, green IR—Not present	R—51.85-52.2 51.7-53.2 QC—(a) 0.315, 0.321 52.5 (b) 0.318, 0.325 51.8 (c) 0.310, 0.317 51.8	VHN—715-1354 1081 on (001) (sf) PH > skutterudite, magnetite PH < pyrite, cobaltite	Commonly observed as euhedral to subhedral crystals with characteristic rhomb shape when a minor phase; also as anhedral granular masses when abundant. Lamellar twinning common. Occurs with pyrite, loellingite, glaucodot, pyrrhotite, chalcopyrite, sphalerite, galena, cobaltite, gold, molybdenite. Good polish, white color, anisotropism, and crystal form are characteristic.
Berthierite $FeSb_2S_4$ Orthorhombic	C—White-gray with a pink or brown tint B/P—Strong and characteristic (//a) brownish pink	R—30.3-42.3 30.9-41.1 QC—0.310, 0.312 30.6	VHN—168-228(f) PH ~ stibnite PH < sphalerite	Occurs as euhedral needlelike crystals and as subhedral aggregates, with stibnite, chalcopyrite, pyrite, arsenopyrite, pyrrhotite,

	(//b) grayish white (//c) white A—Very strong; blue, gray, white; brown, pink IR—Not present	0.301, 0.309 42.1		gudmundite, sphalerite, galena.
Bismuth Bi Trigonal	C—White to creamy white; pinkish cream → Silver, creamy → Arsenic, pinkish creamy → Sulfosalts, pinkish creamy B/P—Weak but distinct, creamy to pinkish A—Distinct to strong IR—Not present	R—59.8–67.2 61.9–69.5 QC—0.325, 0.332 59.9 0.323, 0.328 67.4	VHN—16–18(p) PH < all associated minerals	Occurs as irregular masses or inclusions of anhedral crystals. Twinning is common and may be induced by grinding or scratching. Occurs with sulfosalts, pyrite, pyrrhotite, sphalerite, chalcopyrite, bismuthinite, cassiterite, molybdenite, wolframite, arsenopyrite, Co-Ni arsenides, silver, galena.
Bismuthinite Bi_2S_3 Orthorhombic	C—White; in oil with bluish gray tint → Bismuth, darker, bluish gray → Chalcopyrite, bluish gray → Galena, lighter, creamy white B/P—Weak to distinct (//a) Bluish gray-white (//b) Gray-white (//c) Creamy white	R—37.1–49.0 36.7–48.0 QC—(a) 0.308, 0.315 43.7 (b) 0.308, 0.316 37.0 (c) 0.308, 0.319 48.6	VHN—110–136(sf) PH > bismuth PH < chalcopyrite	Occurs as subhedral lath-like crystals; less commonly as granular masses. Cleavage // (010) common. Stress-induced twinning and undulose extinction often seen. Occurs with bismuth, pyrite, pyrrhotite, arsenopyrite, chalcopyrite, sphalerite, stannite, cassiterite, wolframite, molybdenite.

(*Continued*)

TABLE A1.2 (*Continued*)

Note: Information is reported as follows: Name Formula Crystal System	C—Color B/P—Bireflectance/ pleochroism A—Anisotropy IR—Internal Reflections	R—Reflectance at 546 and 589 nm in Air QC—Quantitative Color Coordinates	VHN—Vickers Micro-hardness at 100g Load PH—Polishing Hardness	Mode of Occurrence; Other Characteristic Properties
	A—Very strong, especially in oil; gray, yellow, violet, straight extinction; large crystals often undulose IR—Not present			
Bixbyite $(Mn,Fe)_2O_3$ Cubic	C—Gray with cream to yellow tint → Braunite, jacobsite, hausmannite, lighter, yellowish → Hematite, brownish B/P—Usually absent; sometimes very weak in oil A—Isotropic; sometimes weakly anomalous IR—Not present	R—22.2 22.0 QC—0.308, 0.316 22.1	VHN—946–1402 (p) PH > hausmannite PH ~ braunite	Occurs as euhedral crystals and as granular aggregates. Cleavage (111), lamellar twinning, and zonal growth may be visible. Occurs with hematite, braunite, pyrolusite, hausmannite.

Bornite Cu_5FeS_4 Orthorhombic Pseudo-Tetragonal	C—Pinkish brown to orange; tarnishes purplish, violet, or iridescent B/P—Slight bireflectance may be visible on grain boundaries A—Very weak IR—Not present	R—21.7 25.2 QC—0.348, 0.338 22.8	VHN—87-100(p-sf) PH > galena, chalcocite PH < chalcopyrite	Occurs as irregular polycrystalline aggregates and as coatings on, or lamellae intergrown with, chalcopyrite. Cleavage may be visible; twinning may be infrequent and difficult to see. Lamellar exsolution and replacement textures with chalcopyrite, enargite, digenite are common; alters on grain boundaries and fractures to covellite. Occurs with pyrite, chalcopyrite, enargite, digenite, covellite, linnaeite, sphalerite, galena, magnetite, tetrahedrite, hematite.
Boulangerite $Pb_5Sb_4S_{11}$ Monoclinic	C—White with bluish gray → Galena, darker greenish gray → Stibnite, slightly lighter → Jamesonite, darker B/P—Distinct, gray-white to green-gray A—Distinct, tan, brown, bluish gray IR—Rare, red	R—37.4–41.8 36.5–40.7 QC—0.303, 0.311 37.2 0.303, 0.312 41.4	VHN—92-125(sf) PH < galena	Usually occurs as granular or fibrous aggregates with galena, sphalerite, chalcopyrite, tetrahedrite, or other Pb-Sb sulfosalts.

(*Continued*)

TABLE A1.2 (***Continued***)

Note: Information is reported as follows:

Name Formula Crystal System	C—Color B/P—Bireflectance/ pleochroism A—Anisotropy IR—Internal Reflections	R—Reflectance at 546 and 589 nm in Air QC—Quantitative Color Coordinates	VHN—Vickers Micro-hardness at 100g Load PH—Polishing Hardness	Mode of Occurrence; Other Characteristic Properties
Brannerite $(U,Ca,Ce)(Ti,Fe)_2O_6$ Monoclinic (metamict)	C—Gray B/P—Not present A—Not present IR—Coarse crystals: brownish gray; fine-grained material: blue-gray to bluish white, dark brown to yellowish	R—15.0–15.1 14.7–14.8	VHN—690(p)	Occurs as euhedral prismatic to needlelike crystals and as subhedral aggregates. Often forms as replacement (sometimes as a pseudomorph) after uraninite and rutile. Usually contains included laths of pyrrhotite and anatase and may have a "dusting" of small radiogenetic galena crystals. Occurs with uraninite, rutile, pitchblende, pyrite, coffinite, galena, sphalerite, tetrahedrite, pyrrhotite, anatase, magnetite.
Braunite $(Mn,Fe,Si)_2O_3$ Tetragonal	C—Gray with brownish tint → Magnetite, less brown → Pyrolusite, psilomelane, darker → Manganite, hausmanite, similar	R—18.9–19.5 18.4–19.3 QC—0.300, 0.306 18.8 0.300, 0.306 19.8	VHN—920–1196(p-sf) PH > magnetite PH < bixbyite	Occurs as anhedral granular masses and as subhedral to euhedral crystals. Zonal textures reported. Associated with jacobsite, bixbyite, hematite, pyrolusite, magnetite.

	but weaker bireflectance → Bixbyite, jacobsite, more gray B/P—Weak but distinct, gray A—Weak but distinct, gray to blue; often undulose IR—Rare, dark brown to deep red			
Bravoite $(Fe,Ni,Co)S_2$ Cubic	C—Composition dependent; Fe-rich: creamy to pinkish; Co- and Ni-rich: pinkish to brownish to violet B/P—Not present A—Not present R—Not present	R—31.0–53.9 (lowest for Co and Ni-rich)	VHN—668–1535 PH < pyrite PH > sphalerite	Zonal texture very characteristic, the darker zones being richer in Ni and Co. Commonly occurs as isolated cube or octahedral crystals but may be associated with chalcopyrite, sphalerite, galena, linnaeite, siegenite, tetrahedrite, maucherite, safflorite, bismuth, niccolite.
Breithauptite NiSb Hexagonal	C—Pink with violet tint → Niccolite, darker, violet tint B/P—Strong, pinkish to pinkish violet A—Very strong, bluish green, bluish gray, violet red IR—Not present	R—48.0–37.8 52.3–43.0 QC—0.326, 0.320 49.6 0.325, 0.310 40.3	VHN—412–584 PH < niccolite, rammelsbergite, safflorite	Occurs as subhedral to euhedral grains, often with zonal structure. Occurs with niccolite, silver, safflorite, galena, chromite, pentlandite, pyrrhotite, Ag-sulfosalts. Color and very strong anisotropism are diagnostic; only similar mineral is

(*Continued*)

TABLE A1.2 (*Continued*)

Note: Information is reported as follows:

Name Formula Crystal System	C—Color B/P—Bireflectance/pleochroism A—Anisotropy IR—Internal Reflections	R—Reflectance at 546 and 589 nm in Air QC—Quantitative Color Coordinates	VHN—Vickers Microhardness at 100g Load PH—Polishing Hardness	Mode of Occurrence; Other Characteristic Properties
				niccolite. Violarite appears similar but does not show the zonal texture.
Carrollite $CuCo_2S_4$ Cubic	C—Creamy white, sometimes with a slight pinkish tint B/P—Not present A—Not present IR—Not present	R—42.95 43.4 QC—0.314, 0.320 43.1	PH > chalcopyrite PH < pyrite	Occurs as anhedral granular masses to subhedral and euhedral octahedra. Usually associated with copper minerals, chalcopyrite, bornite, chalcocite, digenite, cobalt-pyrite, pyrrhotite, siegenite.
Cassiterite SnO_2 Tetragonal	C—Brownish gray → Stannite, wolframite, ilmenite, rutile, magnetite, brownish gray B/P—Distinct, gray to brownish gray A—Distinct, gray; in oil, masked by internal reflections IR—Abundant, yellow to yellow-brown	R—10.7–12.15 10.6–12.0 QC—0.305, 0.311 10.7 0.306, 0.312 12.1	VHN—1168–1332(p) PH very high PH < pyrite	Occurs as compact anhedral masses and as subhedral to euhedral crystals that are often well zoned. Commonly twinned; cleavage may be visible. Occurs with pyrite, arsenopyrite, stannite, wolframite, sphalerite, galena, rutile, hematite, magnetite, bismuth, bismuthinite, pyrrhotite. Resembles sphalerite but is

				anisotropic and usually exhibits lighter internal reflections.
Chalcocite Cu_2S Orthorhombic	C—Bluish white → Galena, pyrite, bornite, copper, bluish gray to bluish white → Covellite, white B/P—Very weak A—Weak to distinct, emerald green to light pinkish IR—Not present	R—33.2–33.45 31.5–32.2 QC—(a) 0.296, 0.304 33.2 (b) 0.295, 0.304 33.1 (c) 0.295, 0.303 32.9	VHN—84–87(p) on (001) PH > acanthite PH ~ digenite PH < bornite	Occurs as anhedral polycrystalline aggregates and vein fillings with iron and copper-iron sulfides such as pyrite, chalcopyrite, bornite, digenite. Also associated with enargite, tetrahedrite-tennantite, sphalerite, galena, stannite. Often in exsolution intergrowth with bornite or low-temperature copper sulfides. Often appears isotropic, especially in supergene fine-grained aggregates.
Chalcophanite (Zn,Fe,Mn) $Mn_2O_5 \cdot nH_2O$ Trigonal	C, B/P—Very strong and characteristic bireflectance especially in oil, white to gray A—Very strong, white to gray IR—Absent except when Zn-rich which have deep red internal reflections	R—9.1–27.0 8.8–25.2 QC—0.301, 0.306 9.0 0.286, 0.291 26.8	VHN—188–253(f) // cleavage	Occurs as aggregates of tabular and radiating crystals and as colloform bands in secondary Mn-ores. Perfect basal cleavage usually visible in crystals. Common as vein filling in other Mn-oxides such as psilomelane, pyrolusite, hausmannite.

(*Continued*)

TABLE A1.2 ***(Continued)***

Note: Information is reported as follows:

Name Formula Crystal System	C—Color B/P—Bireflectance/ pleochroism A—Anisotropy IR—Internal Reflections	R—Reflectance at 546 and 589 nm in Air QC—Quantitative Color Coordinates	VHN—Vickers Micro-hardness at 100g Load PH—Polishing Hardness	Mode of Occurrence; Other Characteristic Properties
Chalcopyrite $CuFeS_2$ Tetragonal	C—Yellow to brassy yellow → Pyrite, more yellow → Gold, distinct greenish tint B/P—Weak A—Weak, but distinct, gray-blue to yellow-green IR—Not present	R—44.6–45.0 46.5–47.2 QC—0.349, 0.369 44.1 0.348, 0.366 45.1	VHN—187–203 (basal section) 181–192 (vertical section) PH ~ galena PH < sphalerite	Occurs as medium- to coarse-grained anhedral aggregates; rarely as well-developed tetrahedra. Commonly twinned; often contains laths of cubanite, "stars" of sphalerite, or "worms" of pyrrhotite or mackinawite. Basket weave exsolution with bornite common. Associated with pyrite, pyrrhotite, bornite, digenite, cubanite, sphalerite, galena, magnetite, pentlandite, tetrahedrite, and many other minerals. Often alters along cracks and grain boundaries to covellite.
Chalcostibite $CuSbS_2$ Orthorhombic	C—White, with pinkish gray tint → Silver, galena, grayish	R—37.8–43.7 35.7–40.2 QC—(a) 0.299, 0.312	VHN—283–309(sf) PH > silver PH < chalcopyrite,	Occurs as anhedral grains; rarely as euhedral prismatic crystals. Cleavage (001) and triangular pits may be vis-

	→ Sphalerite, pinkish B/P—Distinct in oil, creamy to brown A—Distinct; pinkish to greenish or bluish gray IR—Rare, pale red	37.2 (b) 0.298, 0.313 40.3 (c) 0.294, 0.309 42.8	sphalerite	ible. May be intergrown with enargite; occurs with pyrite, sphalerite, chalcopyrite, silver, galena, chalcocite, covellite, jamesonite, arsenopyrite, tetrahedrite, cinnabar.
Chromite $(Fe,Mg)(Cr,Al)_2O_4$ Cubic	C—Dark gray to brownish gray → Magnetite, sphalerite, darker → Ilmenite, less brown-red B/P—Not present A—Usually absent but many show weak anisotropism IR—Common, red brown; absent in Fe-rich samples	R—13.5 13.3 QC—0.305, 0.311 13.5	VHN—1278–1456(p-sf) PH > magnetite PH < hematite	Usually occurs as subhedral (rounded) to euhedral crystals or coarsely crystalline aggregates; cataclastic effects common. Zonal textures with lighter (Fe-enriched) rims very common. "Exsolution" of hematite, ilmenite, magnetite, rutile, ulvöspinel uncommon but observed. Associated with magnetite, ilmenite, platinum, pentlandite, pyrrhotite, millerite.
Cinnabar HgS Trigonal	C—White with bluish gray tint → Galena, darker, bluish B/P—Distinct in oil A—Distinct; in oil often masked by internal reflections IR—Intense and abundant, red	R—24.7–29.7 23.9–28.3 QC—0.298, 0.303 24.6 0.296, 0.305 29.4	VHN—82–156 (at 10g) PH > antimony PH < galena, pyrite	Occurs as subhedral to euhedral crystals and as polycrystalline aggregates of euhedral grains. Associated with metacinnabar (an isotropic polymorph), pyrite, marcasite, stibnite, chalcopyrite, tetrahedrite, bornite, gold, realgar, orpiment, galena, enargite, cassiterite.

(Continued)

TABLE A1.2 (*Continued*)

Note: Information is reported as follows:

Name Formula Crystal System	C—Color B/P—Bireflectance/ pleochroism A—Anisotropy IR—Internal Reflections	R—Reflectance at 546 and 589 nm in Air QC—Quantitative Color Coordinates	VHN—Vickers Micro-hardness at 100g Load PH—Polishing Hardness	Mode of Occurrence; Other Characteristic Properties
				Resembles proustite and pyrargyrite in polished section.
Cobaltite (Co,Fe)AsS Orthorhombic (Pseudocubic)	C—White with pink or violet tint → Arsenopyrite, pinkish → Pyrite, whiter B/P—Weak, white to pinkish A—Weak to distinct in oil, blue-gray to brown IR—Not present	R—50.6 52.3 QC—0.319, O.323 51.0	VHN—935-1,131 PH > skutterudite, arsenopyrite PH < pyrite	Commonly occurs as euhedral crystals and as polycrystalline aggregates. Twinning, zoning, and cleavage may be visible. Occurs with niccolite, silver, gold chalcopyrite, arsenopyrite, bismuth, uraninite, Ni-Co arsenides. The weak anisotropism will distinguish this from niccolite or breithauptite.
Coffinite $U(SiO_4)_{1-X}OH)_{4x}$ Tetragonal	C—Gray B/P—Very weak A—Very weak to absent IR—Air: rare and weak; oil: pronounced, brownish	R—7.9-8.0 7.8-7.9	VHN—230-302(p) PH ~ pitchblende	Occurs as euhedral tetragonal crystals, as fine aggregates and as colloform bands. Botryoidal encrustations and intergranular films, especially near organic matter, are common.

				Associated with pyrite, sphalerite, uraninite, pitchblende, bismuth, loellingite, rammelsbergite.
Cohenite Fe_3C Orthorhombic	C—Creamy white → Pyrrhotite, lighter creamy → Iron, similar B/P—Weak but distinct A—Weak but distinct IR—Not present		PH > iron	A meteoritic mineral, extremely rare on earth. Occurs as irregular grains with kamacite, schreibersite, graphite, and troilite. Found in meteorites with 6–8 wt %. Ni where it is a residual metastable phase. Twinning common in larger grains.
Columbite-Tantalite $(Fe,Mn)(Ta,Nb)_2O_6$ Orthorhombic	C—Gray-white with brown tint → Magnetite, slightly less brown B/P—Weak A—Distinct, straight extinction IR—Fe-rich, deep red	R—15.3–17.4	VHN—240–1,021	Occurs as euhedral crystals and anhedral aggregates. May be zoned and cleavage //(100) may be visible. May contain inclusions of cassiterite, galena, hematite, ilmenite, rutile, uraninite, wolframite, and be contained within cassiterite. Occurs as oriented intergrowths with uraninite.
Copper Cu Cubic	C—Pink, but tarnishes brownish → Silver, pink B/P—Weak A—Isotroic but fine	R—64.6 92.2 QC—0.366, 0.344 74.4	VHN—79–99(p) PH > chalcocite PH < cuprite	Occurs as coarse- to fine-grained aggregates; occasionally as dendritic or spear-like crystals. Lamellar twinning visible if etched.

(*Continued*)

TABLE A1.2 (*Continued*)

Note: Information is reported as follows:

Name Formula Crystal System	C—Color B/P—Bireflectance/ pleochroism A—Anisotropy IR—Internal Reflections	R—Reflectance at 546 and 589 nm in Air QC—Quantitative Color Coordinates	VHN—Vickers Micro-hardness at 100g Load PH—Polishing Hardness	Mode of Occurrence; Other Characteristic Properties
	scratches will appear anisotroic IR—Not present			Zoning due to Ag or As not uncommon. Occurs with cuprite, chalcocite, enargite, bornite, pyrrhotite, iron, magnetite.
Cosalite $Pb_2Bi_2S_5$ Orthorhombic	C—White with pink or gray tint → Galena, yellowish to green tint B/P—Weak to distinct A—Weak to moderate; pinkish yellow, bluish, violet gray IR—Not present	R—41.4–45.7 40.65–45.3 QC—0.301, 0.305 41.4 0.304, 0.308 45.9	VHN—74–161 PH > galena	Occurs as granular masses, bundles of subhedral, elongated laths, and fibrous crystals. Twinning absent. Occurs with other Bi and Sb sulfosalts, pyrite, pyrrhotite, chalcopyrite, gold, bismuth, sphalerite, arsenopyrite, tetrahedrite, wolframite, glaucodot.
Covellite CuS Hexagonal	C—Indigo blue with violet tint to bluish white in air B/P—Purple to violet-red, to blue-gray in oil A—Extreme, red-orange to brownish IR—Not present	R—6.6–23.7 4.0–21.0 QC—0.222, 0.221 6.5 0.280, 0.283 23.6	VHN—128–138(sf) PH < chalcopyrite	Occurs as subhedral to anhedral masses, as laths, and as platelike crystals. The brilliant blue color, and strong pleochroism and anisotropism are unmistakable, even when present as the tiny alteration laths commonly seen on copper

				and iron sulfides, such as pyrite, chalcopyrite, bornite; also with enargite, digenite, tennantite, sphalerite. Blaubleibender (blue-remaining) covellite is similar, except that it remains blue in oil; occurs infrequently with covellite.
Cubanite $CuFe_2S_3$ Orthorhombic	C—Creamy gray to yellowish brown → Pyrrhotite, more yellow, less pink → Chalcopyrite, more gray-brown B/P—Distinct, grayish to brownish A—Strong brownish to blue IR—Not present	R—35.4–39.4 37.65–40.7 QC—0.341–0.349 35.5 0.331, 0.341 39.4	VHN—247–287(sf) PH > chalcopyrite PH < pyrrhotite	Occurs most commonly as sharply bounded laths within coarse-grained chalcopyrite; also as irregular granular aggregates. Recognized by its distinct bireflectance and anisotropism. Also occurs with pyrrhotite, sphalerite, galena, mackinawite, pentlandite, magnetite, arsenopyrite.
Cuprite Cu_2O Cubic	C—Air: light bluish gray; oil: darker, more blue → Chalcopyrite, hematite, darker and greenish B/P—Very weak A—Strong anomalous	R—26.6 24.6 QC—0.287, 0.300 26.3	VHN—193–207(sf) PH > chalcopyrite, copper, tenorite	Occurs as euhedral octahedra and in a fine-grained "earthy" form. Replaces copper sulfides and copper. Also occurs with goethite, tenorite, delafossite, pyrite, marcasite.

(*Continued*)

TABLE A1.2 (*Continued*)

Note: Information is reported as follows:

Name Formula Crystal System	C—Color B/P—Bireflectance/ pleochroism A—Anisotropy IR—Internal Reflections	R—Reflectance at 546 and 589 nm in Air QC—Quantitative Color Coordinates	VHN—Vickers Micro-hardness at 100g Load PH—Polishing Hardness	Mode of Occurrence; Other Characteristic Properties
	anisotropism gray-blue to olive-green IR—Deep red, characteristic			
Delafossite $CuFeO_2$ Trigonal	C, B/P—Distinct bireflectance; air: yellow-rose-brown to rose-brown; oil: pinkish gray to brown-gray → Enargite, tenorite, more yellow A—Distinct to strong, bluish gray, straight extinction IR—Not present	R—22.1–18.4 22.0–18.5 QC—0.312, 0.319 22.0 0.311, 0.316 18.5	VHN—412–488 PH < cuprite, goethite	Occurs as masses of sub-parallel crystals and sheaf-like bundles or as fine inclusions in goethite. Concentric and botryoidal textures common. Occurs with goethite, limonite, cuprite, tenorite, copper, pyrite, bornite, chalcocite, covellite, galena, tennantite.
Digenite Cu_9S_5 Cubic	C—Grayish blue → Galena, bornite, blue → Chalcocite, darker blue B/P—Not present A—Isotropic; some-times with weak	R—21.9 19.3 QC—0.277, 0.288	VHN—86–106 PH ~ chalcocite, galena	Occurs as irregular aggregates of anhedral grains that con-tain lamellar intergrowths with other copper sulfides or bornite. Also with chalcopyrite, pyrite, tetrahedrite, enargite; alters to covellite.

	anomalous anisotropism IR—Not present			
Dyscrasite Ag_3Sb Orthorhombic	C—White → Galena, creamy white → Silver, slightly grayer → Antimony, slightly creamy B/P—Weak, white to creamy white A—Weak to distinct IR—Not present	R—60.1–62.8 59.7–63.0 QC—0.311, 0.319 59.9 0.313, 0.321 62.7	VHN—153–179(p) PH > galena, silver PH < chalcopyrite	Occurs as euhedral platelike to square crystals and as aggregates of anhedral crystals with arsenic, galena, cobaltite, pyrite. (The "dyscrasite" of Cobalt, Ontario, is actually allargentum.)
Enargite Cu_3AsS_4 Orthorhombic	C—Pinkish gray to pinkish brown in air; darker in oil → Bornite, pinkish white → Chalcocite, galena, pinkish to grayish brown B/P—Distinct in oil: (//a) grayish pink (//b) pinkish gray (//c) grayish violet A—Strong, blue, green, red, orange IR—Deep red may occur	R—24.2–25.2 23.8–25.7 QC—0.303, 0.307 24.4 0.312, 0.314 25.5	VHN—285–327 PH > galena, chalcocite, bornite PH ~ tennantite PH < sphalerite	Occurs as anhedral to subhedral grains. Cleavage (110) often seen and usually untwinned. Occurs with pyrite, chalcopyrite, bornite, sphalerite, tennantite, galena, chalcocite, covellite, arsenopyrite.

(*Continued*)

TABLE A1.2 (*Continued*)

Note: Information is reported as follows:

Name Formula Crystal System	C—Color B/P—Bireflectance/ pleochroism A—Anisotropy IR—Internal Reflections	R—Reflectance at 546 and 589 nm in Air QC—Quantitative Color Coordinates	VHN—Vickers Micro-hardness at 100g Load PH—Polishing Hardness	Mode of Occurrence; Other Characteristic Properties
Famatinite Cu_3SbS_4 Tetragonal	C—Pale pinkish orange → Enargite, lighter B/P—Distinct to strong in oil, orange-brown to grayish violet A—Very strong, brown to gray-green IR—Not present	R—24–27.4	VHN—205–397 PH > bornite, chalcopyrite PH ~ enargite PH < sphalerite	Occurs as anhedral to euhedral grains. Polysynthetic twinning nearly always visible, and star-shaped patterns may occur. Occurs with enargite, chalcopyrite, tetrahedrite, bornite, sphalerite, chalcocite, pyrite, galena, proustite, pyrargyrite.
Freibergite Ag-tetrahedrite Cubic	C—Gray, faint yellow-brown tint in oil → Proustite, brownish → Galena, grayish brown → Sphalerite, lighter B/P—Not present A—Isotropic IR—Brownish red when visible	R—33.0 31.9 QC—0.303, 0.313 32.5	VHN—263–340 PH > Ag-sulfosalts PH < galena, sphalerite	Occurs as irregular masses and inclusions of anhedral crystals with, and in, chalcopyrite, bornite, argentite, proustite, galena, silver, Co-Fe-Ni arsenides, enargite.
Galena PbS Cubic	C—White, sometimes with pink tint → Sphalerite, white	R—42.9 42.1	VHN—59–65(p) PH > proustite	Occurs as anhedral masses to euhedral cubes. The perfect (100) cleavage usually vis-

	→ Tennantite, pinkish B/P—Not present A—Isotroic but weak anomalous aniso-tropism may be visible IR—Not present	QC—0.301, 0.304 43.0	PH ~ chalcopyrite PH < tetrahedrite	ible and seen as triangular pits. Very common and occurs with wide variety of common minerals. Often contains inclusions of tetrahedrite, Pb-Bi or Pb-Sb sulfosalts, silver, chalco-pyrite, sphalerite. May occur as inclusions in chalco-pyrite, sphalerite.
Gersdorffite (II) NiAsS Cubic	C—White with yellow or pink tint → Skutterudite, more yellow → Linnaeite, less pink → Niccolite, bluish B/P—Not present A—Isotropic; some anomalous anisotropism IR—Not present	R—54.7 54.9 QC—0.312, 0.318 54.7	VHN—844–935(p-sf) PH > linnaeite PH ~ loellingite PH < pyrite	Occurs as euhedral crystals that may show zonal growth. Cleavage (100) common. Occurs with pyrite, chalco-pyrite, silver, niccolite, skutterudite, bismuth, cobaltite, bornite, uraninite. Sometimes as pseudo-eutectic intergrowths with niccolite, maucherite, pyrrhotite, chalcopyrite.
Glaucodcot (Co,Fe)AsS Orthorhombic	C—White to light cream → Arsenopyrite, more bluish white B/P—Weak, weaker than arsenopyrite A—Distinct, less than for arsenopyrite IR—Not present	R—50.0–50.6 50.4–50.7	VHN—1,097–1,115(sf) PH < arsenopyrite, cobaltite	Usually occurs as subhedral to euhedral crystals, often with inclusions. Associated with cobaltite, pyrite, arseno-pyrite, safflorite, skutterudite, niccolite, galena, rammelsbergite. Polishes very well.

(*Continued*)

TABLE A1.2 (*Continued*)

Note: Information is reported as follows:

Name Formula Crystal System	C—Color B/P—Bireflectance/ pleochroism A—Anisotropy IR—Internal Reflections	R—Reflectance at 546 and 589 nm in Air QC—Quantitative Color Coordinates	VHN—Vickers Micro-hardness at 100g Load PH—Polishing Hardness	Mode of Occurrence; Other Characteristic Properties
Goethite FeO · OH Orthorhombic	C—Gray, with a bluish tint → Sphalerite, more bluish → Hematite, darker → Lepidocrocite, darker B/P—Weak in air; distinct in oil but often masked by internal reflections A—Distinct, gray-blue, gray-yellow, brownish IR—Brownish yellow to reddish brown	R—15.5–17.5 15.0–16.6 QC—0.295, 0.299 15.5 0.291, 0.296 17.5	VHN—667 PH ~ lepidocrocite PH < magnetite, hematite	Common in porous colloform bands with radiating fibrous texture, or as porous pseudomorphs after pyrite. Nearly always secondary, as veins, fracture fillings, or botryoidal coatings. Occurs with hematite, pyrite, lepidocrocite, pyrite, pyrrhotite, manganese-oxides, sphalerite, galena, chalcopyrite. Brownish to yellowish internal reflections help to distinguish from lepidocrocite.
Gold Au Cubic	C—Bright golden yellow → Chalcopyrite, no greenish tint B/P—Not present A—Isotropic but incomplete extinction IR—Not present	R—77.0 88.2 QC—0.386, 0.388 76.1	VHN—53–58(p) PH > galena PH < tetrahedrite, chalcopyrite	Occurs as isolated grains and veinlets in many sulfides, especially pyrite, arseno-pyrite, chalcopyrite. Recognized by its "golden" color and very high reflec-tance; addition of silver to

				form electrum changes color to whitish and increases R%.
Graphite C Hexagonal	C,B/P—Very strong, bireflectance from brownish gray to grayish black → Molybdenite, darker A—Very strong, straw yellow to brown or violet gray IR—Not present	R—26.4–6.2 27.3–6.3 QC—0.320, 0.324 26.6 0.312, 0.316 6.2	VHN—12–16(f) (at 50g) PH < almost all minerals	Occurs as small plates, laths, and bundles of blades. Basal cleavage visible and undulose extinction common. Present as isolated laths in many igneous and metamorphic rocks; also as inclusions in sphalerite, pyrite, magnetite, pyrrhotite. Much more common than molybdenite.
Hausmannite Mn_3O_4 Tetragonal	C—Bluish to brownish gray → Jacobsite, grayer → Bixbyite, darker → Braunite, less brown B/P—Very distinct in oil, bluish gray to brownish gray A—Strong, yellow brown to bluish gray IR—Blood red, especially in oil	R—20.2–16.3 20.0–15.8 QC—0.307, 0.313 20.2 0.300, 0.306 16.2	VHN—437–572(cc-f) PH > manganite, pyrolusite PH < jacobsite PH < bixbyite, braunite	Occurs as coarse-grained equigranular anhedral crystals, often in veinlets. Irregular twinning common. Occurs with other Mn-oxides and alters to pyrolusite and psilomelane.
Hematite α-Fe_2O_3 Hexagonal	C—Gray-white with bluish tint → Ilmenite, magnetite,	R—29.95–26.4 28.9–25.1	VHN—1,000–1,100 PH > magnetite	Usually occurs as bladed or needlelike subparallel or radiating aggregates.

(*Continued*)

TABLE A1.2 (*Continued*)

Name Formula Crystal System	C—Color B/P—Bireflectance/ pleochroism A—Anisotropy IR—Internal Reflections	R—Reflectance at 546 and 589 nm in Air QC—Quantitative Color Coordinates	VHN—Vickers Micro-hardness at 100g Load PH—Polishing Hardness	Mode of Occurrence; Other Characteristic Properties
	white → Pyrite, bluish gray → Goethite, lepidocrocite, white B/P—Weak A—Distinct, gray-blue, gray-yellow IR—Deep red common	QC—0.299, 0.309 29.7 0.297, 0.308 26.1	PH < pyrite	Lamellar twinning common. Also common as exsolution lenses or lamellae in ilmenite or magnetite, or as a host to lamellae of the same. Occurs with magnetite, ilmenite, pyrite, chalcopyrite, bornite, rutile, cassiterite, sphalerite.
Idaite Cu_5FeS_6 → Cu_3FeS_4 Tetragonal	C,B/P—Strong bireflectance from reddish orange or red-brown to yellowish gray A—Extreme, green or gray-green IR—Not present	R—27–33.6	VHN—176–260 PH > covellite	Occurs as hypogene tabular crystals that occur with covellite, pyrite, or bornite, and as supergene alterations of bornite where it occurs as lamellae and veinlets. Recognized by the orangish color and the strong greenish anisotropism. (A new mineral of composition close to idaite has been named "nukundamite.")

Ilmenite $FeTiO_3$ Trigonal	C—Brownish with a pink or violet tint → Magnetite, darker, brownish B/P—Distinct, pinkish brown, dark brown A—Strong, greenish gray to brownish gray IR—Rare, dark brown	R—19.2–16.4 19.6–17.0 QC—0.310, 0.311 19.5 0.312, 0.309 16.9	VHN—566–698(cc-sf) PH > magnetite PH < hematite	Occurs as subhedral to anhedral grains and as "exsolution" lamellae or lenses in hematite or magnetite. Lamellar twinning common. Common accessory in igneous and metamorphic rocks. Occurs with magnetite, hematite, rutile, pyrite, pyrrhotite, chromite, pentlandite, tantalite.
Iron Fe Cubic α-Fe = Kamacite γ-Fe = Taenite	C—White, slight bluish or yellowish →Pentlandite, much whiter → Cohenite, slightly bluish B/P—Not present A—Isotropic IR—Not present	R—58.1 58.1 QC—0.311, 0.317 58.1	VHN—110–117(p-sg) PH < troilite, magnetite, cohenite	Common as irregular patches and drop-like grains in stony meteorites and as a major phase in iron meteorites; extremely rare on earth. α-Fe contains < ~6% Ni and is slightly bluish; γ-Fe contains ~27–60% Ni and is slightly yellowish. (111) intergrowths of γ-Fe and α-Fe form Widmanstätten structures, which are brought out by etching. Fine exsolution of cohenite occurs in α-Fe. Other associated minerals include troilite, copper, schreibersite, ilmenite,

(*Continued*)

TABLE A1.2 (*Continued*)

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Name Formula Crystal System	C—Color B/P—Bireflectance/ pleochroism A—Anisotropy IR—Internal Reflections	R—Reflectance at 546 and 589 nm in Air QC—Quantitative Color Coordinates	VHN—Vickers Micro-hardness at 100g Load PH—Polishing Hardness	Mode of Occurrence; Other Characteristic Properties
				chromite. Oxidizes to hematite, goethite, lepidocrocite.
Jacobsite $(Mn,Fe,Mg)(Fe,Mn)_2O_4$ Cubic	C—Rose brown to brownish gray → Magnetite, braunite, olive-green → Hausmannite, less gray → Bixbyite, olive-gray B/P—Not present A—Isotropic, sometimes slight anomalous anisotropism IR—Deep red, especially when Mn-rich	R—21.1 21.2 QC—0.314, 0.323 21.0	VHN—720–813(p-sf) PH ~ magnetite PH < braunite	Occurs as anhedral grains and rounded subhedral crystals. Occurs with, and alters to, other Fe-Mn minerals such as goethite, pyrolusite, hematite, and psilomelane.
Jamesonite $Pb_4FeSb_6S_{14}$ Monoclinic	C—White → Galena, similar or slightly greenish → Stibnite, lighter B/P—Strong, white to yellow green	R—36.4–44.2 35.6–43.0 QC—0.304, 0.313 36.2	VHN—66–86(p-sf) PH < galena	Occurs as needle- or lath-like crystals or bundles. Cleavage //long dimension common; often twinned. Occurs with galena, pyrite, pyrargyrite, boulangerite,

	A—Strong, gray, tan, brown, blue IR—Reddish in Bi-jamesonite	0.304, 0.314 43.7		chalcopyrite, sphalerite, tetrahedrite, arsenopyrite.
Kamacite—*See* Iron				
Kobellite $Pb_2(Bi,Sb)_2S_5$ Orthorhombic	C—White → Galena, slightly darker B/P—Distinct, greenish white to violet-gray A—Distinct, gray to gray-brown IR—Not present	R—44.8–47.2 44.0–46.2 QC—0.303, 0.310 44.7 0.303, 0.309 47.1	VHN—100–117(sf) PH > bismuth PH < galena	Occurs as granular to tabular aggregates with well-developed (010) cleavage. Commonly twinned. Occurs with arsenopyrite, pyrite, pyrrhotite, chalcopyrite, bismuth, bismuthinite, and as intergrowths with tetrahedrite.
Lepidocrocite γ-FeO · OH Orthorhombic	C—Grayish white → Goethite, lighter and whiter → Hematite, greenish tint B/P—Weak to distinct A—Strong, gray IR—Reddish, common	R—11.6–18.4 11.1–17.4 QC—0.292, 0.297 11.5 0.291, 0.277 18.3	VHN—402 PH < goethite	Occurs as weathering product of iron oxides and sulfides with (but less commonly than) goethite. Present as crusts, veinlets, and even as porous pseudomorphs.
Linnaeite Co_3S_4 Cubic	C—Creamy white → Skutterudite, grayish white → Ullmannite, gersdorffite, creamy or yellowish B/P—Not present A—Isotropic	R—49.5 49.6	VHN—450–613 PH > chalcopyrite, sphalerite PH < pyrite	Occurs as euhedral crystals and subhedral aggregates. May be intergrown in lamellar pattern with millerite, chalcopyrite, bornite, pyrrhotite, pyrite, bismuth, covellite, safflorite, niccolite.

(*Continued*)

TABLE A1.2 (*Continued*)

Note: Information is reported as follows:

Name Formula Crystal System	C—Color B/P—Bireflectance/ pleochroism A—Anisotropy IR—Internal Reflections	R—Reflectance at 546 and 589 nm in Air QC—Quantitative Color Coordinates	VHN—Vickers Micro- hardness at 100g Load PH—Polishing Hardness	Mode of Occurrence; Other Characteristic Properties
	IR—Not present			
Loellingite $FeAs_2$ Orthorhombic	C—White, with yellowish tint → Arsenopyrite, less yellow → Rammelsbergite, safflorite, similar B/P—Weak but distinct, bluish white to yellowish white A—Very strong, orange-yellow, red-brown, blue, green IR—Not present	R—53.4–55.5 51.5–56.3 QC—0.298, 0.304 53.1 0.315, 0.322 55.5	VHN—859–920(p-sf) PH > chalcopyrite, sphalerite PH < arsenopyrite	Commonly occurs as interlocking to radiating aggregates of euhedral crystals; sometimes as skeletal crystals. Commonly twinned. Usually associated with other arsenides, dyscrasite, arsenic, arsenopyrite, uraninite, antimony, chalcopyrite, galena.
Mackinawite $Fe_{1+X}S$ Tetragonal	C—Pinkish to reddish gray → Pyrrhotite, similar B/P—Moderate to strong, pinkish tray to gray A—Very strong, grayish white, bluish,	R—40.4–16.2 43.0–16.7	VHN—74–181 PH ~ pyrrhotite	Occurs as small wormlike grains and lamellae (more rarely as small plates) in pyrrhotite, chalcopyrite, cubanite, pentlandite. Probably much confused with valleriite, which tends to have a more pronounced

	brownish IR—Not present			orange tint to its anisotropism. Most easily found as "bright" grains under nearly crossed nicols.
Maghemite γ-Fe_2O_3 Cubic	C—Bluish gray → Goethite, gray, lighter → Hematite, bluish gray → Magnetite, bluish B/P—Not present A—Isotropic IR—Rare, brownish red	R—24.4 22.8 QC—0.293, 0.304 24.1	VHN—412(at 50g) PH > magnetite PH < hematite	Forms as a rare oxidation product of magnetite. Irregularly present in oxidizing magnetite as lamellae and porous patches.
Magnetite Fe_3O_4 Cubic	C—Gray, with brownish tint → Hematite, darker brown → Ilmenite, less pink → Sphalerite, lighter B/P—Not present A—Isotropic, slight anomalous anisotropism IR—Not present	R—19.9 20.0 QC—0.310, 0.315 19.9	VHN—681-792(p-sf) PH > pyrrhotite PH < ilmenite, hematite, pyrite	Occurs as euhedral, subhedral, and even skeletal crystals and as anhedral polycrystalline aggregates. Often contains exsolution or oxidation lamellae of hematite; lamellae of ilmenite and ulvöspinel also common. Associated with pyrrhotite, pyrite, pentlandite, chalcopyrite, bornite, sphalerite, galena. Alters to hematite and goethite.
Manganite MnO(OH)	C—Gray to brownish gray	R—14.1-20.5 13.6-19.7	VHN—630-743(cc-f)	Occurs as prismatic to lamellar crystal aggregates

(Continued)

TABLE A1.2 (*Continued*)

Note: Information is reported as follows:

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Monoclinic	→ Pyrolusite, darker gray B/P—Weak, brownish gray A—Strong, yellow, bluish gray, violet-gray IR—Blood red, common	QC—0.303, 0.313 14.0 0.301, 0.311 20.3	PH < hausmannite, jacobsite	often intergrown with pyrolusite and psilomelane. Cleavage on (010) and (110) may be visible. Commonly twinned. Occurs also with hausmannite, braunite, goethite.
Marcasite FeS_2 Orthorhombic	C—Yellowish white with slight pinkish or greenish tint → Pyrite, whiter → Arsenopyrite, greenish yellow B/P—Strong, brownish, yellowish green A—Strong, blue, green-yellow, purple-gray IR—Not present	R—49.1–56.2 49.5–55.0 QC—0.319, 0.329 48.6 0.317, 0.333 55.3	VHN—1,288–1,681(f) PH ~ pyrite	Occurs as subhedral to lamellar intergrowths with pyrite as euhedral crystals. Also occurs as radiating colloform bands. Commonly twinned. Forms as hypogene crystals and as supergene veinlets in pyrrhotite and iron oxides. Often with pyrite but also occurs with most other common sulfides. Blue to yellowish anisotropism is diagnostic.

Maucherite $Ni_{11}As_8$ Tetragonal	C—White → Cobaltite, similar → Loellingite, brownish gray → Breithauptite, bluish gray B/P—Not observed A—Weak to distinct in oil, gray IR—Not present	R—48.4–49.6 50.9–52.0	VHN—623–724(p) PH > chalcopyrite, sphalerite PH < safflorite, loellingite	Commonly occurs as euhedral crystals and anhedral aggregates; may be twinned. May be intergrown with niccolite or gersdorffite. Also occurs with chalcopyrite, cubanite, siegenite.
Mawsonite $Cu_7Fe_2SnS_{10}$ Tetragonal	C—Brownish orange B/P—Strong, orange to brown A—Very strong, straw-yellow to royal blue IR—Not present	R—26.9–29.7 29.1–35.1 QC—0.339, 0.340 27.3 0.373, 0.365 30.4	VHN—166–210 PH > bornite	Occurs as irregular inclusions in, or associated with, bornite. Also associated with chalcopyrite, chalcocite, tetrahedrite, pyrite, galena, enargite, stannite.
Miargyrite $AgSbS_2$ Monoclinic	C—White in air; bluish tint in oil → Galena, darker with green-gray tint → Freibergite, bluish → Pyrargyrite, whiter B/P—Moderate, white, bluish gray A—Strong, blue-gray to brownish but masked by internal reflections IR—Deep red	R—31.6–34.5 30.05–32.8 QC—0.293, 0.302 31.4 0.294, 0.303 34.2	VHN—88–130 PH > pyrargyrite PH < stephanite, galena	Occurs as granular anhedral aggregates (sometimes twinned) with sphalerite, galena, tetrahedrite, pyrargyrite, silver, polybasite, stephanite.

TABLE A1.2 ***(Continued)***

Note: Information is reported as follows:

Name Formula Crystal System	C—Color B/P—Bireflectance/ pleochroism A—Anisotropy IR—Internal Reflections	R—Reflectance at 546 and 589 nm in Air QC—Quantitative Color Coordinates	VHN—Vickers Micro- hardness at 100g Load PH—Polishing Hardness	Mode of Occurrence; Other Characteristic Properties
Millerite NiS Trigonal	C—Yellow → Chalcopyrite, lighter, not greenish → Linnaeite, pentlandite, yellower B/P—Distinct in oil, yellow to blue or violet A—Strong, lemon-yellow to blue or violet IR—Not present	R—50.2–56.6 51.9–59.05 QC—0.328, 0.339 50.4 0.340, 0.354 56.2	VHN—192–376 PH > chalcopyrite PH < pentlandite	Occurs as radiating aggregates and as anhedral granular masses. Also common as oriented intergrowths with linnaeite, violarite, pyrrhotite. Twinning and cleavage (1011) often visible. Usually associated with Ni-bearing sulfides, often as a replacement or alteration phase.
Molybdenite MoS_2 Trigonal	C,B/P—Extreme bireflectance, white to gray with bluish tint → Graphite, lighter A—Very strong, white with pinkish tint; dark blue if polars not completely crossed IR—Not present	R—38.5–19.5 38.8–19.0 QC—0.298, 0.299 39.3	VHN—8–100 32–33(f) // cleavage PH < almost all minerals	Usually occurs as small, often deformed plates and irregular inclusions; more rarely as rosettes or colloform bands. Cleavage (0001); twinning and undulatory extinction very common. Often in veins with pyrite, chalcopyrite, bornite, cassiterite, wolframite, bismuth, bis-

				muthinite, but may occur in many sulfides. Softness, bireflectance, and anisotropism allow confusion only with graphite.
Niccolite (nickeline) NiAs Hexagonal	C,B/P—Strong bireflectance, yellowish pink to brownish pink → Maucherite, skutterudite, bismuth, arsenic, more pink → Breithauptite, pinkish yellow A—Very strong, yellow, greenish violet-blue, blue-gray IR—Not present	R—51.4–46.1 55.7–52.3 QC—0.335, 0.334 52.4 0.346, 0.341 47.7	VHN—363-372 PH > chalcopyrite PH ~ breithauptite PH < skutterudite, pyrite	Occurs as isolated subhedral and euhedral crystals, as anhedral aggregates, as concentric bands, and as complex intergrowths (with pyrrhotite, chalcopyrite, maucherite). Commonly intergrown with arsenides. Often twinned and in radial aggregates.
Orpiment As_2S_3 Monoclinic	C—Gray → Realgar, slightly lighter → Sphalerite, lighter B/P—strong Air: (//a) white; (//b) dull gray, reddish; (//c) dull gray-white; oil: (//a) gray-white; (//b) dark gray; (//c) gray-white	R—23.0–27.5 22.1–26.7 QC—0.294, 0.296 27.6 0.290, 0.292 23.1	VHN—22-58 PH > realgar	Occurs as tabular interlocking anhedral masses and as needle- or lath-like crystals. Often formed on realgar; also with stibnite, arsenopyrite, arsenic, pyrite, enargite, sphalerite, loellingite.

(Continued)

TABLE A1.2 (*Continued*)

Note: Information is reported as follows:

Name Formula Crystal System	C—Color B/P—Bireflectance/ pleochroism A—Anisotropy IR—Internal Reflections	R—Reflectance at 546 and 589 nm in Air QC—Quantitative Color Coordinates	VHN—Vickers Micro- hardness at 100g Load PH—Polishing Hardness	Mode of Occurrence; Other Characteristic Properties
	A—Strong; in oil masked by internal reflections IR—Abundant and intense; white to yellow			
Pararammelsbergite $NiAs_2$ Orthorhombic	C—Whiter than associated Co-Ni-Fe arsenides B/P—Very weak to distinct; yellowish to bluish white A—Strong, but less than rammelsbergite and without blue IR—Not present	R—58.9–59.7 58.6–60.5 QC—0.310, 0.318 58.8 0.314, 0.319 59.9	VHN—681–830(p-sf) PH > niccolite PH < skutterudite	Occurs as tabular crystals with rectangular outlines and as mosaics of intergrown crystals. May be zoned but rarely twinned. Occurs with rammelsbergite, niccolite, skutterudite, gersdorffite, cobaltite, silver, pyrite, proustite.
Pearcite $Ag_{16}As_2S_{11}$ Monoclinic	C—Gray → Pyrargyrite, darker brownish → Tetrahedrite, similar B/P—Air: weak; oil: distinct, green to gray	R—29.1–32.2 29.0–31.4 QC—0.301, 0.303 29.4	VHN—180–192(sf) PH > argentite PH ~ pyrargyrite PH < stephanite	Forms complete solid solution with polybasite. Occurs as platelike to equant grains with (or in) galena, tetrahedrite, sphalerite, pyrite. Untwinned. Other

	with violet tint A—Air: moderate; oil: strong, blue, gray, yellow-green, brown IR—Deep red, abundant	0.303, 0.310 32.0		associates include stephanite, pyrargyrite, stromeyerite, argentite, chalcopyrite. May be light etched.
Pentlandite $(Fe,Ni)_9S_8$ Cubic	C—Light creamy to yellowish → Pyrrhotite, lighter → Linnaeite, darker, not pinkish B/P—Not visible A—Isotropic IR—Not present	R—46.5 49.0 QC—0.332, 0.339 46.9	VHN—268–285(sf) PH > chalcopyrite PH < pyrrhotite	Generally occurs as granular veinlets or as "flames" or lamellae in pyrrhotite; less commonly in chalcopyrite. Other associated minerals include magnetite, pyrite, cubanite, mackinawite. Alters to violarite and millerite along cracks and grain boundaries.
Platinum Pt Cubic	C—White B/P—Not observed A—Isotropic but incomplete extinction IR—Not present	R—69.7 71.0 QC—0.318, 0.326 69.8	VHN—297–339(cc-sf) PH > sphalerite PH < pyrrhotite	Occurs as isolated euhedral to subhedral crystals; sometimes zones or with exsolution laths of iridium and osmium. Small grains of other platinum minerals may be present. Chromite, pyrrhotite, magnetite, pentlandite, chalcopyrite may be associated.
Polybasite $Ag_{16}Sb_2S_{11}$	C—Gray → Galena, darker	R—30.7–32.5 30.0–31.4	VHN—108–141	Forms complete solid solution with pearcite. (See remarks

(*Continued*)

TABLE A1.2 (*Continued*)

Note: Information is reported as follows:

Name Formula Crystal System	C—Color B/P—Bireflectance/ pleochroism A—Anisotropy IR—Internal Reflections	R—Reflectance at 546 and 589 nm in Air QC—Quantitative Color Coordinates	VHN—Vickers Micro-hardness at 100g Load PH—Polishing Hardness	Mode of Occurrence; Other Characteristic Properties
Monoclinic	→ Pyrargyrite, darker brownish → Tetrahedrite, similar B/P—Air: weak; oil: distinct, greey to gray with violet tint A—Air: moderate; oil: strong, blue gray, yellow-green, brown IR—Deep red, abundant	QC—0.300, 0.308 30.6 0.302, 0.314 32.2	PH > argentite PH ~ pyrargyrite PH < stephanite	for pearcite; polybasite occurrences are similar but are more likely in Sb-rich environments.)
Proustite Ag_3AsS_3 Trigonal	C—Bluish gray → Pyrargyrite, darker B/P—Distinct, yellowish, bluish gray A—Strong, masked by internal reflection IR—Always, scarlet red	R—24.2–27.7 23.1–26.3 QC—0.287, 0.288 24.2 0.289, 0.292 27.7	VHN—70–105(p-sf) (at 25g) PH ~ pyrargyrite	Forms complete solid solutions with pyrargyrite. Same characteristics as pyrargyrite except found in more As-rich environments.
Psilomelane General name for	C—Bluish gray to grayish white	R—15–30	VHN—203–813	Commonly occurs as botryoidal masses of very

massive, hard manganese oxides	→ Pyrolusite, darker → Braunite, manganite, jacobsite, hausmannite, bixbyite, lighter B/P—Strong, white to bluish gray A—Strong, white to gray IR—Occasional, brown			fine acicular crystals in concentric layers; often intergrown with pyrolusite and cryptomelane. Associated with other Mn-oxides.
Pyrargyrite Ag_3SbS_3 Trigonal	C—Bluish gray → Proustite, slightly lighter → Galena, grayish blue B/P—Distinct to strong A—Strong, gray to dark gray; in oil, masked by internal reflections IR—Intense red	R—30.3–28.5 28.4–26.5 QC—0.287, 0.295 30.2 0.289, 0.289 27.7	VHN—107–144 (at 50g) 66–87 (// cleavage) PH > polybasite PH < galena	Forms complete solution with proustite. Occurs as irregular grains and aggregates. May be twinned and zoned. Often with galena, Sb-sulfosalts, pyrite, sphalerite, chalcopyrite, tetrahedrite, arsenopyrite, Ni-Co-Fe arsenides.
Pyrite FeS_2 Cubic	C—Yellowish white → Marcasite, yellower → Arsenopyrite, creamy yellow → Chalcopyrite, lighter B/P—Not present A—Often weakly anisotropic, blue-green to orange-red IR—Not present	R—51.7 53.5 QC—0.327, 0.335 51.7	VHN—1,505–1,620(f) PH > arsenopyrite, marcasite PH < cassiterite	The most abundant sulfide; occurs as euhedral cubes and pyritohedra, anhedral crystalline masses, and colloform bands of very fine grains. Growth zoning, twinning, and anisotropy of hardness may be visible. Occurs in nearly all ore types and with most common minerals. Hardness,

(*Continued*)

TABLE A1.2 (*Continued*)

Note: Information is reported as follows:

Name Formula Crystal System	C—Color B/P—Bireflectance/ pleochroism A—Anisotropy IR—Internal Reflections	R—Reflectance at 546 and 589 nm in Air QC—Quantitative Color Coordinates	VHN—Vickers Micro-hardness at 100g Load PH—Polishing Hardness	Mode of Occurrence; Other Characteristic Properties
				yellowish white color and abundance usually diagnostic.
Pyrolusite MnO_2 Tetragonal	C—Creamy white → Magnetite, hematite, yellowish → Manganite, white B/P—Distinct in oil, yellowish white to gray-white A—Very strong, yellowish, brownish, blue IR—Not present	R—29.0–40.0 28.1–39.3	VHN—146–243(f) PH—Very variable depending on grain size and orientation	Occurs as coarse-grained tabular crystals or as banded aggregates. Cleavage (110) and twinning may occur. Very fine-grained material may be intergrown with psilomelane, hematite, Fe-hydroxides. Also associated with manganite, braunite, magnetite, bixbyite.
Pyrrhotite $Fe_{1-X}S$ Hexagonal ($\sim Fe_9S_{10}$) Monoclinic ($\sim Fe_7S_8$) FeS is troilite	C—Creamy pinkish brown → Pentlandite, darker → Cubanite, more pinkish B/P—Very distinct, creamy brown to reddish brown	R—36.3–40.1 Hex 38.6–42.0 36.3–41.4 Mono 38.6–43.4	VHN—Hex: 230–259(p) (anisotropic sections) 280–318(p) (isotropic sections) Mono: 373–409(p)	Usually occurs as anhedral granular masses. Not infrequently twinned, especially where stressed. Lamellar exsolution intergrowths of hexagonal and monoclinic forms are common; weathering of hexagonal pyrrhotite yields a rim of

	A—Very strong, yellow-gray, grayish blue IR—Not present		PH > chalcopyrite PH ~ pentlandite PH < pyrite	monoclinic pyrrhotite (usually slightly lighter in color). In Ni-ores, exsolved lamellae and "flames" of pentlandite are common. Also often contains mackinawite lamellae. Occurs with most other common sulfides. Troilite occurs in meteorites usually as anhedral, equigranular masses with iron.
Rammelsbergite $NiAs_2$ Orthorhombic	C—White, more so than other Ni-Co-Fe arsenides B/P—Very weak in air; distinct in oil, yellowish to bluish A—Strong, pinkish, brownish, greenish, bluish IR—Not present	R—56.8–60.9 56.9–60.7 QC—0.311, 0.317 56.8 0.309, 0.316 60.7	VHN—630–758(p) PH ~ skutterudite, PH < safflorite, loellingite	Occurs as fine-grained aggregates of interlocking crystals; often in zonal, spherulitic, radiating, and fibrous textures. Commonly with simple or complex twinning. May be intergrown with niccolite and Co-Ni-Fe arsenides; sometimes overgrowths on dendrites of silver or bismuth. Very similar to safflorite.
Realgar AsS Monoclinic	C—Dull gray → Orpiment, slightly darker → Sphalerite, similar → Cinnabar, darker B/P—Weak but distinct; gray with reddish to bluish tint	R—22.1 20.9 QC—0.288, 0.294 22.1	VHN—47–60 PH < orpiment	Occurs as irregular platelike masses with orpiment. Also associated with stibnite, arsenopyrite, pyrite, arsenic, As-sulfosalts, tennantite, enargite, proustite.

(*Continued*)

TABLE A1.2 (*Continued*)

Note: Information is reported as follows:

Name Formula Crystal System	C—Color B/P—Bireflectance/ pleochroism A—Anisotropy IR—Internal Reflections	R—Reflectance at 546 and 589 nm in Air QC—Quantitative Color Coordinates	VHN—Vickers Micro-hardness at 100g Load PH—Polishing Hardness	Mode of Occurrence; Other Characteristic Properties
	A—Strong; in oil masked by internal reflections IR—Abundant and intense; yellowish red			
Rutile TiO_2 Tetragonal	C—Gray, faint bluish tint → Magnetite, chromite, similar → Ilmenite, no brownish tint → Cassiterite, lighter B/P—Distinct A—Strong but masked by internal reflections IR—Strong, abundant, white, yellowish, reddish brown	R—19.7–23.1 19.2–22.6 QC—0.298, 0.303 19.7 0.301, 0.306 23.0	VHN—894–974(p-sf) PH > ilmenite PH < hematite	Occurs as euhedral to subhedral needlelike to columnar crystals; frequently with hematite. Associated with Ti-hematite, Ti-magnetite, ilmenite, tantalite. Common in hydrothermally altered rocks.
Safflorite $(Co,Fe,Ni)\ As_2$ Orthorhombic	C—White with a bluish tint → Bismuth, bluish → Silver, grayish white	R—54.1–54.6 53.8–53.5 QC—0.310, 0.317	VHN—792–882(p-sf) PH > skutterudite PH < loellingite	Occurs as radiating masses of anhedral to subhedral crystals in concentric layers with other arsenide

	B/P—Very weak, bluish to gray A—Strong IR—Not present	53.9 0.304, 0.311 54.3		minerals. Also present as euhedral crystals and as starlike triplets. Commonly twinned.
Scheelite $CaWOs_4$	C—Gray-white; darker in oil → Gangue, similar in air; lighter in oil B/P—Not observed A—Distinct but masked by internal reflections IR—Common, white	R—9.8–10.1 9.7–10.0 QC—0.305, 0.309 9.8 0.305, 0.310 10.2	VHN—383–464(f) PH < wolframite	Occurs as equant to lath-like polycrystalline aggregates, often as a partial replacement of wolframite. Also intergrown with Fe-oxides, huebnerite, ferberite, cassiterite. Fluoresces pale blue to yellow under ultraviolet light.
Schreibersite $(Fe,Ni)_3P$ Tetragonal	C—White in air; with brownish pint tint in oil → Cohenite, lighter → Iron, similar B/P—In oil distinct, pinkish brown to yellowish A—Weak but distinct in oil IR—Not present		VHN—~ 125 PH > cohenite PH ~ iron	Occurs as oriented needle- and tablet-like inclusions in iron in meteorites.
Siegenite $(Co,Ni)_3S_4$ Cubic	C—Creamy white with slight pink tinge → Cattierite, less pinkish B/P—Not present A—Isotroic IR—Not present	R—46.7 48.5 QC—0.320, 0.324 47.3	VHN—459–548(p-sf) PH ~ linnaeite	Occurs as euhedral and subhedral crystals and anhedral polycrystalline aggregates. Associated with Cu- and Cu-Fe sulfides, pyrite, vaesite, cattierite, uraninite.

(Continued)

TABLE A1.2 ***(Continued)***

Note: Information is reported as follows:

Name Formula Crystal System	C—Color B/P—Bireflectance/ pleochroism A—Anisotropy IR—Internal Reflections	R—Reflectance at 546 and 589 nm in Air QC—Quantitative Color Coordinates	VHN—Vickers Micro-hardness at 100g Load PH—Polishing Hardness	Mode of Occurrence; Other Characteristic Properties
Silver Ag Cubic	C—Bright white with creamy tint; tarnishes rapidly → Antimony, arsenic, brighter and creamy B/P—Not present A—Isotropic; fine scratches often look anisotropic IR—Not present	R—93.3 93.9 QC—0.316, 0.324 92.9	VHN—60–65 PH > proustite, galena PH < tetrahedrite	Occurs as irregular masses, veinlets, and inclusions, and as dendrites within arsenides. Incomplete extinction, tarnishes rapidly. Lamellar intergrowths with allargentum. Also with Ag-sulfosalts, Bi, argentite, galena, Cu-sulfides, Co-Fe-Ni arsenides.
Skutterudite $(Co,Ni)As_{2\text{-}3}$ Cubic	C—Cream-white to grayish white, often in zones → Cobaltite, white → Safflorite, yellowish B/P—Not present A—Isotropic; sometimes anomalous weak anisotropism IR—Not present	R—55.2 54.6 QC—0.307, 0.314 55.1	VHN—606–824(f) PH ~ safflorite PH > linnaeite PH < arsenopyrite, pyrite	Commonly and characteristically occurs as radial blade-like crystals with well-developed growth zoning. Also as euhedral single crystals. May be intergrown with niccolite, bismuth, other Co-Fe-Ni arsenides; often present in Ag-Bi-U mineralization.
Sphalerite (Zn,Fe)S Cubic	C-Gray, sometimes with brown tint → Magnetite, darker	R—16.6 16.3	VHN—138–160(cc-sf) PH > chalcopyrite,	Very common in many ore types. Occurs as irregular anhedral masses with pyrite,

	B/P—Not present A—Isotropic; sometimes weak anomalous anisotropism IR—Common, yellow-brown to reddish brown	QC—0.301, 0.306 16.6	tetrahedrite PH < pyrrhotite, magnetite	galena, chalcopyrite, pyrrhotite. Polishes well and is often featureless except for internal reflections. Also commonly contains rows of (or randomly dispersed) inclusions of chalcopyrite, pyrrhotite, galena, and less commonly, stannite. Common growth zoning of light and dark bands only visible in polished thin sections. Closely resembles magnetite except for internal reflections and absence of cleavage.
Stannite Cu_2FeSnS_4 Tetragonal	C—Brownish olive-green → Tetrahedrite, darker brownish gray → Sphalerite, lighter, yellow-brown to olive-green B/P—Distinct, light brown to brown-olive-gray A—Moderate, yellow-brown, olive-green, violet-gray IR—Not present	R—27.3–26.0 27.3–26.1 QC—0.316, 0.326 27.1 0.321, 0.333 25.8	VHN—140–326 PH > chalcopyrite PH ~ tetrahedrite PH < sphalerite	Occurs as anhedral grains, granular aggregates, and as oriented intergrowths with sphalerite, chalcopyrite, and tetrahedrite. Cleavage may be visible; compound twinning, sometimes in microline pattern, common. In many ore types, as a minor phase, but common with bismuth and tungsten minerals.

(*Continued*)

TABLE A1.2 (*Continued*)

Note: Information is reported as follows:

Name Formula Crystal System	C—Color B/P—Bireflectance/ pleochroism A—Anisotropy IR—Internal Reflections	R—Reflectance at 546 and 589 nm in Air QC—Quantitative Color Coordinates	VHN—Vickers Micro-hardness at 100g Load PH—Polishing Hardness	Mode of Occurrence; Other Characteristic Properties
Stephanite Ag_5SbS_4 Orthorhombic	C—Gray with pinkish violet tint → Galena, darker, pinkish → Polybasite, pyrargyrite, lighter B/P—Weak but distinct, gray to pinkish gray A—Strong in oil, violet to green IR—Not present	R—28.1–30.4 27.5–29.7 QC—0.299, 0.303 28.3 0.301, 0.307 30.5	VHN—26–124 PH $<$ tetrahedrite PH $>$ polybasite, pyrargyrite	Occurs as anhedral aggregates and euhedral columnar crystals. Compound twinning is common. Occurs with silver sulfosalts, Ni-Co-Fe arsenides, and common Cu-Fe sulfides.
Stibnite Sb_2S_3 Orthorhombic	C—White to grayish white → Bismuthinite, darker → Antimony, grayish B/P—Strong, grayish white to white A—Very strong, often undulose, blue, gray, brown, pinkish brown IR—Not present	R—31.1–48.1 30.1–45.2 QC—(a) 0.301, 0.309 41.8 (b) 0.306, 0.317 30.6 (c) 0.294, 0.305 47.3	VHN—42–153 71–86 on (010) section (sf) PH $>$ orpiment PH $<$ chalcopyrite	Occurs as granular aggregates and lath-like crystals that often exhibit deformation textures, pressure twinning, and undulatory extinction. Associated with pyrite, pyrrhotite, sphalerite, chalcopyrite, and Sn, As, and Hg minerals.
Stromeyerite AgCuS	C—Gray with violet pinkish tint	R—26.6–30.9 26.3–29.5	VHN—30–32(sf)	Occurs as a hypogene phase in granular aggregates and

Orthorhombic	→ Chalcocite, lavender-gray B/P—Weak but distinct in oil, gray-brown to light gray with blue or pink tint A—Strong, light violet, purple, brown, orange-yellow IR—Not present	QC—0.302, 0.305 26.7 0.286, 0.286 31.0	PH < galena, chalcocite	as a supergene phase in small veinlets. Often intergrown with other silver minerals, the common Cu-Fe and Fe sulfides, and sphalerite.
Sylvanite $(Au,Ag)Te_2$ Monoclinic	C—Creamy white → Galena, lighter B/P—Distinct, creamy white to brownish A—Strong, light bluish gray to dark brown IR—Not present	R—52.5–63.0 52.5–62.9 QC—0.316, 0.326 52.4 0.315, 0.325 62.7	VHN—154–172(f) PH > argentite PH < pyrargyrite	Occurs as skeletal blades. Well-developed cleavage and characteristic polysynthetic twins. Often intergrown with other gold-tellurides and associated with gold, galena, argentite, sphalerite, bornite, chalcopyrite, pyrite, Sb-, As- and Bi-sulfides.
Tennantite $Cu_{12}As_4S_{13}$ Cubic (May contain Fe, Zn, Sb, etc.)	C—Gray; sometimes with greenish or bluish tint → Galena, chalcocite greenish → Pearcite, similar B/P—Not present A—Isotropic IR—Common, reddish	R—30.1 28.6 QC—0.300, 0.312 29.6	VHN—294–380 PH > galena PH ~ chalcopyrite PH < sphalerite	Forms complete solid solution with tetrahedrite. Occurrences the same as for tetrahedrite except in more As-rich environments.

(Continued)

TABLE A1.2 (*Continued*)

Note: Information is reported as follows:

Name Formula Crystal System	C—Color B/P—Bireflectance/ pleochroism A—Anisotropy IR—Internal Reflections	R—Reflectance at 546 and 589 nm in Air QC—Quantitative Color Coordinates	VHN—Vickers Microhardness at 100g Load PH—Polishing Hardness	Mode of Occurrence; Other Characteristic Properties
Tenorite CuO Monoclinic	C—Air: gray to gray-white B/P—Oil: strongly pleochroic → Cuprite, brownish bluish → Chalcocite, brownish → Goethite, lighter, yellowish A—Strong, blue to gray IR—Not present	R—20.4–27.5 20.2–27.0 QC—0.305, 0.310 20.4 0.309, 0.319 27.3	VHN—190-300(cc-f) PH > chalcocite PH < goethite, cuprite	Occurs as aggregates of acicular crystals and as concentrically grown aggregates. May be twinned in lamellar fashion. Usually occurs with other oxides of Cu and Fe in weathering zone.
Tetradymite Bi_2Te_2S Trigonal	C—White with creamy tint → Chalcopyrite, lighter → Galena, yellowish B/P—Weak A—Distinct, bluish gray to yellow gray IR—Not present	R—60.5–54.8 60.4–55.3 QC—0.314, 0.323 60.1 0.315, 0.322 54.6	VHN—25–76 PH > bismuth PH < galena	Occurs as tabular plates and granular aggregates. Basal cleavage common; twinning rare. Intergrowths with tellurobismuthinite, bismuth. Also occurs with common Cu-Fe and Fe sulfides, galena, gold, and Pb-Bi sulfosalts.
Tetrahedrite $Cu_{12}SbS_{13}$	C—Gray with olive or brownish tint	R—32.5 32.1	VHN—312-351	Forms complete solid solution with tennantite. Irregular

Cubic (May contain Fe, Zn, Ag, As, Hg, etc.)	→ Galena, brownish or greenish → Chalcocite, blue-gray → Sphalerite, lighter B/P—Not present A—Isotropic IR—Uncommon, increasingly common as As-content increases, reddish	QC—0.310, 0.319 32.2 (Note R% and color varies with composition)	PH > galena PH ~ chalcopyrite PH < sphalerite (Note hardness varies with composition)	masses of anhedral grains interstitial to common Cu-Fe-, Fe-sulfides, sphalerite, galena, arsenopyrite, and sulfosalts. Cleavages, twinning usually absent, but growth zoning may be visible in thin section, especially in more As-rich members. Also occurs as rounded inclusions in galena and sphalerite.
Troilite—*See* Pyrrhotite				
Ullmannite NiSbS Cubic	C—White with bluish tint → Gersdorffite, less yellow → Skutterudite, more yellow → Linnaeite, white B/P—Not present A—Isotropic IR—Not present	R—47.3 47.0 QC—0.308, 0.314 47.3	VHN—592–627(p) PH > linnaiete PH ~ gersdorffite PH < pyrite	Occurs as dispersed subhedral to euhedral crystals. Cleavage (100) may be visible, and triangular cleavage pits occasionally seen. A minor phase in a variety of ores but usually associated with Cu-Fe sulfides and other Co-Fe-Ni antimonides and arsenides.
Ulvöspinel Fe_2TiO_4 Cubic	C—Brown to reddish brown → Magnetite, darker brown → //e of ilmenite, similar	R—15.3 16.1 QC—0.315, 0.311 15.7	VHN—~ 650 PH > magnetite	Usually observed as very fine, dark isotropic exsolution lamellae in Ti-magnetite, giving a "cloth weave" texture. More rarely as octahedral crystals and as a

(*Continued*)

TABLE A1.2 ***(Continued)***

Note: Information is reported as follows:

Name Formula Crystal System	C—Color B/P—Bireflectance/ pleochroism A—Anisotropy IR—Internal Reflections	R—Reflectance at 546 and 589 nm in Air QC—Quantitative Color Coordinates	VHN—Vickers Micro-hardness at 100g Load PH—Polishing Hardness	Mode of Occurrence; Other Characteristic Properties
	B/P—Not present A—Isotropic IR—Not present			matrix containing oriented cubes of magnetite. Associated with ilmenite and magnetite.
Uraninite UO_2, usually partly oxidized Cubic	C—Brownish gray → Magnetite, less pink → Sphalerite, brownish B/P—Not present A—Isotropic IR—Dark brown to reddish brown	R—13.6 13.6 QC—0.305, 0.309 13.7	VHN—499–548(sf) (at 50g) PH > magnetite PH < pyrite	Occurs as growth-zoned crystals and as colloform, oolitic, and dendritic masses. (111) twinning common and (100) and (111) cleavage may occur. Often with pyrite, Cu-Fe sulfides, and other uranium minerals; may contain inclusions of gold.
Valleriite $(Fe,Cu)S_2$ $(Mg,Al)(OH)_2$ Hexagonal	C,B/P—Very strong bireflectance and pleochroism, bronze to gray A—Extreme, white to gray-bronze with satin-like texture IR—Not present	R—20.5–10.3 22.9–10.3 QC—0.357, 0.361 20.9 0.307, 0.312 10.3	VHN—30 PH > chalcopyrite PH ~ cubanite PH < pyrrhotite	Occurs as veinlets, interstitial fillings, and tiny inclusions in and around chalcopyrite, pyrrhotite, pentlandite, magnetite. Polishes poorly; has a characteristic bi-reflectance and pleo-chroism. The bronze

				anisotropy appears in a satin-like wavy pattern. Much confused with mackinawite, which tends to have a sharper extinction and less of an orange color or satin-like texture under crossed nicols.
Violarite $FeNi_2S_4$ Cubic	C—Brownish gray with violet tint → Pentlandite, darker, violet tint → Pyrrhotite, lighter → Millerite, brownish violet B/P—Not present A—Isotropic IR—Not present	R—45.3 46.9 QC—0.320, 0.322 46.0	VHN—241-373 PH > chalcopyrite, sphalerite PH ~ pentlandite PH < pyrrhotite	Most commonly occurs as a porous alteration product along grain boundaries and fractures of pentlandite, pyrrhotite, and millerite. Hypogene violarite occurs as equant anhedral grains with pyrite, millerite, pyrrhotite. Sometimes as fine lamellar intergrowths with millerite and chalcopyrite.
Wolframite $(Fe,Mn)WO_4$ Monoclinic	C—Air: gray to white; oil: gray with brown or yellow tint → Sphalerite, similar → Magnetite, darker → Cassiterite, lighter B/P—Weak A—Weak to distinct, yellow to gray IR—Deep red,	R—15.2-16.3 15.1-16.2 QC—0.303, 0.307 15.3 0.303, 0.306 16.4	VHN—319-390(cc) PH > magnetite, scheelite PH < pyrite, arsenopyrite	Occurs as euhedral platelets and as masses of interpenetrating laths. Cleavage distinct; twinning common. Often associated with scheelite, arsenopyrite, chalcopyrite, molybdenite, bismuth, bismuthinite, gold, and cassiterite.

(Continued)

TABLE A1.2 (*Continued*)

Note: Information is reported as follows: Name Formula Crystal System	C—Color B/P—Bireflectance/pleochroism A—Anisotropy IR—Internal Reflections	R—Reflectance at 546 and 589 nm in Air QC—Quantitative Color Coordinates	VHN—Vickers Microhardness at 100g Load PH—Polishing Hardness	Mode of Occurrence; Other Characteristic Properties
	especially in oil			
Zincite ZnO Hexagonal	C—Pinkish brown B/P,A—Masked by internal reflections IR—Abundant, red to yellowish	R—11.1–11.3 10.8–11.1 QC—0.299, 0.304 11.1 0.299, 0.303 11.3	VHN—205–221(cc-sg) PH < franklinite, hausmannite	Occurs as rounded grains; cleavage (0001) may be visible. Forms oriented intergrowths with hausmannite. Associated with franklinite.

APPENDIX 2

CHARACTERISTICS OF COMMON ORE MINERALS

TABLE A2.1 The Common Ore Minerals in Order of Increasing Mininum Reflectance (in Air) at 546 nm

Mineral	R%	Mineral	R%
	Reflectance Between 1 and 10%		
Graphite	6.2–26.4	Chalcophanite	9.1–27.0
Covellite	6.6–23.7	Scheelite	9.8–10.2
Coffinite	7.9– 8.0		
	Reflectance Between 10 and 20%		
Graphite	6.2–26.4	Psilomelane	~15–30
Covellite	6.6–23.7	Wolframite group	15.2–16.3
Chalcophanite	9.1–27.0	Columbite-tantalite	15.3–17.4
Scheelite	9.8–10.1	Ulvöspinel	15.5
Valleriite	10.3–20.5	Goethite	15.5–17.5
Cassiterite	10.7–12.2	Hausmannite	16.3–20.2
Zincite	11.1–11.3	Ilmenite	16.4–19.2
Lepidocrocite	11.6–18.4	Sphalerite	16.6
Chromite	13.5	Braunite	18.9–19.9
Uraninite	13.6	Molybdenite	19.5–38.5
Manganite	14.1–20.5	Magnetite	19.9
Brannerite	15.0–15.1		
	Reflectance Between 20 and 30%		
Graphite	6.2–26.4	Alabandite	22.8
Covellite	6.6–23.7	Orpiment	23.0–27.5

TABLE A2.1 (***Continued***)

Mineral	R%	Mineral	R%
Reflectance Between 20 and 30% (Continued)			
Chalcophanite	9.1–27.0	Famatinite	24 –27.4
Valleriite	10.3–20.5	Enargite	24.2–25.2
Manganite	14.1–20.5	Proustite	24.2–27.7
Psilomelane	~15–30	Maghemite	24.4
Mackinawite	16.2–40.4	Cinnabar	24.7–29.7
Hausmannite	16.3–20.2	Stannite	26.0–27.3
Delafossite	18.4–22.1	Hematite	26.4–29.9
Molybdenite	19.5–38.5	Cuprite	26.6
Rutile	19.7–23.1	Stromeyerite	26.6–30.9
Tenorite	20.4–27.5	Mawsonite	26.9–29.7
Jacobsite	21.1	Idaite	27 –33.6
Bornite	21.7	Stephanite	28.1–30.4
Digenite	21.9	Pyrargyrite	28.5–30.3
Realgar	22.1	Pyrolusite	29.0–40.0
Bixbyite	22.2	Freibergite	33.0
Reflectance Between 30 and 40%			
Mackinawite	16.2–40.4	Stibnite	31.1–48.1
Molybdenite	19.5–38.5	Miargyrite	31.6–34.5
Stephanite	28.1–30.4	Tetrahedrite	32.5
Pyrargyrite	28.5–30.3	Chalcocite	33.2–33.4
Pyrolusite	29.0–40.0	Cubanite	35.4–39.4
Pearcite	29.1–32.2	Pyrrhotite	36.3–43.4
Tennantite	30.1	Jamesonite	36.4–44.2
Berthierite	30.3–42.3	Bismuthinite	37.1–49.0
Polybasite	30.7–32.5	Boulangerite	37.4–41.8
Nickeloan pyrite "bravoite"	~31–54	Chalcostibite	37.8–43.7
		Breithauptite	37.8–48.0
Acanthite	31.0		
Reflectance Between 40 and 50%			
Mackinawite	16.2–40.4	Carrollite	42.9
Pyrolusite	29.0–40.0	Galena	42.9
Berthierite	30.3–42.3	Chalcopyrite	44.6–45.0
Bravoite	~31–54	Kobellite	44.8–47.2
Stibnite	31.1–48.1	Violarite	45.3
Pyrrhotite	36.3–43.4	Nickeline	46.1–51.4
Jamesonite	36.4–44.2	Pentlandite	46.5
Bismuthinite	37.1–49.0	Siegenite	46.7
Boulangerite	37.4–41.8	Ullmannite	47.3
Chalcostibite	37.8–43.7	Maucherite	48.4–49.6
Breithauptite	37.8–48.0	Marcasite	49.1–56.2
Cosalite	41.4–45.7	Linnaeite	49.5

TABLE A2.1 (*Continued*)

Mineral	R%	Mineral	R%
	Reflectance Between 50 and 60%		
Nickeloan pyrite "bravoite"	~31–54	Sylvanite	52.5–63.0
		Löllingite	53.4–55.5
Nickeline	46.1–51.4	Safflorite	54.1–54.6
Marcasite	49.1–56.2	Gersdorffite	54.7
Glaucodot	50.0–50.6	Tetradymite	54.8–60.5
Millerite	50.2–56.6	Skutterudite	55.2
Cobaltite	50.6	Rammelsbergite	56.8–60.9
Arsenic	51.7–55.7	Iron	58.1
Pyrite	51.7	Pararammelsbergite	58.9–59.7
Arsenopyrite	51.8–52.2	Bismuth	59.8–67.2
	Reflectance Over 60%		
Sylvanite	52.5–63.0	Platinum	69.7
Tetradymite	54.8–60.5	Allargentum	~70
Rammelsbergite	56.8–60.0	Antimony	74.4–77.9
Bismuth	59.8–67.2	Gold	77.0
Dyscrasite	60.1–62.8	Silver	93.3
Copper	64.6		

TABLE A2.2 Examples of Common Ore Minerals Arranged in Order of Increasing Minimum Vickers Microhardness (at 100g Load)

Mineral	VHN	Mineral	VHN
	VHN from 1 to 100		
Molybdenite	8–100	Jamesonite	66–86
Graphite	12–16	Proustite	70–105
Bismuth	16–18	Arsenic	72–173
Orpiment	22–58	Cosalite	74–161
Acanthite	23–26	Mackinawite	~74–181
Tetradymite	25–76	Copper	79–99
Stphanite	26–124	Cinnabar	82–156
Stromeyerite	30–32	Chalcocite	84–87
Stibnite	42–153	Digenite	86–106 (001 section)
Realgar	47–60		
Antimony	50–69	Bornite	87–100
Gold	53–58	Miargyrite	88–130
Galena	59–65	Boulangerite	92–125
Silver	60–65		