

Mineralogy

Mineralogy

Physical properties

The Science of Mineralogy

The science of mineralogy is the study of the physics and chemistry of natural, solid, crystalline materials.

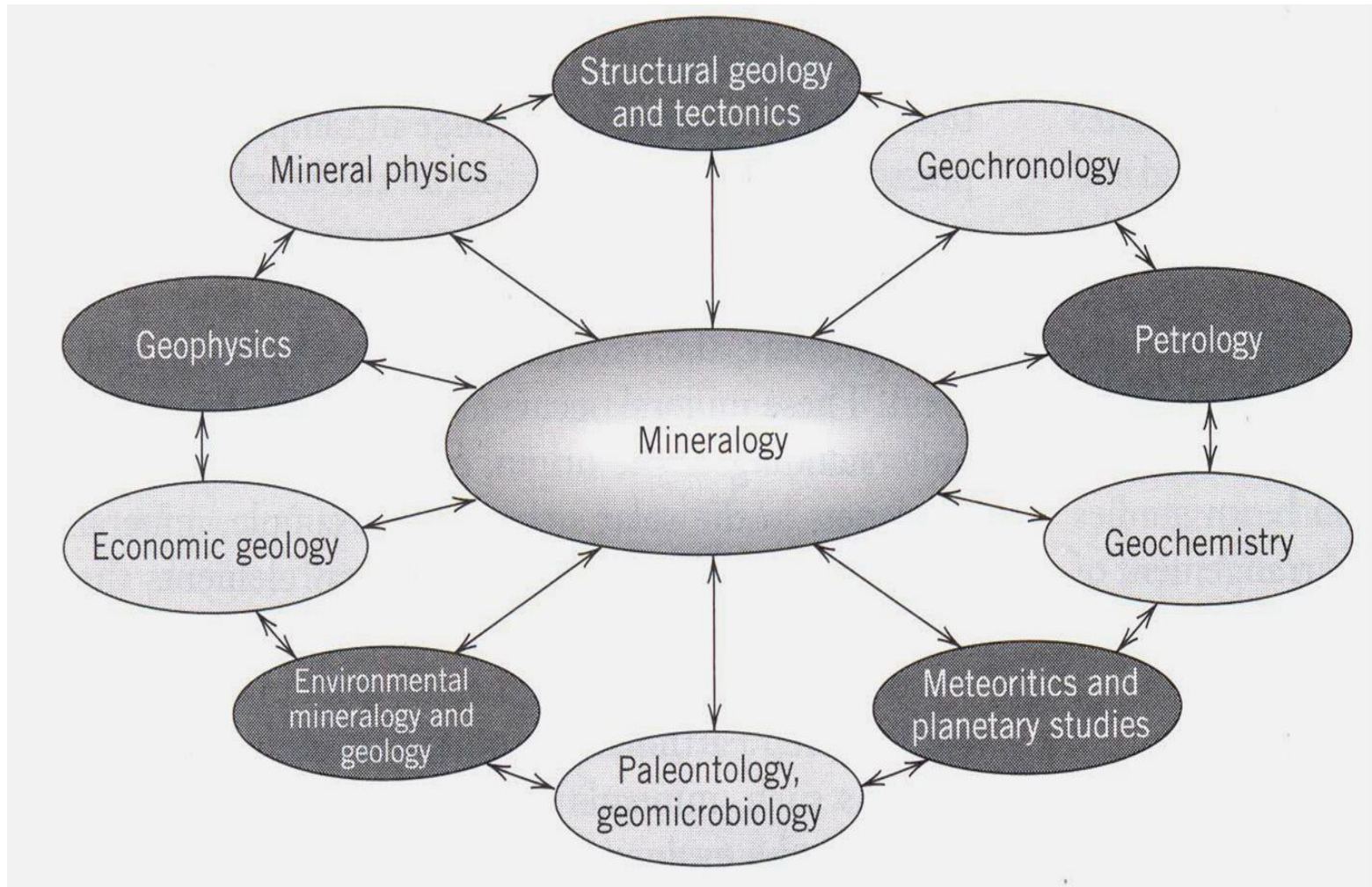


Fig. 1.1: The central role of mineral science in the earth sciences. The double arrows portray linkages of subdisciplines to one another and to mineral science; they indicate an especially close relation between subdisciplines.

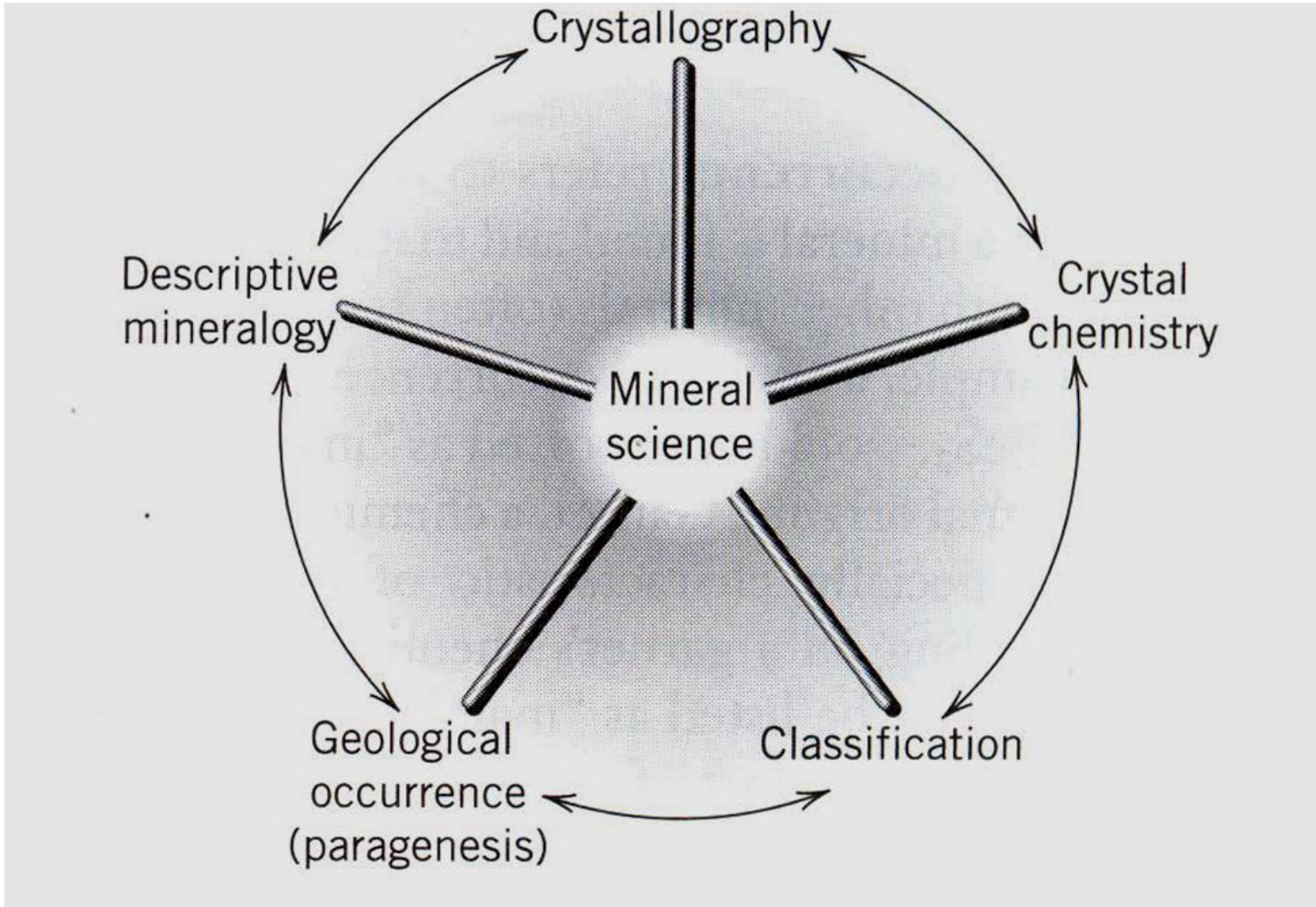


Fig. 1.9: Diagram showing the major subdisciplines that constitute mineral science. Arrows imply a major contribution of one subfield to another

Definition of a Mineral

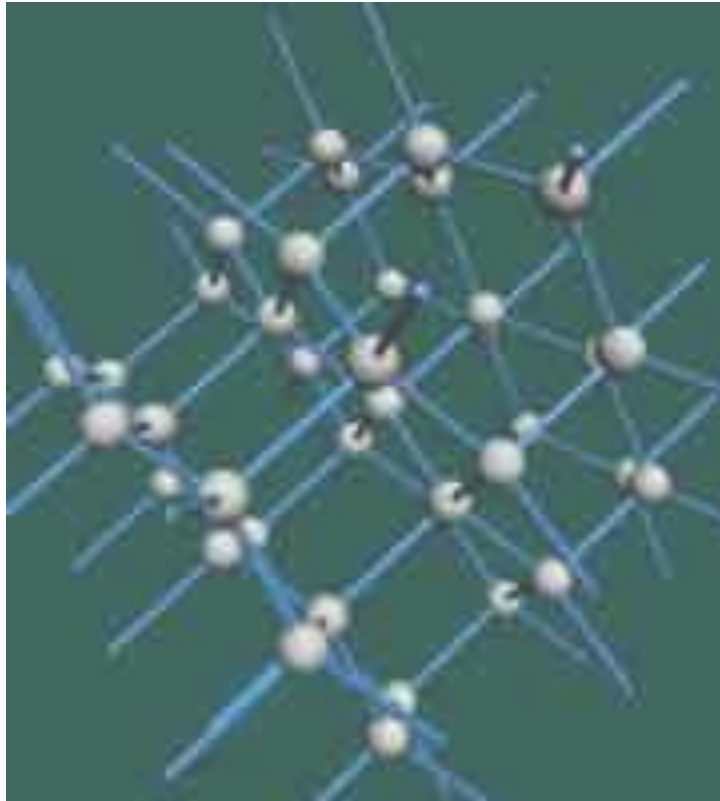
A mineral is a naturally occurring, homogeneous solid with a definite, but generally not fixed, chemical composition and an ordered atomic arrangement. It is usually formed by inorganic processes.

Properties of minerals

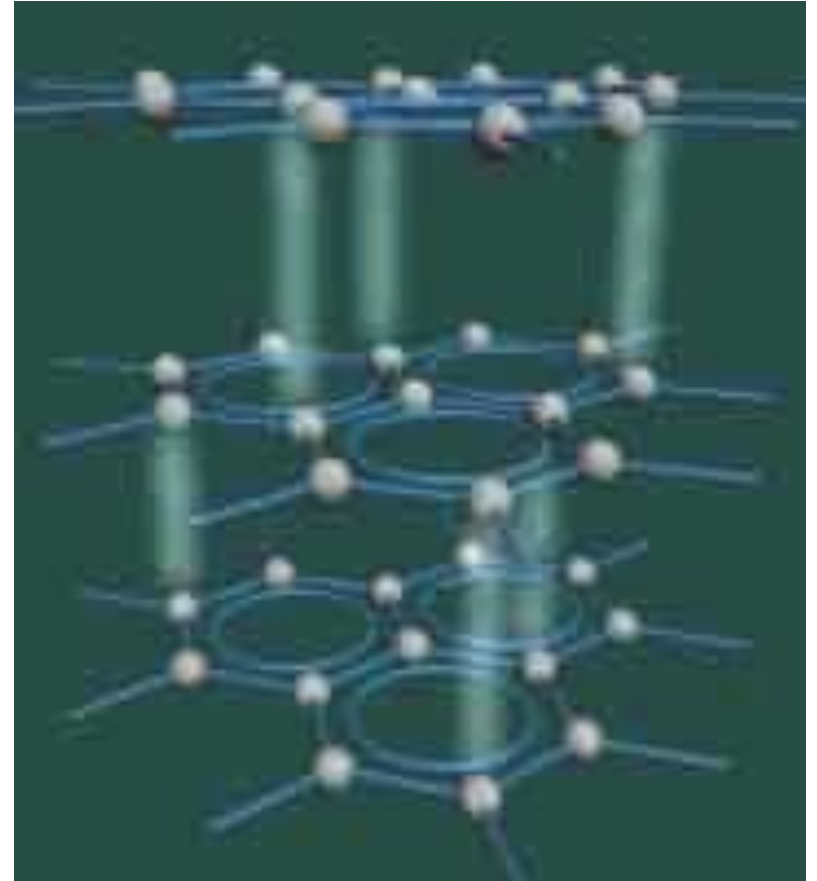
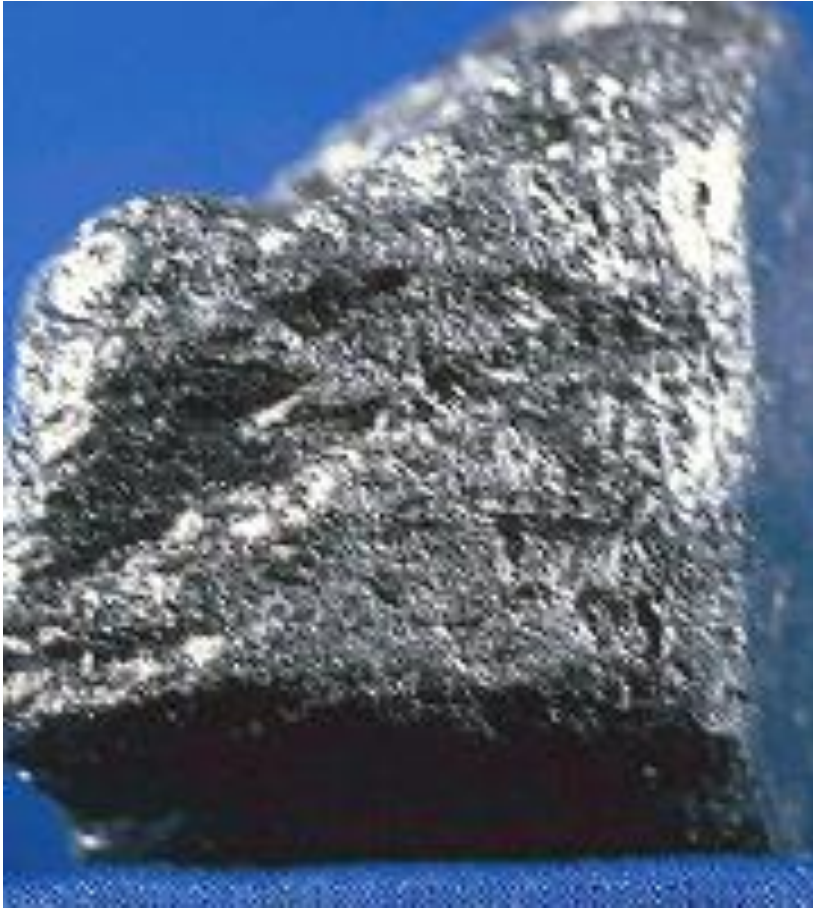
Each mineral is unique and each has a distinct chemical and physical properties. These physical and chemical properties depend upon:

- a) which elements they contain, and**
- a) b) the arrangement of these elements in space.**

For example graphite and diamond have the same exact chemical composition (pure carbon), but because of their atomic arrangement:

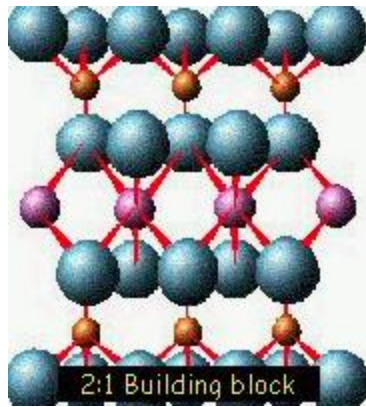


Diamond: extremely hard, brilliant and transparent.

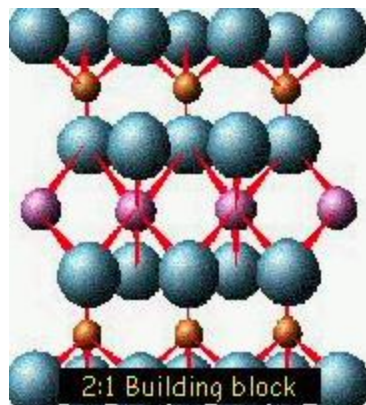


Graphite: extremely soft, dull and metallic.

There are some minerals that have a almost similar atomic structure but a different chemical composition, then their properties also change:



Muscovite: No iron in its structure, colorless, transparent and an excellent insulator.



Biotite: Iron on its structure, black and a conductor of electricity

Let's look at the five parts of this definition:

1.) "Naturally occurring" means that synthetic compounds not known to occur in nature cannot have a mineral name.

However, it may occur anywhere, other planets, deep in the earth, as long as there exists a natural sample to describe.

2.) **"Homogeneous solid"** means that it must be chemically and physically homogeneous down to the basic repeat unit of the atoms.

It will then have absolutely predictable physical properties (density, compressibility, index of refraction, etc.). This means that rocks such as granite or basalt are not minerals because they contain more than one compound.

Solid excludes materials that are gases and liquids.

In solids, there is a fixed position for atoms. Thus, H₂O as ice in a glacier is a mineral, but H₂O as a liquid (water) is not.

Conversely, liquid mercury, found in some mercury deposits, is excluded as a mineral by the above definition.

3.) "Definite, but generally not fixed, composition" means that atoms, or groups of atoms must occur in specific ratios.

For ionic crystals (i.e. most minerals) ratios of cations to anions will be constrained by charge balance, however, atoms of similar charge and ionic radius may substitute freely for one another; hence definite, but not fixed.

4.) **"Ordered atomic arrangement"** means crystalline. Crystalline materials are three-dimensional periodic arrays of precise geometric arrangement of atoms. Glasses such as obsidian, which are disordered solids, liquids (e.g., water, mercury), and gases (e.g., air) are not minerals.

5.) **"Inorganic processes"** means that crystalline organic compounds formed by organisms are generally not considered minerals. However, carbonate shells are minerals because they are identical to compounds formed by purely inorganic processes.

An abbreviated definition of a mineral would be "a natural, crystalline phase". Chemists have a precise definition of a phase:

A phase is that part of a system which is physically and chemically homogeneous within itself and is surrounded by a boundary such that it is mechanically separable from the rest of the system.

The third part of our definition of a mineral leads us to a brief discussion of **stoichiometry**, the ratios in which different elements (atoms) occur in minerals.

Because minerals are crystals, dissimilar elements must occur in fixed ratios to one another. However, complete free substitution of very similar elements (e.g., Mg^{+2} and Fe^{+2} which are very similar in charge (valence) and radius is very common and usually results in a crystalline solution (solid solution).

For example, the minerals **forsterite** (Mg_2SiO_4) and **fayalite** (Fe_2SiO_4) are members of the **olivine group** and have the same crystal structure, that is, the same geometric arrangement of atoms.

Mg and Fe substitute freely for each other in this structure, and all compositions between the two extremes, forsterite and fayalite, may occur.

However, Mg or Fe do not substitute for Si or O, so that the three components, Mg/Fe, Si and O always maintain the same 2 to 1 to 4 ratio because the ratio is fixed by the crystalline structure.

These two minerals are called **end-members** of the olivine series and represent extremes or "pure" compositions.

Because these two minerals have the same structure, they are called **isomorphs** and the series, an **isomorphous series**.

it is also common for a single compound (composition) to occur with different crystal structures.

Each of these structures is then a different mineral and, in general, will be stable under different conditions of temperature and pressure.

Different structural modifications of the same compound are called **polymorphs.**

An example of polymorphism is the different minerals of SiO₂ (silica); **alpha-quartz, beta-quartz, tridymite, cristobalite, coesite, and stishovite.**

Although each of these has the same formula and composition, they are different minerals because they have different crystal structures.

Each is stable under a different set of temperature and pressure conditions, and the presence of one of these in a rock may be used to infer the conditions of formation of a rock.

Another familiar example of **polymorphism is **graphite and diamond**, two different minerals with the same formula, C (carbon).**

Glasses (obsidian), liquids, and gases however, are not crystalline, and the elements in them may occur in any ratios, so they are not minerals.

So in order for a natural compound to be a mineral, it must have a unique composition and structure.

Where do we find minerals?

Minerals are found throughout our universe. They are the products of complex Earth and planetary processes that take place over a wide range of temperatures and pressures.

They not only occur on beaches, covering the ocean floor, and in the cores of mountain belts but also on other planets, their moons, in asteroids, and far beyond.

These mineral occurrences provide clues to the understanding of the origin, evolution, and behavior of planets in the solar system..

For example, minerals found in meteorites contain chemical elements that record the evolution of our solar system.

As such, minerals are basic to earth science as well as to the evaluation of the sustainability of mineral resources

Properties of Minerals

Mineral Properties in Hand Specimen

Learning to recognize hand specimens of approximately 100 of the most common rock-forming minerals is an important part of this course.

This recognition is based on seven easily examined properties plus a few unique properties such as magnetism or radioactivity that are strong clues to a mineral's identity.

The seven physical properties are:

- 1. Crystal form and habit (shape).**
- 2. Luster and transparency**
- 3. Color and streak.**
- 4. Cleavage, fracture, and parting.**
- 5. Tenacity**
- 6. Density**
- 7. Hardness**

1. Crystal form (shape) and habit.

Recognizing crystal forms (a crystal face plus its symmetry equivalents) in the various crystal systems is one of the reasons we spend some time in lab studying block models.

The crystal faces developed on a specimen may arise either as a result of **growth or of **cleavage**. In either case, they reflect the internal symmetry of the crystal structure that makes the mineral unique.**

Crystal shape can be helpful in identification. Most minerals have a crystalline structure and can form perfect crystals if allowed to grow in an unrestricted space.

Crystal faces resemble cleavage faces because they are flat and reflect light as a single plane, but they are different from cleavage surfaces because crystals have complex geometric shapes.

Perfect crystals are rare and are seldom encountered.

The crystal faces commonly seen on quartz are growth faces and represent the slowest growing directions in the structure. Quartz grows rapidly along its c-axis (three-fold or trigonal symmetry axis) direction and so never shows faces perpendicular to this direction.

On the other hand, calcite rhomb faces and mica plates are cleavages and represent the weakest chemical bonds in the structure.

There is a complex terminology for crystal faces, but some obvious names for faces are **prisms and **pyramids**.**

A prism is a face that is perpendicular to a major axis of the crystal, whereas a pyramid is one that is not perpendicular to any major axis.

- Crystals that commonly develop prism faces are said to have **prismatic or columnar habit**.
- Crystals that grow in fine needles are **acicular**;
- crystals growing flat plates are **tabular**.

- Crystals forming radiating sprays of needles or fibers are **stellate**.
- Crystals forming parallel fibers are **fibrous**,
and
- crystals forming branching, tree-like growths are **dendritic**.

Types of Habits

- 1. Prismatic or columnar habit**
- 2. Acicular**
- 3. Tabular**
- 4. Bladed**
- 5. Stellate.**
- 6. Fibrous, and**
- 7. Dendritic**

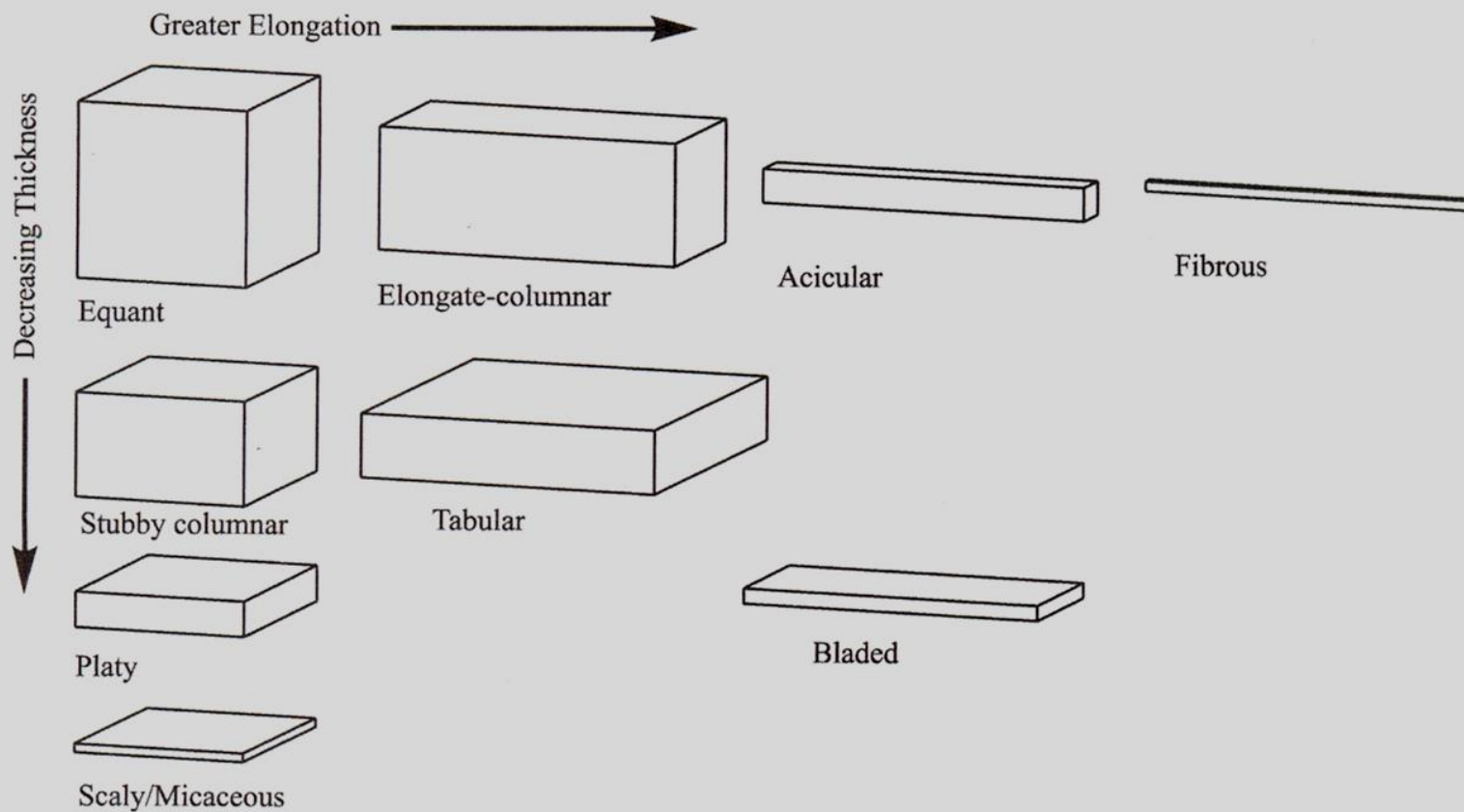


Figure 2.49 Nomenclature for describing the habit of individual mineral grains as a function of relative dimensions.

Mineral habits

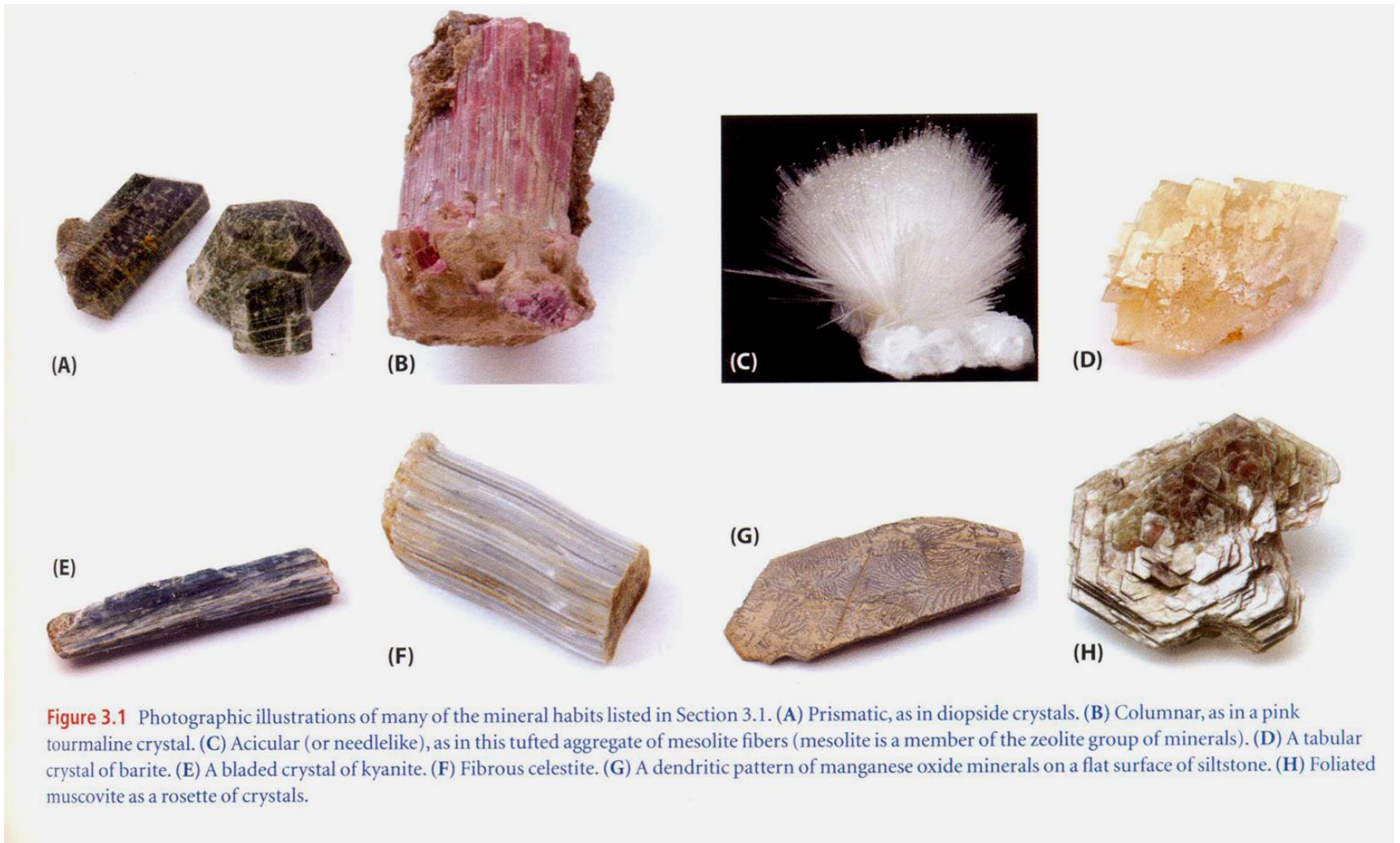


Figure 3.1 Photographic illustrations of many of the mineral habits listed in Section 3.1. (A) Prismatic, as in diopside crystals. (B) Columnar, as in a pink tourmaline crystal. (C) Acicular (or needlelike), as in this tufted aggregate of mesolite fibers (mesolite is a member of the zeolite group of minerals). (D) A tabular crystal of barite. (E) A bladed crystal of kyanite. (F) Fibrous celestite. (G) A dendritic pattern of manganese oxide minerals on a flat surface of siltstone. (H) Foliated muscovite as a rosette of crystals.

FIGURE 2.14 Some common crystal habits. **A. Bladed.** Elongated crystals that are flattened in one direction. **B. Prismatic.** Elongated crystals with faces that are parallel to a common direction. **C. Banded.** Minerals that have stripes or bands of different color or texture. **D. Botryoidal.** Groups of intergrown crystals resembling a bunch of grapes. (Photos by Dennis Tasa)



A. Bladed



B. Prismatic



C. Banded



D. Botryoidal

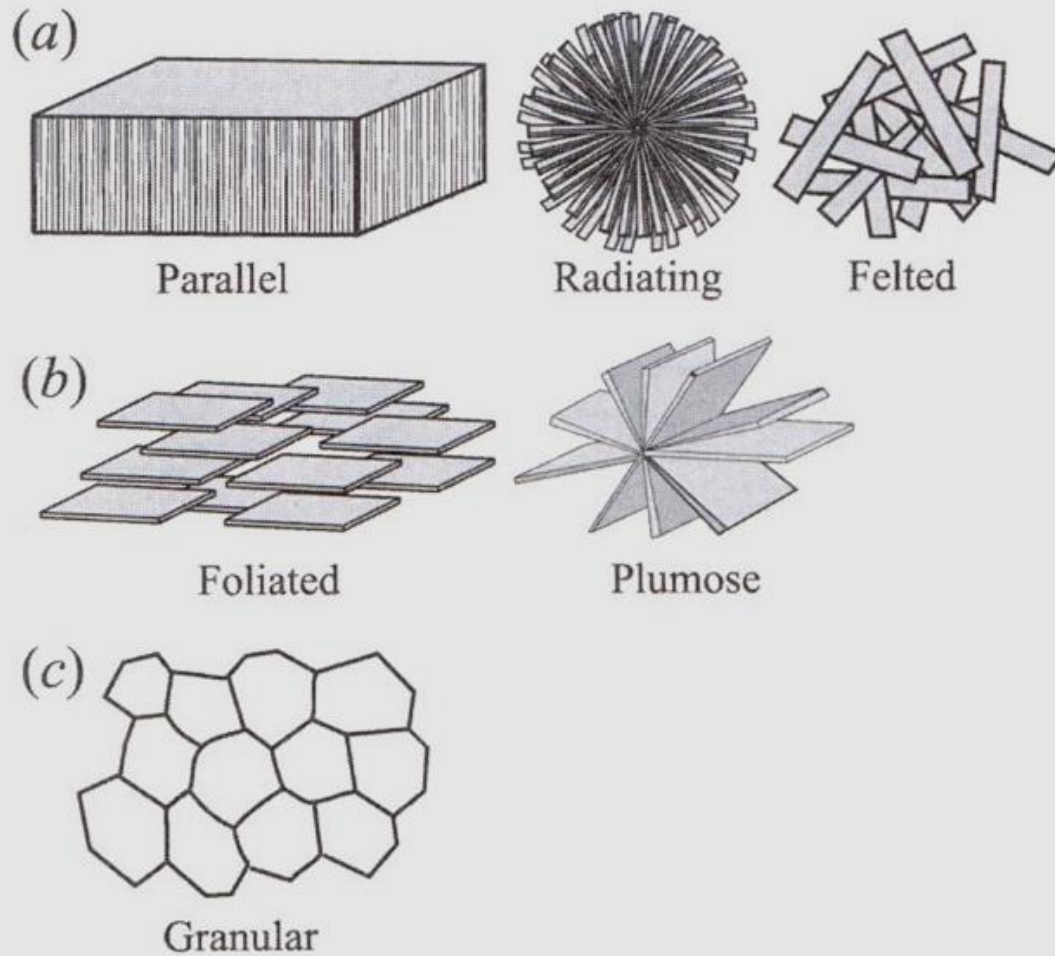


Figure 2.50 Patterns of mineral growth. (a) Elongate minerals can form parallel, radiating, or felted masses. (b) Platy or micaceous minerals can form foliated or plumose arrangements. (c) Equant minerals can form fine-to coarse-grained granular masses.

masses.

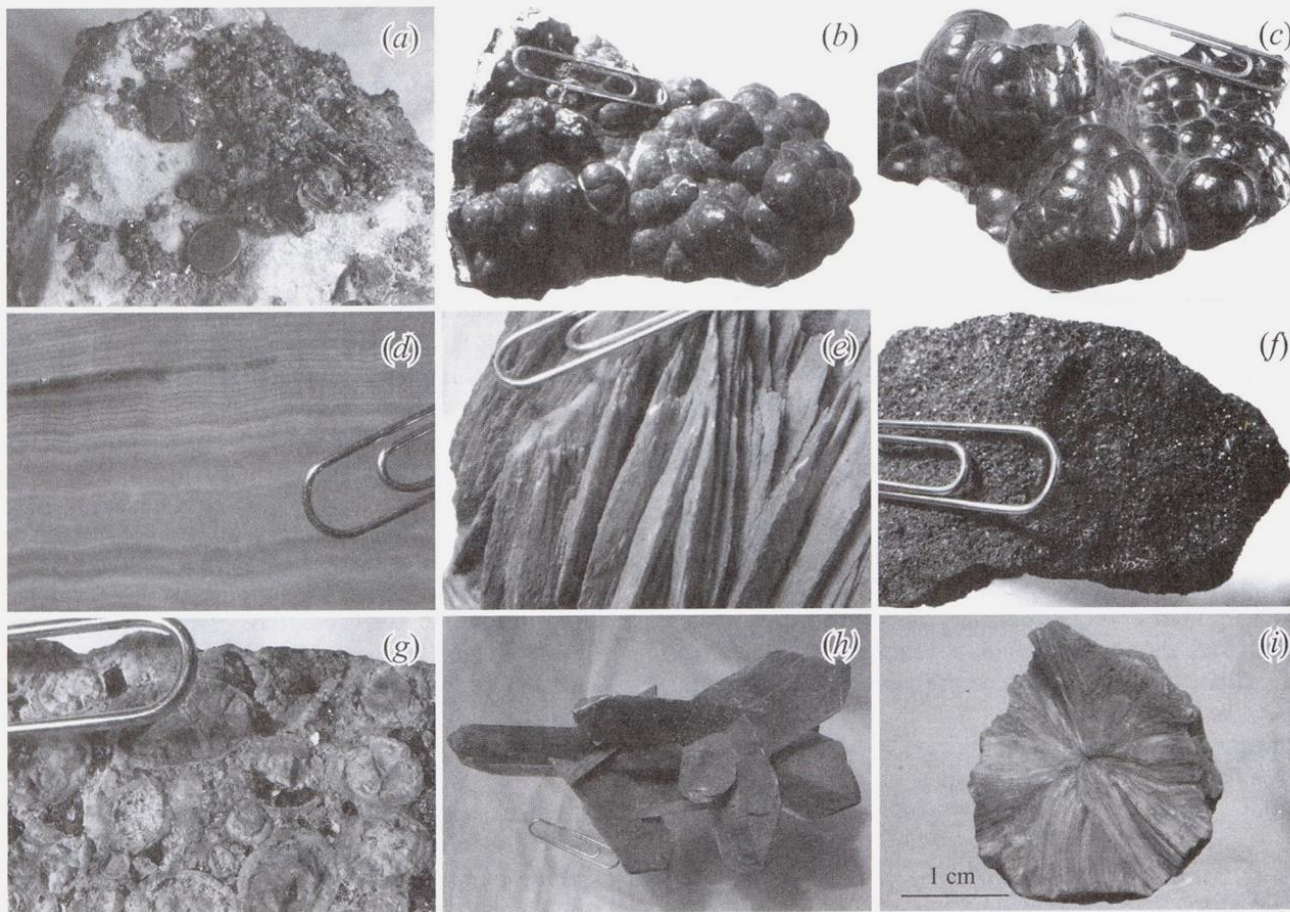


Figure 2.51 Habits of crystalline masses. (a) Drusy encrustation of sphalerite and galena on white quartz. (b) Botryoidal hematite. (c) Mammillary hematite. (d) Banded chalcedony. (e) Lamellar intergrowth of tabular barite crystals. (f) Granular massive chromite. (g) Pisolitic aluminum oxides in bauxite. (h) Reticulated crystals of gypsum. (i) Radiating concretion of barite.

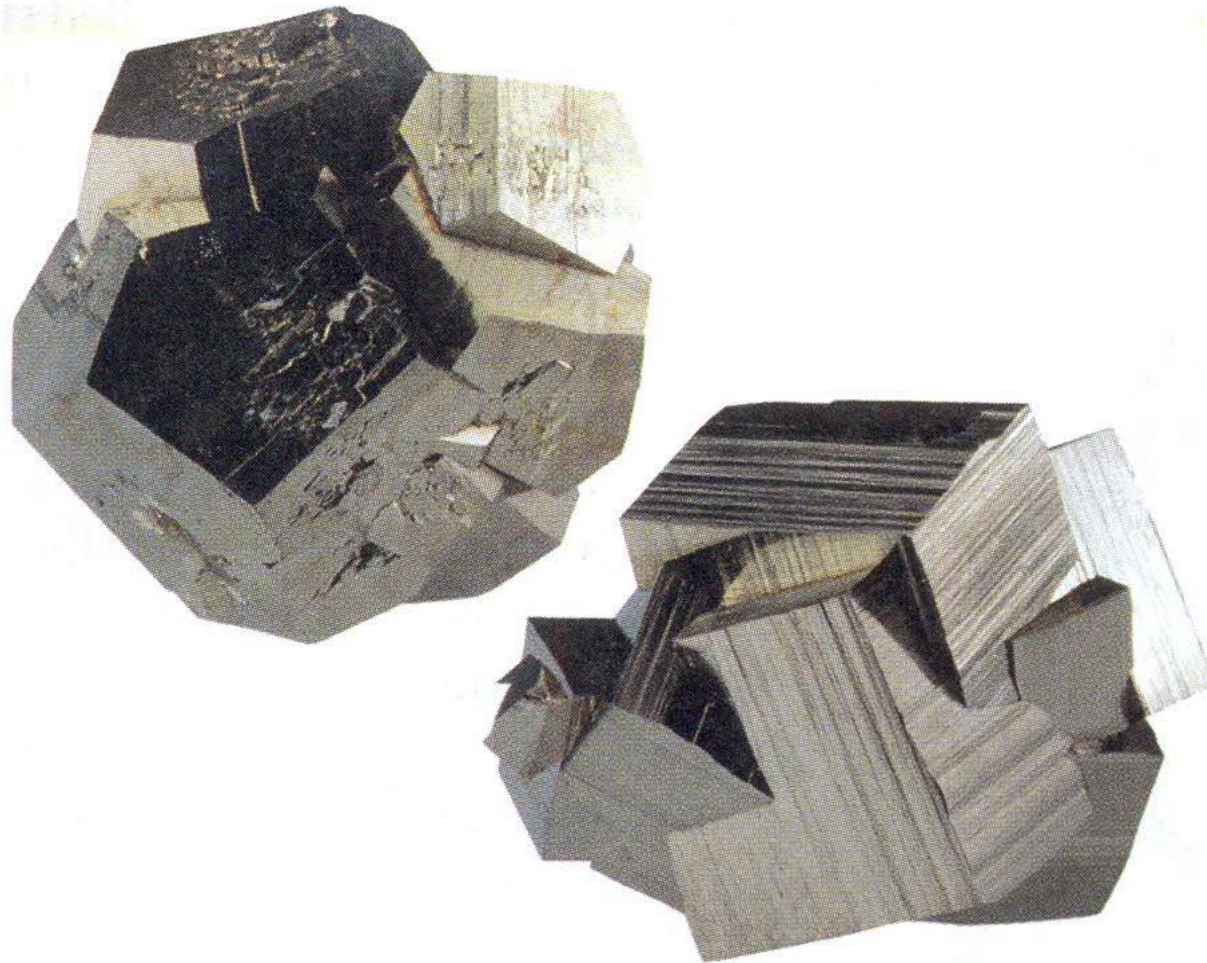


FIGURE 2.13 Although most minerals exhibit only one common crystal shape, some, such as pyrite, have two or more characteristic habits. (Photos by Dennis Tasa)

Garnet crystals

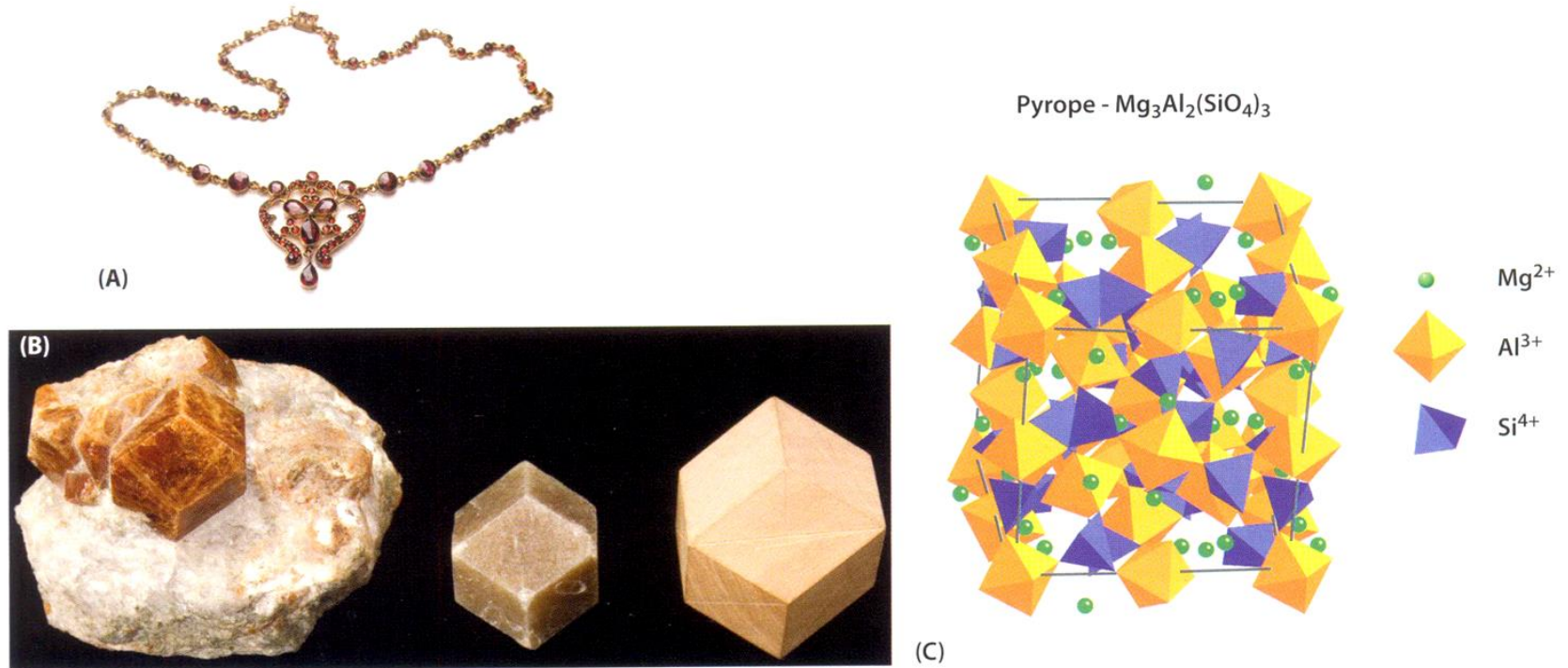


Figure 2.5 (A) A garnet necklace of Victorian design. This type of red garnet is referred to as Bohemian garnet in the trade. It is a red garnet of pyrope composition. (Courtesy of Ron Beauchamp, Beauchamp Jewelers, Albuquerque, NM.) (B) Examples of the relatively common occurrence of garnet in well-formed (euhedral) dodecahedrons. Two almost perfect crystals, as well as a small wooden model of the same dodecahedron, used in laboratory teaching of crystal forms. (C) A perspective view of the complex and densely packed atomic structure of a garnet of composition $Mg_3Al_2(SiO_4)_3$, known as pyrope. The overall outline of the structure is that of a cube.

Crystals of amazonite and smoky quartz

Figure 2.6 A hand specimen of beautifully crystallized green microcline feldspar (known as amazonite) and smoky quartz crystals. The crystals in this museum-quality specimen grew freely in an open space (a vug) without interference from adjoining minerals.



2. Luster and transparency.

The way a mineral **transmits** or **reflects** light is a diagnostic property. The transparency may be either **opaque**, **translucent**, or **transparent**.

This **reflectance** property is called **luster**. Native metals and many sulfides are opaque and reflect most of the light hitting their surfaces and have a **metallic** luster. Other opaque or nearly opaque oxides may appear dull, or **resinous**.

Lustre

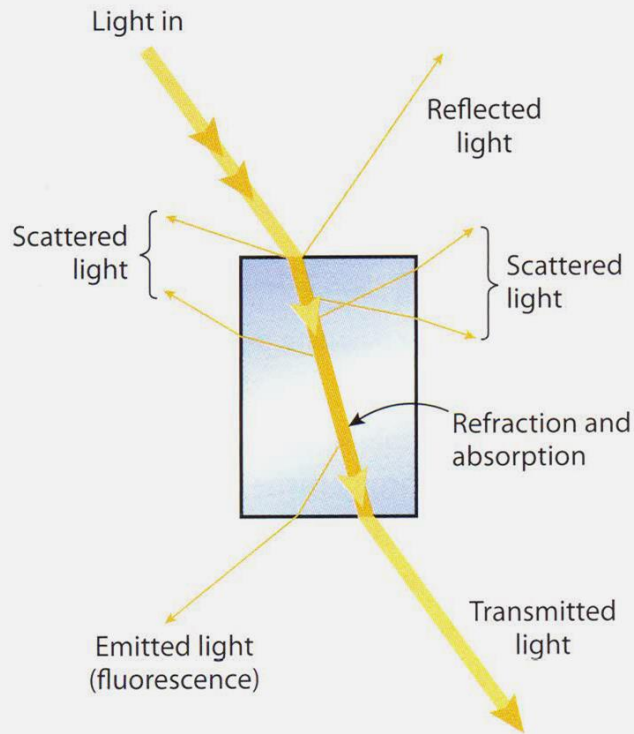


Figure 3.4 The various processes that occur when light passes through a piece of a transparent substance (adapted from Nassau, 1980).



Figure 3.5 Metallic luster of hematite, Fe_2O_3 . This type of hematite is commonly referred to as specularite.

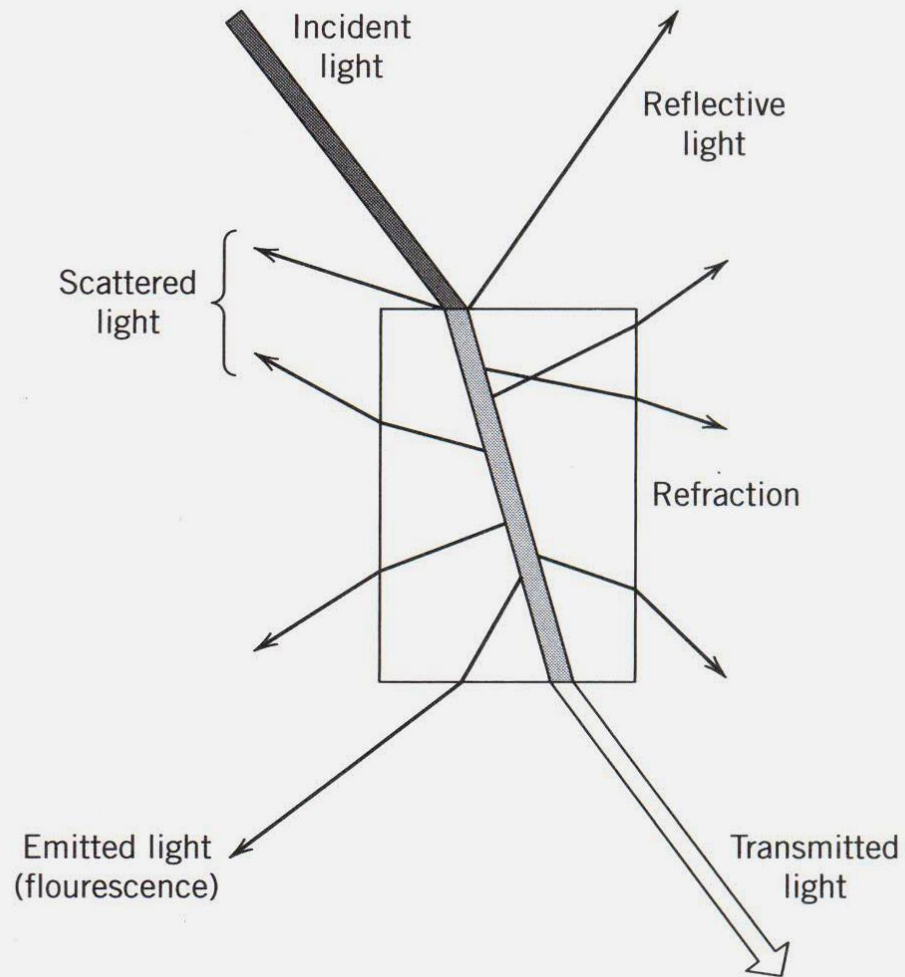
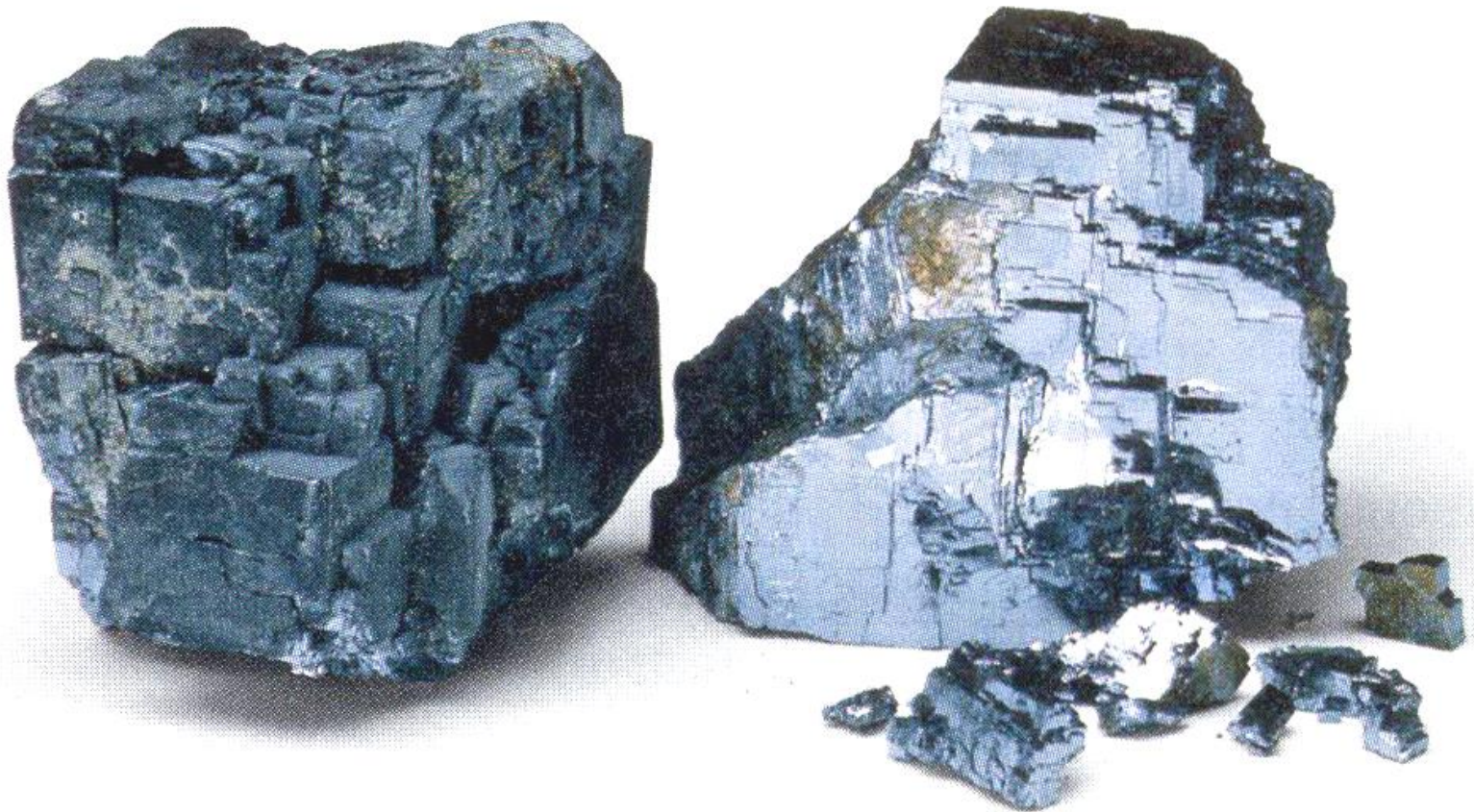
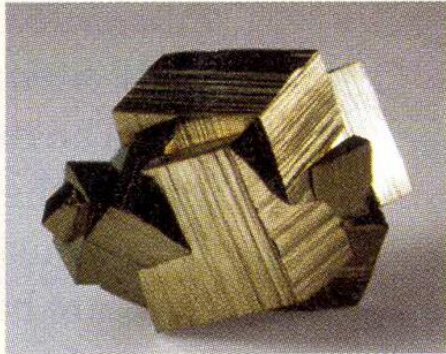


FIG. 2.5 Light interactions with minerals. Luster is a combination of scattered and reflected light, and color is transmitted light. Some absorbed light can be reemitted (usually at longer wavelengths) as fluorescence. (Adapted from Nassau, K. 1980. The causes of color. *Scientific American* 243: 124–156.)

FIGURE 2.10 The freshly broken sample of galena (right) displays a metallic luster, while the sample on the left is tarnished and has a submetallic luster. (Photo courtesy of E. J. Tarbuck)



Lustures



C.



E.

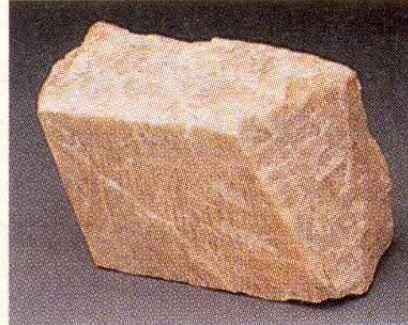
Metallic lusture



A.



B.



D.



Cleaved sample

Non-metallic lusture

Transparent minerals with a high index of refraction such as diamond appear brilliant and are said to have an **adamantine** luster,

whereas those with a lower index of refraction such as quartz or calcite appear glassy and are said to have a **vitreous** luster.

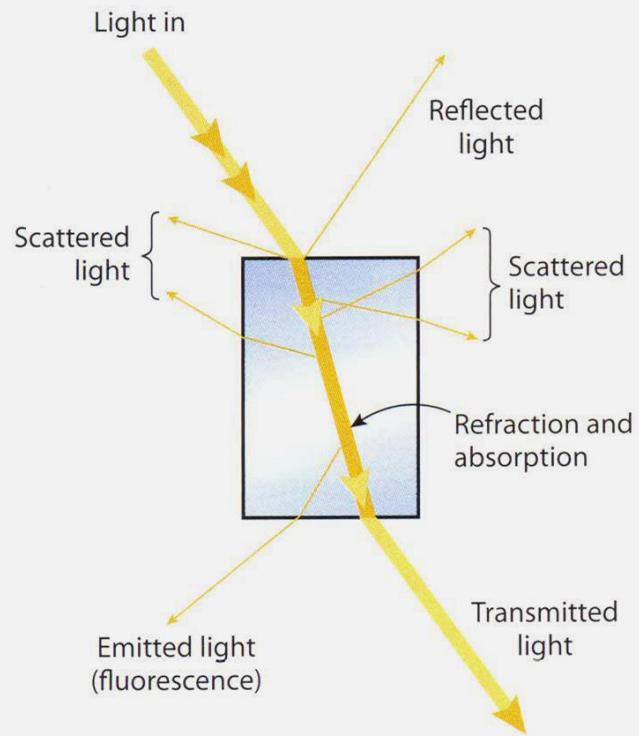


Figure 3.4 The various processes that occur when light passes through a piece of a transparent substance (adapted from Nassau, 1980).



Figure 3.5 Metallic luster of hematite, Fe_2O_3 . This type of hematite is commonly referred to as specularite.

3. Color and streak.

Color is fairly self-explanatory property describing the reflectance.

Minerals having the same chemical composition but small variations of the quantity and distribution of some elements will give the same mineral different colors.

Metallic minerals are either white, gray, or yellow.

The presence of transition metals with unfilled electron shells (e.g. V, Cr, Mn, Fe, Co, Ni, and Cu) in oxide and silicate minerals causes them to be opaque or strongly colored so that the streak, the mark that they leave when scratched on a white ceramic tile, will also be strongly colored.

Colour

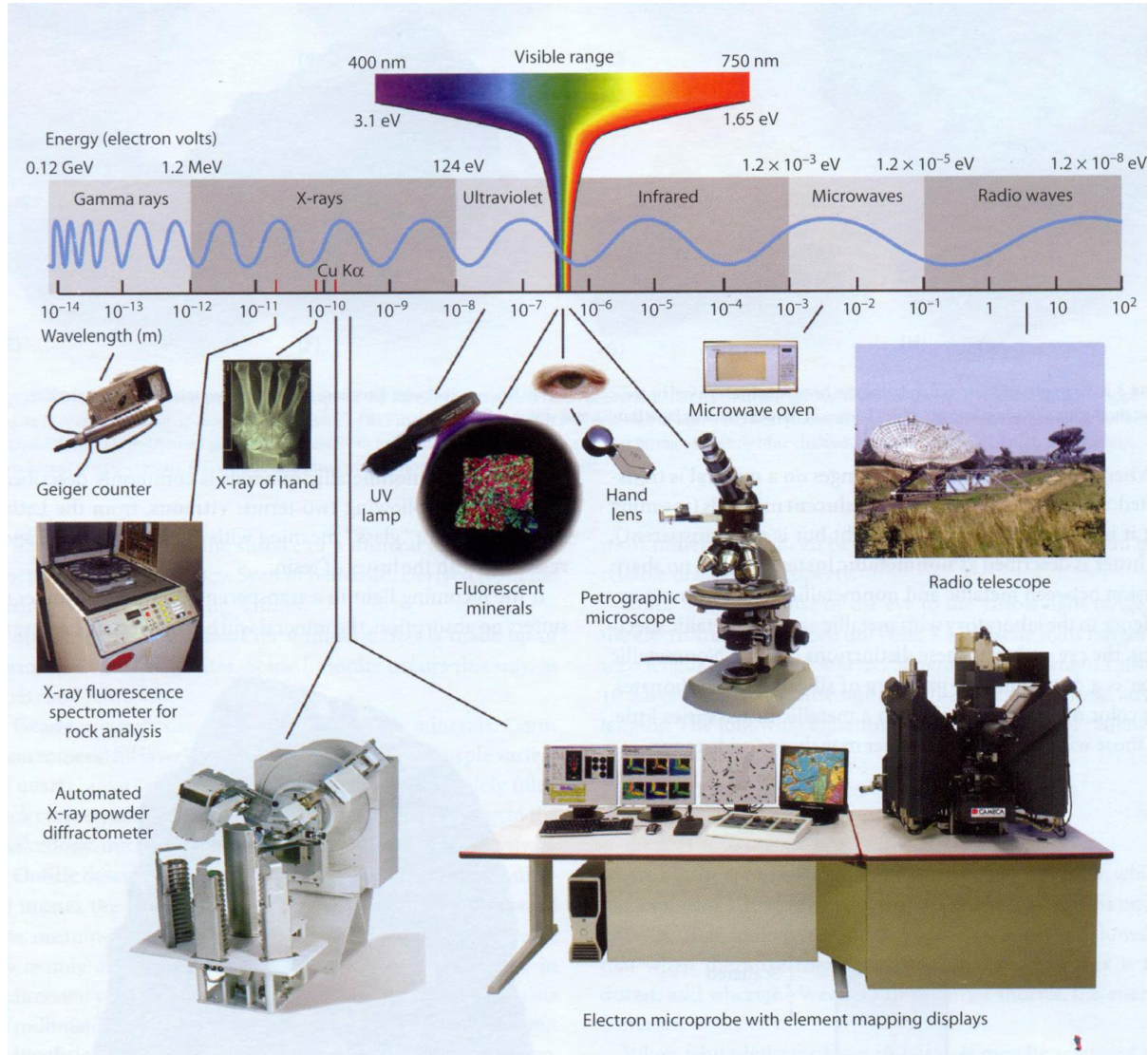




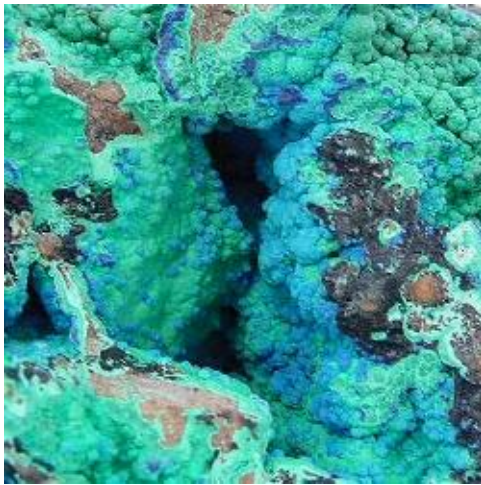
FIGURE 2.11 Quartz. Some minerals, such as quartz, occur in a variety of colors. These samples include crystal quartz (colorless), amethyst (purple quartz), citrine (yellow quartz), and smoky quartz (gray to black). (Photo courtesy of E. J. Tarbuck)



Calcite Yellow



Calcite colorless



Malachite bluish green



Olivine green

Colour



Figure 3.3 Examples of a few minerals that can be uniquely identified by their color. From left in a clockwise direction: turquoise, turquoise in color; malachite, green; rhodochrosite, pink; lazurite, blue (known in the gem trade as lapis lazuli); and sulfur, yellow.

The **streak** of a mineral is the color it displays in finely **powdered form**. The streak maybe completely different from the color of the hand specimen.

One of the simplest ways of determining the streak of a mineral is to rub a specimen across a piece of unglazed porcelain known as a **streak plate**.

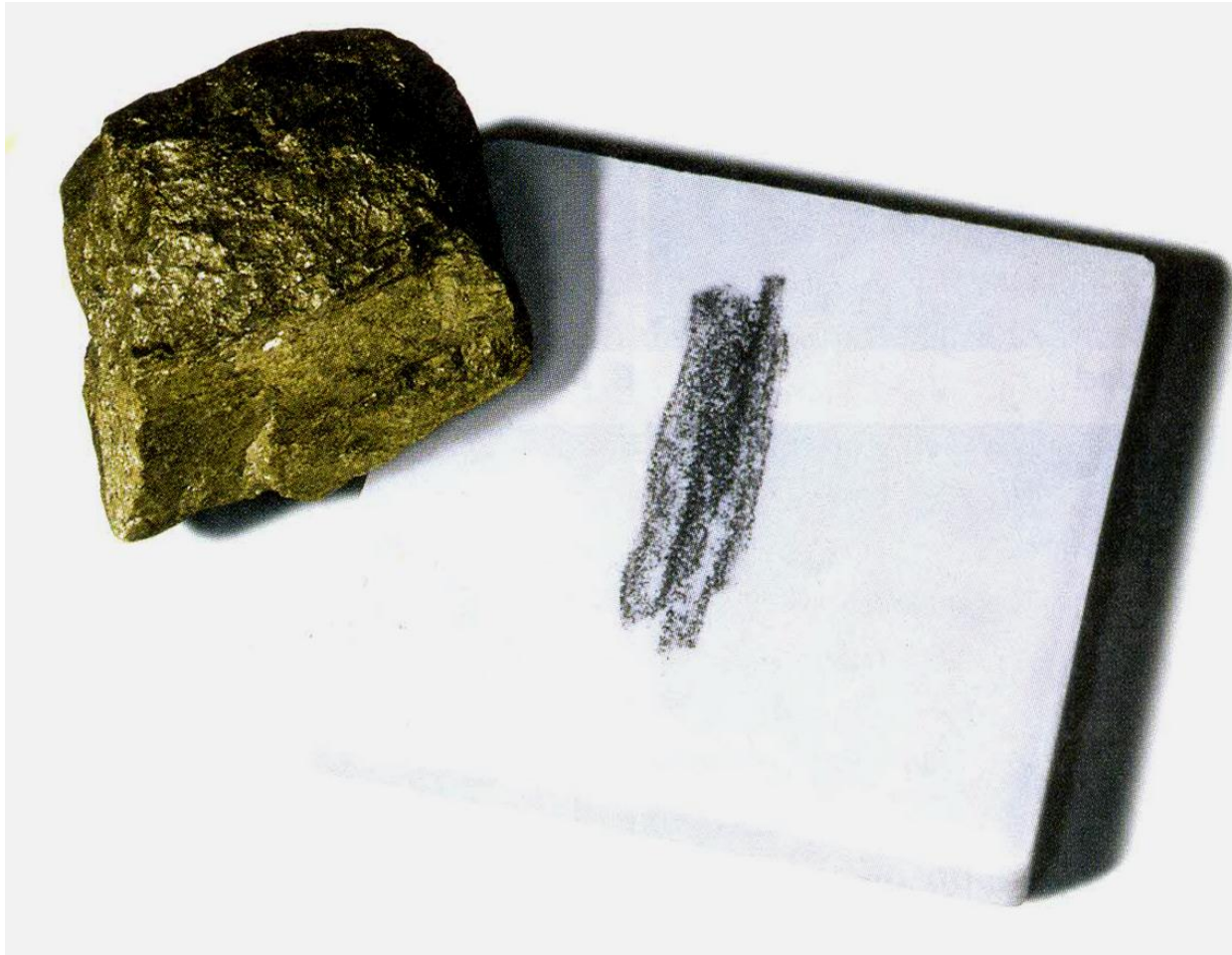


FIGURE 2.12 Although the color of a mineral is not always helpful in identification, the streak, which is the color of the powdered mineral, can be very useful. (Photo by Dennis Tasa)



4. Cleavage, fracture, and parting

All have to do with the positioning of atoms in a mineral and how it breaks when put under stress.

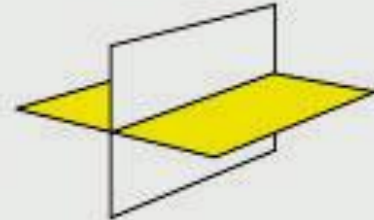
Because bonding is not of equal strength in all directions in most crystals, they will tend to break along crystallographic directions giving them a fracture property that reflects the underlying structure and is frequently diagnostic.

Cleavage

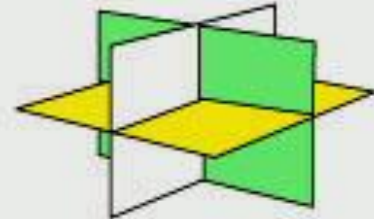
Cleavage is the tendency of a mineral to break along smooth planes parallel to zones of weak bonding.



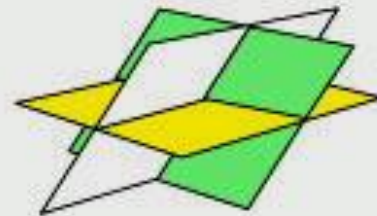
Cleavage in one direction. Example: MUSCOVITE



Cleavage in two directions. Example: FELDSPAR



Cleavage in three directions. Example: HALITE



Cleavage in two directions. Example: CALCITE

Halite Mineral



CLEAVAGE Cleavage in three directions at right angles (90°). Cubic cleavage.



Octahedral (fluorite)



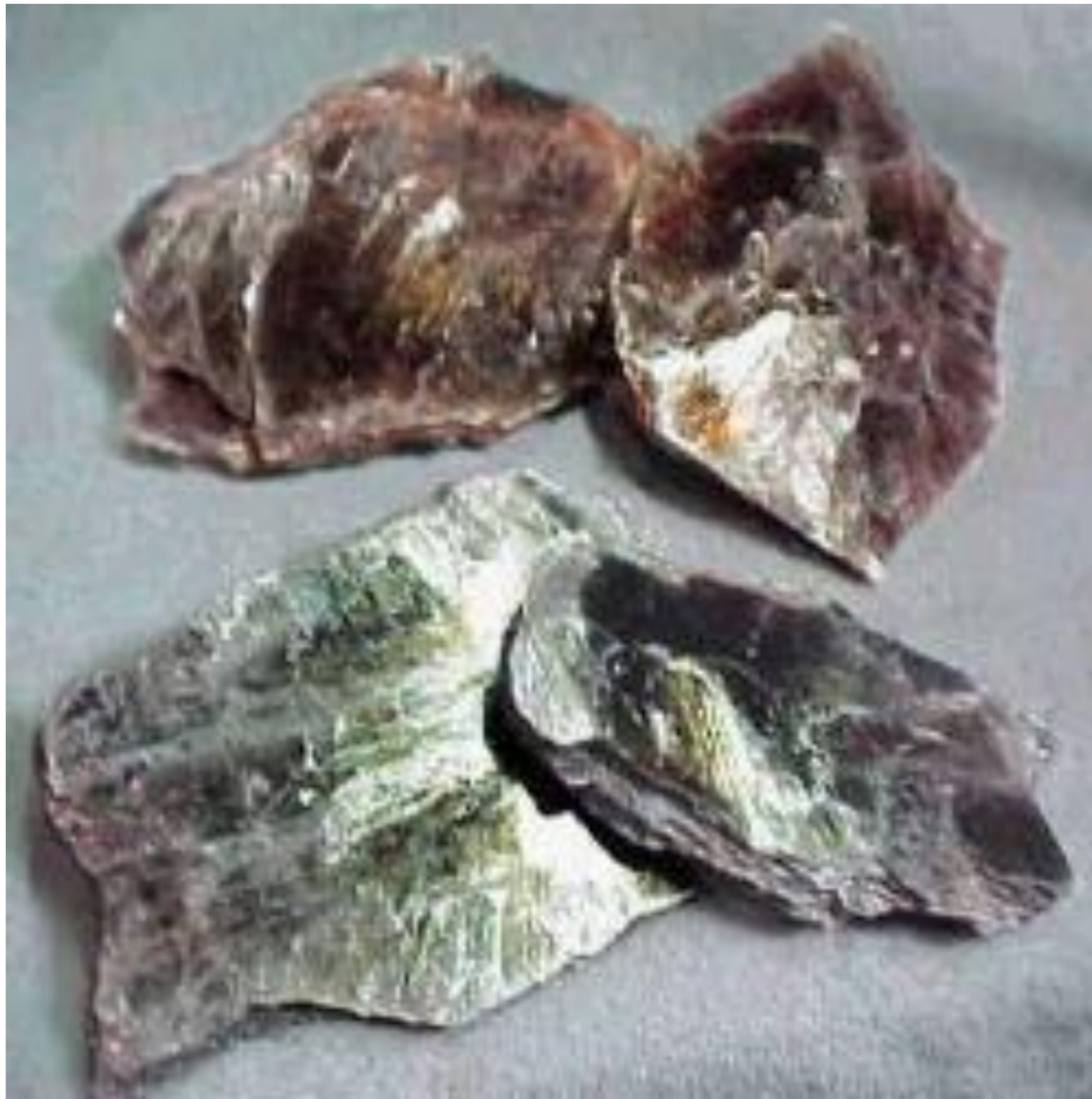
Calcite

Calcite Cleavage in three directions not at right angles (120° and 60°). Rhombohedral cleavage.



Gypsum

CLEAVAGE Cleavage in one direction.



Muscovite

Cleavage in one direction.

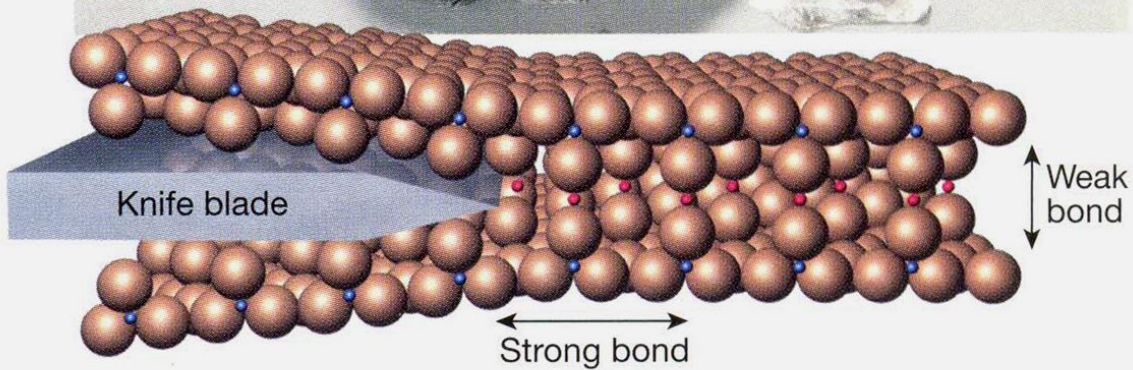


FIGURE 2.16 The thin sheets shown here were produced by splitting a mica (muscovite) crystal parallel to its perfect cleavage. (Photo by Chip Clark)



Quartz

FRACTURE Mineral does not exhibit cleavage, it breaks or fracture in an irregular manner.




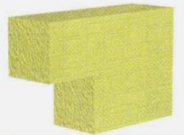
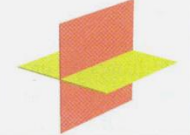


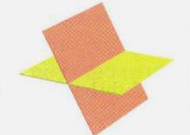

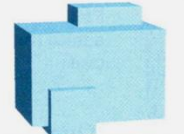
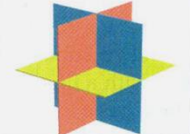


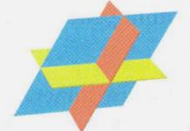




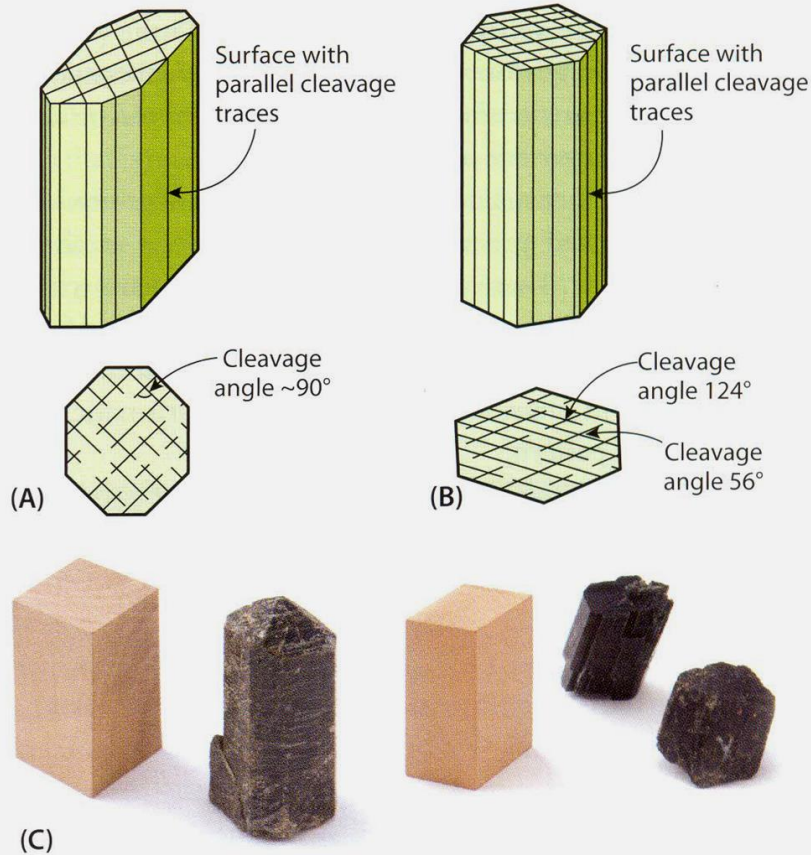
Number of Cleavage Directions	Shape	Sketch	Directions of Cleavage	Sample
1	Flat sheets			 Muscovite
2 at 90°	Elongated form with rectangle cross section (prism)			 Feldspar
2 not at 90°	Elongated form with parallelogram cross section (prism)			 Hornblende
3 at 90°	Cube			 Halite
3 not at 90°	Rhombohedron			 Calcite
4	Octahedron			 Fluorite

FIGURE 2.17 Common cleavage directions exhibited by minerals. (Photos by E. J. Tarbuck and Dennis Tasa)



Cleavages

Figure 3.14 Perspective sketches of pyroxene (A) and amphibole crystals (B) that show pronounced prismatic cleavage traces on the top faces of the crystals. With the top faces redrawn (parallel to the page) the actual angles between the two cleavage directions can be shown. These are at about 90° to each other in the pyroxene crystal, and at 124° and 56° to each other in the amphibole. (C) Photograph (on the left) of a pyroxene crystal and (on the right) two amphibole crystals. The external prismatic faces are parallel to their internal cleavage directions. The two small wooden models illustrate (on the left) the pyroxene cleavage angles and (on the right) amphibole cleavage angles.

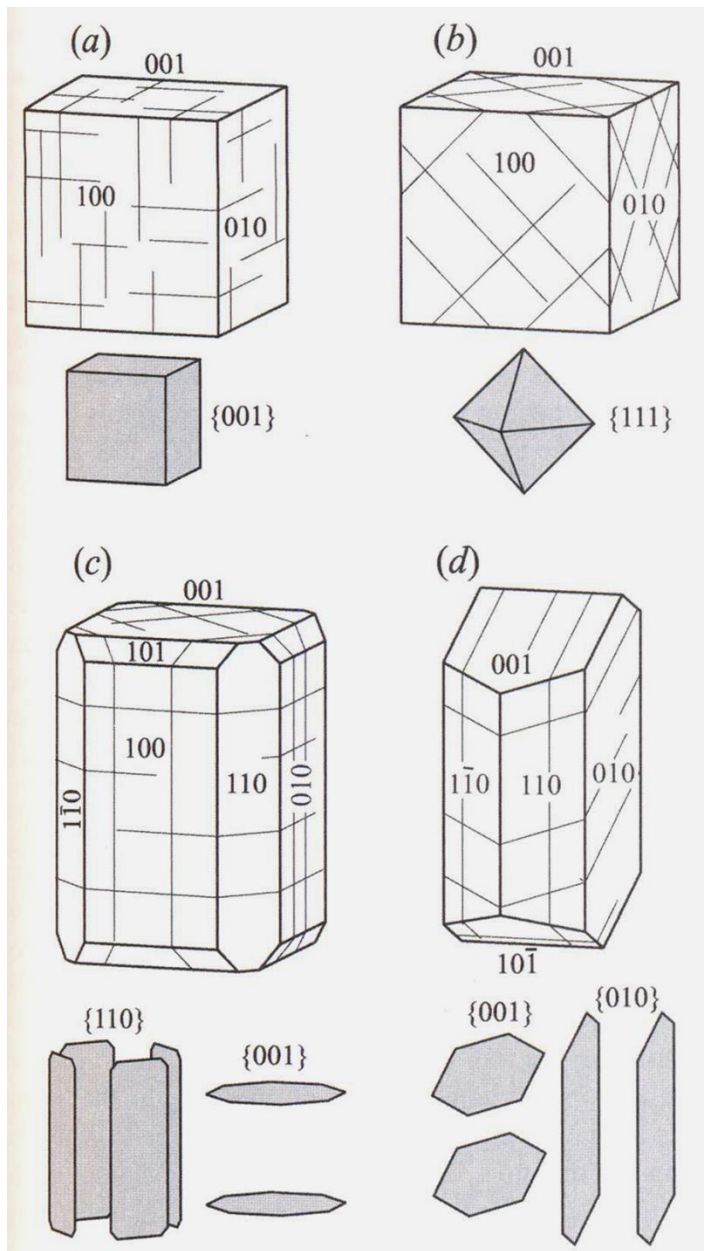
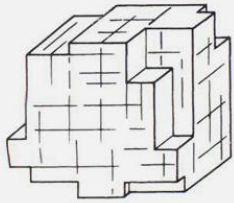
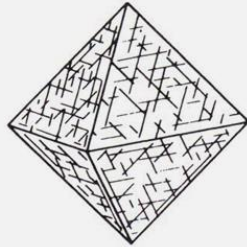


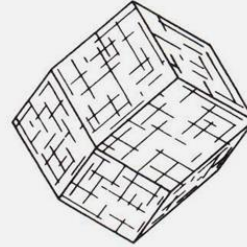
Figure 6.5 Cleavage. (a) Isometric $\{001\}$ cleavage (cubic). (b) Isometric $\{111\}$ cleavage (octahedral). (c) Tetrahedral $\{110\}$ (prism) and $\{001\}$ (pinacoid) cleavage. (d) Monoclinic $\{001\}$ (pinacoid) and $\{010\}$ (pinacoid) cleavage.



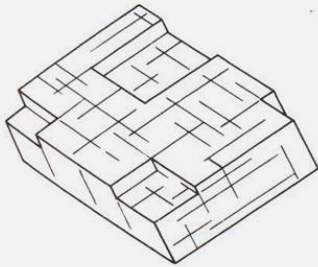
(a)



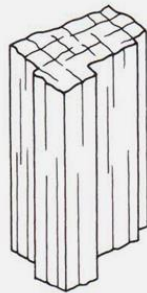
(b)



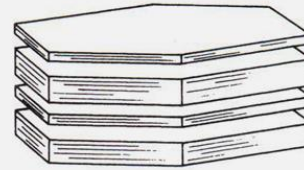
(c)



(d)



(e)



(f)

FIG. 2.12 Cleavage and its relationship to forms. (a) Cubic (3 cleavage directions parallel to faces of the cube). (b) Octahedral (4 directions). (c) Dodecahedral (6 directions). (d) Rhombohedral (3 directions). (e) Prismatic (2 directions) and pinacoidal (1 direction). (f) Pinacoidal, basal (1 direction).

Quality of Cleavage:

Quality of cleavage can be categorized into five qualities:

- **Perfect**
- **Good**
- **Poor**
- **Indiscernible (Indistinct)**
- **None**

Also termed as : perfect, imperfect, distinct, good, fair, and poor

Minerals with *perfect cleavage* will cleave without leaving any rough surfaces; a full, smooth plane is formed where the crystal broke.

Minerals with *good cleavage* also leave smooth surfaces, but often leave over minor residual rough surfaces.

On minerals with *poor cleavage*, the smooth crystal edge is not very visible, since the rough surface is dominant.

If a mineral exhibits cleavage, but it so **poor** that it is hardly noticeable, it has "***indiscernible***" cleavage.

Minerals with ***no cleavage*** never exhibit any cleavage, thus broken surfaces are fractured and rough.

Categorization of cleavage qualities is **not scientifically affirmed.**

The above categorization is used by most mineral references, but some guides categorize cleavage in three or four groups, and may give them different names, such as "excellent**" and "**distinct**".**

Number of Sides Exhibiting Cleavage

Many minerals exhibit cleavage only on one side, and some may exhibit different quality cleavage on different crystal sides. The following criteria may be expected when analyzing the cleavage of any particular mineral:

- One Direction**
- Two Directions**
- Three Directions**
- All Directions**

These identify how many "directions", or planes, the crystal is exhibiting the cleavage on. Each direction signifies the two opposite sides of a three-dimensional figure, (since opposite sides will always exhibit the same cleavage properties).

If a mineral has cleavage in three directions, then every side of the mineral has cleavage (i.e. length, width, and height).

If a mineral occurs in modified crystals with more than six sides (i.e. an octahedron) and exhibits cleavage on all the sides, then it has cleavage in "all directions".

Combining the cleavage level together with the number of sides will measure the cleavage of a mineral.

For example, if a mineral has Good Cleavage, Two Directions, this means that it has good cleavage on four out of six sides (while the other two sides exhibit no cleavage).

If a mineral has Perfect Cleavage, One Direction; Poor Cleavage, Two Directions, this means that the mineral has perfect cleavage on two sides, and poor cleavage on the other four.

If a mineral exhibits indistinct or no cleavage, Indiscernible or None is written in the cleavage field.

Cleavage Habit

Different habits of cleavage exist on different minerals, depending on their mode of crystallization. These forms of cleavage are:

Basal cleavage:

Cleavage exhibited on a horizontal plane of the mineral by way of its base. Minerals with basal cleavage can sometimes be "peeled".

An example of basal cleavage are the mica minerals.

Cubic cleavage:

Cleavage exhibited on minerals of the isometric crystal system that are crystallized as cubes. In this method of cleavage, small cubes evenly break off of an existing cube.

An example is Galena.

Octahedral cleavage:

Cleavage exhibited on minerals of the isometric crystal system that are crystallized as octahedrons. In this method of cleavage, flat, triangular "wedges" peel off of an existing octahedron. An example is Fluorite.

Prismatic cleavage:

Cleavage exhibited on some prismatic minerals in which a crystal cleaves as thin, vertical, prismatic crystals off of the original prism.

An example is Aegirine.

Pinicoidal cleavage:

Cleavage exhibited on some prismatic and tabular minerals in which a crystal cleaves on the pinacoidal plane, which is the third dimension aside from the basal and prismatic sides. An example is Barite.

Rhombohedral cleavage

Cleavage exhibited on minerals crystallizing in the hexagonal crystal system as rhombohedrons, in which small rhombohedrons break off of the existing rhombohedron. An example is Calcite.

A perfect cleavage results in regular flat faces resembling growth faces such as in mica, or calcite.

A less well developed cleavage is said to be imperfect, or if very weak, a **parting.**

If a fracture is irregular and results in a rough surface, it is **hackly. If the irregular fracture propagates as a single surface resulting in a shiny surface as in glass, the fracture is said to be **conchoidal**.**

Fracture

In some crystal structures, the strength of the bonds is approximately the same in all directions and breaking of these minerals generally will not follow a particular direction.

The breakage of minerals when they do not yield along cleavage or parting surfaces is fracture.

Fracture patterns can be distinctive and diagnostic in mineral identification.

For example **FIG. 2.13 (a) Basal parting, pyroxene, (b) Rhombohedral parting, corundum**

Parting

Parting is characteristically similar to cleavage. It is easily confused with cleavage, and it may be present on minerals that do not exhibit any cleavage. There are two causes of parting:

Two separate pressures pushed toward the center of a crystal after its formation, causing the crystal interior to evenly dislodge on a flat, smooth plane.

Twinned crystals that separated from one another, leaving a flat, smooth plane.

Parting

Some minerals which do not exhibit cleavage do have a characteristic that is similar, called *parting*.

It occurs in minerals that are crystallographically twinned, or which have been stressed by pressure.

It is usually not as well, or regularly, developed as cleavage surfaces - resembling an indistinct or poorer cleavage, and it is hard to difficult to produce in specimens.

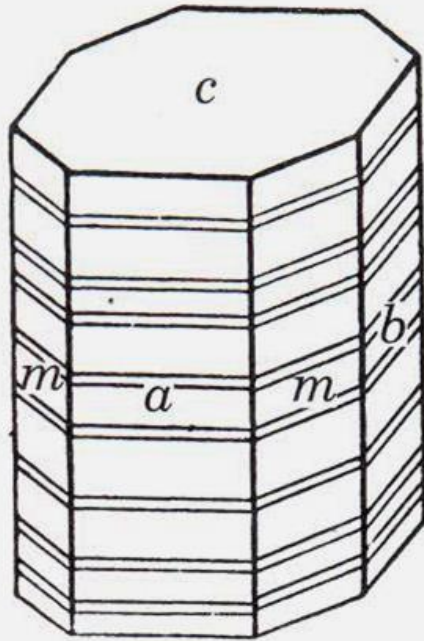
Perhaps the three best examples of it are the basal parting seen in the pyroxene minerals, the micaceous appearing parting in "specular" hematite, and the rhombic parting seen in corundum.

With enough perception, a distinction can be made between parting and cleavage. If fracture marks are present on a crystal in addition to a cleaved plane, the "cleaved" surface is usually the result of parting, not cleavage.

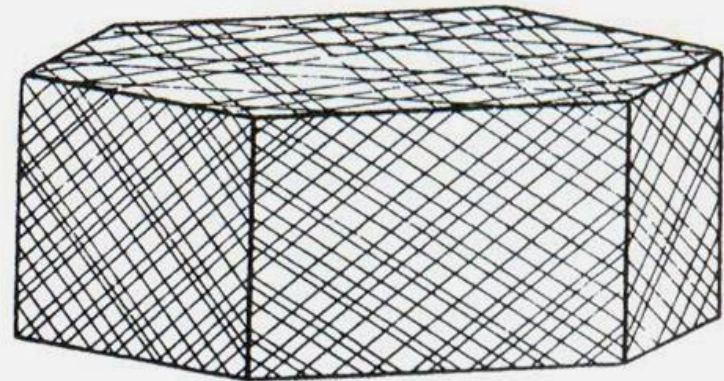
An outline of a crystal etched in a mineral is also the result of parting, in the form of twinned crystals that separated.

In general, one need not worry about confusing parting with cleavage. Parting is uncommon, and it can usually be determined by the distinguishing characteristics mentioned above.

FIG. 2.13 (a) Basal parting, pyroxene. (b) Rhombohedral parting, corundum.



(a)



(b)

Fracture patterns are given names based on their appearance. A few examples follow.

Conchoidal fracture produces the smooth, curved surfaces or ridges resembling the interior surface of a shell (**Fig. 2.14**). This is commonly observed in materials such as broken glass and quartz.

Conchoidal.

This fracture is also known as "shelly" in some reference guides.

Subconchoidal - Fracture that falls somewhere between conchoidal and even; smooth with irregular rounded corners.

Some references may describe additional fractures not mentioned above, but those terms are either synonymous or simply used as a verbal depiction of the authors inference.

Conchoidal Fracture

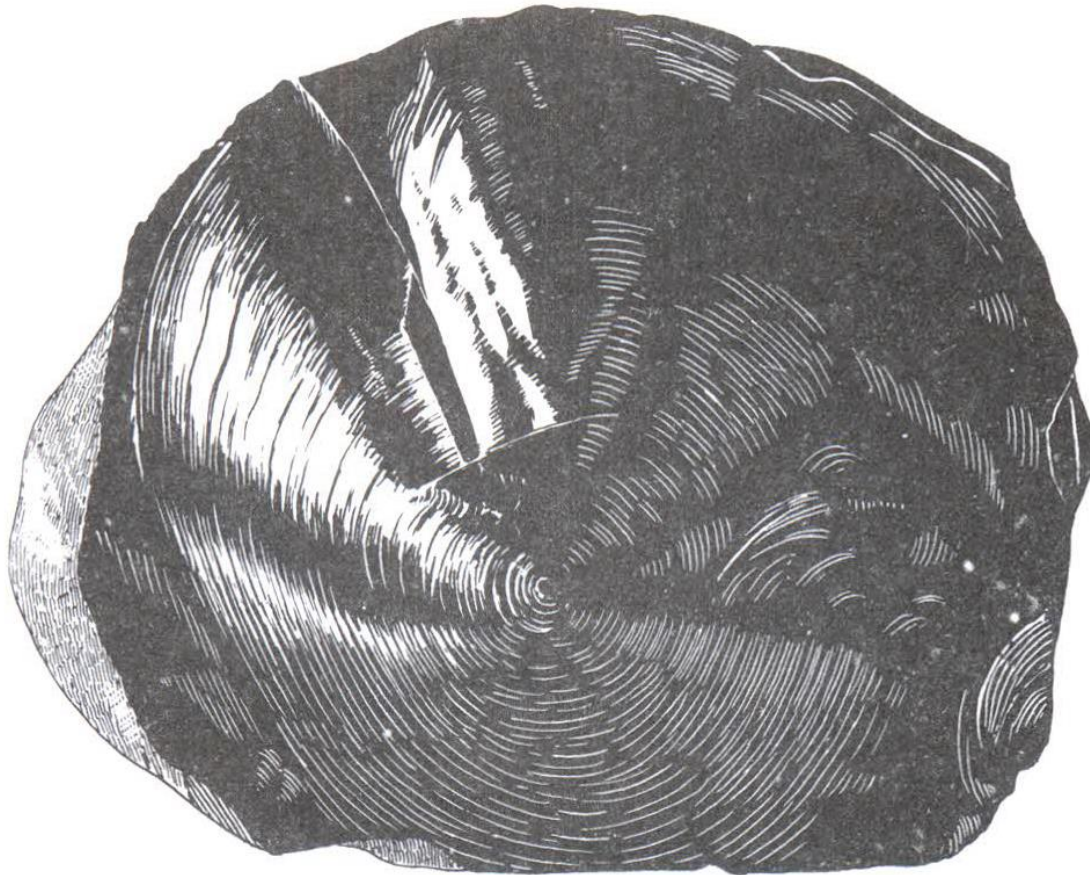


Fig. 2.14: Conchoidal fracture, as seen in obsidian (volcanic glass)

Fibrous and splintery fracture results in pieces that are fibrous or as splinters. Hackly fracture produces a jagged and sharp edge.

Uneven or irregular fractures produce rough and irregular surfaces.

Hackly - Fracture that resembles broken metal, with rough, jagged, points. True metals exhibit this fracture. (This fracture is also known as "jagged".)

Earthy or crumbly - Fracture of minerals that crumble when broken.

Even or smooth - Fracture that forms a smooth surface.

Conchoidal Fracture



Figure 3.18 Conchoidal fracture as seen in a specimen of clear quartz.

Conchoidal fracture



FIGURE 2.18 Conchoidal fracture. The smooth, curved surfaces result when minerals break in a glasslike manner. (Photo courtesy of E. J. Tarbuck)

5. Tenacity

is the ability of a mineral to deform plastically under stress. Minerals may be brittle, that is, they do not deform, but rather fracture, under stress as do most silicates and oxides.

They may be **sectile**, or be able to deform so that they can be cut with a knife. Or, they may be **ductile** and deform readily under stress as does gold.

Density

is a well-defined physical property measured in g/cm^3 .

Most **silicates** of light element have densities in the range 2.6 to 3.5.

Sulfides are typically 5 to 6.

Iron **metal** about 8, lead about 13, gold about 19, and osmium, the densest substance, and a native element mineral, is 22.

Density may be measured by measuring the volume, usually by displacing water in a graduated cylinder, and the mass.

Specific gravity is very similar to density, but is a dimensionless quantity and is measured in a slightly different way.

Specific gravity is measured by determining the weight in air (W_a) and the weight in water (W_w) and computing specific gravity from

$$\mathbf{SG = W_a / (W_a - W_w).}$$

In practice this is done using a Jolly balance.

Table 3.2 Some rock-forming minerals arranged according to light, average, and heavy values of specific gravity (**G**).

Light	Average	Heavy
Bauxite (an ore of aluminum) 2.0–2.5	Microcline 2.5	Barite 4.5
	Albite 2.6	Pyrolusite
Halite 2.1	Quartz 2.6 Calcite 2.7	Pyrite 5.0
Serpentine 2.2–2.6	Plagioclase 2.6–2.8	Magnetite
Sodalite 2.3	Dolomite 2.85 Tremolite 3.0–3.3 Apatite 3.1–3.2	Galena 7. Silver 10.5 Gold 15.0

7. Hardness

Hardness is a measure of a mineral's resistant to abrasion. This property is easily determined and is used widely for field identification of minerals.

More than a century ago. Friedrich Mohs (1773-1839), a German mineralogist, assigned arbitrary relative numbers to ten common minerals in order of their hardness.

It is usually tested by seeing if some standard minerals are able to scratch others. A standard scale was developed by Friedrich Mohs in **1812**. The standard minerals making up the Mohs scale of hardness are:

1. Talc
2. Gypsum
3. Calcite
4. Fluorite
5. Apatite
6. Orthoclase
7. Quartz
8. Topaz
9. Corundum
10. Diamond

This scale is approximately linear up to corundum, but **diamond is approximately 5 times harder than corundum.**

Mineral Hardness

Table 3.1 Mohs hardness scale minerals.

Hardness number (H)	Mineral name	Chemical formula	Remarks
1	Talc	$Mg_3Si_4O_{10}(OH)_2$	Soft, greasy feel; flakes are left on the fingers
2	Gypsum	$CaSO_4 \cdot 2H_2O$	Can be easily scratched by the fingernail <i>fingernail hardness ~2.2</i>
3	Calcite	$CaCO_3$	Can be easily scratched with a knife and just scratched by a copper penny <i>copper penny hardness ~3.2</i>
4	Fluorite	CaF_2	Less easily scratched by a knife than calcite
5	Apatite	$Ca_5(PO_4)_3(F, Cl, OH)$	Is scratched by a knife with difficulty <i>pocket knife hardness ~5.1</i> <i>glass plate hardness ~5.5</i>
6	Orthoclase	$KAlSi_3O_8$	Not scratched by a knife and will scratch ordinary glass
7	Quartz	SiO_2	Scratches glass easily <i>porcelain streak plate hardness ~7</i>
8	Topaz	$Al_2SiO_4(F, OH)_2$	Scratches glass very easily ^a
9	Corundum	Al_2O_3	Cuts glass ^a
10	Diamond	C	Used as a glass cutter ^a

^a There are few minerals that are as hard as, or harder than, quartz, and these include several of the highly prized gems.

FIGURE 2.15 Hardness scales. **A.** Mohs scale of hardness, with the hardness of some common objects. **B.** Relationship between Mohs relative hardness scale and an absolute hardness scale.

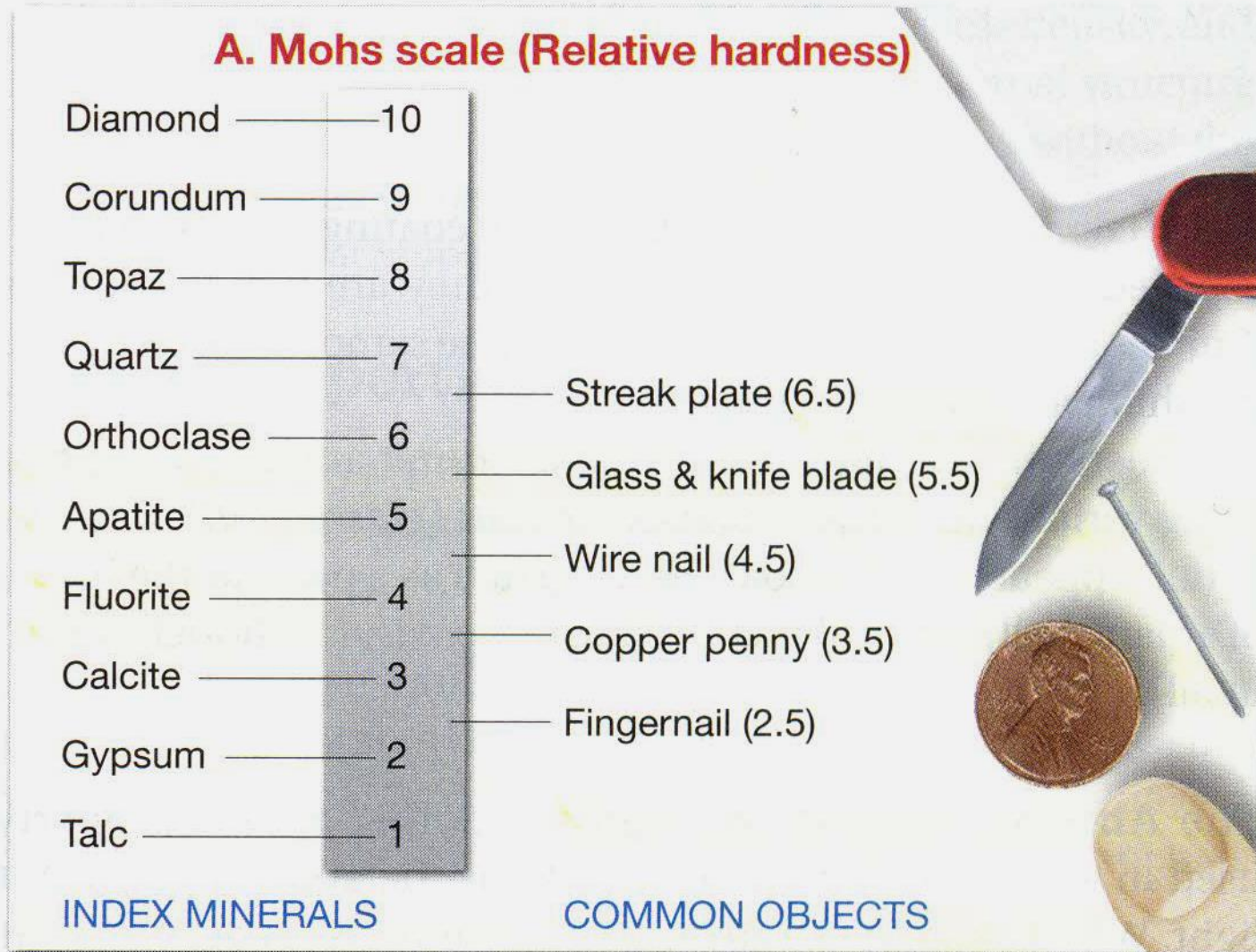
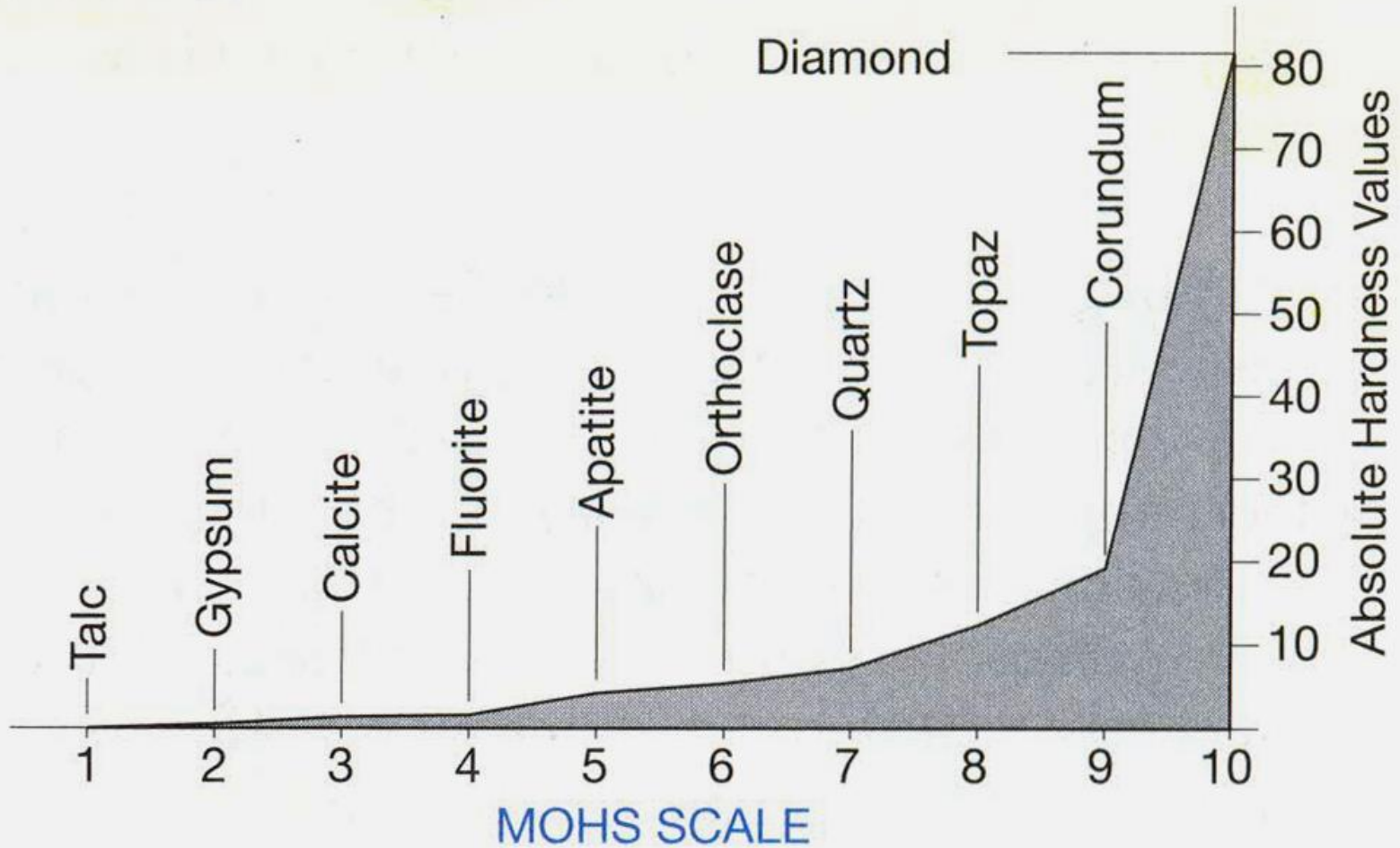


Table 2.3

Mohs Hardness Scale and Additional Observations (From C. Klein, 2008, *Minerals and rocks: Exercises in crystal and mineral chemistry, crystallography, X-ray powder diffraction, mineral and rock identification, and ore mineralogy*. 3rd ed. Wiley, New York.)

Mineral	Mohs Hardness	Other Materials	Observations on the Minerals
Talc	1		Very easily scratched by the fingernail; has a greasy feel
Gypsum	2	~2.2 fingernail	Can be scratched by the fingernail
Calcite	3	~3.2 copper penny	Very easily scratched with a knife and just scratched by a copper coin
Fluorite	4		Easily scratched with a knife but not as easily as calcite
Apatite	5	~5.1 pocket knife ~5.5 glass plate	Scratched with a knife, with difficulty
Orthoclase	6	~6.5 steel file	Cannot be scratched with a knife, but scratches glass
Quartz	7	~7.0 streak plate	Scratches glass easily
Topaz	8		Scratches glass very easily
Corundum	9		Cuts glass
Diamond	10		Used as a glass cutter

B. Comparison of Mohs scale and an absolute scale



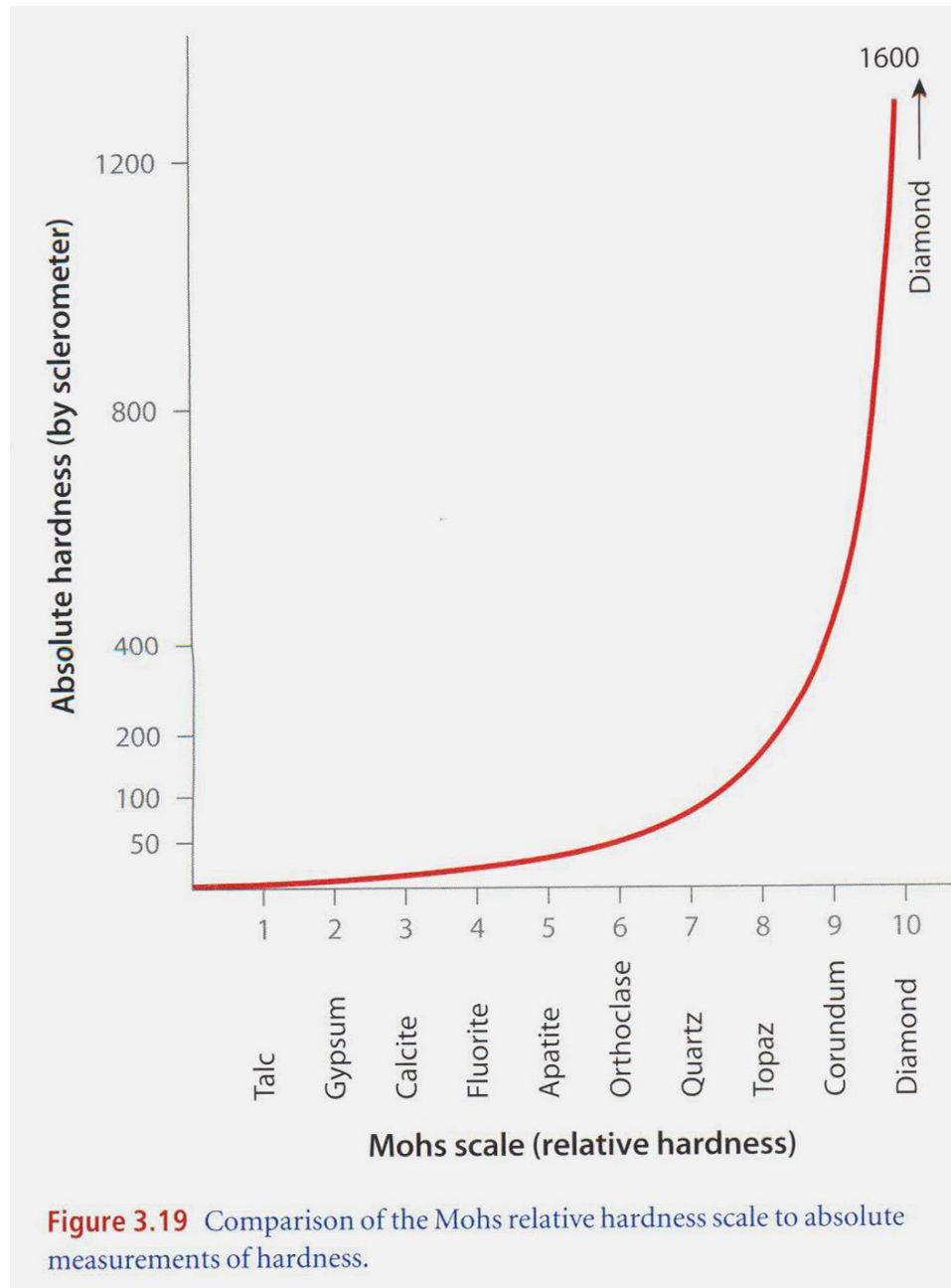


Figure 3.19 Comparison of the Mohs relative hardness scale to absolute measurements of hardness.

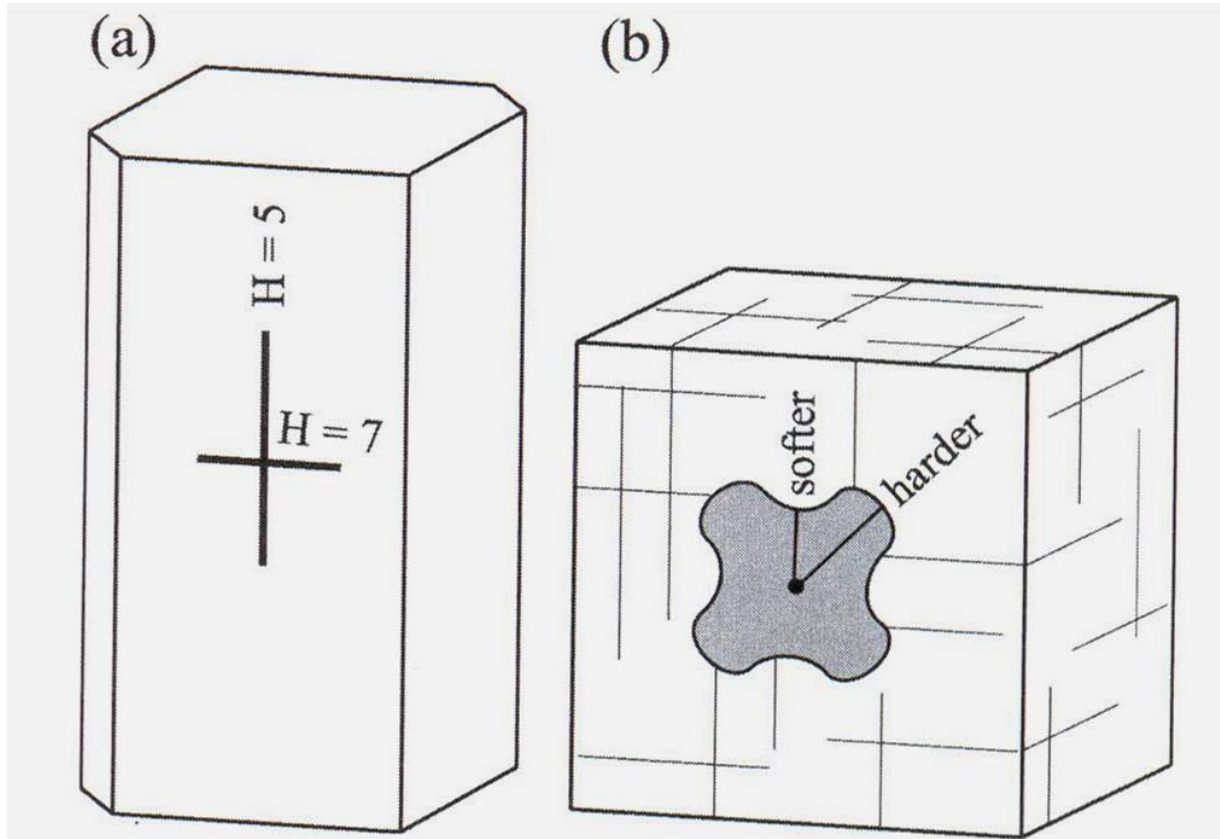


Figure 6.3 Variation of mineral hardness with direction. (a) Kyanite. Scratch hardness parallel to the length of crystals is 5 and at right angles is 7. (b) Halite. Scratch hardness parallel to the trace of cleavage is slightly less than hardness at 45° . The length of a line drawn from the central dot to the edge of the shaded figure schematically shows the hardness parallel to that line.

Relation between Hardness and Chemical composition

Because there is a general link between hardness and chemical composition, the following generalizations can be made:

- Most hydrous minerals are relatively soft ($H < 5$).
- Halides, carbonates, sulfates, and phosphates are also relatively soft ($H < 5.5$).
- Most sulfides are relatively soft ($H < 5$) with pyrite being an exception ($H \sim 6$ to 6.5).
- Most anhydrous oxides and silicates are hard ($H > 5.5$).

Unique Properties

A few minerals may have easily tested unique properties that may greatly aid identification.

For example, halite (NaCl) (common table salt) and sylvite (KCl) are very similar in most of their physical properties, but have a distinctly different taste on the tongue, with sylvite having a more bitter taste.

Whereas it is not recommended that students routinely taste mineral specimens (some are toxic), taste can be used to distinguish between these two common minerals.

Another unique property that can be used to distinguish between otherwise similar black opaque minerals is **magnetism**.

For example, **magnetite** (Fe_3O_4), **ilmenite** (FeTiO_3), and **pyrolusite** (MnO_2) are all dense, black, opaque minerals which can easily be distinguished by testing the magnetism with a magnet.

Magnetite is strongly magnetic and can be permanently magnetized to form a lodestone; ilmenite is weakly magnetic; and pyrolusite is not magnetic at all.

Other Properties

There are numerous other properties that are diagnostic of minerals, but which generally require more sophisticated devices to measure or detect.

For example, minerals containing the elements U or Th are **radioactive** (although generally not dangerously so), and this radioactivity can be easily detected with a Geiger counter or scintillation counter.

Examples of radioactive minerals are **uraninite** (UO_2), **thorite** (ThSiO_4) etc.

Some minerals may also be **fluorescent** under **ultraviolet** light, that is they absorb UV light and emit in the visible.

Other optical properties such as **index of refraction** (refractive index R.I.) and **pleochroism** (differential light absorption) require an optical microscope to measure and are the subject of a major section of this course.

Double refraction: e.g. Calcite

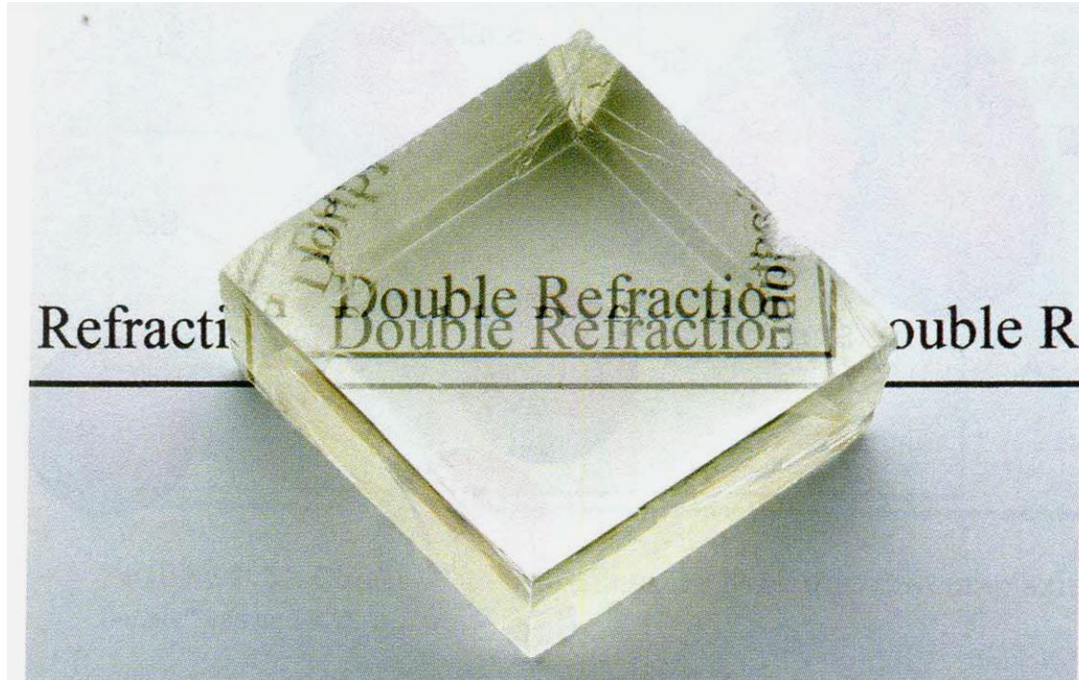


FIGURE 2.19 Double refraction illustrated by the mineral calcite.
(Photo by Chip Clark)

Electrical conductivity is an important physical property but requires an impedance bridge to measure.

In general native metals are good **conductors**, sulfides of transition metals are **semi-conductors**, whereas most oxygen-bearing minerals (i.e., silicates, carbonates, oxides, etc.) are **insulators**.

Additionally, quartz (SiO_2) is **piezoelectric** (develops an electrical charge at opposite end under an applied mechanical stress);

and tourmaline is **pyroelectric** (develops an electrical charge at opposite end under an applied thermal gradient).

Determination of Hardness of a mineral

Some cautions

In making a determination of hardness, one should always use a fresh mineral surface, and observe the following:

1. Sometimes, when one mineral is softer than another, portions of the first will leave a mark on the second that may be mistaken for a scratch. Such a mark can be rubbed off, whereas a true scratch will be permanent.

2. The surfaces of some minerals are frequently altered to a material that is much softer than the original mineral. A *fresh surface* of the specimen to be tested must be used.

3. The physical nature of a mineral may prevent a correct determination of its hardness. For instance, if a mineral is granular, or splintery, it may break but appear to be scratched by a mineral much softer than itself. It is always advisable when making the hardness test to confirm it by reversing the order of procedure; that is, try to scratch mineral *A* by mineral *B*, but also try to scratch *B* by *A*.

Hardness is a vectorial property, and some minerals show varying degrees of hardness depending on the directions in which they are scratched.

In most common minerals, this difference is so slight that it is only detected through the use of sophisticated instruments.

Two exceptions are kyanite and calcite.

In kyanite, $H = 5.5$ parallel to the length, but $H = 7$ across the length of the crystal. Consequently, a knife will scratch kyanite parallel to the blade but not across the blade.

The hardness of calcite is 3 on all surfaces except on a planar surface that may appear at the top of a calcite crystal; on this face it can be scratched by a fingernail and has a hardness of 2.

Because hardness is a highly diagnostic property in mineral identification, most determinative tables use relative hardness as a primary sorting parameter, as is done in the Determinative Table 22.1 in Chapter 22.

Thank you