

**Volume I**



An  
Introduction to  
Minerals

By Vivien Gornitz



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# AN INTRODUCTION TO MINERALS



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New York City

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# PREFACE

This booklet has grown from a set of notes prepared for the Study Group of the New York Mineralogical Club, held at the American Museum of Natural History in New York City between 1995 and 1996. It provides an introduction to basic concepts of mineralogy and crystallography that govern the physical properties and morphology of crystals, mineral clusters, and aggregates. This information will give mineral collectors and rockhounds a sounder basis for recognizing and identifying minerals. In addition, mineral enthusiasts will also develop a keener esthetic appreciation of the factors that contribute to the formation of a well-crystallized specimen. The material in this booklet is intended to bridge a gap between the colorfully-illustrated field guides and the more technically-oriented texts and reference books.

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# CHAPTER 1

# PHYSICAL PROPERTIES OF

# MINERALS

## Introduction

Minerals exist everywhere — in the soil underfoot, the arid wastelands of deserts, the rocks of the loftiest mountain ranges, the ocean depths, and beyond the earth, to the farthest reaches of the solar system. Minerals have benefitted human society, from the most ancient flint and chert tools, to the metal and pottery artifacts and colorful pigments of the early civilizations, to the steel, glass, ceramic, and silicon products of our technological era.

Mineralogy, or the scientific study of minerals, is one of the oldest of the physical sciences. It has contributed extensively to the development of geology, crystallography, inorganic chemistry, physics, and materials science. The observation of Nicolaus Steno, in 1669, that the angles between crystal faces of quartz remained constant, no matter how distorted or misshapen the crystal, became the foundation for the science of crystallography. In the 18th and 19th centuries, new discoveries in chemistry and mineralogy were closely intertwined. The famous Swedish chemist, Jon Jacob Berzelius (1799-1848) devised the basis for the chemical classification of minerals, still widely used today (see Chapter 6).

The modern phase of mineralogy began in 1913, when the Bragg father and son team used X-ray diffraction of crystals, for the first time, to infer the internal arrangement of sodium and chlorine atoms in halite. Within the last few decades, highly sophisticated new instruments have been devised that can probe extremely minute portions of a crystal to detect subtle variations in chemical composition, study tiny inclusions, and even “see” the actual atoms in a crystal.

Aside from their value to human society and to science, an important motivation for collecting minerals is their sheer beauty and variety. The dramatic shapes and vivid colors of well-formed crystals have a sculptural quality that represents nature's finest artwork. A keener appreciation of the attributes of a desirable, collectible specimen depends on a knowledge of how crystals grow in nature, as well as a recognition of their shapes, symmetries, and physical characteristics.

This booklet provides the basic information needed by the novice collector or mineral enthusiast to begin to recognize and identify the common minerals. The material presented here can be used in conjunction with well-illustrated field guides. Although not all-inclusive, this booklet highlights some of the more important topics that will give the collector a basic understanding of mineralogy.



# Mineral — Definition

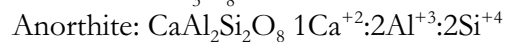
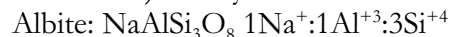
A mineral is a homogeneous solid that occurs in nature and that has a specific, but not always fixed, chemical composition, and repetitive atomic arrangement. It is usually formed by inorganic processes.

*Occurs in nature.* Materials having the same chemical composition as minerals, but produced in the laboratory are, strictly speaking, not true minerals. Such gemstones or crystals should be described as “lab-grown” or “synthetic.”

*Homogeneous solid.* This implies a uniform material or phase. However, homogeneity may depend on **scale**. What appears to be homogeneous to the naked eye may be inhomogeneous under higher magnification. For example, microcline often contains very fine narrow blebs or streaks of albite that are visible even to the naked eye.

*Specific but not always fixed chemical composition.* Atoms are usually present in specific proportions. For example, quartz has one atom of silicon for each two atoms of oxygen ( $\text{SiO}_2$ ). However, for many minerals, atoms or ions (atoms that have either lost or gained electrons and therefore carry an electrical charge) can be interchangeable within certain limits. The degree of chemical variability is constrained by two basic principles:

1. **Preservation of electrical neutrality.** The crystal has to remain electrically neutral, overall. This means that the sum of the positive charges has to equal the sum of the negative charges. For example, one potassium ( $\text{K}^+$ ) ion can replace one sodium ( $\text{Na}^+$ ) ion in the alkali feldspars (both carry the same charge). On the other hand, for the plagioclase feldspars, one  $\text{Na}^+$  and one aluminum ( $\text{Al}^{+3}$ ) replace one calcium ( $\text{Ca}^{+2}$ ) and two  $\text{Al}^{+3}$  ions. To maintain electrical neutrality, the number of silicon atoms must therefore be reduced from three in albite (the sodium end-member of the series) to only two in anorthite (the calcium end member of the plagioclase series).



2. **Atomic or ionic size.** The size of the substituting atom or ion has to fall within certain limits, due to the constraints of solid geometry, i.e., the way in which spheres are packed in three-dimensional space.

*A repetitive atomic arrangement.* This is characteristic of all crystalline solids. **Crystalline** implies a repeating pattern of atoms, ions, or molecules arranged in a three-dimensional array or lattice. The term crystalline should not be confused with **crystal**, which is a solid bounded by flat (planar) surfaces (called faces) that are related to each other by symmetry. (Symmetry will be explained further in the next chapter). The external symmetry of a crystal is a reflection of its internal (atomic-level) symmetry. A crystalline solid does not necessarily have well-developed crystal faces, but does have an ordered arrangement of its atoms. For example, obsidian (volcanic glass) and opal do not have an internal crystalline arrangement. They are called **mineraloids**.<sup>1</sup>

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<sup>1</sup> Glass (both volcanic and man-made) and opal are warmer to the touch than quartz, which is crystalline. The repetitive array of atoms in quartz allows heat to be conducted more efficiently, which makes it feel cooler.

*Usually formed by inorganic processes.* This is a tricky part of the definition, as interactions between minerals and living systems are fairly common in nature. For example, calcite or aragonite found in mollusk shells, corals, and pearls, as well as hydroxyapatite in bone are **inorganic** compounds that form as a result of biological processes. Hence, these are not considered to be true minerals. On the other hand, whewellite, or calcium oxalate, is a **naturally-occurring organic** compound and therefore qualifies as a mineral. The term **organic** as used in chemistry refers to compounds of carbon other than carbonate or carbon dioxide. Note that there are two different connotations of the word **inorganic**: 1. non-biological and 2. non-carbon-containing (other than carbonates).

## Physical Properties of Minerals

Physical properties of minerals arise from their chemical and structural makeup. Inasmuch as many physical properties can be rapidly evaluated by visual inspection of hand specimens or by fairly simple tests, they are very useful to the mineral collector for identification.

### **Crystal Habits** (see Figure 1.1).

Crystals are solids bounded by smooth, flat faces, producing characteristic forms. **Crystal forms** consist of a set of faces that are related to each other by symmetry (for example, the 6 faces of a cube, the 8 faces of an octahedron, or the 6 faces of a hexagonal prism). Crystal forms and principles of symmetry will be described further in Chapter 2. Minerals tend to occur in specific **habits**. The habit of a crystal refers to its overall shape or morphology — the ensemble of commonly-occurring forms. Some common habits of groups or aggregates of crystals are listed here.

**Acicular** — thin needles, e.g., rutile, tremolite-actinolite.

**Capillary, filiform** — hairlike or threadlike crystals, e.g., native silver.

**Fibrous** — thin fibrous crystals, e.g., asbestiform serpentine (chrysotile), crocidolite (amphibole asbestos).

**Dendritic** — branched like a tree, e.g., pyrolusite, native gold, silver.

**Reticulated** — intersecting groups of crystals, e.g., cerussite.

**Bladed** — elongated, flat crystals, e.g., kyanite.

**Drusy** — thin layer of small crystals, often coating another mineral, e.g., quartz on chrysocolla.

**Botryoidal** — grapelike, e.g., hematite, malachite. (Reniform — kidney-shaped; mammillary, colloform — spherical masses — generic term).

**Scaly or Lamellar** — flat, thin plates, e.g., molybdenite, specular hematite

**Micaceous** — very thin flakes, like mica e.g., muscovite, biotite, chlorite, talc.

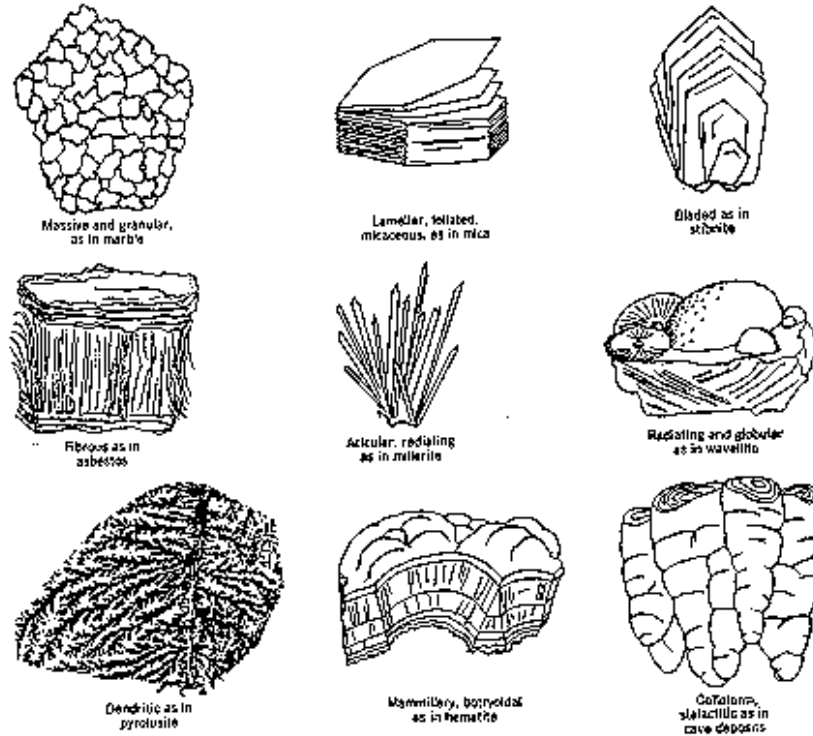
**Plumose** — feathery, e.g., some agates.

**Prismatic** — elongated crystal prisms, e.g., beryl, tourmaline, quartz.

**Granular** — composed of more-or-less equally-sized small grains (also used to describe certain igneous rocks like granite or diabase).

**Massive** — nondescript, formless compact masses.

Figure 1.1. Common mineral habits.



## Luster and Color

Luster refers to the way in which light is reflected from a mineral surface, creating a particular kind of sheen. It depends on a) the index of refraction (the ratio of the speed of light in air to the speed of light in the mineral) and b) the state of aggregation or surface polish (e.g., a well-polished surface of hematite is steel-gray, but its powder or streak is reddish-brown).

### Types of Luster

**Metallic** — opaque, no light transmitted. Polished surfaces are very reflective, e.g., native metals (gold, silver, copper), hematite, magnetite, pyrite.

**Submetallic** — duller on a polished surface. May be translucent in thin slices, e.g., cuprite, cinnabar, wolframite.

#### Non-Metallic:

**Adamantine** — diamond-like, brilliant, sparkling. Characteristic of minerals with a high index of refraction; e.g., diamond, zircon, cerussite, (sphalerite).

**Vitreous or Glassy** — most common minerals, e.g., quartz, garnet.

**Pearly** — like pearl or mother-of-pearl, weakly iridescent, e.g., talc, apophyllite cleavage faces.

**Resinous** — resin-like as with sphalerite, sulfur.

**Silky** — characteristic of fibrous minerals like asbestos, pectolite, malachite.

**Waxy** — chalcedony, nephrite.

**Earthy** — dull luster due to rough surface or microcrystalline aggregate.

Color can be either characteristic of the mineral (*ideochromatic*), because of the internal presence of a color-producing element, such as copper in azurite (blue) and malachite (green), manganese in rhodochrosite (pink-red), or due to occasional impurities, inclusions, or lattice defects (*allochromatic*) e.g. fluorite, quartz, topaz, beryl, etc.

The color of a mineral that we see is light that has been reflected from the surface of the mineral. It is caused by the selective absorption of various wavelengths of light. The wavelengths of reflected light are complementary to the wavelengths that have been absorbed by the mineral.

In anisotropic crystals (e.g., non-cubic or non-isometric crystal systems — see Chapter 2), light is broken into two rays that travel through the crystal with slightly different velocities, creating double refraction, as in calcite. In such crystals, light can also be absorbed to varying extents in different directions — hence the color changes depending on how the crystal is oriented. This phenomenon is called *pleochroism*. Pleochroism is best observed in plane polarized light — using a Polaroid filter (see also Chapter 7). Extremely pleochroic minerals where color changes can be seen with the naked eye include kunzite, tanzanite, tourmaline, iolite (cordierite).



## Optical Phenomena

These are phenomena in which the luster or color of the mineral surface seems to shift or move as the viewing angle changes.

**Play-of-Colors** e.g., opal; caused by diffraction from tiny, regularly-spaced microscopic spheres, causing changing flashes of color as the stone is moved.

**Labradorescence** e.g., labradorite; caused by diffraction from platy structures due to microscopic-scale intergrowth of two plagioclase phases that differ slightly in chemical composition.

**Chatoyancy** — a band of light forming at right angles to closely-packed parallel fibers (e.g. rutile) producing a cat's eye effect (e.g. chrysoberyl) or tiger's eye (fibrous crocidolite replaced by quartz). Other minerals occasionally displaying chatoyancy include tourmaline, sillimanite, aquamarine (Fig. 1.2).

**Asterism** results from the intersection of parallel sets of fibers in more than one direction. Six-rayed stars (ruby, sapphire, rose quartz) form when fibers intersect in three directions at  $120^\circ$  apart (Fig 1.2). A cross results from the intersection of two sets of inclusions or fibers at  $90^\circ$  (e.g., almandine garnet, black diopside).

Figure 1.2 (Left). Chatoyancy. Orientation of inclusions at right angles to the beam of light. (Right) Star effect produced by intersection of three sets of inclusions  $120^\circ$  apart.



















































































































