CHRISTOPHER BOOTS

WUNDERKAMMER

TWO THOUSAND AND
TWENTY THREE

INTRODUCTION

Wunderkammer is the start of a journey through the lens of curiosity and geology: a grand scale through which I've interpreted the mineral world. It's a world that has fascinated me since the discovery of my first crystal on a beach as a young boy, its structure speaking of patterns and otherworldly possibilities, made physical.

This exhibition is my little love letter to rocks and crystals, echoing my connection with nature, reminding me of the importance of grounding in our physical world. Each mineral is a testament to the shifting landscapes of time. With the physicality of design, I aim to share the joy of creation. Like portals to other worlds, each piece embodies a synergy of nature and human skill.

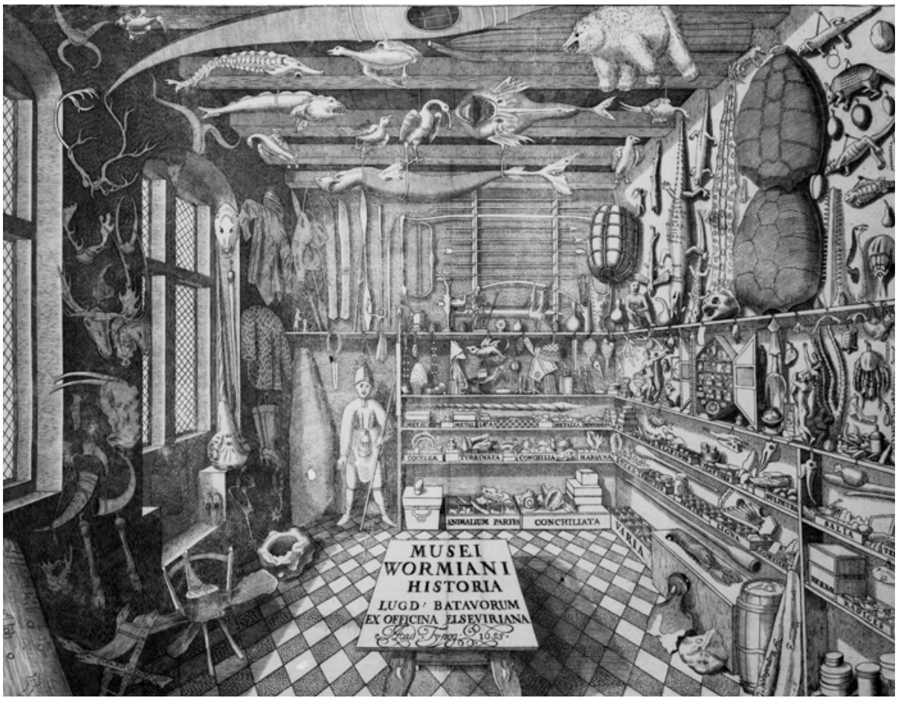
The WINGS OF PEGASUS lighting series and the SPECIMEN TABLE are not simply objects; they act as silent narrators, telling stories of far-off lands and the mesmerising dance between nature and craftsmanship. The CABINETS are prototypes for a future museum I'd love to build one day.

Transporting ideas across time and space is my big question. I hope I can answer that, through inspiration, through casting new light on the intricate beauty of minerals and their profound influence on our world. May you feel the allure of that first crystal in your hand, opening up another world of possibility, here made physical.

— Christopher Boots

WHAT IS A WUNDERKAMMER?

According to the Oxford Reference, Wunderkammer (German) translates as 'wonder chamber'. The word was originally used to describe a room containing a private collection of rare natural history specimens but above all curiosities. These days definitions vary and include, 'a place where a collection of curiosities and rarities is exhibited' (Halsey Institute of Contemporary Art at the College of Charleston) or 'cabinet of curiosity' (Oxford Dictionary).



"*Musei Wormiani Historia*", *the frontispiece from the Museum Wormianum depicting Ole Worm's cabinet of curiosities.*

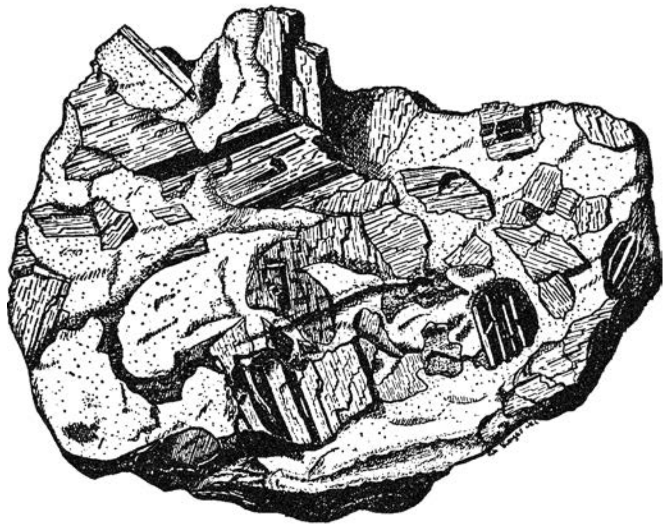
WHAT IS THIS WUNDERKAMMER?

Christopher Boots' Wunderkammer is all of the above, but better. It is an imaginative place filled with the objects he loves – minerals, rocks, gemstones and crystals. They come from the earth and are incorporated into his bespoke designs, that literally, light up our lives.

To understand just how precious these minerals are, we must explore the back story, for there is a fascinating history behind each of these naturally created wonders.

In the following pages there is the opportunity to discover Christopher's Wunderkammer, a real-life cabinet of curiosities that fills his life and work and contains that which has been naturally conceived over centuries, discovered and re-imagined for us today.

LAPIS LAZULI



MINERAL:	AGGREGATE ROCK
CHEMICAL FORMULA:	(NA,CA)8 AL6 SI6 O24 (S,SO)4
MOHS HARDNESS:	5 – 5.5
SPECIFIC GRAVITY:	2.75 (+/- 0.25)
REFRACTIVE INDEX:	1.5 – 1.67
BIREFRINGENCE:	NONE
COLOUR:	THROAT OF A BLUE TITMOUSE

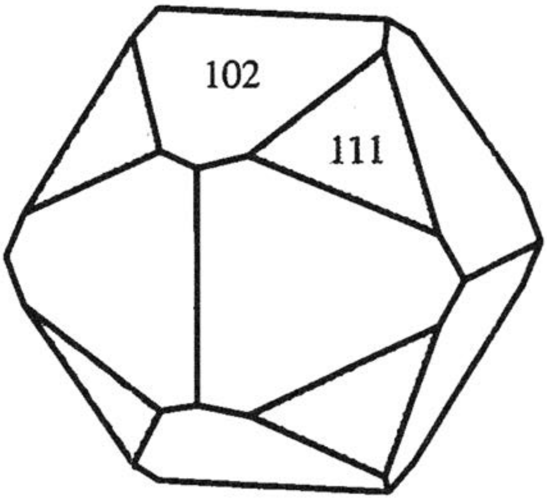
Lapis lazuli is a rock, an aggregate of several minerals. This ancient gem contains three minerals in varying amounts: lazurite, calcite, and pyrite. Sometimes, it also contains one or more of the following: diopside, amphibole, feldspar, and mica. Lapis frequently contains varying amounts of whitish calcite matrix—the host rock that surrounds the gem—or flecks or veins of glinting yellow pyrite, or both. The gem can also have a smoothly uniform bodycolour, free of visible pyrite and calcite.

Lapis is semi-translucent to opaque, with a waxy to vitreous luster. It has fair toughness, and its hardness ranges from five to six on the Mohs scale, depending on the mix of minerals.

Variously described as indigo, royal, midnight, or marine blue, lapis lazuli's signature hue is slightly greenish blue to violetish blue, medium to dark in tone, and highly saturated. In its most-prized form, lapis lazuli has no visible calcite, although it might have gold-coloured pyrite flecks. If the flecks are small and sprinkled attractively throughout the gem, their presence doesn't necessarily lower lapis lazuli's value. The lowest-quality lapis looks dull and green, the result of an excess of pyrite. Lapis with white calcite streaks is less valuable.

Although many people associate lapis with dark blue, it's also found in other shades of blue, and even other hues. Its colour can range from deep violet blue and royal blue to light blue to turquoise blue to a greenish blue. The combination of different minerals in the aggregate determines the colour. For example, lazurite is responsible for producing royal blue lapis, while a mineral called afghanite creates a pale blue shade.

PYRITE



MINERAL:	SULFIDE
CHEMICAL FORMULA:	FES2
MOHS HARDNESS:	6 – 6.5
SPECIFIC GRAVITY:	4.9 – 5.2
REFRACTIVE INDEX:	1.73 – 1.83
BIREFRINGENCE:	NONE
COLOUR:	TAIL COVERTS OF GOLDEN PHEASANT

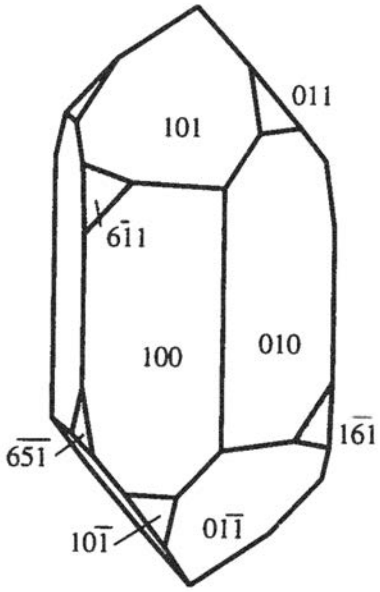
Pyrite is a brass-yellow mineral with a bright metallic luster. It has a chemical composition of iron sulfide and is the most common sulfide mineral. It forms at high and low temperatures and occurs, usually in small quantities, in igneous, metamorphic, and sedimentary rocks worldwide. Pyrite is so common that many geologists would consider it to be a ubiquitous mineral.

The name “pyrite” is after the Greek “pyr” meaning “fire.” This name was given because pyrite can be used to create the sparks needed for starting a fire if it is struck against metal or another hard material. Pieces of pyrite have also been used as a spark-producing material in flintlock firearms.

Pyrite has a nickname that has become famous - “Fool’s Gold.” The mineral's gold colour, metallic luster, and high specific gravity often cause it to be mistaken for gold by inexperienced prospectors. However, pyrite is often associated with gold. The two minerals often form together, and in some deposits pyrite contains enough included gold to warrant mining.

Pyrite has long been valued as a strong protection stone that shields the wearer from negative energy as well as environmental pollutants. Thus, this stone helps promote physical well-being as well. Stimulating the second and third chakras, pyrite enhances strength of mind and willpower. Pyrite is also sometimes considered to be lucky, attracting wealth and abundance. Though not a birthstone, pyrite is most commonly associated with the zodiac sign of Leo.

QUARTZ



MINERAL:	QUARTZ
CHEMICAL FORMULA:	SIO2
MOHS HARDNESS:	7
SPECIFIC GRAVITY:	2.6 – 2.7
REFRACTIVE INDEX:	1.55
BIREFRINGENCE:	0.009
COLOUR:	COLOURLESS TO SNOW WHITE

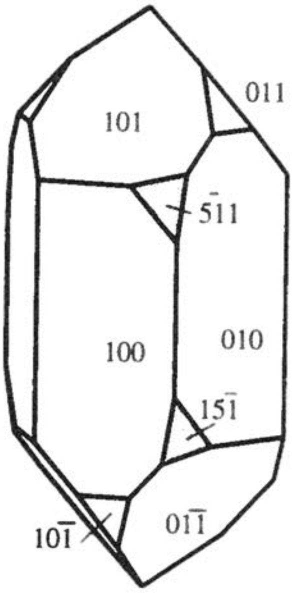
Quartz is a mineral composed of silicon and oxygen, with a chemical composition of SiO_2. It is the most abundant mineral in Earth's crust and is resistant to both chemical and physical weathering. When rocks weather away, the residual material usually contains quartz. This is why the sand at most of the world's beaches is quartz.

One of the most amazing properties of quartz is the ability of its crystals to vibrate at a precise frequencies. These frequencies are so precise that quartz crystals can be used to make extremely accurate time-keeping instruments and equipment that can transmit radio and television signals with precise and stable frequencies. Today, billions of quartz crystals are used to make oscillators for watches, clocks, radios, televisions, electronic games, computers, cell phones, electronic meters, and GPS equipment.

Pure quartz, traditionally called rock crystal or clear quartz, is colourless and transparent or translucent, and has often been used for hardstone carvings, such as the Lothair Crystal. Common coloured varieties include citrine, rose quartz, amethyst, smoky quartz, milky quartz, and others. These colour differentiations arise from the presence of impurities which change the molecular orbitals, causing some electronic transitions to take place in the visible spectrum causing colours.

Roman naturalist Pliny the Elder believed quartz to be water ice, permanently frozen after great lengths of time. He supported this idea by saying that quartz is found near glaciers in the Alps, but not on volcanic mountains, and that large quartz crystals were fashioned into spheres to cool the hands.

SMOKY QUARTZ



MINERAL:	QUARTZ
CHEMICAL FORMULA:	SIO2
MOHS HARDNESS:	7
SPECIFIC GRAVITY:	2.65
REFRACTIVE INDEX:	1.55
BIREFRINGENCE:	0.009
COLOUR:	EYES OF THE LARGEST FLESH FLY

The colour of smoky quartz crystals can be light brown to yellowish brown to a shade so dark they almost look black. They can also be slightly grey. These dark coloured crystals are known as morion. Morion seems to have originated from the works of the ancient Roman author, naturalist and natural philosopher Pliny the Elder. In the chapter on minerals in his encyclopaedia Naturalis Historia, he refers to mormorion as being a very dark translucent stone from India. It's reported 'morion' was a misreading of this name.

The colour of smoky quartz is caused when natural radiation from the surrounding rock interacts with impurities of aluminium. Crystals can be transparent to translucent or look almost opaque in very dark varieties.

Cairngorm is a variety of smoky quartz mined on Cairn Gorm. This mountain is located in the eastern Highlands of Scotland. Crystals from Cairn Gorm have a smokey yellowish brown colour but can also be greyish brown.

When used for its metaphysical healing properties smoky quartz repels negative energy. It's particularly effective for dealing with anger and resentment. It can help ease panic attacks, anxiety and nightmares and brings deep emotional calmness.

MINERALOGY

1. INTRODUCTION

The science of mineralogy is a branch of the earth sciences that is concerned with studying minerals and their physical and chemical properties. Within mineralogy there are also those who study how minerals are formed, where they are geographically located, as well as their potential uses. Like many sciences, mineralogy has its origins in several ancient civilizations, and it has been concerned primarily with the various methods of classification of minerals for most of its history. Modern-day mineralogy has been expanded by advances in other sciences, such as biology and chemistry, to shed even more light on the nature of the materials that form the earth we live on.

The ancient Greek philosopher Aristotle was one of the first people to theorize extensively about the origins and properties of minerals. His ideas were new and advanced for the time, but he and his contemporaries were largely incorrect in their assumptions. For example, it was a widely held belief in ancient Greece that the mineral asbestos was a kind of vegetable. Nevertheless, these ancient theories provided a starting point for the evolution of mineralogy as we have come to know it. It was not until the 16th century that mineralogy began to take a form that is recognizable to us, largely thanks to the work of German scientist Georgius Agricola.

2. DEFINITION OF 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. 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.
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 threedimensional 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 (Mg2SiO4) and fayalite (Fe2SiO4) 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 ayalite, 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 endmembers 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.

In contrast to the 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); alphaquartz, 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 (Blackburn & Dennen, 1988).

3. COMPOSITION OF THE EARTH’S CRUST

The earth’s crust is composed of many kinds of rocks, each of which is an aggregate of one or more minerals. In geology, the term mineral describes any naturally-occurring solid substance with a specific composition and crystal structure. A mineral’s composition refers to the kinds and proportions of elements making up the mineral. The way these elements are packed together determines the structure of the mineral. More than 3,500 different minerals have been identified. There are only 12 common elements (oxygen, silicon, aluminum, iron, calcium, sodium, potassium, magnesium, titanium, hydrogen, manganese, phosphorus) that occur in the earth’s crust. All other naturally occurring elements are found in very minor or trace amounts. Silicon and oxygen are the most abundant crustal elements, together comprising more than 70 percent by weight (Rudnick & Fountain, 1995). It is therefore not surprising that the most abundant crustal minerals are the silicates (e.g. olivine, Mg2SiO4), followed by the oxides (e.g. hematite, Fe2O3). Other important types of minerals include: the carbonates (e.g. calcite, CaCO3) the sulfides (e.g. galena, PbS) and the sulfates (e.g. anhydrite, CaSO4). Most of the abundant minerals in the earth’s crust are not of commercial value. Economically valuable minerals (metallic and nonmetallic) that provide the raw materials for industry tend to be rare and hard to find. Therefore, considerable effort and skill is necessary for finding where they occur and extracting them in sufficient quantities. Table 1 shows the elemental chemical composition of the Earth's crust in order of abundance (Lutgens & Tarbuck, 2000).

ELEMENT NAME	SYMBOL	% BY WEIGHT OF THE EARTH'S CRUST
OXYGEN	O	46.6
SILICON	SI	27.7
ALUMINIUM	AL	8.1
IRON	FE	5.0
CALCIUM	CA	3.6
SODIUM	NA	2.8
POTASSIUM	K	2.6
MAGNESIUM	MG	2.1
ALL OTHER ELEMENTS		1.5

Table 1. The elements in the Earth's crust (Lutgens & Tarbuck, 2000).

This table that shows the elemental chemical composition of the Earth's crust. They will vary depending on the way they were calculated and the source. 98.5% of the Earth's crust consists of oxygen, silicon, aluminum, iron, calcium, sodium, potassium and magnesium. All other elements account for approximately 1.5% of the volume of the Earth's crust.

4. THE SOME CHARACTERISTICS OF MINERALS

The physical properties of a mineral are determined by its chemical composition and its crystalline structure. Within the limits of the permissible variation in chemical composition, different samples of a single mineral species are expected to display the same set of physical properties. These characteristic physical properties are therefore very useful to the field geologist in identifying and describing a specimen (Zoltai & Stout,1984).

Properties which describe the physical appearance of a mineral specimen include colour, streak, and luster. Mass-dependent properties include density; mechanical properties include hardness, cleavage, fracture, and tenacity. Properties relating to the growth patterns and physical appearance of crystals, both individually and in aggregate, are described in terms of crystal habit, crystal form, and crystal system (Klein & Hurlbut, 1985).

1. CRYSTAL FORM AND HABIT (SHAPE).
2. LUSTER AND TRANSPARENCY
3. COLOUR AND STREAK.
4. CLEAVAGE, FRACTURE, AND PARTING.
5. TENACITY
6. DENSITY
7. HARDNESS

4.1 CRYSTAL FORM AND HABIT

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. The crystal faces commonly seen on quartz are growth faces and represent the slow est growing directions in the structure. Quartz grows rapidly along its caxis (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 a 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.

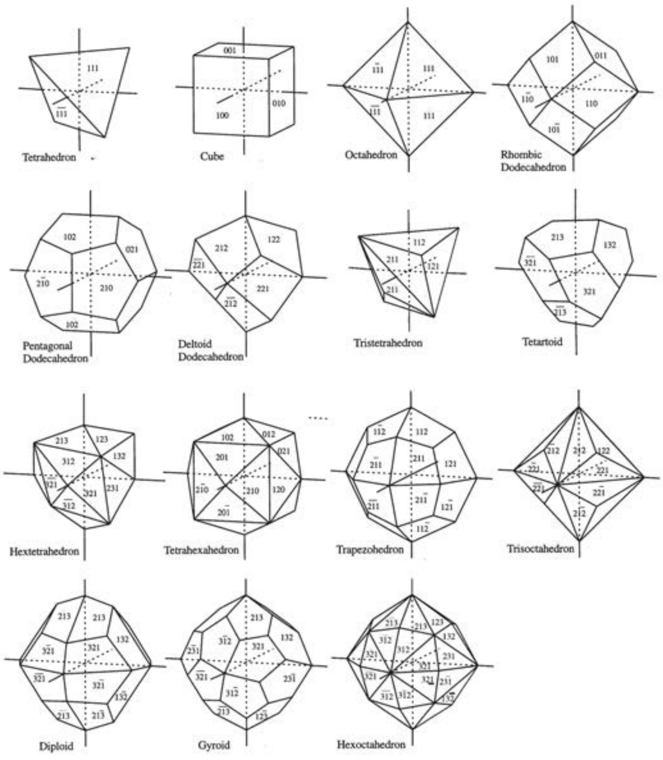


Fig 1. Crystal forms in the isometric crystal system.

4.2 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.

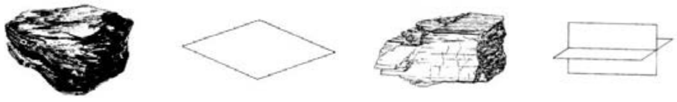
Native metals and many sulfides are opaque and reflect most of the light hitting their surfaces and have a metallic luster. Other opaque or nearly opaque oxides may appear dull, or resinous. Transparent minerals with a high index of refraction such as diamond appear brilliant and are said to have an 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.

4.3 COLOUR AND STREAK

Colour is fairly self-explanatory property describing the reflectance. 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 coloured so that the streak, the mark that they leave when scratched on a white ceramic tile, will also be strongly coloured.

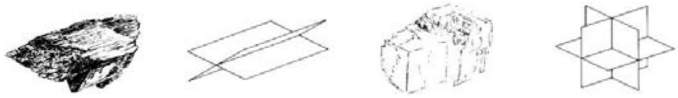
4.4 CLEAVAGE, FRACTURE, AND PARTING

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. 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.



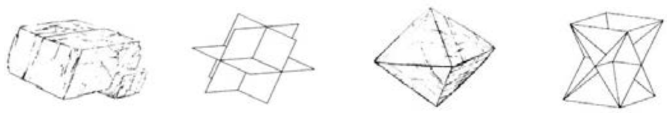
A. Cleavage in one direction

B. Cleavage in two directions at right angles



C. Cleavage in two directions not at right angles

D. Cleavage in three directions at right angles



E. Cleavage in three directions not at right angles

F. Cleavage in four directions

Fig 2. Types of cleavage

4.5 TENACITY

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.

4.6 DENSITY

Density is a well-defined physical property measured in g/cm3. 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.

4.7 HARDNESS

Hardness 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.

4.8 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. Another unique property that can be used to distinguish between otherwise similar back opaque minerals is magnetism. For example, magnetite (Fe3O4), ilmenite (FeTiO3), and pyrolusite (MnO2) 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.

4.9 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, and this radioactivity can be easily detected with a Geiger counter. Examples of radioactive minerals are uraninite (UO2), thorite (ThSiO4), and carnotite (K2(UO2)(VO4)2 rH2O). Some minerals may also be fluorescent under ultraviolet light, that is they absorb UV lighta and emit in the visible. Other optical properties such as index of refraction and pleochroism (differential light absorption) require an optical microscope to measure. 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 (SiO2) 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).

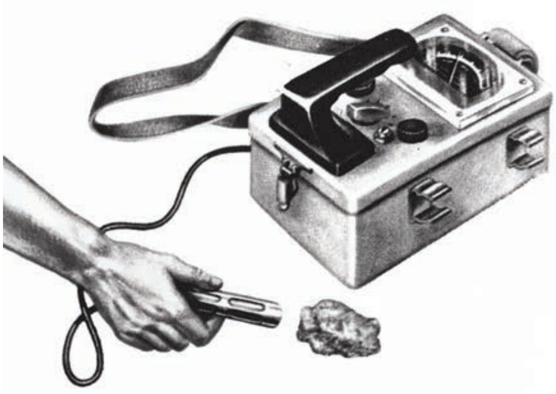


Fig 3. Using a Geiger counter to measure mineral radioactivity

5. MINERAL OCCURENCES AND ENVIRONMENTS

In addition to physical properties, one of the most diagnostic features of a mineral is the geological environment in which it is occurs (Deer, Howie & Zussman, 1992).

5.1 IGNEOUS MINERALS

Minerals in igneous rocks must have high melting points and be able to co-exist with, or crystallize from, silicate melts at temperatures above 800 ° C. Igneous rocks can be generally classed according to their silica content with low-silica (< 50 % SiO2) igneous rocks being termed basic or mafic, and high-silica igneous rocks being termed silicic or acidic. Basic igneous rocks (BIR) include basalts, dolerites, gabbros, kimberlites, and peridotites, and abundant minerals in such rocks include olivine, pyroxenes, Ca-feldspar (plagioclase), amphiboles, and biotite. The abundance of Fe in these rocks causes them to be dark-coloured.

Silicic igneous rocks (SIR) include granites, granodiorites, and rhyolites, and abundant minerals include quartz, muscovite, and alkali feldspars. These are commonly light-coloured although colour is not always diagnostic. In addition to basic and silicic igneous rocks, a third igneous mineral environment representing the final stages of igneous fractionation is called a pegmatite (PEG) which is typically very coarse-grained and similar in composition to silicic igneous rocks (i.e. high in silica). Elements that do not readily substitute into the abundant minerals are called incompatible elements, and these typically accumulate to form their own minerals in pegmatites. Minerals containing the incompatible elements, Li, Be, B, P, Rb, Sr, Y, Nb, rare earths, Cs, and Ta are typical and characteristic of pegmatites.

5.2 METAMORPHIC MINERALS

Minerals in metamorphic rocks have crystallized from other minerals rather than from melts and need not be stable to such high temperatures as igneous minerals. In a very general way, metamorphic environments may be classified as low-grade metamorphic (LGM) (temperatures of 60° to 400°C and pressures < .5 GPa (=15km depth) and high-grade metamorphic (HGM) (temperatures > 400 ° and/or pressures > .5 GPa). Minerals characteristic of low- grade metamorphic environments include the zeolites, chlorites, and andalusite. Minerals characteristic of high grade metamorphic environments include sillimanite, kyanite, staurolite, epidote, and amphiboles.

5.3 SEDIMENTARY MINERALS

Minerals in sedimentary rocks are either stable in low-temperature hydrous environments (e.g. clays) or are high temperature minerals that are extremely resistant to chemical weathering (e.g. quartz). One can think of sedimentary minerals as exhibiting a range of solubilities so that the most insoluble minerals such as quartz, gold, and diamond accumulate in the coarsest detrital sedimentary rocks, less resistant minerals such as feldspars, which weather to clays, accumulate in finer grained siltstones and mudstones, and the most soluble minerals such as calcite and halite (rock-salt) are chemically precipitated in evaporite deposits. Sedimentary minerals can classify into detrital sediments (DSD) and evaporites (EVP). Detrital sedimentary minerals include quartz, gold, diamond, apatite and other phosphates, calcite, and clays. Evaporite sedimentary minerals include calcite, gypsum, anhydrite, halite and sylvite, plus some of the borate minerals.

5.4 HYDROTHERMAL MINERALS

The fourth major mineral environment is hydrothermal, minerals precipitated from hot aqueous solutions associated with emplacement of intrusive igneous rocks. This environment is commonly grouped with metamorphic environments, but the minerals that form by this process and the elements that they contain are so distinct from contact or regional metamorphic rocks that it us useful to consider them as a separate group. These may be sub-classified as high temperature hydrothermal (HTH), low temperature hydrothermal (LTH), and oxydized hydrothermal (OXH). Sulfides may occur in igneous and metamorphic rocks, but are most typically hydrothermal. High temperature hydrothermal minerals include gold, silver, tungstate minerals, chalcopyrite, bornite, the tellurides, and molybdenite. Low temperature hydrothermal minerals include barite, gold, cinnabar, pyrite, and cassiterite. Sulfide minerals are not stable in atmospheric oxygen and will weather by oxidation to form oxides, sulfates and carbonates of the chalcophile metals, and these minerals are characteristic of oxidized hydrothermal deposits. Such deposits are called gossans and are marked by yellow-red iron oxide stains on rock surfaces. These usually mark mineralized zones at depth.

6. THE MINERAL CLASSIFICATION

Minerals are classified on their chemistry, particularly on the anionic element or polyanionic group of elements that occur in the mineral. An anion is a negatively charge atom, and a polyanion is a strongly bound group of atoms consisting of a cation plus several anions (typically oxygen) that has a net negative charge. For example carbonate (CO3)2-, silicate (SiO4)4- are common polyanions. This classification has been successful because minerals rarely contain more than one anion or polyanion, whereas they typically contain several different cations (Nesse, 2000).

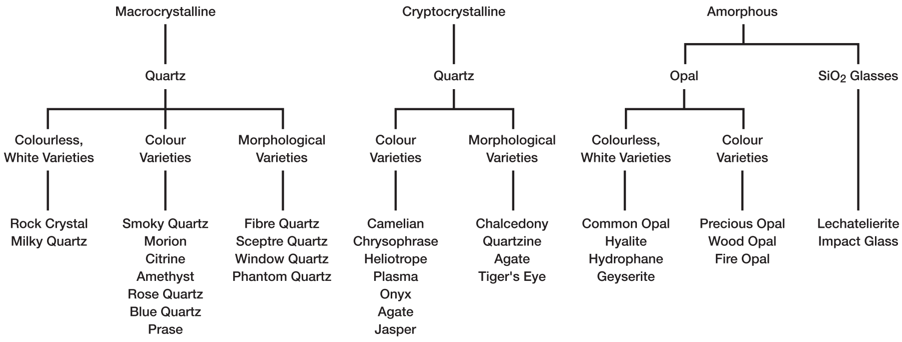


Fig 4. Varieties of SiO_2

7. THE CLASSIFICATION OF CRYSTALS

The descriptive terminology of the discipline of crystallography is applied to crystals in order to describe their structure, symmetry, and shape. This terminology describes the crystal lattice, which provides a mineral with its ordered internal structure. It also describes and analyzes various types of symmetry. By considering what type of symmetry a mineral species possesses, the species may be categorized as a member of one of six crystal systems and one of thirty-two crystal classes.

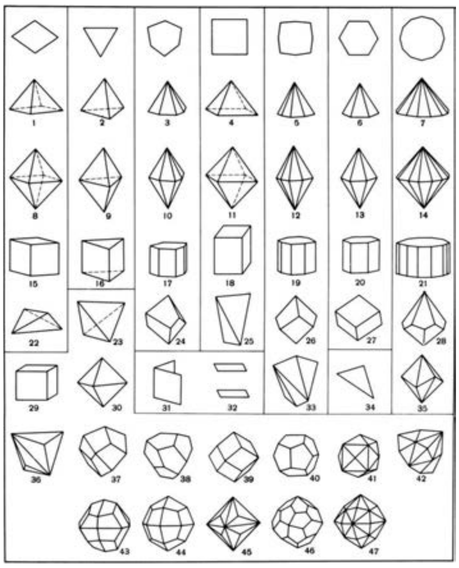


Fig 5. The 47 forms that crystals may take

The concept of symmetry describes the periodic repetition of structural features. Two general types of symmetry exist. These include translational symmetry and point symmetry.

Translational symmetry describes the periodic repetition of a motif across a length or through an area or volume. Point symmetry, on the other hand, describes the periodic repetition of a motif about a single point. Reflection, rotation, inversion, and rotoinversion are all point symmetry operations.

A specified motif which is translated linearly and repeated many times will produce a lattice. A lattice is an array of points which define a repeated spatial entity called a unit cell. The unit cell of a lattice is the smallest unit which can be repeated in three dimensions in order to construct the lattice.

The number of possible lattices is limited. In the plane only five different lattices may be produced by translation. The French crystallographer Auguste Bravais (1811-1863) established that in three-dimensional space only fourteen different lattices may be constructed. These fourteen different lattices are thus termed the Bravais lattices.

The reflection, rotation, inversion, and rotoinversion symmetry operations may be combined in a variety of different ways. There are thirty-two possible unique combinations of symmetry operations. Minerals possessing the different combinations are therefore categorized as members of thirty-two crystal classes. In this classificatory scheme each crystal class corresponds to a unique set of symmetry operations. Each of the crystal classes is named according to the variant of a crystal form which it displays. Each crystal class is grouped as one of the six different crystal systems according to which characteristic symmetry operation it possesses. A crystal form is a set of planar faces which are geometrically equivalent and whose spatial positions are related to one another by a specified set of symmetry operations. If one face of a crystal form is defined, the specified set of point symmetry operations will determine all of the other faces of the crystal form. A simple crystal may consist of only a single crystal form. A more complicated crystal may be a combination of several different forms. Example crystal forms are the parallelohedron, prism, pyramid, trapezohedron, rhombohedron and tetrahedron.

Each crystal class is a member of one of six crystal systems. These include the isometric, hexagonal, tetragonal, orthorhombic, monoclinic, and triclinic crystal systems. Every crystal of a certain crystal system shares a characteristic symmetry element - for example, a certain axis of rotational symmetry - with the other members of its system. The crystal system of a mineral species may sometimes be determined by examining a particularly well-formed crystal of the species (Nesse, 2004).

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